Overview of Approaches for Numeric Nutrient Criteria Development in Marine Waters

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2012

Table of Contents

List of Tables

List of Figures

Executive Summary

This document summarizes the approaches that the Florida Department of Environmental Protection (Department) and local Florida scientists are using to develop numeric nutrient criteria (NNC) for Florida's estuarine and coastal waters. The primary purpose of NNC in Florida is to protect healthy, well-balanced natural populations of flora and fauna from the effects of excess anthropogenic nutrient enrichment.

In 2009 and early 2010, the Department conducted a series of technical workshops throughout the state to elicit input from the many expert scientists (from universities, resource protection agencies, and consulting firms) with relevant information on Florida's estuaries and coastal waters. The Department then established a Marine Technical Advisory Committee (MTAC) in July 2010 consisting of experts in marine ecology, and held three meetings (on August 29, 2010, November 17, 2010, and January 29, 2011) to discuss approaches to NNC development in estuaries and coastal waters. This document reflects the input of the MTAC.

The Department divided Florida's estuaries into approximately 30 distinct units, and then compiled and synthesized all available information for each specific estuary. This information consisted of a physical/chemical description, including **causal parameters** (nutrients), **supporting variables** [such as hydrodynamics, water residence time, transparency, salinity, and dissolved oxygen (DO)], and a biological description of each system, including key biological **response variables.** Working with local scientists, the Department identified the most sensitive, valued ecological attributes for each estuary and is in the process of determining the nutrient regime that would result in the protection of that resource (maintaining full support of aquatic life use). In general, the Department's overall scheme for NNC could be described as an "estuary-specific, ecosystem-based" methodology.

The Department proposes four main approaches, as follows, for NNC development for Florida's estuarine and coastal waters:

- *Maintain healthy existing conditions approach;*
- *Historical conditions approach;*
- *Response-based approach using modeling or empirical evidence; and*
- *Reference site approach.*

This document describes the rationale used by the Department, with assistance from local scientists, in developing NNC values using these approaches. The criteria generated using these methods should serve to protect healthy, well-balanced natural populations of flora and fauna from the effects of excess anthropogenic nutrient enrichment. This "ecosystem-based" methodology recognizes the complex array of factors that are not only responsible for the formation of each marine community type, but that influence each system's unique response to anthropogenic nutrient enrichment.

A key step in the "maintain healthy existing conditions approach" is the demonstration that an estuary has a healthy, well-balanced community. The Department and EPA have historically considered a healthy community as one that maintains a characteristic community structure and function (specific to the resource), while allowing for modest changes in biological community structure compared with background. A healthy, well-balanced community is therefore **not** restricted to one described as "pristine" or "100% natural." Anthropogenically induced ecosystem change is acceptable if the following conditions are present:

- *There continue to be reproducing populations of sensitive taxa;*
- *An overall balanced distribution of all expected major groups is maintained; and*
- *Ecosystem functions are largely intact due to redundant system attributes (Davies and Jackson 2006).*

To determine whether a system is healthy versus "imbalanced," the Department has considered the acceptable change from natural background described above, and historically used a "weight-of-evidence approach." Using the best available information, the normal structural and functional attributes of the ecosystem type are estimated (while accounting for inherent variability), and then a particular system is evaluated to determine if significant departures from the expected conditions have occurred (beyond natural variation).

The primary objective of the healthy existing conditions approach is to establish magnitude, duration, and frequency limits, which, if exceeded in the future, would allow the Department to identify with sufficient statistical certainty when a new distribution of data is not consistent with the baseline distribution. In establishing these limits, the Department has made the management decision to limit the Type I error rate to 10%, and has utilized the upper 80 percent prediction limit. The Department's proposed approach is to set the magnitude as an annual geometric mean limit established at the upper 80 percent prediction limit of the spatially averaged annual geometric means, with a frequency and duration of no more than 1 annual geometric mean exceeding the limit in a 3-year period.

Nutrient criteria may also be established using the historical conditions approach if excessive anthropogenic nutrient loading has resulted in biological impairment in a marine system, and if nutrient and biological data are available both before and after this disturbance. This approach requires the following:

- *An affirmative demonstration that the system was biologically healthy during the reference period;*
- *Adequate nutrient and biological data associated with pre- and post-disturbance; and*
- *A response variable that links the nutrients to impairment.*

The "response-based approach" is the preferred method for developing NNC, but the approach to date has generally been limited to cases where there have been demonstrated adverse biological responses to anthropogenic nutrient enrichment. For this approach to be scientifically defensible, the dose-repose relationship must be explicitly quantified, within a range of uncertainty, and criteria must be established at a concentration (or loading) where the adverse response is not expected to occur, given a specified confidence level. This type of information is available for estuaries that have been identified as impaired by nutrients and for which nutrient Total Maximum Daily Loads (TMDLs) were developed. Nutrient TMDLs have been developed for several major estuarine systems in Florida, including the Lower St. Johns River (LSJR), Indian River Lagoon (IRL), St. Lucie River and Estuary (SLE), and Tampa Bay. These TMDLs have generally been based on one of two main approaches: (1) combined hydrodynamic and water quality models that use literature-based relationships between nutrient levels and algal growth; or (2) empirical relationships between nutrient levels (concentration or load) and some biological response, typically chlorophyll a or seagrass distribution.

Because nutrient TMDLs have the same goal as NNC (to establish the amount of nutrients the waterbody can assimilate and still maintain applicable water quality standards), the Department plans to submit the adopted nutrient TMDLs to EPA as the estuary-specific NNC for each of these systems. However, a variety of issues must be addressed when translating nutrient TMDLs into NNC, including whether to convert TMDL loads into concentration, how to convert loads into concentrations (if necessary), clarification of the frequency and spatial component of the TMDL, and how to develop NNC for causal variable not addressed by the TMDL.

The underlying concept behind the reference site approach is to identify areas characterized by minimal human disturbance to establish expectations for comparable, usually nearby system types. Some estuaries with a relatively natural nutrient regime may be subject to some degree of human stress, such as physical habitat disruption or hydrologic alterations, meaning the system could not be considered minimally disturbed. However, if the nutrient regime in such estuaries is comparable to other similar, minimally disturbed estuaries, the reference site approach would be a line of evidence to “maintain existing conditions” in the system.

1 Background Information

1.1 *Purpose and Scope of Document*

This document summarizes the approaches that the Florida Department of Environmental Protection (Department) and local Florida scientists are using to develop numeric nutrient criteria (NNC) for Florida's estuarine and coastal waters. The primary purpose of NNC in Florida is to protect healthy, well-balanced natural populations of flora and fauna from the effects of excess anthropogenic nutrient enrichment.

The development of quantitative, accurate, and scientifically defensible NNC is extremely challenging. Nutrients exist naturally in the environment and are absolutely necessary for life (for oxygen and organic carbon production via photosynthesis). Nutrients are not directly toxic (with the exception of un-ionized ammonia, which is controlled by existing water quality criteria); therefore, the use of a "toxics-based" risk model is not appropriate for nutrients. Instead, an "ecosystem-based" methodology must be used, recognizing the complex array of factors that are not only responsible for the formation of each marine community type, but that influence each system's unique response to anthropogenic nutrient enrichment. This includes the consideration of mitigating factors (such as salinity flux, tides, geomorphology, and hydrologic residence time) that define each system's inherent assimilative capacity. These site-specific issues, including the variability of natural nutrient inputs (from soils and detritus) and the relative sensitivity of ecological communities inhabiting a particular estuarine segment, require that extreme care be taken to establish NNC that are neither over- nor under-protective.

Although these concepts are further discussed in Section 1.3 below, it is important to note that legal proceedings have forced an extremely compressed time frame for developing NNC in Florida. The Department is concerned that, in some estuaries and for specific resources (tidal creeks, marine lakes, and bayous, for example), there is insufficient information to develop accurate criteria. It recommends that NNC not be promulgated in those systems where there is insufficient information, rather than adopt criteria simply to meet artificial deadlines.

Florida estuaries and coastal systems exhibit significant variation in many factors, such as daily tidal fluxes, seasonal freshwater inflows, temperature regime, habitat, system morphology, and biogeochemistry. As examples of the variability found through the state, Florida has been divided into 6 U.S. Department of Agriculture (USDA) climate zones along the coasts, 19 EPA ecological subregions, and 3 general marine provinces (Louisianan, West Indian, and Carolinian). The state's estuaries and coastal systems are subject to an assortment of freshwater sources and are characterized by wide variations in geology, bathymetry, driving forces, and ecological system organization. These differing influences result in a range of characteristic biological communities, each of which must be understood in the context of potential nutrient responses. Florida's estuarine ecosystem types range from river-dominated alluvial systems (*e.g.*, Apalachicola Bay); to those characterized by extensive seagrass communities (*e.g.*, Apalachee Bay), salt marshes (*e.g.*, Tolomato–Matanzas Rivers), or mangroves (*e.g.*, Southwest Coast), to those with inputs from blackwater rivers (Nassau–St. Marys Estuaries), to those where coral reefs are a dominant feature (*e.g.*, Florida Keys and Southeast Coast). Because of the diversity of Florida's marine systems, the Department has fundamentally pursued an "estuary-specific" approach, where all existing information for each individual estuary was synthesized, and criteria were based on the ecological endpoints most relevant for each particular system.

After evaluating specific estuaries, the Department decided to use chlorophyll *a* and seagrasses as the primary response variables to nutrient enrichment when developing criteria for Florida estuaries and coastal waters. There is a clear, established link between nutrients and water column chlorophyll *a* response, and it is a valid measure of ecosystem health. There is also a strong relationship between nutrient loading and loss of seagrass areal coverage through the reduction of available light, whether that light reduction is caused by phytoplankton or epiphyte shading. In addition to clear causal links between nutrients and these responses, there are adequate data of known quality available to develop the numeric criteria for nutrients and to set targets for chlorophyll *a* as well as for seagrass areal coverage (whether maintaining levels or restoring historic levels). The Department also considered other response variables, such as epiphytic algal coverage on seagrasses and macroalgal growth, but found that data were insufficient for quantifying relationships between nutrient enrichment and these variables.

The Department has used the terms "estuaries and coastal waters" in this document because the EPA used these terms in its determination letter that NNC were required to implement the federal Clean Water Act (CWA) in Florida, and because they are commonly understood terms. EPA's Nutrient Criteria Technical Guidance Manual (EPA 2001) broadly defines estuaries to include all shallow coastal ecosystems, including "tidal rivers, embayments, lagoons, coastal river plumes, and river dominated coastal indentations," and defines coastal waters as those 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." However, Florida water quality standards do not define "estuaries." Instead, they define "coastal waters" as "all waters in the state that are not classified as fresh waters or as open waters" and define "open waters" as "all waters in the state extending seaward from the most seaward 18-foot depth contour line (3-fathom bottom depth contour) which is offshore from any island; exposed or submerged bar or reef; or mouth of any embayment or estuary which is narrowed by headlands. Contour lines shall be determined from Coast and Geodetic Survey Charts." Thus, "coastal waters" as defined in Florida's water quality standards are equivalent to EPA's definition of estuary, and "open waters" are equivalent to EPA's term "coastal waters."

This document does not address NNC development for freshwater systems in Florida. The Department plans to rely on the definition of "predominantly fresh waters" [defined as "surface waters in which the chloride concentration at the surface is less than 1,500 milligrams per liter"(Subsection 62-302.200(22), Florida Administrative Code (F.A.C.)] to clearly indicate where estuarine criteria do not apply. However, as noted in Section 6.1, the Department recommends that criteria developed for open estuaries should not apply to tidal creeks, embayments, or marine lakes, even if they meet the definition of predominantly marine waters (defined as "surface waters in which the chloride concentration at the surface is greater than or equal to 1,500 milligrams per liter" [Subsection 62-302.200(23), F.A.C.]. It should also be noted that salinity and salinity flux significantly complicate quantifying the nutrient concentration expected for a given estuarine segment. The temporal dynamics associated with the mixing of naturally higher nutrient fresh waters with lower nutrient oceanic waters makes it difficult to establish "static" criteria for a given spatial area. This is also discussed in more detail in Section 6.

1.2 *Overall Approach and Work Conducted to Date*

Under the "estuary-specific" approach outlined above, the Department first identified the major estuarine/coastal systems in Florida and then synthesized all available, relevant information for each distinct area (see Figure 1). The Department, working with local scientists, then identified the most sensitive, valued ecological attributes for each system and subsequently determined the nutrient regime that would result in the protection of that resource (maintaining full support of aquatic life use). The following information was compiled for each individual estuary or marine system throughout the state:

- *A physical/chemical description of each system, including **causal or driver parameters** (nutrients) and **supporting variables** [hydrodynamics, water residence time, transparency, salinity, dissolved oxygen (DO), etc];*
- *A biological description of each system, including key biological **response variables**. The type, quality, community structure, and areal extent of valued ecological attributes were documented, emphasizing those expected to respond to anthropogenic nutrient enrichment, including seagrass, coral, hardbottom, phytoplankton, epiphytes, benthic invertebrates, and fish;*
- *The main sources of nutrients, including any point sources and dominant land uses in the watershed;*
- *The available scientific evidence quantifying the relationship between anthropogenic nutrient inputs and adverse effects on biological communities, including both primary responses (e.g., excess phytoplankton or macroalgal growth) and secondary responses (e.g., reduction in depth to seagrass);*
- *Existing regional nutrient loading and hydrodynamic models, especially those able to predict the fate and transport of nutrients to estimate assimilative capacity; and*
- *Proposed numeric targets needed for protecting or restoring the system, including a demonstration of the bases for the nutrient targets.*

The Department's initial effort consisted of soliciting input from local area experts by conducting a series of nine public workshops in February and March 2010. Information about the public meetings, including the presentations provided by the Department and local scientists, are available at the Department's website (http://www.dep.state.fl.us/water/wqssp/nutrients/estuarine.htm). Scientists most familiar with each estuary were fully engaged in the process, with the goal of describing relationships between nutrient loading/concentrations and valued ecological attributes (Figure 2). These experts provided presentations and literature, and, in some cases, assisted in writing the documents for each system. The

Department then synthesized the information in reports, focusing on the requirements for developing water quality standards outlined in the Clean Water Act (CWA).

The Department established a Marine Technical Advisory Committee (MTAC) in July 2010, and held three meetings (on August 29, 2010, November 17, 2010, and January 27, 2011) to discuss approaches to NNC development in estuaries and coastal waters. The MTAC comprised experts in marine ecology with a background in nutrient dynamics in Florida's environment (Table 1). Curricula vitae for each MTAC member are available on the Department's website. Note that this NNC Approaches document reflects the input of the MTAC.

The Department intends to propose in December 2011 criteria for Clearwater Harbor, St. Joseph Sound, Sarasota Bay, Tampa Bay, Charlotte Harbor, Estero Bay, Southwest Coast, Florida Bay, Keys, and Biscayne Bay (Figure 2) as well as previously adopted TMDLs developed by DEP to achieve the no imbalance of flora or fauna narrative nutrient criterion. The Clearwater Harbor, St. Joseph Sound, Sarasota Bay, Tampa Bay, Charlotte Harbor, and Estero Bay criteria were developed and proposed by the National Estuary Programs and are described in technical support documentation prepared by Janicki Environmental. Criteria for the remaining four south Florida systems were developed by DEP using the "Existing Conditions" approach described in Section 2 of this document. It is DEP's intention by establish by rule or final order estuary specific numeric interpretations of the narrative nutrient criteria for TN and TP for Perdido Bay, Pensacola Bay (including Escambia Bay), St. Andrew Bay, Choctawhatchee Bay, and Apalachicola Bay by June 30, 2013. Furthermore, the Department plans to establish by rule or final order the estuary specific numeric interpretation of the narrative nutrient criteria for TN and TP for the remaining estuaries by June 30, 2015.

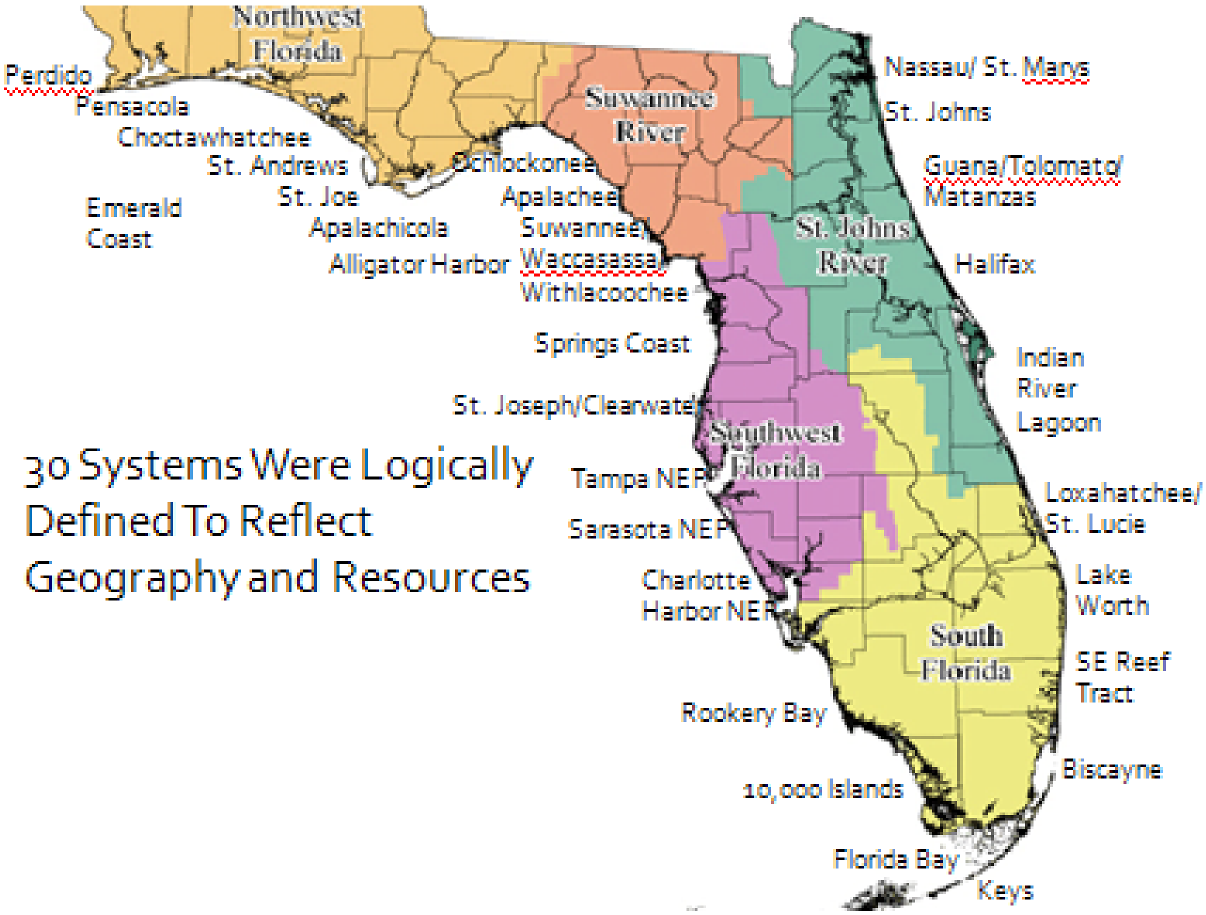

Figure 1. Regionalization of Florida estuaries and marine systems for NNC development purposes.

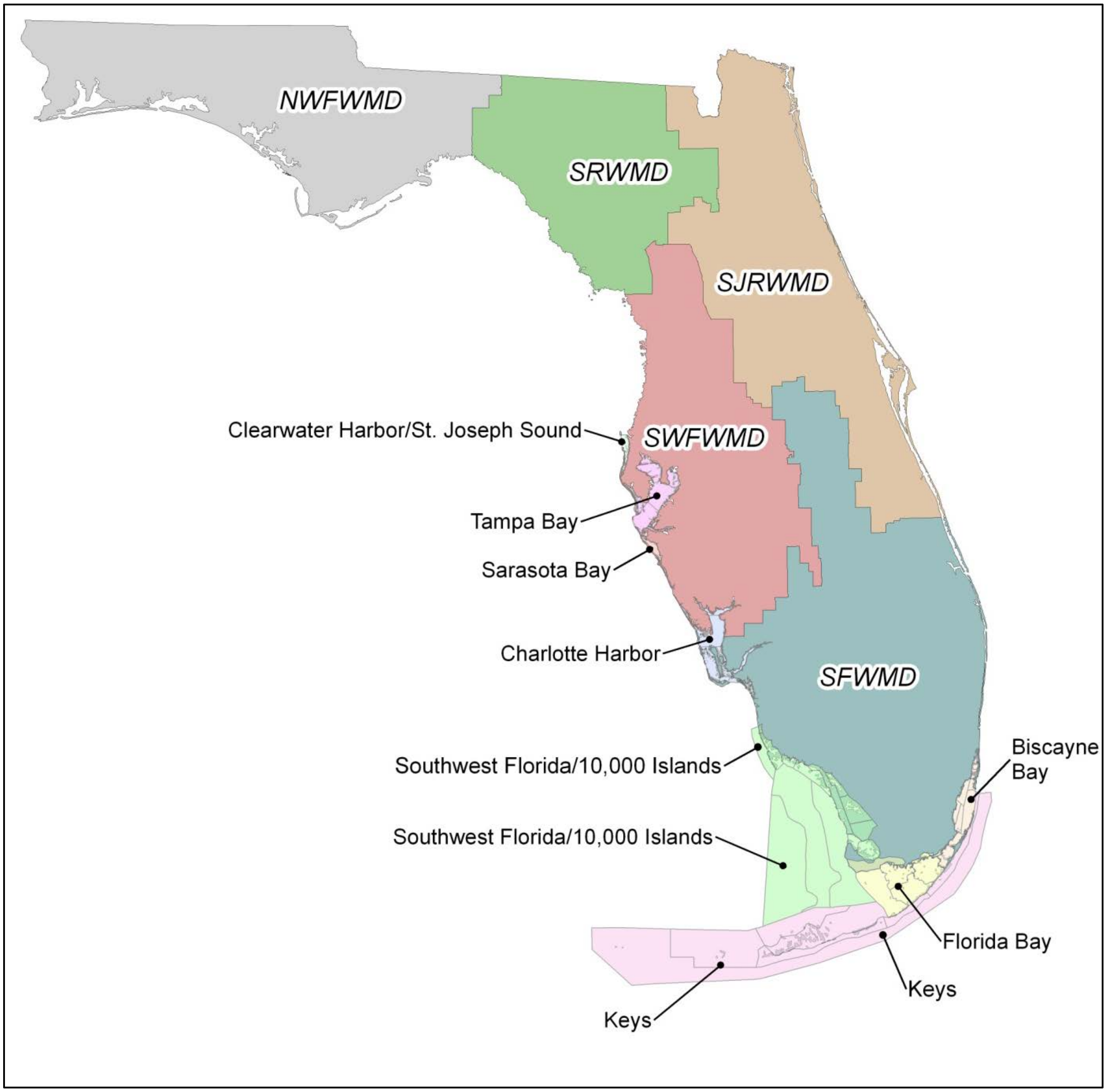

Figure 2. Segmentation of Florida estuaries included in DEP's 2011 numeric nutrient criteria proposal.

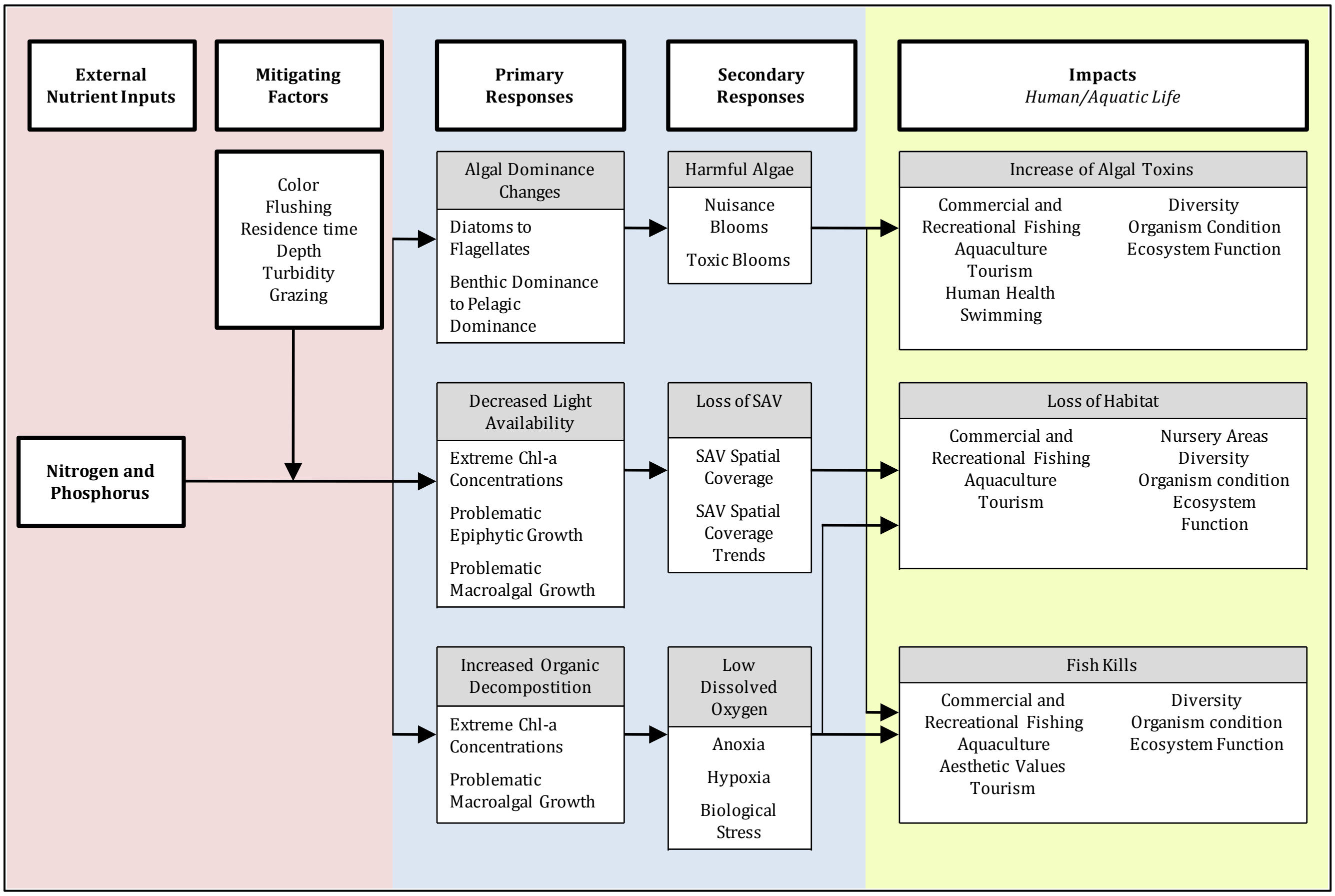

Figure 3. Simplified eutrophication conceptual model used to assess impacts of nutrients on aquatic life and human uses. Model adapted from National Oceanic and Atmospheric Administration (NOAA) 1999. Relationships between nutrients and biological responses are highly influenced by system type and mitigating factors.

Table 1. MTAC membership and affiliations

Name	Affiliation	Expertise
Dr. Joe Boyer	Florida International University	Water quality and marine ecosystems of South Florida
Dr. Tom Frazer	University of Florida	Marine water quality and seagrass biology
Mr. Tom Gallagher	HydroQual, Inc.	Hydrodynamic water quality modeling
Dr. Frank Marshall	Cetacean Logic Foundation, Inc.	Hydrodynamic water quality modeling
Dr. Clay Montague	University of Florida	Marine systems dynamics and ecology
Dr. Edward Phlips	University of Florida	Phytoplankton community dynamics and harmful algal blooms (HABs)
Mr. Joel Steward	St. Johns River Water Management District	Marine ecology and water quality modeling
Dr. David Tomasko	Post Buckley Schuh and Jernigan, Inc.	Marine ecology and water quality modeling

1.3 *Linking* NNC *to Designated Use*

This section provides background on federal and state requirements for developing water quality standards and on how the Department has historically defined biological impairment caused by anthropogenic nutrient enrichment (imbalances of flora or fauna). Additional concepts for developing scientifically defensible criteria are presented, including key ecological considerations and the need to account for confounding environmental factors.

The CWA directs EPA and the states to maintain the "physical, chemical and biological integrity" of the nation's waters by developing and implementing water quality standards, which consist of the following:

- *Designated uses (waterbody goals);*
- *Criteria designed to protect those uses;*
- *An antidegradation policy; and*
- *Moderating provisions.*

Water quality standards are designed to protect public health or welfare, enhance the quality of the water, serve the purposes of the CWA, and provide a regulatory basis for source control and waterbody assessment. These standards may be expressed as a concentration, level (*e.g.*, loading), or narrative statement, and define the level of water quality needed to support a particular designated use.[1] In Florida, the vast majority of waters are designated to support "recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife" (Section 62-302.400, F.A.C.).

[1] 40 CFR § 131.3[b]) states that criteria can be "expressed as constituent concentrations, levels, or narrative statement, representing a quality of water that supports a particular use."

When developing water quality criteria, federal regulations require not only that the criteria protect the designated use, but they must also be based on a sound, scientific rationale, include sufficient parameters to protect the designated use, and support the most sensitive use.

For over 30 years, Florida has relied on narrative nutrient criteria: "In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna." This document provides various approaches to translate this narrative statement into NNC.

A key consideration for criteria development is how one defines a healthy, well-balanced community. The Department and EPA have historically considered a healthy community as one that maintains a characteristic community structure and function (specific to the resource), while allowing for modest changes in biological community structure compared with background. A healthy, well-balanced community is therefore **not** restricted to one described as "pristine" or "100% natural." As part of the development of the EPA Biological Condition Gradient, national experts from academia, EPA, and state environmental protection agencies agreed that anthropogenically induced ecosystem change is acceptable if the following conditions are present:

- *There continue to be reproducing populations of sensitive taxa;*
- *An overall balanced distribution of all expected major groups is maintained; and*
- *Ecosystem functions are largely intact due to redundant system attributes (Davies and Jackson 2006).*

To determine whether a system is healthy versus "imbalanced," the Department has considered the acceptable change from natural background described above, and historically used a "weight-of-evidence approach." Using the best available information, the normal structural and functional attributes of the ecosystem type are estimated (while accounting for inherent variability), and then a particular system is evaluated to determine if significant departures from the expected conditions have occurred (beyond natural variation). Structural attributes examined by the Department include taxonomic composition and life history characteristics, such as taxa richness and tolerance, dominance, relative abundance, feeding strategies, organism habit, and the presence of keystone taxa. Functional attributes considered by the Department include trophic dynamics, productivity, recruitment, and materials cycling.

Standardized multimetric biological indices, constructed with metrics derived from these ecosystem attributes, have been established for freshwater streams and lakes in Florida. However, the complexity of marine systems has thus far precluded the development of a marine standardized index, making the weight-of-evidence approach the best option for assessing marine system biological health. This involves gathering site-specific information for each distinct marine system (*e.g.,* see eutrophication symptoms in Table 2), carefully evaluating the many factors that influence the biological integrity of the ecosystem, and using scientific reasoning to reach a conclusion about the system's relative health with respect to all natural and human influences. During this process, special scrutiny is given to determining if human nutrient additions have led to unacceptable reductions of sensitive or keystone taxa, adverse shifts in the overall balance of expected major taxonomic groups, and/or more than minor effects on ecosystem functions.

Note that some systems may have factors other than nutrients (*e.g.,* inappropriate freshwater delivery) causing stress, and it is the Department's intent to focus available resources on the human factors causing ecosystem harm. Therefore, these other factors need to be identified and understood to avoid significant, and potentially costly, resource management errors (*i.e.,* reducing nutrients when doing so would not result in environmental benefit).

When developing NNC to protect and maintain a healthy, well-balanced community, it is important to account for natural variability in both the nutrient regime and in the biological communities, and account for other influences on the ecosystem (Figure 4). As discussed earlier, healthy, well-balanced communities may at times exhibit moderate changes in community structure compared with natural background conditions, yet may remain fully functional systems. Nutrient criteria must be based on a sound scientific rationale, which includes employing legally defensible data (following the Department's Quality Assurance Rule) and providing a reasonable ecological demonstration linking nutrients to designated use. The criteria should also be reproducible by other scientists, account for and manage confounding factors during derivation, and control for Type I [incorrectly concluding that a system is impaired, when it is actually healthy (a "false positive"] and Type II errors [incorrectly concluding that a system is healthy, when it is actually impaired (a "false negative")].

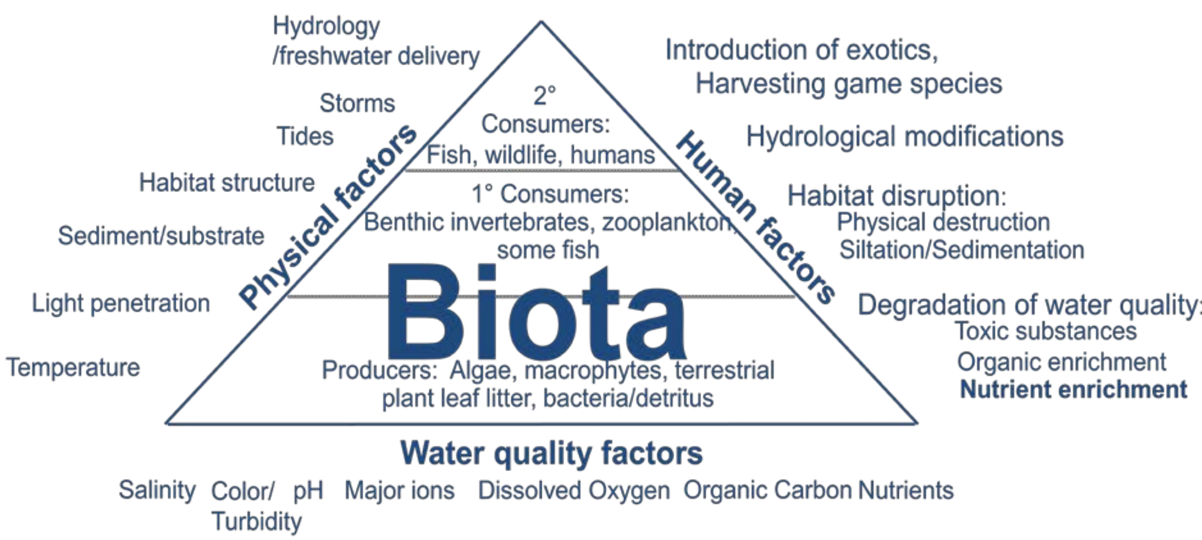

Figure 4. Natural and human factors affecting marine ecosystems. Nutrient effects must be understood in the context of how these factors interact and their ultimate influence on ecosystem structure and function.

1.4 *Symptoms of Eutrophication and Confounding Issues*

During the Department's extensive data-gathering exercise, each estuary report included a checklist that summarized all available information related to the symptoms of nutrient enrichment, including hypoxia, algal blooms, loss of seagrass, and fish kills (Table 2). The checklist of symptoms of eutrophication for each estuary provides very important information relevant to the development of NNC, particularly in those cases where the Department determined that the estuarine system was healthy. However, as noted previously, the determination of whether an estuary is healthy is best conducted using a site-specific, weight-of-evidence approach, and individual symptoms of eutrophication should not automatically exclude estuaries from being considered as having a healthy aquatic community. Issues that should be taken into account include the timing, duration, frequency, and spatial extent of any observed symptoms, and whether the symptoms are likely due to natural factors.

The Department recognizes that the presence of some factors, such as low DO, fecal coliform bacteria, mercury-contaminated fish, and/or harmful algal blooms, such as red tide (*Karenia brevis*), while potentially related to human effects, do not necessarily equate with the effects of anthropogenic nutrient enrichment. Non-nutrient related effects, such as past toxic discharges, past or present physical habitat issues, and/or high-volume freshwater releases (resulting in adverse salinity fluctuations) can also be a factor. The information in Appendix A provides a perspective on these issues related to the Department's nutrient criteria development efforts and provides supporting information on the specific parameters that the Department has concluded should **not** automatically qualify a system as being impacted by excess nutrients from anthropogenic sources. In the example of St. Joseph Bay shown in Table 2, the Department concluded that the biological condition is healthy despite the sporadic occurrence of red tide events, because those events cannot be attributed to local anthropogenic nutrient sources.

Table 2. Example of checklist of nutrient enrichment symptoms for St. Joseph Bay, Florida

Response Variable	Observed Historically?	Observed Currently?	Explanation	Source
Low DO (hypoxia/anoxia)	No	No	The St. Joseph Bay system is shallow, well-mixed, and open to the Gulf of Mexico.	Department (Office of Coastal and Aquatic Managed Areas [CAMA]) 2009
Reduced clarity	No	No	Secchi depths long-term average 7 to 8 feet.	Department (CAMA) 2009
Increased chlorophyll *a* concentrations	No	No	Chlorophyll *a* concentrations are low throughout the bay.	Department/coast data (2000–09)
Phytoplankton blooms (nuisance or toxic)	Yes	Sporadic	Episodic *K. brevis* blooms, which begin in offshore waters and are transported into the bay by currents. Conditions within the bay are not responsible for the blooms.	Florida Fish and Wildlife Conservation Commission (FWC) Fish and Wildlife Research Institute (FWRI) http://research.myfwc.com/features/category_main.asp?id=2309; Livingston 2010
Problematic epiphyte growth	No	No	No problematic epiphyte growth reported.	-
Problematic macroalgal growth	No	No	No problematic macroalgal growth has been reported for the system.	-
Submersed aquatic vegetation (SAV) community changes or loss	No	No	Estimates of SAV coverage vary, but areas with SAV are stable. Communities dependent on seagrasses are characterized as healthy.	Sargent 1995; Florida Environmental Research Institute (FERI) 2007; Department (CAMA) 2009
Emergent vegetation community changes or loss	No	Yes	Some small amount of marsh loss due to physical disturbance, not nutrient enrichment.	-
Coral/hardbottom community changes or loss	Not applicable	Not applicable	-	-
Impacts to benthic community	No	No	A 3-year study by CAMA shows a diverse, abundant juvenile fish and invertebrate community associated with seagrass. Scallop population healthy.	Department (CAMA) 2009
Fish kills	Yes	Sporadic	Related to *K. brevis* blooms or brevetoxins present in the water column when bloom observed. The source of the blooms is offshore water.	FWRI http://research.myfwc.com/fishkill/

1.5 *Main Approaches for Estuarine NNC Development*

The generally preferred approach for deriving a numeric water quality criterion is via a demonstrated cause-effect or dose-response relationship that clearly links a meaningful threshold (a sensitive biological indicator endpoint) to a level of the given pollutant. The meaningful threshold must be linked to designated use support, which, in Florida's case, is a healthy, well-balanced aquatic community. Criteria must be established at a level that will support the designated use and will protect against responses in the biological community that are inconsistent with the designated use.

After synthesizing extensive nutrient and biological information, the Department identified dose-response relationships in only a few of Florida's marine systems, although a relationship between nutrients and chlorophyll *a* was observed using a statewide data set, see Section 2.4. During the data-gathering phase of this project, many Florida expert marine scientists provided information that most Florida estuaries were currently healthy, or did not suffer from nutrient-related issues. Because of this, alternate approaches for criteria development were necessary for most systems. Through this process of gathering site-specific information, the Department identified four main approaches (described in subsequent sections of this report) appropriate for establishing numeric criteria in Florida estuaries:

1. ***Maintain healthy existing conditions approach:*** *This approach provides for maintaining the current nutrient regime in a system determined to be biologically healthy (from the standpoint of nutrient enrichment). Variations of this approach are used in systems that historically exhibited adverse responses, but due to restoration actions or other reasons, their current status is healthy; or in systems that may not currently be biologically healthy, but nutrients are not the cause of the impairment.*
2. ***Historical conditions approach:*** *This method identifies a protective nutrient regime based on a historical period associated with biologically healthy conditions. The healthy conditions typically occurred prior to subsequent nutrient enrichment and biological imbalances.*
3. ***Response-based approach using modeling or empirical evidence:*** *This method involves determination of the maximum allowed nutrient loadings based on demonstrated cause-effect relationships between biological (or response-based) indictors and nutrients. A variation of this approach includes the use of an estuarine model that predicts nutrient response variables (chlorophyll, DO, etc.) and sets nutrient limits that ensure protection of the designated use.*
4. ***Reference Site Approach:*** *Using data from areas with minimal human disturbance to establish expectations (and numeric criteria) for comparable, but potentially anthropogenically affected systems.*

2 Maintain Healthy Existing Conditions Approach

2.1 *Information Requirements for the Healthy Existing Conditions Approach*

While nutrient loads have resulted in nutrient impairment for some marine systems in Florida, information gathered during this effort to develop estuarine NNC indicates that many of Florida estuaries have no demonstrated adverse effects from anthropogenic nutrient inputs. EPA NNC development guidance recommends a "reference condition" approach for criteria development in the absence of cause-effect relationships. "Reference-based" approaches are predicated on the premise that the continued maintenance of nutrient levels (the data distribution) associated with healthy biological conditions will fully support the designated use and will protect and support those uses into the future. However, it must be emphasized that exceeding a criterion derived from a "reference-based approach" **does not** automatically mean that deleterious biological responses, or use impairment, will occur. Criteria derived using a reference-based approach are inherently protective of the resource, provided the following are true:

- *Information indicates that the waterbody fully supports a healthy, well-balanced community;*
- *The reference waterbody must be similar and comparable to the target population of estuaries with which it will be compared; and*
- *The nutrient regime (data distribution) is sufficiently characterized, including the* ***full range of temporal and spatial variability.***

EPA guidance also states that "criteria should attempt to provide a reasonable and adequate amount of protection, with only a small possibility of considerable over-protection or under-protection" (Stephan *et al.* 1985). The Department interprets this guidance to mean that criteria should attempt to minimize the likelihood of both Type I and II statistical errors.

Because Florida estuaries are unique systems with differing natural nutrient concentrations and loading, assimilative capacities, moderating factors, and biological communities, it is not feasible to establish a few reference estuaries that would be representative of statewide conditions. Therefore, the Department decided to apply the method such that **each estuary that is documented to be healthy is used to describe its own reference condition**. The concept behind the "healthy existing conditions approach" is to derive criteria based on the distribution of nutrient data during a "baseline period," which is defined as a period when it can be demonstrated that the waterbody was biologically healthy and achieved its designated use.

The Department, in cooperation with statewide marine experts, identified a number of estuaries that can be characterized as healthy and attaining designated use. These systems either exhibit the minimal eutrophication responses illustrated in Figure 3, or, if biological stress was observed, evidence was presented that nutrients were reasonably **not the cause** for the response. For the "healthy existing conditions" approach, it was concluded that the observed nutrient regime was inherently protective of the system under the conditions unique to that system. Although some signs of biological stress may have been observed in some of these estuaries, the preponderance of the information indicates that nutrient enrichment did not cause or contribute to the degradation. The technical arguments supporting these healthy existing condition determinations are presented in a series of technical support documents assembled by the Department and local experts (contents described earlier), and are available on the Department's website (http://www.dep.state.fl.us/water/wqssp/nutrients/estuarine.htm).

Potential deleterious nutrient responses were summarized into checklists of nutrient enrichment symptoms for each system (*e.g.,* Table 2), and the weight-of-evidence approach described above was used to determine if designated use was being supported. These checklists summarize the detailed information presented within each individual estuary report. The "healthy existing conditions" approach can be used to derive protective NNC for an estuary where the supporting information documents that the estuary is currently meeting its designated use.

2.2 *Components of Water Quality Criteria*

In addition to the requirements discussed in Section 1.3, the CWA states that water quality criteria include magnitude, frequency, and duration components. **Magnitude** is a measure of how much of a pollutant may be present in the water without an unacceptable adverse effect. **Duration** is a measure of how long a pollutant may be above the magnitude, and **frequency** relates to how often the magnitude may be exceeded without adverse effects. As discussed above, it is preferable to derive the magnitude component of a criterion through a cause-effect relationship (such as that measured through toxicity testing). The magnitude would then be set at a level that would protect a majority of the sensitive aquatic organisms inhabiting the system. Absent a demonstrated cause-effect relationship (as is the case for many estuaries), the magnitude may be set at a level designed to maintain the current data distribution, accounting for natural temporal variability.

If response-based data are available, frequency and duration components for criteria are established at levels that result in minimal long-term effects on aquatic life uses. Note, however, that a criterion derived using a reference distribution has no direct link to any observed cause-and-effect relationship. One can only conclude that maintaining the reference distribution will preserve the uses associated with that distribution. Therefore, the frequency and duration components are best established as additional descriptors of the reference condition data distribution. Specifically, these components should be part of a statistical test designed to determine whether the long-term distribution has shifted upward (or potentially downward) from the reference distribution. This test could then be used to establish whether future monitoring data are consistent with the magnitude (*e.g.*, long-term average) defined by the baseline period.

As part of this approach, it is critical to account for the natural variability surrounding the magnitude expression and to control for statistical errors in future assessments of the criteria. The magnitude component can be set to maintain the long-term central tendency (geometric mean) of the distribution, while the frequency and duration components describe how often, and by how much, the nutrient concentrations can be above the central tendency while still being consistent with the reference distribution. Ideally, existing conditions (or reference) based criteria should be set at a level that minimizes the future likelihood of Type I errors (false positives), while simultaneously minimize the rate at which true human-induced effects are not identified (Type II error). It is important to note that statistical Type I and II errors are related to the null (H_o) and alternative (H_A) hypotheses and not whether the waterbody is achieving its designated use. In general form, the H_o states that the mean of (future) monitoring data is not greater than the baseline or reference long-term mean condition; while the H_A states that the mean of (future) monitoring data is greater than the baseline or reference long-term mean condition. Attainment of the designated use (and narrative nutrient criterion) is a related issue; however, decision errors related to the attainment of designated use are not strictly speaking Type I or II errors. In fact, these attainment decision errors occur because the wrong null hypothesis or baseline condition is being evaluated; that is, the criterion is either overly stringent or under-protective than is necessary. Statistical error rates may be assessed once proper null and alternative hypotheses are stated and an appropriate and representative baseline distribution has been established (Table 3). An appropriate baseline distribution is a nutrient data distribution that has been documented to be associated with maintenance of natural populations of flora and fauna (*e.g.*, propagation and maintenance of expected fish and macroinvertebrate populations, healthy seagrass, absence of algal blooms or nuisance algal mats).

Table 3. Hypothesis testing decision error framework.

Decision	True Environmental Condition	
Decision Made by Applying Statistical Hypothesis Test to Data	Waterbody Achieves Reference or Baseline Condition	Waterbody Does Not Achieve Reference or Baseline Condition
Decide that Waterbody Achieves Reference or Baseline	Correct Decision	Decision Error (False Acceptance or type II error)
Decide that Waterbody Does Not Achieve Reference or Baseline	Decision Error (False Rejection or type I error)	Correct Decision

Previous reference based proposals, such EPA's January 26, 2010 for Florida streams (U.S. EPA 2010; Table 4) can result in high Type I errors. For example, previous attempts to describe the frequency and duration component of a numeric nutrient criterion have generally been stated as follows: "the annual geometric mean for a waterbody shall not surpass the reference site 75th percentile more than one time in a three-year period." The problem with this approach is that it results in a high Type I error rate for waterbodies with long-term geometric mean concentrations near the 75th percentile. In fact, a waterbody with a long-term geometric mean at the 75th percentile would be expected to exceed this test 50% of the time. The problem with these approaches arises from that fact that there no attempt to link the selected percentile with frequency and duration. That is, there was little consideration of how frequently the threshold percentile would be expect to reoccur given the baseline variability. A binomial distribution can be used to estimate the frequency of exceeding a threshold given a specific number of trials. The probability of getting exactly *X* successes in *n* trials is given by the function:

$$P(X) = \frac{n!}{X!\,(n-X)!}\,p^x q^{n-x} \qquad (1)$$

Where,

> *p* = probability of selecting at random a member of the category (*i.e.,* probability of exceedance), and
>
> *q* = the probability of selecting a member of the second category (*i.e.,* probability of nonexceedance) = 1-*p*.

Given a log-normal distribution, where a median is near the threshold value, the long-term geometric mean is a good estimate of the median. Thus, the long-term geometric mean will be expected to have an annual exceedance probability (*p*) of 0.5. Given this *p,* one would expect a 0.125, 0.375, 0.375, and 0.125 probability of observing 0, 1, 2, or 3 exceedances, respectively, of the long-term average threshold in any 3-year period due to natural variability alone. Compliance with the criterion would be achieved if there is either 0 or 1 exceedance, which is associated with a cumulative probability of 0.5 (Table 5).

Table 4. EPA-proposed NNC for Florida flowing waters (January 26, 2010). The criteria included magnitude, duration (annual), and frequency (not be surpassed more than once in a three-year period or as a long-term average).

Nutrient watershed region	Instream protection value criteria	
	TN (mg/L) [a]	TP (mg/L) [a]
Panhandle [b]	0.824	0.043
Bone Valley [c]	1.798	0.739
Peninsula [d]	1.205	0.107
North Central [e]	1.479	0.359

[a] Concentration values are based on annual geometric mean not to be surpassed more than once in a three-year period. In addition, the long-term average of annual geometric mean values shall not surpass the listed concentration values. (Duration = annual; Frequency = not to be surpassed more than once in a three-year period or as a long-term average).

Table 5. Probability and cumulative probability of observing X and ≤ X exceedances, respectively, in a 3-year period given an annual exceedance probability of 0.5. Probabilities were calculated based on the binomial probability function (Equation 1). A site or waterbody with a long-term average concentration equivalent to the nutrient criterion has an annual exceedance probability of 0.5.

X (# exceedances)	P(X) (probability of X exceedances in three trials)	Cumulative P (probability of ≤X exceedances)
0	0.125	0.125
1	0.375	0.500
2	0.375	0.875
3	0.125	1.000

Estuarine criteria based on the reference approach as outlined here are, by their nature, less likely to have Type II decision errors because the criteria are derived from a long-term dataset representing an ecological condition that is not harmed by excess nutrients. Therefore, it is very unlikely that a strategy designed to maintain the existing distribution of nutrient values would result in Type II errors. From a biological standpoint, the biological community is entirely adapted to the existing nutrient regime (including its range of variability, which includes some naturally higher levels). Therefore, harmful ecological changes would not be expected to occur unless the overall nutrient regime was increased in a statistically significant manner over the baseline nutrient regime. Furthermore, due to mitigating factors such as assimilation, transparency, and water residence time, statistically significant increases in nutrients (when compared with a baseline period) may still support a healthy, well-balanced community.

For the reasons stated above, the Department believes that it is important to control Type I errors, and proposes to establish a reasonable Type I error rate target of 10%. With this target in mind, the Type I error could potentially be reduced by increasing the assessment period (number of years) and the allowable number of exceedances. Figure 5 depicts the cumulative binomial frequency distributions for assessment periods, ranging from 3 to 7 years, where the annual probability of is 0.5. A 10% Type I error rate is achieved at the point where the cumulative probability of exceedance (probability of *X* or fewer exceedances) intersects 0.9—*i.e.,* the point where there is only a 10% probability of observing greater than *X* exceedances in *n* trials. Although increasing the assessment period and number of exceedances would reduce the Type I error, the number of exceedances required to achieve an acceptable Type I error (*e.g.*, 10%) would also increase and would result in an impractical assessment tool due to the delayed response time. A more viable alternative is to adjust the probability of annual exceedance (*p*). This alternative is discussed in more detail below.

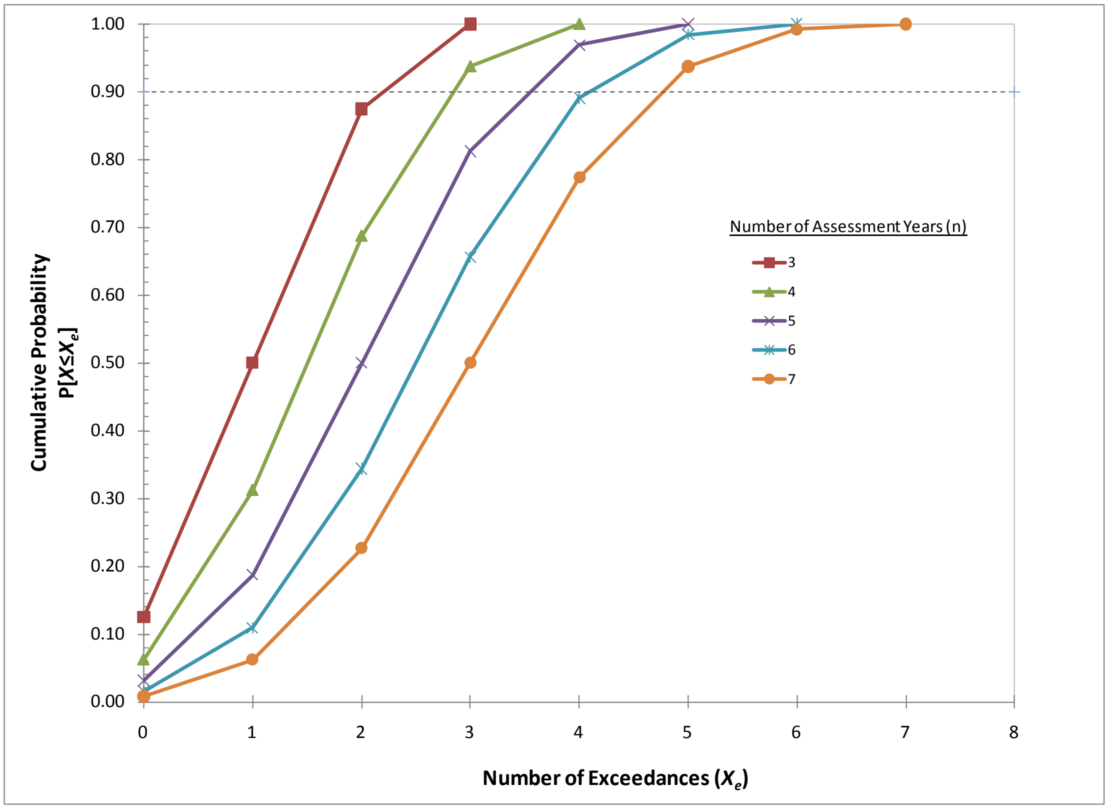

Figure 5. Cumulative binomial frequency distribution of observing X exceedances given n assessment years when the probability of exceeding the criterion in any given year is 50%. Note that for a 3-year assessment period, the probability of observing 1 or fewer exceedances is 50% based on random chance alone.

2.3 *Magnitude*

The magnitude component represents a level of nutrients demonstrated to be protective of the designated use. For the "healthy existing conditions" approach, the magnitude may be interpreted as the central tendency of the baseline data distribution and may be set at a level that represents a long-term average condition of that distribution. St. Joseph Bay is an excellent example of this approach, as it has been clearly demonstrated to be biologically healthy and has been monitored for 9 years (2001–09) across 8 stations in the bay. For this example, natural log-transformed total phosphorus (TP) data were averaged by station and year for years with at least 4 samples. The resulting station annual averages were then averaged by year and then across years to calculate a long-term network geometric mean of 13.14 micrograms per liter (µg/L). This magnitude component therefore represents the maximum allowable central tendency of a frequency distribution and would be protective of the designated uses. However, due to the lack of cause-effect relationships between nutrients and biological response, it may still be somewhat overly protective.

The geometric mean was used in the St. Joseph Bay example because nutrient data are typically positively skewed (Figures 5 and 6), and the geometric mean is considered to be the most robust estimate of the central tendency for positively skewed data. It is the mean of the logarithms, transformed back to the original data. For positively skewed data, the geometric mean is typically very close to the median. In fact, when the logarithms of the data are symmetric, the geometric mean is an unbiased estimate of the true median (Helsel and Hirsch 2002). For distributions that are positively skewed and vary over orders of magnitude (such as nutrients or bacteria counts), the geometric mean is a more accurate indicator of the central tendency than the arithmetic mean (Sanders *et al.* 2003). The use of a geometric mean, coupled with a defined period, has precedent both within Florida and nationally. The Everglades phosphorus criterion is expressed as both annual and long-term geometric means. Geometric means are used in EPA-approved NNC in Hawaii and Oklahoma.

Dr. Xufeng Niu, Florida State University (FSU) Professor of Statistics, evaluated the nutrient data used for this analysis and supported the Department's assumption of a log-normal distribution. He noted that nutrient data typically follow or approximate a log-normal distribution, but acknowledged that this assumption can only be verified with large datasets (such as those with over 200 data points). He concluded that it is acceptable to assume a log-normal distribution even if deviations from a true log-normal distribution occur at the tails of the sampled distribution, as long as the fit is very good at the upper percentile under consideration (e.g., 75^{th} or 90^{th}). He also noted that no sample data follow a "true" log-normal distribution, but that finding the best approximation is an acceptable practice (Niu, pers. comm. 2010).

For the "healthy existing conditions" approach, the Department proposes establishing the magnitude as an annual geometric mean, not to be exceeded more than once over a three- year period.

The objective of the magnitude component is to maintain the long-term average concentration at the level observed in the baseline data set (*e.g.,* 13.1 µg/L TP in St. Joseph Bay). Exceedance of the magnitude component more frequently than once in a three-year period would provide strong evidence that waterbody nutrient levels had increased above the baseline distribution.

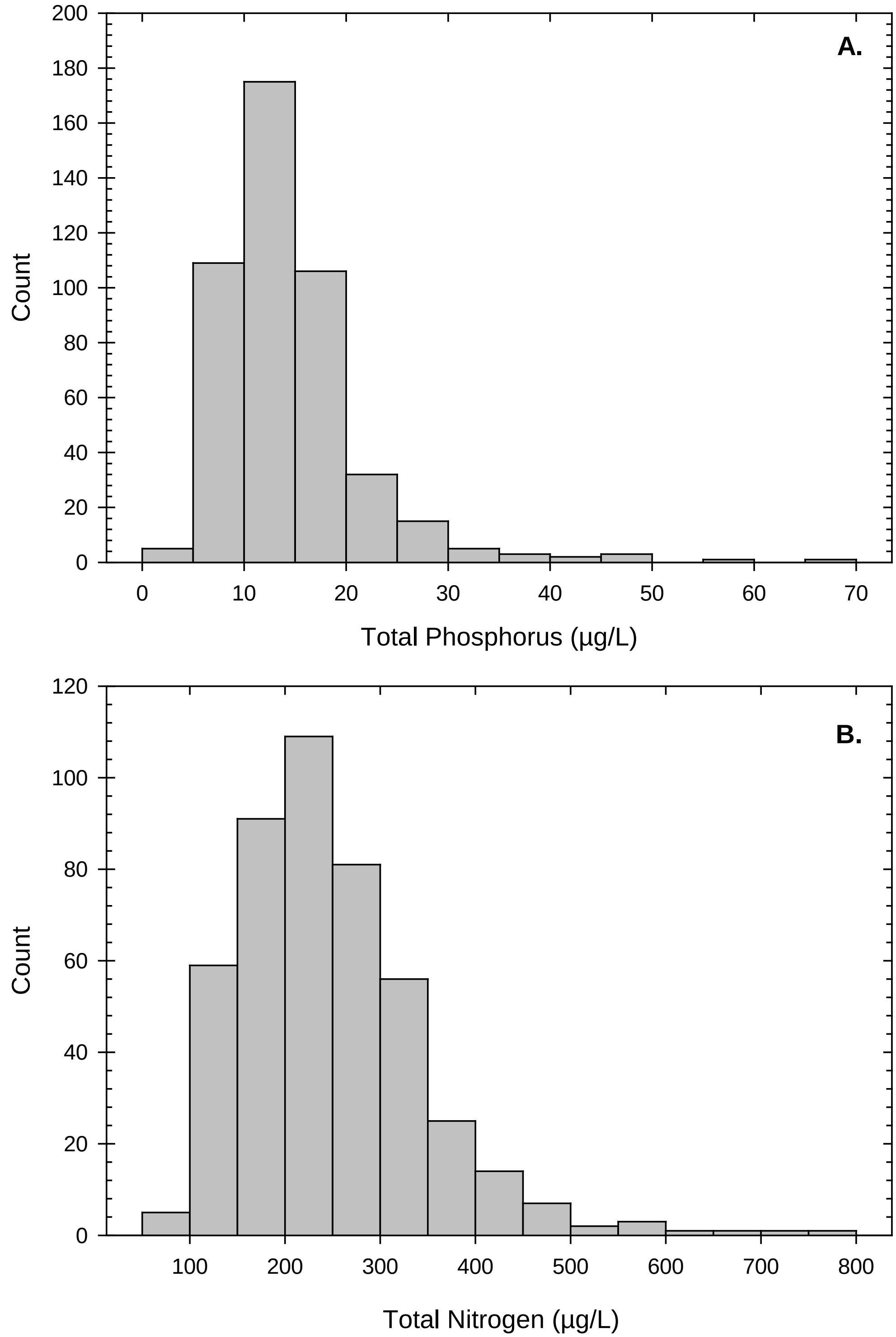

Figure 6. Histograms of (A) TP and (B) total nitrogen (TN) values in St. Joseph Bay, May 2001–July 2009

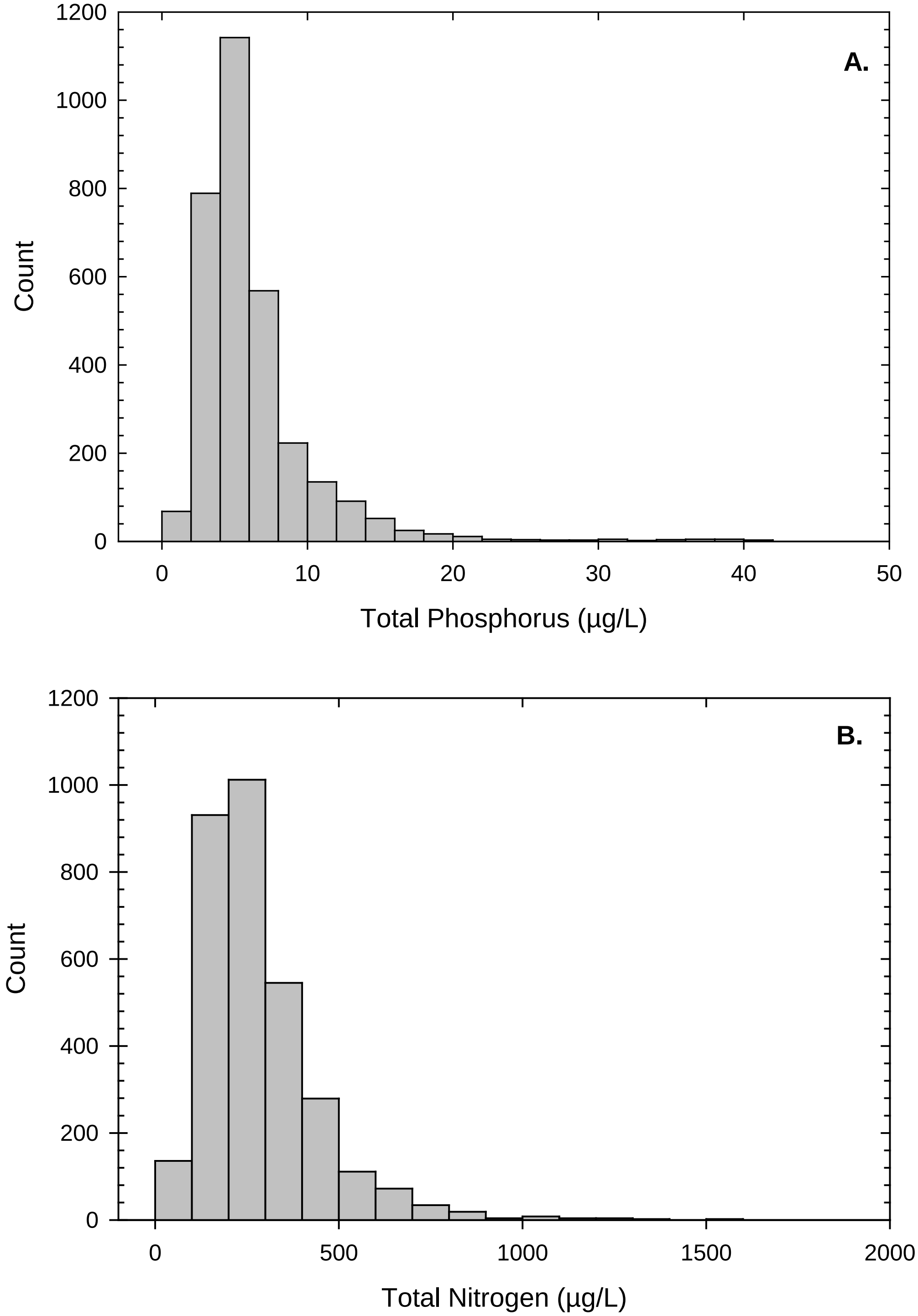

Figure 7. Histograms of (A) TP and (B) TN values in Biscayne Bay, June 1989–July 2009

2.4 *Frequency and Duration*

To be protective, the duration of the criteria (*e.g.,* annual geometric mean, long-term mean) must be linked to the response time frame of the sensitive endpoint. For example, when criteria are derived based on 96-hour acute toxicity testing, a 1- to 24-hour averaging period would be fully appropriate. Likewise, a 4-day averaging period is protective when criteria are based on chronic toxicity testing. If a sufficiently robust cause-effect relationship demonstrates that an adverse response occurs over a short time frame, then short-term averaging periods (*e.g.*, 1 to 30 days) would be appropriate for nutrient criteria, provided the response can be linked to nonattainment of the designated use. If, however, such a short-term response cannot be demonstrated, or there is no indication of designated use impairment, then longer averaging periods are scientifically defensible.

For example, nutrient averaging periods over the period of a year were used by the Department and EPA to assess the chlorophyll *a* response to nutrient enrichment in Florida lakes. Regression analyses using daily sample data were extremely weak. When data were evaluated based on annual average natural log-transformed data, sufficiently robust relationships were found. EPA used these relationships to propose nutrient criteria for Florida lakes expressed as annual geometric means. Coincidentally, the use of an annual geometric mean was consistent with the derivation of the magnitude and observed response time frame.

Because criteria derived using the “healthy existing conditions” approach are not linked to any particular response time frame, this approach does not suggest any inherently protective duration. However, an analysis of the relationships between chlorophyll *a* and phosphorus and nitrogen concentration in Florida’s healthy estuaries demonstrates the linkage between long-term nutrient levels and response. The Department has preliminary evidence suggesting that a long-term duration is in fact appropriate for the purposes of establishing NNC (Figure 8). Additionally, decisions regarding the duration of the averaging period should involve practical considerations, such as establishing an effective strategy for describing the baseline distribution and the development of a reasonable assessment test for determining whether future monitoring data are consistent with the baseline.

As previously stated, there is an established precedent for using annual geometric means for this type of application. Since the goal of a reference-based approach is to maintain the long-term average condition (trophic status), describing and assessing the variability around the annual geometric mean is especially suitable for this purpose. Durations over shorter periods would be associated with much greater variability around the central tendency and would not be any more effective at detecting deviations from the baseline distribution. Therefore, the Department is proposing that the duration be expressed over a period of one to five year.

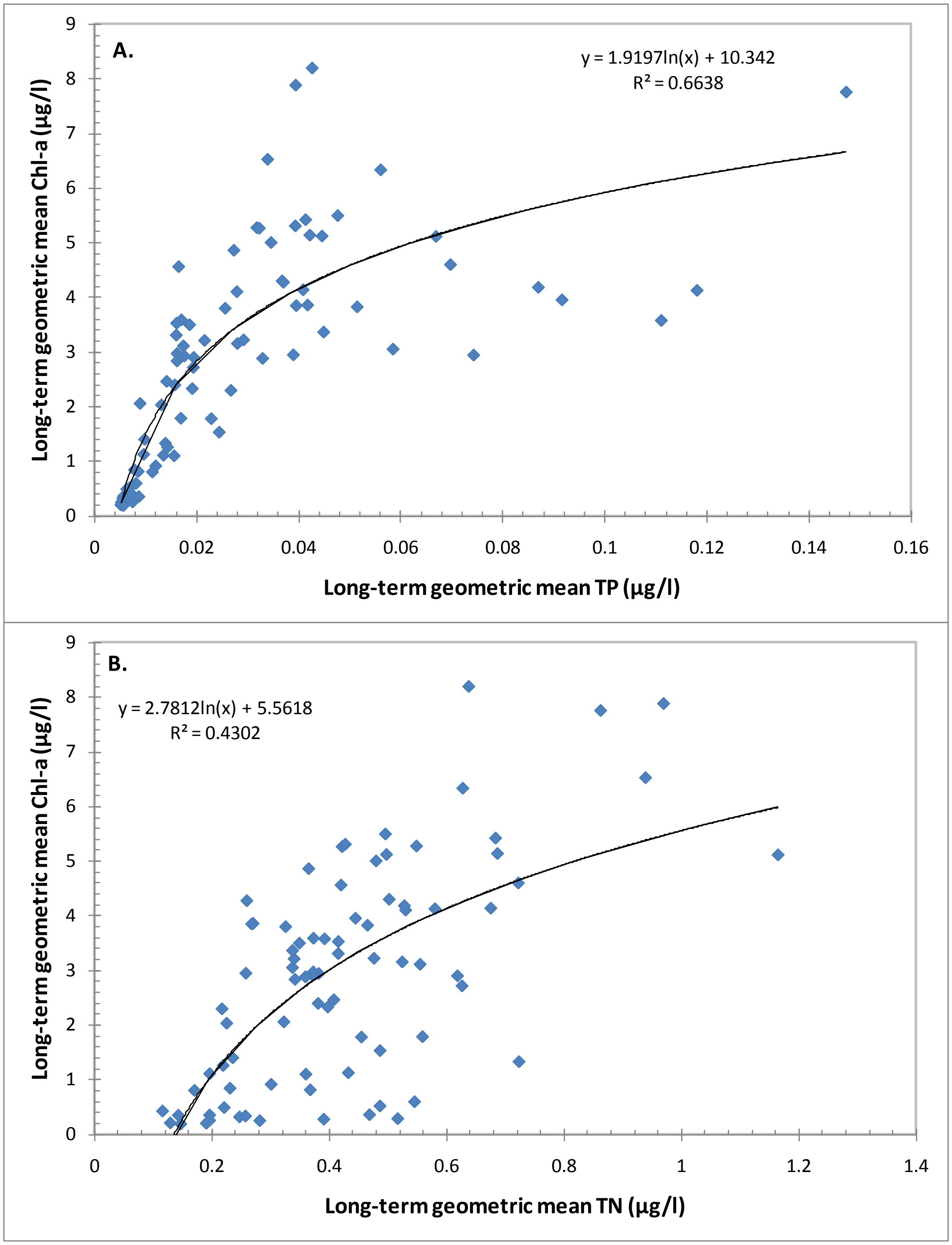

Figure 8. Relationship between long-term geometric mean chlorophyll a and TP (upper panel) and TN (lower panel) from 75 healthy Florida estuary segments.

Annual Limit

Given the goal of maintaining an existing frequency distribution, a scientifically defensible approach would be to use the frequency and duration components, in conjunction with magnitude, to assess whether the distribution has shifted upward (or potentially downward in estuaries such as Apalachicola Bay). Such an assessment methodology may be derived statistically when given the stated management goal of no more than a 10% Type I error rate. This assessment of the Type I error rate is related only to addressing the null hypothesis that future monitoring data are equivalent to the baseline distribution. This Type I error does not take into account the possibility that a higher nutrient threshold would be fully protective of the use. The Type I error rate, for the current application, may be defined as the rate of incorrectly identifying waters as nutrient impaired, based simply on an exceedance of the statistically derived threshold, when in fact the system is biologically healthy.

The target error rate may be achieved by establishing a NNC that acknowledges inherent natural and analytical variability of the dataset that represents the current condition. This involves targeting maintenance of the current condition on average by utilizing representations of confidence limits around the mean of the dataset, with a specified frequency and duration. Setting a cap using this upper confidence level (assessment limit) represents an upper end of the frequency distribution around the long-term average target. If conditions remain below that limit, then confidence is provided that long term concentrations have not increased. Previous proposals by EPA have utilized 3-year assessment periods to express the magnitude and duration nutrient criteria components. Although it is possible to construct a test that achieves the 10% Type I error rate target over a 3-year period, a slightly longer period (5 years) will provide better long-term control Type I errors where there is significant autocorrelation between years, Type II error rates, and will more fully capture climatic cycles [*e.g.*, El Niño, La Niña, and the Atlantic Multidecadal Oscillation (AMO)].

An acceptable excursion frequency can be set using a 3-year period as the basis of assessment. The excursion frequency should account for inter-annual nutrient patterns and be established at a frequency that allows for effective and timely nutrient control; that is, it should account for and allow natural inter-annual variability associated with climatic cycles, and recognize that multiple high nutrient years can occur in succession. A consideration of this inter-annual correlation would suggest that the excursion frequency should allow for multiple excursions in a three-year period, such as two out of five or three out of five years. However, regulatory agencies often target a more rapid assessment period to allow for the implementation of corrective action in a timely manner, making less frequent excursions more desirable for expressing the criteria (*e.g.*, only once in a 3-year period).

Once an acceptable excursion frequency has been selected, a nutrient target can be set at a level that is expected to result in no more than a 10% Type I error rate, given the observed variability in the baseline dataset. The target is set at a percentile or upper prediction interval that corresponds with a 3-year cumulative exceedance probability of no more than 0.8, calculated using Equation 1. For example, an exceedance frequency of no more than once in a 3-year period can be set at the long-term 80^{th}

percentile (Table 6).[2] The appropriate exceedance probability was selected by using the Excel goal seek function to find a percentile (*i.e*., the probability of an annual geometric mean greater than the given percentile) that would achieve a cumulative 1- out of 3-year probability of an exceedance rate of no more than 0.9.[3]

In this example, an exceedance of the 1-in-3-year test accurately predicts that the long-term average concentration has increased. Likewise, the target of a 10% Type I error can also be achieved by setting the allowable excursion frequency to 0 or 2 years out of 3 years by setting the annual criterion magnitude to approximately the long-term 97th or 54thpercentiles, respectively. From a management perspective, allowing less frequent excursions (*e.g*., once in a 3-year period) would provide a more effective nutrient control strategy than waiting for a full 3 years to take corrective actions. Furthermore, not allowing for any exceedances (*i.e*., 0 in 3 years) is not realistic, since this would not allow for the full range of natural variability and would result in an excessive number of false positive exceedances. Therefore, the Department is proposing to derive protect nutrient thresholds based on a no more than 1-in-3 year excursion frequency.

Table 6. Probability and cumulative probability of observing X and ≤X exceedances, respectively, in a 3-year period, given an annual exceedance probability of 0.20. Probabilities were calculated based on the binomial probability function (Equation 1).

X (# exceedances)	P(X) (probability of X exceedances in 3 trials)	Cumulative P (probability of ≤X exceedances)
0	0.512	0.512
1	0.384	0.896
2	0.096	0.992
3	0.008	1.000

Because nutrient data very typically follow or approximate a log-normal distribution, the Department has historically used a geometric mean and log-normal statistics to describe nutrient distributions and calculate upper percentiles (Section 62-302.530, F.A.C.; Payne *et al.* 1999, 2000, 2003). The approximation of a percentile using this method requires knowing or estimating the long-term mean (μ) and standard deviation (σ). For the determination of applicable NNC, the mean is set to the long-term network geometric mean (*e.g.,* 13.1 µg/L for the example of St. Joseph Bay), and the standard deviation is based on the variability observed within the baseline dataset.

The parameters μ and σ are estimated from available data that were collected over a given period. Because the goal of the criterion is to maintain a long-term average concentration, it is imperative to estimate the full range of variability within a waterbody, given all sources of variance. Furthermore, Section 62-302.530, F.A.C., states that "in applying the water quality standards, the Department shall take into account the variability occurring in nature and shall recognize the statistical variability inherent

[2] Twenty percent of the future annual geometric mean values are expected to be above the upper 80th prediction interval.
[3] The 10% Type I error rate may be confirmed by using Equation 1 and summing the probabilities of observing 0 and 1 exceedances, given that *p* equals 0.20.

in sampling and testing procedures." The full range of variability or true inter-annual variance is composed of annual, spatial, and within-year (sampling) effects, such that the annual average concentration on the log scale is given as:

> Ln (annual geometric mean concentration) = mean + year effect + site effect + within year effect + error.

The variances associated with site and year effects are based on TP concentrations that have been averaged over spatial or temporal scales and are thus less influenced by short-term events. The site effect provides an estimate of the spatial variability within the waterbody, while the year effect represents inter-annual variability, which is largely driven by climatic and hydrologic cycles. However, it also important to realize that long-term variability is still influenced to some degree by shorter-term phenomena. The overall influence of these phenomena will diminish with longer averaging periods. For example, a single storm event can result in TP concentrations that are elevated well above the long-term average concentrations for a short period (due to factors such as sediment resuspension). If by chance a sample were collected during this period, then the influence of the storm would clearly affect the results for the given sample date and the within-year variance, and the event would also result in a higher overall annual average for the year. Furthermore, the influence of this single short-term event would affect longer term averages of the annual averages (*e.g*., 3, 4, and 5 years). However, the overall influence of a single event, no matter how unusually high, will diminish as more data over longer periods are averaged.

In ecosystems minimally affected by human disturbance, the observed or sampled average condition within a waterbody (and resulting data distribution) is the result of the sum of a number of random processes operating on different temporal and spatial scales. Criteria established to maintain an existing condition must account for the full range of variance so that realistic expectations of future conditions may be established. Estimates of variance that do not include both spatial and temporal components fail to fully account for the range of natural variability within a system, and thus criteria derived from such estimates are prone to more statistical error, particularly Type I, than intended.

Methods of sampling to measure compliance with established nutrient criteria should be compatible with the procedures to establish the criteria (Davis *et al.* 2001). The compatibility of sampling methods, for distributional derived criteria, would require that future sampling be conducted across the same number of stations within a specified geographic area (or even the same set of stations) and with a consistent sampling methodology, including number of annual samples (for additional discussion on this topic, see Section 6). However, while regulatory agencies are required to assess criteria compliance at all times and all places, funding to conduct fixed long-term monitoring is limited. To meet the requirements of the CWA within budgetary constraints, regulatory agencies are typically forced to use "found data"—*i.e.,* agencies are not typically making ambient compliance determinations based on fixed monitoring stations or consistent monitoring designs. The "found data" are collected for a variety of purposes over varying spatial and temporal scales, with a range of sampling frequencies. Therefore, it is highly unlikely that future compliance data will be wholly consistent with the baseline dataset used to derive NNC. The location of stations will change over time, as will the number of samples used to assess waters, and thus the true long-term variance in the system will be greater than would be calculated based on a straight calculation of inter-annual variance. In other words, spatial and within-year variance cannot be assumed to be fixed.

One solution to this problem is to account for the influence of spatial and sample (within-year) variance. This approach attempts to account for the added variability expected from a non-fixed monitoring design. The true inter-annual standard deviation for a network of stations is calculated as:

$$\sigma_{tyr} = \sqrt{\sigma_{yr}^2 + \frac{\sigma_s^2}{n} + \frac{\sigma_{sd}^2}{n \cdot k}} \tag{2}$$

where,

σ_{tyr} = true interannual standard deviation
σ^2_{yr} = the year-to-year variance (year effect)
σ^2_s = variance among stations (site effect)
σ^2_{sd} = within year variance for a station (date effect)
n = average number of stations within the network
k = average number of annual samples collected at a station

The within-year variance is calculated as the pooled within-year variance across stations and years. Equation 2 applies if criteria are intended to be applied as a spatial average across a waterbody and was developed based on the variance analysis describe by Walker (1981) and Knowlton *et al.* (1984). The use of this approach assumes that the baseline dataset was drawn from a reasonably homogeneous waterbody and that there are not significant temporal trends in the dataset. If the waterbody is not homogenous, then it should further segmented prior to criteria derivation. The values of *n* and *k* are not fixed and could be assumed to be random variables, although the values will fall within a limited range. The average number of stations and annual number of samples per station were used as the best estimates of expected *n* and *k*, respectively.

Alternatively, the set values of *n* or *k* could be used to investigate the influence of more or less intensive future monitoring designs. Equation 2 can be used to calculate the true (expected) long-term inter-annual variability around the network long-term average network concentration. An example of a calculation for the Central Florida Bay segment of Florida Bay is presented to illustrate the approach. Only site-years with at least four samples were included in the calculations. Table 7 summarizes the spatial and temporal variance components and potential criterion components.

Table 7. Summary of TP, TN, and chlorophyll a variance components, long-term average concentrations, and upper prediction limits for the Central Florida Bay segment of Florida Bay. The variance components and average network concentrations are on the natural log scale. Calculations were based on sites with at least four samples per year. Limits are presented for illustration purposes and do not represent final criteria recommendations or proposal. The segmentation of Florida Bay is explained in the Florida Bay technical support document.

Component	TP (mg/L)	TN (mg/L)	Chlorophyll *a* (µg/L)
Spatial variance (σ^2_s)	0.2767	0.0636	0.3208
Inter-annual variance(σ^2_{yr})	0.2992	0.3446	0.4621
Within-year standard variance (σ^2_{sd})	0.5039	0.3780	0.9820
Average number of stations within the network (n)	4	4	4
Average number of annual samples collected at a station (k)	11.7	11.7	11.6
Average network Ln	-4.274	-0.324	0.315
Spatially averaged geometric mean (µg/L)	0.0139	0.723	1.371
True inter-annual standard deviation (σ_{tyr})	0.3384	0.3504	0.5098
N (Number of Years	14	14	14
One-sided *t* value	0.870	0.870	0.870
Upper 80% prediction limit (1:3 years)	**0.0189**	**0.992**	**2.17**

The primary objective of the healthy existing conditions approach is to establish magnitude and frequency limit(s), which if exceeded in the future, would allow one to conclude with sufficient statistical certainty that the new distribution is not consistent with the baseline distribution. In other words, the Department wants to be confident that a future annual geometric mean is consistent with the baseline dataset distribution, rather than from some different data distribution. Given this goal, the use of a **"prediction interval"** is the most appropriate statistical tool. Prediction intervals are used to estimate the range of future data, such that 100(1-α) % of the future data will fall within the prediction interval and 100(α) % will fall outside the interval (Helsel and Hirsch 2002). Helsel and Hirsch (2002) provide an equation to calculate an asymmetric (log-normal) prediction interval. An upper prediction limit can be calculated as:

$$P.I. = e^{\left(\bar{y}+t_{(\alpha,n-1)}*\sqrt{\sigma_y^2+\sigma_y^2/n}\right)} \quad (3)$$

where,

$\bar{y}$ = the mean of the log-transformed data
σ^2_y = the variance of the log-transformed data
n=sample size (number of years)

Equation 3 and the estimate of the true long-term standard deviation (σ_{tyr}) from Equation 2 were used to calculate the upper 80 percent[4] prediction limits on annual geometric mean nutrient concentrations for Florida's estuaries. The upper limit is used because the resulting value represents a level that should not be routinely exceeded, resulting in maintenance of current conditions or lower. In other words, if the cap is not exceeded, we have confidence that nutrient concentration conditions have not increased. These limits correspond to annual geometric mean concentrations that are expected to be higher in only 10% of future years, given the range of spatial and temporal variability measured during the baseline periods for these waters. Therefore, it also represents a level that would be expected to result in a no more than 10% Type I error if applied as an annual geometric mean, not to be exceeded more than once in a 5-year period. Table 7 presents an example of the upper 80 percent prediction limits for Central Florida Bay.

It should be noted that prediction limits are generally greater than the corresponding percentile value and may be thought of as the percentile plus a confidence interval. While the Department concluded that this is appropriate given the uncertainty associated with future monitoring data, MTAC members requested an example the magnitude of difference between an upper prediction interval and the corresponding percentile. For the Central Florida Bay segment, the 80 percent prediction limit (not to be exceeded more than once in a 3-year period), is 0.0189 mg/L for TP, 0.992 mg/L for TN, and 2.17 µg/L for chlorophyll. For the same dataset, the 80th percentile of the data distribution is 0.0185 mg/L for TP, 0.971 mg/L for TN, and 2.10 µg/L for chlorophyll.

2.5 *Criteria Expression*

For a "healthy existing conditions" dataset, the Department's proposed criterion expression is to set the magnitude expression as an annual geometric established at the upper 80 percent prediction limit of the spatially averaged annual geometric means, with a frequency and duration of no more than 1 annual geometric mean exceeding the limit in a 3-year period.

The above proposed expression of the criteria is illustrated in the following example using data from for Central Florida Bay segment of Florida Bay. The long-term geometric mean for Central Florida Bay is 0.014 µm/L (Table 7). Using the true long-term standard deviation from the monitoring data (σ_{tyr}; 0.34), criterion annual TP limit of 0.0189 mg/L was calculated based on equation 3. The criterion would be expressed as follows: "the annual geometric mean TP shall not surpass 0.019 mg/L more than once a year in a 3-year period." This establishes the magnitude component as an annual geometric mean of a network of sites, with the frequency and duration components used to assess whether the inter-annual variability is consistent with the maintenance of the long-term geometric mean (0.014 mg/L), considering natural variability around that average.

Evaluation of Type I Error Rate

A Monte Carlo simulator was developed by DEP to evaluate whether the assessment test is expected to achieve the target Type I error rate (Figure 9). The simulator is based on a random effects model**:**

[4] An upper (one-sided) 80% prediction limit is equivalent to a (two-sided) 60% prediction interval.

$$Y_{nyr} = \ln(\text{nutrient concentration}) = \mu + \delta_{yr} + \delta_s + \delta_{sd} \tag{4}$$

where,

Y_{nyr} = natural log network annual average concentration on year (yr)
μ = natural log of the long-term geometric mean
δ_{yr} = year effect (mean = 0, standard deviation = σ_{yr})
δ_s = site effect (mean = 0, standard deviation = σ_s)
δ_{sd} = replicate error (mean = 0, standard deviation = σ_{sd})

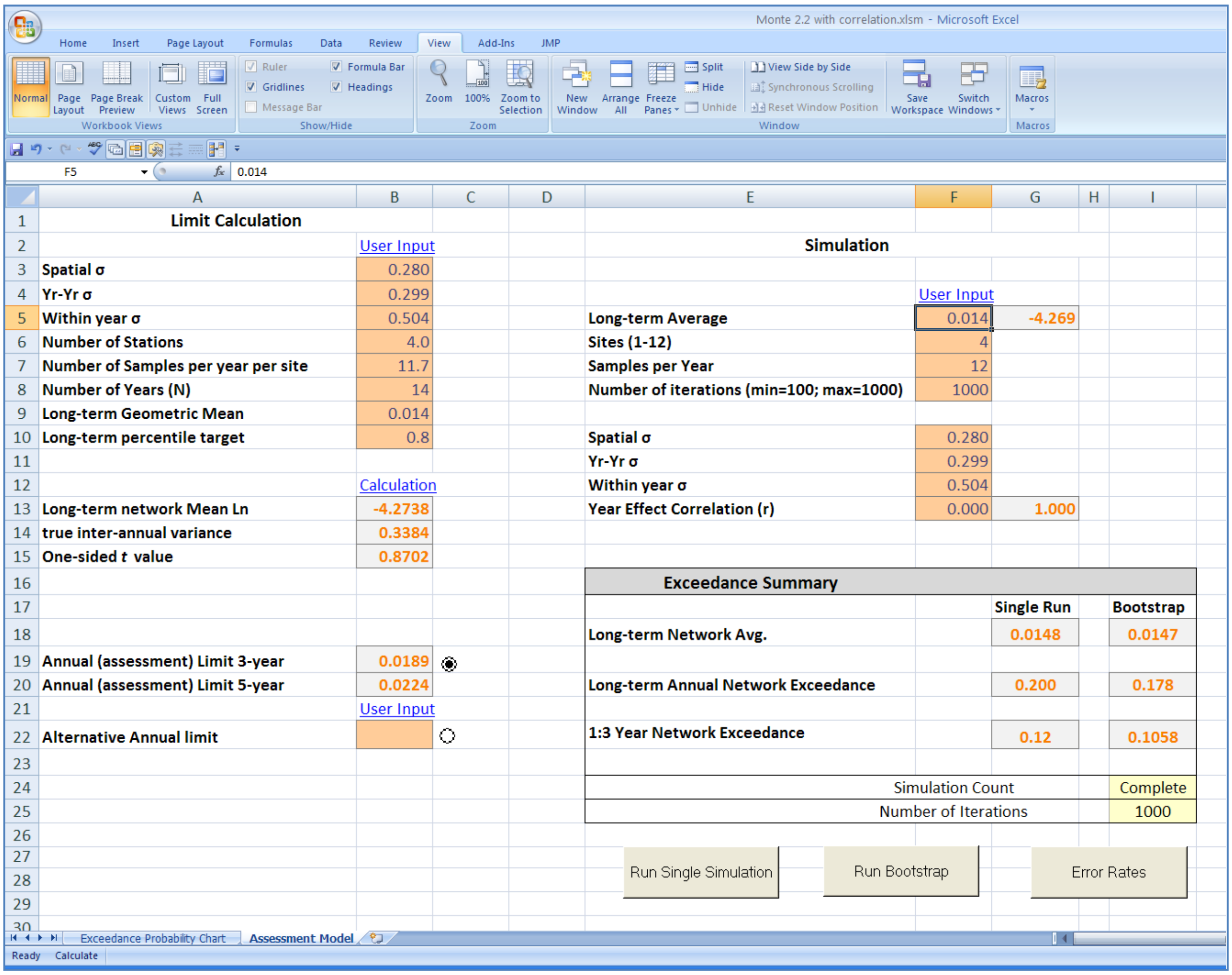

Figure 9. Example of output from the Marine Nutrient Criterion assessment method simulator. The example uses Central Florida Bay TP. A single simulation run projects expected results over a 100-year period.

In addition to assessing the Type I error rate of a given criterion for a waterbody, the Monte Carlo simulator can be used to estimate Type II error rates given scenarios of an increasing long-term geometric mean and/or increasing variability around the mean. It is important to note that Type II error only relates to the statistical question of whether the true long-term geometric mean is greater than the criterion magnitude allows. Because of the inherent limitations of this reference data distributional approach, this error estimate **does not** relate to whether a given waterbody would actually experience use impairment at the higher long-term geometric mean.

For the Central Florida Bay example, 1,000 simulations (of 100 years each) were run under long-term geometric mean TP concentration scenarios ranging from 0.009 to 0.045 mg/L. These scenarios were used to estimate the probability of exceeding the annual geometric mean of 0.019 mg/L more than once in a 3-year period (Figure 10). A network with a long-term average of 0.014 mg/L would be expected to exceed the frequency and duration test no more than 10% of the time, a level that achieves the target Type I error. Conversely, a Type II error of 10% would be achieved at a long-term geometric mean concentration of approximately 0.025 mg/L; that is*,* there is a 90% chance of exceeding the criteria tests at a long-term average concentration of 0.025 mg/L.

The error rates could be improved by increasing the sampling intensity both in terms of the number of stations and annual samples. It is impossible to achieve equivalent Type I and II error rates at the long-term limit, unless one accepts error rates of 50%. A 50% Type I error rate is unacceptable, as it would result in incorrectly targeting many perfectly healthy waterbodies for unneeded restoration activities, thus inappropriately using public and private resources that would be better spent addressing truly impaired systems. Type II error rates are controlled by increasing sample size. Longer assessment periods could be considered, but this would necessitate waiting longer to take action in response to a potential problem. The balance between Type I and II errors is highly reasonable, given that no threshold of imbalance or use impairment has been identified for the Florida estuaries proposed for the "healthy existing conditions" approach. The proposed approach seeks to maintain these systems at their current long-term geometric condition and within the range of natural variability.

2.6 *Healthy Existing Conditions Approach Summary*

The primary objective of the healthy existing conditions approach is to establish magnitude, duration and frequency limits, which if exceeded in the future, would allow the Department to identify with sufficient statistical certainty when a new distribution of data is not consistent with the baseline distribution. In establishing these limits, the Department has made the management decision to limit the Type I error rate to 10%, and has utilized the upper 80th percent prediction limit. The Department proposes a test to determine if the data distribution has shifted:

> *Establish an annual geometric mean limit at the upper 80 percent prediction limit of the spatially averaged annual geometric means, with a frequency and duration of no more than 1 annual geometric mean exceeding the limit in a 3-year period.*

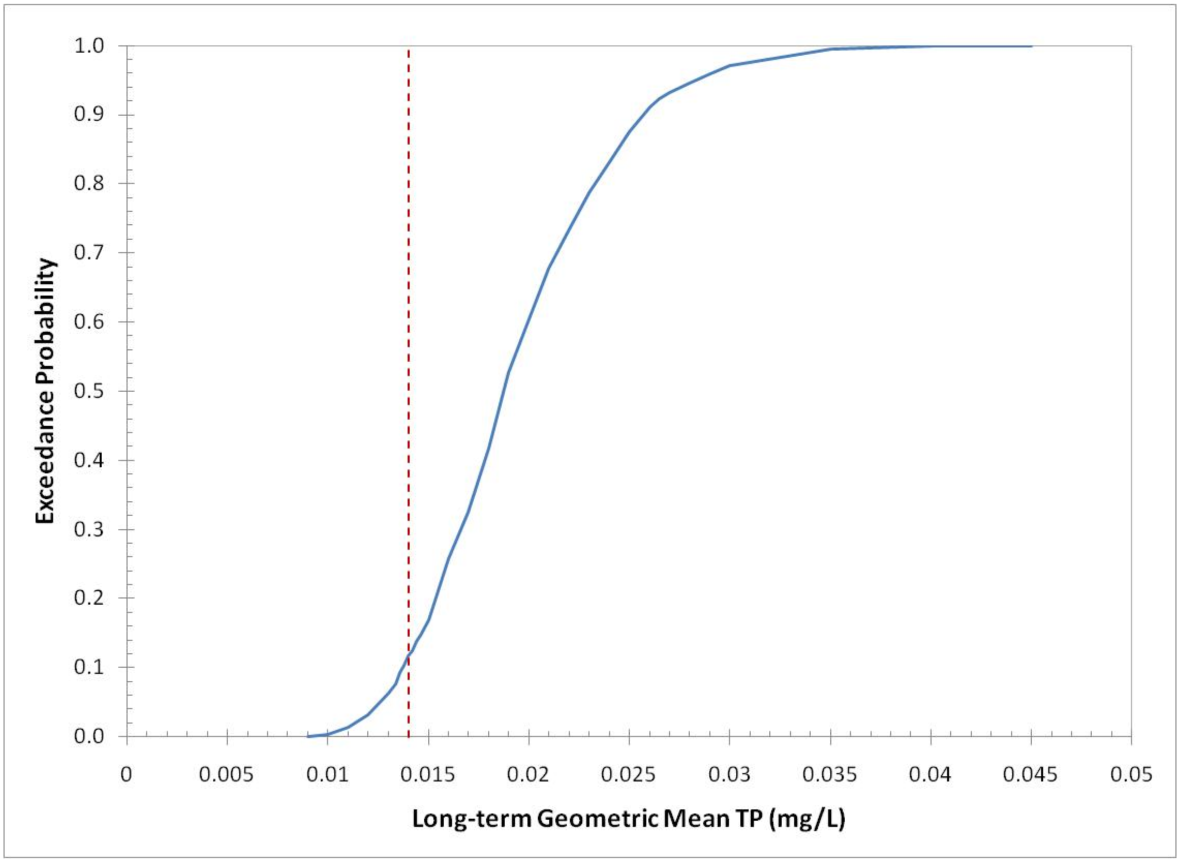

Figure 10. Probability of exceeding an annual geometric of 0.019 mg/L more than once in a 3-year period within Central Florida Bay, given a long-term average TP level (x-axis). Probabilities were generated using a Monte Carlo simulation assuming variance components equivalent to the existing conditions dataset and a network of 4 stations with 12 samples each per year, consistent with baseline period sampling regime. Note: The variance around higher TP averages (>0.014 mg/L) is likely to be greater than observed in the existing conditions dataset, and thus the exceedance probabilities would likewise also be greater than shown in the plot.

2.7 2011 Estuary Specific Criteria Development

The Department has concluded it has sufficient data available to move forward with estuary specific criteria in systems from Clearwater Harbor south to Biscayne Bay. To establish protective criteria, DEP has used a weight of evidence approach to demonstrate that existing nutrient conditions (including assessing SAV, macroalgae, and epiphytes, as well as other information) are appropriate, or used cause-effect relationships between nutrients and seagrass coverage targets. In both cases, TP, TN, and chlorophyll a criteria were established as the most effective methods to maintain healthy, well balanced communities.

3 Historical Conditions Approach

If excessive anthropogenic nutrient loading has resulted in biological impairment in a marine system, and if nutrient and biological data are available both before and after this disturbance, nutrient criteria may be established based on the historical conditions approach. This approach requires the following:

- *An affirmative demonstration that the system was biologically healthy during the reference period;*
- *Adequate nutrient and biological data associated with pre- and post-disturbance; and*
- *A response variable that links the nutrients to impairment.*

Extensive pre- and post-disturbance data are available from Perdido Bay, which represents a suitable example of this approach. These data document a period when a healthy, well-balanced biological community was characteristic of the system, before anthropogenic nutrient loading resulted in adverse responses. The Department proposes to derive criteria based on the distribution of nutrient data during the healthy "baseline period," when the waterbody was biologically healthy and achieved its designated use. The derivation of the criteria would then follow the procedure described in the "maintaining healthy existing conditions" section.

The principal response to anthropogenic nutrient enrichment observed in Perdido Bay was the proliferation of HABs, during a period of elevated point source nutrient loading, that resulted in secondary effects on the bay's trophic functioning (Livingston 2010). From 1988 to 1991, the plankton and fish/invertebrate communities were indicative of healthy, well-balanced conditions in Perdidio Bay, with a low occurrence of plankton blooms (> 106 cells per liter). The numerically dominant phytoplankton species included the diatom *Cyclotella choctawhatcheeana*, with the highest numbers of phytoplankton noted in midbay areas. *Miraltia throndsenii*, *Prorocentrum cordatum*, *Gymnodinium splendens*, and *Skeletonema costatum* were present in the bay, but were noted in relatively low numbers. Cryptophytes and nannoplankton were most numerous in mid-bay areas. Biomass of consumer trophic levels (including commercially valuable shrimp, crab, and fish species) in Perdido Bay during this period indicated healthy conditions.

Beginning in 1996, aftr two years of increased nutrient loading to the bay from a large point source, there were major changes in the phytoplankton assemblages in the bay. Phytoplankton abundance was highest in the upper bay, where the raphidophyte *Heterosigma akashiwo* became dominant. *H. akashiwo* is well known for ichthyotoxic blooms (Honjo 1994). Concurrently, the formerly dominant diatom, *C. choctawhatcheeana*, was greatly reduced in the upper bay, although this taxon was still dominant in mid- and lower bay areas.

Starting in 1998, there were reduced (but variable) nutrient discharges from the point source to Elevenmile Creek, and the phytoplankton community began to shift again by 2001–02 (Livingston 2010). *M. tenuissima* became the top dominant in the upper bay, and phytoplankton abundance in the upper bay largely consisted of cryptophytes and nannoflagellates. In the mid- and lower bay areas, *C. choctawhatcheeana* was dominant, and although *H. akashiwo* was still present in all parts of the bay, it had reduced in abundance.

Both ammonia and orthophosphate loading from Elevenmile Creek were significantly ($P<0.05$) associated with *H. akashiwo* cell numbers (Livingston 2010). The number of Heterosigma blooms in the upper bay was inversely related to the number of *C. choctawhatcheeana* blooms ($R2 = -0.36$, $P< 0.05$). Annual averages of *Cyclotella* reached peaks with the downward trend of Heterosigma during the period of high but diminishing nutrient loading from Elevenmile Creek (1994–99). While the changes in abundance for several species were clearly linked to changes in nutrients, there were also general increases in salinity stratification during the drought periods of 1999–2002 and 2006–07, and the salinity changes also impacted algal species composition. For example, the blue-green alga *M. tenuissima* was directly associated with bottom salinity ($R^2 = 0.38$, $p< 0.05$) and salinity stratification ($R^2 = 0.45$, $p<0.05$). The cryptophytes and nannoflagellates in the bay near Elevenmile Creek peaked during the drought of 1999–2002, with nannococcoids reaching peak values at the end of the drought. The combination of the history of nutrient loading and drought appeared to affect the long-term distribution of these phytoplankton groups.

The series of HABs that initially occurred in 1996 (described above) resulted in a significant adverse effect on the trophic functioning of Perdido Bay's fauna (Livingston 2010). Livingston developed a Fish/Infauna/Invertebrate (FII) Index to describe the health of estuaries based on trophic relationships. The index includes determining the biomass (grams per square meter [g/m^2]) of herbivores, omnivores, and three levels of carnivores (primary= C1, secondary= C2, and tertiary=C3). Figure 11 depicts the pattern and distribution of the various FII trophic levels in Perdido Bay over the 19-year study period. The biomass of consumer trophic levels (including commercially valuable shrimp, crab, and fish species) in Perdido Bay decreased markedly after the occurrence of *H. akashiwo* blooms. This is evidence that the nutrient loading responsible for the HABs interfered with the designated use of the bay, and that reducing nutrients to the level that occurred prior to the HAB proliferation would return the system to a healthy, well-balanced state.

After 2003, reductions in nutrient loadings to the bay were implemented, and partial, but not complete, biological recovery was observed. The Department proposes that the nutrient loading that was characteristic of the bay prior to the proliferation of HABs be adopted as protective numeric criteria. This specific nutrient loading, which was associated with healthy, well-balanced aquatic communities, would protect the designated use of Perdido Bay. This concept was recently upheld by a Florida Administrative Law judge during 2010 court proceedings:

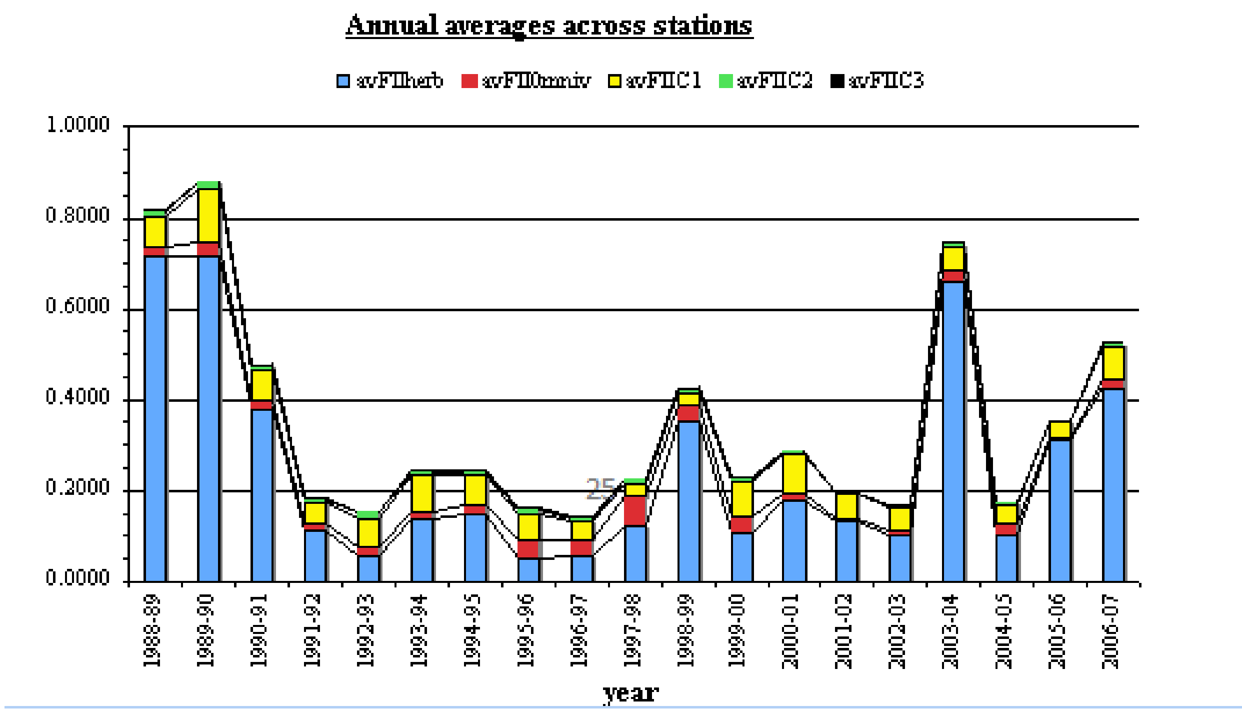

Figure 11. Annual averages of the FII Index trophic organization across stations from 1988–89 through 2006–07. Blue=herbivores, Red=omnivores, Yellow= Level 1 consumers, Green = Level 2 consumers, Black = Level 3 consumers.

> *"Because Dr. Livingston determined that the nutrient loadings from the mill that occurred in 1988 and 1989 did not adversely impact the food web of Perdido Bay, he recommended effluent limits for ammonia nitrogen, orthophosphate, and total phosphorous that were correlated with mill loadings of these nutrients in those years. The Department used Dr. Livingston's data, and did its own analyses, to establish WQBELs [water quality–based effluent limits] for orthophosphate for drought conditions and for nitrate-nitrite. WQBELs were ultimately developed for total ammonia, orthophosphate, nitrate-nitrite, total phosphorus, BOD [biochemical oxygen demand], color, and soluble inorganic nitrogen.*
>
> *The WQBELs in the proposed permit were developed to assure compliance with water quality standards under conditions of pollutant loadings at the daily limit (based on a monthly average) during low flow in the receiving waters. Petitioners failed to prove that any new data in the December 2007 report of the Livingston team demonstrate that the proposed WQBELS are inadequate to prevent water quality violations in Perdido Bay."*

The Department proposes to derive criteria based on the distribution of nutrient data during the healthy "baseline period," which was the period when the waterbody was biologically healthy and achieved its designated use. The derivation of the criteria could then conceptually follow the procedure outlined in the "maintaining healthy existing conditions" section, but only using pre-disturbance data. Coupled with this, the Department is also pursuing the use of a hydrodynamic/water quality model of Perdido Bay to determine the nutrient loading to the bay during the reference (healthy conditions) period, but the model results have not yet been fully analyzed. The Department is requesting feedback on this approach.

4 Response-Based Approach

4.1 *General Overview and Key Issues*

The "response-based approach" is the preferred method for developing NNC, but the approach to date has generally been limited to cases where there have been demonstrated adverse biological responses to anthropogenic nutrient enrichment. For this approach to be scientifically defensible, the dose-repose relationship must be explicitly quantified, within a range of uncertainty, and criteria must be established at a concentration (or loading) where the adverse response is not expected to occur, given a specified confidence level. This type of information is available for estuaries that have been identified as impaired by nutrients and for which nutrient Total Maximum Daily Loads (TMDLs) were developed. Nutrient TMDLs have been developed for several major estuarine systems in Florida, including the Lower St. Johns River (LSJR), Indian River Lagoon (IRL), St. Lucie River and Estuary (SLE), and Tampa Bay. These TMDLs have generally been based on one of two main approaches: (1) combined hydrodynamic and water quality models that use literature-based relationships between nutrient levels and algal growth; or (2) empirical relationships between nutrient levels (concentration or load) and some biological response, typically chlorophyll *a* or seagrass distribution.

Because nutrient TMDLs have the same goal as NNC (to establish the amount of nutrients the waterbody can assimilate and still maintain applicable water quality standards), the Department plans to submit the adopted nutrient TMDLs to EPA as the estuary-specific NNC for each of these systems. However, a variety of issues must be addressed when translating nutrient TMDLs into NNC, including whether to convert TMDL loads into concentration, how to convert loads into concentrations (if necessary), clarification of the frequency and spatial component of the TMDL, and how to develop NNC for causal variable not addressed by the TMDL.

Expression of Criteria as Loads or Concentration

Most TMDLs developed to date for estuaries have been expressed as loads, and a key issue is whether the loads should be converted to concentrations, given that EPA has indicated a general preference for criteria to be expressed as concentrations. This preference seems to be driven by the fact that concentrations can be directly measured, while loads from many sources must be estimated, which means it is easier to determine compliance with criteria expressed as concentrations. EPA guidance has also indicated that water quality criteria for the protection of fish and aquatic life be expressed as concentrations, with concentrations established for both a "criterion maximum concentration (CMC) to protect against acute (short-term) effects, and a criterion continuous concentration (CCC) to protect against chronic (long-term) effects." However, these recommendations apply to **toxic** pollutants and not nutrients. Furthermore, federal regulations (40 CFR § 131.3[b]) specifically allow the flexibility to express criteria as "constituent concentrations, levels, or narrative statement, representing a quality of water that supports a particular use."

Given that federal regulations allow for NNC to be expressed as loads, the Department discussed this issue at length with the MTAC, which recommended that the Department have the flexibility to establish NNC as either loads or concentrations, whichever is most appropriate for the protection of a given estuary. MTAC members noted that they have observed strong relationships between nutrient loading and SAV health in some estuaries, such as Sarasota Bay (Tomasko *et al.* 1992) and the IRL (Steward *et al.* 2010), without these relationships being mediated through either nutrient concentrations or levels of chlorophyll *a*. In Chesapeake Bay, Orth *et al.* (2010) found that in some areas of the bay, trends in SAV coverage were better correlated with nutrient loads, while in other areas, nutrient concentration was a better predictor. The MTAC strongly supported using the most scientifically sound relationship when establishing NNC, whether it was based on load or concentration.

The **health** of the dominant benthic community should be the determinant factor whether load or concentration is the best expression for NNC, rather than changes in water column concentrations of nutrients or even response variables. For example, the interactions between water quality, sediment quality, and nutrient loads and how these factors relate to the macrobenthic community were examined in a detailed study of Chesapeake Bay (Dauer *et al.* 2000). While this study found chlorophyll levels correlated well with nutrient concentrations in the water column, it was nitrogen loading that (negatively) correlated with the health of the benthic community.

The complexity inherent in this determination is illustrated by a 3-year study conducted by Dr. Nikki Dix from the University of Florida (UF) in the Guana-Tolomato National Estuarine Research Reserve (NERR). The system has a natural lack of SAV, and the dominant biological resources are oysters. The study investigated oyster growth rates at 2 sites with different nutrient loading scenarios, and found that oyster biomass and abundance were greater at a site where the TN and TP loads were an order of magnitude or greater than the other site. Although the loads differed significantly between the 2 sites, the mean TN concentrations (0.375 and 0.365 milligrams per liter [mg/L]) and TP (0.056 and 0.052 mg/L) were similar, suggesting that the oyster communities are capable of extracting significant amounts of nutrients from the water column and incorporating nutrients into the benthic communities. Although oysters are not considered to be very sensitive to nutrient enrichment, this study suggests that some nutrient loading may be tolerated in systems where there is a naturally occurring lack of more nutrient-sensitive organisms. However, if excess nutrient loading caused the phytoplankton community to shift to one dominated by low food quality or harmful taxa, the Department could potentially consider this to be an imbalance (depending on the frequency and duration of the response).

It should be noted that the other approaches that the Department plans to use to develop NNC for estuaries produce criteria expressed as concentrations. This is driven by the methodology, which relies on existing concentration data to determine appropriate NNC, and does not indicate a preference for concentration-based criteria. It would require extensive additional resources to determine accurate estimates of loads to these systems.

Translating Loads into Concentrations

If appropriate for the estuary or if required by EPA, the most straightforward way to translate a TMDL load into a concentration is to calculate the long-term average concentration for the period addressed by the TMDL. For example, many TMDLs are expressed as annual average loads, and the Department can calculate annual average concentrations from model output and express the criteria as an annual average concentration. In those cases where the TMDL is expressed as a longer-term average load (*e.g.,* five years), the NNC could be similarly expressed as a five-year average concentration.

Under this approach, the criterion would be set with a long duration/averaging period. While the Department believes this is appropriate given the observed variability in nutrient concentrations, this approach means that even with concentration-based criteria it will not be possible to take individual samples to determine compliance with the criteria. Compliance determinations will require long-term monitoring consistent with the expression of the criteria. Some environmental groups have requested that the Department establish single-sample criteria that would prevent HABs, but the Department has yet to determine consistent relationships between nutrients and HABs. While it would be possible to statistically determine appropriate single-sample expressions for the "maintain healthy conditions approach," the Department does not recommend this approach because the resultant criteria would be extremely high in order to account for the observed variability.

Allowable Frequency of Exceedances

The Department will also need to decide on the appropriate frequency component of the criteria (see **Section 2** for a more complete description of the three components of NNC). For a TMDL expressed as an annual load, the most logical allowable frequency of exceedances is that the load cannot be exceeded in any year. However, TMDLs are sometimes established for a specific flow condition or season, and the Department believes that any NNC based on a TMDL should be consistent with the conditions for which the TMDL was developed.

Spatial Component

Another important issue that must be considered when translating TMDLs into NNC is the spatial component of the criteria. TMDLs are typically expressed as the total allowable load that can be discharged to a waterbody or to a specific segment of the waterbody (the Department uses the term "WBID" or "**W**ater**b**ody **Id**entification number" to refer to segments of rivers). In contrast, water quality criteria have typically been expressed in Florida such that they apply throughout the waterbody. The Department intends to express the NNC based on TMDLs as waterbody or WBID averages.

Establishing NNC for Nutrients Not Addressed by the TMDL

Another issue related to translating TMDLs into NNC is that some TMDLs only address the limiting nutrient,[5] while EPA has requested that states develop criteria for both causal variables (both TN and TP). The Department would like feedback on whether the NNC should address both causal variables even if one is unlikely to ever be the limiting nutrient (for example, natural TP levels in parts of Florida make it highly unlikely that TP will ever be limiting in these areas). The Department is currently considering the option of establishing NNC for the non-limiting nutrient at a concentration (or load) that would maintain existing conditions (using a method similar to that described for healthy systems).

Evaluation of Water Quality Target Used

Finally, when translating nutrient TMDLs into NNC, it is important to review the water quality target that was used when determining the allowable loading. Because there are currently no adopted NNC, part of the development process for nutrient TMDLs has been to determine an appropriate interpretation of the NNC for the system.[6] Water quality targets for nutrient TMDLs have typically been based on a response variable such as chlorophyll *a*, DO, or a multiple parameter index such as the Trophic State Index (TSI), which includes TN, TP, and chlorophyll *a*.

When using models to determine the allowable nutrient levels that will maintain DO concentrations at levels that will support aquatic life, it is very important to acknowledge that many of Florida's estuaries naturally do not meet the generally applicable DO criteria (see example in next section).[7] While the Department plans to revise the DO criteria for predominantly marine waters (likely based on EPA's Virginian Province approach for the development of DO criteria [EPA-822-D-99-002]), the rulemaking needed to revise the DO criteria may not be completed before the adoption of the estuarine criteria. As such, the Department may use water quality models to determine natural background DO levels by conducting model runs with the anthropogenic sources of nutrients removed, and then determine the nutrient loading that would limit reductions in DO levels below background to an agreed-upon amount. EPA has historically considered a 10% change in a water quality parameter to represent an insignificant departure from the existing condition (a "*de minimus"* determination), and this EPA policy was upheld during court proceedings (U.S. 6th Circuit Court 2008).

Calculating Assimilative Capacity of Unimpaired Waters

It should be noted that water quality models and empirical relationships can also be used to determine the assimilative capacity of unimpaired waters. Given the time constraints for NNC adoption imposed by the Consent Decree between EPA and EarthJustice, the Department did not attempt to use this

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[5] The Department typically determines the limiting nutrient by calculating the TN-to-TP ratio: systems with ratios less than 10 are considered TN limited, systems with ratios between 10 and 30 are considered co-limited, and systems with ratios greater than 30 are considered TP limited.

[6] In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna.

[7] The DO criteria for marine waters states, " . . . shall not average less than 5.0 in a 24-hour period and shall never be less than 4.0. Normal daily and seasonal fluctuations above these levels shall be maintained."

approach to develop NNC for unimpaired estuaries because it typically takes years to develop a scientifically defensible hydrodynamic/water quality model. However, the Department can revisit the NNC developed for an unimpaired waterbody if that waterbody is demonstrated to be healthy even though it consistently exceeds the NNC. In that event, the Department may determine if, and to what magnitude, any additional, allowable nutrient levels (loading or concentration) would still result in maintaining full aquatic life use support.

4.2 *Example of Response-Based Approach Derived Via Hydrodynamic/Water Quality Model*

The LSJR TMDL is an excellent example of the hydrodynamic/water quality modeling approach, and can be used as an example to explore how the Department interpreted the NNC. Background information about the river and details on the modeling conducted is available at http://www.dep.state.fl.us/water/wqssp/nutrients/estuarine.htm.

The LSJR is a sixth-order, blackwater river estuary, which exhibits characteristics associated with riverine, lake, and estuarine aquatic environments. Impacts associated with anthropogenic nutrient enrichment that have been documented in the LSJR include elevated algal biomass, periodic blooms of nuisance and/or toxic algae, and fish kills. Portions of the LSJR were placed on the 1998 303(d) list for the development of nutrient TMDLs, and through a collaborative approach with the St. Johns River Water Management District (SJRWMD), a nutrient TMDL for the main stem of the LSJR was adopted by the state and subsequently approved by EPA. A Basin Management Action Plan (BMAP), adopted in October 2008, identified a series of programs and projects that must be implemented by stakeholders in the basin to achieve the TMDL.

During the development of the TMDL, the LSJR was divided into two segments, a freshwater and a marine segment (oligohaline, lacustrine and meso-polyhaline ecozones were combined). In the freshwater segment, a reduction in chlorophyll *a* was determined to be necessary, since chlorophyll *a* was observed to exceed 160 µg/L and cyanobacteria blooms can last for months. The SJRWMD worked with a number of scientific researchers and determined that a chlorophyll *a* target of 40 µg/L, not to be exceeded more than 10% of the time, would be protective of the aquatic biota (see the LSJR Estuary Technical Report for the technical basis for the freshwater target). However, in the marine segment, algal biomass levels were generally low and relatively insensitive to nutrient loading due to the high volume of tidal mixing, meaning that chlorophyll *a* was not a good target for the TMDL.

As an alternative, the Department decided to use DO as the water quality target because low DO levels in the marine portion of the river had previously led to fish kills. However, the Department determined that, while anthropogenic sources of nutrients had depressed DO levels in the estuary, DO levels in the marine portion of the river were naturally below the generally applicable Class III DO criterion (shall not average less than 5.0 mg/L in a 24-hour period and shall never be less than 4.0). As a result, the Department developed and adopted a Site-Specific Alternative Criterion (SSAC) for DO for the marine segment of the river, and the TMDL established the allowable nitrogen loading to the river that would attain the SSAC.

The SSAC for DO was based on the EPA Ambient Aquatic Saltwater Criteria (Virginian Province, EPA-822-D-99-002), which establishes appropriate DO levels based on the biological response of sensitive aquatic organisms to hypoxic stressors and provides for protection from acute and chronic effects of exposure to low DO levels in marine waters. In the LSJR, the SSAC is a minimum DO concentration of 4 mg/L and a Total Fractional Exposure in the range of 4.0 to 5.0 mg/L of 1.0 or less, as determined by the following equation (presented graphically in Figure 12):

$$\begin{pmatrix}\text{Total Fractional}\\ \text{Exposure}\end{pmatrix} = \frac{\begin{matrix}\text{Days between}\\ 4.0 - < 4.2\,\text{mg/L}\end{matrix}}{16\text{day Max}} + \frac{\begin{matrix}\text{Days between}\\ 4.2 - < 4.4\,\text{mg/L}\end{matrix}}{21\,\text{day Max}} + \frac{\begin{matrix}\text{Days between}\\ 4.4 - < 4.6\,\text{mg/L}\end{matrix}}{30\,\text{day Max}} + \frac{\begin{matrix}\text{Days between}\\ 4.6 - < 4.8\,\text{mg/L}\end{matrix}}{47\,\text{day Max}} + \frac{\begin{matrix}\text{Days between}\\ 4.8 - < 5.0\,\text{mg/L}\end{matrix}}{55\text{day Max}}$$

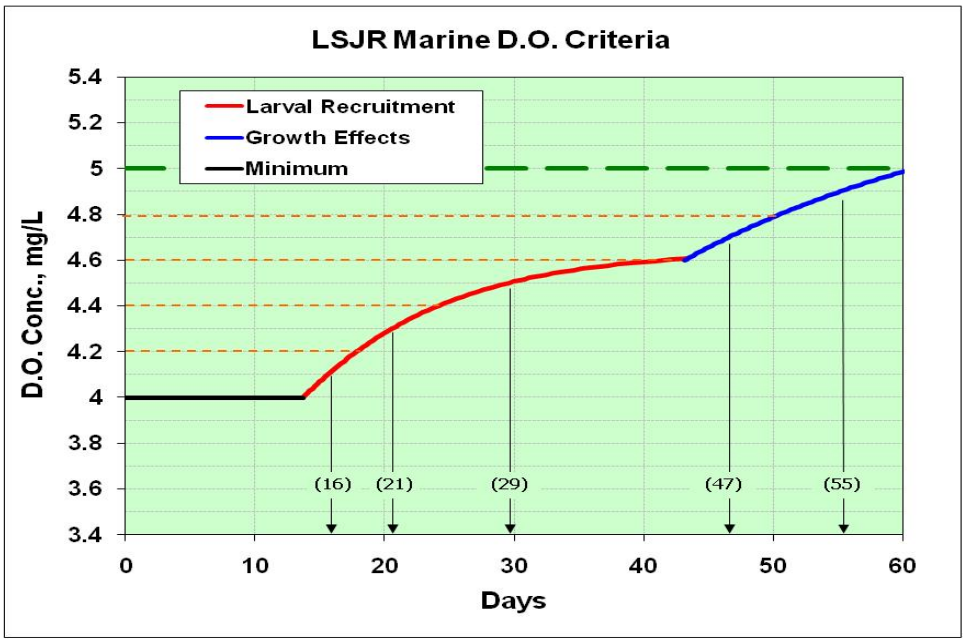


Figure 12. LSJR marine DO SSAC

The nutrient TMDL analysis determined that that the following allowable annual loads (Tables 8a and 8b) would attain the chlorophyll *a* targets in the freshwater portions of the river and the SSAC for DO in the marine portions of the river, and as a result, would restore the LSJR and fully support designated uses.

It should be noted that the TMDLs are expressed as annual loads applied over the entire freshwater and marine portions of the river. To determine a comparable concentration-based NNC, annual average concentrations for these portions of the river could be calculated from the model simulation that included the nutrient reductions and allocations in the TMDL, which in this case was based on conditions between December 1, 1994, and November 29, 1999. TN and TP concentrations averaged 1.21 and 0.062 mg/L, respectively, at Racy Point.

Table 8a. Allowable annual loads to freshwater WBIDs to restore the LSJR and fully support designated uses

Freshwater WBIDs	Parameter	TMDL (kilograms per year [kg/yr])	WLA (kg/yr)	LA (kg/yr)
2213I to 2213N	TN	8,571,563	236,695	8,334,868
2213I to 2213N	TP	500,325	46,357	453,968

Table 8b. Allowable annual loads to marine WBIDs to restore the LSJR and fully support designated uses

Marine WBIDs	Parameter	TMDL (kg/yr)	WLA (kg/yr)	LA (kg/yr)
2213A to 2213H	TN	1,376,855	1,027,590	349,265

4.3 *Example of Response-Based Approach: Empirical Relationships*

The Department considers statistically significant empirical relationships between nutrient levels and biological responses to be a response-based approach, but acknowledges concerns by some parties that "correlation is not causation" and that there can be spurious correlations. Any empirical relationships used to establish NNC should be based on well-established ecological relationships, and the correlations should be used to support the conceptual model and quantify the relationship, rather than to establish the relationship.

One of the best examples of an empirical approach for the development of estuarine NNC is the work done for Tampa Bay. Between the 1950s and 1982, approximately 20,000 acres of seagrass were lost in Tampa Bay due to reduced water column transparency associated with increased phytoplankton chlorophyll a. Studies by the Tampa Bay Estuary Program (TBEP) and others indicated that excess anthropogenic nitrogen loading was clearly the cause for this increased chlorophyll, and that reductions in nitrogen loading would be the primary method for seagrass restoration. The TBEP has established the restoration of seagrass in the bay to levels estimated in the 1950s as the principal goal for overall bay restoration, and management actions during the past 25 years have resulted in significant SAV recovery (Figure 13).

As depicted in Figure 14, a conceptual model for restoring Tampa Bay was developed through the observed empirical relationship that excess TN loading ultimately resulted in reduced SAV. Nitrogen is consistently the limiting nutrient in the Tampa Bay Estuary, and it has been established that phosphorus loadings to the bay from the TP-enriched Bone Valley region do not control estuarine production.

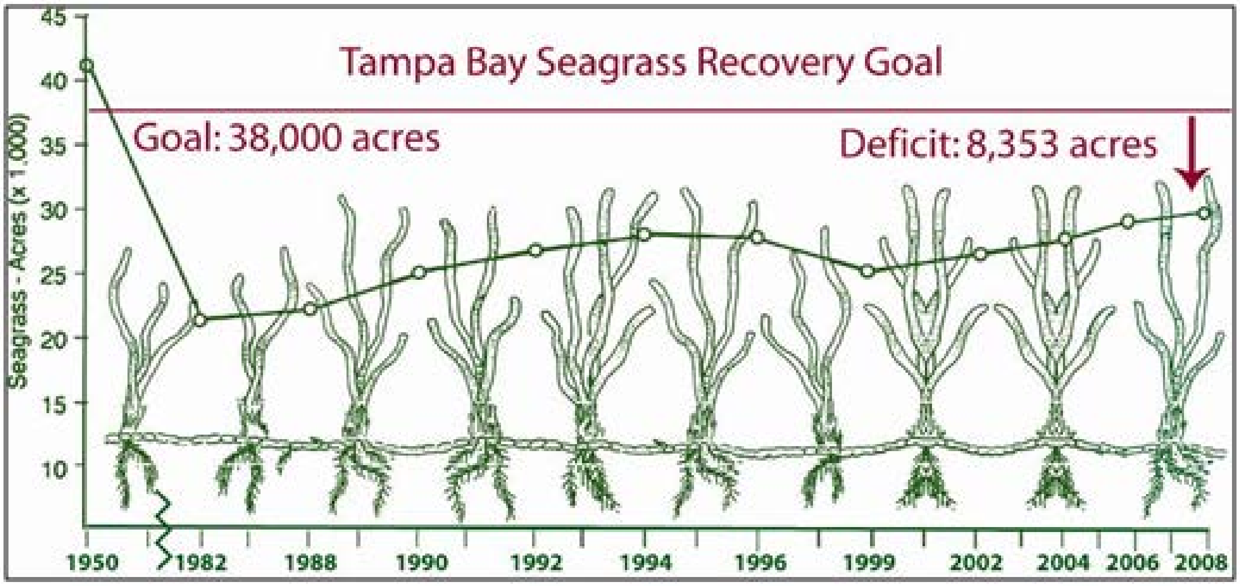


Figure 13. SAV coverage in Tampa Bay, 1950s–2008

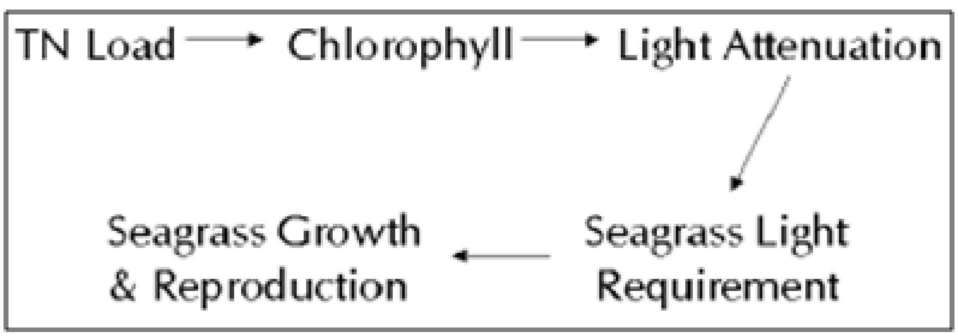


Figure 14. Conceptual model for restoring Tampa Bay through observed empirical relationships

Both empirical (Janicki and Wade 1996) and mechanistic (Wang *et al.* 1999) models were used to relate nitrogen loads to chlorophyll *a* concentrations within the four major segments of Tampa Bay. Results from each modeling approach were consistent with one another (Morrison *et al.* 1996), and the TBEP adaptive nutrient management strategy was further developed through the application of the empirical models initially established by Janicki and Wade (1996).

The empirical regression equation used by Janicki and Wade (1996) to relate TN loads and chlorophyll a concentrations was expressed as:

$$C_{t,s} = \alpha + \beta_s * L_{t,s}$$

Where:

$C_{t,s}$ = The average chlorophyll a concentration at month t and segment s

$L_{t,s}$ = The total nitrogen load at month t and segment s

α and β_s = Regression parameters

A plot comparing the observed chlorophyll a concentrations (horizontal axis) and the empirical model-predicted chlorophyll *a* concentrations (vertical axis) demonstrate the goodness of fit of the model to the empirical data (Figure 15).

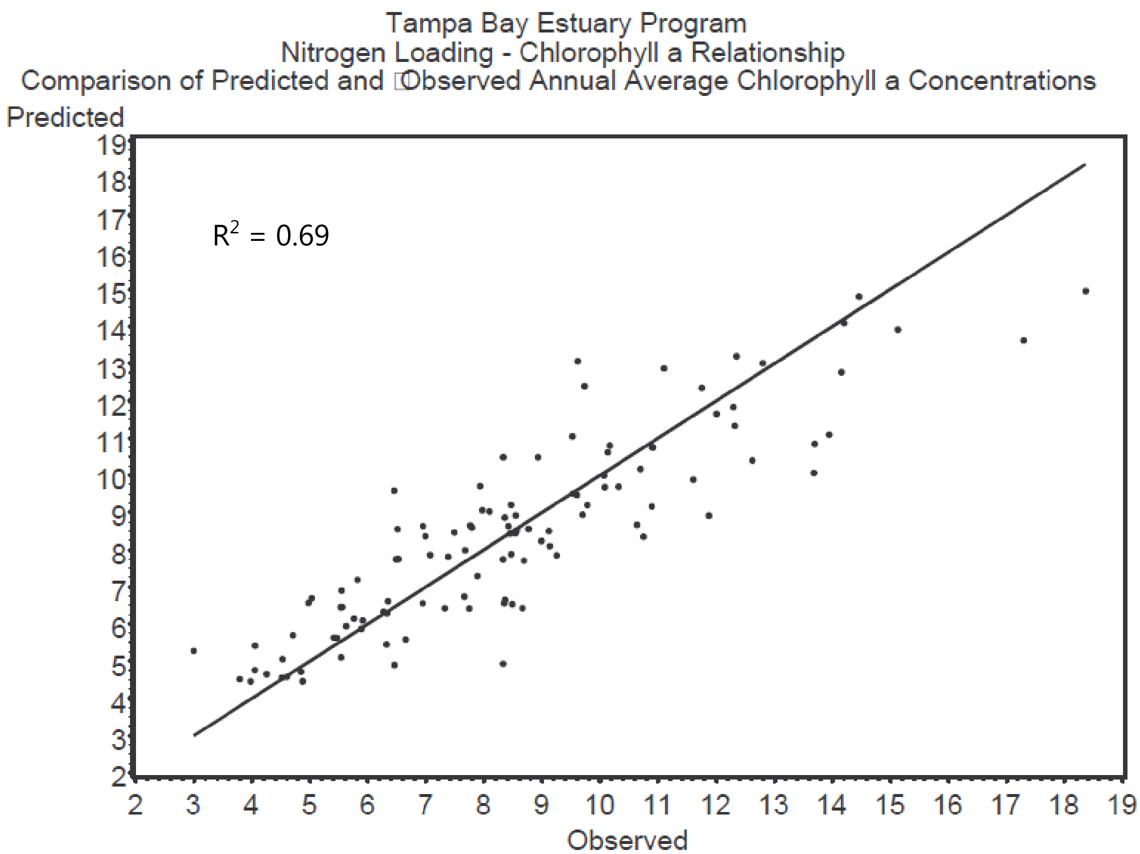


Figure 15. Comparison of observed Tampa Bay chlorophyll a concentrations (horizontal axis) and model-predicted chlorophyll a concentrations (vertical axis)

Once this TN load and chlorophyll *a* concentration relationship was established, Janicki and Wade (1996) empirically established the relationship between chlorophyll *a* concentrations and light attenuation in each of the major bay segments. The TN load-chlorophyll *a* model takes into account the hydrologic exchange and the nonconservative properties of nitrogen within the estuary through various least-square regression approaches (Janicki and Wade 1996). The application of this model reinforced the TBEP adaptive nutrient management strategy of reducing nitrogen loadings to the bay at annual average levels estimated during the 1992–94 period.

Appropriate bay segment–specific chlorophyll *a* concentrations were derived from the second stage of the Janicki and Wade (1996) empirical modeling approach. Chlorophyll *a* levels were related to light attenuation (via estimates derived from Secchi disk depths) using a functional form of Beers' law in a linear regression, and this served as a proxy for light availability to seagrass in the bay. Concomitant to these modeling approaches, Dixon (1999) determined that 20.5% of incident light was required to maintain *Thalassia testudinum* shoot density and biomass at the deepest edge of seagrass beds in lower Tampa Bay. Given this minimum light requirement, predictions of chlorophyll *a* levels and Secchi disk depths (light penetration) necessary to restore seagrass to average depths observed in each of the major bay segments during the 1950s (1.0 meter in Hillsborough Bay to 2.5 meters in lower Tampa Bay) were used to assess the development of annual targets for these parameters (Janicki and Wade 1996; Greening and Janicki 2006).

Based on the improving seagrass coverage and water quality observed over the 1990–96 period, secondary targets were developed from the average annual chlorophyll *a* levels seen during 1992–94 (a period with high and low rainfall during which seagrass was expanding). The ultimate selection of bay segment–specific chlorophyll *a* targets were conservatively established as the average annual levels developed from the empirical model predictions (Janicki and Wade 1996) or the 1992–94 average annual levels—whichever were lower (Table 9; TBEP 1996, 2001). During this same time, the 1992–94 average annual TN loads were established as the appropriate nitrogen load management targets by TBEP partners to support the maintenance of the chlorophyll *a* and light attenuation targets developed for each of Tampa Bay's major bay segments.

Table 9. Various mean annual chlorophyll a (lower and upper 95% confidence interval [C.I.]) target levels developed to address seagrass recovery goals of TBEP partners. Note: An asterisk and bold text indicate targets adopted by TBEP partners in 1996.

Chlorophyll *a* (µg/L)	Old Tampa Bay	Hillsborough Bay	Middle Tampa Bay	Lower Tampa Bay
Mean 1992–94 (95% C.I.)	**8.5*** (8.2-8.8)	**13.2*** (11.9-14.5)	8.1 (7.3-8.9)	**4.8*** **(4.5-5.0) ***
Required level to reach 90% of recovery goal illuminated at 20.5% light (95% C.I.)	10.3 (9.6-11.1)	17.6 (15.7-19.7)	8.6 (7.7-9.6)	5.4***** (4.1-7.1) *****
Required level to reach 95% of recovery goal illuminated at 20.5% light (95% C.I.)	**9.2*** **(8.7-9.8) ***	**16.1*** **(14.6-17.8) ***	**7.4*** **(6.8-8.0) ***	**4.6*** **(4.0-5.2) ***

Since 1996, the chlorophyll *a* and light attenuation targets developed as part of the adaptive nutrient management strategy for Tampa Bay have been periodically re-evaluated (Janicki *et al.* 2001a, 2001b). Also during this time, bay managers have used the annual assessments of the agreed-upon bay segment–specific chlorophyll *a* and light attenuation targets (developed from Secchi disk depths) to guide decisions related to nitrogen management in each of the four major bay segments (Janicki *et al.* 2000). These assessments, termed the annual "decision matrix," have shown that the bay segment water clarity targets developed by the TBEP have been largely met and that a general improvement in annual water clarity conditions in the bay has been seen since the early 1990s (TBEP 2010). Consequently, seagrass coverage in Tampa Bay continues to increase over time (Figure 13).

The maintenance of other designated uses has occurred in response to the nitrogen management strategy developed in Tampa Bay. DO conditions in the bay have been maintained at appropriate levels during the time when nitrogen loads and bay chlorophyll *a* concentrations have been actively managed. Typically, the lowest DO conditions occur during the summer months in Hillsborough Bay; however, no apparent increasing trends have been detected for the areal extent of hypoxia during these months in this bay segment (Janicki *et al.* 2001c). More recently, baywide monitoring data indicate that the overall variability in annual DO concentrations (the difference between the observed maximum and minimum values) appears to be declining over time, and median DO conditions in all major bay segments are protective of aquatic life support (Poe 2006). As a result, fish and wildlife populations in Tampa Bay have either shown stable or increasing trends in abundance due to the overall ecosystem improvements that have occurred in response to nitrogen load reductions in Tampa Bay (Poe 2006).

The premise and rationale for the maintenance of nitrogen loads and chlorophyll *a* concentrations at levels commensurate with 1992–94 conditions to support the recovery of seagrass and other designated uses in Tampa Bay have been accepted through separate state and federal administrative actions. In 2002, the Department approved the target chlorophyll *a* levels that were developed for the major bay segments as site-specific thresholds for nutrient impairment under Section 62-303.450, F.A.C. (Joyner 2002). Based on this determination, the Tampa Bay Nitrogen Management Consortium (NMC) has formally developed an annual assessment and compliance framework that takes into account the frequency and duration of exceeding the chlorophyll *a* thresholds (Figure 16; NMC 2009). If the chlorophyll *a* threshold for a particular bay segment in Tampa Bay is exceeded in two consecutive years of a five-year period and the federally recognized TMDL has not been exceeded, then a re-evaluation of the nitrogen load targets established as the federally recognized TMDL for Tampa Bay for that particular bay segment is prompted (NMC 2009). If the federally recognized TMDL is exceeded, then this re-evaluation may require adjustments of nitrogen load targets (allocations) developed for all major sources discharging to that particular bay segment (NMC 2009; EPA 1998).

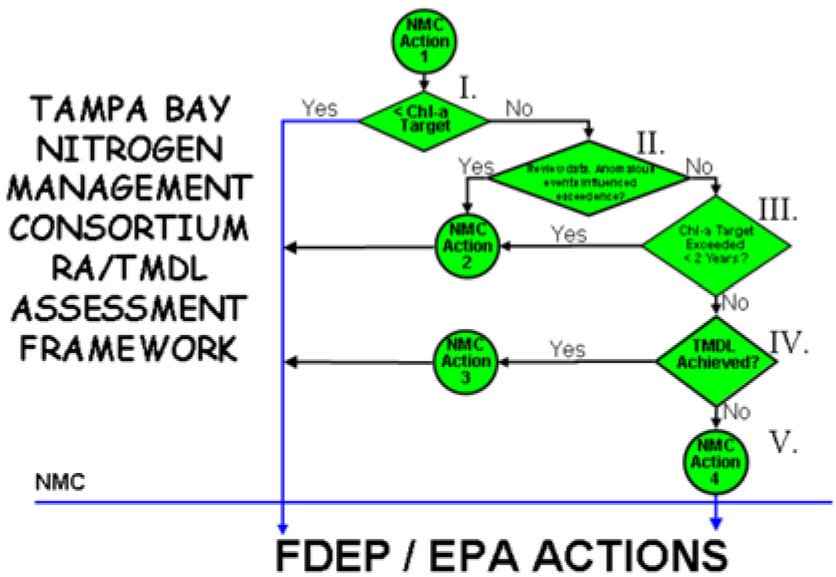


Figure 16. NMC decision framework to assess future reasonable assurance of Tampa Bay nitrogen load and chlorophyll a targets. Actions and steps to be conducted by the NMC are shown in green.

4.4 *Example: Modeling Pensacola Bay to Predict a Natural Conditions Scenario*

In some Florida estuaries, factors other than nutrient loadings (such as sediment toxicity and loss of habitat) preclude full aquatic life use support. In these cases, the influence of nutrients is obscured by the confounding factors. However, the use of an estuarine model to predict nutrient response variables (chlorophyll, transparency, and DO) under a natural conditions scenario could determine if existing levels of nutrients are associated with conditions that would be expected to a support healthy biological community. Additionally, this same model could be used to establish the maximum nutrient loading that would still protect a healthy, well balanced community.

The primary example for this approach is Pensacola Bay, where SAV (the most nutrient-sensitive biological endpoint) was largely eliminated due to toxic point source discharges (primarily ammonia) in the 1970s. Although these point sources have since been mitigated, seagrasses have not been re-established, and it has been suggested that physical restoration (replanting and potential sediment modification) will likely be required to restore the historical seagrass and oyster beds in Pensacola Bay (Hagy *et al*. 2008). An appropriate strategy for seagrass restoration would involve the development of protective depth-to-seagrass light targets, which would ensure sufficient transparency for SAV photosynthesis. The Department conducted a transparency workshop in 2009 that included seagrass experts from Florida and the southeast United States (DEP 2009). Consensus recommendations from the workshop included the following:

- *Depth-to-seagrass or transparency targets should be regionally defined, because there is regional variation in minimum light needs, even for the same species;*

- *Depth-to-seagrass targets should account for algal turbidity (chlorophyll), mineral turbidity, color, and potential epiphyte load.*

While some have argued that nutrient levels are a factor hindering seagrass recovery in Pensacola Bay, the Department has concluded that existing nutrient and transparency conditions are conducive to seagrass recruitment and growth because current chlorophyll *a* levels approximate those that are expected to have occurred under natural conditions. Figure 17 shows the spatial extent of the historical and current seagrass coverage.

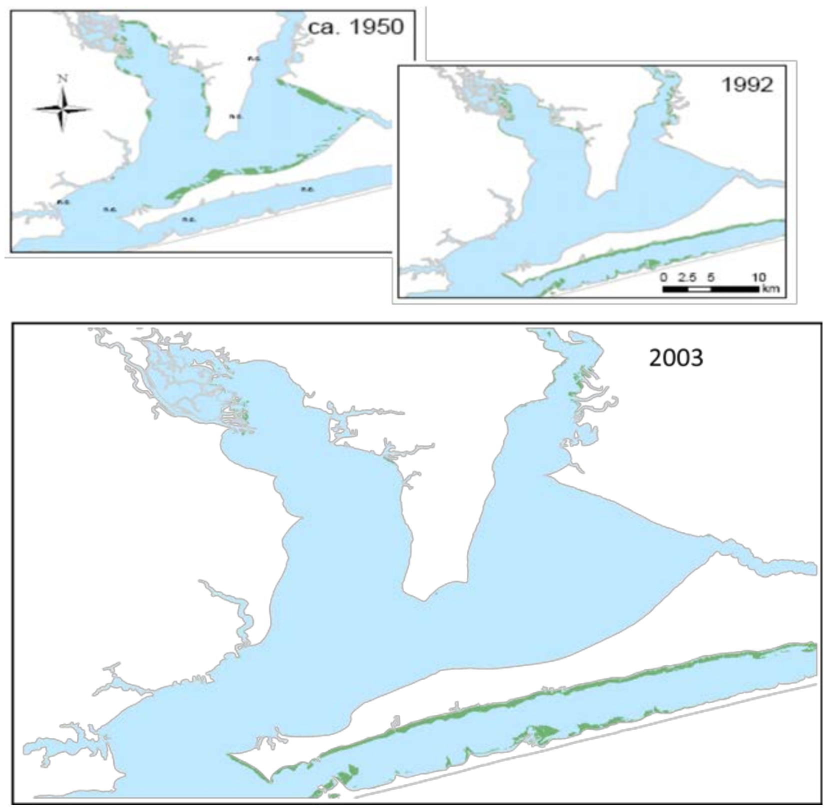


Figure 17. Spatial extent of seagrass in the Pensacola Bay system, 1950–2003. Note that the SAV was historically found only in nearshore areas at depths of less than 2 meters.

HydroQual (2010) developed working and calibrated hydrodynamic and water quality models (estuary models) that were used to evaluate whether the current chlorophyll *a* and transparency levels are adequate for seagrass growth and to evaluate the processes that control the nutrient, phytoplankton, and DO conditions in the Escambia/Pensacola Bay system.

The models are three-dimensional, time variable, and include the Escambia River upstream to Molino, Escambia Bay, Pensacola Bay, Blackwater Bay, and East Bay (Figure 18). The models were calibrated with data collected by Woodward-Clyde (now URS), Environmental Planning & Analysis (EP&A), and International Paper (IP, formerly Champion International). Monthly water quality data collected by

EP&A and weekly water quality data collected by IP were used to calibrate the water quality model. The calibrated hydrodynamic and water quality models resulted in a reasonable representation of both the complex mixing and circulation patterns observed in the study area and the observed nutrient, phytoplankton, and DO dynamics of the system.

Hydroqual (2010) developed a nutrient criteria approach for the Pensacola Bay system based on an EPA proposal identifying three nutrient-related endpoints: chlorophyll a, Secchi depth, and DO. The following were the key steps of the Hydroqual approach:

- *Used the estuary models described above (expanded to include color as a variable and a submodel of sediment flux) to link nutrient loads to nutrient responses (chlorophyll a, bottom light levels, and DO).*
- *Determined bottom light levels sufficient to support seagrass communities in the bay. Bottom light requirements for SAV ranged from 15% to 25% of surface light and were set as a goal in water depths where historical seagrasses existed. The amount of surface light that reaches the bottom was a function of the light extinction in the water column, which is controlled by ambient particulate matter, color, and chlorophyll a levels. These parameters were calculated in the model, with chlorophyll a programmed to be a function of nutrient loading.*
- *Determined natural background DO levels and compared natural background conditions, which are presumed to have supported a healthy bay system, to current DO conditions to determine if nutrient reductions are needed to maintain background DO levels. Modeling demonstrated that natural vertical stratification processes cause bottom waters in the bay to be periodically less than state water quality criteria of 5 mg/L (daily average) and 4 mg/L (daily minimum). The DO goals proposed were that surface waters must meet the water quality standards, and that bottom waters must not differ significantly from natural background levels. DO was directly modeled as a function of nutrient loading.*
- *Determined acceptable chlorophyll a levels using the modeling framework based on the protective nutrient loads that met the seagrass bottom light requirement and DO goals.*

"Natural background conditions" were estimated using the model by removing all point source discharges and converting all agricultural, range, urban, and barren land uses to forest land use. These changes resulted in a reduction in nutrient loads of approximately 44% in the Escambia River, 35% in the Blackwater River, 44% in the Yellow River, and 42% in the East Bay River. A critical component of this analysis was a comparison of the "current" with "natural background" modeling output (Figures 18 through 20). Note that this comparison resulted in extremely minor differences for chlorophyll a, DO, and bottom light levels. Therefore, current modeled conditions in Pensacola Bay confirmed that existing nutrient loadings do not result in significantly different response variables in the system compared with natural background conditions. These conclusions, which indicate that current nutrient loads support the bay's designated use, are as follows:

- *Areas where growing season average bottom light levels are ≥20% compare well with bay areas where seagrass beds have historically existed. This supports the conclusion that existing nutrients and chlorophyll are not the factors preventing SAV recovery.*
- *Calculated DO conditions in the bay indicate that existing conditions in the surface layer meet the expectations based on a natural background scenario.*
- *At the existing loading conditions analyzed that met the bottom light and DO goals, growing season average chlorophyll a levels in upper Escambia Bay were approximately 4 to 5 µg/L .*

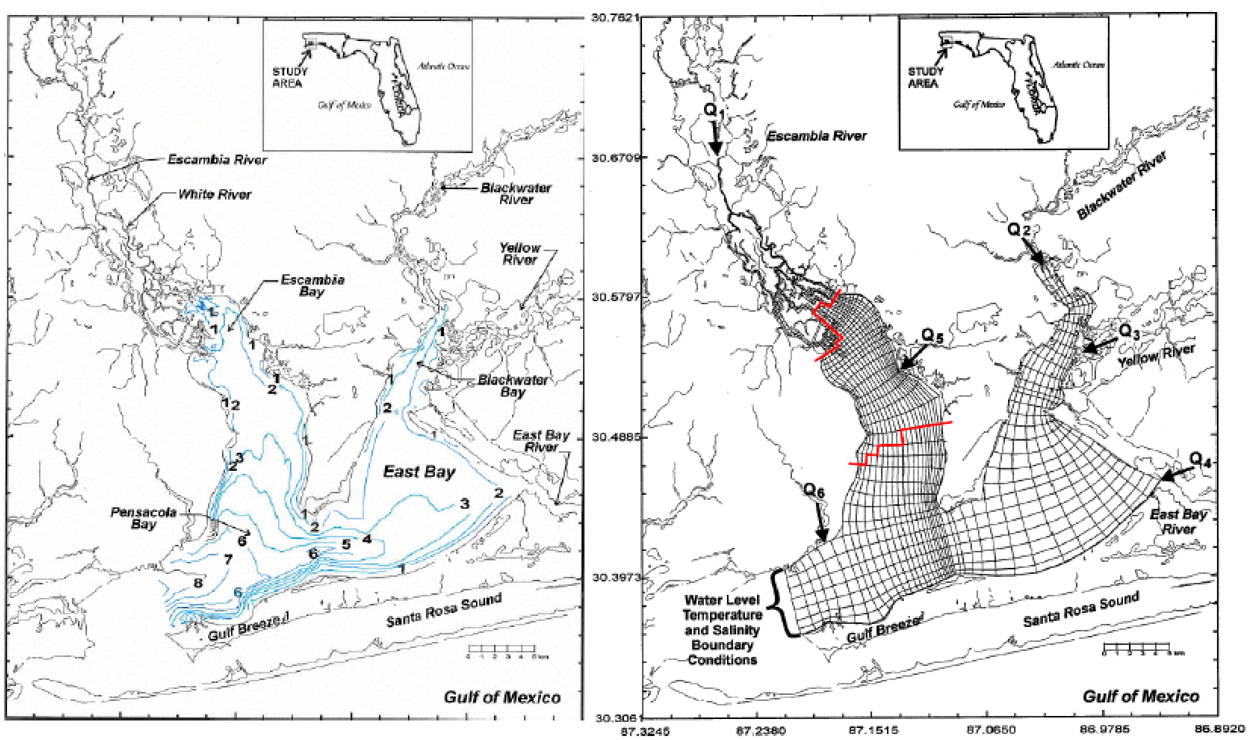
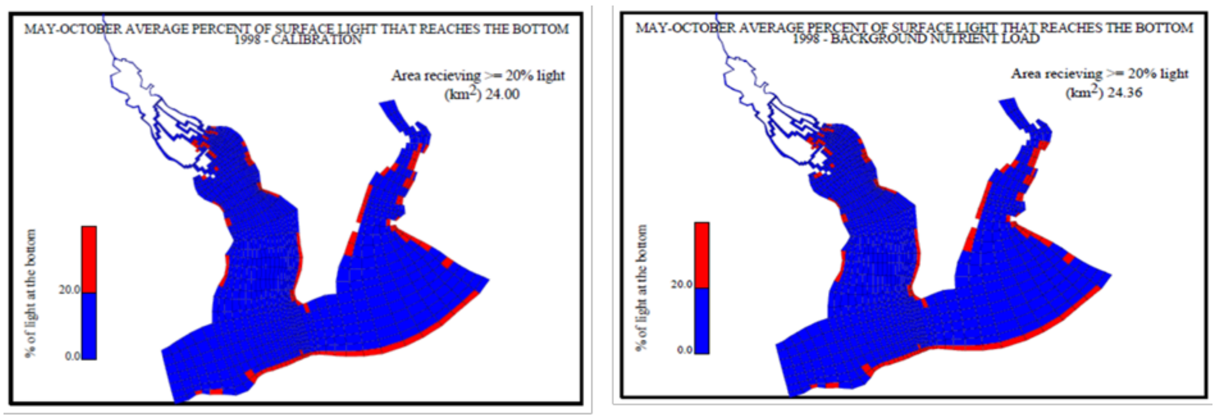
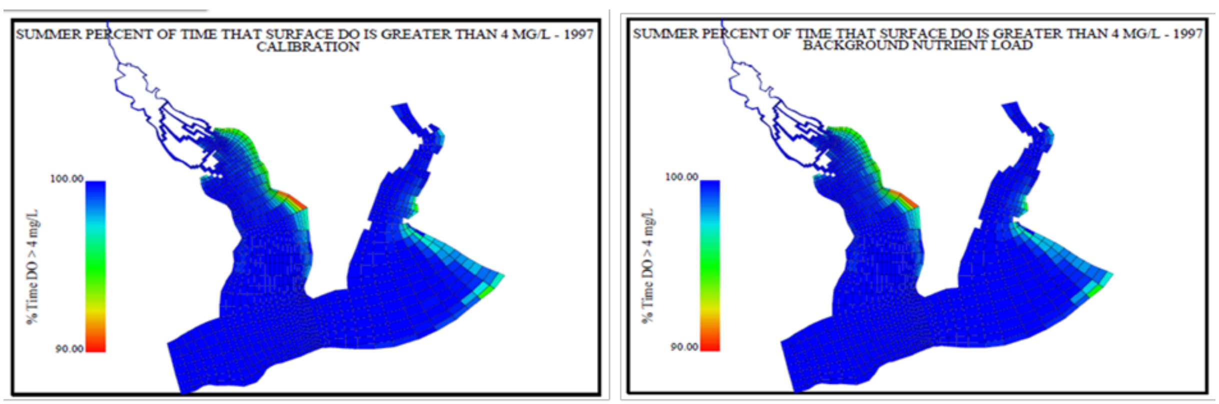


Figure 18. Hydroqual estuary model study area and model grid for Pensacola Bay system (Hydroqual 2010)



Existing Condition **Natural Background Condition**

Figure 19. Calculated areas of bottom light ≥ 20% (growing season average) for 1998 model calibration compared with natural background conditions (Hydroqual 2010)



Existing Condition **Natural Background Condition**

Figure 20. Calculated percentage of time (summer) surface DO concentrations are > 4 mg/L, for 1998 model calibration compared with natural background conditions (Hydroqual 2010)

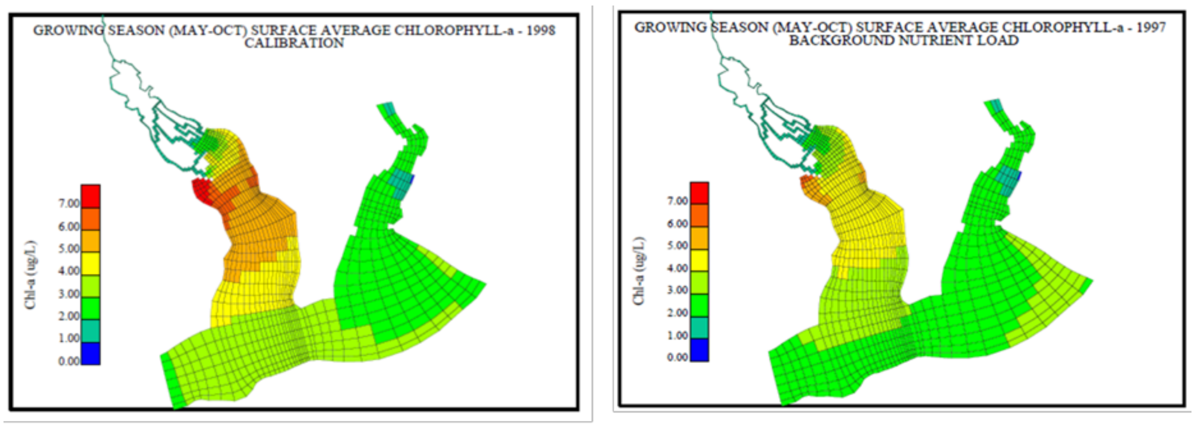


Figure 21. Calculated growing season average of chlorophyll a, for 1998 model calibration compared with natural background conditions (Hydroqual 2010)

The results of this modeled natural conditions scenario, which indicate that current nutrient levels are acceptable, are consistent with conclusions by other scientists who have researched Pensacola Bay. For example, Hagy (2009) remarked that the existing nutrient concentrations in the Pensacola Bay system were relatively low compared with those of many other southeast U.S. estuaries. Further, Hagy *et al*. (2008) stated they were unaware of any study directly implicating chlorophyll *a* concentrations in the low range observed in Pensacola Bay with failure to support any human or aquatic life use. Hagy *et al.* (2008) concluded that water quality criteria for nutrients and nutrient-related water quality measures for Pensacola Bay "could be based reasonably on currently observed conditions because evidence that more stringent criteria are scientifically defensible, necessary, or even achievable, is lacking."

Despite the relatively low chlorophyll values, both East Bay and Escambia Bay were placed on the Verified List of impaired waters using a provision in the Impaired Surface Waters Rule (IWR) that tests whether a waterbody segment has chlorophyll *a* levels that are 50% higher than the lowest historical 5-year annual average chlorophyll *a*. This IWR provision is very conservative, particularly at low chlorophyll *a* levels, and does not take into account the possibility that historical algal levels were artificially depressed due to toxicity and only partially account for the variation in chlorophyll related to natural hydrologic variability in estuaries. In Pensacola Bay, peaks in chlorophyll tend to occur directly after high-flow events from the river systems (Hagy and Murrell 2007). Given the above evidence that existing chlorophyll values (at the current nutrient loads) do not prevent seagrass photosynthesis or recruitment in Pensacola Bay, the Department has concluded that this information should take precedence over the IWR listing methodology.

5 Reference Site Approach

The underlying concept behind the reference site approach is to identify areas characterized by minimal human disturbance to establish expectations for comparable, usually nearby system types. Some estuaries with a relatively natural nutrient regime may be subject to some degree of human stress, such as physical habitat disruption or hydrologic alterations, meaning the system could not be considered minimally disturbed. However, if the nutrient regime in such estuaries is comparable to other similar, minimally disturbed estuaries, the reference site approach would be a line of evidence to "maintain existing conditions" in the system.

5.1 Statewide Comparison of Potential Reference Systems: Multivariate Analyses

The Department compiled the data from the Florida systems where the existing levels of nutrients were determined to be acceptable (described above) and conducted multivariate cluster analyses to determine the relative similarities between these systems and to assess potential statewide trends (Niu 2010). The basic objective of cluster analysis is to discover natural groupings of the estuarine segments, thus reducing the complexity of the relationships. Both "agglomerative" and "divisive hierarchical" cluster analysis methods were conducted on long-term geometric means of TN, TP, and chlorophyll *a* for 75 estuarine segments. Figure 22 shows the clusters identified by the agglomerative cluster (AGNES) analysis for the 75 segments, and Figures 23 through 25 show the results for chlorophyll *a*, TN, and TP, including a classification dendrogram and concentration boxplots. Table 10 lists the names of the actual estuarine segments that were grouped together. Note that these preliminary analyses were conducted to explore the relative similarity of nutrients and chlorophyll *a* in healthy estuaries throughout the state, and that further analyses are planned.

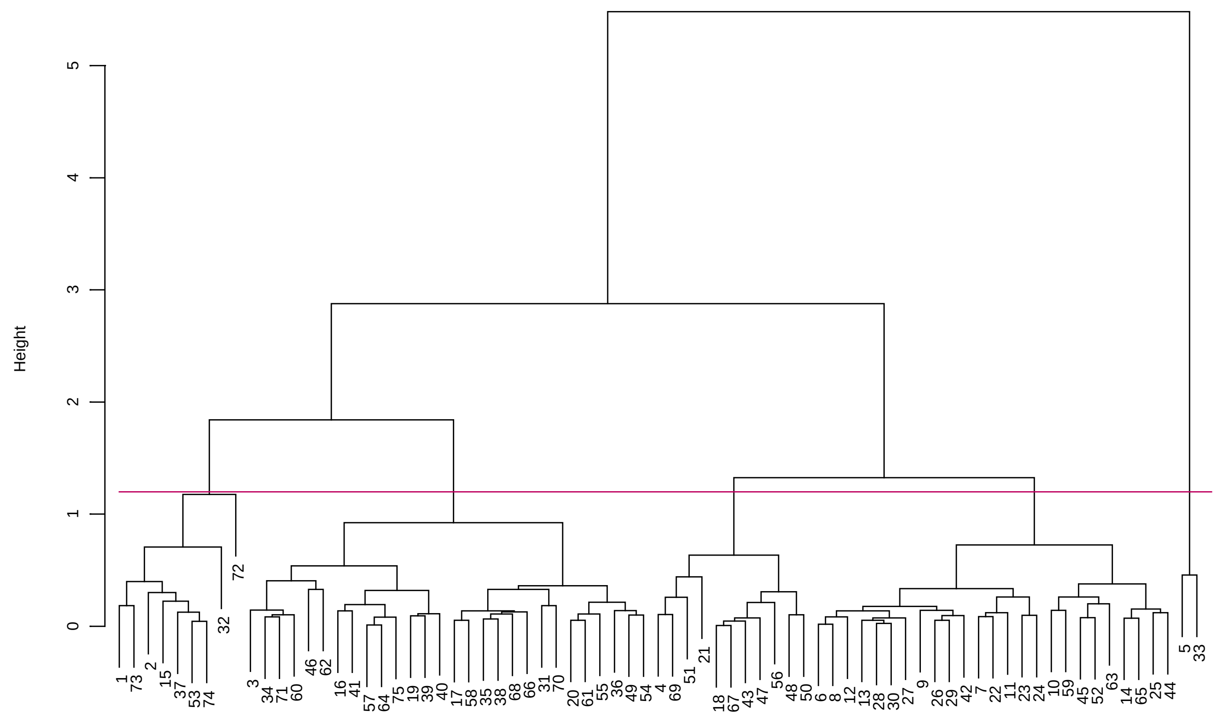


Figure 22. Clusters identified by the AGNES analysis for the 75 estuarine segments (cut at height = 1.2). Height is a measurement of the dissimilarity between the corresponding clusters.

Table 10. Clusters identified by the AGNES analysis for the 75 estuarine segments (cut at height = 1.2)

ID#	System-Segment	TP_LT_GM	TN_LT_GM	Chla_LT_GM	Cluster
5	Apalachicola-St. Vincent Sound	0.043	0.638	8.196	1
33	Loxahatchee River-Polyhaline	0.039	0.970	7.884	1
72	Waccasassa-Nearshore	0.056	0.627	6.335	2
15	Boca Ciega Bay-W7	0.048	0.496	5.498	2
74	Withlacoochee-Nearshore	0.039	0.427	5.310	2
37	Pensacola-Escambia Bay	0.032	0.549	5.278	2
53	Suwannee-Offshore	0.032	0.422	5.266	2
2	Apalachicola-Apalachicola Bay	0.042	0.687	5.140	2
32	Loxahatchee River-Meso/Oligo	0.067	1.165	5.117	2
73	Waccasassa-Offshore	0.035	0.480	5.006	2
1	Alligator Harbor	0.027	0.365	4.864	2
46	St. Andrew Bay-Central Bay	0.017	0.420	4.564	3
62	Southwest-Marco Island	0.037	0.259	4.278	3
71	Tolomato	0.087	0.528	4.186	3
3	Apalachicola-East Bay	0.041	0.675	4.141	3
34	North Halifax River	0.118	0.580	4.130	3
60	Southwest-Inner Waterway	0.028	0.530	4.106	3
41	South Matanzas	0.092	0.445	3.956	3
57	Southwest-Estero Bay	0.042	0.270	3.862	3
64	Southwest-Naples Bay	0.040	0.268	3.851	3
16	Boca Ciega Bay-W8	0.051	0.465	3.828	3
75	Withlacoochee-Offshore	0.026	0.326	3.802	3
19	Choctawhatchee Bay-West Bay	0.017	0.373	3.591	3
40	South Halifax River	0.111	0.392	3.580	3
39	Pensacola-Santa Rosa Sound	0.019	0.349	3.502	3
54	Southwest-Blackwater River	0.045	0.337	3.367	3
49	St. Andrew Bay-West Bay	0.016	0.415	3.311	3
55	Southwest-Coastal Transition Zone	0.029	0.476	3.224	3
36	Pensacola-East Bay	0.022	0.340	3.214	3
20	Clearwater Harbor-W2	0.028	0.524	3.158	3
61	Southwest-Mangrove Rivers	0.017	0.555	3.115	3
68	Southwest-San Carlos Bay	0.058	0.337	3.056	3
38	Pensacola-Pensacola Bay	0.016	0.373	2.975	3
66	Southwest-Pine Island Sound	0.039	0.258	2.951	3
35	North Matanzas	0.074	0.382	2.946	3
31	Loxahatchee River-Marine	0.019	0.618	2.904	3
58	Southwest-Gulf Islands	0.033	0.359	2.886	3
17	Choctawhatchee Bay-Central Bay	0.016	0.342	2.839	3
70	Southwest-Whitewater Bay	0.019	0.626	2.720	3
18	Choctawhatchee Bay-East Bay	0.023	0.399	-	4

ID#	System-Segment	TP_LT_GM	TN_LT_GM	Chla_LT_GM	Cluster
47	St. Andrew Bay-Grand Lagoon	0.014	0.408	2.466	4
43	Springs Coast-<20 PSU	0.016	0.381	2.400	4
67	Southwest-Ponce De Leon	0.019	0.397	2.334	4
56	Southwest-Collier Inshore	0.027	0.217	2.300	4
48	St. Andrew Bay-Mouth	0.009	0.323	2.062	4
50	St. Joseph Bay	0.013	0.225	2.036	4
69	Southwest-Shark River Mouth	0.017	0.559	1.791	4
4	Apalachicola-St George Sound	0.023	0.455	1.784	4
51	St. Joseph Sound -W1	0.024	0.487	1.536	4
21	Florida Bay-Central Florida Bay	0.014	0.723	1.334	4
10	Biscayne Bay-Northern North Bay	0.010	0.235	1.405	5
59	Southwest-Inner Gulf Shelf	0.014	0.219	1.264	5
45	Springs Coast-20-25 PSU	0.010	0.432	1.131	5
63	Southwest-Middle Gulf Shelf	0.014	0.196	1.114	5
52	Steinhatchee	0.016	0.360	1.105	5
25	Florida Bay-Western Florida Bay	0.012	0.301	0.920	5
14	Biscayne Bay-Southern North Bay	0.008	0.231	0.848	5
44	Springs Coast->25 PSU	0.009	0.368	0.818	5
65	Southwest-Outer Gulf Shelf	0.011	0.170	0.809	5
23	Florida Bay-Northern Florida Bay	0.008	0.545	0.601	5
24	Florida Bay-Southern Florida Bay	0.007	0.486	0.523	5
9	Biscayne Bay-North Central Outer-Bay	0.006	0.221	0.494	5
42	Southeast Coast	0.007	0.116	0.431	5
7	Biscayne Bay-Manatee Bay-Barnes Sound	0.006	0.469	0.364	5
26	Keys-Back Country	0.009	0.196	0.358	5
29	Keys-Marquesas	0.006	0.143	0.354	5
6	Biscayne Bay-Card Sound	0.006	0.257	0.339	5
8	Biscayne Bay-North Central Inshore	0.006	0.247	0.324	5
22	Florida Bay-East Central Florida Bay	0.006	0.517	0.291	5
11	Biscayne Bay-South Central Inshore	0.006	0.391	0.282	5
27	Keys-Bayside	0.007	0.196	0.261	5
12	Biscayne Bay-South Central Mid-Bay	0.005	0.282	0.255	5
28	Keys-Dry Tortugas	0.006	0.129	0.213	5
13	Biscayne Bay-South Central Outer-Bay	0.005	0.190	0.207	5
30	Keys-Oceanside	0.006	0.147	0.194	5

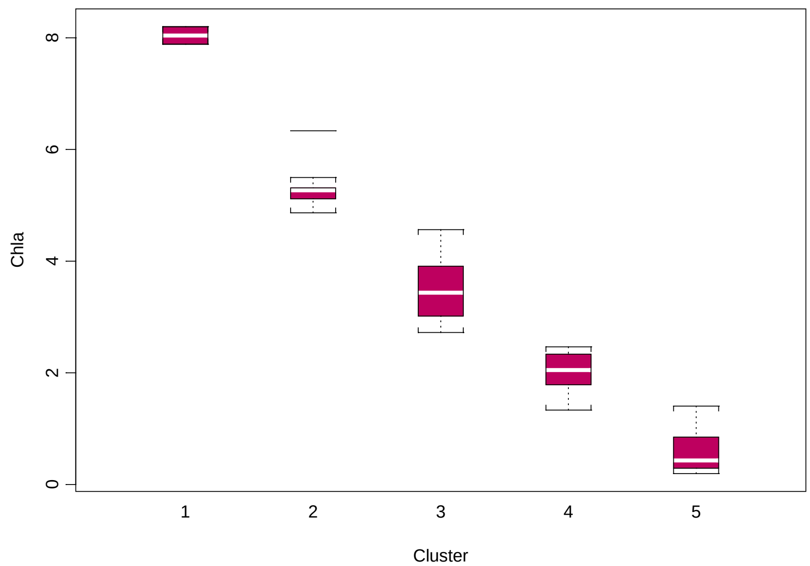


Figure 23. Boxplot of long-term geometric mean chlorophyll a for the 5 clusters generated by the AGNES analysis for 75 healthy estuarine segments

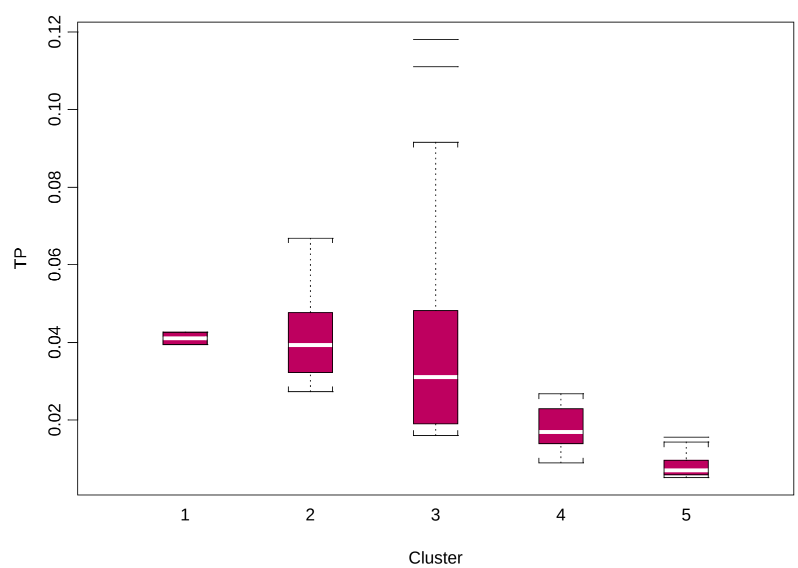


Figure 24. Boxplot of long-term geometric mean TP for the 5 clusters generated by the AGNES analysis for 75 healthy estuarine segments

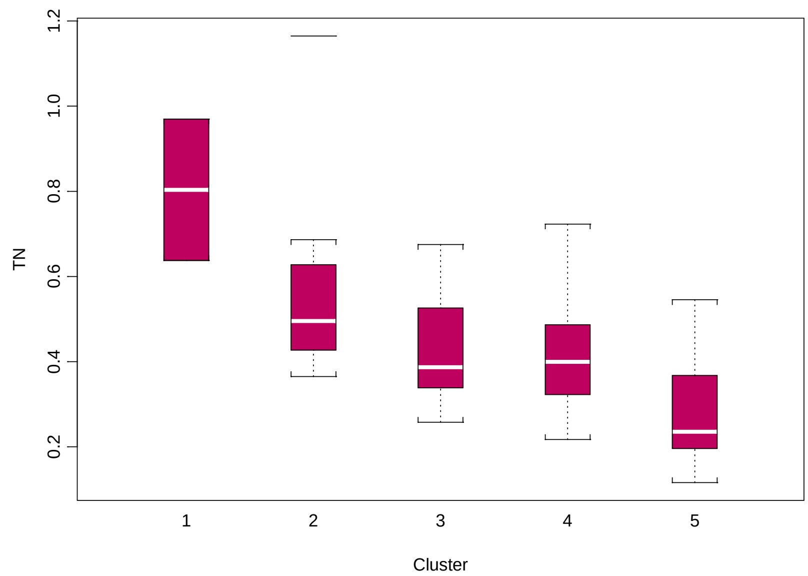


Figure 25. Boxplot of long-term geometric mean TN for the 5 clusters generated by the AGNES analysis for 75 healthy estuarine segments

The groupings derived from cluster analysis appear to largely be driven by chlorophyll *a* concentrations, with the five groups defined across a gradient from higher to lower chlorophyll *a* values (Figure 23). The box plots reveal no distributional overlap in chlorophyll between the five groups, suggesting that this biological response attribute is an effective method to discriminate natural groupings in Florida's marine systems. While there was more overlap in the TP and TN box plots, the medians followed the same overall pattern, as distinguished by chlorophyll *a*.

A statewide geographic examination of the systems belonging to each group (Figure 26) is informative:

- ***Group 1*** *had a median chlorophyll a of 8 µg/L and contained polyhaline reaches of Loxahatchee and Apalachicola Bays (St. Vincent Sound).*
- ***Group 2*** *had a median chlorophyll a of approximately 5 µg/L and contained systems with higher freshwater inputs, such as Escambia Bay, Waccasassa Bay, Withlacoochee (nearshore), Suwannee (offshore), Loxahatchee (oligo-mesohaline), and Apalachicola (main bay). However, Alligator Harbor, which has relatively small freshwater inputs, was also in this group.*

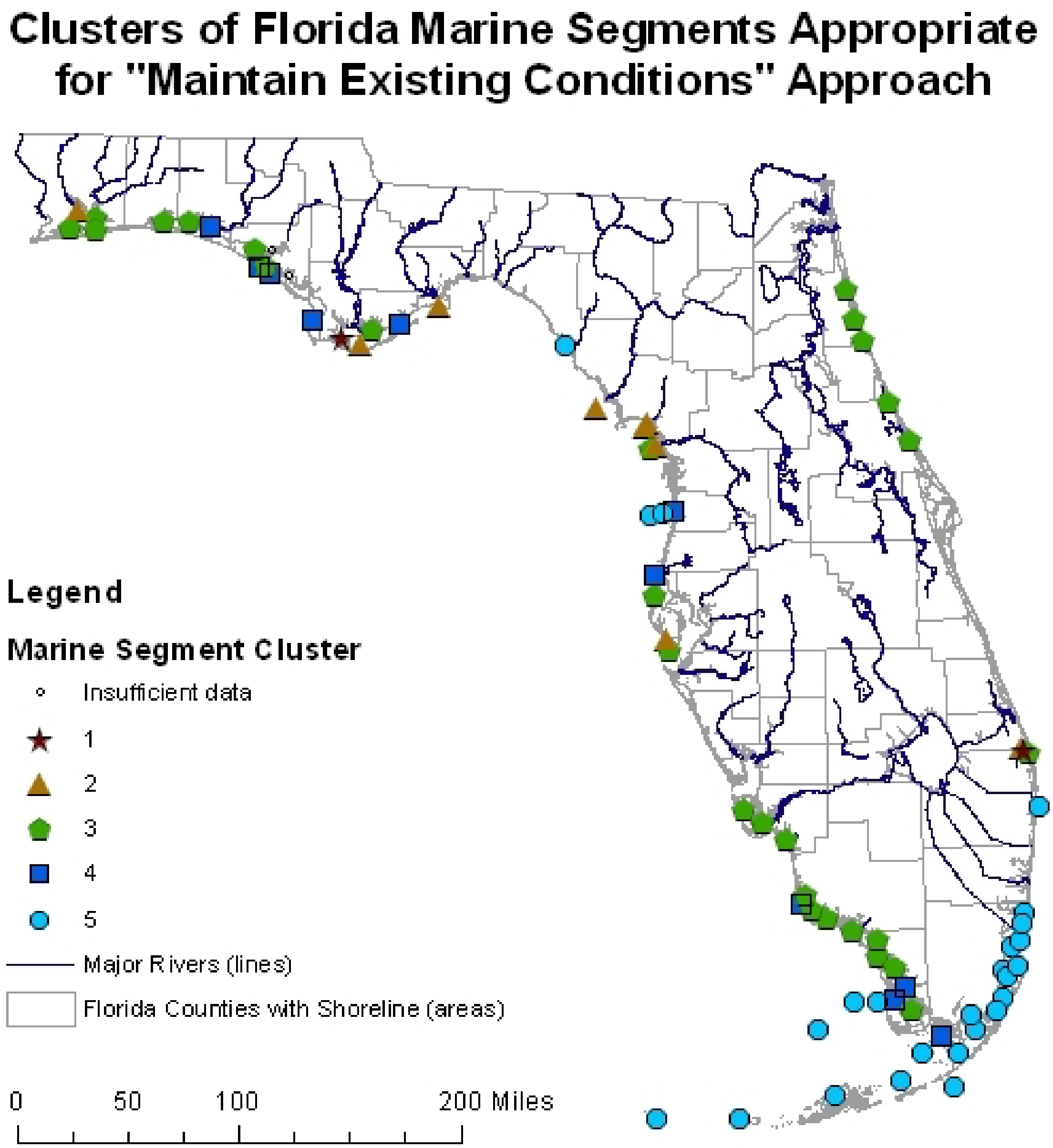


Figure 26. Statewide map of the 75 healthy estuarine segments and the clusters to which they belong, from the AGNES analysis

- ***Group 3*** *had a median chlorophyll of approximately 3 µg/L, and contained higher salinity lagoon systems, including the Matanzas Estuary, Halifax Estuary, Santa Rosa Sound, and St. Joseph Bay. Additional systems in this group included Pensacola (East Bay), portions of St. Andrews Bay (West Bay and Grand Lagoon), Choctawhatchee Bay, Loxahatchee Estuary (marine portion), many nearshore Southwest Coast segments, and Apalachicola (East Bay).*

- ***Group 4,** with a median chlorophyll of around 2 µg/L, included systems with little or only occasional freshwater inputs, such as St. Joseph Bay, St. Andrews Bay (mouth), Apalachicola (St. George Sound), Springs Coast (<20 practical salinity units [PSU]), and a few Southwest Coast segments (e.g., Shark River mouth).*
- ***Group 5** consisted of systems where TP and chlorophyll were very low (with a median of < 1 µg/L), but where a moderate range in TN was observed. These were well-flushed systems characterized by offshore, high-salinity oceanic water, and included the Florida Keys, Florida Bay, Biscayne Bay, the Southeast Coast, the Steinhatchee Estuary, Springs Coast (>25 PSU), and the Gulf shelf stations of the Southwest Coast.*

The same data were also analyzed via divisive hierarchical (DIANA) methods. The two approaches yielded the same results, except for four individual estuarine segments (Table 11).

Table 11. Four estuarine segments were grouped differently by agglomerative (AGNES) vs. divisive hierarchical (DIANA) clustering methods

System–Segment	TP_LT_GM	TN_LT_GM	Chla_LT_GM	Cluster by AGNES	Cluster by DIANA
Biscayne Bay– Northern North Bay	0.010	0.235	1.405	5	4
Choctawhatchee Bay– East Bay	0.023	0.399	-	4	3
St. Andrew Bay–Central Bay	0.017	0.420	4.564	3	2
Waccasassa–Nearshore	0.056	0.627	6.335	2	1

The Department would like to emphasize that the cluster analysis results are preliminary in nature and that future analyses are planned. The results were presented because the Department anticipates that the cluster analysis may be a useful tool that could provide supporting information for NNC development. For example, due to confounding issues, there may be some uncertainty regarding the biological health of a particular estuary and the resultant protectiveness of existing nutrient and chlorophyll levels. However, if the nutrient and chlorophyll levels in the estuary (*e.g.*, Naples Bay, which has habitat and hydrologic limitations) grouped with other similar and clearly healthy systems (*e.g.*, the nearby Blackwater River estuary), the Department believes that this would provide additional confidence in the appropriateness of maintaining the existing conditions.

6 Issues Requiring Further Resolution

6.1 Spatial Restrictions of Criteria

Working With "Found Data"

The marine NNC that are being developed by the Department, particularly those developed using the "maintain existing conditions" approach, are based on data that were not specifically collected for the purpose of water quality criteria development. Some datasets available to the Department represent probabilistic networks of sites designed to represent the water quality of waterbodies in a region. Other datasets consist of data from fixed stations that are considered to be representative of the waterbody but were not explicitly established for water quality criteria development. The Department examines the locations of stations in each system to ensure that the "found data" used for criteria development are representative of the overall estuarine segment conditions. However, it is important to realize that future sampling for assessment purposes cannot be restricted only to those exact sites used for criteria development.

Future data collection may include sites in locations of estuarine segments that represent a different set of conditions than those used for criteria development. Additionally, given the potential for budget cuts, there is no guarantee that the sites sampled for NNC development purposes will continue to be sampled in the future. Therefore, it is critical that guidelines be developed to ensure that implementation of the criteria is consistent with the way in which the criteria were derived. These guidelines should include the spatial aspects of site selection, temporal considerations, and data processing procedures. Note that field sampling methods and laboratory analysis protocols are already controlled via Florida's Quality Assurance Rule (Chapter 62-160, F.A.C.)

Stations for Compliance Purposes Should be Representative of Baseline Period Locations

In general, the Department used data for criteria development from sites that were representative of the overall conditions found at a particular estuarine segment. Sites directly adjacent to a particular source of human disturbance (*e.g.,* a point source discharge) or sites within a distinctly different habitat (*e.g*., a tidal marsh or tidal river instead of open water) were excluded. Consequently, samples for compliance purposes should also exclude data collected from areas that do not represent the overall segment.

For example, an arbitrary change in the locations of sampling sites in Rookery Bay had a profound effect on the waterbody yearly averages for nutrients and chlorophyll *a*. As shown in Figure 27, sampling stations were generally situated in the better flushed, more open areas of the system (depicted by red dots) from 1999 to 2005 (a baseline period). In 2006, water quality sampling mostly took place in canals (many adjacent to roadways and near boat ramps), and the previously sampled, more open waters of the bay were excluded (green dots). During the 1999 to 2005 period, the yearly mean chlorophyll a in Rookery Bay, collected from 10 sites, was 5.5 µg/L (ranging from 4.9 to 7.3 µg/L). In 2006, the mean chlorophyll a for the 9 (different) sites sampled was 14 µg/L). Because the locations sampled in 2006 were less affected by tide and other mixing actions than the stations sampled prior to 2006, it is likely that the higher chlorophyll *a* levels reported in 2006 reflect changes in characteristics of the sampling locations, rather than a true temporal change in water quality. This example demonstrates the need for consistency in establishing sampling locations representative of the assessed waterbody segment.

Tidal Marshes, Swamps, and Bayous

The Department's MTAC unanimously agreed that tidal marshes, swamps, and bayous are distinct and separate ecosystems, with different nutrient expectations than the adjacent, more open waters of estuaries. Additionally, EPA's determination letter explicitly excluded wetlands from this current nutrient development effort, implying that criteria in wetland-dominated systems would be deferred. Creeks draining tidal marshes and swamps, which are highly wetland-influenced systems, subject to organic inputs from naturally derived leaf litter, typically have higher nutrients than the adjacent open water system. Therefore, the use of data from such systems would not be appropriate when assessing the adjacent open waters. Note that sufficient data are currently not available to develop criteria for creeks in tidal marshes (*Spartina/Juncus*), tidal swamps (mangroves), or similar wetland-influenced bayous. These systems tend to not only exhibit higher nutrient values, but higher temporal variability, suggesting that this variability must be properly addressed during criteria development, including the possibility of expressing the criteria as a range.

While the Department has confidence that we can proceed with criteria development in many bays and estuaries, lack of data in these wetland-influenced tidal creek systems clearly indicates that NNC for these distinct waterbody types cannot occur until additional study takes place. As an interim way to handle this issue, the Department suggests that if nutrients in the open water areas of a given estuary are acceptable, then nutrients in the adjacent wetland influenced tidal creeks should also be deemed non-problematic.

Similarly, because the ongoing criteria development for Florida systems is based on the mixed, open water portions of bays and lagoons, samples collected at the mouths of tributary rivers or streams would generally not be representative of the mixed, open water portions. Therefore, nutrient values at such sites would not be part of the original data distribution from which the criteria were developed, and it would be inappropriate to use data from those sites to assess compliance.

Homogeneity of Assessment Units

For criteria development and assessment, it is important that waterbody segments be grouped into relatively homogeneous units. When assessing homogeneity, the department plans to ensure that the overall data distribution within a given spatial unit (including mean and variance terms) are sufficiently similar to justify a grouping. While gathering the data for individual estuaries, it was noted that that some WBID boundaries needed to be adjusted to achieve homogeneity. Such adjustments are necessary to assure that the concepts discussed above are properly implemented. Collecting instantaneous salinity measurements at estuarine sites is one mechanism to determine if the data are comparable. Because nutrient concentrations are correlated with salinity (see below), the salinity of the sites used for assessment purposes should be within the salinity distribution of the sites used for deriving the criteria. Identifying tidal nodes, where appropriate, is another potential way to demarcate system boundaries.

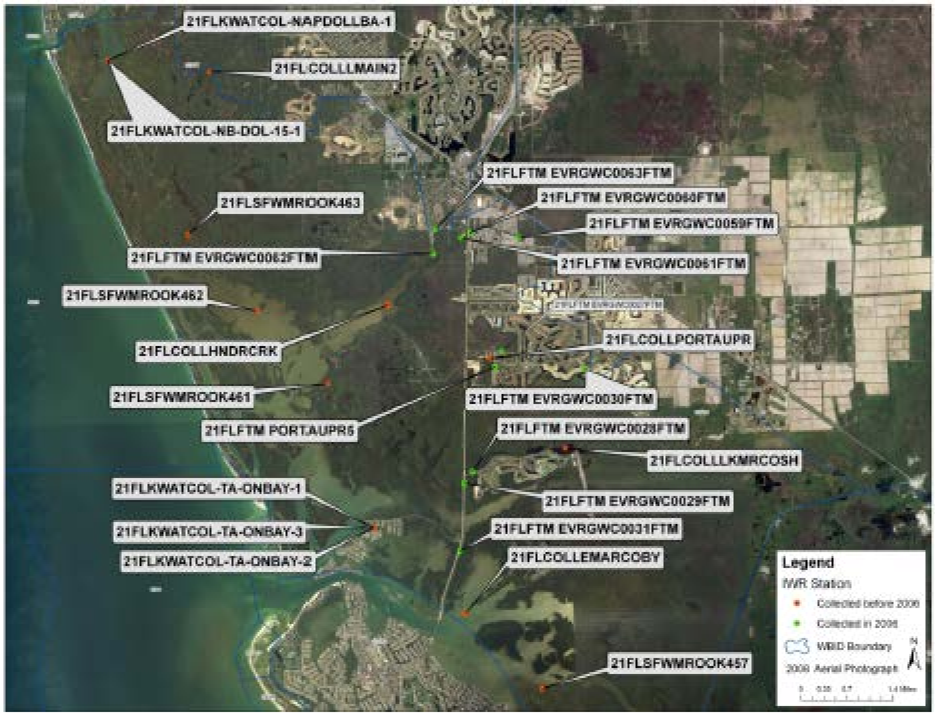


Figure 27. Locations of sampling stations within Rookery Bay (WBID 3278U), including the 1990–2005 stations (red dots) and the different 2006 sampling locations (green dots).

6.2 Salinity Effects

Coastal areas and estuaries are places where fresh water mixes with salt water, and so by definition, there is a degree of salinity gradient in all coastal areas. If the volume of fresh water is very small, then the zone of freshwater influence is small. However, if the volume of fresh water is large, especially when coupled with particular bay morphologies, there could be a large area in which the fresh water influences the salinity and subsequently, the nutrient content of estuarine water. Nutrient concentrations are typically higher in fresh waters; thus nutrient concentrations typically decrease with increasing salinity (due to the increasing dilution of the fresh water as well as from biological assimilation). The data presented in this document show that minimally disturbed, low-salinity estuaries have higher nutrient concentrations than high-salinity waters, and thus the NNC should be adjusted for salinity. Salinity gradients can be in both space and time; salinity increases with distance from the freshwater source, and salinity is higher during periods of low freshwater flow.

Adjusting nutrient expectations as a function of salinity is analogous to the methodology used for assessing anthropogenic enrichment of metals in marine sediments, where metals concentrations are normalized against aluminum. The Department could potentially use salinity mixing models, or similar techniques, to define the acceptable nutrient regime at a given salinity.

There are several options, as follows, for addressing this salinity gradient in nutrient criteria development:

1. *If the volume of fresh water is low and the spatial influence is small, the following are options:*
    a. Delineate an area of freshwater influence and establish less restrictive NNC for that area.
    b. Establish a salinity minimum for criteria application in the overall marine waterbody segment, such that low-salinity samples would not be appropriate for the assessment of criteria compliance in the overall segment.
2. *If the volume and spatial influence of the fresh water are large and there are sufficient data along the salinity gradient, the following are potential options:*
    a. Develop a relationship between salinity and nutrient concentrations and model the criteria after that relationship. The criteria would be in the form of an equation, with the magnitude of the criterion dependent upon the salinity of the sample.
    b. Develop theoretical salinity "bins," in which unique criteria would apply to each salinity bin, and assess an area based on its average annual salinity.
    c. Develop geographical salinity zones based on long-term average salinity values and apply unique criteria to each zone.
    d. Through the use of a mixing model, normalize nutrient expectations to salinity, potentially establishing a salinity-based, rather than a spatially based method to assess compliance. For example, if the acceptable nutrient regime was established for a 20 practical salinity units (PSU) salinity in a given estuary, all future sampling for compliance determination would only occur at areas with 20 PSU salinity.

Salinity Zone Example

The Suwannee, Waccasassa, and Withlacoochee are large, swamp-dominated rivers in the Big Bend coast of Florida that discharge into wide coastal areas rather than defined enclosed embayments. Ten sites in each coastal system were sampled monthly since 1997, and 10 years of data were available for analysis by the Department. The sites were staggered along the salinity gradient in each of these systems (Figure 28). While river flows influence the marine waters of all 3 systems, the Suwannee has the greatest flow and volume of fresh water. A strong relationship between salinity and TN and between salinity and TP was observed for all 3 rivers, with the strongest relationship in the Suwannee system (Figures 29 and 30). For these particular systems, there are sufficient data to develop predictive equations for NNC based on salinity values. This option for nutrient criteria complicates the assessment because the criterion depends on the salinity, but this degree of complexity may be necessary to control for Type I errors.

For example, areas off the coast of the Suwannee River experience wide swings in freshwater flow from year to year, leading to a situation where a site could erroneously be deemed out of compliance due to unusually high freshwater flows. Mean salinities at Suwannee River Estuary sites ranged from 10 to 15 PSU over a 10-year period (Table 12), meaning that a given site does not have a fixed salinity regime from year to year. The Department created salinity zones for these river sites, with proposed NNC based on the long-term means for sites in nearshore and offshore zones of long-term salinity less than or greater than 25 PSU, respectively. Although fixed sites were used to develop proposed criteria for each salinity zone, criteria applied to a station could change over time if the salinity regime changes over time.

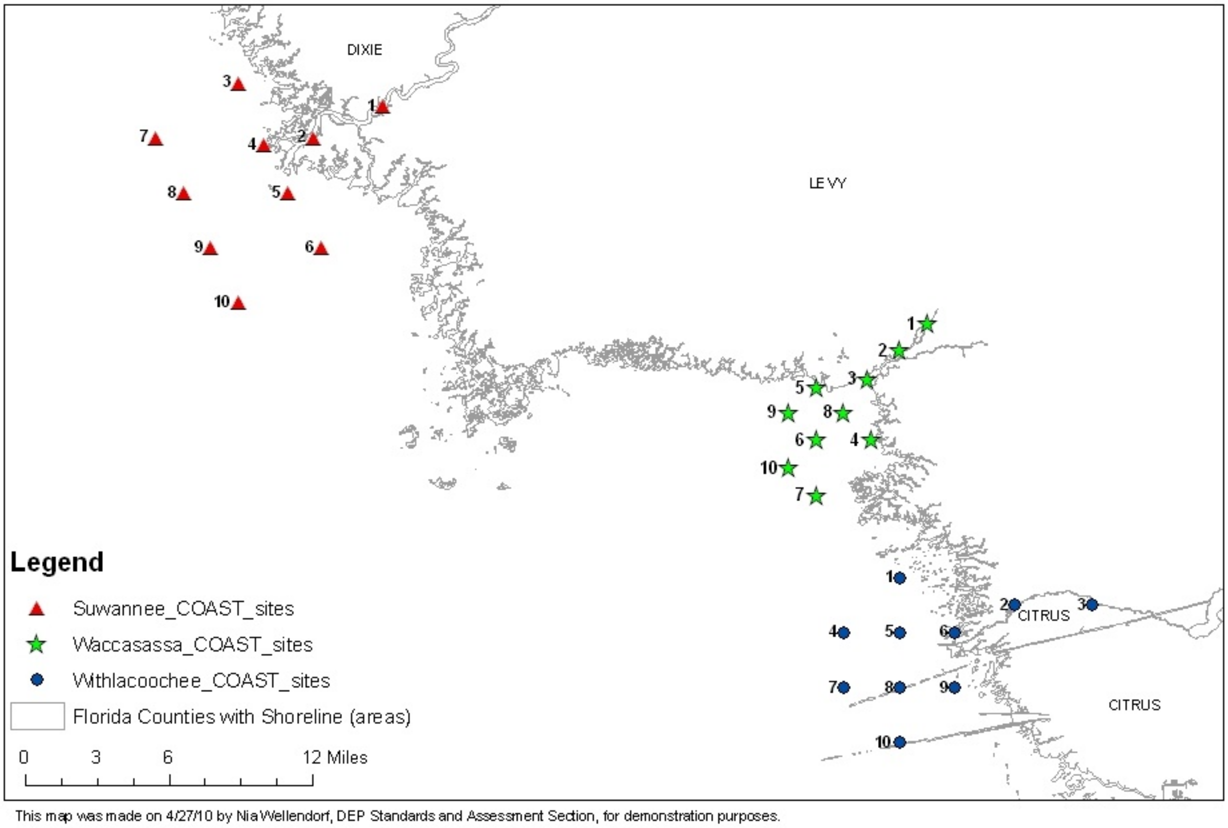


Figure 28. Project COAST sampling sites in the Suwannee, Waccasassa, and Withlacoochee Estuaries

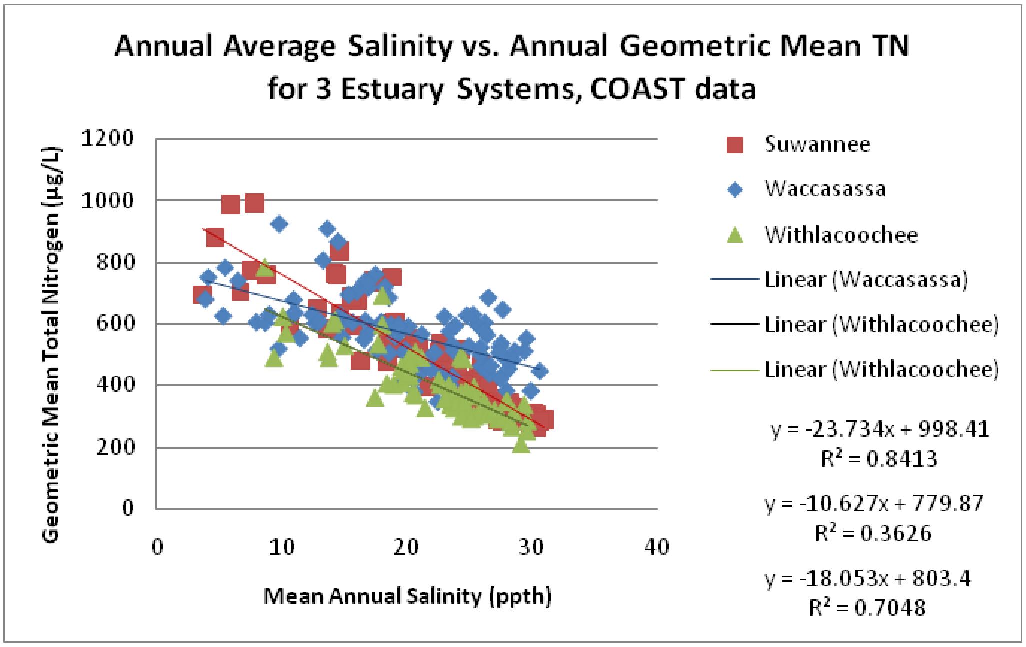


Figure 29. Regression of average annual salinity and annual geometric mean TN for monitoring stations sampled monthly at the mouths of the Suwannee, Waccasassa, and Withlacoochee (South) Rivers, 1997–2007. R^2= 0.84 for Suwannee, R^2= 0.36 for Waccasassa, R^2= 0.70 for Withlacoochee. Predominantly freshwater sites excluded. N = 88, 99, and 71 site-years for Suwannee, Waccasassa, and Withlacoochee, respectively.

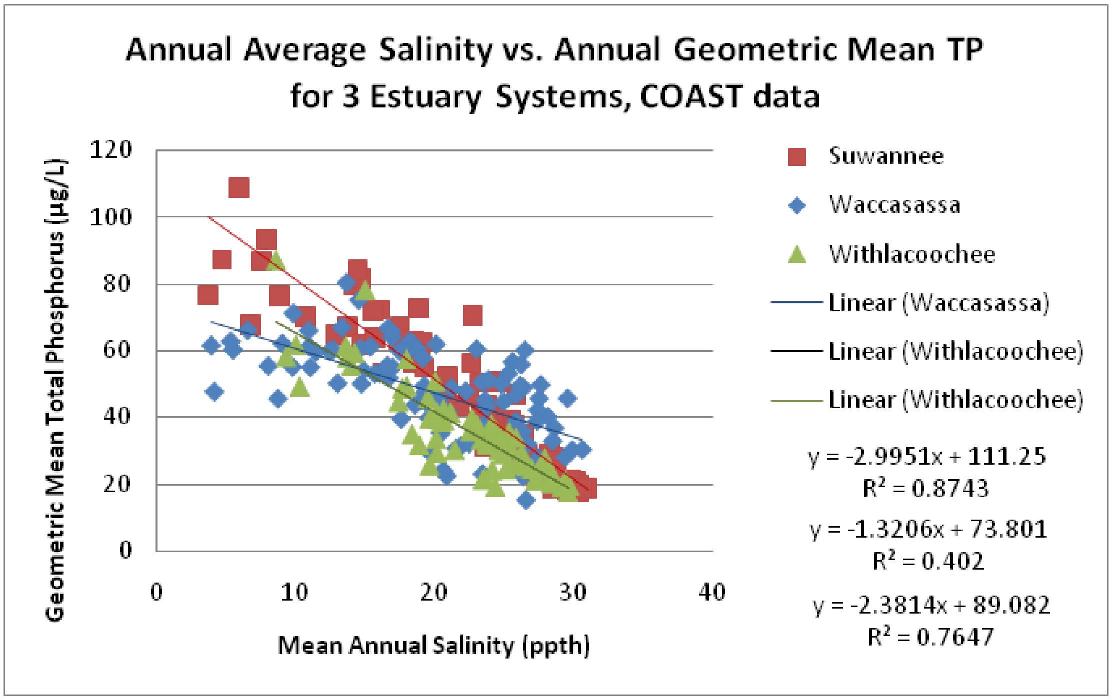


Figure 30. Regression of average annual salinity and annual geometric mean TP for monitoring stations sampled monthly at the mouths of the Suwannee, Waccasassa, and Withlacoochee (South) Rivers, 1997–2007. R^2= 0.87 for Suwannee, R^2= 0.40 for Waccasassa, R^2= 0.76 for Withlacoochee. Predominantly freshwater sites excluded. N = 88, 99, and 71 site-years for Suwannee, Waccasassa, and Withlacoochee, respectively.

Station 3				Station 4				Station 5				Station 6			
Year	Average	Minimum	Maximum	Year	Average	Minimum	Maximum	Year	Average	Minimum	Maximum	Year	Average	Minimum	Maximum
1997	18.50	8.00	26.00	1997	3.67	0.00	9.00	1997	10.67	7.00	15.00	1997	21.00	14.00	31.00
1998	14.22	2.00	26.30	1998	4.68	0.00	22.90	1998	13.70	0.00	25.70	1998	16.28	2.00	26.00
1999	22.47	14.40	34.30	1999	6.73	0.60	26.90	1999	21.77	10.30	30.60	1999	23.89	11.70	29.70
2000	24.28	16.20	28.60	2000	14.72	3.40	22.76	2000	20.54	13.80	26.80	2000	23.41	20.77	28.40
2001	23.46	9.46	29.79	2001	12.85	0.15	23.29	2001	20.96	14.02	28.17	2001	23.79	14.56	30.55
2002	23.30	13.33	25.50	2002	18.50	2.26	25.24	2002	22.75	13.52	26.46	2002	25.57	16.77	32.24
2003	18.86	10.41	28.70	2003	7.88	0.04	20.93	2003	14.69	0.30	29.61	2003	17.52	3.64	27.73
2004	18.51	5.50	24.31	2004	7.55	0.05	19.25	2004	15.72	0.52	25.27	2004	19.26	1.21	26.16
2005	16.08	0.09	30.14	2005	5.92	0.09	15.70	2005	14.48	0.04	26.85	2005	19.06	4.83	28.45
2006	18.98	3.06	29.26	2006	8.79	0.06	21.18	2006	17.42	9.02	27.80	2006	20.85	10.76	29.15
2007	25.91	21.66	29.77	2007	15.61	6.58	27.91	2007	22.63	15.49	29.24	2007	24.52	17.91	28.62
all data	20.42	0.09	34.30	all data	9.86	0.00	27.91	all data	18.02	0.00	30.60	all data	21.34	1.21	32.24

Station 7				Station 8				Station 9				Station 10			
Year	Average	Minimum	Maximum	Year	Average	Minimum	Maximum	Year	Average	Minimum	Maximum	Year	Average	Minimum	Maximum
1997	28.33	22.00	31.00	1997	27.67	23.00	33.00	1997	28.33	24.00	33.00	1997	28.50	22.00	35.00
1998	23.56	15.00	32.20	1998	23.67	8.00	31.40	1998	24.03	12.00	30.80	1998	25.07	10.00	32.00
1999	28.05	15.50	34.60	1999	28.18	15.40	34.00	1999	29.84	20.70	34.10	1999	30.38	20.00	34.50
2000	30.43	27.40	33.00	2000	30.14	26.80	32.40	2000	30.39	25.60	33.58	2000	31.00	27.03	34.30
2001	29.43	23.01	33.60	2001	28.46	22.26	32.72	2001	28.81	22.06	32.18	2001	29.61	26.02	32.36
2002	28.26	23.26	31.23	2002	28.84	21.10	31.65	2002	29.95	22.96	32.84	2002	30.18	24.54	33.13
2003	24.12	17.30	30.82	2003	23.20	14.72	31.41	2003	25.10	19.68	31.45	2003	26.91	21.99	31.51
2004	24.70	17.53	29.64	2004	24.96	10.00	30.48	2004	25.62	14.40	29.03	2004	25.49	8.49	30.26
2005	24.35	17.11	32.70	2005	25.50	16.74	30.90	2005	25.76	13.03	30.77	2005	26.50	9.29	31.41
2006	26.74	16.43	31.79	2006	26.20	19.32	31.05	2006	26.34	18.87	31.81	2006	27.31	20.27	33.03
2007	29.57	24.86	33.24	2007	29.67	25.89	32.73	2007	29.78	26.50	32.76	2007	30.66	27.12	32.90
all data	26.95	15.00	34.60	all data	26.85	8.00	34.00	all data	27.56	12.00	34.10	all data	28.28	8.49	35.00

Table 12. Annual average, minimum, and maximum salinity values for marine sites off the Suwannee River. Sites as in Figure 27. N = 12 for all years except N = 6 for 1997 and N = 9 for 2007.

6.3 Extreme Climatic Events

Florida is subject to extreme rain events, typically during tropical storms and hurricanes. These extreme high-water events mobilize terrestrial and riverine organic material and floodplain sediments, both of which contain TP,TN, and oxygen-demanding substances, and transport these materials to the estuary. While these extreme events may deliver substantial nutrient loads to a given minimally disturbed system, it is possible that no extreme events occurred in a particular system during the period when nutrient data were available for criteria development. In this case, a future extreme event would not be representative of the baseline period, and the Department believes that such events should be excluded for subsequent assessment purposes. Another approach would be to recalculate the baseline data distribution, adjusted to include data from the extreme event, and develop modified criteria for the system.

For example, Tomasko *et al.* (2006) described the effects of three hurricanes on water quality in Charlotte Harbor. Hurricane wind and flooding caused massive defoliation and mortality of native vegetation, as well as substantial damage to human habitation and various infrastructure elements. Eight days after landfall of the first hurricane, a water quality monitoring effort documented hypoxic (< 2 mg/L) to nearly anaerobic (< 0.5 mg/L) DO values throughout the vast majority of the Peace River's 6,000-square-kilometer (km^2) watershed. Low DO values appeared to be related to high values of both dissolved organic matter and suspended materials. Hypoxic conditions in Charlotte Harbor itself occurred within 2 weeks of the first hurricane, and the bay did not recover to pre-hurricane levels for approximately 3 months (Tomasko *et al.* 2006). In this example, the Department would exclude data from the period associated with the hurricanes (for compliance assessment), because such extreme events were not previously part of the baseline dataset.

While developing criteria for Barnes Sound (a subunit of Florida Bay), which is typically very low in TP and chlorophyll, it was noted that a hurricane delivered a substantial pulse of agriculturally derived TP to the system, resulting in an algal bloom that lasted approximately two years. In this case, the data from the extreme event were excluded from the baseline criteria development dataset because the system was not deemed healthy under that set of conditions.

An additional possibility would be to conduct a statistical outlier analysis; however, the basis to include or exclude outliers must have a sound scientific rationale. The Department believes that extreme events need to be closely examined to determine when to include or exclude data associated with these events, both during criteria development and subsequent assessment, to ensure that any assessments are consistent with the criteria derivation. Additional factors to consider include defining the extreme event (*e.g.,* 25-year storm event) and adjusting the period of exclusion to reflect the residence time of the system.

6.4 Potential Need for Seasonally Distinct (e.g., Warm Weather) Nutrient Criteria

Some MTAC members expressed concern that phytoplankton communities in some estuaries may sporadically become dominated by harmful algal taxa (*e.g., Prorocentrum*) during prolonged summer droughts, and that some consideration should be given for developing seasonal criteria to prevent such imbalances. Unfortunately, neither the MTAC nor the Department is currently aware of data or studies that could sufficiently quantify this issue to allow for seasonal criteria development using a response-based approach. However, the Department is exploring the option for the "maintain existing conditions" approach.

7 Conclusions

This document highlights not only the Department's proposed NNC approaches, but the difficult challenges faced by resource management agencies to ensure the criteria are scientifically defensible. Working with local scientists, the Department identified the most sensitive, valued ecological attributes for each of Florida's 30 estuarine and coastal waters, and is in the process of determining the nutrient regime that would result in the protection of that resource (maintaining full support of aquatic life use). In general, the Department's overall scheme for NNC could be described as an "estuary-specific, ecosystem-based" methodology.

The Department proposes four main approaches for NNC development for Florida's estuarine and coastal waters:

- *Maintain healthy existing conditions approach;*
- *Historical conditions approach;*
- *Response-based approach using modeling or empirical evidence; and*
- *Reference site approach.*

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Appendix: Confounding Issues

Although potentially related to human effects, the presence of factors such as of low DO, coliform bacteria, mercury-contaminated fish, and/or red tide (*K. brevis*) does not necessarily equate with anthropogenic nutrient enrichment effects. Additionally, legacy or present non nutrient–related effects, such as past toxic discharges, past or present physical habitat issues, and/or inappropriate water releases (resulting in adverse salinity fluctuations) must also be considered. The information in this section provides perspective on these issues related to the Department's nutrient criteria development efforts.

Bacteria

Because fecal coliform bacteria originate from any warm-blooded animal, including deer, bear, otter, raccoons, birds, and other wildlife that frequent undisturbed streams and coastal areas, and because *Klebsiella* bacteria (measured as a component of fecal coliform) are prevalent during the decomposition of wood, it is not surprising that some estuaries naturally have levels of coliform bacteria that exceed the fecal coliform criterion. As early as 1965, researchers concluded that the assessment of the impact of human activities on water quality is complicated by naturally occurring populations of coliform bacteria because these natural sources exist in substantial numbers in the absence of human activity (Hanes *et al.* 1965). Hardina and Fujioka (1991) concluded that the primary source of coliforms in Hawaiian streams was from native soils, where these "indicator" bacteria were naturally reproducing down to soil depths of 36 centimeters (cm), and not from human sources. Hendricks (1971) suggested that, even in minimally disturbed oligotrophic streams, enteric bacteria multiply in stream sediments because of the ability of sediments to concentrate overlying dissolved nutrients. McSwain and Swank (1974) agreed with these conclusions and found that undisturbed oligotrophic streams (within national forests) in western North Carolina supported large populations of naturally reproducing coliform bacteria, meaning that significant Type I errors would occur if assessing a site only on the basis of coliform counts.

Nieman and Brion (2001) state," It is not enough to know that fecal coliforms (FC) are present in surface waters. Information about the most probable animal source and age of fecal materials is requisite to estimate the potential risk indicated and set standards for recreational contact." In several Florida estuaries, the only likely sources of coliforms are from native wildlife and resident reproducing populations of bacteria in the sediments and adjacent wetlands.

Because of these issues, the use of fecal coliforms as indicators of the presence of human pathogens has been under scrutiny in Florida for the past decade. The Gulf of Mexico Alliance (GOMA) has placed a high priority on improving microbial source tracking (MST) and pathogen-detection methods for use under environmental conditions that occur in the southeast US (GOMA 2009). The GOMA Pathogens Workgroup recently submitted comments regarding the status of EPA recreational water quality criteria (GOMA 2009). The workgroup expressed concern that EPA recreational criteria were derived in places that do not represent Gulf of Mexico (or southern Atlantic) conditions, and that the use of fecal indicators was not appropriate for waters primarily influenced by animal sources (not human pathogens). Areas for which EPA criteria may not be appropriate include low-population-density coastal areas, areas of heavy rainfall, subtropical latitudes, and areas where waters contain a large amount of organic detritus material and/or colored dissolved organic matter (CDOM) (GOMA 2009). Boehm *et al.* (2009) expressed similar concerns about the current and proposed recreational criteria, and specifically call attention to the need for further research and revision in tropical waters and waters adversely impacted by urban runoff and animal feces. It is the Department's position that fecal coliform and *Enterococci* bacteria may potentially indicate human sources, but there is ample evidence to caution against making the assumption that the presence of these bacteria is automatically associated with the presence of anthropogenic nutrients.

The following text (in quotations) is from a review conducted by Dr. V. Jody Harwood of the University of South Florida (USF) as part of an MST project that USF is conducting for the Department:

> *"The main groups of indicator bacteria for recreational water quality assessment in use today include fecal coliforms, or a specific member of that group, Escherichia coli, in fresh water and the genus Enterococcus in both fresh and estuarine/marine waters. However, in order for the indicator concept to work optimally there are many assumptions that must hold true. One of the most important assumptions is that indicator bacteria must co-occur with human pathogens when pathogens are present and pose a human health risk. Unfortunately, recent research has indicated that this assumption is often false by showing that the presence of indicator bacteria do not always correlate well with the presence of pathogens such as Salmonella, Campylobacter, Cryptosporidium, Giardia, or enteric viruses (Anderson et al. 2005, Bonadonna et al. 2002, Harwood et al. 2005, Lemarchand and Lebaron 2003, Lund 1996, Rees et al. 1998).*
>
> *One important reason for the lack of correlation between traditional fecal indicator bacteria and pathogens is that the indicator bacteria are not specific to humans, nor to other hosts known to shed human pathogens in their feces, but are present in the intestines of all warm-blooded animals and some cold-blooded animals (Souza et al. 1999). Because not all animals are equally likely to carry human pathogens, contamination from all sources does not represent an equal health risk. Thus, some sources of fecal contamination in water are of greater concern than others. Furthermore, there is increasing evidence of naturalized or environmentally adapted strains indicator bacteria (both coliforms and Enterococci) that are capable of persisting in a culturable form for extended periods, or even growing in a wide variety of environmental matrices, including terrestrial soils, aquatic sediments, and attached to aquatic vegetation (Byappanahalli and Fujioka 1998, Byappanahalli et al. 2003, Ishii et al. 2006, Jeng et al. 2005, Ksoll et al. 2007, Solo-Gabriele et al. 2000). If indicator bacteria are persisting in environmental matrices, their reintroduction into the water column, such as might occur during storms or high recreational activity, may lead to false positive indications regarding contamination and public health risk. As a result of*

these two confounding factors, it is now clear that simply measuring concentrations of waterborne indicator bacteria do not offer detailed enough information to properly determine health risks associated with recreational water use. Furthermore, this practice does not allow specific sources of contamination to be identified or targeted for remediation of water quality."

Based on the above information, it is the Department's position there may be natural sources of bacteria in estuaries that are minimally disturbed by human activities and in estuaries that fully support aquatic life use. Therefore, the presence of these organisms, when other data indicate unimpaired conditions, should not disqualify a system from being considered healthy and well balanced.

Harmful Algal Blooms, Including Red Tide

Those not familiar with the scientific literature may assume that noxious or toxic algae did not occur in Florida prior to human disturbance, and that anthropogenic nutrient enrichment is solely responsible for modern harmful algal bloom events. This is a false assumption. Significant red tide (*Karena brevis*) events have been documented to occur prior to significant human habitation in the State. Red tides causing massive fish kills in the Gulf of Mexico have been reported anecdotally since the 1500s, and written records documenting a *K. brevis* bloom exist since 1844 (Stiedinger et al. 1999). For example, during the 1800s, red water or "poisoned water" off Florida's coast was associated with fish, invertebrate, and bird kills; toxic shellfish; and a human respiratory irritant (Rounsefell and Nelson 1966). In 1947, naturally occurring *Karenia* blooms caused massive sponge mortality in Tarpons Springs, Key West, and the Bahamas (Florida Dept. of State 2010).

Walsh *et al.* (2006), outline a compelling case for the underlying cause(s) of Florida's long history of west coast red tides. The authors describe in detail how Saharan dust, rich in iron, stimulates the growth of *Trichodesmium spp.*, a genus of cyanobacteria capable of fixing atmospheric nitrogen. *Trichodesmium* on the West Florida Shelf migrate vertically to take advantage of fossil phosphorus concentrations in near bottom waters and light and iron in near surface waters. *K. brevis* vertically migrate with *Trichodesmium* and take advantage of the dissolved organic nitrogen (DON) released by *Trichodesmium*. The combined bloom moves to nearshore waters where the *Trichodesmium* bloom collapses, releasing large amounts of DON. This initiates the *K. brevis* bloom which can then maintain itself on nutrients released by decaying fishes as well as landward sources of nutrients.

Walsh *et al.* (2006) also hypothesize that some of the perceived increase in red tide blooms may be related to significant increase in the desertification of the Sahara region of Africa, which is resulting in the delivery of greater amounts of iron to the Gulf of Mexico. The authors also note that increased public awareness and increased state and federal monitoring efforts following a large red tide event in 1957 may also have contributed to the perceived increase in bloom occurrence and frequency. The Florida Fish and Wildlife Conservation Commission contracted with biostatisticians at the University of Florida (UF) to analyze the red tide data for long-term trends to determine what valid statistical conclusions could be drawn. UF concluded that the nature of the data prevented any valid statistical interpretation concerning trends and human influences on *K. brevis* blooms. A summary of the UF analysis is available on the FWC-FWRI website.

As seen in the fossil record, *Pyrodinium* blooms have been occurring naturally at levels toxic to nearshore Florida fishes and seabirds for 25 million years (Emslie et al. 1996). Reports of seafood intoxication West Indies were noted during 1457–1526 by the historian Peter Martyr, and the problem was later identified as naturally occurring populations of *Gambierdiscus toxicus*, the alga that causes ciguatera poisoning (Stiedinger et al. 1999). Stiedinger et al. (1999) noted that *Pfiesteria (*and *Pfiesteria-like species)* have probably been present in Florida waters for many years and misidentified as gymnodinioids.

Paleolimnology, including pigment analyses, shows that cyanobacteria were dominant in many Florida lakes prior to human disturbance, in the late 1800s (Riedinger-Whitmore et al. 2005). Historic data show that *Lyngbya wollei* was found in springs in 1939 and 1957 (Stevenson et al. 2007).

While most blooms of the dinoflagellate *K. brevis* occur on the west coast of Florida, red tides occasionally are entrained by the Gulf Stream and move to the east coast. Florida's red tides have contributed to significant economic losses, causing declines in economically valued fisheries resources and impacting businesses that depend on local tourism. Historically, *K. brevis* red tides producing brevetoxins, which disrupt normal neurological processes, have caused the most significant problems. They have led to threats to the public from Neurotoxic Shellfish Poisoning (NSP) or from aerosolized toxins, annually caused the deaths of thousands of fish, and severely impacted endangered marine mammals, turtles, and birds. Fish kills caused by *K. brevis* were first documented in 1844 (prior to any significant human environmental disturbance in North American marine waters), but the cause was not identified until the 1946–47 red tide outbreak.

Although human shellfish poisonings have been known in Florida since the 1880s, the connection with filter-feeding shellfish, toxicity, and *K. brevis* red tides was not identified until the 1960s. Over the past 40 years, human cases of NSP in Florida have only occurred when shellfish were harvested illegally from state-regulated closed shellfish beds or unapproved areas. There have been no human fatalities. People can suffer respiratory irritation and other pulmonary effects when brevetoxins become aerosolized through the disruption of *K. brevis* cells by breaking waves, surf, or onshore winds.

Many studies indicate that red tide blooms are natural events originating in deep, offshore waters, and are subsequently transported to shallower waters and bays by wind and currents. However, there is an ongoing scientific debate concerning whether land-based human influences may be affecting the longevity and persistence of red tides once they come close to shore.

The existing red tide database suffers from a number of inconsistencies, including the presence of data collected for different purposes (experiments versus monitoring), different sampling efforts over the years, and differences in collection and analysis techniques. Because of these issues, the Florida Fish and Wildlife Conservation Commission (FWCC) contracted with UF biostatisticians to analyze the red tide data for long-term trends and to determine what valid statistical conclusions could be drawn. UF concluded that the nature of the data prevented any valid statistical interpretation concerning trends and human influences on *K. brevis* blooms. A summary of the UF analysis is available on the FWC-FWRI website.

Current available data from the past 10 years suggest that *K. brevis* blooms may utilize a multitude of nutrient sources, which vary in significance depending on long shore and offshore locations (Vargo *et al.* 2008). The data suggest that no single nutrient source (including terrestrially derived nutrients) is sufficient to support these blooms, and that while *K. brevis* can utilize these nearshore sources, the salinity restriction on *K. brevis* survival (*K. brevis* does not occur at salinity < 24 PSU) argues against a direct quantifiable link to land-based sources of nutrients. While data linking nutrient loading with *K. brevis* occurrence does not currently exist, FWC-FWRI is currently conducting research on this issue.

The Department considered harmful algal blooms/mats as a potential response endpoint for numeric nutrient criteria development, and concluded that protection of natural populations of flora and fauna would be effective in limiting harmful algal events to frequencies that would have expected to occur under natural conditions. Based on the above information, it is the Department's position that many harmful algal blooms, including red tide events are natural occurrences, even in estuaries that are minimally disturbed by human activities and in estuaries that fully support aquatic life use. Therefore, the presence of blooms, including red tide, when other data indicate unimpaired conditions, should not disqualify a system from being considered healthy and well balanced.

Dissolved Oxygen

Florida adopted its existing DO criteria for marine waters in the early 1970s, largely based on early water quality criteria recommendations from the Federal Water Pollution Control Administration (FWPCA) (1968) and EPA (1972). This initial 1970s guidance concerning the establishment of DO criteria was based on very limited scientific information. Specifically, there ere inadequate data regarding the response of marine organisms to low DO concentrations; therefore the criteria were largely driven by the responses of sensitive freshwater fish (largely coldwater species) to depressed DO levels. After extensive review, the Department has determined that the current marine DO criteria are in need of revision, and therefore, the Department is currently pursuing such revisions to state water quality standards (Chapter 62-302, F.A.C.), using the following two lines of evidence:

1. *An application of the methodology developed by the EPA for the Virginian Province (EPA 2000). As described below, EPA's Virginian Province approach uses knowledge regarding the biological response of sensitive aquatic organisms to hypoxic stressors to derive DO criterion that provide sufficient protection from acute and chronic effects of exposure to low DO levels in marine waters; and*

2. *An analysis of empirical DO data from several minimally disturbed systems that represent natural background DO distributions expected in Florida marine waters.*

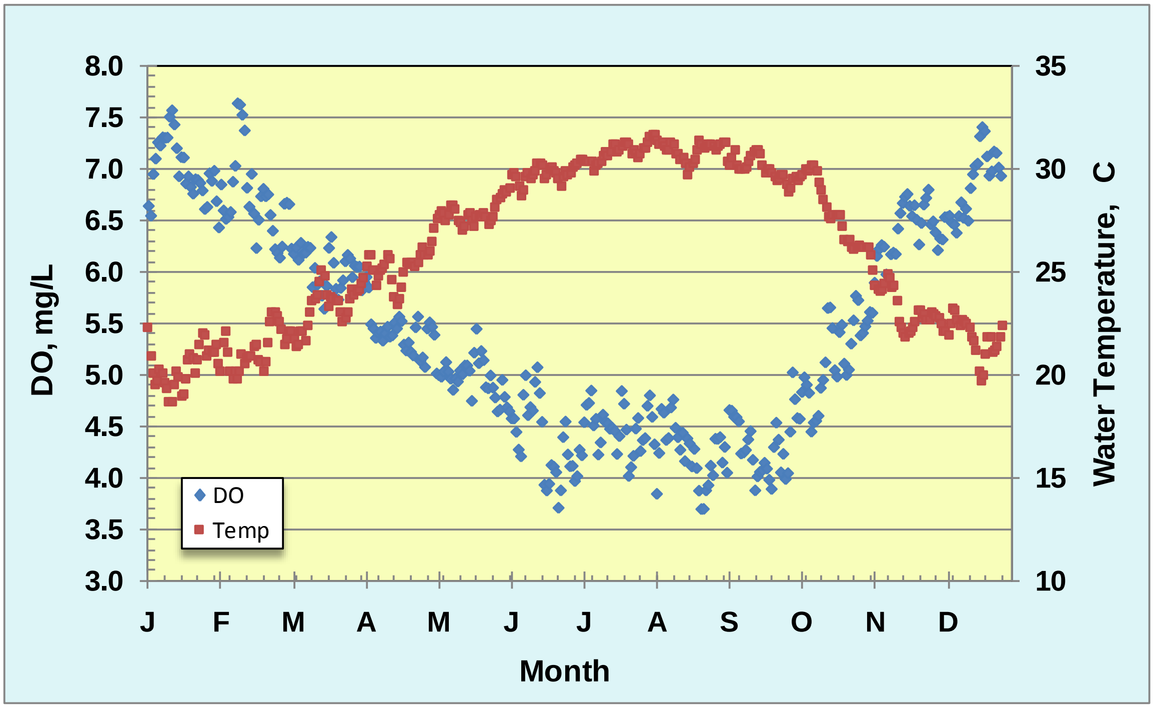
EPA guidance regarding DO criteria for marine waters recognizes that a number of natural conditions can result in DO levels below the recommended criteria and acknowledged that in these cases, the default criteria would not be appropriate. Additionally, the recommended DO criterion was qualified with the following statement; "The committee would like to stress that, due to a lack of fundamental information on the DO requirements of marine and estuarine organisms, these requirements are tentative and should be changed when additional data indicate that they are inadequate" (FWPCA 1968). In the 42 years since the preliminary EPA recommendation on DO criteria for marine waters was incorporated into Florida's water quality standards, numerous studies have been conducted to understand the biological response to low DO levels using a wide range of organisms. These studies have vastly improved the knowledge base needed to develop more appropriate revised criteria for Florida's marine waters.

Florida's current DO criteria for Class II and III marine waters specify that DO concentrations "shall not average less than 5.0 in a 24-hour period and shall never be less than 4.0.") (Section 62-302.530, F.A.C.). Additionally, the criteria indicate that normal daily and seasonal fluctuations above these levels shall be maintained.

Need for Revised DO Criteria for Florida's Marine Waters

Persistent, low DO concentrations (below the existing DO criteria) have been documented in many of Florida's minimally disturbed and healthy estuarine systems. Natural estuaries especially subject to low DO include those receiving significant drainage from wetlands or marshes, those in areas surrounded by mangrove forests, or those where salinity stratification occurs (Hendrickson 2010). Because the dissolution of oxygen into water is an inverse function of water temperature, the low DO conditions typically occur during high summertime temperatures, but Florida has generally high water temperatures compared with most states.

DO concentrations in Fakahatchee Bay, located in one of the most pristine estuarine areas in the state (the Ten Thousand Islands Aquatic Preserve) are frequently below the existing criteria. Fakahatchee Bay is surrounded by extensive mangrove forests and is located downstream of a highly undeveloped Everglades watershed, with nearly 90% of the watershed consisting of conservation lands (*e.g.*, Fakahatchee Strand State Park, Cape Romano Aquatic Preserve, Big Cypress National Preserve). DO concentrations have been monitored continuously (*i.e.*, measured at 15-minute intervals) by the Rookery Bay NERR as part of the NERR Program since January 2002. The DO data collected in Fakahatchee Bay show the expected seasonal and daily fluctuations, with DO concentrations being inversely related to water temperature (Figure A-1). Note that during the summer months (mid-May through mid-October), none of the daily average DO concentrations met the current 5.0 mg/L criterion. From January 2002 through June 2010, 37% of measured daily average DO concentrations were below the current 5.0 mg/L criterion. Additionally, Figure A-1 summarizes the average daily fluctuation in DO



concentrations for Fakahatchee Bay for the summer months (*i.e.*, June through September) when DO levels are normally low. The data indicate that the DO concentration is typically below the existing 4.0 mg/L instantaneous limit for nearly half of the day. Based on the January 2002 through June 2010 period of record, approximately 21% of the measured DO concentrations were below the 4.0 mg/L limit.

Figure A-1. Average daily mean DO concentrations and water temperatures for Fakahatchee Bay calculated using data collected from January 2002 through May 2010

Additionally, the individual DO measurements for Fakahatchee Bay for the summer months (*i.e.*, June through September) are commonly below the existing 4.0 mg/L instantaneous limit for nearly half of the day (Figure A-2). Based on the January 2002 through June 2010 period of record, approximately 18% of the measured DO concentrations were below the 4.0 mg/L limit. Despite the periodic low DO conditions, Fakahatchee Bay supports a very productive fishery as well as other biological (*e.g.,* shellfish, seagrass) communities (see the Department's Southwest Coast Nutrient Criteria Document). However, as the result of the frequent exceedances of both the existing 4.0 mg/L instantaneous limit and the 5.0 mg/L daily average DO concentration criterion, Fakahatchee Bay could erroneously be determined to be impaired for DO even though the observed DO levels represent natural DO conditions from a system with minimal anthropogenic input.

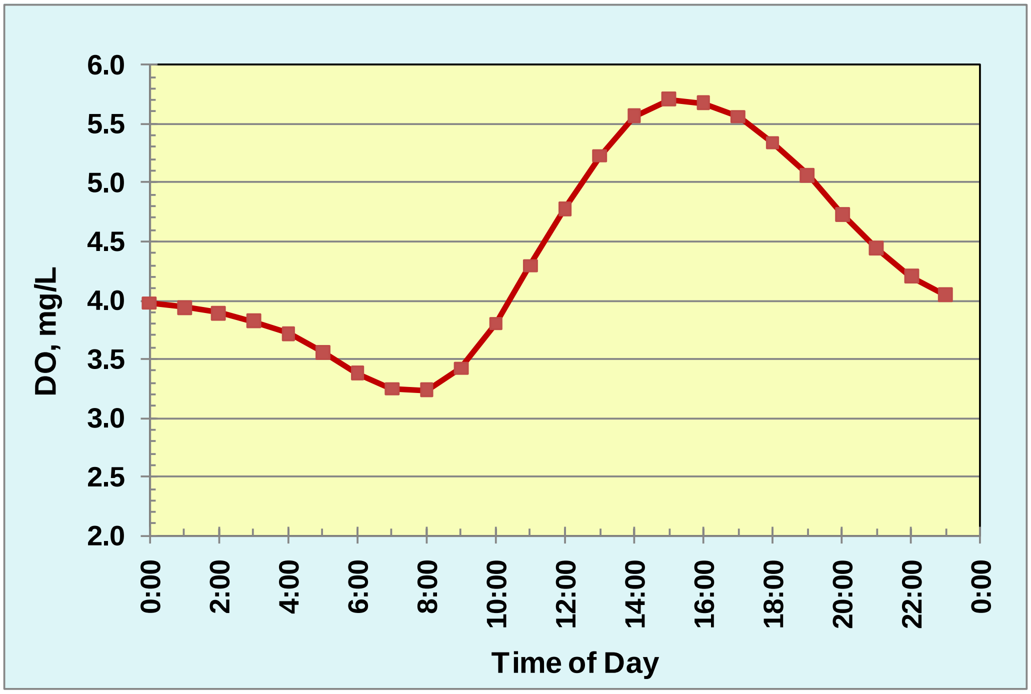


Figure A-2. Average diel fluctuation in DO concentrations for Fakahatchee Bay during the summer months (June through September) calculated using data collected from January 2002 through May 2010

A similarly low DO regime was observed in the East Bay portion of the Apalachicola Estuary system in northern Florida. East Bay receives an abundance of organic matter inputs from the Tate's Hell State Forest, a watershed predominantly consisting of swamp forest and wet pine flatwoods. East Bay is the epicenter of secondary productivity for the Apalachicola system, a bay renowned for its beneficial yield of oysters, crab, shrimp, and finfish (Livingston 2010). In fact, 90% of Florida's oysters, and 10% of the nation's oysters are produced in Apalachicola Bay.

DO concentrations in East Bay have been continuously monitored as part of the NERR Program since January 2002. Figure A-3 illustrates daily average DO concentrations in East Bay over the period of record. As in Faka Union Bay in south Florida, DO concentrations in East Bay are inversely related to temperature, with the lowest DO levels occurring during the late summer. The low DO concentrations in surface waters during the summer are the result of both higher water temperatures and increased rainfall, which transports larger amounts of organic matter from the natural forested area upstream of the bay, resulting in greater natural DO demand.

DO concentrations in the bottom waters in East Bay are depressed further by the stratification that frequently occurs in the deeper water during the summer. During these periods, the water is not mixed vertically and the denser seawater settles to the bottom, while the incoming fresh water remains near

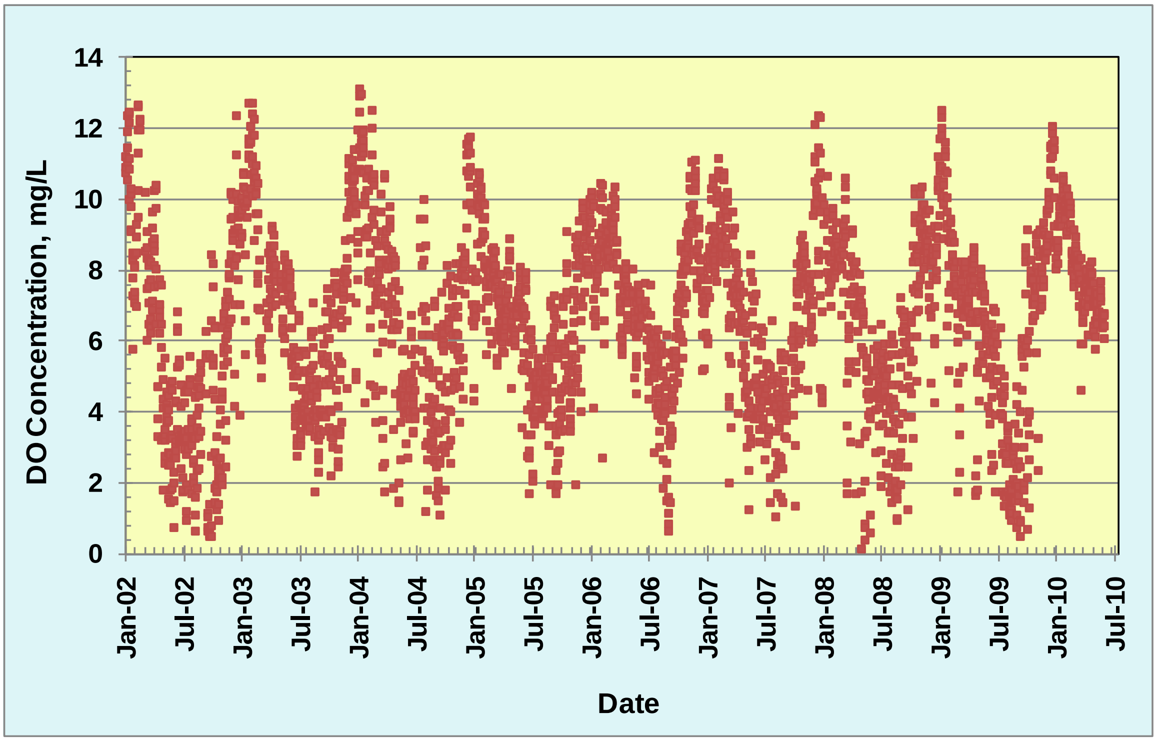


Figure A-3. Daily average DO concentrations for East Bay (Apalachicola) during the period of record, January 2002–June 2010

the surface. Most of the oxygen sources (*e.g.*, photosynthesis and reaeration) occur predominately in surface waters, while most of the oxygen demand occurs at depth due to the respiration of bottom organisms and the decomposition of the organic material in the sediment. Since the density gradient formed during stratification acts as a physical barrier, bottom waters can become isolated from the oxygenated fresh water near the surface. As a result, DO concentrations in the bottom water can quickly become depleted during periods of stratification, since the oxygen demands far outweigh the sources of oxygen.

Over the 8-year period of record, approximately 29% of the daily average DO concentrations in East Bay were below the current 5.0 mg/L criterion, with 18% of the individual DO measurements being below the 4.0 mg/L instantaneous limit. Despite having minimal anthropogenic inputs (similar to Faka Union Bay), East Bay could erroneously be determined to be impaired based on the frequent exceedances of both the existing 4.0 mg/L instantaneous limit and the 5.0 mg/L daily average DO concentration criterion. When estuaries are minimally disturbed by humans and are characterized by a healthy, well-balanced aquatic community, it is critical that natural low DO not be misinterpreted as a response to other pollutants such as nutrients or oxygen-demanding substances.

Since drainage from natural wetlands, swamps, marshes, and mangrove forests typically contain high CDOM and elevated natural nutrient levels (especially, nitrogen), it is important not to erroneously identify nutrients as the pollutant responsible for low DO levels when the low DO actually results from natural conditions. This expends valuable resources in attempting to rectify a natural condition.

This phenomenon (natural waterbodies exhibiting DO levels below the existing DO criteria) is commonly found around the state. It is extremely important to note that the low DO conditions in these systems do not adversely affect the biological communities in the waterbodies. Since Florida's existing DO criteria would erroneously indicate that these systems are impaired, despite supporting healthy biological communities and existing uses, it can logically be concluded that the existing criteria are often overly protective and that more accurate DO criteria should be developed. This document uses the knowledge gathered over the past 40 years (since the adoption of the original criteria) concerning DO regimes in natural systems and biological response to DO to propose refinements to the DO criteria.

Relationship Between Nutrients, Chlorophyll, and DO in Tampa Bay

TBEP tasked Janicki Environmental with characterizing DO concentrations in Tampa Bay's major bay segments, assessing the principal drivers of DO exceedances in Tampa Bay, and evaluating the relevance of the empirical distribution of DO concentrations in the context of existing DO criteria (Janicki Environmental 2010). This section summarizes the results of the Janicki (2010) analysis.

The assessment included a descriptive characterization of the spatial and temporal attributes of observed DO concentrations using over 30 years of data, 4 different sampling agencies, and over 17,000 individual data points. The following conclusions can be drawn from the Janicki Environmental (2010) analyses:

- *The empirical evidence suggests that all major segments of Tampa Bay are meeting full aquatic life uses with respect to DO.*
- *Examination of the spatial distribution of DO samples shows that DO exceedances < 4 mg/L are most likely to occur in Hillsborough Bay near the mouths of the Hillsborough and Alafia Rivers, and along the western half of Hillsborough Bay. These are deeper areas, more likely to be stratified due to freshwater inputs, and have high organic sediment content.*
- *The principal factor affecting DO in Tampa Bay is temperature. That is evident in both the descriptive temporal plots and in the generalized linear model assessed in the quantitative assessment of those factors affecting the probability of DO being less than 4 mg/L. The model results indicate that stratification, bottom type, and sample depth were other factors that contributed to the probability of low DO conditions (i.e., < 4 mg/L). Furthermore,* ***it was determined that chlorophyll a concentrations were not a significant factor contributing to probability of low DO conditions in Tampa Bay****. In other words, the occurrence of DO values below 4 mg/L was not significantly related to observed chlorophyll a concentrations at the time of sampling.*

- *Based on the weight of evidence, it is reasonable to conclude that the NNC proposed for Tampa Bay are fully protective of aquatic life uses with respect to DO.*

The quantitative assessment consisted of developing an empirical regression model to estimate the probability of a bottom DO value less than 4 mg/L as a function of hypothesized major drivers of DO in Tampa Bay. These drivers included temperature, bottom depth, the interpolated silt-clay values, chloro phyll *a*, surface salinity, and a measure of stratification calculated as the rate of change between surface and bottom salinity as a function of depth. A generalized linear mixed-effects model was developed for this assessment. The model estimates the probability of a DO exceedance (*i.e.*, DO < 4.0 mg/L) as a function of several predictor variables. The fixed effect model equivalent is a logistic regression model; a class of generalized linear models.

An analysis showed that the influence of temperature and salinity on the capacity of estuarine water to hold oxygen is critical. There are very few values below 4 mg/L in winter months, while in summer months a higher preponderance of observations with a DO value below 4 mg/L. Hillsborough Bay was the only segment where the percentage of DO values < 4 mg/L exceeded 10% in any month (Figure A-4).

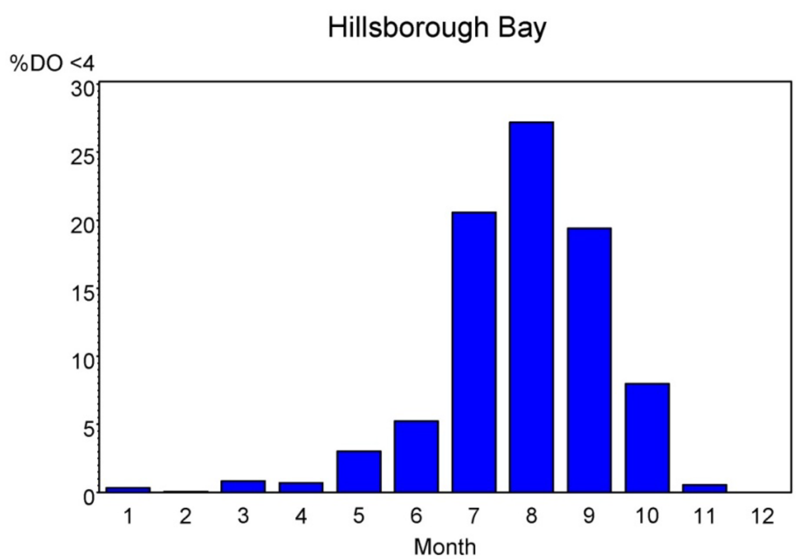


Figure A-4. Percent of values below 4 mg/L in Hillsborough Bay per month (Janicki 2010)

To investigate the relationship between primary production and DO in Tampa Bay, the fixed station data collected between 1974 and 2009 were used to calculate annual average chlorophyll *a* concentrations and annual DO exceedance frequencies in each bay segment over the entire period of record (see Figure A-5 for Hillsborough Bay). A visual comparison of the time series plots suggests little correspondence between annual chlorophyll averages (green broken line) and DO exceedance frequencies (blue solid line) within each segment. The Pearson correlation statistic (Rho) confirmed a lack of relationship in any segment (p values > 0.05).

However, it is clear in all segments that a reduction in chlorophyll *a* concentrations was evident after 1985 following the implementation of regulatory actions to control wastewater and stormwater impacts to Tampa Bay (Greening and Janicki 2006). During this same period, the annual percentage of DO exceedances remained variable and did not trend in either direction. It should be noted that data used in this analysis show that the percentage of DO values < 4 mg/L consistently remained below 10% in all bay segments.

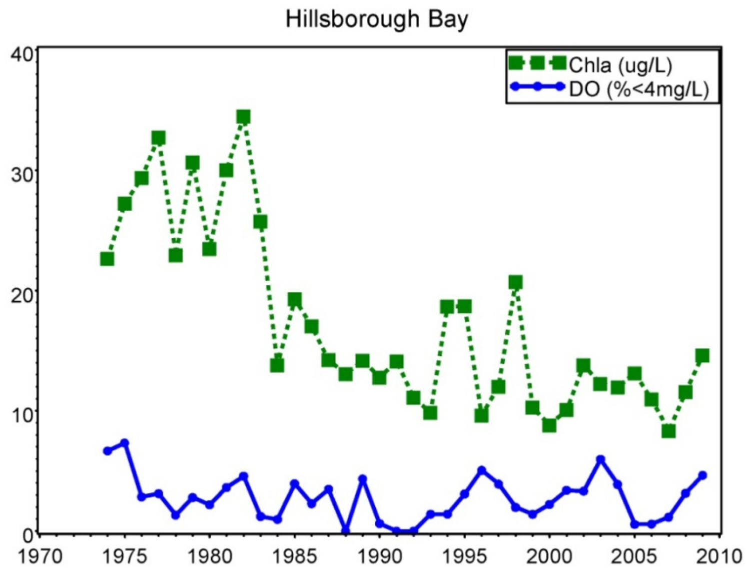


Figure A-5. Long-term relationship between DO exceedances and chlorophyll a in Hillsborough Bay, 1973–2009. Note that chlorophyll has no effect on the percent exceedances <4 mg/L (Janicki 2010).

As described above, a generalized linear mixed-effects model was constructed to identify the principal factors (including physical and water quality factors) affecting the probability of observing a bottom DO value less than 4 mg/L. This analysis used the Environmental Protection Commission of Hillsborough County (EPCHC) fixed station data collections from 1974 through 2009, since both DO and chlorophyll *a* concentration measurements are taken concurrently. The model was constructed using all months (full model) and separately using a subset of data collected between July and August. Table A-1 provides the parameter estimates, resulting odds ratio estimates, and p-values. The relative effect of individual parameter estimates on the change in probability of observing a bottom DO < 4 mg/L can be assessed using either the odds ratio estimate or the F values associated with the significance test. An odds ratio of 1 is equivalent to a rate of change of 0 and indicates a variable has little influence on the predicted probability.

Model results suggest that temperature, the degree of salinity stratification between surface as bottom waters, sample depth, and sediment silt-clay content were the primary factors positively associated with the probability of a bottom DO exceedance. **In neither model was chlorophyll *a* concentration a significant predictor of a bottom DO exceedance.**

Therefore, physical influences have a greater influence on the probability of observing a low DO value than chlorophyll *a* concentrations. These results agree with the descriptive assessment of the ambient DO data and provide additional weight of evidence that DO values < 4 mg/L in Tampa Bay are affected more by physical processes than nutrient-driven processes. Therefore, any NNC that are proposed as being protective of primary production for the attainment of seagrass targets would be equally protective for DO conditions within the bay.

Table A-1. Fixed effects parameter estimates from GLIMMIX model output with associated odds ratios and significance levels for full model (top) and model for summer only (bottom). The response variable is the probability of a bottom DO < 4 mg/L (Janicki 2010).

- = Empty cell/no data

Parameter	Coefficient	Odds Ratio	F Value	Prob>F
Full model	-	-	-	-
Intercept	-19.962	-	-	-
Percent silt-clay	0.130	1.138	11.550	0.001
Bottom depth	0.339	1.403	57.550	<.0001
Stratification	0.308	1.360	47.070	<.0001
Chlorophyll *a*	0.004	1.004	3.150	NS
Surface Salinity	-0.030	0.971	7.520	0.006
Bottom temperature	0.456	1.578	324.540	<.0001
Summer Only	-	-	-	-
Parameter	Coefficient	Odds Ratio	F Value	Prob>F
Intercept	-14.441	-	-	-
Percent silt-clay	0.119	1.126	14.390	0.000
Bottom depth	0.229	1.257	12.110	0.001
Stratification	0.321	1.379	24.690	<.0001
Chlorophyll *a*	0.003	1.003	0.850	NS
Surface Salinity	0.010	1.010	0.330	NS
Bottom temperature	0.271	1.311	17.090	<.0001

Data for both the fish and benthic communities were available in Tampa Bay and provided an opportunity to examine the potential relationships between community structure and DO conditions. For benthic communities, the TBEP designed and implemented a baywide probabilistic benthic sampling program in 1993 (Coastal Environmental, 1993). Benthic samples are collected during a late summer index period following methods developed by the EPA Estuarine Environmental Monitoring and Assessment Program (EMAP). For fish and nekton communities, the FWC began the Fisheries Independent Monitoring (FIM) Program in 1989 with seasonal monitoring. In 1996, the program switched to monthly monitoring using a stratified random sampling design. The FIM Program uses small seines to collect juvenile and small-bodied fishes in water depths of 1.8 meters or less. Trawls are used to collect samples in deeper waters. Larger subadult and adult fishes are collected using 183-meter haul seines (along shorelines) and purse seines (in open bay waters less than 3.3 meters deep). Generally, 25 samples are collected with each gear type in Tampa Bay each month, and physical chemistry and habitat information are recorded along with each sample.

An examination of the benthic data included the calculation and depiction of the annual mean number of taxa/sample, mean number of individuals/sample, and mean species diversity (H') for those years in which the percentage of all DO samples < 4 mg/L exceeds 10% and those years when the percentage of all DO samples < 4 mg/L is less than 10% (this classification was based on all available DO data). Figures A-6 through A-8 present the results of this examination for Hillsborough Bay, the only segment that displayed any year with DO exceedances greater than 10%. Clearly, there are no demonstrable differences in the number of taxa, number of individuals, or species diversity between those years in which the percentage of DO samples < 4 mg/L exceeds 10% and those years when the percentage of DO samples < 4 mg/L is less than 10% in Hillsborough Bay.

These results indicate that the Hillsborough Bay benthic and fish community structure did not differ in years when DO exceedances were greater than 10% from that observed in years in which exceedances were below 10%. Further, the data indicate that factors other than nutrients and chlorophyll were responsible for the naturally low DO in portions of Tampa Bay.

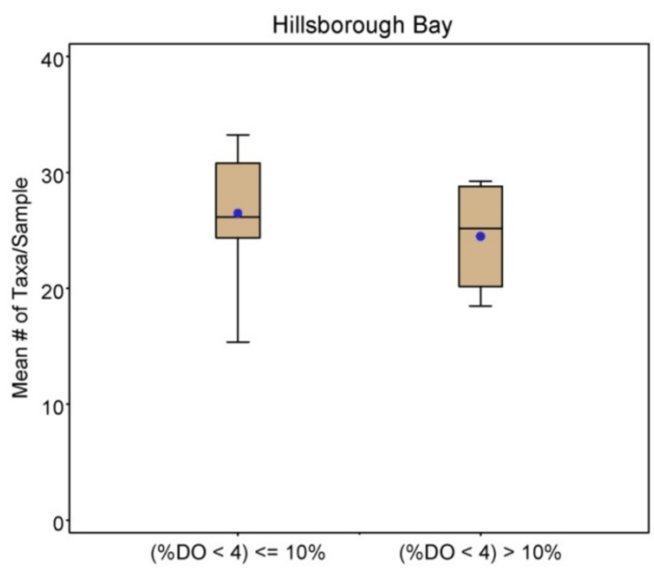


Figure A-6. Comparison of the mean number of benthic taxa/sample in Hillsborough Bay for those years in which the percentage of DO samples < 4 mg/L exceeds 10% and those years when the percentage of DO samples < 4 mg/L is less than 10%. The DO classification was based on all available DO data.

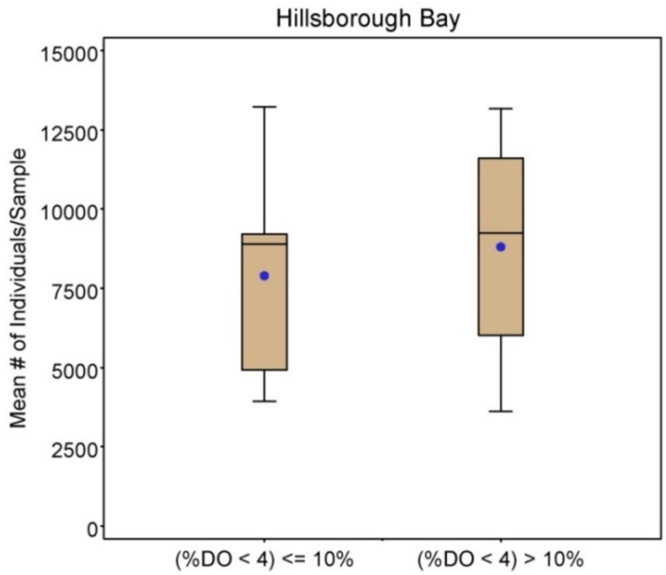


Figure A-7. Comparison of the mean number of benthic individuals/sample in Hillsborough Bay for those years in which the percentage of DO samples < 4 mg/L exceeds 10% and those years when the percentage of DO samples < 4 mg/L is less than 10%. The DO classification was based on all available DO data.

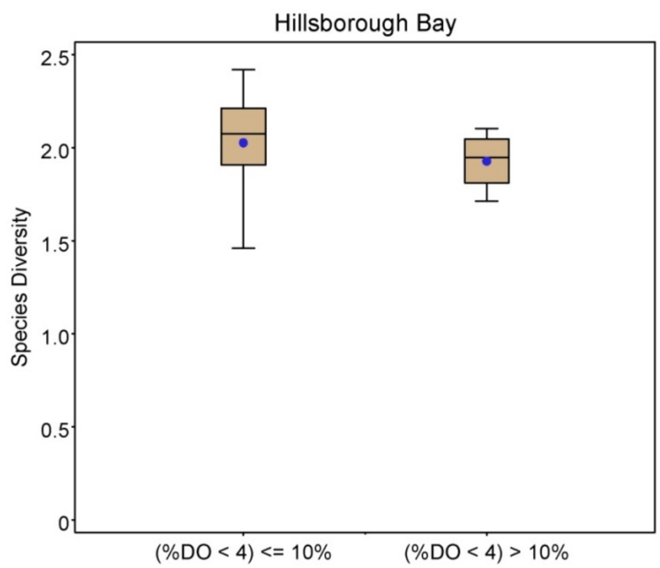


Figure A-8. Comparison of the mean benthic species diversity/sample in Hillsborough Bay for those years in which the percentage of DO samples < 4 mg/L exceeds 10% and those years when the percentage of DO samples < 4 mg/L is less than 10%. The DO classification was based on all available DO data.

Similarly, the fish data were examined using the annual mean species richness, number of fish/haul, and mean species diversity (H') to compare those years in which the percentage of DO samples < 4 mg/L exceeded 10% and those years when the percentage of all DO samples < 4 mg/L was lower than 10%. Figures A-9 through A-11 present the results of this examination for Hillsborough Bay, the only segment that displayed any year with all DO exceedances greater than 10%. Each figure presents the results for 4 gear types: 20-meter seines, 183-meter seines, 183-meter purse seines, and 6-meter trawls. As was the case with the benthic metrics, there were no significant differences in species richness, number of fish/haul, or fish species diversity between those years in which the percentage of all DO samples < 4 mg/L exceeds 10% and those years when the percentage of all DO samples < 4 mg/L is less than 10% in Hillsborough Bay.

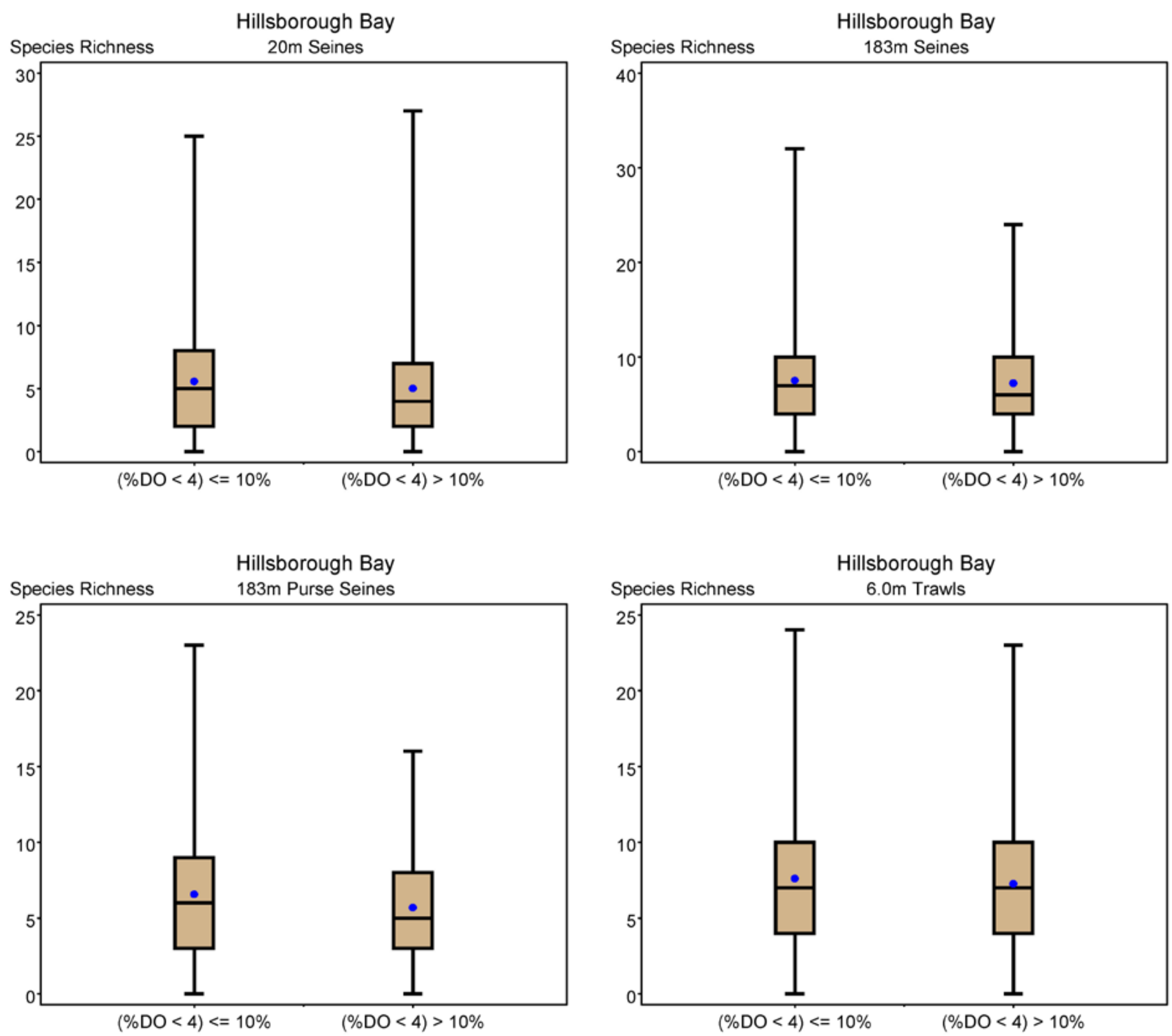


Figure A-9. Comparison of the mean fish species richness in Hillsborough Bay for those years in which the percentage of DO samples < 4 mg/L exceeds 10% and those years when the percentage of DO samples < 4 mg/L is less than 10%. DO data are from samples taken concurrently with fish collections.

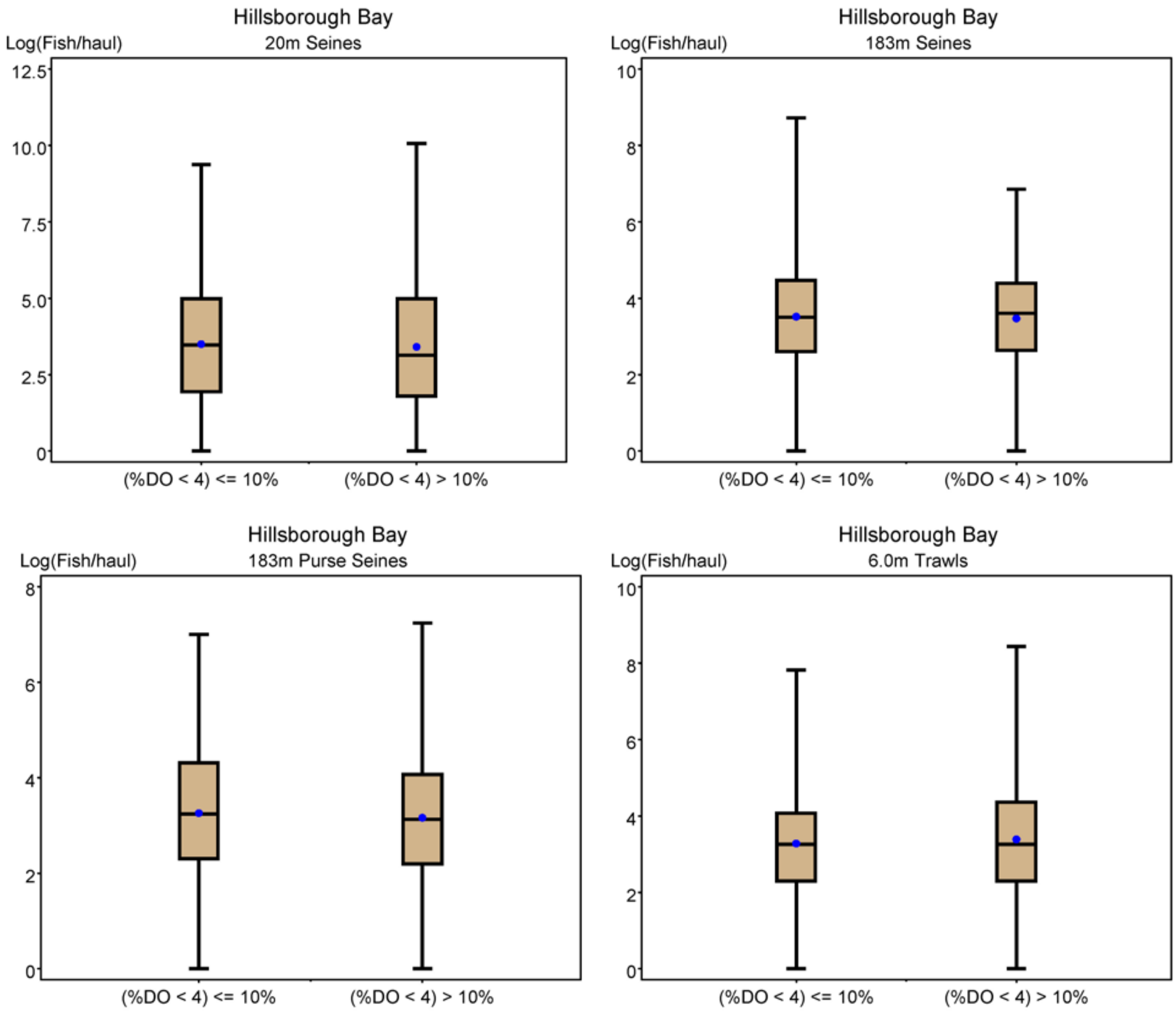


Figure A-10. Comparison of the mean number of fish/haul in Hillsborough Bay for those years in which the percentage of DO samples < 4 mg/L exceeds 10% and those years when the percentage of DO samples < 4 mg/L is less than 10%. DO data are from samples taken concurrently with fish collections.

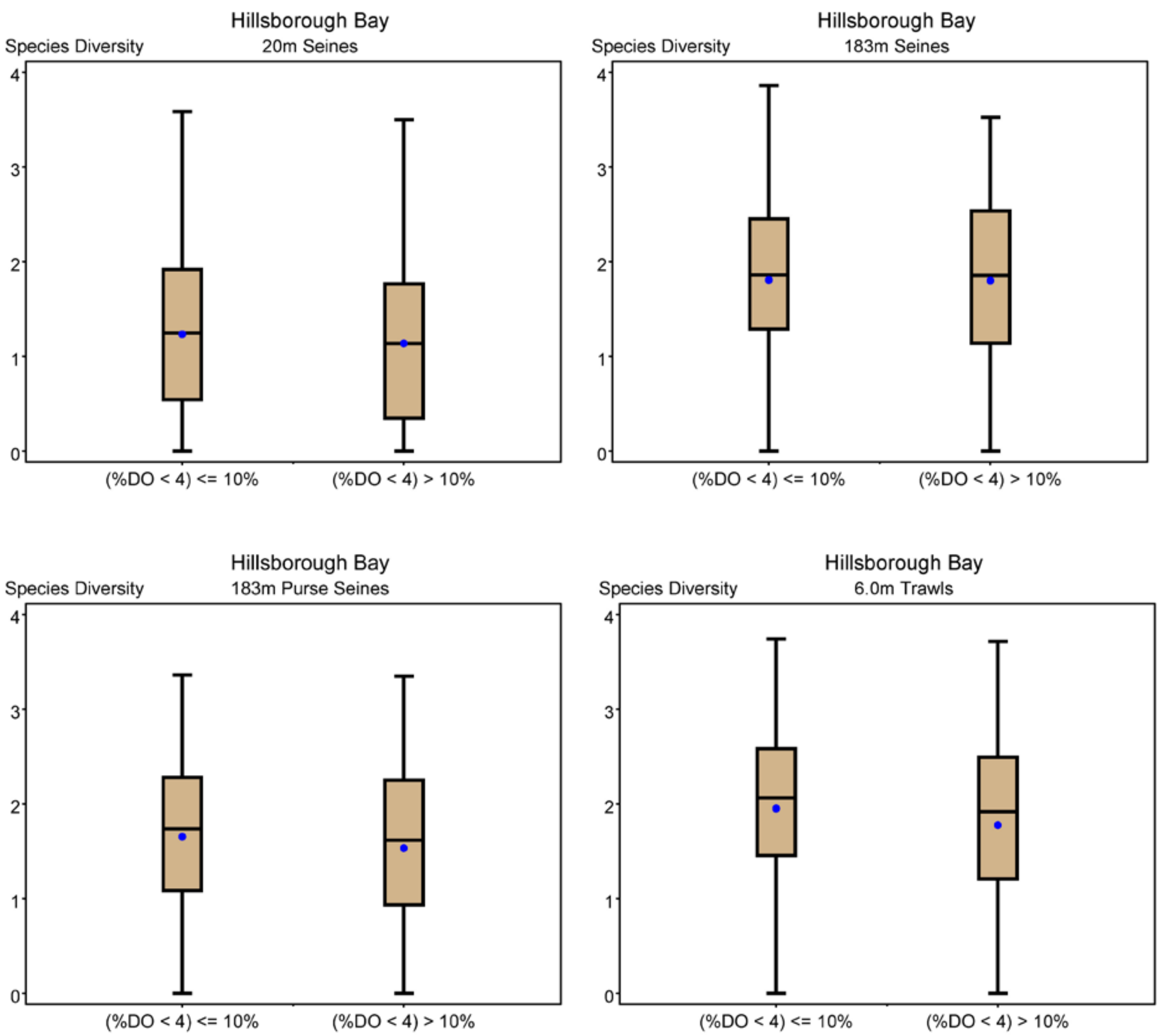


Figure A-11. Comparison of the mean fish species diversity in Hillsborough Bay for those years in which the percentage of DO samples < 4 mg/L exceeds 10% and those years when the percentage of DO samples < 4 mg/L is less than 10%. DO data are from samples taken concurrently with fish collections.

SSAC for DO

Florida's Water Quality Standards (Section 62-302.800, F.A.C.) allow for the development of SSAC that more accurately reflect the DO levels required to maintain healthy biological communities. To be approved for a Type I SSAC, a petition must demonstrate that an alternative criterion is more appropriate for a specified portion of waters of the state. The petition needs to accomplish the following:

- *Document that the proposed alternative concentrations that are different from the otherwise applicable Class III criteria exist because of natural background conditions;*

- *Establish the levels and duration of the naturally occurring concentrations and other parameters or conditions that may affect it;*
- *Describe the historical and existing biology, including variations that may be affected by the parameters in question;*
- *Show that normal fluctuations of an analyte are being maintained; and*
- *Show that the designated use is being attained and not adversely affecting adjoining waters.*

EPA has previously approved 12 DO SSACs for Florida waters. However, the development of SSACs for individual waterbodies to address a global problem with the existing DO criteria is both time consuming and costly. Historically, most DO SSACs have been derived using a reference site approach (relying on a minimally disturbed waterbody to establish a natural background DO distribution). However, the DO SSAC for the LSJR was developed by using the measured responses of multiple sensitive organisms exposed to low DO (a modification of the EPA Virginian Province approach). Examples of both types of SSAC are provided below.

Examples of DO SSAC Based on Reference Conditions

Nassau/Amelia River Estuary DO SSAC

In the Amelia River Estuary, DO levels observed during the summer are below 4.0 mg/L approximately 10% of the time due to natural conditions. Extensive marsh and swamp systems adjacent to the system contribute vast amounts of leaf litter, which in turn cause the waters to contain high amounts of organic tannins, lignans, and other humic acid substances. These naturally occurring water quality conditions contribute to periodic low DO in the estuary. A DO SSAC was developed for the Amelia River using the reference site approach. Due to its minimal level of human disturbance, the nearby Nassau River, which is part of the Nassau River–St. Johns River Marshes State Aquatic Preserve, was selected as the reference system for the derivation of the Amelia River DO SSAC.

The DO regime in the Nassau River exhibited seasonal DO patterns similar to those observed in the Amelia River. The documented seasonal variations were strongly linked to seasonal temperature fluctuations (Figure A-12). All recorded values below the existing 4.0 mg/L criterion were associated with temperatures above 20°C. that occurred during the warmer summer months. Based on the reference conditions observed in the Nassau River Estuary, the Amelia River Estuary SSAC specifies that, during the summer months of July through September, the instantaneous DO concentration shall not fall below 3.2 mg/L and that a daily average DO concentration of 5.0 mg/L shall be maintained. During the other months, the existing marine criterion remains in effect.

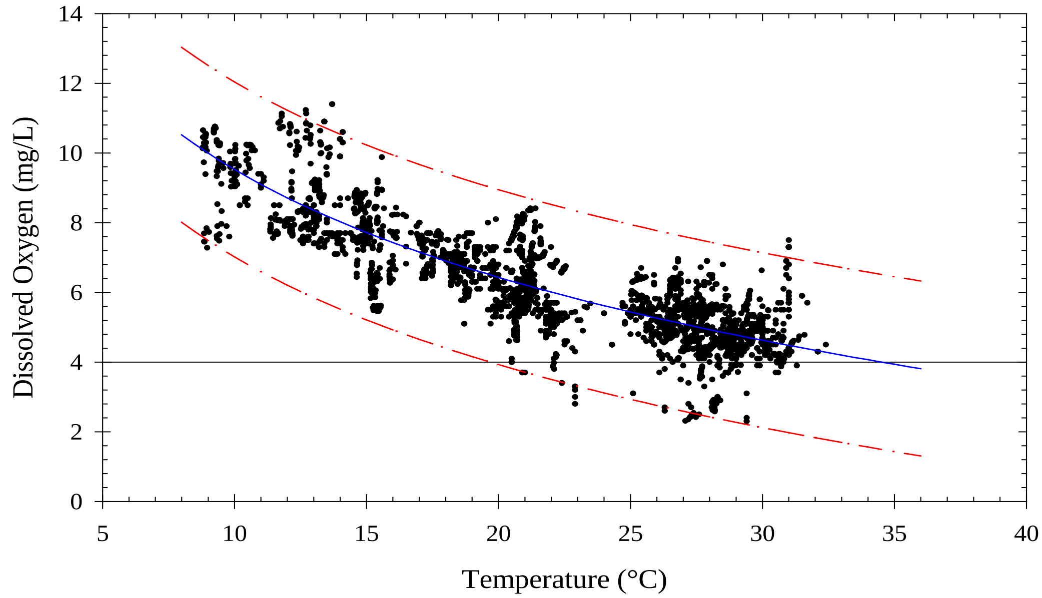


Figure A-12. Relationship between DO concentration and water temperature in the Nassau River reference waterbody. The blue solid and red dashed curves indicate the regression curve and the 95 percent prediction interval for that regression curve, respectively. The black horizontal line depicts the existing 4.0 mg/L minimum DO criterion.

Econfina/Fenholloway River Estuary SSAC

Much like DO concentrations in the Amelia and Nassau Rivers, DO concentrations in the Fenholloway River and adjacent coastal area exhibited expected seasonal variations; however, exceedances of the existing DO criteria were not only limited to the summer months and frequently occurred throughout the year. As for the Amelia River, a DO SSAC for the Fenholloway River was derived based on the DO regime in a minimally disturbed reference system. Based on the surrounding benign land use, the lack of anthropogenic inputs, and the presence of healthy biological communities, the adjacent Econfina River was demonstrated to be an appropriate reference system for use in deriving a DO SSAC for the Fenholloway.

Due to the natural seasonal fluctuations in the expected DO levels, the SSAC petition requested that the SSAC vary on a seasonal basis. Figure A-13 provides a monthly summary of the DO data from the lower Econfina River and estuary. Based on similarity in DO levels among the months, the DO data were grouped into three seasonal periods for the purpose of derivation and application of the SSAC: (1) April 1 through September 30; (2) February 1 through March 31, and October 1 through November 30; and (3) December 1 through January 31.

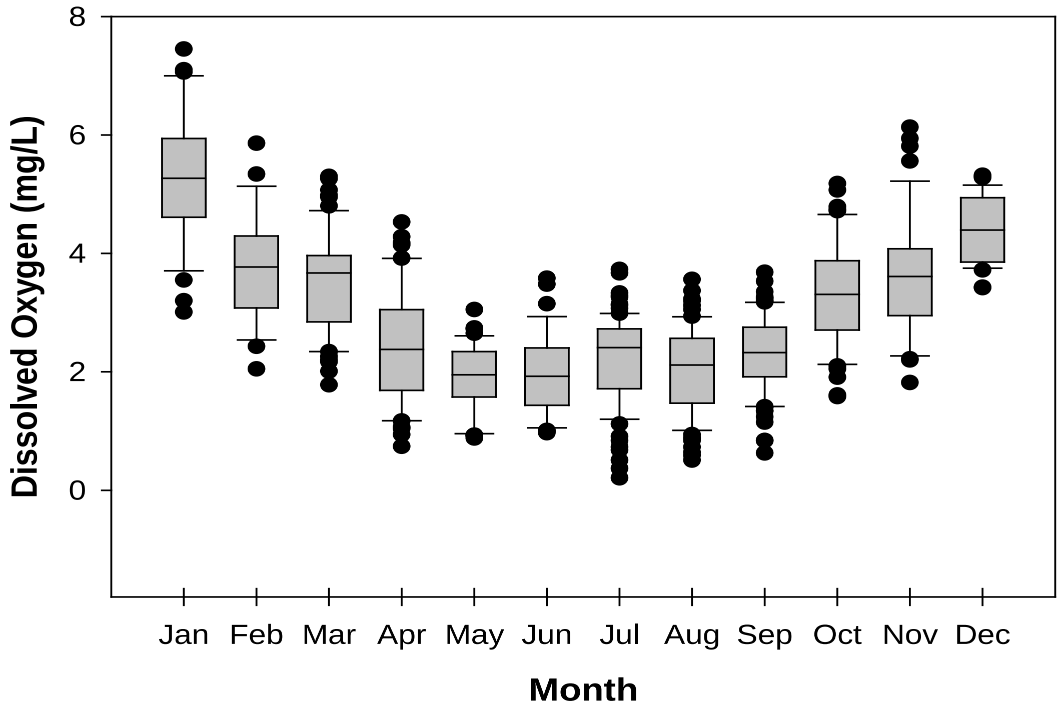


Figure A-13. Monthly distribution of daily minimum DO concentrations at Econfina River and Estuary monitoring sites

The DO SSAC for the Fenholloway River consisted of two components for each seasonal period that were derived as follows:

- *The 10th percentile of the daily average DO levels; and*
- *The 10th percentile of the daily DO minimum concentrations.*

Table A-2 provides the results of the analyses.

Alternative DO criteria derived using the reference site approach are considered to be inherently protective. However, since no cause-and -effect relationship is identified, the exact level of protection provided by the reference site approach is not easily assessed and can vary based on a number of factors, including the objectives for deriving the SSAC, the appropriateness of the reference waterbody, the method used to derive the new criterion, and the sufficiency and robustness of available data.

Table A-2. Seasonal DO SSAC for estuarine and coastal areas based on the 10th percentiles of DO concentrations at Econfina River reference sites

[1] The 24-hour average DO at any location within the described area shall not be less than the level specified for that seasonal period.
[2] No more than 10% of the measurements made during a 24-hour period at any location within the described area shall be less than the minimum level specified for that seasonal period.
- = Empty cell/no data

Annual Period	Daily Average DO Criterion (mg/L)[1]	Daily Minimum DO Criterion (mg/L)[2]
River/Estuarine Areas	-	-
April – September	2.1	1.2
February–March and October–November	3.4	2.4
December – January	5.0	3.6
Adjacent Coastal Areas	-	-
April – September	3.2	1.7
February–March and October–November	5.0	3.5
December–January	5.0	4.0

Example of DO SSAC Derived Using Virginian Province Method

Due to the limitations associated with the reference site approach, basing criteria on a cause-and-effect relationship would be a more robust method for developing alternative DO criteria. This method provides a known level of protection (neither under- or overprotective) and provides reproducible results that may be extrapolated statewide. To develop the DO SSAC for the marine portions of the LSJR, the Department used a modification of the EPA Virginian Province method (EPA 2000). This method utilizes the measured response of multiple sensitive organisms exposed to low DO conditions. These data are then used to determine the DO level necessary to protect sensitive taxa from significant decreases in recruitment or growth. Figure 11 [in the main document] illustrates the growth and larval recruitment response curves used to derive the DO SSAC for the LSJR.

In accordance with EPA recommendations for the Virginian Province (EPA 2000), the DO range was divided into intervals. For the proposed LSJR SSAC, intervals were established from 4.0 to 4.2 mg/L, 4.2 to 4.4 mg/L, 4.4 to 4.6 mg/L, 4.6 to 4.8 mg/L, and 4.8 to 5.0 mg/L based on the applicable portions of the larval population recruitment/ survival function and the larval growth function. The applicable larval population recruitment/survival curve or larval growth curve can then be used to derive the acceptable exposure durations for each interval.

Since the biological effect of low DO exposure is cumulative across the DO intervals, the fractional exposures within each range would be summed as proposed by EPA (2000). The final DO SSAC for the LSJR was expressed as the sum of the fractional exposures between 4.0 and 5.0 mg/L, expressed as:

$$\left(\begin{array}{c}\textbf{Total Fractional}\\ \textbf{Exposure}\end{array}\right)=\frac{\begin{array}{c}\textbf{Days between}\\ \textbf{4.0 - < 4.2 mg/L}\end{array}}{\textbf{16 day Max}}+\frac{\begin{array}{c}\textbf{Days between}\\ \textbf{4.2 - < 4.4 mg/L}\end{array}}{\textbf{21 day Max}}+\frac{\begin{array}{c}\textbf{Days between}\\ \textbf{4.4 - < 4.6 mg/L}\end{array}}{\textbf{30 day Max}}+\frac{\begin{array}{c}\textbf{Days between}\\ \textbf{4.6 - < 4.8 mg/L}\end{array}}{\textbf{47 day Max}}+\frac{\begin{array}{c}\textbf{Days between}\\ \textbf{4.8 - < 5.0 mg/L}\end{array}}{\textbf{55 day Max}}$$

where the number of days within each interval is based on the daily average DO concentration. To achieve the SSAC, the annual sum of the fractional exposures must be less than 1.

Given the ubiquitous nature of low DO conditions throughout the state, a similar method could be used to develop more appropriate regional or statewide criteria. Not only would the application of this method on a broader spatial scale be more efficient and cost effective than developing criteria for individual waterbodies, it would provide an equal and known level of protections to all state waters. However, it should be noted that some waterbodies exhibit DO levels that may naturally fall below the levels derived using this method and may continue to require SSAC development. For example, the application of this method to the Amelia River may yield satisfactory results. However, as can be seen in Table A-2, some of the SSAC values for the Econfina River are below the limits that would likely be derived from the application of this method.

Diel and Habitat Type DO Effects

DO was measured for 7 consecutive days, on a continuous basis, in the vicinity of healthy seagrass beds in Sarasota Bay (Tomasko *et al.* 1992). In Figure A-14, the DO concentration in these healthy seagrasses is graphed as a function of the time after sunrise. Note that DO during the night and early morning hours consistently was below 4 mg/L due to the significant ecosystem respiration (and lack of photosynthesis) associated with these seagrass beds. It should be emphasized that these seagrass beds are inhabited by a diverse community of invertebrates and fish, despite the daily natural low DO, another indicator that the Department’s existing DO criteria are subject to a high Type I error rate.

DO Summary

The above information clearly demonstrates the complexity associated with DO regimes in Florida’s marine systems, and that the presence of low DO does not necessarily coincide with anthropogenic nutrient enrichment.

Mercury

Extensive study within Florida has demonstrated that mercury contamination in fish tissue is caused by atmospheric deposition from a variety of emission sources, including power plants, incinerators, and cement kilns, rather than surface water discharges. As such, 303(d) listings for mercury impairment are not indicative of local sources and are not relevant to nutrient criteria development in estuaries. In fact, extensive evidence has shown that fresh waterbodies with biota most contaminated by mercury are those with low alkalinity and low nutrients, or low trophic status. Therefore, many of the Department’s low-nutrient, minimally disturbed reference sites have fish tissue levels of mercury above the consumption advisory. The presence of mercury in fish tissue, which is a human health issue, does not disqualify the aquatic community in a particular system from being considered healthy and well balanced in the context of nutrient criteria development. An ongoing Statewide Mercury TMDL Study is scheduled to be completed in 2012 and will establish maximum mercury emissions from Florida sources.

Confounding Issues Summary

As shown above, the presence of factors such as of low DO, coliform bacteria, mercury-contaminated fish, and/or red tide (*K. brevis*) does not necessarily equate with anthropogenic nutrient enrichment effects. During the information-gathering process, the Department considered these factors and determined, on a site-specific basis, whether anthropogenic nutrients were or were not associated any particular disturbance.

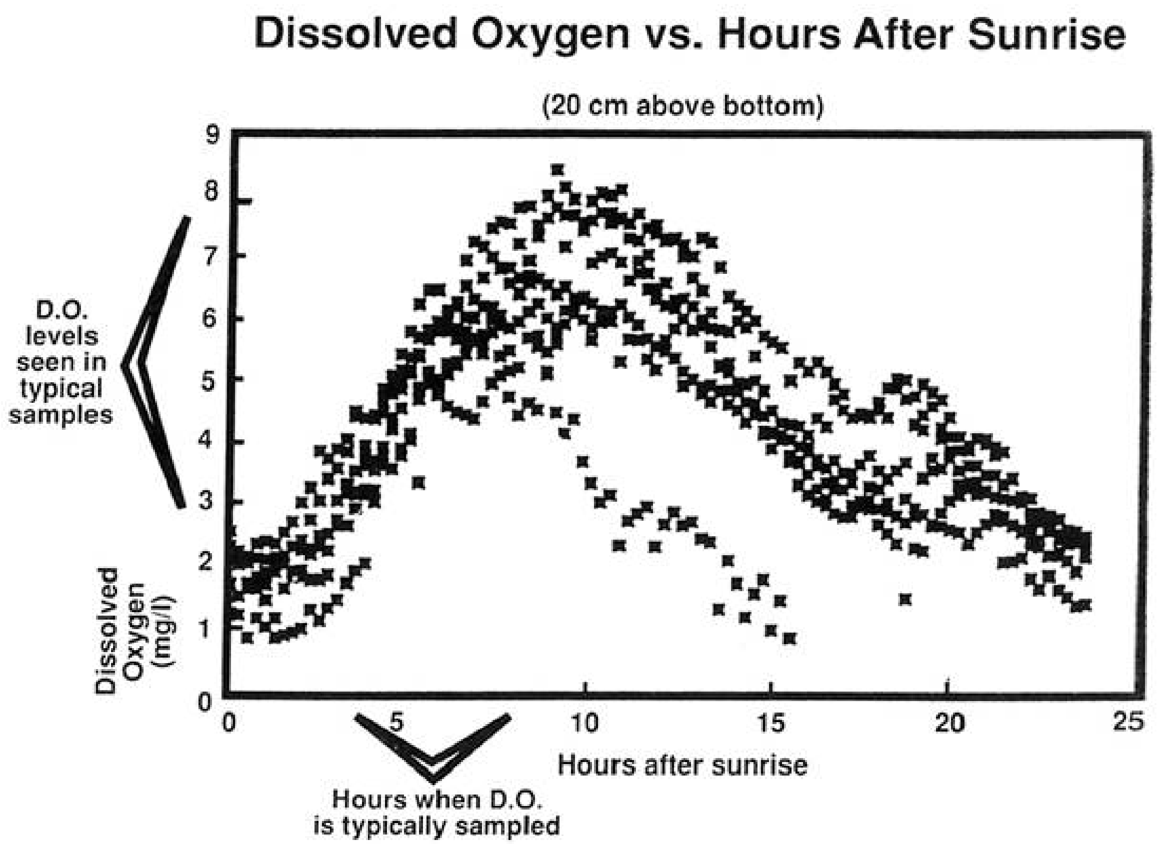


Figure A-14. Diel measurements of DO 20 cm above the sediment surface in a seagrass bed (from Tomasko et al. 1992).