PROPOSED NUMERIC NUTRIENT CRITERIA FOR TAMPA BAY

Prepared for:

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EXECUTIVE SUMMARY

FDEP is developing a rule to establish numeric nutrient criteria for a number of water body types. The overarching FDEP goal is to "manage nutrients in surface (and groundwater) at loadings or concentrations that result in protection and maintenance of healthy, well-balanced aquatic communities". Absent site-specific analyses, criteria should be based on a quantifiable linkage between anthropogenic nutrient enrichment and a biological response. FDEP recognizes the role of site-specific factors that affect numeric responses and proposes to base new standards on establishing a systematic numeric interpretation of the existing narrative criteria. Nutrient TMDLs, Site Specific Alternative Criteria (SSAC), and other site-specific actions written to achieve the narrative nutrient criteria should be given preference over more broadly applicable interpretations.

The TBEP and the Tampa Bay Nitrogen Management Consortium (TBNMC) have developed a nitrogen management strategy linking seagrass growth to external nitrogen loadings. FDEP has accepted this strategy as providing reasonable assurance that the state water quality criteria would be met in Tampa Bay. In addition, the EPA has recognized the TN loading targets developed as part of the strategy as the TMDL for Tampa Bay. The TBEP and TBNMC have previously recommended to EPA numeric nutrient criteria as segment-specific annual TN loads.

The recommended TN loads followed development of seagrass targets and corresponding water quality targets and thresholds for Tampa Bay. Extensive empirical evaluations found strong links between TN loads, resultant chlorophyll and light attenuation, and seagrass response. Water quality has been improving since the mid-80s, and corresponding responses in seagrass acreage have occurred. During this same period, however, TN loads often exceeded the TMDL targets.

The TBNMC further investigated relationships between TN loads and water quality, and found that residence time should be accounted for. As residence time shortens when freshwater inputs are greater, loadings move through the system more quickly and thus biological processes have less time to convert nutrients to chlorophyll. Given that both TN loads and hydrologic loads affect the chlorophyll within the bay, the annual hydrologic loads are considered along with the annual TN loads when assessing target compliance.

A more appropriate predictor of the likelihood of good water quality, as defined by meeting the FDEP-approved chlorophyll *a* thresholds, is expected to be the amount of TN delivered per unit water. This is denoted as the Nitrogen Delivery Ratio, and is defined as the amount of TN delivered, in tons, per million cubic meters of freshwater delivered. The proposed criteria are expressed as the segment-specific Nitrogen Delivery Ratios observed during the 1992-1994 reference period, provided in the table below. TBEP has also developed alternative criteria, specifically concentration-based TN criteria and both loading and concentration-based TP criteria for each bay segment.

TBEP estuarine numeric nutrient criteria expressed as Nitrogen Delivery Ratio (tons TN per million m^3 hydrologic load) based on 1992-1994 conditions.

Segment	Nitrogen Delivery Ratio Threshold (tons/million m^3)
Old Tampa Bay	1.08
Hillsborough Bay	1.62
Middle Tampa Bay	1.24
Lower Tampa Bay	0.97

1.0 Introduction

The Florida Department of Environmental Protection (FDEP) is currently developing a rule to establish numeric nutrient criteria for a number of water body types. The following summarizes FDEP's view on the development of numeric nutrient criteria in Florida (FDEP website, 2011).

The overarching FDEP goal is to "manage nutrients in surface water (and groundwater) at loadings or concentrations that result in protection and maintenance of healthy, well-balanced aquatic communities". Absent site-specific analyses, water quality criteria should be based on a quantifiable linkage between anthropogenic nutrient enrichment and a biological response (such as seagrass growth) that can be used to numerically interpret the narrative nutrient criteria. There is value in knowing whether nutrient concentrations are elevated to potentially environmentally harmful levels, but, conversely, it is equally important to identify adverse biological effects and determine if they are linked to nutrients before deciding that nutrient reduction strategies should be pursued.

The Department recognizes the role of site-specific factors that affect nutrient responses and proposes to base new standards on establishing a systematic numeric interpretation of the existing narrative criteria. This concept is intended to implement Rule 62-302.530 (47)(b), FAC, which states, "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."

As envisioned by FDEP, the narrative nutrient criteria would continue to apply to all waterbodies, and numeric interpretations would be applied when adequate scientific information is available. The narrative criteria would be implemented using a hierarchical approach that numerically interprets the narrative nutrient criteria for each waterbody.

Numeric interpretations are most accurate when determined as a site-specific function. Therefore, nutrient Total Maximum Daily Loads (TMDLs), Site Specific Alternative Criteria (SSAC), and other site-specific actions written to achieve the narrative nutrient criteria should be given preference over more broadly applicable interpretations.

The first tier of the hierarchical approach entails an evaluation of previously established site-specific numeric interpretations of the narrative criteria (including TMDLs, SSACs, and other interpretations embodied in an official Department action) as the primary interpretation of the narrative nutrient criteria. Currently, Tampa Bay has an FDEP-approved Reasonable Assurance and Water Quality Based Effluent Limitation (WQBEL) in addition to an EPA-recognized TMDL. Therefore, Tampa Bay would be included in this first tier of the hierarchical approach.

FDEP has also stated that if nutrient TMDLs are expressed as loads instead of concentrations, the loads do not have to be translated into concentrations to be deemed the numeric interpretation of the narrative nutrient criteria. This document presents loading-based numeric nutrient criteria for the four mainstem bay segments of Tampa Bay.

Finally, FDEP recognizes that future TMDL rules may include a response target (chlorophyll a, for example) designed to implement the narrative nutrient criterion. Currently, the recommended assessment of the proposed numeric nutrient criteria for Tampa Bay is built on assessing the achievement of a series of segment-specific chlorophyll *a* targets.

In November 2002, FDEP concluded that the nitrogen management strategy developed by the Tampa Bay Estuary Program (TBEP) and Tampa Bay Nitrogen Management Consortium (TBNMC) provided reasonable assurance that the state water quality criteria for nutrients would be met in Tampa Bay. Prior to this state determination, the U.S. Environmental Protection Agency (EPA) recognized a 1998 action by FDEP that proposed a total maximum load ("federally-recognized TMDL") of nitrogen that could be discharged to the bay annually and still meet state water quality standards related to nutrients. Both FDEP's reasonable assurance determination and the total maximum nitrogen loading recognized by EPA are based on statistical modeling and data analyses peer-reviewed by the TBEP, its partners, and state and federal regulators. Thus, the TBNMC's nitrogen loading targets developed for the major bay segments of Tampa Bay have been acknowledged by both FDEP and EPA as protective nutrient loads for this estuary. A five-year renewal of the Tampa Bay Reasonable Assurance (RA) was recently approved by order of the FDEP Secretary.

The TBEP and TBNMC have previously recommended to EPA numeric nutrient criteria for the Tampa Bay estuary as segment-specific annual total nitrogen (TN) loads (TBNMC, 2010a). These recommendations were based on the previous work to develop a Reasonable Assurance (RA) plan and eventual nitrogen load allocations (TBNMC, 2010b).

This document provides background information concerning the Tampa Bay estuarine system, including a brief physical characterization of the system and a summary of previous work completed with respect to Tampa Bay estuarine targets. In addition, this document provides the data and methodology utilized for developing estuarine numeric nutrient criteria for Tampa Bay, the targets resulting from application of the methodology, the proposed criteria, and the proposed methodology for implementation and compliance of the Tampa Bay estuarine numeric nutrient criteria.

1.1 Tampa Bay and Its Watershed

Tampa Bay is on the west central coast of Florida, and has been divided into seven bay segments for purposes of management activities. The bay covers approximately 1,030 km^2, extends approximately 56 km inland from the Gulf of Mexico, is 8-16 km wide along most of its length, and is the largest open water estuary in Florida (Figure 1-1). Tampa Bay is crossed by four major causeways, and has about 42 nautical miles of dredged channels with designed mean low water depths of 6-13 meters. The major shipping channel has been dredged from the mouth of the bay to the port facilities near Tampa. The average depth of the bay is approximately 4 meters.

The four mainstem segments of the bay include Lower Tampa Bay, Middle Tampa Bay, Hillsborough Bay, and Old Tampa Bay (Figure 1-1). Lower Tampa Bay connects the mouth of the bay to the Gulf of Mexico, and is joined on the southeast by the Manatee River and Terra Ceia Bay segments and on the north by the Boca Ciega Bay segment. Middle Tampa Bay is northeast of Lower Tampa Bay, and connects to the Hillsborough Bay segment to the northeast and the Old Tampa Bay segment to the north.

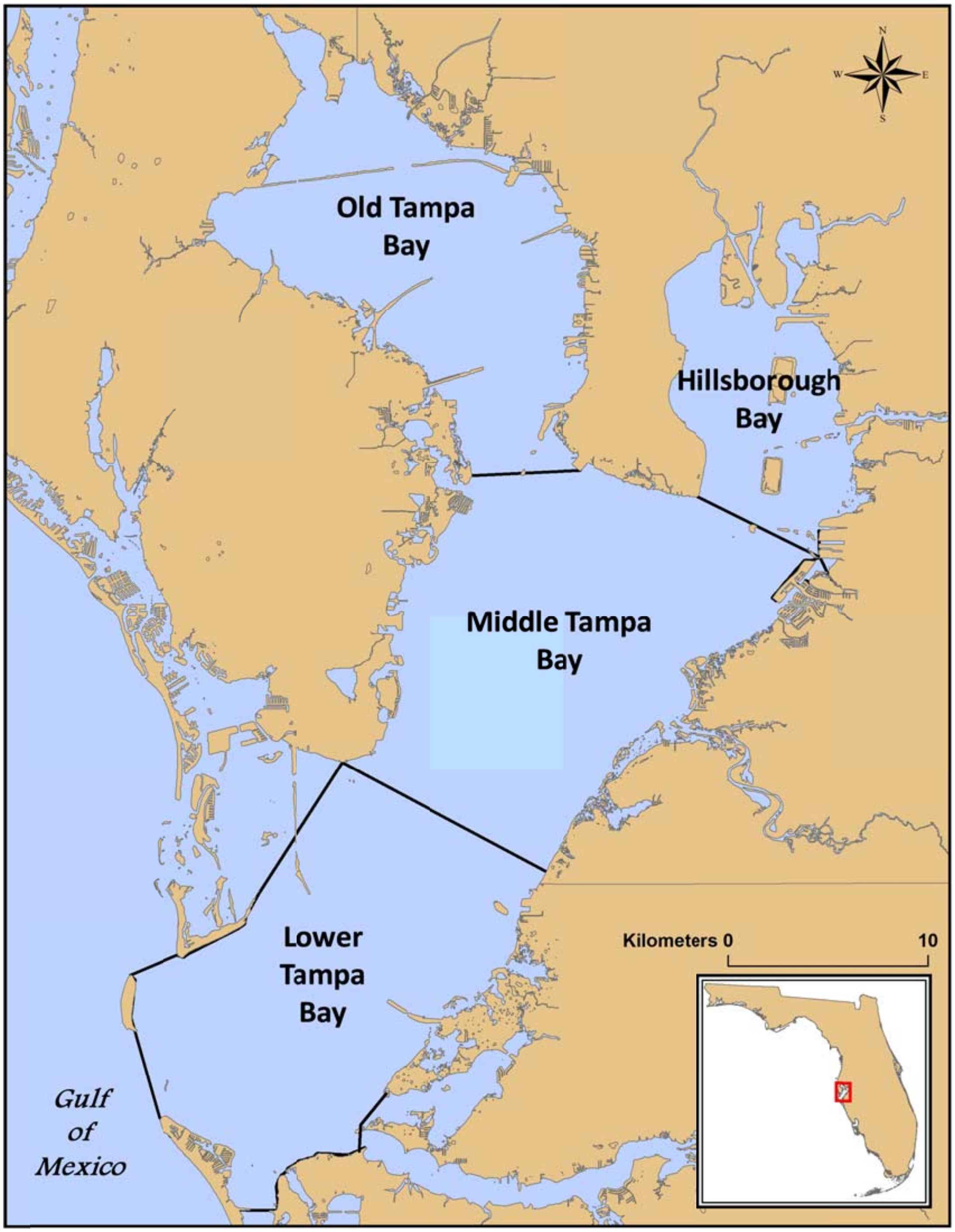

Figure 1-1. Tampa Bay mainstem segments.

Movement of water in the bay is controlled by tidal processes, winds, morphology, and freshwater inflows. Average tidal range in the bay is about 0.7 m (Pribble, 2006). Four major rivers provide freshwater inflow to the bay, with the Hillsborough River/Tampa Bypass Canal system and the Alafia River discharging to Hillsborough Bay, the Little Manatee River to Middle Tampa Bay, and the Manatee River to Lower Tampa Bay. Runoff to the bay other than that from the rivers contributes about 15-30% of the total.

The Tampa Bay watershed covers approximately 5,700 km^2, and includes all or parts of Pasco, Pinellas, Hillsborough, Polk, Manatee, and Sarasota counties, with more than 2 million current residents and a projected population doubling by 2050. Land use is mixed, with about 40% of the watershed undeveloped, 35% agricultural, 16% residential, and the remaining commercial and mining. Major habitats in the Tampa Bay estuary include mangroves, salt marshes, and submerged aquatic vegetation.

The watershed is divided into seven drainage basins, corresponding to the seven bay segments. The watershed contains various source types supplying freshwater runoff and associated nutrients and other pollutants to Tampa Bay (Greening and Janicki, 2006). These sources have been categorized as nonpoint sources (representative of runoff), atmospheric deposition (directly to the open water of the estuary), point sources (domestic and industrial wastewater facilities), springs, and groundwater. An additional source of nutrient loadings to the bay is loss from fertilizer handling operations at the two port facilities, in Hillsborough Bay and Lower Tampa Bay.

The TBEP, in cooperation with local scientists and FDEP, has developed a tabular listing of symptoms of nutrient enrichment in Tampa Bay, along with potential explanations of these expressions, to aid in development of numeric nutrient criteria for the bay. This listing is provided in Tables 1-1 and 1-2 below. These tables provide a summary of potential responses expressed in the bay related to nutrient loads, and notes whether these responses are currently or historically found in the bay.

Table 1-1. Checklist of nutrient enrichment symptoms in Tampa Bay.

Response Variable	Observed Historically or Currently?	Explanation	Source
Low dissolved oxygen (DO) (hypoxia/anoxia)	Yes, limited in space and time	Typically, the lowest dissolved oxygen 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 . Hypoxic events in this bay segment appear to be largely driven by physical processes rather than nutrient effects.	Janicki et al. 2001; Poe 2006.
Reduced clarity	No.	Long-term monitoring of bay water clarity via Secchi disk depths by the EPCHC has indicated a significant improvement.	Sherwood 2010.
Increased chlorophyll *a* concentrations	No.	Long-term monitoring of bay chlorophyll-a concentrations by the EPCHC has indicated a significant decline.	Sherwood 2010.
Phytoplankton blooms (nuisance or toxic)	Yes, limited in space and time	Red tide blooms originating in the Gulf of Mexico have occasionally entered the lower bay. Most recently in Old Tampa Bay, nuisance blooms of *Pyrodinium bahamense* have occurred as a result of anomalous spring/summer rainfall events in 2008 and 2009. Blooms did not reoccur in 2010, but did occur in late summer 2011.	Phlips et al. 2006; Badylak et al. 2007; Heil et al. 2007.
Problematic epiphyte growth	No	No significant trends in epiphyte growth have been reported as result of monitoring conducted by the Tampa Bay Interagency Seagrass Monitoring Program.	Avery and Johansson 2010.
Problematic macroalgal growth	Yes (historical), No (current)	Macroalgal blooms have been reported and observed in the past; however, nuisance blooms have not occurred over the recent period or have only been associated with distinct events and restricted to minor embayments (e.g. in 2003 in Bishop Harbor from FDEP-endorsed Piney Point controlled releases).	Johansson 1991; Johansson and Lewis 1992.
Submerged aquatic vegetation (SAV) community changes or loss	Yes, historically. Currently increasing.	The Tampa Bay estuary is one of only a few estuaries worldwide that has shown recovery of seagrass resources despite continuing population growth and urbanization within the watershed. Seagrass coverage has increased by approximately 3,200 ha since 1982.	Greening and Janicki 2006; Bricker et al. 2008; Waycott et al. 2009.
Emergent or shoreline vegetation community changes or loss	Yes, historically. Currently increasing.	The 2010 Tampa Bay Habitat Master Plan Update has identified restoration and protection goals for critical coastal habitats in the Tampa Bay watershed. The TBEP and its partners have adopted a strategy to "restore the balance" of coastal habitats to levels commensurate to the 1950s. Significant progress has been made in restoring and protecting coastal habitats in Tampa Bay since 1996.	Robison 2010.
Coral/hardbottom community changes or loss	Unknown	No information on change or loss has been developed. Current hardbottom communities within Tampa Bay have been tentatively identified, but no historical reference exists for comparison.	Robison 2010.
Impacts to benthic community	No	Benthic communities have been monitored since 1993 in Tampa Bay and have shown stable populations as evidenced by the Tampa Bay Benthic Index.	Karlen et al. 2008.
Fish kills	Yes, limited in space and time	Periodic fish kills have occurred as a result of red tide blooms entering the lower bay and cold-water induced shock; however, no significant kills have been reported as a direct result of nutrient inputs into the estuary.	-

Table 1-2. Checklist of additional factors in Tampa Bay.			
Nutrient Factors	**Observed?**	**Explanation**	**Source**
Increased nutrient loading or concentrations	No	Phosphorus and nitrogen levels have been stable and/or declining in the major bay segments of Tampa Bay over recent decades. Nitrogen delivery (i.e. N load per unit hydrologic input) from the watershed to the major bay segments of the estuary has been declining since 1985	TBNMC 2010b.
Mitigating factors that could prevent nutrient expression	Yes	Bay hydrologic residence times and circulation; highly-colored seasonal, freshwater inflows.	-
Other significant stressors to biological communities	No	-	-
Natural high-nutrient episodes (e.g., seasonal or event driven)	Yes	During periods of extremely high rainfall (e.g., the El Niño event in 1998), other storm events (hurricanes), and/or domestic/industrial spills elevated nutrient and/or chlorophyll-a concentrations have been observed.	-

2.0 Objective

The objective of this document is to propose estuarine numeric nutrient criteria specific to the four mainstem segments of Tampa Bay: Old Tampa Bay, Hillsborough Bay, Middle Tampa Bay, and Lower Tampa Bay. The remaining three segments (Boca Ciega Bay, Terra Ceia Bay, and Manatee River) will be addressed in a separate document. The criteria are expressed as TN and TP loadings to the bay. The proposed TN loading criteria for the four mainstem segments were based on the nitrogen management strategy developed by the TBNMC.

3.0 Development of Seagrass, Light Attenuation, Chlorophyll a, and Nitrogen Loading Targets

This section provides detailed summary of work previously completed by the TBEP and TBNMC in establishment of the seagrass target, the associated water quality (light attenuation and chlorophyll) targets, and TN loading targets to each segment. An assessment of the seagrass, water quality, and TN loading data utilized in this effort is provided in Appendix A. Appendix B contains a description of the derivation of the recently proposed TP loading targets and TN and TP concentration thresholds which may be utilized as criteria if necessary.

3.1 Background and Rationale

Between 1950 and 1990, an estimated 40-50% of the seagrass acreage in Tampa Bay was lost due to excess nitrogen loading and related increases in algae concentration which caused light limitation detrimental to seagrass survival and growth, in addition to shoreline modifications. In 1980, all municipal wastewater treatment plants were required to provide Advanced Wastewater Treatment (AWT) for discharges directly to the bay and its tributaries. In addition to the significant reductions in nitrogen loadings from municipal wastewater treatment plants, stormwater regulations enacted in the 1980s also resulted in reduced nitrogen loads to the bay. Estimated TN loads in 1976 are more than twice recent (2003-2007) estimates.

The Comprehensive Conservation and Management Plan (CCMP) of the TBEP (TBEP, 1996a) established the restoration of seagrass in the bay to levels estimated in the 1950s as a primary goal for overall bay restoration. In establishing and addressing this goal, a conceptual paradigm was developed to identify the primary, manageable factors thought to influence the recovery and sustainability of seagrass resources within the bay (Figure 3-1). As depicted in the TBEP's nitrogen management paradigm, reduced water clarity as a result of excessive nitrogen loads to the bay and resulting light attenuation by phytoplankton responding to these loadings were the key water quality indicators by which seagrass recovery could be managed.

A number of studies since the 1990s clearly established that nitrogen loads were the limiting nutrient in the Tampa Bay estuary and that phosphorus loadings to the bay from the enriched Bone Valley region were not controlling estuarine production (Johansson, 1991, 2009; Janicki Environmental, 2011a).

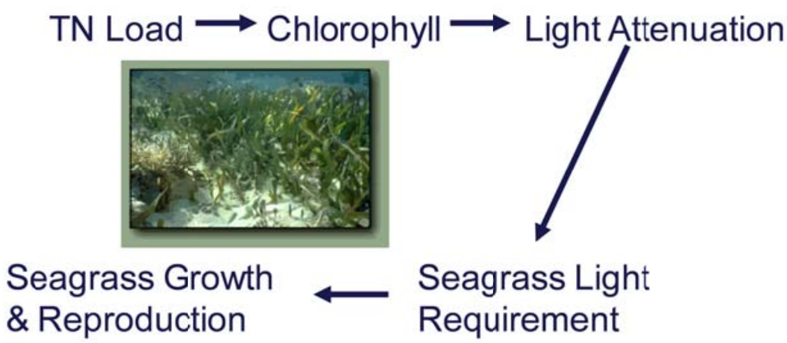

Figure 3-1. Conceptual paradigm describing the nitrogen management strategy employed by Tampa Bay Estuary Program partners to relate nitrogen loading to seagrass response in Tampa Bay.

3.2 Development of Seagrass Targets

Detailed explanation of the derivation of the seagrass target for Tampa Bay is provided in Janicki et al. (1995). The circa 1950 time period was selected as the historical benchmark period for development of restoration targets, as a dataset providing estimation of seagrass coverage in Tampa Bay was available for that period. A GIS coverage of seagrass in the bay was developed from a dataset developed for a Florida Department of Natural Resources and the U.S. Fish and Wildlife Service cooperative study (TBRPC, 1986). To develop the seagrass target for Tampa Bay, areas supporting seagrasses in 1990 were identified as resource protection areas. Combining the 1990 seagrass coverage with the 1950s-era coverage provided an estimate of those areas supporting seagrasses in 1950 but not in 1990, providing potential restoration areas for seagrasses. Those areas which had been physically altered since the 1950s so that there was no reasonable possibility that the areas could support seagrasses were identified using mapping completed for the TBEP Physical Impacts Project (TBEP, 1994). These non-restorable areas were removed from the potential restoration areas, resulting in seagrass protection areas (areas with seagrass in 1990) and restoration areas (areas with seagrass in 1950 but not in 1990 less any non-restorable areas).

The seagrass targets (Figure 3-2) were developed from these protection and restoration areas as described in Janicki and Wade (1996). The seagrass target for the bay was set based on 95% of the seagrass acreage resulting from summing the restoration and protection areas, so that the seagrass target was 38,000 acres baywide.

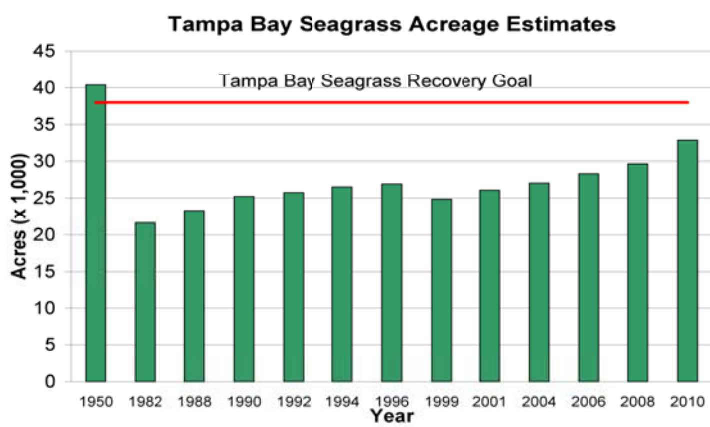

Figure 3-2. Seagrass acreage estimates for Tampa Bay for 1950-2010.

The segment-specific seagrass targets for the four mainstem bay segments were established as:

- Old Tampa Bay 10,545 acres,
- Hillsborough Bay 1,663 acres,
- Middle Tampa Bay 8,930 acres, and
- Lower Tampa Bay 7,030 acres.

3.3 Development of Chlorophyll *a*, Light Attenuation, and Nitrogen Loading Targets

The TBEP developed targets for light and chlorophyll *a* in support of the seagrass target for the bay, based on a specified percentage of incident light reaching segment-specific depths as determined from historical (1950s) seagrass distribution. Target depths were chosen based on conservative estimates of the deepest edges of seagrass meadows in the 1950s period (Janicki et al., 1995). The minimum light requirement at these targets depths was established as 22.5% of incident light, based on data obtained during a SWFWMD study conducted by Mote Marine Laboratory (Dixon and Leverone, 1995). Further evaluation included accounting for bottom reflectance, resulting in the light requirement target being adjusted to 20.5% of incident light (Janicki and Wade, 1996).

Following establishment of depth and light targets, relationships were developed between water quality and light attenuation. Least squares regression methods were used to estimate parameters relating average monthly chlorophyll *a* concentrations to light availability (Janicki and Wade, 1996). 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 served as a proxy for light availability to seagrass in the bay (Figure 3-3). Given the minimum light requirement of 20.5% of incident light, 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 were used to assess the development of annual targets for these parameters (Janicki and Wade, 1996; Greening and Janicki, 2006).

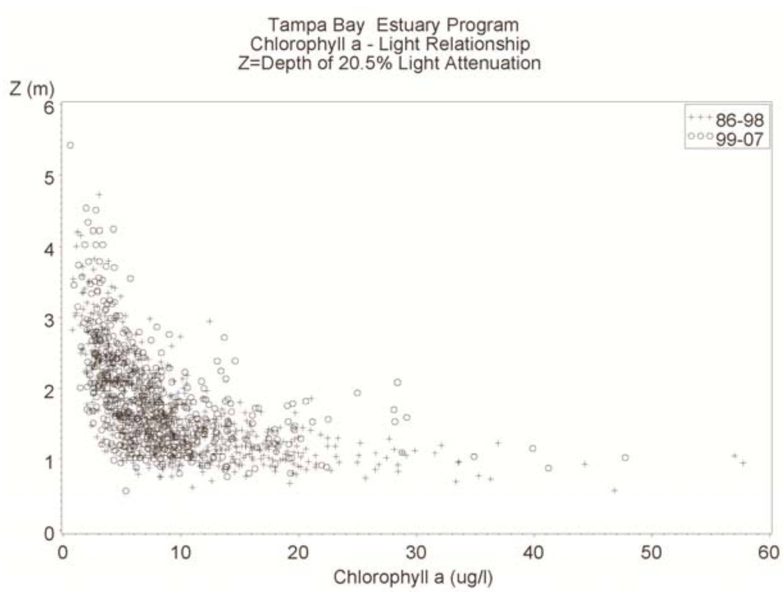

Figure 3-3. Relationship between chlorophyll a and depth of 20.5% light attenuation.

The next step in the TBEP paradigm (Figure 3-1) was linking chlorophyll *a* concentrations to loadings. As described in Janicki and Wade (1996), the net flux of water and nitrogen between segments must be considered. First, a series of dilution equations were written for the four mainstem segments of the bay, and fit to observed salinity and freshwater inflow data. Next, the dilution equations were used to predict nitrogen concentrations, and a regression parameter was used to relate the observed and predicted nitrogen concentrations to account for the net of all non-conservative processes affecting nitrogen (such as sediment uptake or release) (Figure 3-4).

The chlorophyll *a* targets developed from this effort were segment-specific. Potential chlorophyll *a* targets were developed utilizing two methods: the TN loading-chlorophyll *a* model described above, and annual average values from the 1992-1994 period. The TN loading-chlorophyll *a* model was used to identify the chlorophyll a needed for sufficient light to reach depths in each segment corresponding to recovery to seagrass target. Recall from above that the seagrass target was set as 95% of the sum of the protection and restoration areas. Based on improving seagrass coverage and water quality seen over the 1990–1996 period, secondary targets were developed from the average annual chlorophyll *a* levels seen during 1992-1994 (a period of time with high and low rainfall during which seagrass was expanding). The ultimate selection of bay segment-specific chlorophyll *a* targets was determined as the average annual levels developed from the empirical model predictions (Janicki and Wade, 1996) or the 1992-1994 average annual levels – which ever were lower (TBEP, 1996b and 2001).

The TBEP TAC further recognized that there may be years in which these targets may be exceeded without causing significant reductions in seagrass cover. This means that there is some allowable amount of variation that should not elicit a significant degradation in water quality and therefore seagrass coverage. This level of variation was defined as two standard errors around the period of record mean annual chlorophyll *a* concentrations in each segment. Therefore, a distinction is made between a **target**, i.e., a desired chlorophyll *a* concentration and a **threshold**, i.e., a chlorophyll *a* concentration above which undesirable chlorophyll *a* concentrations exist. The chlorophyll *a* threshold for each segment is the sum of the target and two standard errors around the mean annual chlorophyll *a* concentrations in each segment. These thresholds have been recognized both in the recent WQBEL and RA documents (FDEP, 2010; TBNMC, 2010b). The chlorophyll *a* targets and thresholds are shown in Table 3-1.

Table 3 1. Tampa Bay chlorophyll a targets and thresholds.

Segment	Chlorophyll *a* Target (μg/L)	Chlorophyll *a* Threshold (μg/L)
Old Tampa Bay	8.5	9.3
Hillsborough Bay	13.2	15.0
Middle Tampa Bay	7.4	8.5
Lower Tampa Bay	4.6	5.1

Finally, TN loads from both external sources and intersegment transport were related to the observed chlorophyll *a* using a regression model (Figure 3-4) (Janicki and Wade, 1996). During this same time, the 1992-1994 average annual total nitrogen loads were established as the appropriate nitrogen load management targets by TBEP partners (Table 3-2) in order to support the maintenance of the chlorophyll *a* and light attenuation targets developed for each of Tampa Bay's major bay segments. These targets have subsequently been adopted by EPA as the federally-recognized nitrogen TMDL for Tampa Bay.

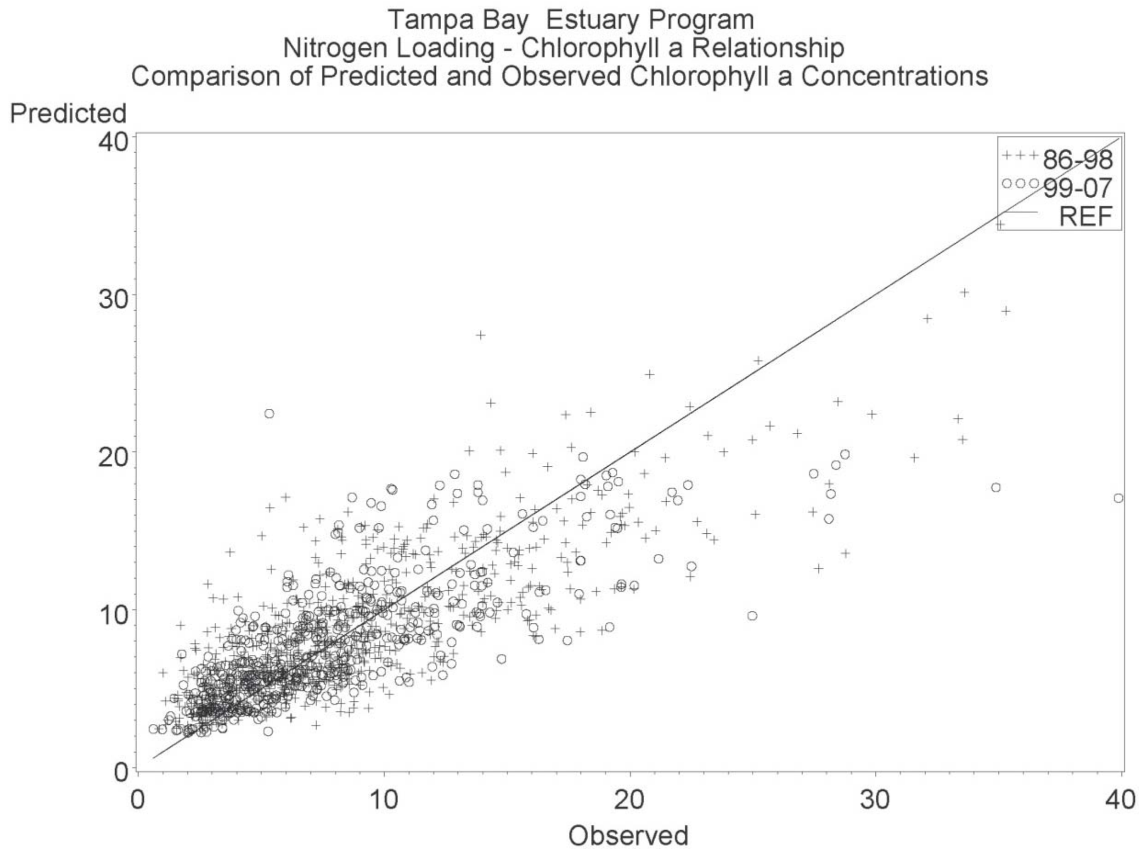

Figure 3-4. Comparison of observed chlorophyll *a* and that predicted from the TN load – chlorophyll *a* relationships, all four mainstem bay segments, for 1986-1998 and 1999-2007.

Table 3 2. Tampa Bay TN loading targets.

Segment	**TN Load Target (tons/year)**
Old Tampa Bay	486
Hillsborough Bay	1,451
Middle Tampa Bay	799
Lower Tampa Bay	349

4.0 Proposed Criteria

The TBNMC annual assessment of the water quality conditions in the four mainstem segments of the bay is accomplished by completion of the previously developed Decision Matrix, which compares annual average chlorophyll *a* and light conditions to targets (Janicki et al., 2000). The Decision Matrix results through 2010 are provided in Figure 4-1. Chlorophyll *a* values were less than the thresholds in most segments for most years following the 1992-1994 period (see Appendix A). Exceptions were linked either to excessive rainfall conditions or to an emergency action taken associated with the closure of an industrial point source (TBNMC, 2010b).

Year	OTB	HB	MTB	LTB
1975	No	No	No	Yes
1976	No	No	No	Yes
1977	No	No	No	No
1978	No	No	No	Yes
1979	No	No	No	No
1980	No	No	No	No
1981	No	No	No	No
1982	No	No	No	No
1983	No	No	No	No
1984	Yes	Yes	No	Yes
1985	No	No	No	Yes
1986	No	No	Yes	Yes
1987	No	Yes	No	Yes
1988	Yes	Yes	Yes	Yes
1989	No	Yes	Yes	Yes
1990	No	Yes	Yes	Yes
1991	Yes	Yes	Yes	Yes
1992	Yes	Yes	Yes	Yes
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1994	No	No	No	No
1995	No	No	No	Yes
1996	Yes	Yes	Yes	Yes
1997	Yes	Yes	Yes	Yes
1998	No	No	No	No
1999	Yes	Yes	Yes	Yes
2000	Yes	Yes	Yes	Yes
2001	Yes	Yes	Yes	Yes
2002	Yes	Yes	Yes	Yes
2003	No	Yes	Yes	Yes
2004	No	Yes	Yes	Yes
2005	Yes	Yes	Yes	No
2006	Yes	Yes	Yes	Yes
2007	Yes	Yes	Yes	Yes
2008	Yes	Yes	Yes	Yes
2009	No	Yes	Yes	Yes
2010	Yes	Yes	Yes	Yes

Figure 4-1. Decision Matrix results through 2010 showing assessment of chlorophyll *a* threshold values.

During the development of the 2009 Reasonable Assurance (TBNMC, 2010b), the TBNMC investigated the temporal trends in TN loading. While the chlorophyll *a* thresholds were being met, the TN loading targets were exceeded in some years (Figure 4-2). The TBNMC investigated the relationships between TN loads and chlorophyll *a* to better understand how the bay responds to varying nitrogen loads. Non-anthropogenic factors can significantly influence the relationship between chlorophyll *a* and TN loadings. One such factor is rainfall and its role in determining estuarine residence time, which in turn has been shown to influence this relationship in many lakes and other estuaries. As residence time shortens, and loadings move more quickly out of the estuary, biological processes have less time to convert nutrients to chlorophyll. As residence time lengthens, loadings remain within the system longer, and thus more nutrients can be converted to chlorophyll. Given the same nutrient loads, different residence times within the system can result in very different expressions in water quality constituents. Given this paradigm, that both TN loads and hydrologic loads affect the chlorophyll *a* within the systems, the annual hydrologic loads to each of the segments must be considered along with the annual TN loads to establish loading thresholds for each segment. Figure 4-3 provides a schematic of these influences.

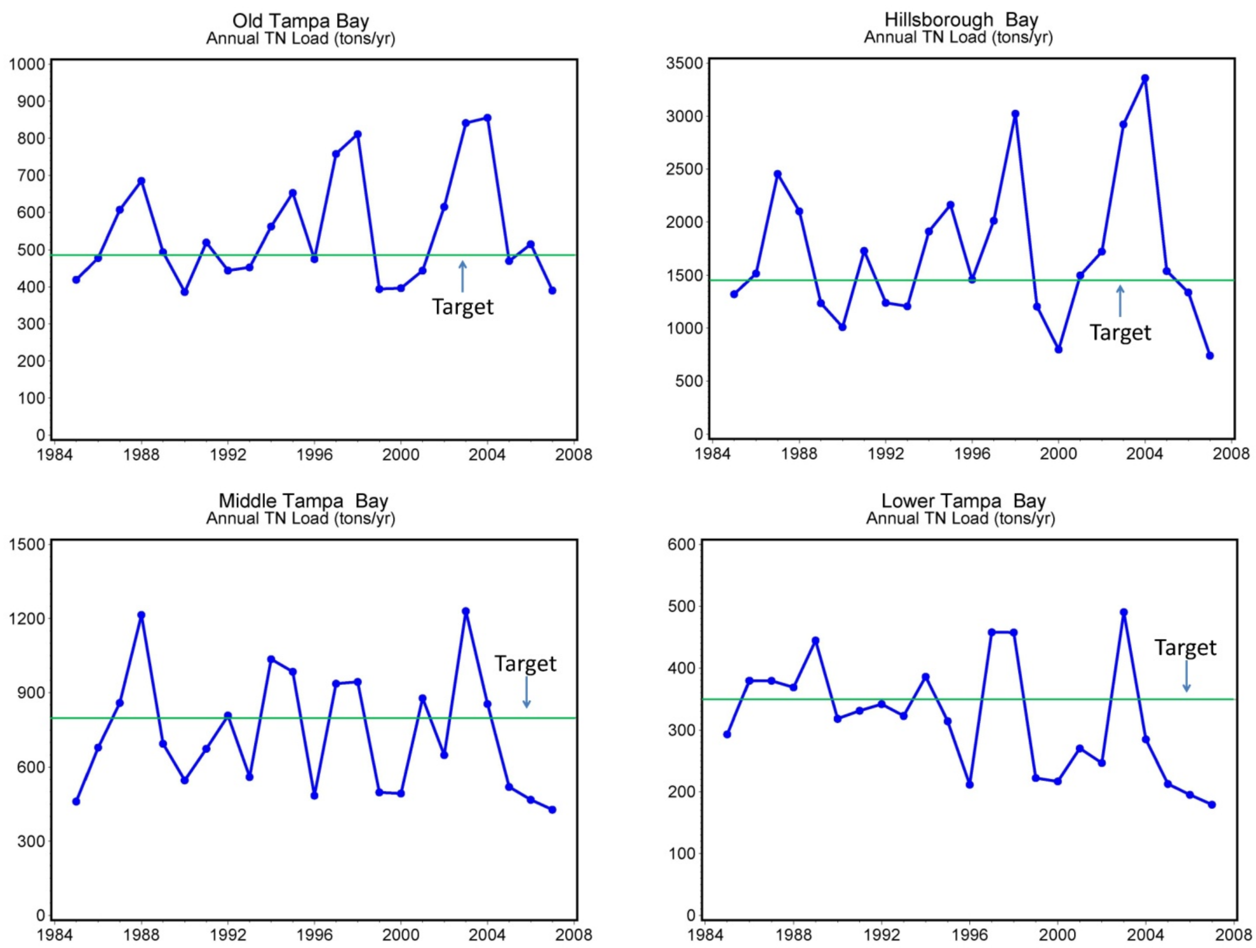

Figure 4-2. Comparison of annual loading to the four mainstem segments to the segment-specific targets.

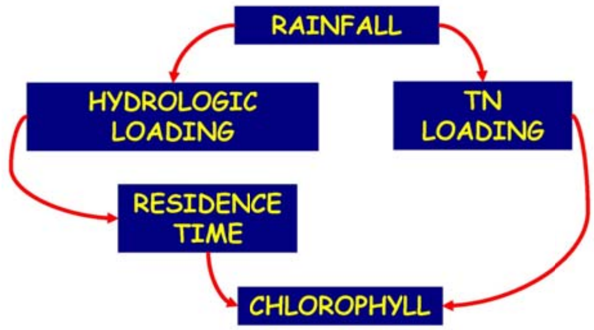

Figure 4-3. Schematic of the effects of TN and freshwater loadings on chlorophyll *a* concentrations.

Given the combined influence of both TN loads and hydrologic loads on water quality, a more appropriate predictor of the likelihood of adequate water quality, as defined by meeting the FDEP-approved chlorophyll *a* thresholds, is expected to be the amount of TN delivered per unit water delivered to the bay. This is denoted as the Nitrogen Delivery Ratio, and is defined as the amount of TN delivered, in tons, per million cubic meters of freshwater delivered. Figure 4-4 presents a comparison of the observed annual Nitrogen Delivery Ratios to the 1992-1994 ratios in each bay segment. These data agree with the observed chlorophyll *a* concentrations and therefore, the Nitrogen Delivery Ratios are a more appropriate expression of the numeric nutrient criteria for the four mainstem bay segments within Tampa Bay. Conceptually, these ratios are identical to the hydrologic normalization agreed upon during the RA development (TBNMC, 2009). Appendix C presents the relationship between TN and hydrologic loads in each segment and compared to the Nitrogen Delivery Ratio from the 1992-1994 reference period.

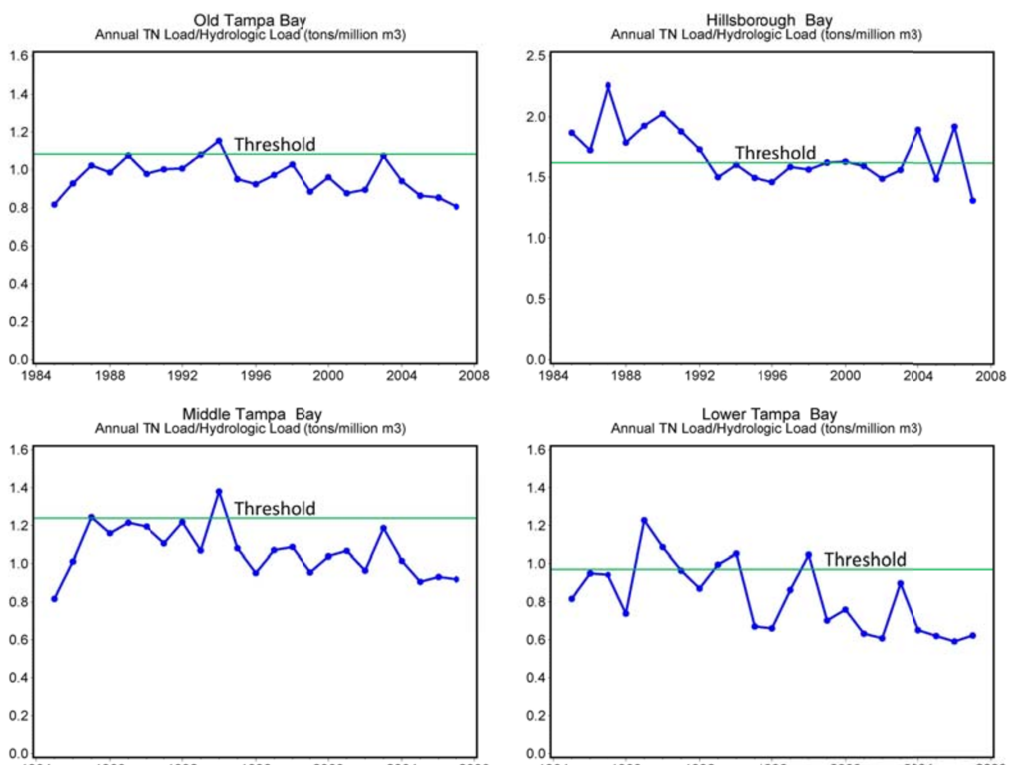

Figure 4-4. Comparison of annual Nitrogen Delivery Ratios to the segment-specific thresholds as defined by the 1992-1994 average ratios.

Given the critical contributions of both TN load and hydrologic load to chlorophyll *a* concentrations, the proposed criteria are expressed as the segment-specific Nitrogen Delivery Ratios observed during the 1992-1994 reference period. The proposed criteria for the four mainstem segments are provided in Table 4-1 below.

Table 4-1. TBEP estuarine numeric nutrient criteria expressed as Nitrogen Delivery Ratio (tons TN per million m^3 hydrologic load) based on 1992-1994 conditions.

Segment	**Nitrogen Delivery Ratio Threshold (tons/million m^3)**
Old Tampa Bay	1.08
Hillsborough Bay	1.62
Middle Tampa Bay	1.24
Lower Tampa Bay	0.97

5.0 Implementation

The TBNMC and TBEP have recommended that FDEP and EPA compliance assessments should first consider whether the mean annual bay segment chlorophyll *a* concentration is above the FDEP-approved threshold, and as a result, whether seagrass resources within the bay segment have been or are likely to be impacted (TBNMC, 2010b). The RA defines a series of management actions to be taken in response to various threshold exceedances. The following assessment strategy builds on that approved by FDEP for the Tampa Bay RA.

The proposed compliance assessment strategy involves two steps. The initial step is the comparison of the mean annual chlorophyll *a* concentrations in each bay segment to the established chlorophyll *a* **thresholds**. Compliance is achieved if the threshold is met in that year. If the chlorophyll *a* threshold is exceeded in more than two years during any five-year period, an assessment of nitrogen loading (relative to the hydrologic loads, i.e., the Nitrogen Delivery Ratios) during that period will be completed. The justification for this "2-in-5 year" compliance assessment has been developed (Janicki Environmental, 2010b) and summarized in Appendix D.

The recommendation for compliance assessment also hinges on the availability of the appropriate data for a defensible assessment. Thus, how the specific spatial and temporal averaging has been conducted in the development of the targets and thresholds as well as the compliance assessment is critical. The following discusses this aspect of the implementation of the proposed numeric nutrient criteria for Tampa Bay.

From the initial efforts to establish defensible water quality targets through the development of the RA, the primary data source has been the Environmental Protection Commission of Hillsborough County (EPC). The EPC has monitored water quality at more than 50 sites on a monthly basis since 1974. Investigation of the available data resulted in the identification of 46 sites for use in the establishment of water quality targets in Tampa Bay. The suite of segment-specific EPCHC sites utilized for establishment of segment-specific chlorophyll *a* targets and thresholds, and for the annual assessment, and location maps for each segment are provided in Appendix E. Defensible assessment will depend upon continued monitoring at these sites to ensure that the annual assessment for attainment of the FDEP-adopted chlorophyll *a* thresholds, implementation of the FDEP-approved Reasonable Assurance Plan, and implementation of the proposed TN loading criteria presented here.

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APPENDIX A.
Data Description and
Assessment of Seagrass, Water Quality, and TN Loading

1.0 Data Description

This section provides identification and description of the data utilized for developing relationships between seagrass extent, water quality, and loadings.

1.1 Seagrasses

An estimate of seagrass extent is available for 1950 (Figure 1-1). The areal coverage of the 1950 seagrass beds was developed using data collected by the Florida Department of Natural Resources (FDNR) and the U.S. Fish and Wildlife Service (USFWS). Seagrass meadows were mapped from 1:24,000-scale color photography, and obtained in digital form from the FDNR. A GIS coverage of the data was created, and horizontally rectified to geographically coincide with mapped data for the time period (Janicki et al., 1995).

Aerial photography of seagrasses in the bay has been gathered approximately every two years since 1988 by the Southwest Florida Water Management District (SWFWMD), resulting in seagrass coverages for 1988, 1990, 1992, 1994, 1996, 1999, 2001, 2004, 2006, 2008, and 2010. Some of the 1988 areas mapped as seagrasses were later found to actually represent attached macro-algae. From 1990 on, the aerial photography was field checked to verify presence of seagrasses (Figures 1-1, 1-2, and 1-3).

Additional aerial photography exists for 1982, as described in Lewis et al. (1985a). The methodology used in developing the 1982 seagrass coverage was different than that employed by the SWFWMD, so that it should be understood that direct comparisons of specific seagrass areas between the 1982 coverage and later coverages are not appropriate. However, the 1982 coverage does provide some measure of the baywide extent of seagrasses, and is useful for tracking seagrass changes on a baywide basis.

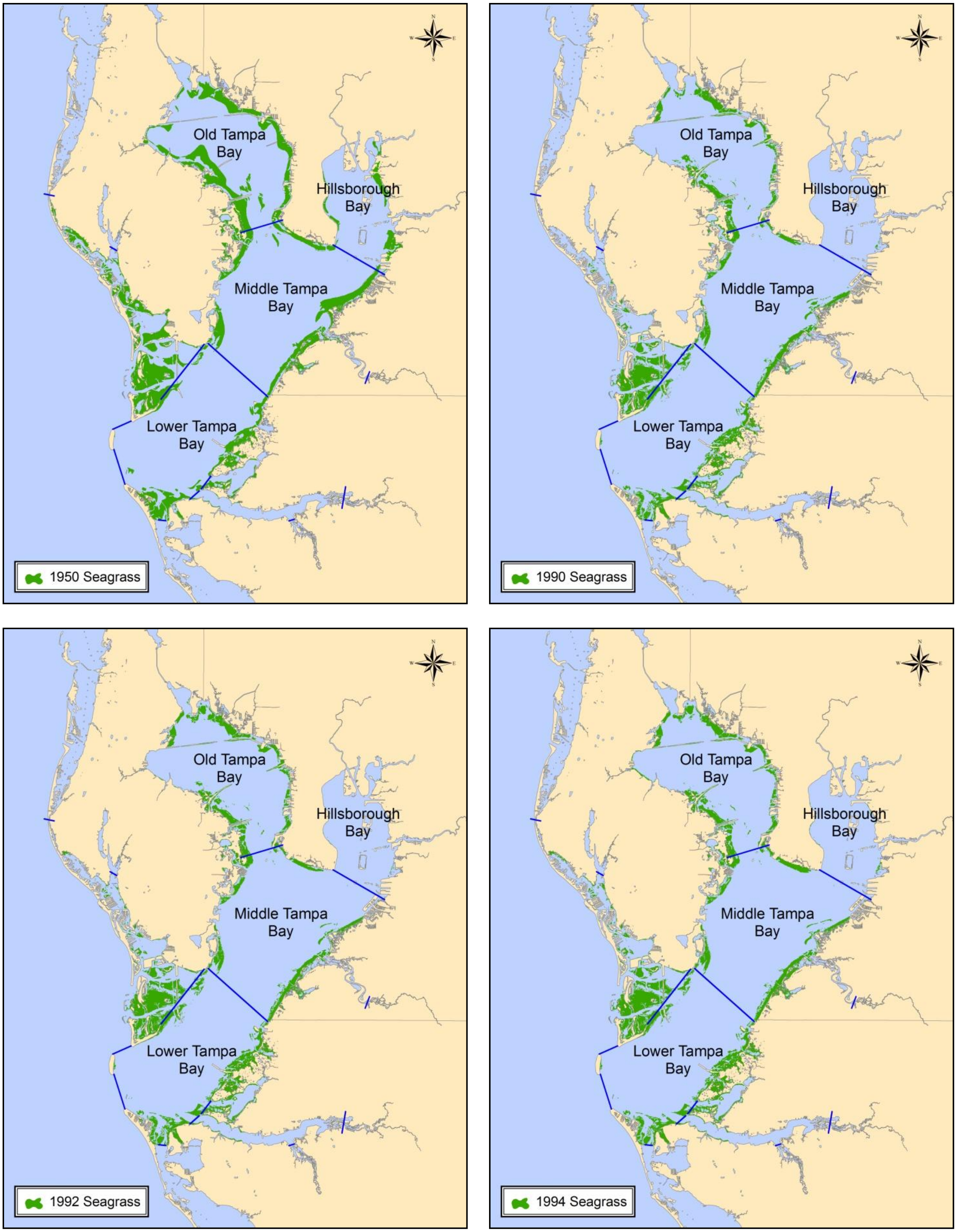

Figure 1-1. Tampa Bay seagrass, 1950 (FDNR and USFWS); 1990-1994 (SWFWMD), with four mainstem segments identified.

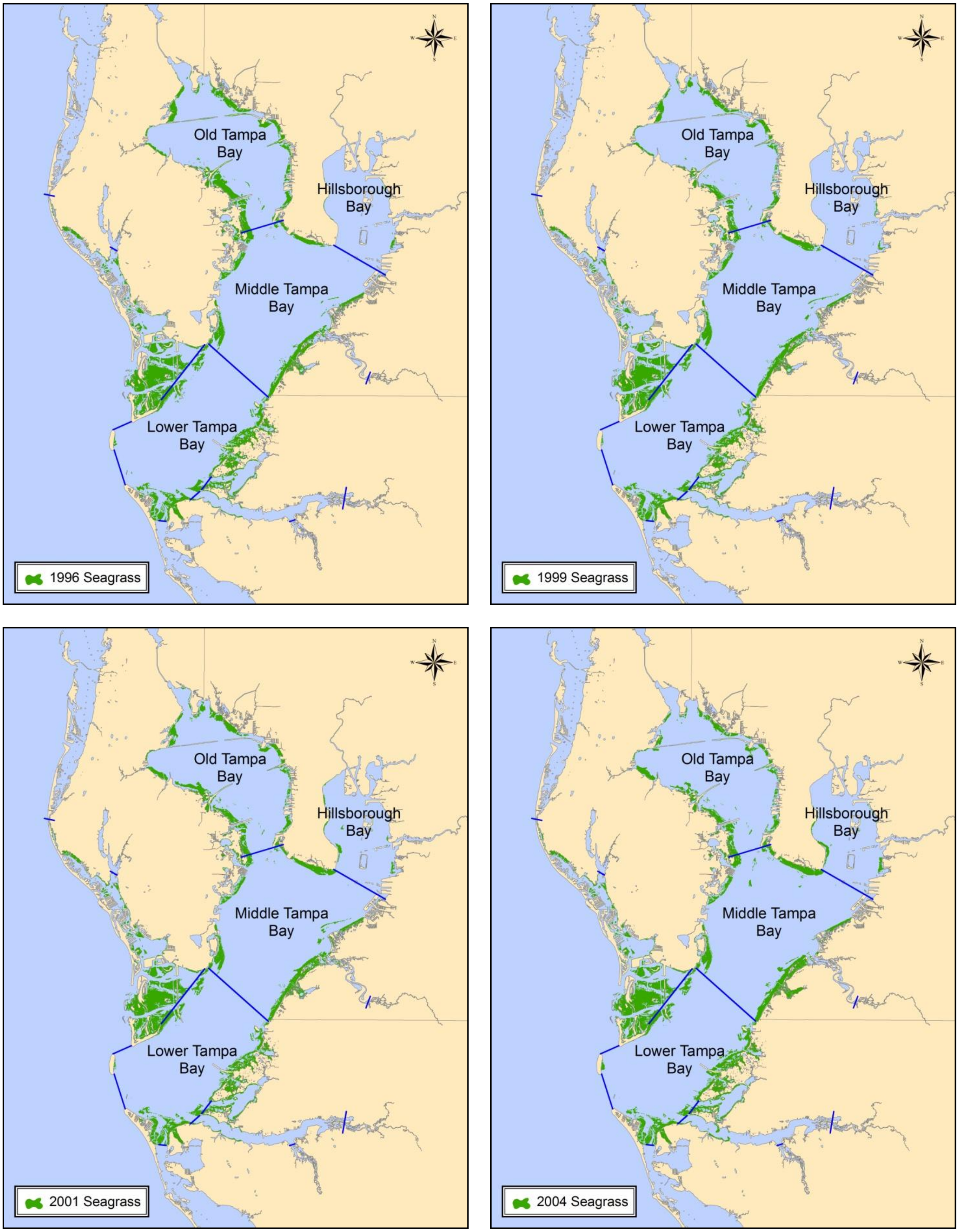

Figure 1-2. Tampa Bay seagrass, 1996-2004 (SWFWMD), with four mainstem segments identified.

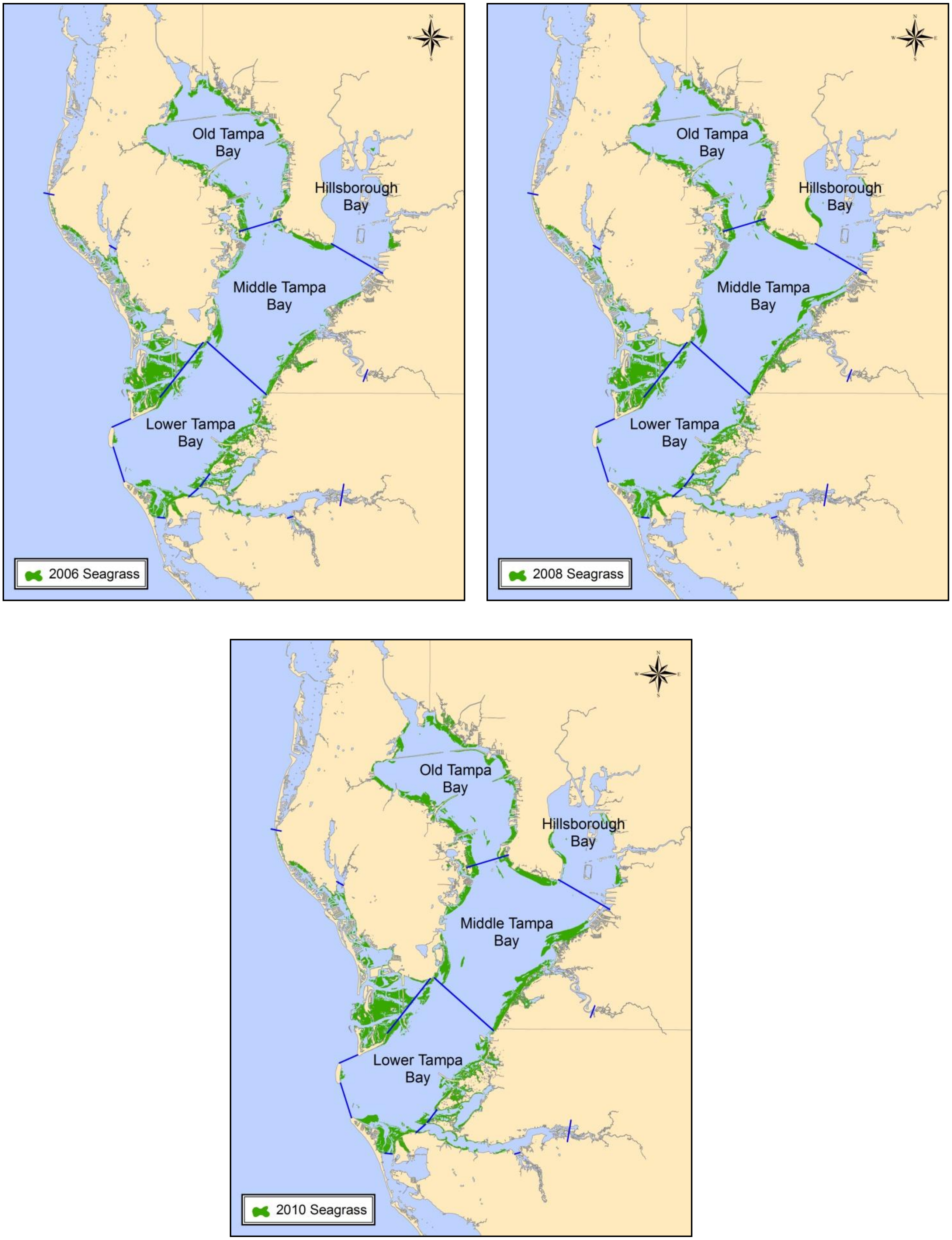

Figure 1-3. Tampa Bay seagrass, 2006-2010 (SWFWMD), with four mainstem segments identified.

1.2 Water Quality and Loadings

Water quality data utilized previously for establishment of targets in Tampa Bay, and here for developing numeric nutrient criteria in the bay, are those collected by the Environmental Protection Commission of Hillsborough County (EPCHC). The EPCHC has conducted monthly monitoring of ambient water quality in Tampa Bay since 1972, with complete records for most stations since 1974. Monitoring is performed at 52 fixed stations in Old Tampa Bay, Hillsborough Bay, Middle Tampa Bay, and Lower Tampa Bay. Monitoring is also performed in several bay tributaries. Water quality samples are collected at mid-depth, and are analyzed for nutrients, chlorophyll, and biochemical oxygen demand (BOD). Hydrolab measurements are taken of dissolved oxygen (DO), specific conductivity, temperature, and pH at the surface, mid-depth, and bottom. Water clarity is measured using a Secchi disc. Full descriptions of the EPCHC water quality monitoring program and data summaries are found in Boler (1998), including the methods employed for sampling and analysis. The selected sites displayed in Figure 1-4 are those utilized for target setting efforts in the past, and used for developing estuarine numeric nutrient criteria for the four mainstem segments.

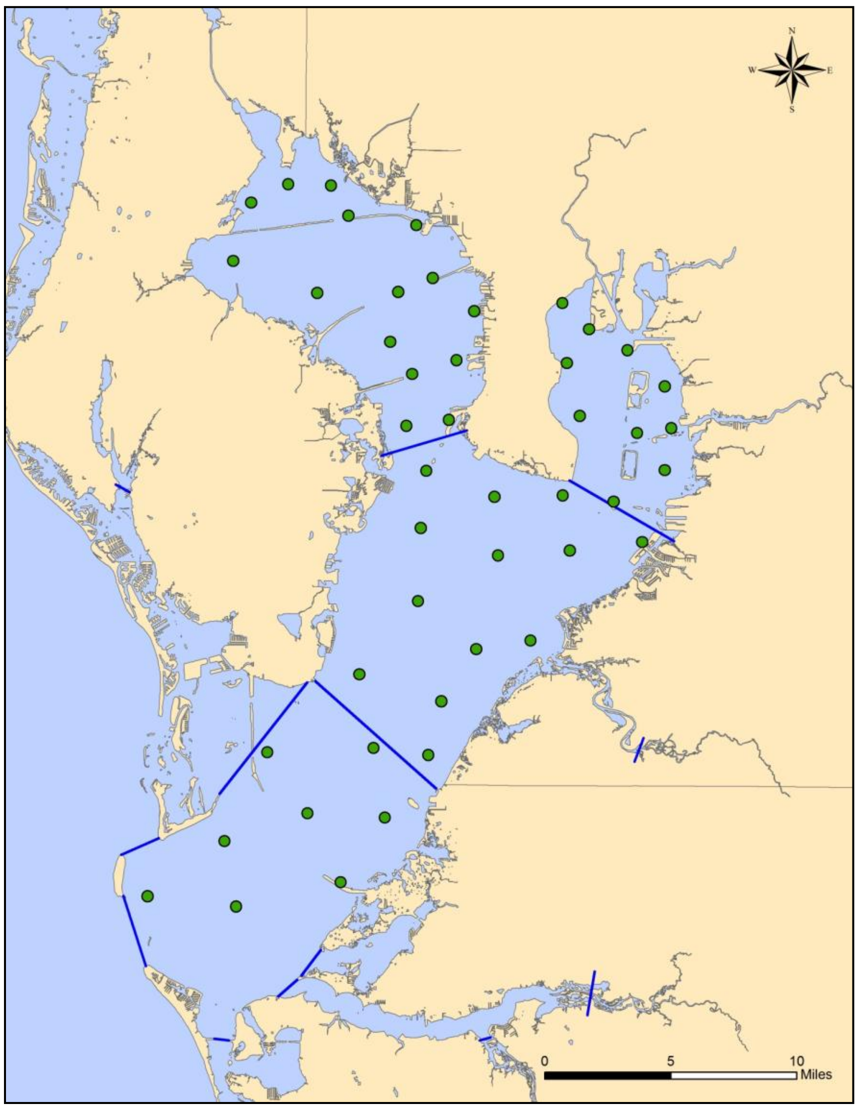

Figure 1-4. Locations of EPCHC water quality monitoring sites used in analyses.

2.0 Assessment of Conditions

Evaluation of the success of the TBNMC nitrogen management strategy is accomplished by an annual review of water quality data and biannual review of baywide seagrass extent. The following sections provide segment-specific comparisons of observed conditions to the seagrass targets, chlorophyll *a* targets and regulatory thresholds, and TN loading targets. For reference, segment-specific tables at the end of this appendix contains the annual mean chlorophyll *a* concentrations utilized in the Decision Matrix tool, the geometric mean annual TN and TP concentrations, and the annual hydrologic, TN, and TP loads for each of the four mainstem segments.

2.1 Old Tampa Bay

Time series plots of seagrass acreages, mean annual chlorophyll *a* concentrations, mean annual light attenuation and nutrient concentrations, and annual TN loadings are provided in Figures 2-1 through 2-6, respectively. Seagrasses in Old Tampa Bay have increased since 1990, with the exception of the period following the 1997-1998 El Niño event and during 2004 (Figure 2-1). The TBEP has funded several studies in Old Tampa Bay to evaluate the potential cause of the less rapid increase in seagrass acreage here as compared to the bay as a whole, and is initiating additional studies in the near future. As seen from the time series of annual chlorophyll *a* concentrations (Figure 2-2), the regulatory threshold has been met in most years, indicating that light should be sufficient for seagrass recovery, with observed improvements in the available light (Figure 2-3). Improvements in TN and TP concentrations have also occurred (Figures 2-4 and 2-5, respectively). Evaluation of the external TN load to the segment, which has been related to chlorophyll *a* concentrations via the empirical modeling effort (Janicki and Wade, 1996), shows that the target TN loads have been exceeded in some years since 1994, even in years when chlorophyll *a* targets and thresholds were met (Figure 2-6). The apparent contradiction in meeting chlorophyll *a* targets and thresholds while not meeting external TN loading targets has been related to the effects of varying hydrologic loading rates and residence time.

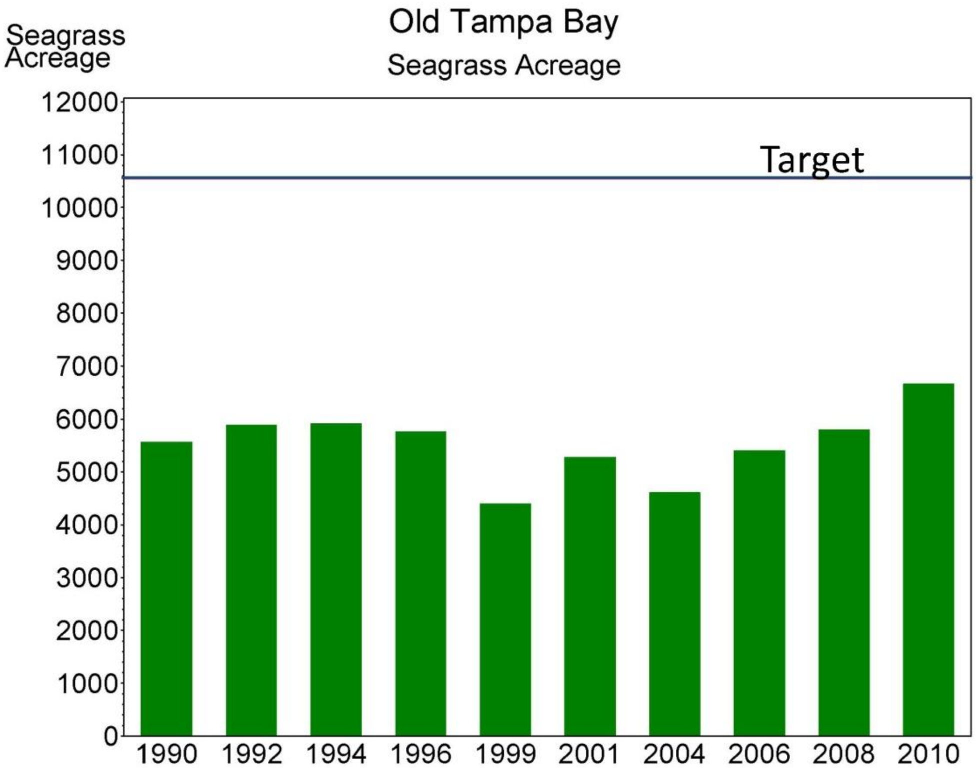

Figure 2-1. Comparison of observed Old Tampa Bay seagrass acreage to target.

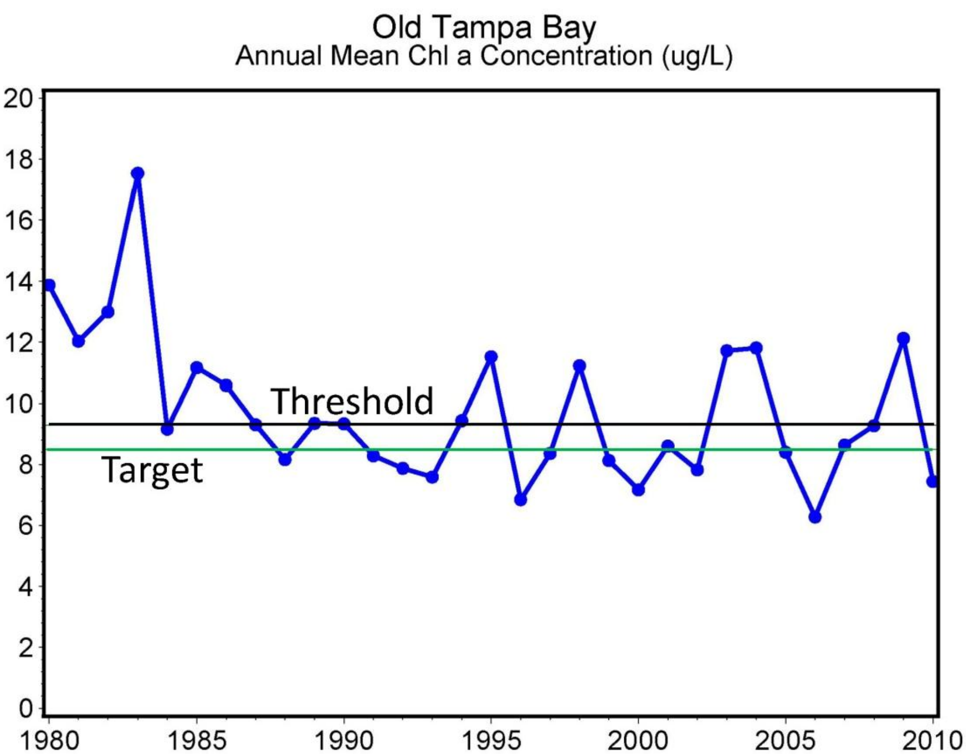

Figure 2-2. Comparison of observed Old Tampa Bay chlorophyll *a* concentrations to target and regulatory threshold.

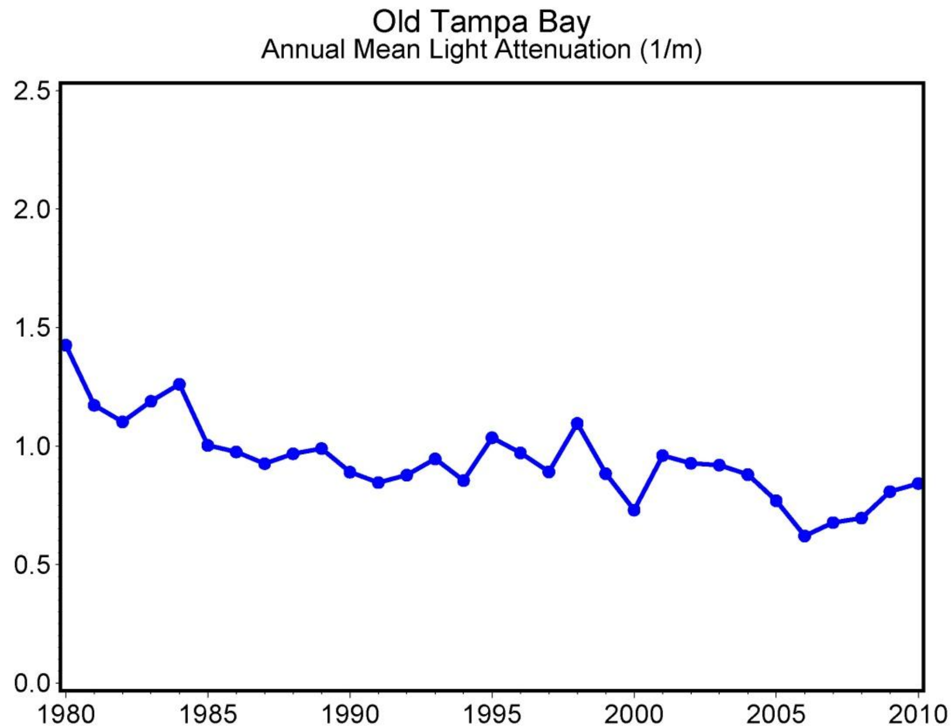

Figure 2-3. Time series of Old Tampa Bay annual mean light attenuation, 1980-2010.

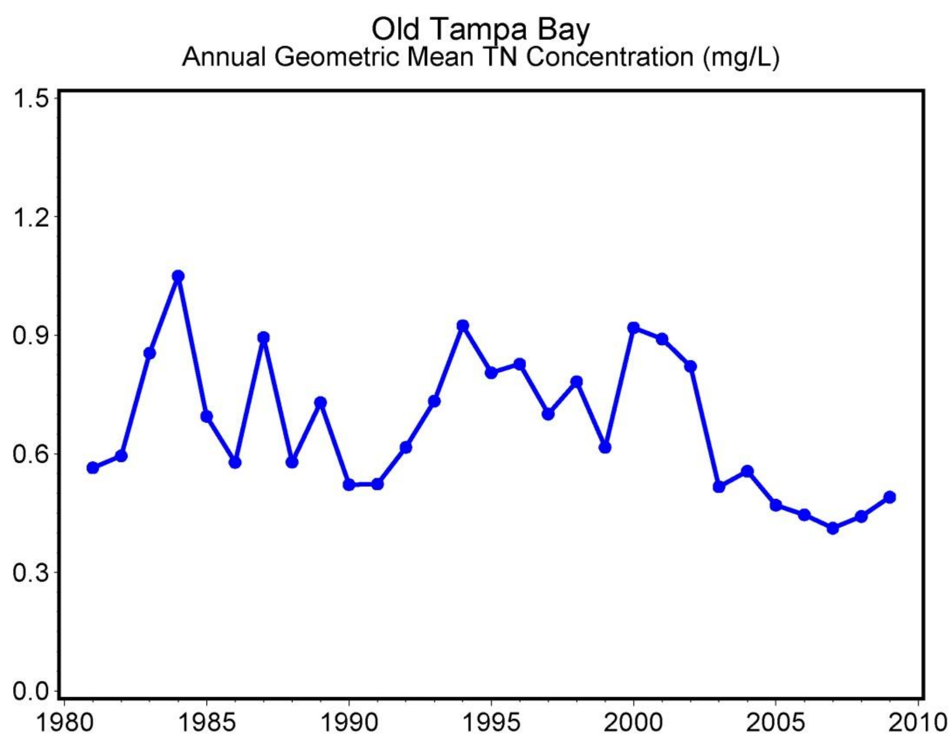

Figure 2-4. Time series of Old Tampa Bay annual geometric mean TN concentrations, 1981-2009.

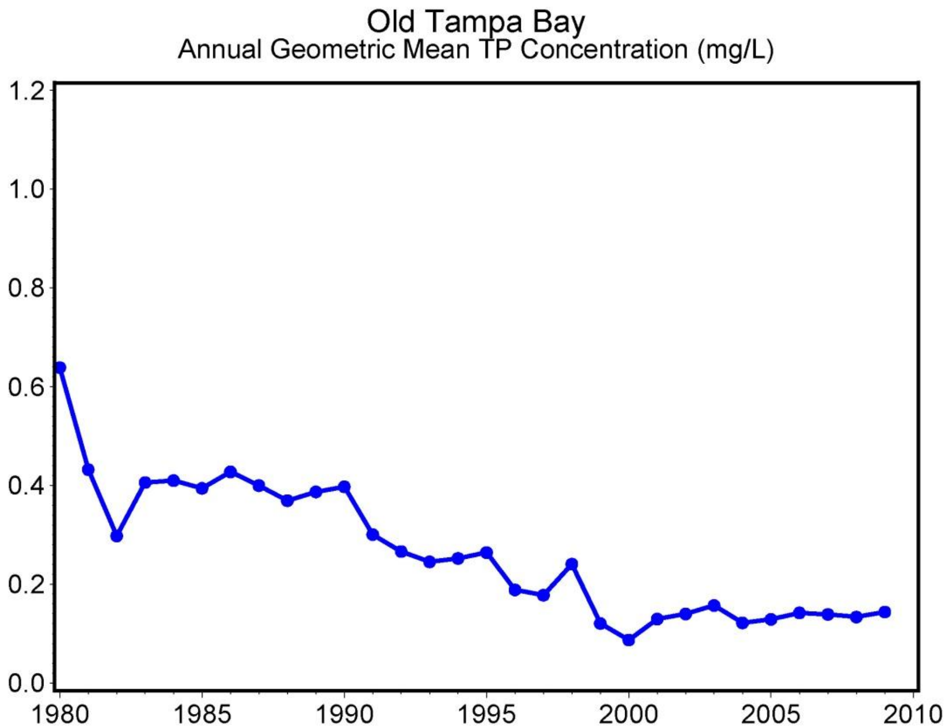

Figure 2-5. Time series of Old Tampa Bay annual geometric mean TP concentrations, 1980-2009.

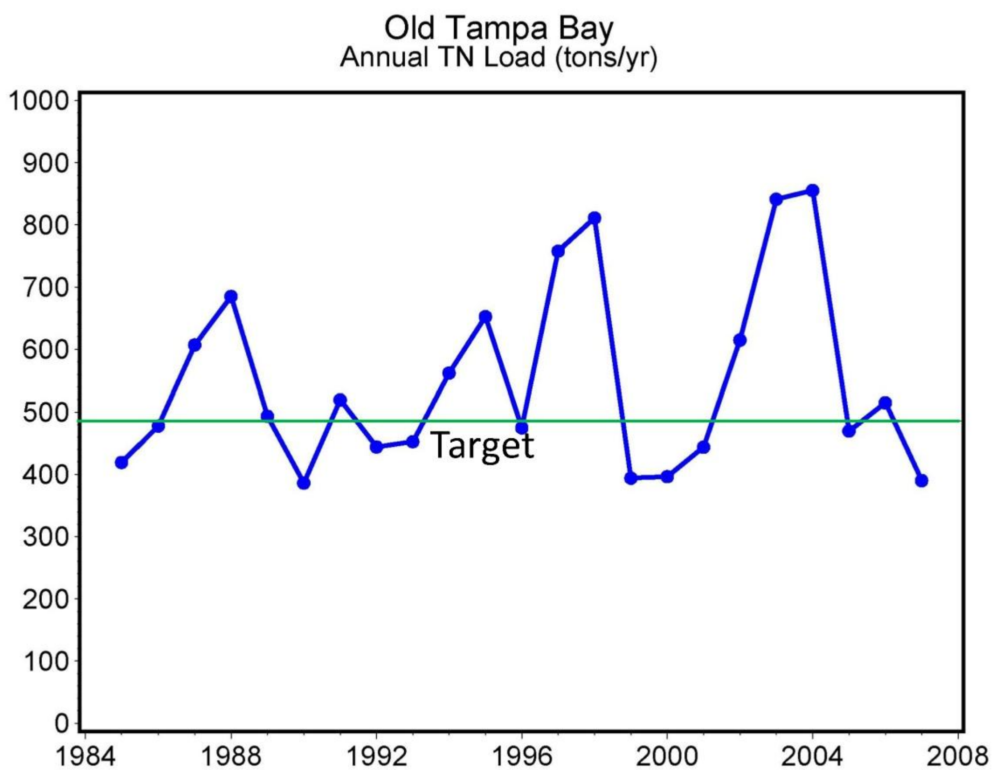

Figure 2-6. Comparison of observed Old Tampa Bay TN loadings to target.

2.2 Hillsborough Bay

Time series plots of seagrass acreages, mean annual chlorophyll *a* concentrations, mean annual light attenuation and nutrient concentrations, and annual TN loadings are provided in Figures 2-7 through 2-12, respectively, for Hillsborough Bay. Seagrasses in this segment have increased considerably since 1990 (Figure 2-7). As seen from the time series of annual chlorophyll *a* concentrations, the regulatory threshold has been met in most years since 1994, and continuously for more than a decade, so that water quality conditions are appropriate for the observed increase in seagrasses (Figure 2-8). This is reinforced by the time series of light attenuation (Figure 2-9), with improved light availability. Nutrient concentrations have declined as well (Figures 2-10 and 2-11), especially TP. As in Old Tampa Bay, evaluation of the external TN load to the segment shows that the target TN loads have been exceeded several times since 1994, during the same period in which the segment was meeting chlorophyll *a* targets and thresholds. This has been related to the effects of varying hydrologic loading rates and residence time.

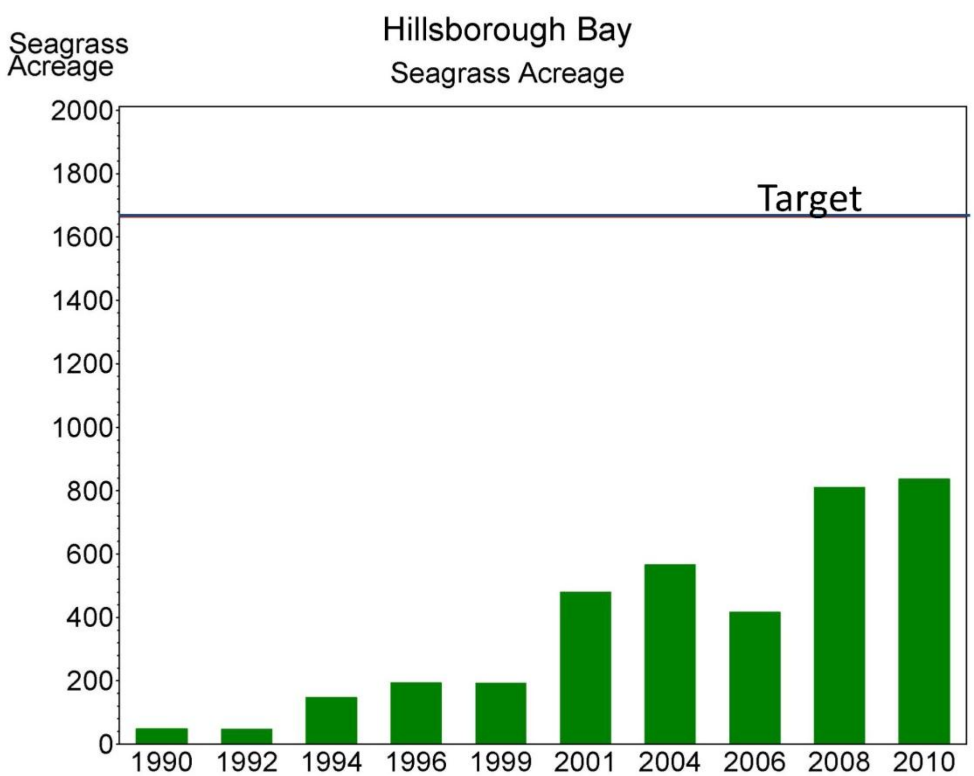

Figure 2-7. Comparison of observed Hillsborough Bay seagrass acreage to target.

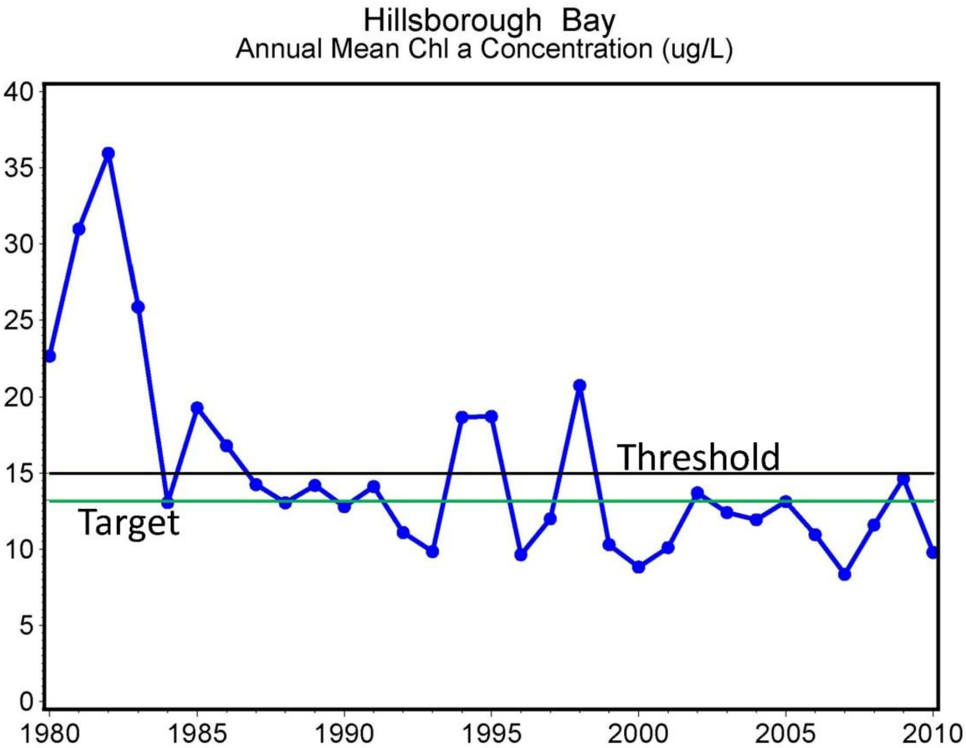

Figure 2-8. Comparison of observed Hillsborough Bay chlorophyll *a* concentrations to target and regulatory threshold.

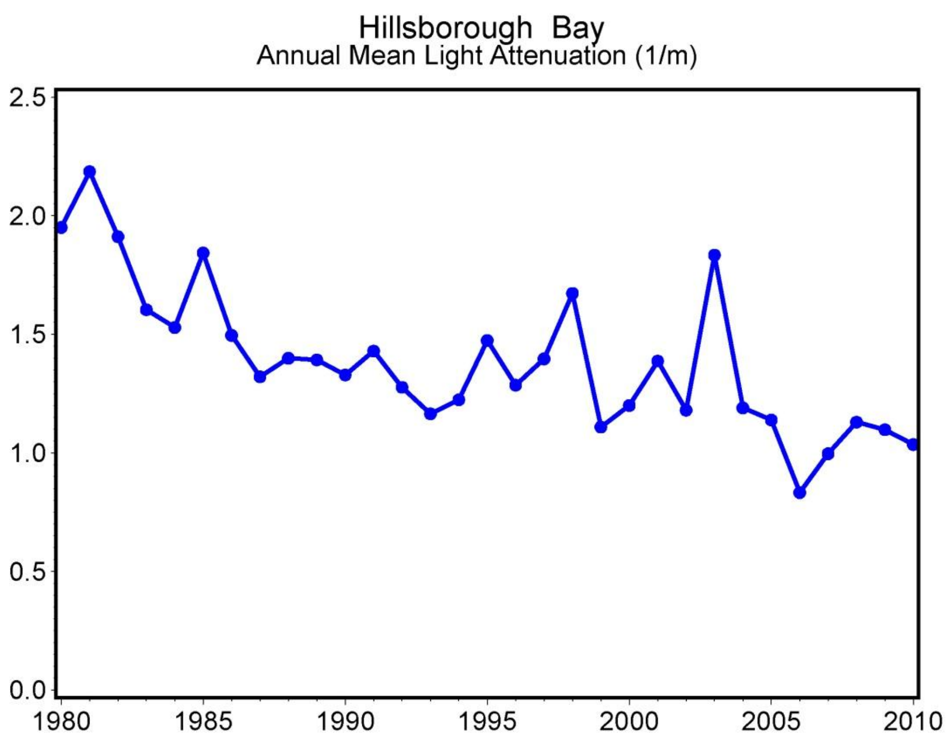

Figure 2-9. Time series of Hillsborough Bay annual mean light attenuation, 1980-2010.

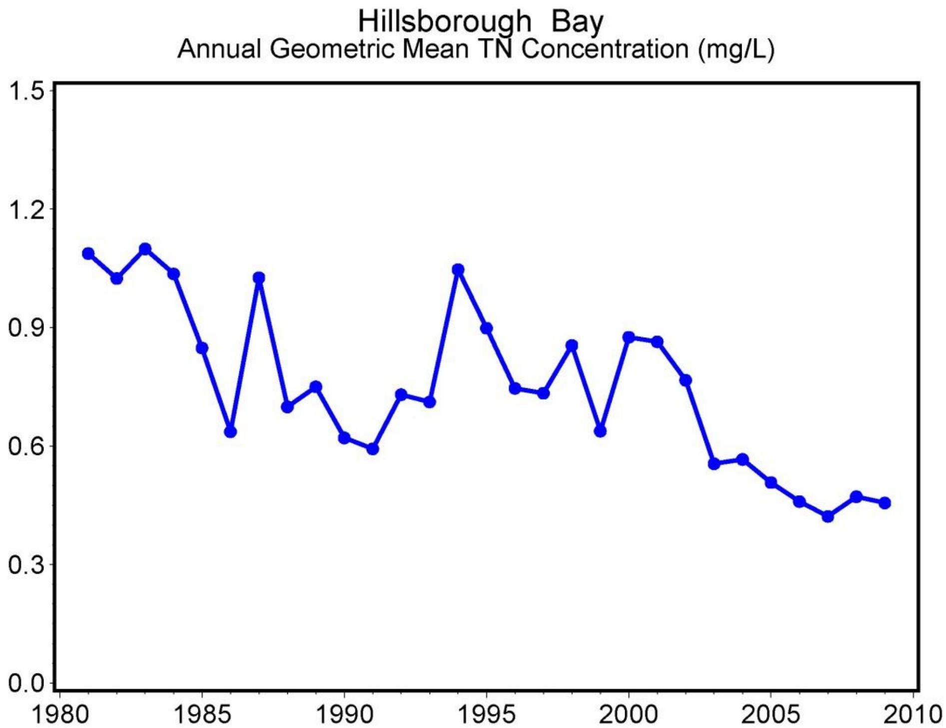

Figure 2-10. Time series of Hillsborough Bay annual geometric mean TN concentrations, 1981-2009.

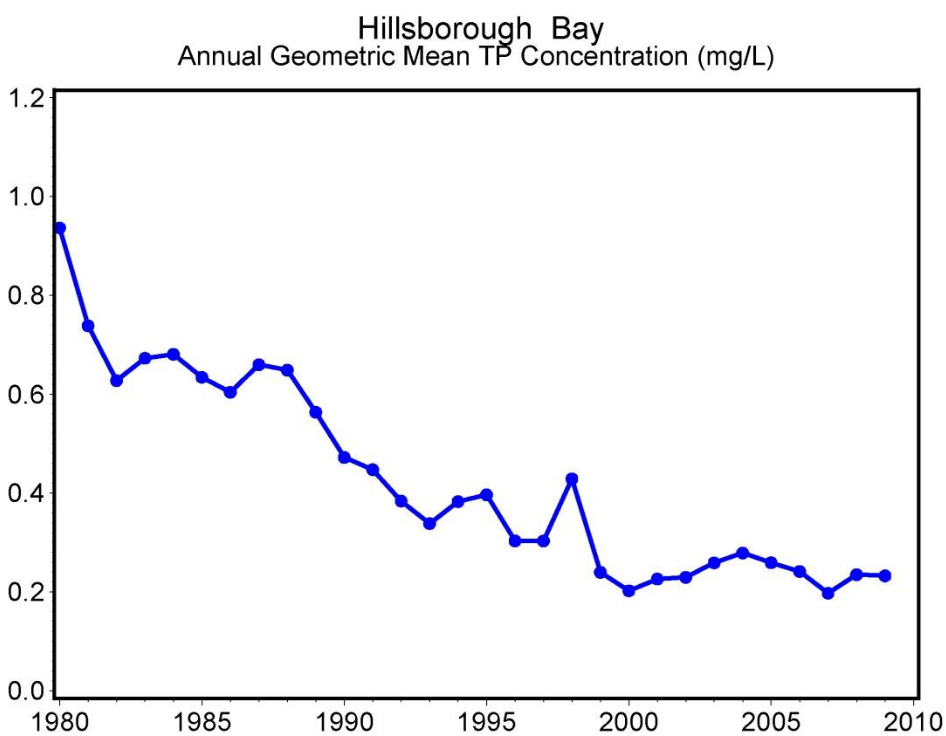

Figure 2-11. Time series of Hillsborough Bay annual geometric mean TP concentrations, 1980-2009.

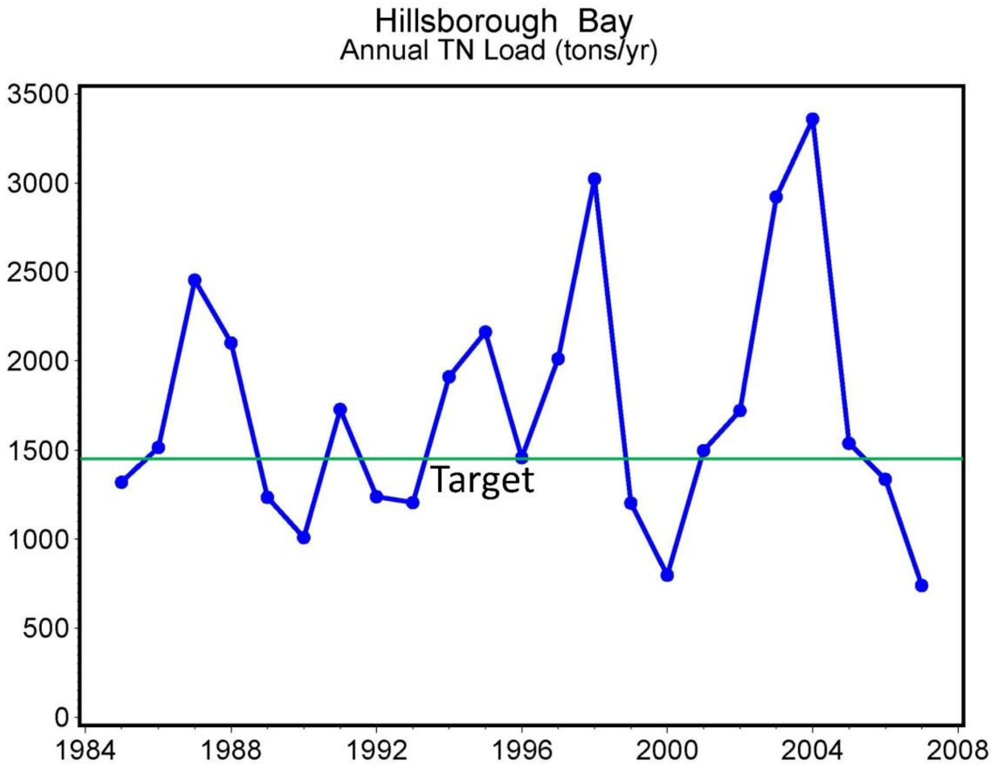

Figure 2-12. Comparison of observed Hillsborough Bay TN loadings to target.

2.3 Middle Tampa Bay

Time series plots of seagrass acreages, mean annual chlorophyll *a* concentrations, mean annual light attenuation and nutrient concentrations, and annual TN loadings are provided in Figures 2-13 through 2-18, respectively, for Middle Tampa Bay. Seagrasses in this segment have increased by almost 3,000 acres since 1990 (Figure 2-13). As seen from the time series of annual chlorophyll *a* concentrations, the regulatory threshold has been met in most years since 1994, and continuously for more than a decade, so that water quality conditions are appropriate for the observed increase in seagrasses (Figure 2-14). This is supported by the time series of light attenuation (Figure 2-15), with improved light availability. Nutrient concentrations have declined as well (Figures 2-16 and 2-17), especially TP. As in Old Tampa Bay and Hillsborough Bay, evaluation of the external TN load to the segment shows that the target TN loads have been exceeded many times 1994, during the same period in which the segment was meeting chlorophyll *a* targets and thresholds (Figure 2-18). This has been related to the effects of varying hydrologic loading rates and residence time.

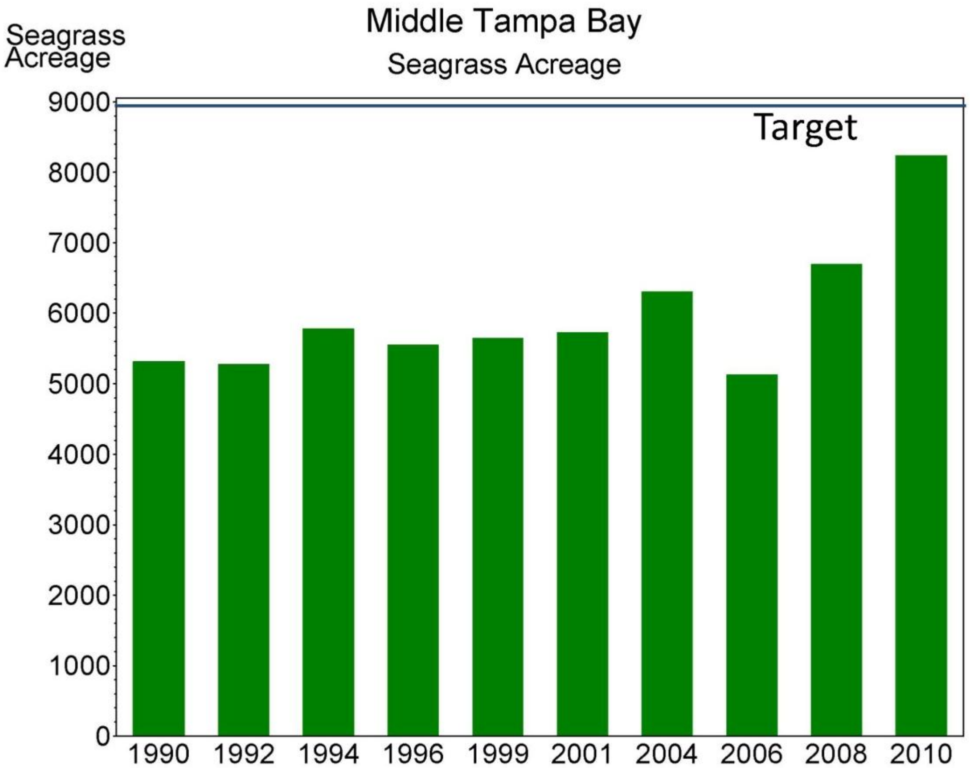

Figure 2-13. Comparison of observed Middle Tampa Bay seagrass acreage to target.

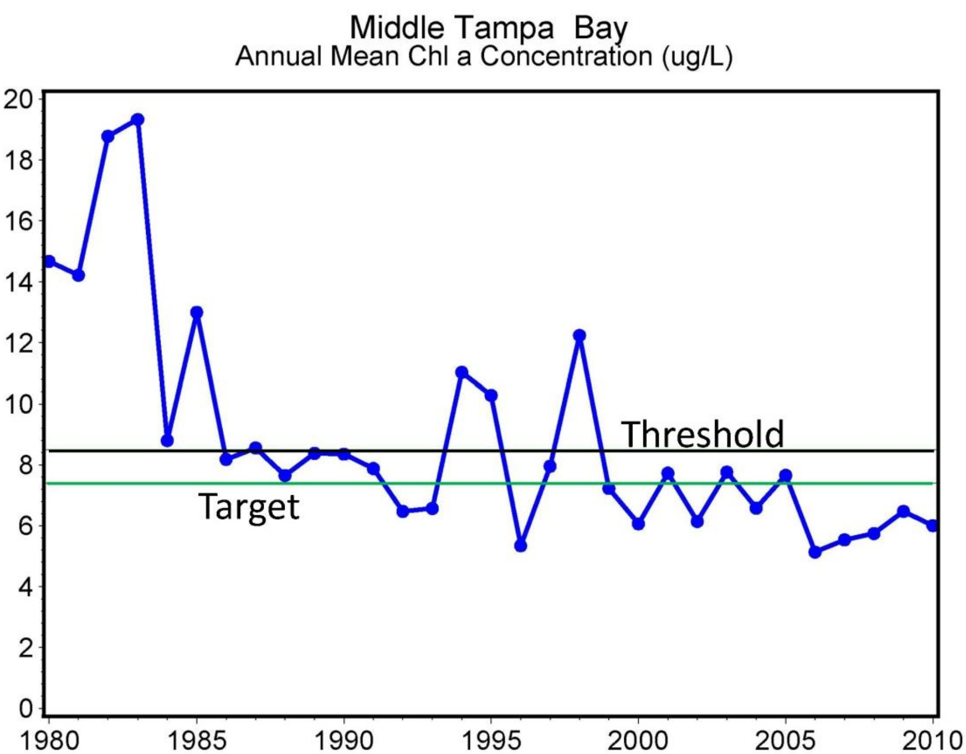

Figure 2-14. Comparison of observed Middle Tampa Bay chlorophyll *a* concentrations to target and regulatory threshold.

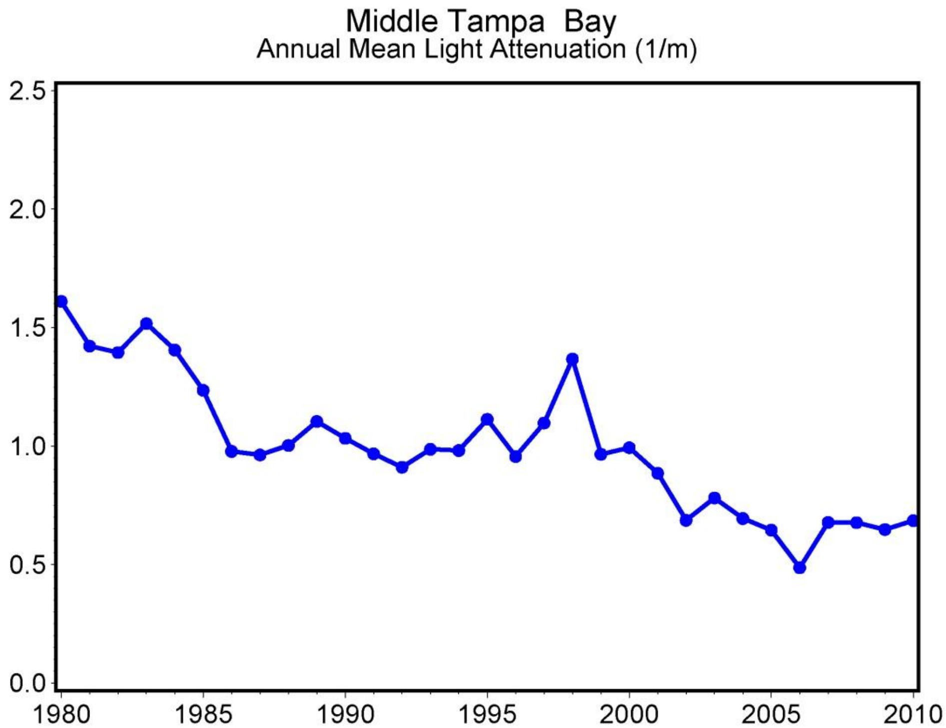

Figure 2-15. Time series of Middle Tampa Bay annual mean light attenuation, 1980-2010.

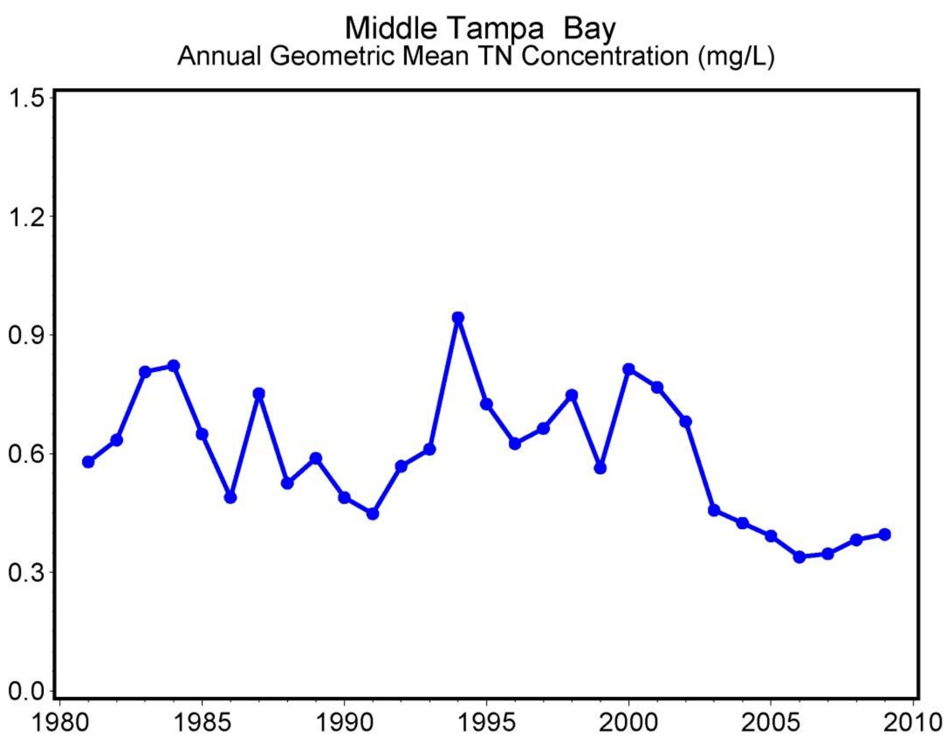

Figure 2-16. Time series of Middle Tampa Bay annual geometric mean TN concentrations, 1981-2009.

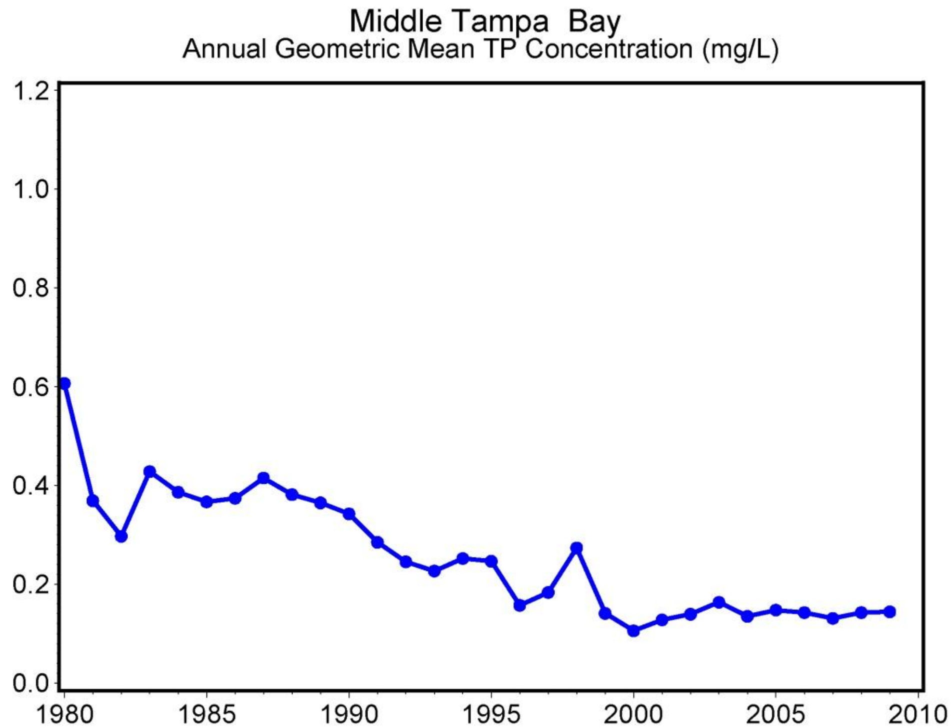

Figure 2-17. Time series of Middle Tampa Bay annual geometric mean TP concentrations, 1980-2009.

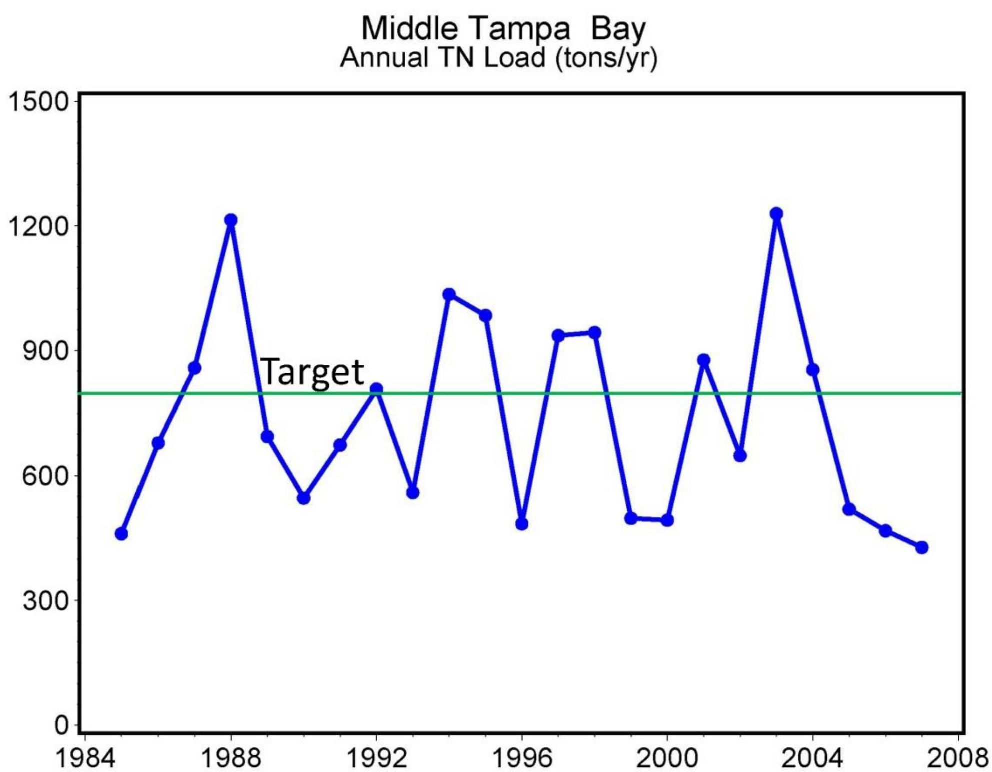

Figure 2-18. Comparison of observed Middle Tampa Bay TN loadings to target.

2.4 Lower Tampa Bay

Time series plots of seagrass acreages, mean annual chlorophyll *a* concentrations, mean annual light attenuation and nutrient concentrations, and annual TN loadings are provided in Figures 2-19 through 2-24, respectively, for Lower Tampa Bay. Seagrass acreages in this segment have remained more or less steady since 1990, with an increase during the last decade to nearly the segment target (Figure 2-19). As seen from the time series of annual chlorophyll *a* concentrations, the regulatory threshold has been exceeded only twice since 1994, so that water quality conditions are appropriate for the observed increase in seagrasses (Figure 2-20). This is supported by the time series of light attenuation (Figure 2-21), with improved light availability. Nutrient concentrations have declined as well (Figures 2-22 and 2-23). Evaluation of the external TN load to the segment shows that the target TN loads have been exceeded only three times since 1994 (Figure 2-24). As for the other segments, exceedance of target load while attaining chlorophyll *a* targets and thresholds has been related to the effects of varying hydrologic loading rates and residence time.

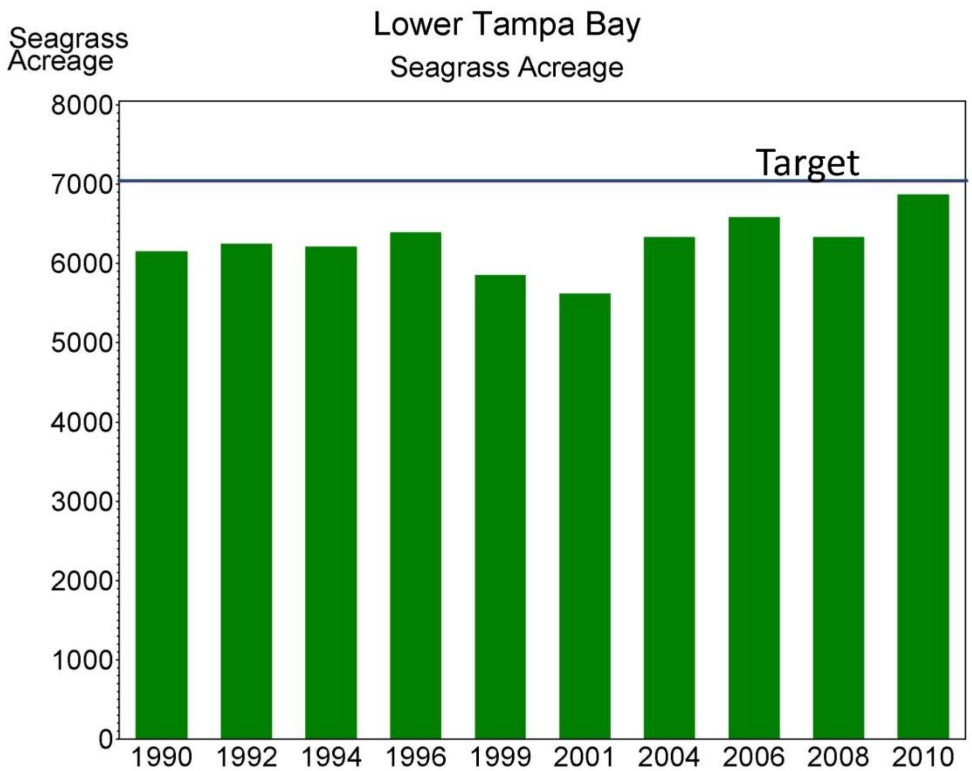

Figure 2-19. Comparison of observed Lower Tampa Bay seagrass acreage to target.

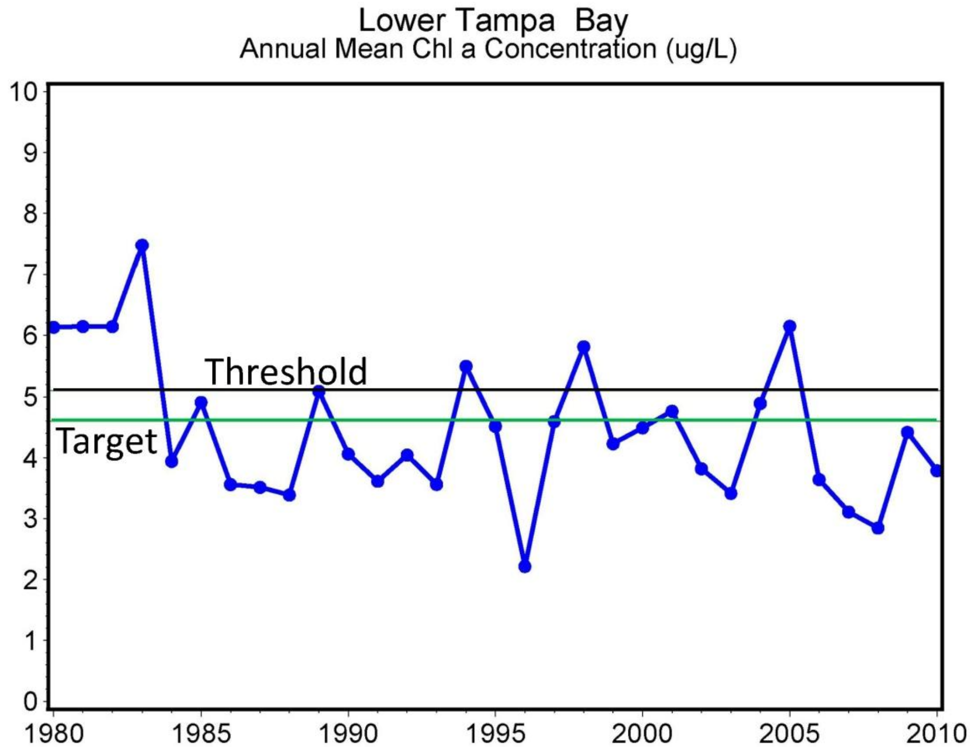

Figure 2-20. Comparison of observed Lower Tampa Bay chlorophyll *a* concentrations to target and regulatory threshold.

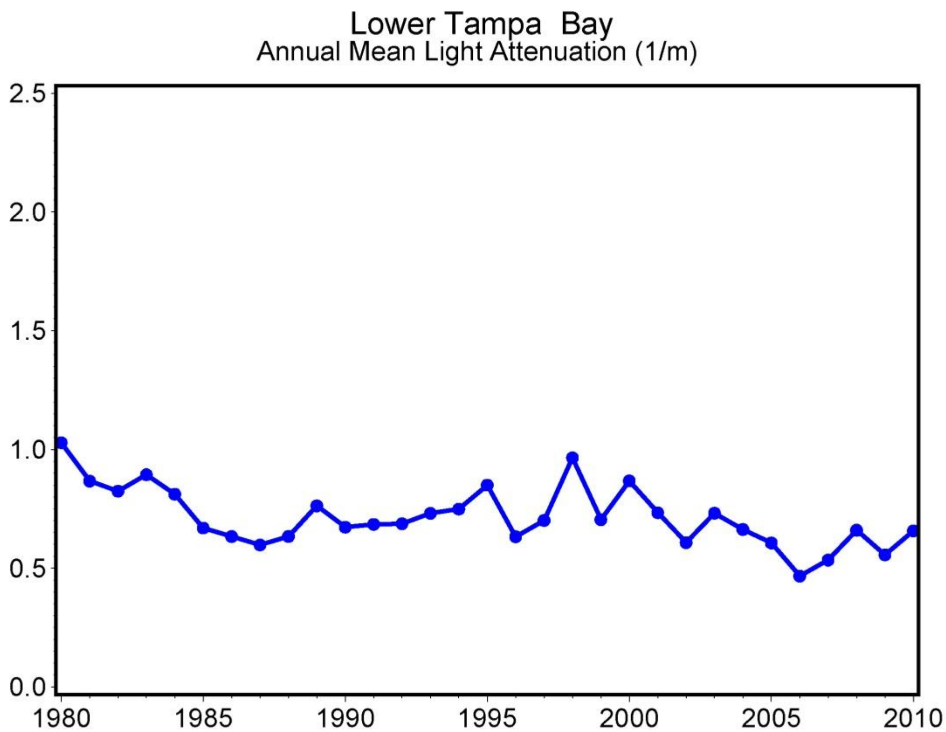

Figure 2-21. Time series of Lower Tampa Bay annual mean light attenuation, 1980-2010.

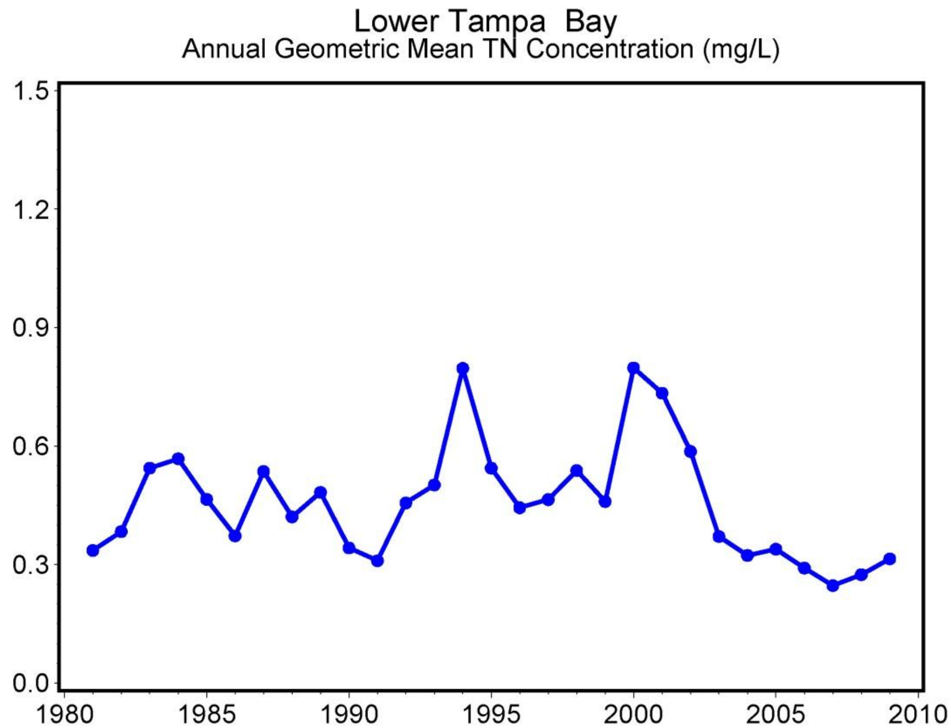

Figure 2-22. Time series of Lower Tampa Bay annual geometric mean TN concentrations, 1981-2009.

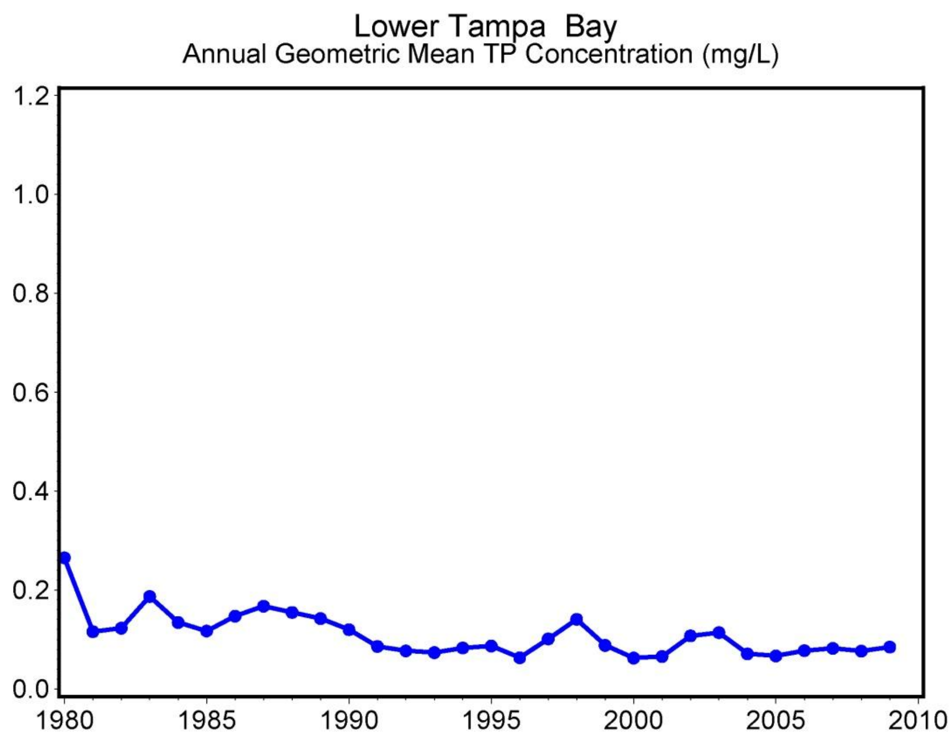

Figure 2-23. Time series of Lower Tampa Bay annual geometric mean TP concentrations, 1980-2009.

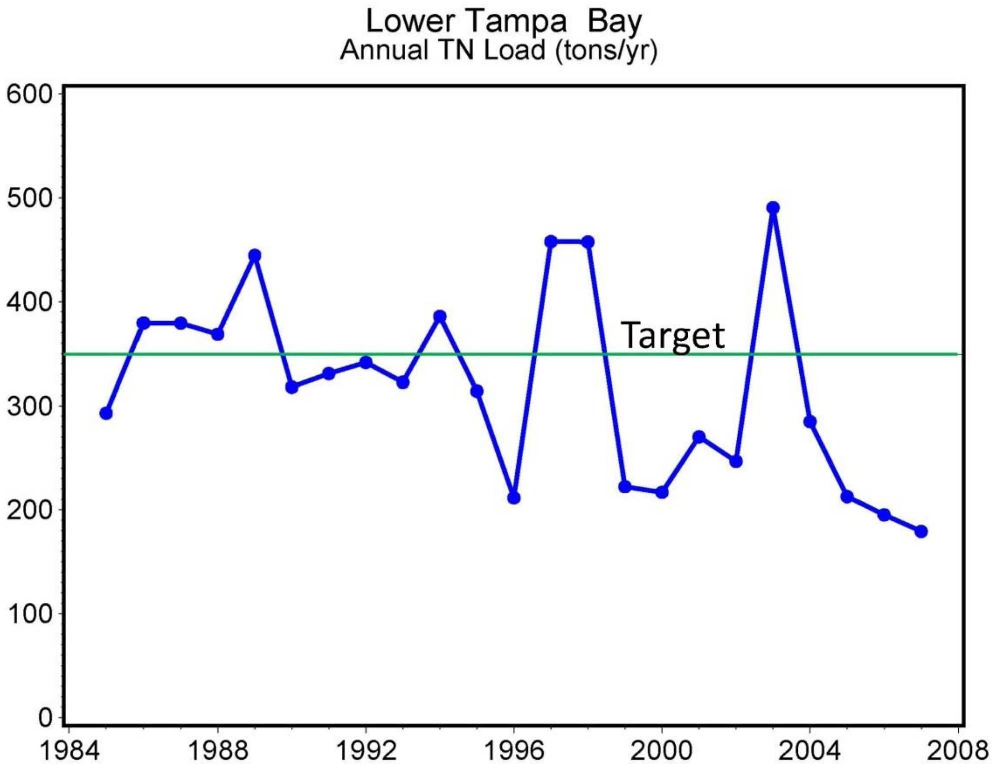

Figure 2-24. Comparison of observed Lower Tampa Bay TN loadings to target.

Old Tampa Bay mean annual chlorophyll *a*, geometric mean annual TN and TP concentrations, and annual hydrologic, TN, and TP loads.						
Year	**Chl a (μg/L)**	**TN Conc (mg/L)**	**TP Conc (mg/L)**	**TN Load (tons/yr)**	**TP Load (tons/yr)**	**Hydrologic Load (10^6 m3/yr)**
1980	13.87		0.64			
1981	12.03	0.56	0.43			
1982	12.99	0.59	0.30			
1983	17.54	0.86	0.41			
1984	9.16	1.05	0.41			
1985	11.16	0.70	0.39	419	114	513
1986	10.59	0.58	0.43	478	111	515
1987	9.30	0.89	0.40	607	131	594
1988	8.16	0.58	0.37	685	187	695
1989	9.35	0.73	0.39	493	96	459
1990	9.34	0.52	0.40	386	88	395
1991	8.29	0.52	0.30	519	109	518
1992	7.88	0.62	0.27	444	105	441
1993	7.59	0.73	0.25	453	97	420
1994	9.43	0.92	0.25	562	109	488
1995	11.52	0.81	0.26	653	276	687
1996	6.85	0.83	0.19	475	191	514
1997	8.36	0.70	0.18	758	158	780
1998	11.23	0.78	0.24	811	179	789
1999	8.13	0.62	0.12	394	146	446
2000	7.17	0.92	0.09	396	106	413
2001	8.60	0.89	0.13	444	107	507
2002	7.83	0.82	0.14	615	134	688
2003	11.72	0.52	0.16	841	185	784
2004	11.81	0.56	0.12	855	190	910
2005	8.40	0.47	0.13	470	119	544
2006	6.28	0.45	0.14	515	116	604
2007	8.64	0.41	0.14	390	91	484
2008	9.27	0.44	0.13			
2009	12.12	0.49	0.14			

Hillsborough Bay mean annual chlorophyll *a*, geometric mean annual TN and TP concentrations, and annual hydrologic, TN, and TP loads.						
Year	**Chl a (μg/L)**	**TN Conc (mg/L)**	**TP Conc (mg/L)**	**TN Load (tons/yr)**	**TP Load (tons/yr)**	**Hydrologic Load (10^6 m3/yr)**
1980	22.64		0.94			
1981	30.98	1.09	0.74			
1982	35.95	1.02	0.63			
1983	25.86	1.10	0.67			
1984	13.05	1.04	0.68			
1985	19.27	0.85	0.63	1321	1474	707
1986	16.78	0.64	0.60	1516	1384	880
1987	14.23	1.03	0.66	2454	1862	1087
1988	13.04	0.70	0.65	2101	2006	1177
1989	14.18	0.75	0.56	1236	1352	642
1990	12.78	0.62	0.47	1010	1149	499
1991	14.10	0.59	0.45	1731	1603	921
1992	11.09	0.73	0.38	1240	1102	717
1993	9.84	0.71	0.34	1206	1166	804
1994	18.65	1.05	0.38	1911	1019	1192
1995	18.70	0.90	0.40	2163	1782	1447
1996	9.63	0.75	0.30	1459	991	1000
1997	11.99	0.73	0.30	2012	2507	1270
1998	20.74	0.85	0.43	3023	1910	1933
1999	10.29	0.64	0.24	1204	838	743
2000	8.83	0.88	0.20	799	584	490
2001	10.10	0.86	0.23	1499	1071	941
2002	13.69	0.77	0.23	1723	1193	1159
2003	12.40	0.56	0.26	2922	2055	1873
2004	11.93	0.57	0.28	3359	3929	1774
2005	13.12	0.51	0.26	1540	1128	1035
2006	10.95	0.46	0.24	1337	757	697
2007	8.34	0.42	0.20	741	550	565
2008	11.58	0.47	0.23			
2009	14.63	0.46	0.23			

Middle Tampa Bay mean annual chlorophyll *a*, geometric mean annual TN and TP concentrations, and annual hydrologic, TN, and TP loads.						
Year	**Chl a (μg/L)**	**TN Conc (mg/L)**	**TP Conc (mg/L)**	**TN Load (tons/yr)**	**TP Load (tons/yr)**	**Hydrologic Load (10^6 m3/yr)**
1980	14.67		0.61			
1981	14.21	0.58	0.37			
1982	18.78	0.63	0.30			
1983	19.33	0.81	0.43			
1984	8.80	0.82	0.39			
1985	13.00	0.65	0.37	461	92	565
1986	8.18	0.49	0.37	679	117	671
1987	8.56	0.75	0.42	859	140	690
1988	7.65	0.53	0.38	1215	249	1048
1989	8.38	0.59	0.36	694	109	572
1990	8.35	0.49	0.34	546	77	458
1991	7.88	0.45	0.28	674	130	610
1992	6.47	0.57	0.25	808	164	663
1993	6.57	0.61	0.23	560	87	524
1994	11.03	0.94	0.25	1036	221	751
1995	10.28	0.73	0.25	985	378	912
1996	5.35	0.63	0.16	484	177	509
1997	7.96	0.66	0.18	936	157	875
1998	12.24	0.75	0.27	944	201	869
1999	7.23	0.56	0.14	498	75	521
2000	6.07	0.81	0.11	493	66	475
2001	7.73	0.77	0.13	877	203	823
2002	6.14	0.68	0.14	649	103	673
2003	7.76	0.46	0.16	1230	246	1037
2004	6.58	0.42	0.14	854	213	842
2005	7.66	0.39	0.15	519	121	574
2006	5.13	0.34	0.14	468	89	502
2007	5.54	0.35	0.13	427	58	466
2008	5.75	0.38	0.14			
2009	6.47	0.40	0.14			

Lower Tampa Bay mean annual chlorophyll *a*, geometric mean annual TN and TP concentrations, and annual hydrologic, TN, and TP loads.

Year	Chl a (μg/L)	TN Conc (mg/L)	TP Conc (mg/L)	TN Load (tons/yr)	TP Load (tons/yr)	Hydrologic Load (10^6 m3/yr)
1980	6.13		0.27			
1981	6.15	0.34	0.12			
1982	6.14	0.38	0.12			
1983	7.48	0.54	0.19			
1984	3.94	0.57	0.13			
1985	4.91	0.47	0.12	293	141	359
1986	3.56	0.37	0.15	379	128	399
1987	3.51	0.54	0.17	379	76	403
1988	3.39	0.42	0.15	369	119	499
1989	5.09	0.48	0.14	444	81	362
1990	4.06	0.34	0.12	318	53	293
1991	3.61	0.31	0.09	331	59	343
1992	4.04	0.46	0.08	341	63	393
1993	3.56	0.50	0.07	323	39	324
1994	5.49	0.80	0.08	386	55	367
1995	4.52	0.54	0.09	314	180	469
1996	2.21	0.44	0.06	211	95	321
1997	4.59	0.46	0.10	458	41	531
1998	5.81	0.54	0.14	457	57	437
1999	4.23	0.46	0.09	222	13	317
2000	4.49	0.80	0.06	217	13	286
2001	4.76	0.73	0.07	270	30	428
2002	3.82	0.59	0.11	247	16	406
2003	3.41	0.37	0.11	490	41	547
2004	4.89	0.32	0.07	285	35	438
2005	6.15	0.34	0.07	213	22	343
2006	3.64	0.29	0.08	195	18	330
2007	3.11	0.25	0.08	179	12	288
2008	2.85	0.27	0.08			
2009	4.42	0.31	0.08			

APPENDIX B.
Alternative Criteria Expressed as TN Concentrations, and as TP Loads and Concentrations

1.0 TN Concentrations

The TBEP has developed recommended segment-specific numeric nutrient criteria in terms of TN concentrations should these be necessary for Tampa Bay (Janicki Environmental, 2011a). The development of these criteria is described below.

Multiple analyses were completed in the evaluation of potential TN criteria expressed as in-bay concentrations, as described in Janicki Environmental (2011a). These included:

- examination of the relationships between TN loadings and in-bay TN concentrations;
- examination of relationships between monthly TN concentrations and chlorophyll *a* concentrations;
- examination of relationships between annual TN concentrations and chlorophyll *a* concentrations; and
- application of a reference period approach to establishing TN concentration-based criteria.

Since the previously proposed TN criteria are expressed as loads, the simplest method to propose criteria expressed as in-bay concentrations would be based on the potential relationships between in-bay TN concentrations and TN loads delivered to each segment. All four mainstem segments have annual TMDL TN target loads recognized by both EPA and DEP. If significant relationships were found between the nutrient loads and their respective in-bay concentrations, then the proposed numeric nutrient criteria could be expressed as concentrations.

Monthly segment-specific TN concentrations were merged with monthly segment-specific TN loads resulting in a dataset of monthly values of TN concentrations and loads. Plots of these data were inspected, with TN concentrations as functions of TN loads, including various lag and cumulative load effects.

No relationships were found between TN concentrations and potential TN load explanatory variables that explained more than 20% of the variation in TN concentrations in Hillsborough Bay or more than 10% of the variation in concentrations in the other three bay segments. This suggests that there are some in-bay processes (e.g., sedimentation, denitrification, and transport within the bay and exchange with the Gulf of Mexico) that affect the relationship between the TN loads and the resultant in-bay TN concentrations.

The results of these analyses did not provide adequate evidence to support recommendations for TN concentration criteria based on the relationships between the in-bay nutrient concentrations and the nutrient loads to those segments.

The next method used in evaluation of potential TN concentration criteria was to examine potential relationships between monthly TN concentrations and monthly chlorophyll *a* concentrations in each segment. Given the existing chlorophyll *a* targets and associated FDEP chlorophyll *a* thresholds in each segment, sufficiently predictive relationships between nutrient and chlorophyll a concentrations would allow derivation of TN concentration criteria commensurate with the threshold values.

No relationships were found between chlorophyll *a* and TN concentrations that explained more than 24% of the variation in chlorophyll *a* concentrations.

The third method evaluated was to examine relationships between annual mean chlorophyll *a* and annual mean TN concentrations as a potential means of developing nutrient criteria. The annual mean TN concentrations were classified according to whether the annual chlorophyll *a* threshold in a given segment was met or not. Based on this classification, the TN concentrations for those years in which the threshold was met could be compared to those TN concentrations for those years when the threshold was exceeded.

The results of this analysis indicated that on an annual basis, there are apparent differences in the in-bay TN concentrations during years in which the threshold chlorophyll *a* targets are met and those in which they are not met. This is particularly the case in Hillsborough Bay and Middle Tampa Bay. These findings indicate that establishment of nutrient criteria should be linked to the annual chlorophyll *a* and loading targets already established for Tampa Bay.

The fourth approach to developing concentration-based numeric nutrient criteria was the reference period approach. Segment-specific chlorophyll *a* targets (values at this level or below indicate desirable conditions) have been previously established (Janicki and Wade, 1996). These targets were based on the 1992-1994 reference period. In 2000, a protocol for assessing whether the Tampa Bay segments were achieving these targets was developed (Janicki et al., 2000). This protocol, referred to as the Decision Matrix approach, considered the year-to-year variability in chlorophyll *a* concentrations and arrived at segment-specific chlorophyll *a* thresholds (values above this level indicate undesirable conditions). The threshold was the sum of the chlorophyll *a* target and 2X the standard error of the long-term chlorophyll *a* concentrations. FDEP has adopted these thresholds to assess compliance with the Tampa Bay Reasonable Assurance.

Applying the reference period approach to deriving concentration-based numeric nutrient criteria also considered the effects of year-to-year variability, similar to that included in the development of the segment-specific chlorophyll *a* targets and thresholds discussed above.

The 1992-1994 segment-specific annual geometric mean TN concentrations are provided below, with the standard deviation based on the 1992-2009 period:

Segment	Geometric Mean	Standard Deviation
• Old Tampa Bay	0.75 mg/L	0.18 mg/L
• Hillsborough Bay	0.82 mg/L	0.19 mg/L
• Middle Tampa Bay	0.69 mg/L	0.18 mg/L
• Lower Tampa Bay	0.57 mg/L	0.17 mg/L

The proposed alternative concentration-based TN criteria (Table 1-1) are defined as the sum of the annual geometric mean concentration and the standard deviation of the long-term mean annual TN concentrations.

Table 1-1. TBEP estuarine numeric nutrient criteria for TN expressed as concentrations.	
Segment	**TN Concentration (mg/L)**
Old Tampa Bay	0.93
Hillsborough Bay	1.01
Middle Tampa Bay	0.87
Lower Tampa Bay	0.74

The proposed TN concentration criteria are compared to the observed geometric mean annual TN concentrations in Figures 1-1 through 1-4. The green horizontal lines represent the proposed alternative criteria; the data to the right of the vertical lines depict the TN concentrations since the reference period (1992-1994).

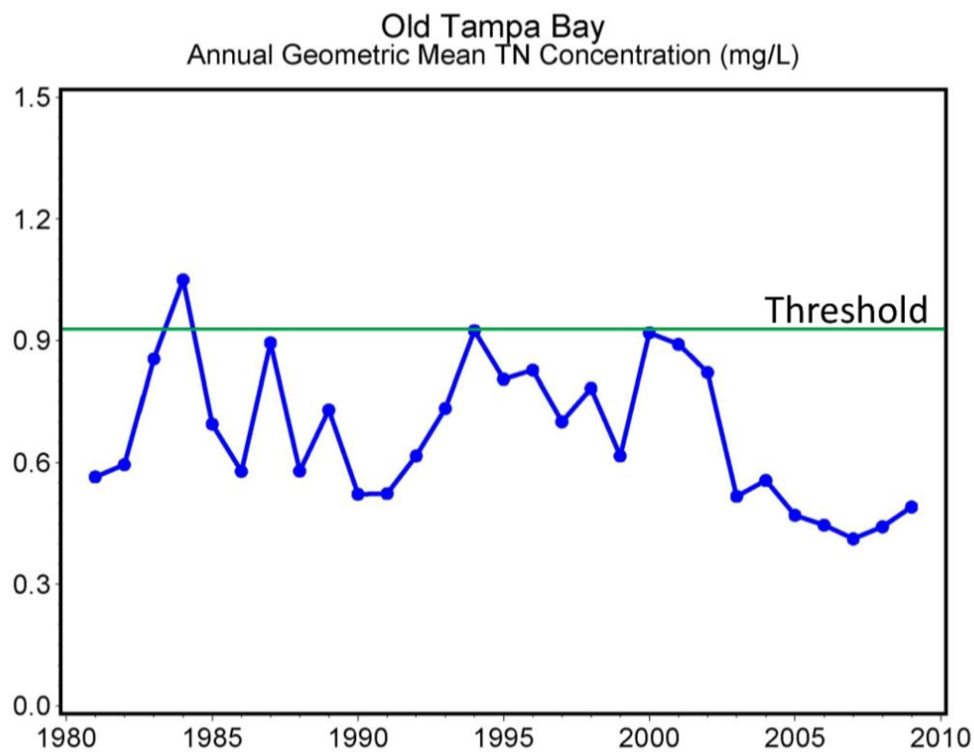

Figure 1-1. Comparison of proposed alternative TN concentration criterion for Old Tampa Bay to the annual geometric mean TN concentrations from 1981 through 2009.

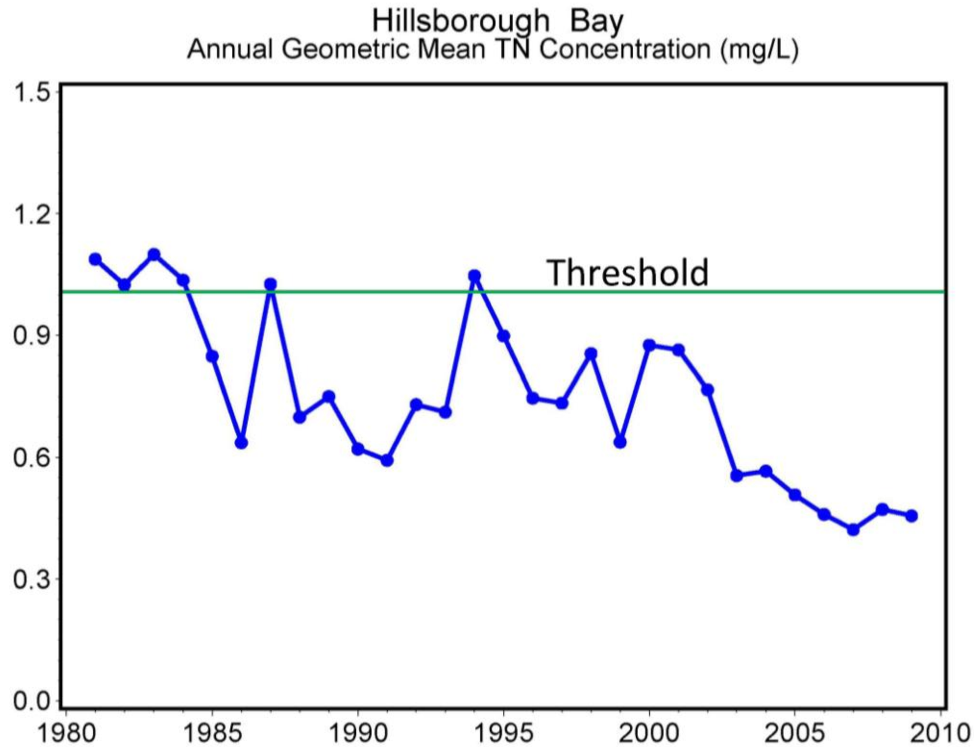

Figure 1-2. Comparison of proposed alternative TN concentration criterion for Hillsborough Bay to the annual geometric mean TN concentrations from 1981 through 2009.

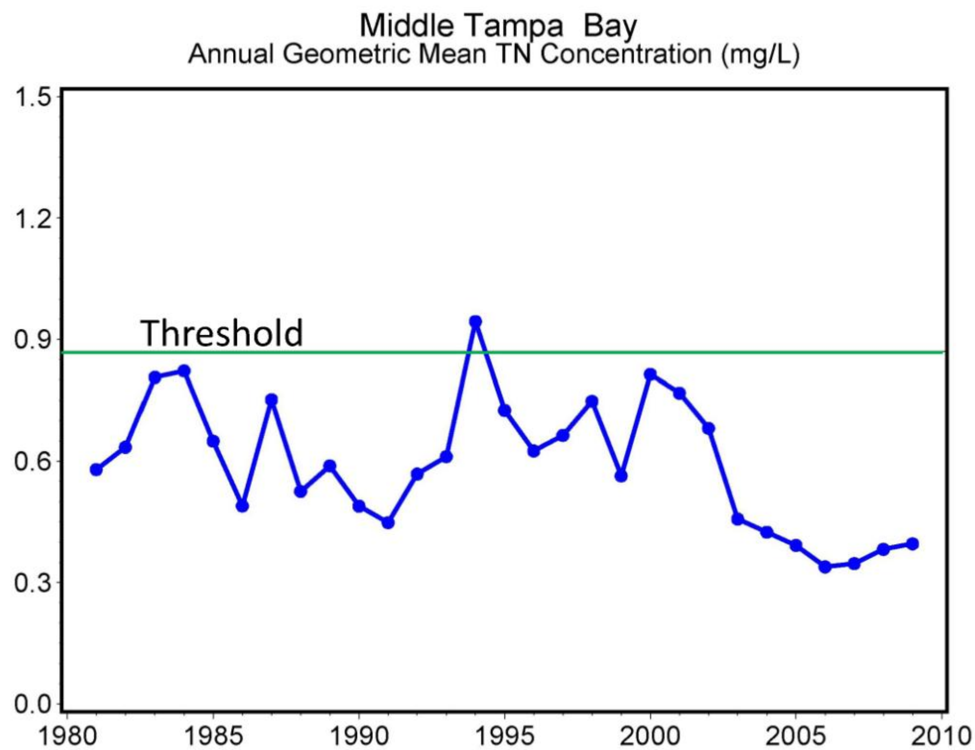

Figure 1-3. Comparison of proposed alternative TN concentration criterion for Middle Tampa Bay to the annual geometric mean TN concentrations from 1980 through 2009.

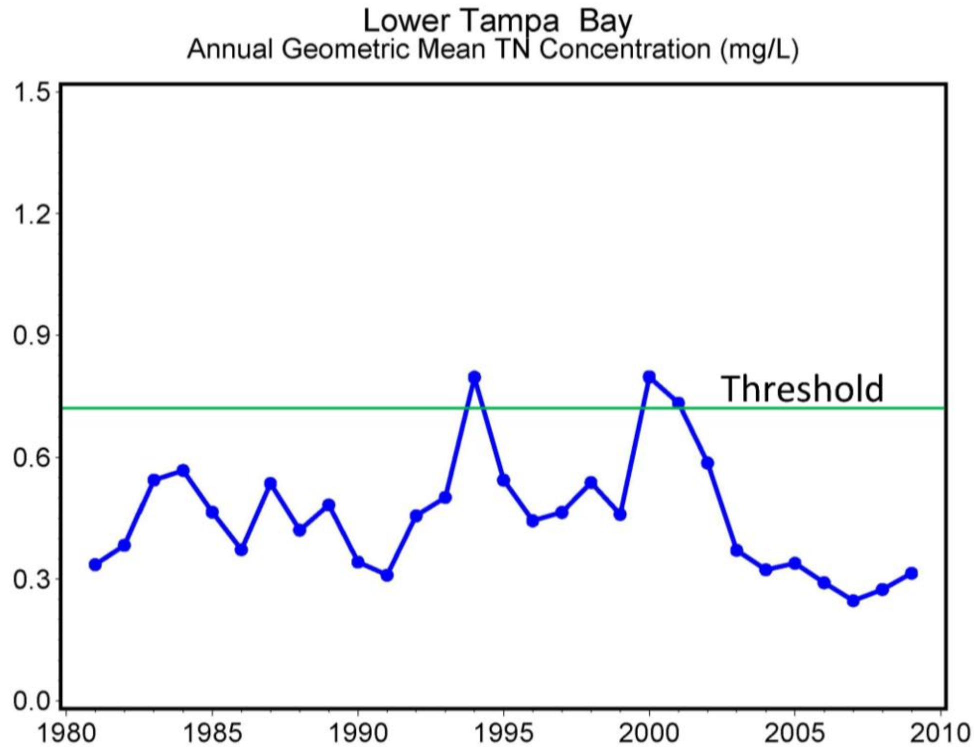

Figure 1-4. Comparison of proposed alternative TN concentration criterion for Lower Tampa Bay to the annual geometric mean TN concentrations from 1980 through 2009.

2.0 TP Load and Concentration Alternative/Supplementary Criteria

The 1992-1994 average annual total nitrogen loads were established as the appropriate nitrogen load management targets by TBEP partners in order to support the maintenance of the chlorophyll *a* and light attenuation targets developed for each of Tampa Bay's major bay segments. The TN loading threshold criteria were defined as the segment-specific Nitrogen Delivery Ratio based on the mean 1992-1994 conditions. In keeping with this approach, the TP loading target and TP loading threshold criteria are defined as the segment-specific Phosphorus Delivery Ratio based on the mean 1992-1994 conditions. The TP loading targets and loading threshold criteria expressed as the Phosphorus Delivery Ratio are provided in Table 2-1. Time series plots of annual Phosphorus Deliver Ratio to the threshold are provided in Figures 1-5 through 1-8, indicating that the threshold value has been exceeded infrequently during the recent (2000 on) period.

Table 2-1. TBEP estuarine numeric nutrient criteria for TP target loads and threshold criteria expressed as the Phosphorus Delivery Ratio.

Segment	TP Load Target (tons/yr)	TP Load Threshold Expressed as Phosphorus Delivery Ratio (tons/million m^3)
Old Tampa Bay	104	0.23
Hillsborough Bay	1093	1.28
Middle Tampa Bay	140	0.24
Lower Tampa Bay	112	0.14

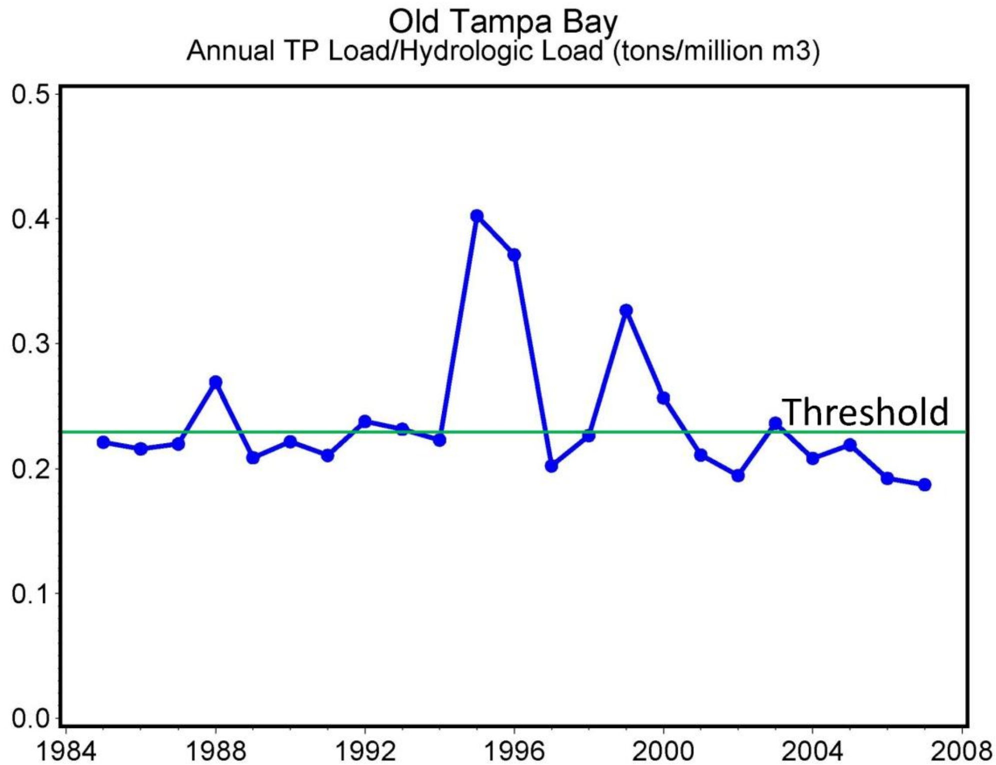

Figure 2-1. Comparison of annual Phosphorus Delivery Ratio to proposed TP loading threshold criteria for Old Tampa Bay.

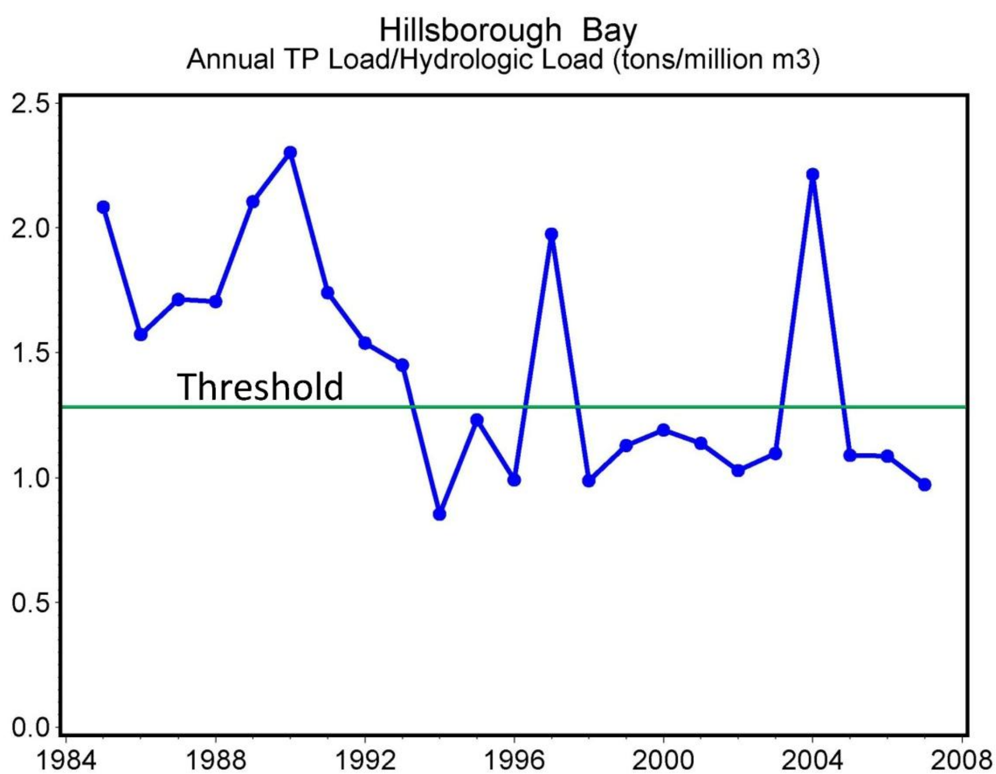

Figure 2-2. Comparison of annual Phosphorus Delivery Ratio to proposed TP loading threshold criteria for Hillsborough Bay.

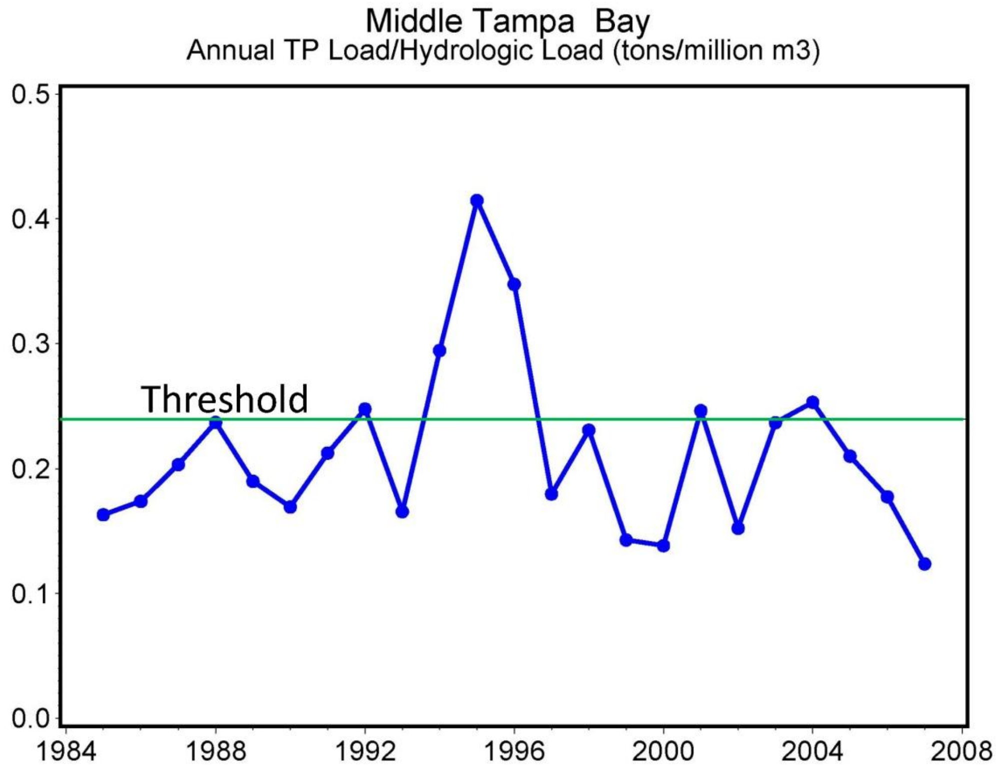

Figure 2-3. Comparison of annual Phosphorus Delivery Ratio to proposed TP loading threshold criteria for Middle Tampa Bay.

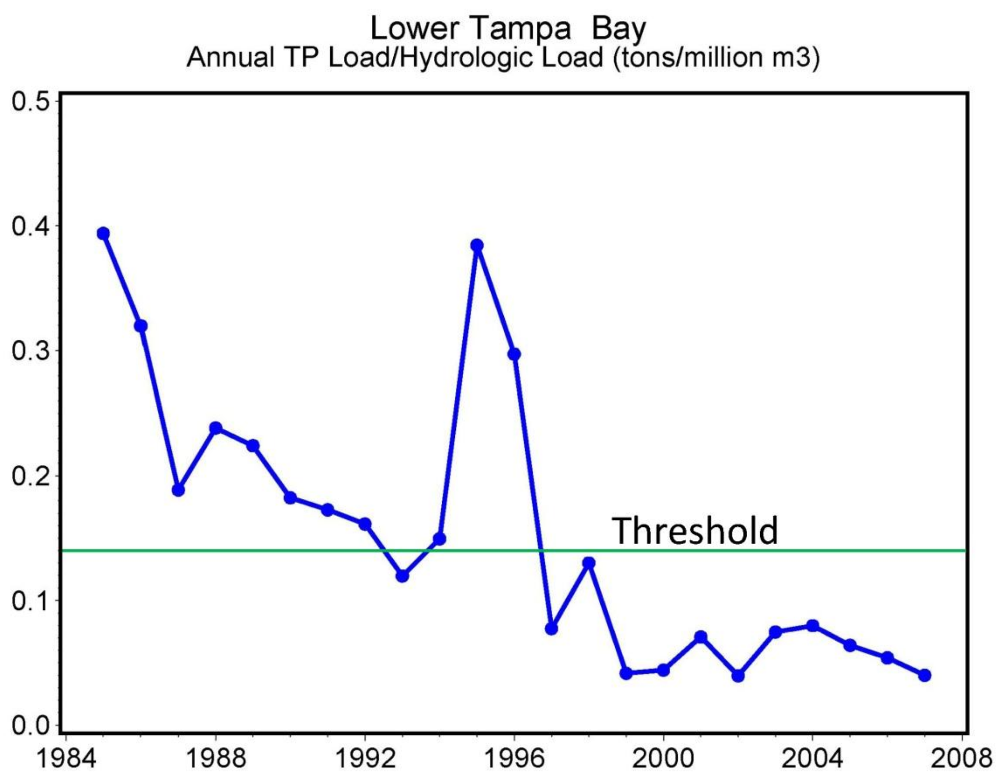

Figure 2-4. Comparison of annual Phosphorus Delivery Ratio to proposed TP loading threshold criteria for Lower Tampa Bay.

In the same manner as described above for development of the TN criteria in terms of concentrations, evaluation of TP concentration criteria was completed. As for the TN concentration methodology, the most appropriate method was determined to be the Reference Period approach, in keeping with the existing TN loading targets and proposed threshold criteria, the proposed TN concentration criteria, and the proposed TP loading targets and threshold criteria.

The 1992-1994 segment-specific annual geometric mean TP concentrations are provided below, with the standard deviation based on the 1992-2009 period:

Segment	Geometric Mean	Standard Deviation
• Old Tampa Bay	0.25 mg/L	0.06 mg/L
• Hillsborough Bay	0.37 mg/L	0.08 mg/L
• Middle Tampa Bay	0.24 mg/L	0.05 mg/L
• Lower Tampa Bay	0.08 mg/L	0.02 mg/L

The proposed alternative concentration-based TP criteria (Table 2-2) are defined as the sum of the annual geometric mean concentration and the standard deviation of the long-term mean annual TP concentrations.

Table 2-2. TBEP estuarine numeric nutrient criteria for TP expressed as concentrations.

Segment	TP Concentration (mg/L)
Old Tampa Bay	0.31
Hillsborough Bay	0.45
Middle Tampa Bay	0.29
Lower Tampa Bay	0.10

The proposed TP concentration criteria are compared to the observed geometric mean annual TP concentrations in Figures 2-5 through 2-8. The green horizontal lines represent the proposed criteria. As seen in these graphics, the proposed TP concentration criteria have been met in most years in all segments since the early 1990s.

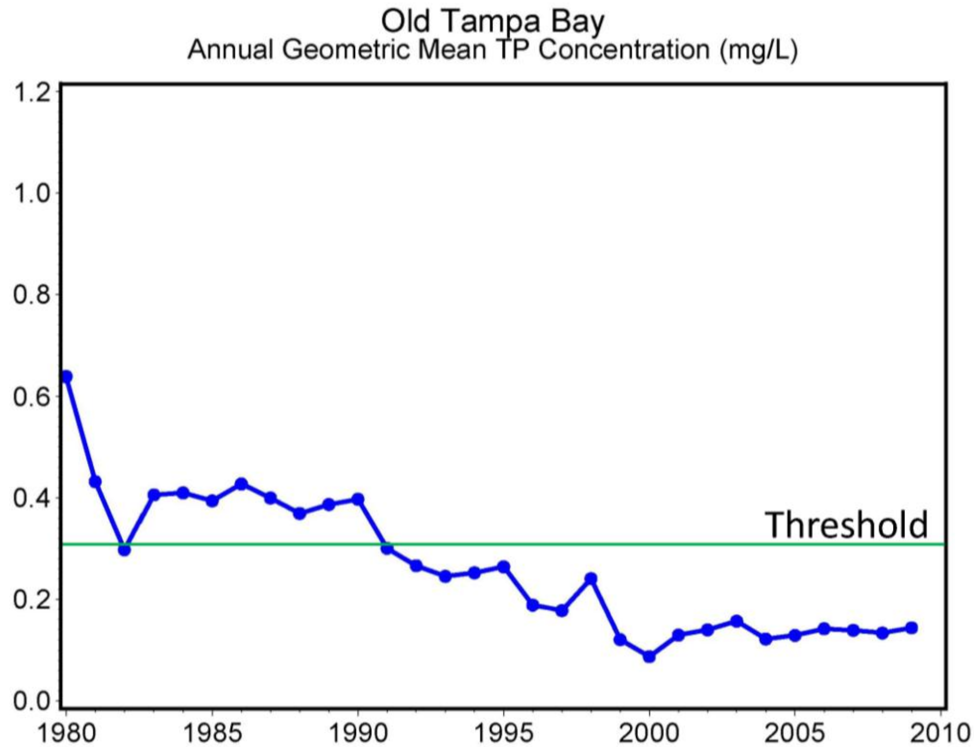

Figure 2-5. Comparison of proposed TP concentration criterion for Old Tampa Bay to the annual geometric mean TP concentrations from 1980 through 2009.

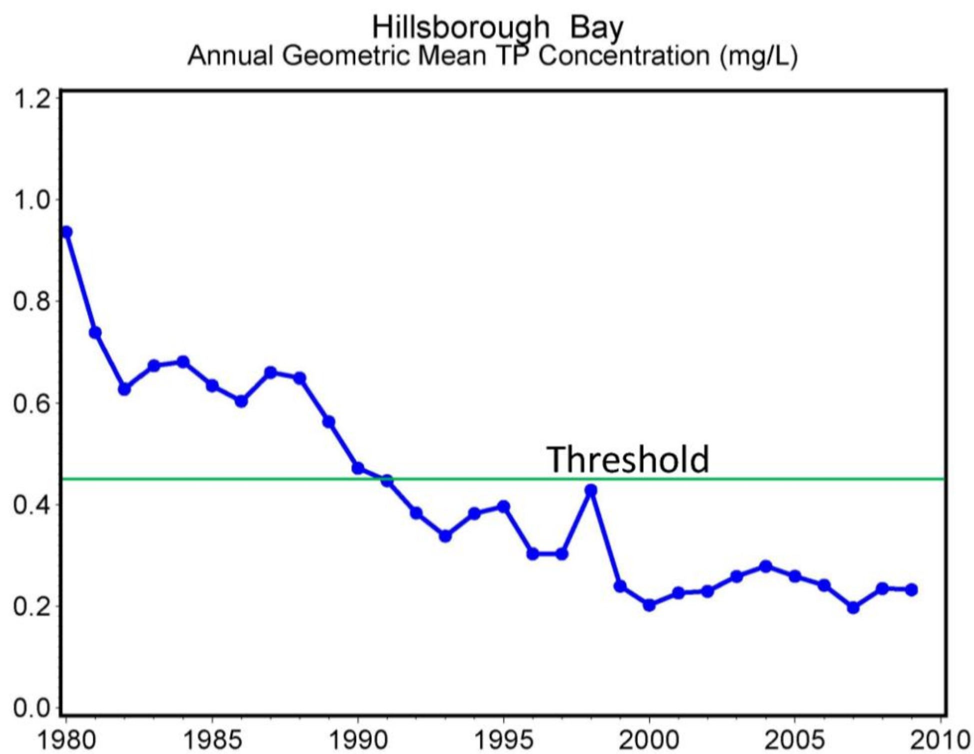

Figure 2-6. Comparison of proposed TP concentration criterion for Hillsborough Bay to the annual geometric mean TP concentrations from 1980 through 2009.

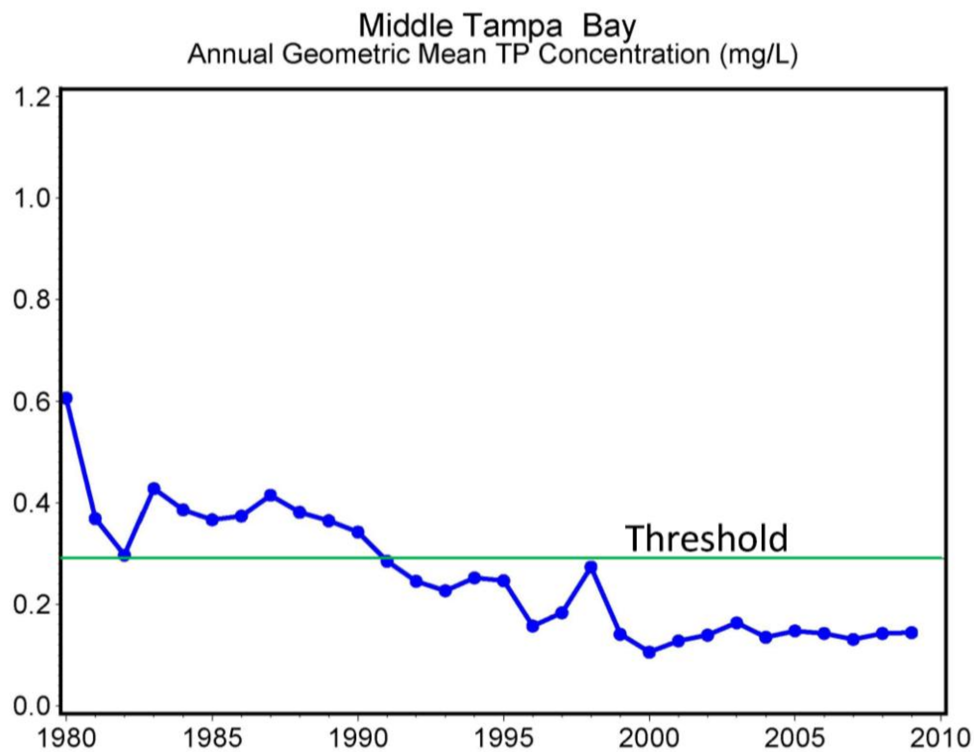

Figure 2-7. Comparison of proposed TP concentration criterion for Middle Tampa Bay to the annual geometric mean TP concentrations from 1980 through 2009.

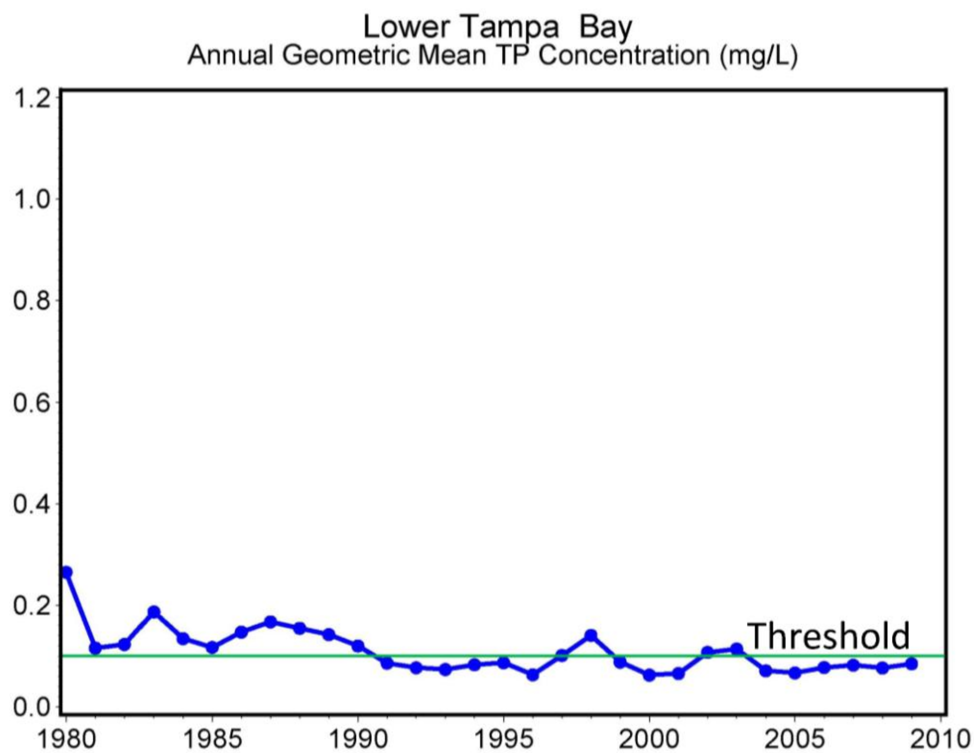

Figure 2-8. Comparison of proposed TP concentration criterion for Lower Tampa Bay to the annual geometric mean TP concentrations from 1980 through 2009.

APPENDIX C.
Comparison of Annual TN Loads to Annual Hydrologic Loads: Nitrogen Delivery Ratio

A comparison of the annual TN loads to annual hydrologic loads for each bay segment between 1995 and 2007 is shown graphically in Figures 1-4 below. The vertical axis is the annual TN load, and the horizontal axis is the annual hydrologic load. The slanted blue line represents the loads corresponding to those expected using the 1994-1994 Nitrogen Delivery Ratio, in terms of tons TN/year per million m^3 hydrologic load/year. Points falling below the line represent those years when the Nitrogen Delivery Ratio was less than that observed during the 1992-1994 period. Points above the blue line in each graphic denote years when the loads would be in excess of the thresholds. The Hillsborough Bay threshold as denoted by the Nitrogen Delivery Ratio was exceeded in 2004 and 2006, and the Lower Tampa Bay threshold was exceeded in 1998. In all the remaining years for those bay segments, and in all years during the 1995-2007 period for Middle Tampa Bay and Old Tampa Bay, the Nitrogen Delivery Ratios were below the threshold.

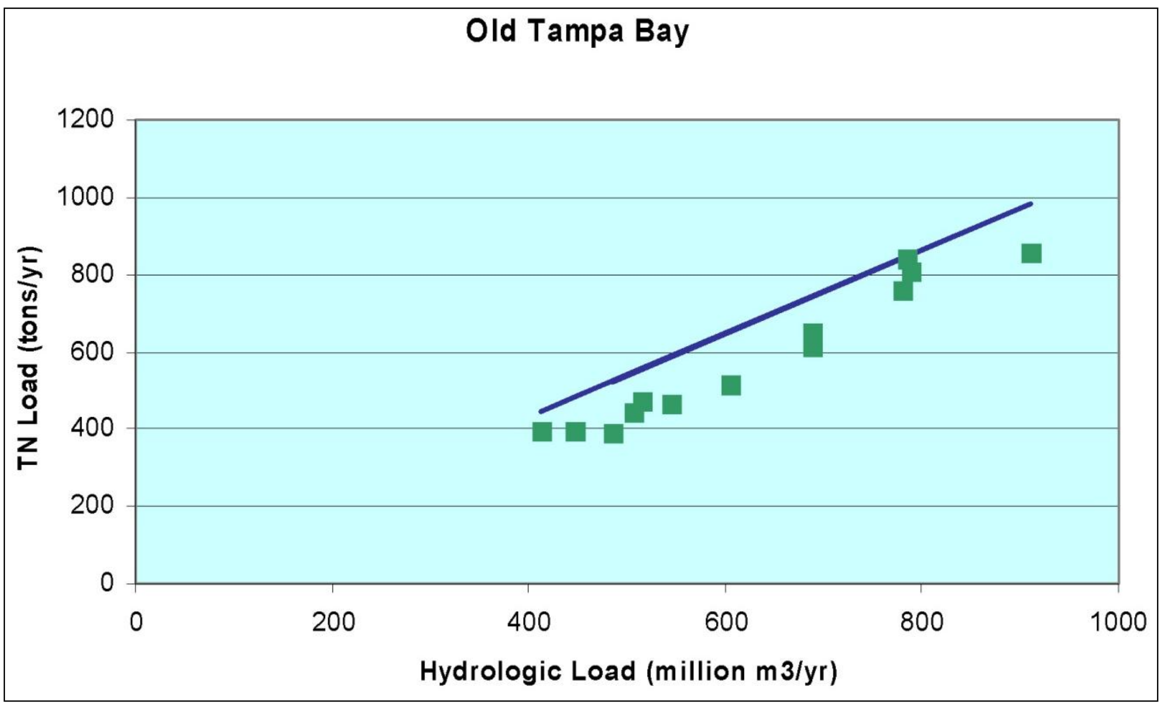

Figure 1. Relationship between annual TN load and annual hydrologic load in Old Tampa Bay for 1995-2007. The slanted blue line is what the expected relationship would be given the Nitrogen Delivery Ratio of 1.08 tons TN load/million m^3 hydrologic load from the 1992-1994 period.

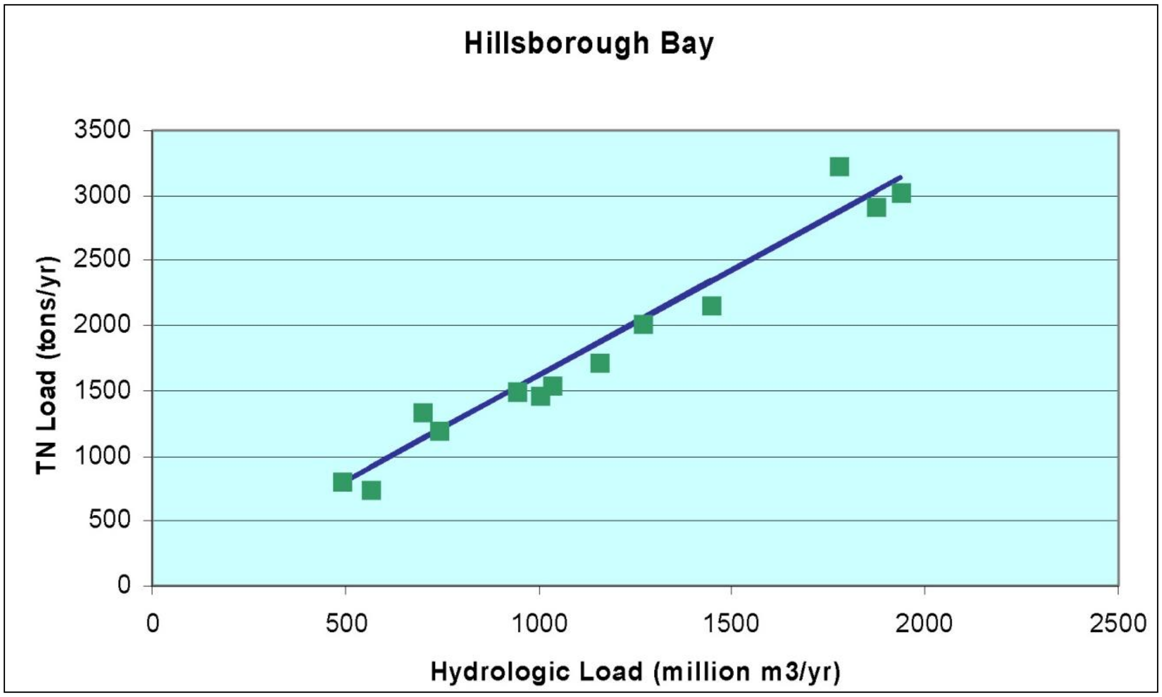

Figure 2. Relationship between annual TN load and annual hydrologic load in Hillsborough Bay for 1995-2007. The slanted blue line is what the expected relationship would be given the Nitrogen Delivery Ratio of 1.62 tons TN load/million m^3 hydrologic load from the 1992-1994 period.

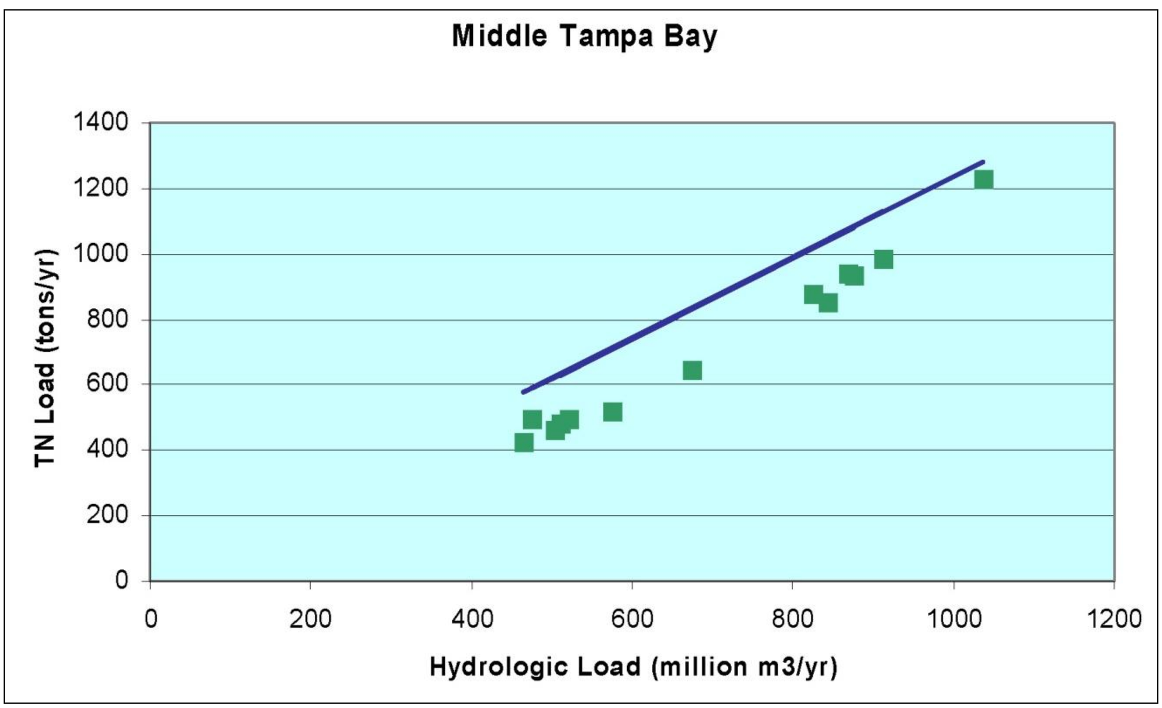

Figure 3. Relationship between annual TN load and annual hydrologic load in Middle Tampa Bay for 1995-2007. The slanted blue line is what the expected relationship would be given the Nitrogen Delivery Ratio of 1.24 tons TN load/million m^3 hydrologic load from the 1992-1994 period.

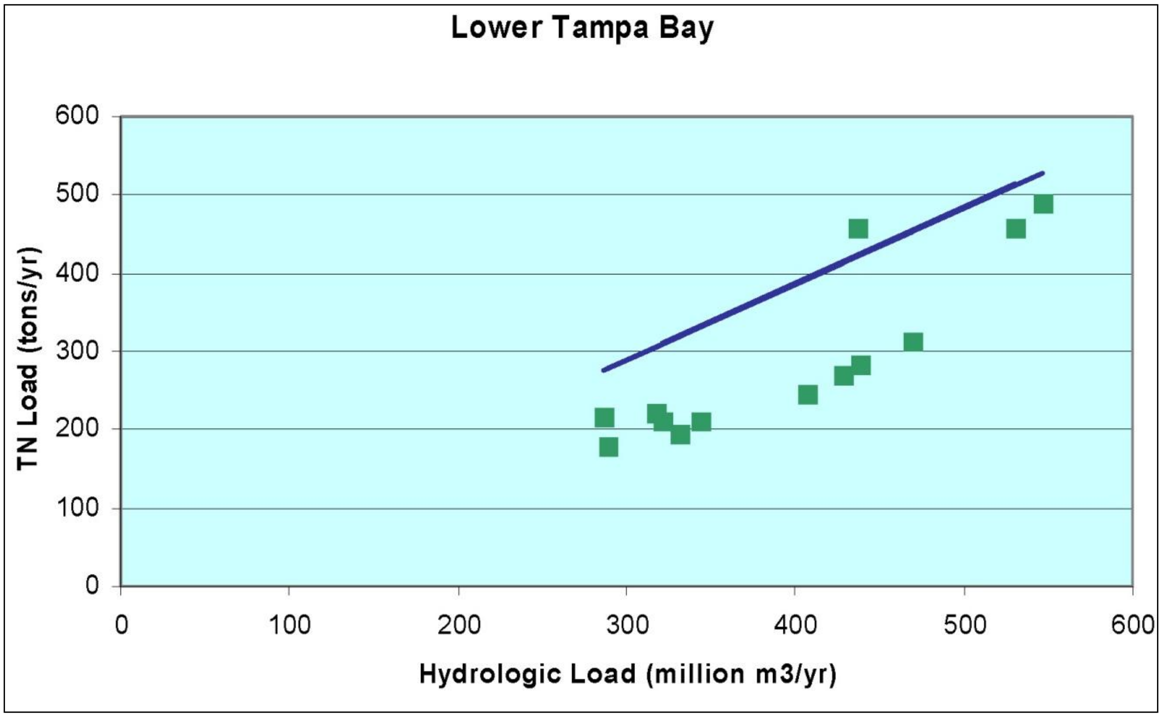

Figure 4. Relationship between annual TN load and annual hydrologic load in Lower Tampa Bay for 1995-2007. The slanted blue line is what the expected relationship would be given the Nitrogen Delivery Ratio of 0.97 tons TN load/million m^3 hydrologic load from the 1992-1994 period.

APPENDIX D.
Implementation Issues and Compliance Assessment

Background

As part of this document, site specific numeric nutrient criteria are being proposed as alternatives to the application of regional or state wide model based standards. These site specific criteria rely on the identification of a response endpoint which has been defined for Tampa Bay as chlorophyll *a* concentrations and their effect on light attenuation to seagrasses. The temporal scale has been defined as annually. The implementation of the Florida numeric nutrient criteria proposed by EPA will require the definition of an implementation and assessment cycle. Consideration of the potential ramifications of an assessment that is either too lenient or too strident is a critical element of the evaluation of alternative assessment cycles. Both EPA and FDEP are considering allowances of criteria exceedance due to natural variability. The draft freshwater numeric nutrient criteria proposed by EPA identified a 3-year assessment cycle which incorporates a "1 in 3" rule to allow one exceedance in a three-year assessment cycle to account for natural variability. The Florida Department of Environmental Protection (FDEP) currently uses a 5-year assessment cycle for evaluation of impairment in waterbodies, as well as NPDES, MS4, and other regulatory permitting cycles. FDEP was initially considering a "2 in 5" rule for compliance but has since proposed "1 in 5" as the allowable exceedance frequency.

Climate anomalies and criteria exceedances

Janicki Environmental (2011a,b,c) examined the effects of these different temporal assessment schemes on the likelihood of concluding that a waterbody was in exceedance based solely on natural meteorological variability and concluded that the 2 in 5 rule would be most appropriate to allow for natural variability due to climatological anomalies and yet remain sensitive to detecting a deviation in water quality due to anthropogenic activities. The investigation was based on a conceptual model expressed by the EPA that the regulatory compliance assessment cycle should allow for natural disturbance patterns resulting from episodic events in Florida. These events could include hurricanes and ENSO-related droughts and floods that influence water quality independent of anthropogenic effects. The relationship between these events and water quality has been substantiated in several southwest Florida estuaries. (e.g. Morrison et al., 2006; Sherwood, 2010).

Janicki Environmental (2011c) used long-term stream flow records to characterize natural variability in the hydrologic conditions in Tampa Bay since the 1930s. This estimate of natural variability was then used to test two potential temporal assessment schemes with respect to their ability to account for natural variability and identify exceedances related to anthropogenic activities. Since the objective of the rule is to account for exceedances due to natural environmental variability, the analysis suggested that a "2 in 5" rule is more likely to absorb natural variability than the "1 in 3" rule. Based on these analyses, the "1 in 3" rule would result in more exceedances due to natural variability alone and, therefore, be overly sensitive to non-anthropogenic variability compared to the "2 in 5" rule. For example, it is easy to see in Figure 1 that when El Niño or La Niña events occur they tend to last more than a single year. In fact, it's quite possible for many of the single events to cross a calendar year. Further information on the frequency and duration of ENSO events can be found at: http://www.esrl.noaa.gov/psd/enso/mei/

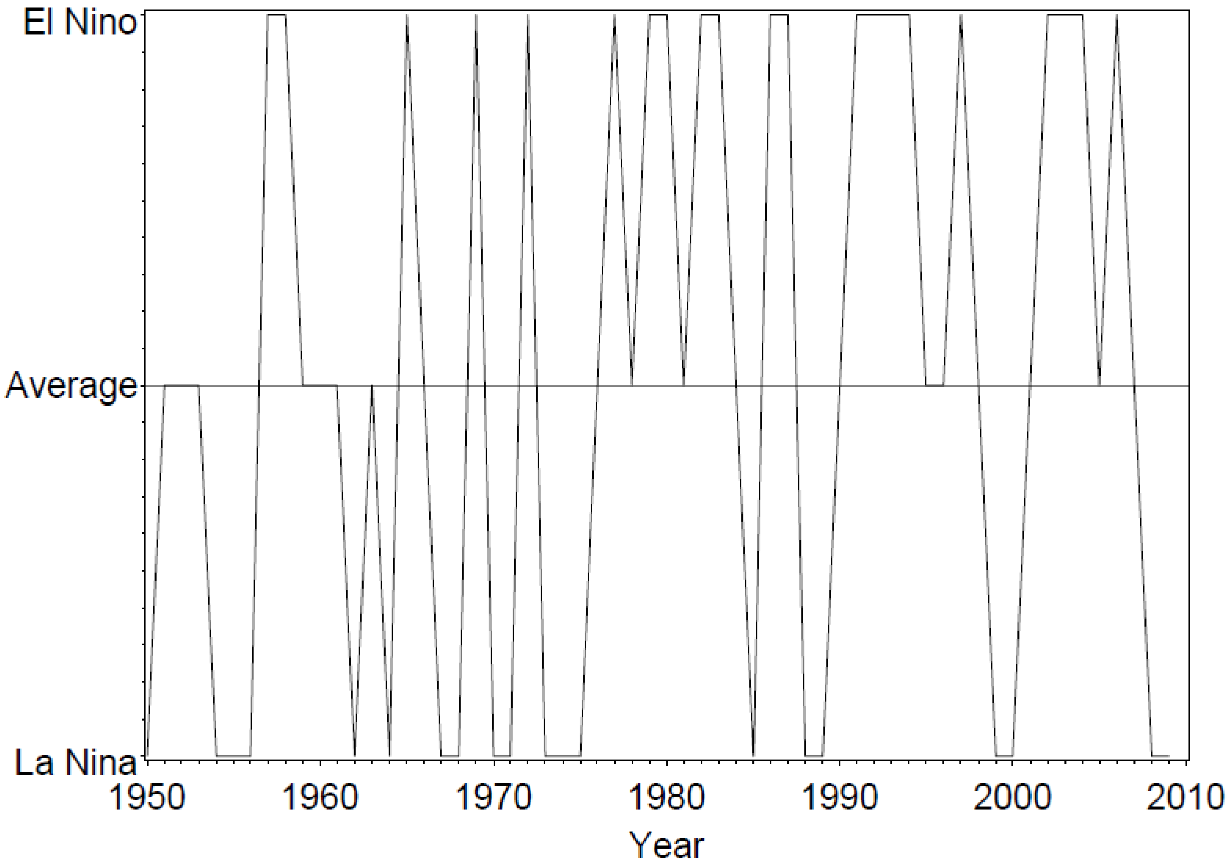

Figure 1. Classification of El Niño and La Niña events as described in Janicki Environmental 2011a.

FDEP is also considering allowances for the misclassification of an impairment due to sampling variability. This type of misclassification is called the "Type 1 error" of "False Positive Rate". The type 1 error rate is defined when establishing targets and threshold values using any estimate of a population of water quality data with variability. Such is the case with many of the estuaries that are developing criteria based on the reference period approach. An example of that discussion follows.

Type 1 Error and the Reference Period Approach

To begin this example, a hypothetical reference period distribution of chlorophyll a concentrations was generated. Chlorophyll *a* concentrations in estuaries typically exhibit "lognormal" distribution characteristics. This implies that when a natural log transformation is applied to the distribution, it becomes normally distributed which conforms to most parametric statistical tests. Therefore, a lognormal distribution of chlorophyll *a* concentrations was simulated using a mean of 6.75 μg/L and a standard deviation of 4.49 μg/L. This distribution composed of 10000 observations is shown in Figure 2. Once the data are natural log transformed, the distribution becomes bell shaped corresponding to the normal distribution (Figure 2). Since FDEP and EPA have proposed using annual geometric means as regulatory statistics for parameters with lognormal distributions such as chlorophyll *a,* we now consider the log transformed values to represent the data underlying this hypothetical evaluation and back transform the averages to obtain the geometric means.

Given the theoretical distribution of Figure 3, we can generate annual averages to simulate the product of a typical monitoring program. For example, we can randomly select 12 observations from the distribution of log values, and calculate an average and back transform that average to obtain the geometric mean. Further, we can repeat this experiment many times, each time selecting 12 samples and calculating the average of the log values. We expect each average to be close to the overall average of the reference period since it is a random sub-sample, however, we know that variability will exist due to sampling. For example, in Figure 4, we have generated 100 annual averages from the reference period distribution. As can be seen in Figure 4, the distribution of annual averages is centered on a value very close to the overall average in Figure 3 which is expected.

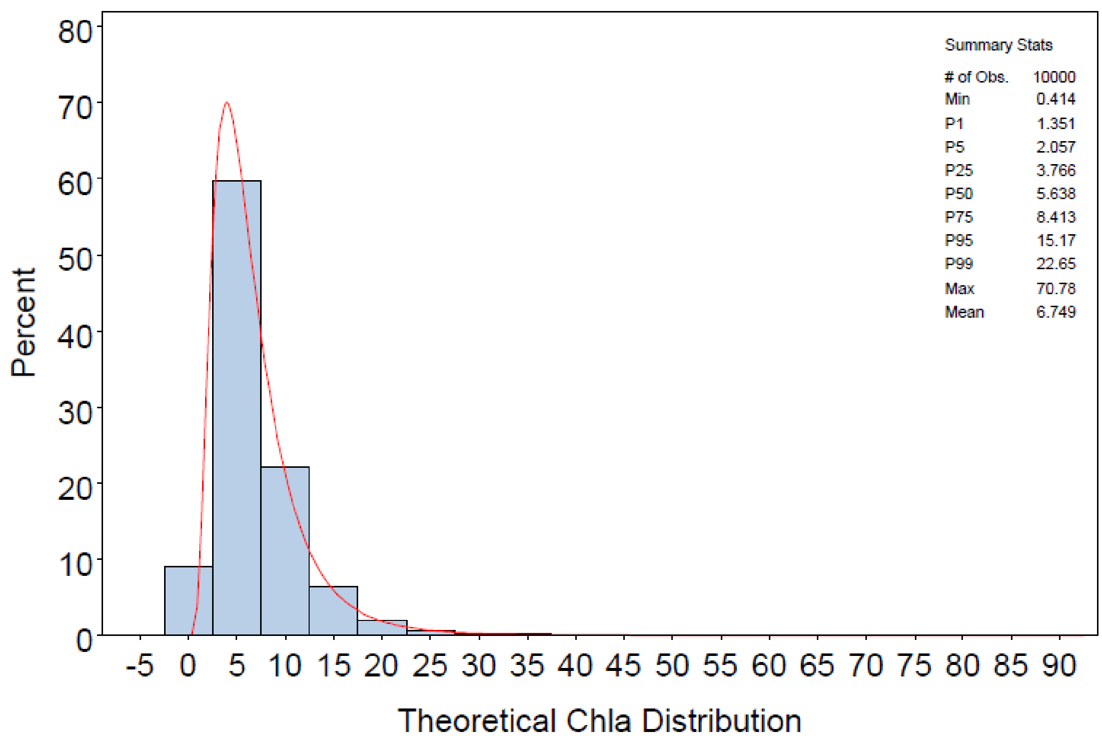

Figure 2. Simulated distribution of chlorophyll *a* concentrations.

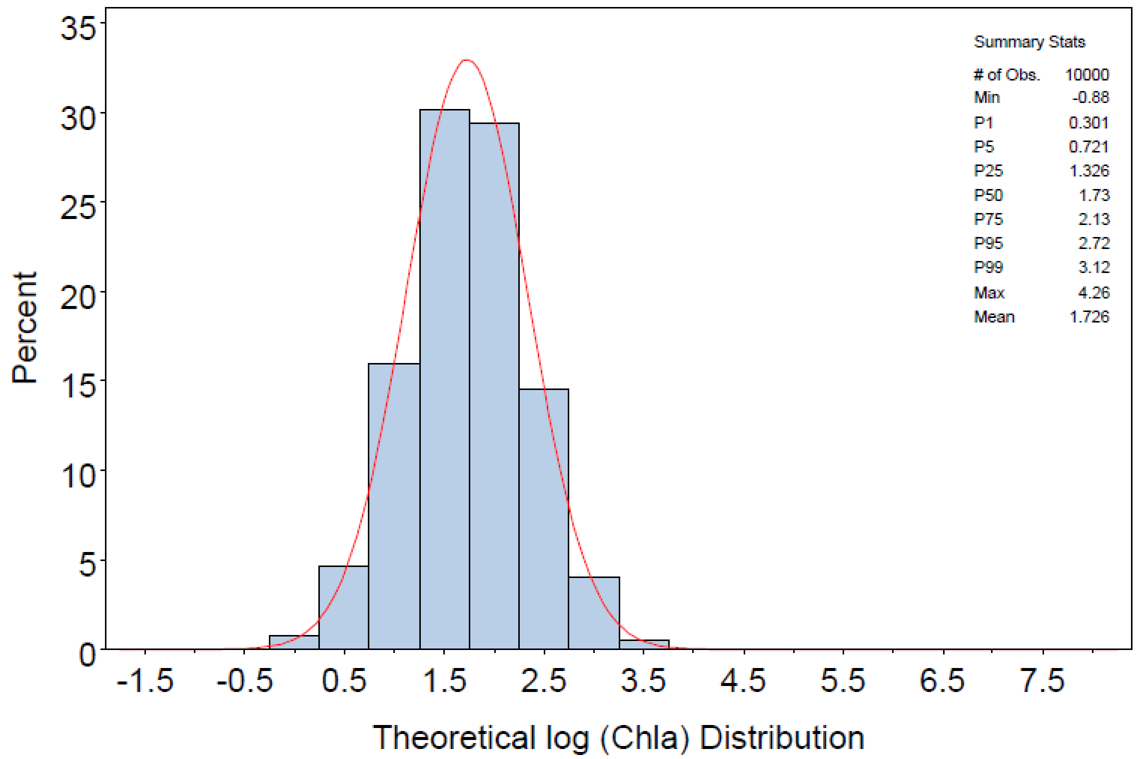

Figure 3. Distribution of the natural log transformed values of the simulated distribution above.

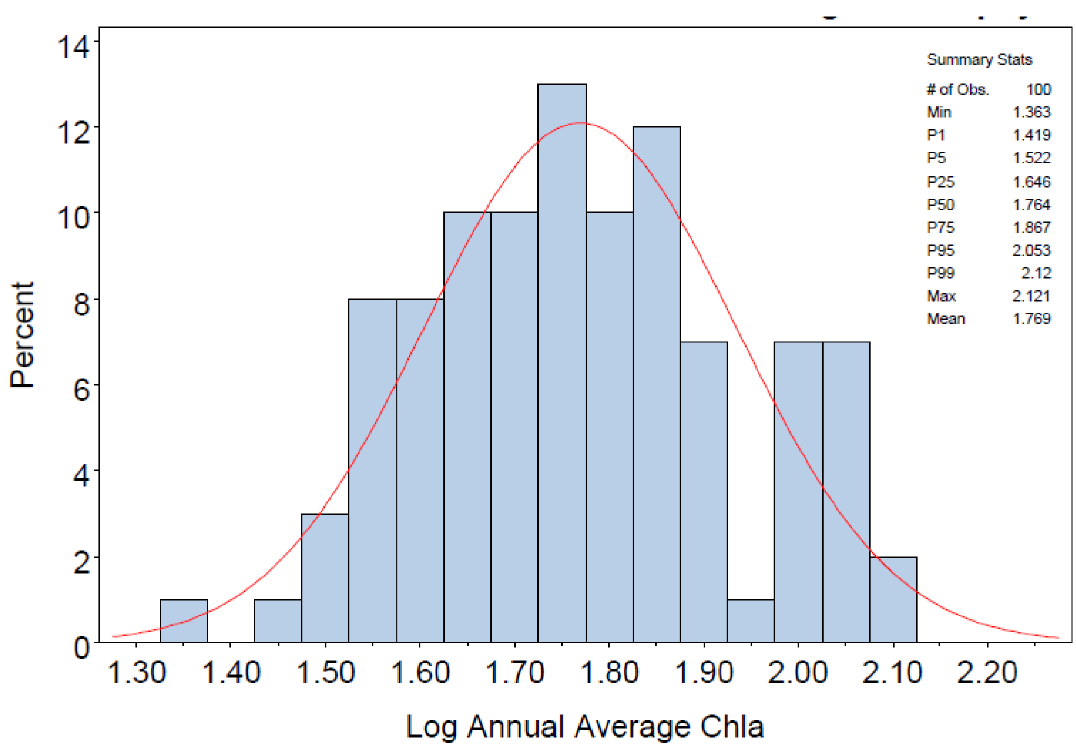

Figure 4. Distribution of 100 annual averages of the log transformed chlorophyll values using 12 samples per year.

To derive the geometric annual averages, we simply back transform the annual averages of Figure 3. This distribution is shown in Figure 5.

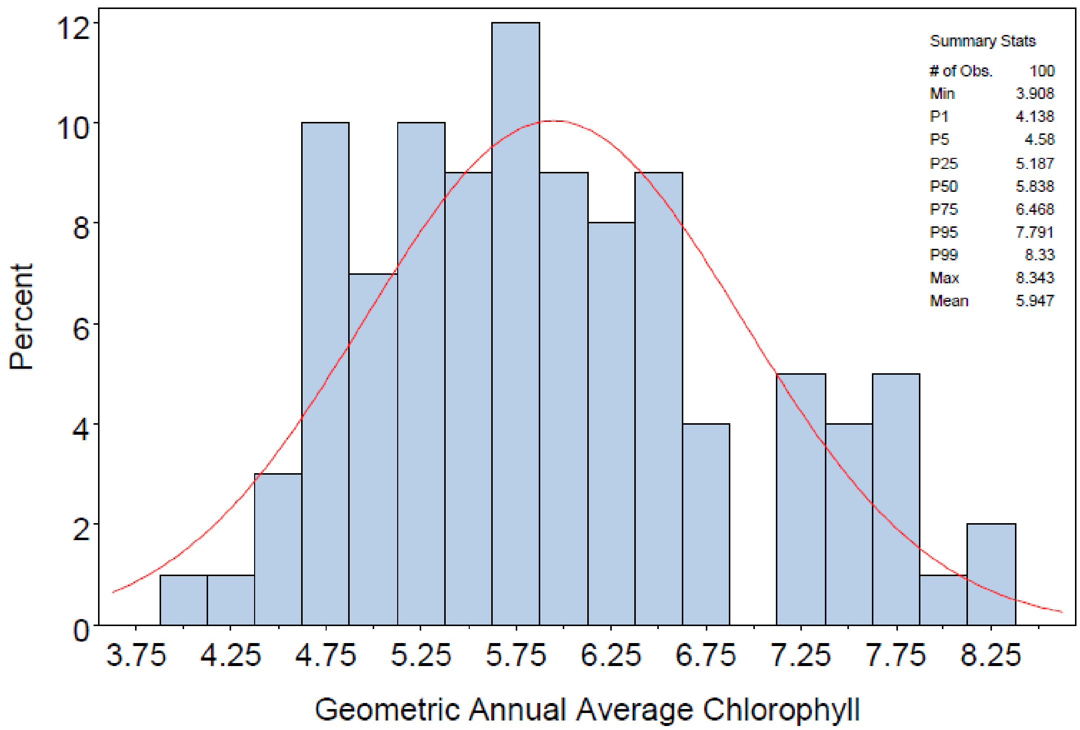

Figure 5. Geometric means taken from the simulated chlorophyll concentrations above.

Targets and Thresholds

Once the geometric means have been calculated we have all the information necessary to develop **targets** and **thresholds** for this theoretical reference period distribution.

The **reference period target** for this distribution can be defined as the overall average of all the geometric means. That is, 5.947 μg/L is our goal for the water body to ensure that it remains similar to the reference period condition we identified as being indicative of full aquatic life support. However, it can be seen from Figure 4 that the distribution of annual geometric means for this population ranges between 3.9 μg/L and 8.3 μg/L. Therefore, the distribution of geometric means can be considered a population of values that represent the expected distribution of annual averages of the reference period. Based on normal distribution theory, we can assign a **threshold** value to represent an annual average above which we would reject the hypothesis that the value was from the same population as the reference period distribution of annual geometric means. Using the z table of standard statistical tests, only 5% of a normal distribution with a mean and standard deviation of the distribution in Figure 4 would lie above the mean+1.65*the standard deviation of the population of geometric means. Therefore, a **threshold** can be constructed for this distribution that defines with 95% confidence what value a given geometric mean would need to exceed to reject the hypothesis that it belonged to the reference period distribution. For this distribution that **threshold** value equals 7.59 μg/L.

The threshold value provides a level of certainty that a future single geometric mean value (i.e. a sample) is not declared to exceed the reference distribution simply due to sampling. As was demonstrated above, we know that some portion of the reference distribution values will be above the **target** value. In fact, nearly 50% of the annual geometric means will be higher than the **target**. However, only 5% of the values will be higher than the **threshold** value of 7.59 μg/L due to chance. This construct defines what is known as the **Type I error rate** or False Positive rate**.** That is, we are willing to accept that 1 in 20 times we may get a value that is higher than 7.59 μg/L that still belongs to the reference period distribution. As was seen in Figure 5, 5% of the values did exceed 7.59 μg/L even though we know the entire population of values.

Therefore, the type I error rate is a value that is selected based on judgment and while 5% is typically used, there is no definitive rationale for 5% versus 1% or 10%. If we wish to be more conservative, we would select a lower type I error rate by choosing a larger value (e.g., 1.96) to multiple against the standard deviation to minimize the potential for falsely declaring that a value was different from the reference distribution. If we have reason to believe that the water body may not fully meet its designated use at values at the higher end of the reference distribution, one could select a higher type I error rate which in turn would equate to a smaller z score to multiply by the standard deviation (e.g., 1). For example, selecting 1 standard deviation equates to a type 1 error rate of 16%. Therefore, the type 1 error rate does obviously have implications on the compliance assessment that also need to be accounted for.

Recommendations

Based on this analysis, it makes sense to allow for the potential that an anomalous event could result in higher annual geometric average than the reference period threshold value in more than one year in a 5 year cycle as is currently proposed by FDEP.

Therefore, the recommended allowance as an exceedance frequency in a five year assessment cycle is to allow for no more than 2 exceedances in a 5 year assessment cycle.

It is possible that the type I error rate and the probability of an anomalous event could be estimated such that both the probability of an exceedance occurring by chance and the probability that an exceedance occurs due to anomalous conditions could be integrated. That is, over a 5 year cycle one might calculate the probability of either an exceedance due to chance or an exceedance due to a natural anomaly. This was beyond the scope of this memorandum but one that might be pursued as the implementation process is refined. Because the proposed criteria are based on threshold values with known type 1 error rates, the criteria and the 2 in 5 year implementation criteria are inextricably linked and should not be separated. Further information supporting the use of the 2 in 5 implementation rule is provided in Janicki Environmental (2011a,b,c).

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APPENDIX E.
Maps of EPCHC Monitoring Sites Utilized for Water Quality Assessment in Each Segment

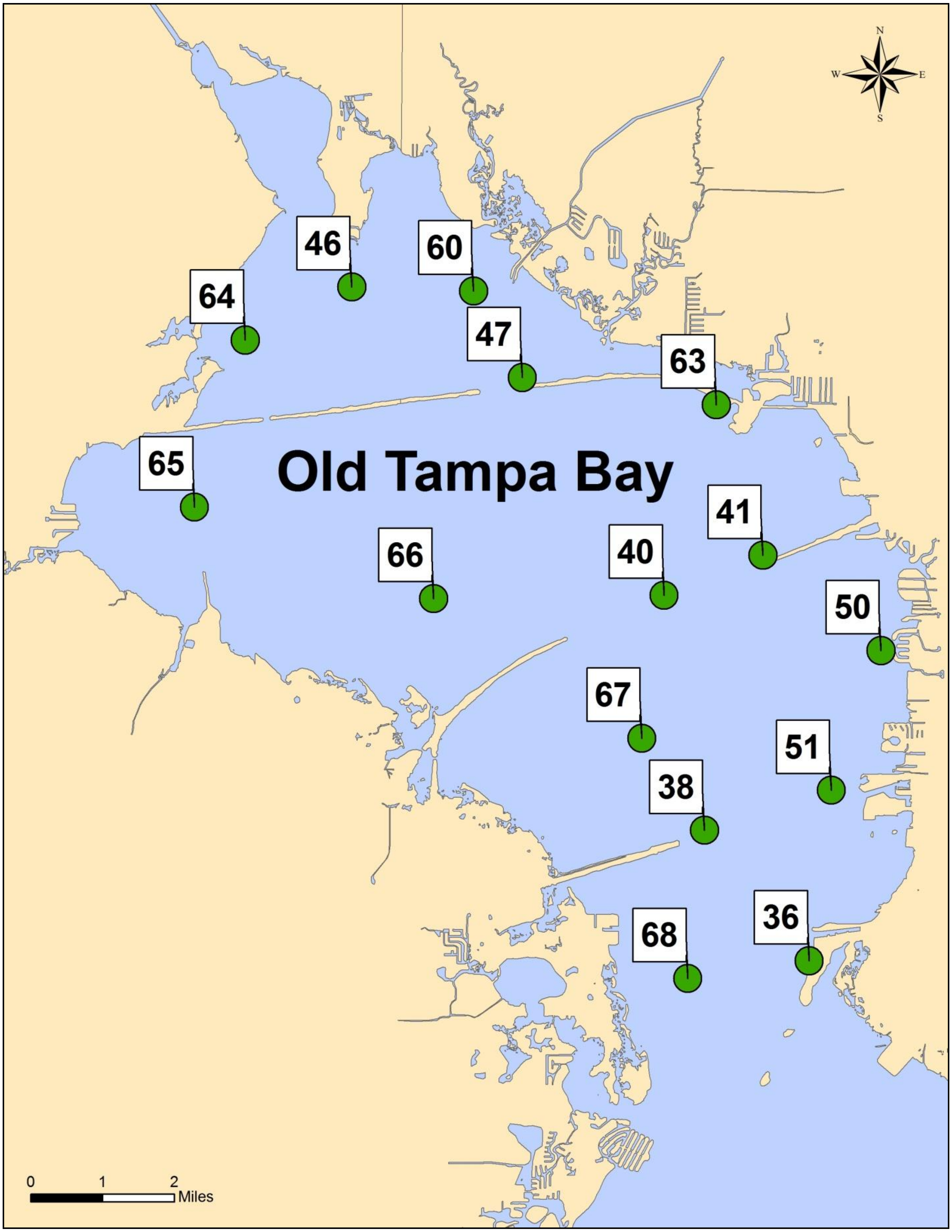

Figure 1. EPCHC sites used for assessment of water quality conditions in Old Tampa Bay.

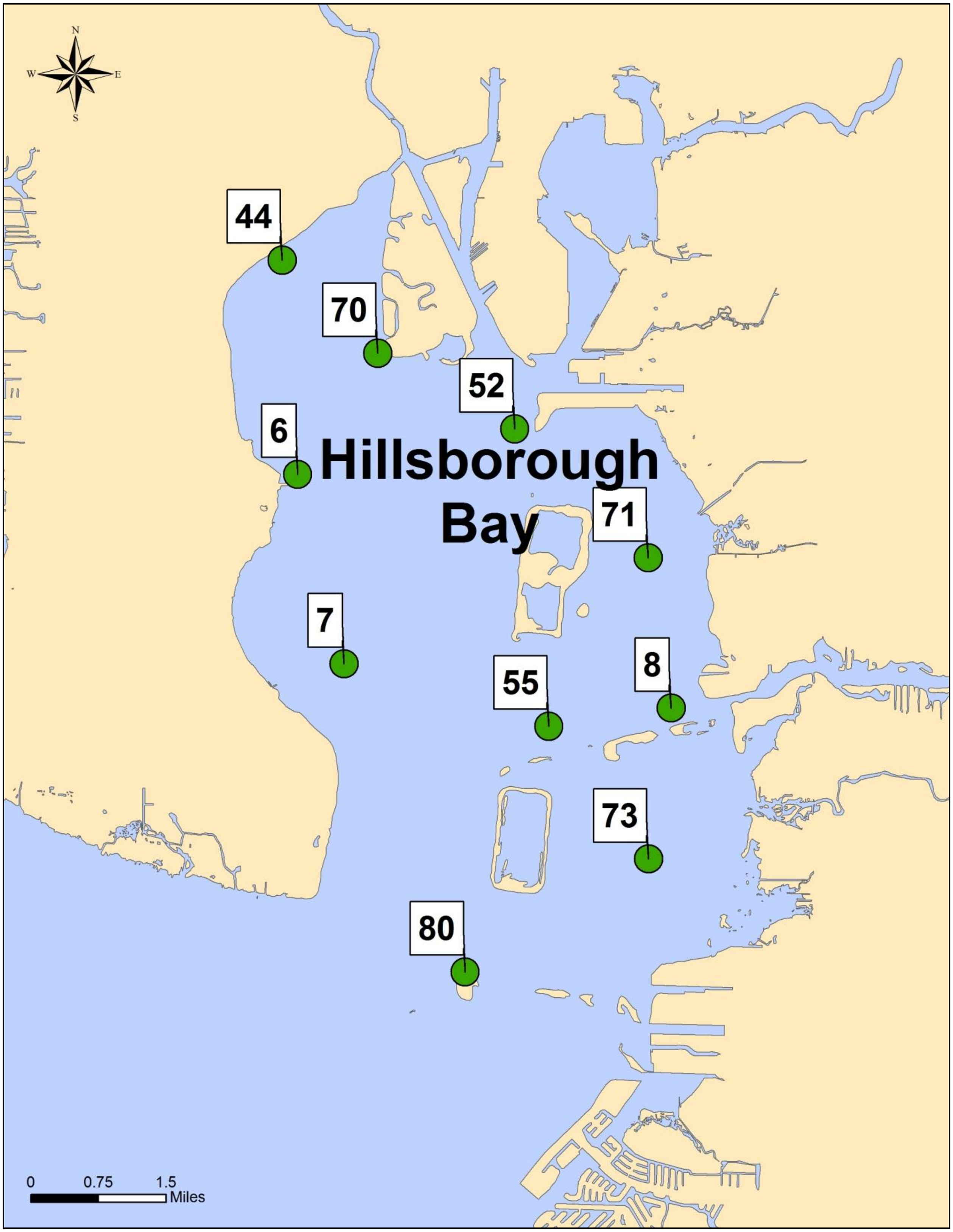

Figure 2. EPCHC sites used for assessment of water quality conditions in Hillsborough Bay.

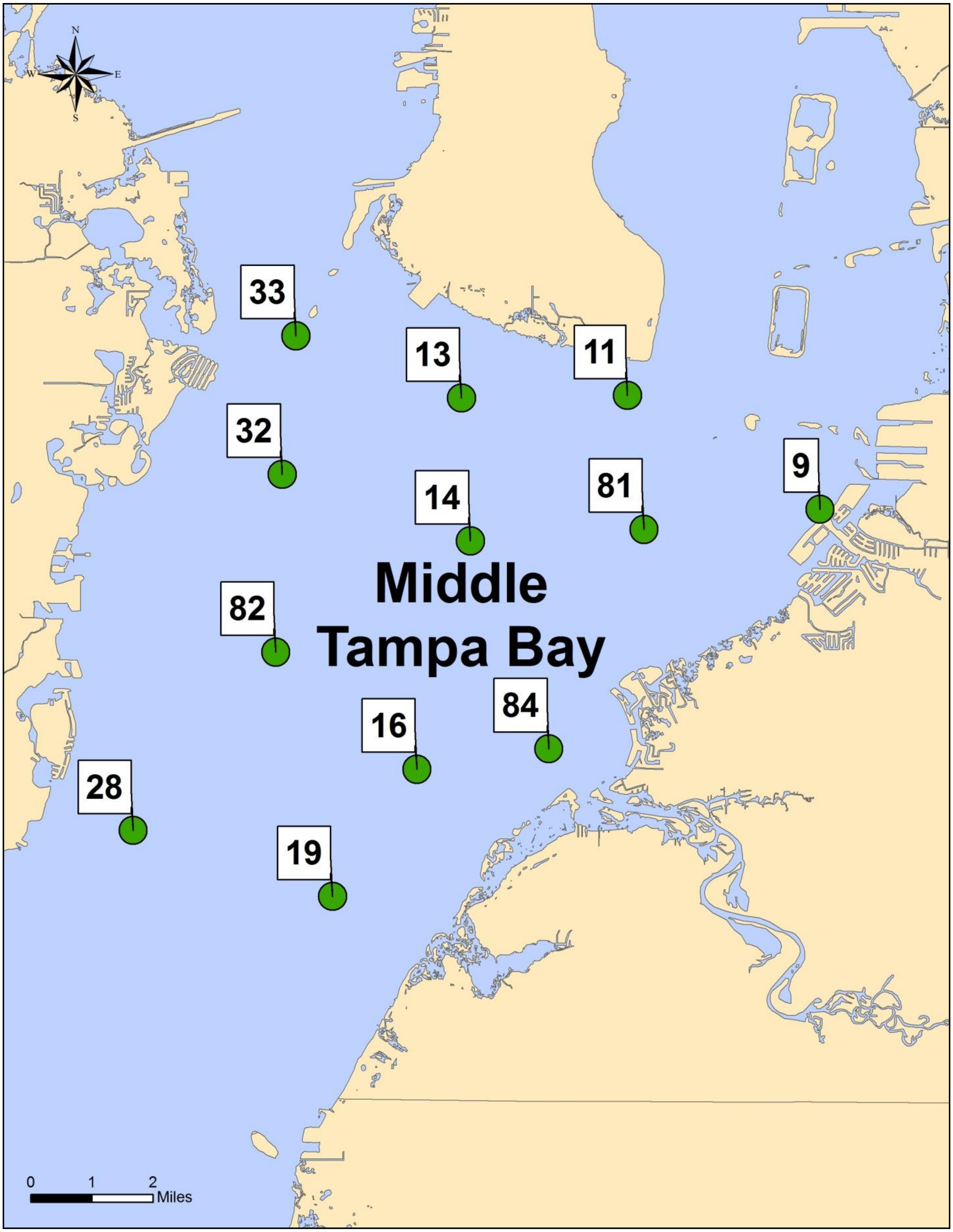

Figure 3. EPCHC sites used for assessment of water quality conditions in Middle Tampa Bay.

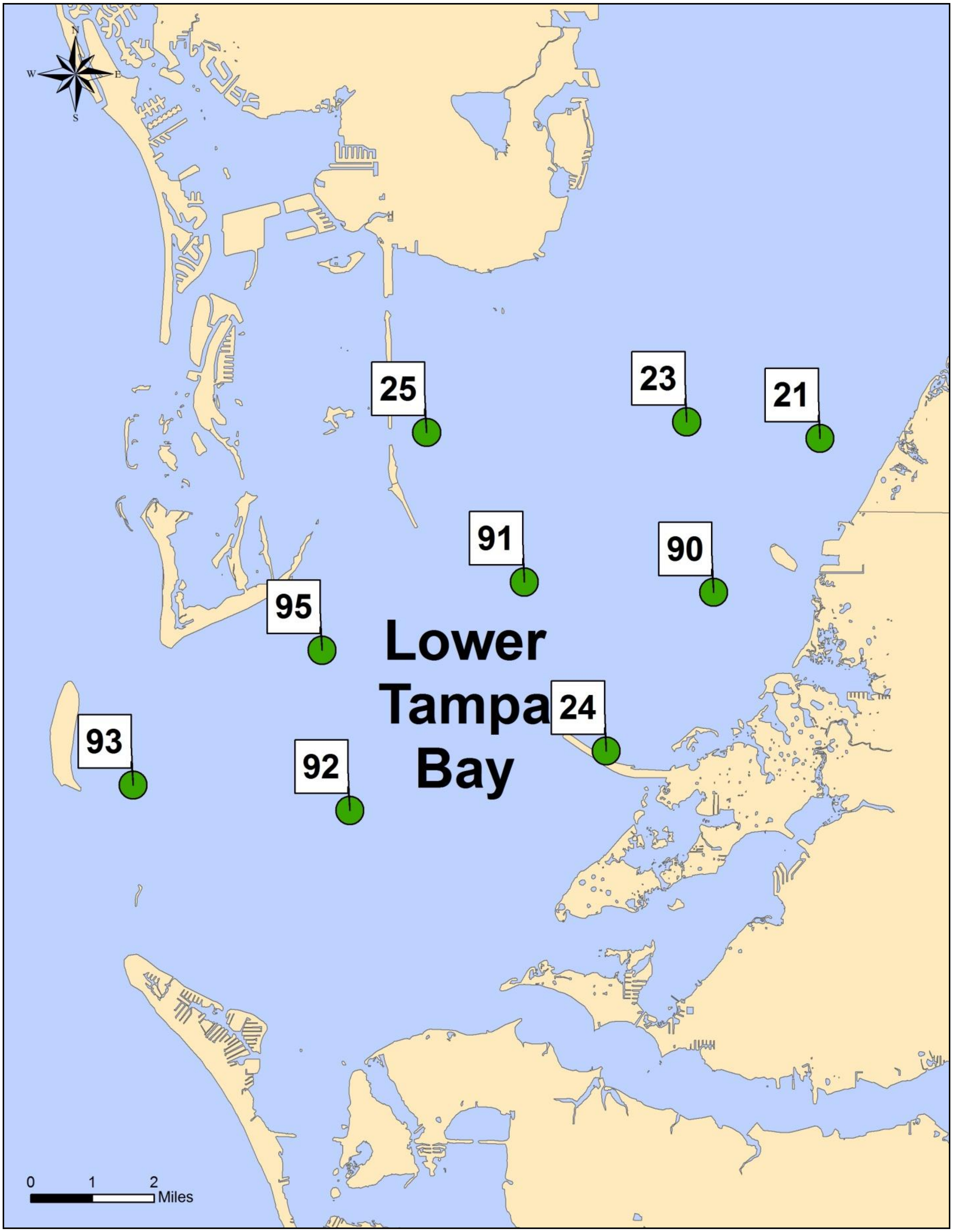

Figure 4. EPCHC sites used for assessment of water quality conditions in Lower Tampa Bay.