Development of Numeric Nutrient Criteria for Boca Ciega Bay, Terra Ceia Bay, and Manatee River, Florida

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FOREWORD

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ACKNOWLEDGEMENTS

We wish to thank the Partners of the Tampa Bay Estuary Program and members of the Tampa Bay Nitrogen Management Consortium for the numerous conversations providing direction and insight into concerns regarding numeric nutrient criteria establishment and appropriate methodology for developing the proposed criteria. Ms. Holly Greening and Mr. Ed Sherwood (Tampa Bay Estuary Program), Ms. Kris Kaufman (Southwest Florida Water Management District), Ms. Kelli Hammer-Levy (Pinellas County), and Mr. Rob Brown (Manatee County) were particularly helpful in their insights to this issue. Funding for this work was provided by SWFWMD's Hillsborough Basin Board.

1.0 Introduction

In this section, pertinent background information pertaining to the development of numeric nutrient criteria and the objectives of the work order are discussed.

1.1 Background

The Florida Department of Environmental Protection (FDEP) began development of numeric nutrient standards in December 2001. The FDEP formed a technical advisory committee and an agency work group to assist in identifying appropriate nutrient standards. FDEP conducted a number of workshops and meetings as well as several studies that were conducted since 2002.

In 2008, several environmental groups filed suit against the U. S. Environmental Protection Agency (EPA) in Federal Court alleging that EPA had determined in 1998 that Florida's current narrative nutrient standard did not comply with the Clean Water Act and that EPA had not established numeric nutrient standards pursuant to Section 303(c)(4)(B) of the Clean Water Act. As a consequence of this lawsuit, EPA sent FDEP a letter on January 14, 2009 finding that FDEP's narrative nutrient standard did not comply with the Clean Water Act and directing the State of Florida to develop its own numeric nutrient standards for rivers and lakes by January 2010 and estuarine and coastal waters by January 2011 or EPA would adopt its own nutrient standards. In August 2009, these groups and EPA agreed to a Consent Decree formally establishing these deadlines with EPA responsible for establishing these criteria.

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. As part of the RA process, the Boca Ciega Bay segment was divided into the a southern portion which exchanges primarily with Lower Tampa Bay and a northern portion which exchanges primarily with the Gulf of Mexico through several passes. In order to be consistent with the analyses conduct for the RA, the Boca Ciega Bay segment has been divided in two for the purposes of numeric nutrient criteria development.

The TBEP and the TBNMC have recommended numeric nutrient criteria to EPA for the four main stem segments of the bay (Tampa Bay Nitrogen Management Consortium, 2010). These criteria are specific to the bay segments of Tampa Bay and are expressed as annual TN loads. Despite the commonly held view that phosphorus is not limiting in Tampa Bay, criteria for TP loads have also been recommended to EPA. EPA has noted its intention to express the numeric nutrient criteria for Tampa Bay as TN and TP concentrations. Therefore, segment-specific TN and TP concentrations were developed (Janicki Environmental, 2010a). This is in keeping with recognition of the importance of maintaining consistency with existing management goals and specifically with the recent load allocations to comply with the existing TMDL for Tampa Bay.

1.2 Objective

The overall objective of this work effort was to provide support to the TBEP in development of chlorophyll *a* targets and commensurate total nitrogen (TN) loading and concentration criteria for Boca Ciega Bay, Terra Ceia Bay, and Manatee River (Figure 1-1). There were three objectives:

- propose chlorophyll *a* targets and thresholds,
- develop empirical relationships between chlorophyll *a*, light and nutrients, and
- propose TN loading- and concentration-based criteria.

Figure 1-1. Location of Boca Ciega Bay, Terra Ceia Bay and Manatee River segments and their watersheds.

2.0 Data Analysis

In this section, nutrient limitation and the approach and rationale used to develop numeric nutrient criteria are discussed, along with the available data that were used and finally the recommended approach.

2.1 Nutrient Limitation

The establishment of numeric nutrient criteria depends upon knowledge of the nutrient most likely limiting in the waterbodies of concern. Marine systems, including estuaries, are generally considered nitrogen limited (Thomas, 1970a,b; Ryther and Dunstan, 1971; Boynton et al., 1982; Smith, 1984; Howarth, 1988, 2008; Howarth et al., 1988a,b; Nixon et al., 1996; Howarth and Marino, 2006; Chapra, 1997; National Research Council, 2000;), although there may be times and locations when phosphorus limitation may occur (Conley, 2000; Conley et al., 2009; Malone et al., 1996). Nutrient limitation in Tampa Bay has been examined using both the N:P ratio method and nutrient addition bioassays.

Using the N:P ratio method, nutrient limitation was previously analyzed for the main bay segments of Tampa Bay (Janicki Environmental, 2010a). All segments except Lower Tampa Bay have molar N:P ratios less than 10:1, while that for Lower Tampa Bay is just slightly greater than 10:1. According to the FDEP guidelines (FDEP, 2002), a system is nitrogen limited if it has a molar N:P less than ten, a system with an N:P between 10 and 30 is considered co-limited, and a system with an N:P greater than 30 is phosphorus limited. According to these guidelines, all segments are considered nitrogen-limited (Janicki Environmental, 2010a). Seasonal variation in nutrient limitation has been observed in other waterbodies (Fisher et al., 1992; Lee et al., 1996; Malone et al, 1996; Conley et al., 2009). Therefore, season-specific TN:TP ratios were also previously estimated and the findings continue to support the conclusion that the four main segments of Tampa Bay are nitrogen-limited (Janicki Environmental, 2010a).

In addition to the TN:TP ratio method, nutrient addition bioassays were routinely performed by the City of Tampa Bay Study Group throughout Tampa Bay during 1993-2009 as part of the evaluation of the effects of discharge from the H.F. Curren wastewater facility (Johansson, 2009). Bioassays in late winter and late summer have been conducted for most of this period. This work was in support of the phosphorus waiver held by the City, as regulations require all point sources that discharge directly to Tampa Bay not to exceed TP concentrations of 1 mg/L. The results of these 152 bioassays have supported that nitrogen is the primary limiting nutrient in the bay, with no results showing phosphorus as the limiting nutrient in the bay, including within that portion of the bay which receives the wastewater effluent. Therefore, the discharge phosphorus limitation is not required for this facility.

Janicki Environmental (2010a) concluded that the four mainstem bay segments in Tampa Bay are nitrogen-limited. This conclusion contributed to the development of TN loading targets for Tampa Bay (Janicki and Wade, 1996), without consideration of TP loading targets in the original target setting effort.

Because nutrient bioassays have not been conducted for the segments in this study, the TN:TP ratio method was used to determine nutrient limitation for Boca Ciega Bay North, Boca Ciega Bay South, Terra Ceia Bay, and Manatee River. The findings of the TN:TP ratio analyses are presented in Table 2-1. Terra Ceia Bay and Manatee River have ratios that are less than ten and are clearly nitrogen limited. Boca Ciega Bay North and Boca Ciega Bay South have ratios that are 18.86 and 16.98, respectively, indicating that Boca Ciega Bay is likely co-limited. Additional ratios were calculated for seasonal data in order to determine if seasonal differences occur. However the analysis of seasonal TN:TP (Table 2-2) confirm the results of Table 2-1, with ratios less than ten for Terra Ceia Bay and Manatee River and ratios in the range of 16 to 19 for the sub-segments of Boca Ciega Bay.

Table 2-1. TN and TP concentrations and TN:TP by segment.

Bay Segment	TN (mg/L)	TP (mg/L)	TN:TP (Weight)	TN:TP (Molar)
Boca Ciega Bay North	0.54	0.07	8.53	18.86
Boca Ciega Bay South	0.45	0.07	7.68	16.98
Terra Ceia Bay	0.57	0.21	4.43	8.54
Manatee River	0.61	0.23	3.86	9.79

Table 2-2. Seasonal mean TN:TP ratios by segment.

Bay Segment	Dry Season		Wet Season	
	TN:TP (Weight)	TN:TP (Molar)	TN:TP (Weight)	TN:TP (Molar)
Boca Ciega Bay North	8.49	18.78	8.60	19.01
Boca Ciega Bay South	7.95	17.59	7.17	15.87
Terra Ceia Bay	4.44	9.82	4.40	9.73
Manatee River	3.92	8.67	3.75	8.29

2.2 Approach and Rationale

The Tampa Bay Comprehensive Conservation and Management Plan (TBNEP, 1996) established the restoration of seagrass in the bay to levels estimated in the 1950s as a primary goal for overall bay restoration. To this end, segment-specific seagrass targets were developed for all seven segments in Tampa Bay (Janicki et al., 1995). 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. 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.

Given the influence of chlorophyll *a* concentrations on water clarity, segment-specific chlorophyll *a* targets were established for the main segments of Tampa Bay (Janicki and Wade, 1996). Targets are defined as levels that represent desirable conditions. These targets were based on a 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.

It is not unreasonable to expect exceedences of the targets that are due primarily to natural variability, and not necessarily harmful to seagrass health. To allow for the effects of natural variability, segment-specific chlorophyll *a* thresholds (i.e., values above this level indicate undesirable conditions) were defined. The threshold was the sum of the chlorophyll *a* target and twice the standard error of the long-term chlorophyll *a* concentrations. FDEP has adopted these thresholds to assess compliance with the Tampa Bay Reasonable Assurance.

In November 2002, the FDEP concluded that the TBNMC's nitrogen management strategy 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 Southwest Florida Water Management District recently reported on the seagrass acreage in Tampa Bay from its survey conducted in 2010. The results from this survey show an increase of approximately 3,250 acres since the 2008 survey. Therefore, there is tangible evidence that the TBNMC nitrogen loading strategy continues to support seagrass recovery in the Tampa Bay Estuary.

Three analytical approaches have been identified for the development of numeric nutrient criteria (USEPA, 2009; Janicki Environmental, 2010b):

- the reference condition approach,
- stressor-response analysis, and
- mechanistic modeling.

The reference condition approach can be further divided into two different approaches, the historical and comparative reference approaches. The historical reference approach is a strong candidate if sufficient data are available for the waterbody of interest during a minimally-impacted reference period. If sufficient data are not available for the waterbody for a minimally-impacted reference period, it is possible to use the comparative reference approach. The comparative reference approach consists of using data from a minimally-impacted waterbody that is similar to the waterbody for which criteria are being developed. The reference waterbodies are selected from among a group of like waterbodies (e.g., the same class of waterbodies) that represent minimally disturbed conditions (Stoddard et al., 2006) and have similar characteristics. Obviously, the historical reference approach is superior to the comparative reference approach because it is based on data from the waterbody of interest for a minimally-impacted period. It is important to point out that the historical reference condition could be the current condition if the current condition is deemed minimally-impacted and is supporting balanced, natural populations of aquatic flora and fauna.

The stressor-response approach consists of developing relationships between nutrient concentrations or loads and biological responses. The biological responses should be related to the "designated use of a waterbody (e.g., a biological index or recreational use measure) either directly or indirectly, but ideally quantitatively" (USEPA, 2009). After quantitative relationships have been developed, the nutrient criterion that is protective of the specific designated uses can be determined.

USEPA (2009) has provided guidance on the development of stressor-response relationships using empirical data analysis approaches and a review of these approaches by the Science Advisory Board (SAB, 2010) has provided additional insights as to how evidence of stressor-response relationships may be used in establishing numeric nutrient criteria.

The mechanistic modeling approach is used to predict specific constituents based on a series of equations and algorithms that represent physical, chemical, biological, and ecological processes and interactions. Mechanistic models include a wide variety of water quality models, some of which were briefly described in previous USEPA nutrient criteria guidance documents (USEPA 2000a, 2000b). A much more in depth discussion of water quality modeling theory and practice can be found in a wealth of references (e.g., Chapra, 1997; Martin and McCutcheon, 1998; Edinger, 2002).

Mechanistic models are valuable tools and where available and useful we intend to explore their use in supporting the development of numeric nutrient criteria for southwest Florida estuaries. Mechanistic models tend to integrate information on the interactions of major ecosystem processes to derive quantitative estimates of effects and may be valuable in interpreting the stressor-response relationship (SAB, 2010). However, their first-order approximations can underestimate the variability and uncertainty in the predictions.

2.3 Available Data

Water quality data used to develop chlorophyll *a* targets and thresholds and nutrient criteria were collected during routine monitoring by the Pinellas County Watershed Management and the Manatee County Environmental Protection Division. The locations of sample sites in Boca Ciega Bay are shown in Figure 2-1. Ambient water quality fixed sample stations in Terra Ceia Bay and in the Manatee River are shown in Figure 2-2. In the Manatee River, only sites located within the known extent of seagrasses were used in the analysis of this bay segment. Samples from sites at the mouth of the Braden River (LM3) and further upstream on the Manatee River (LM4, LM5, LM6) were not included as they were located upstream of seagrasses.

Hydrologic and nutrient data utilized in these analyses are segment-specific monthly estimates developed by TBEP and FDEP for the period 1985 through 2007.

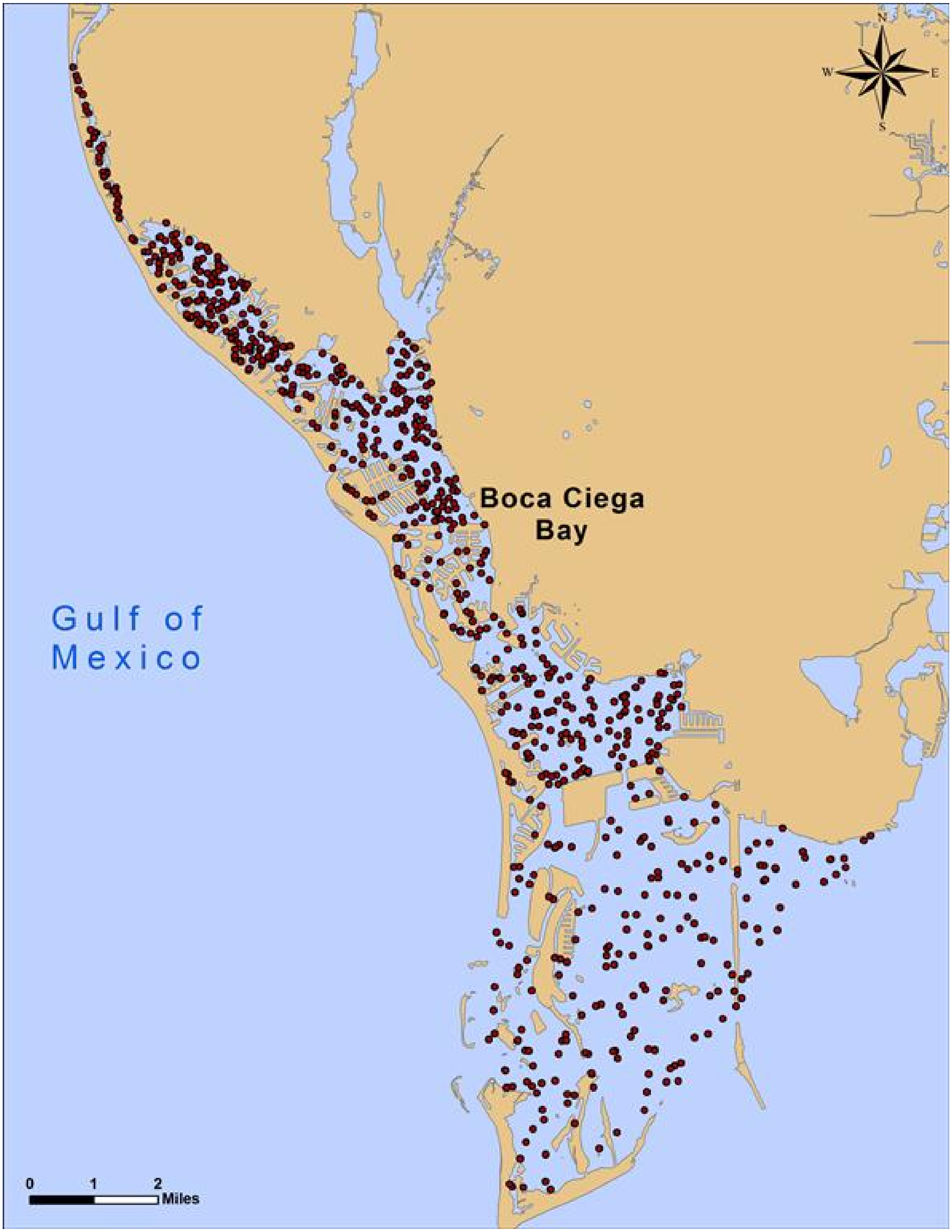

Figure 2-1. Location of water quality sites in Boca Ciega Bay.

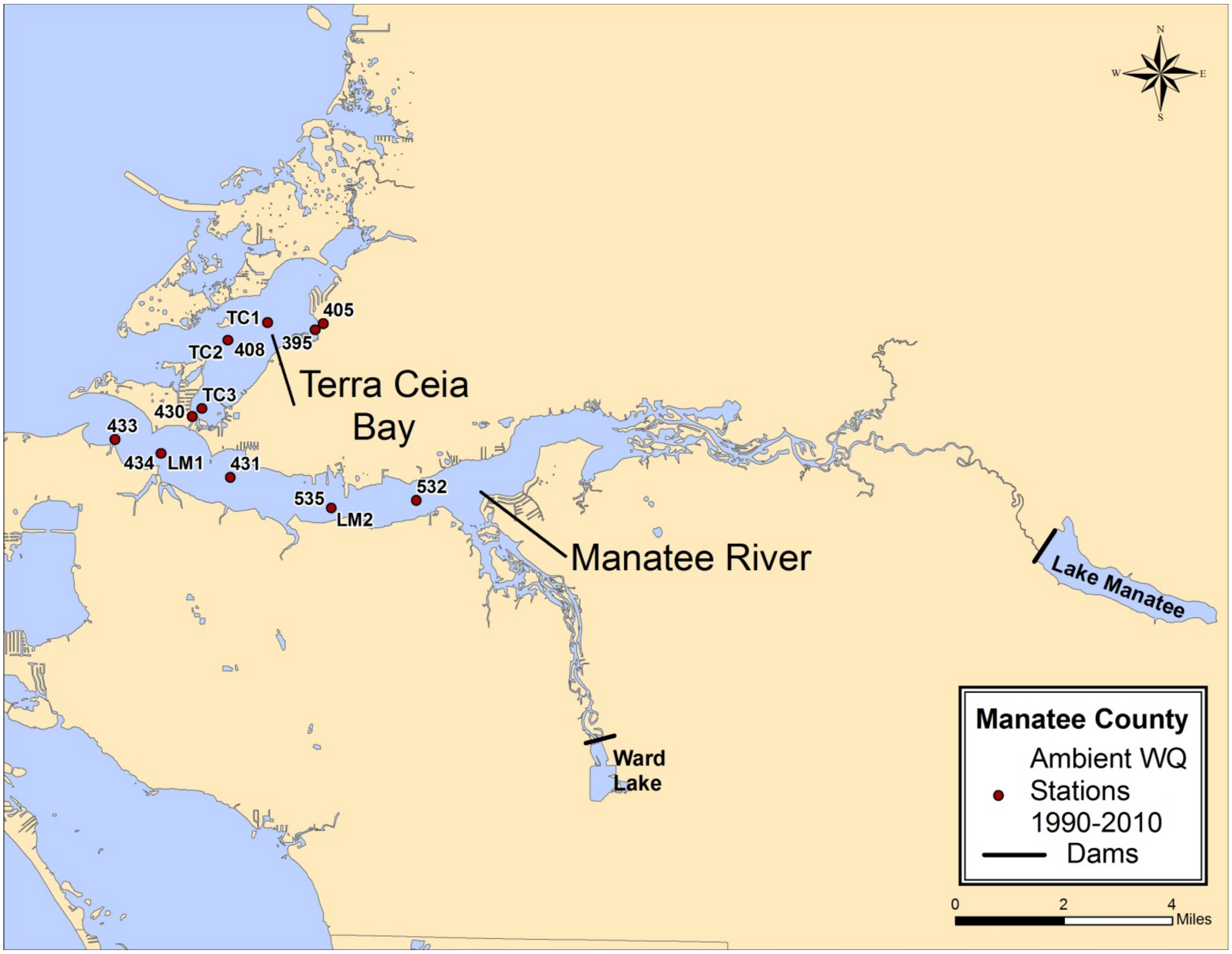

Figure 2-2. Location of water quality stations in Terra Ceia Bay and the Manatee River.

2.4 Recommended Approach

Though mechanistic modeling is a viable approach, it is the most data and labor intensive of the three proposed methods. Therefore, we investigated statistical relationships between chlorophyll *a* and nutrients. The methods included a series of techniques that can be used to estimate statistically defensible relationships between chlorophyll *a* concentrations and nutrient concentrations and/or loadings. If statistically defensible relationships were identified, these relationships were used to develop numeric nutrient criteria. If because of the complexity of the systems, it is not possible to identify statistically defensible relationships for all segments, the reference period approach would be used to develop numeric nutrient criteria, assuming a defensible reference period could be identified.

3.0 Terra Ceia Bay

In this section, the development of numeric nutrient criteria for Terra Ceia Bay is presented, including:

- a general description of the watershed,
- a summary of seagrasses, including the seagrass target
- a description of water quality and loadings,
- a description of empirical relationships between chlorophyll *a* and light attenuation,
- the proposed chlorophyll *a* target,
- a description of empirical relationships between chlorophyll *a* and nutrients, and
- the recommended nutrient criteria.

Terra Ceia Bay is a small embayment located at the south end of Lower Tampa Bay (Figure 3-1). Terra Ceia Bay's open water area is approximately eight mi^2. No major surface water features drain into the bay, although two small tidal creeks, Frog Creek and McMullen Creek, provide some freshwater inflows to the north end of the estuary. The southern portion of the bay is shallow. A narrow channel leading to Lower Tampa Bay is over 10 feet deep but surrounding waters are mainly 5 feet or less. The main body of the bay reaches depths of over 10 feet.

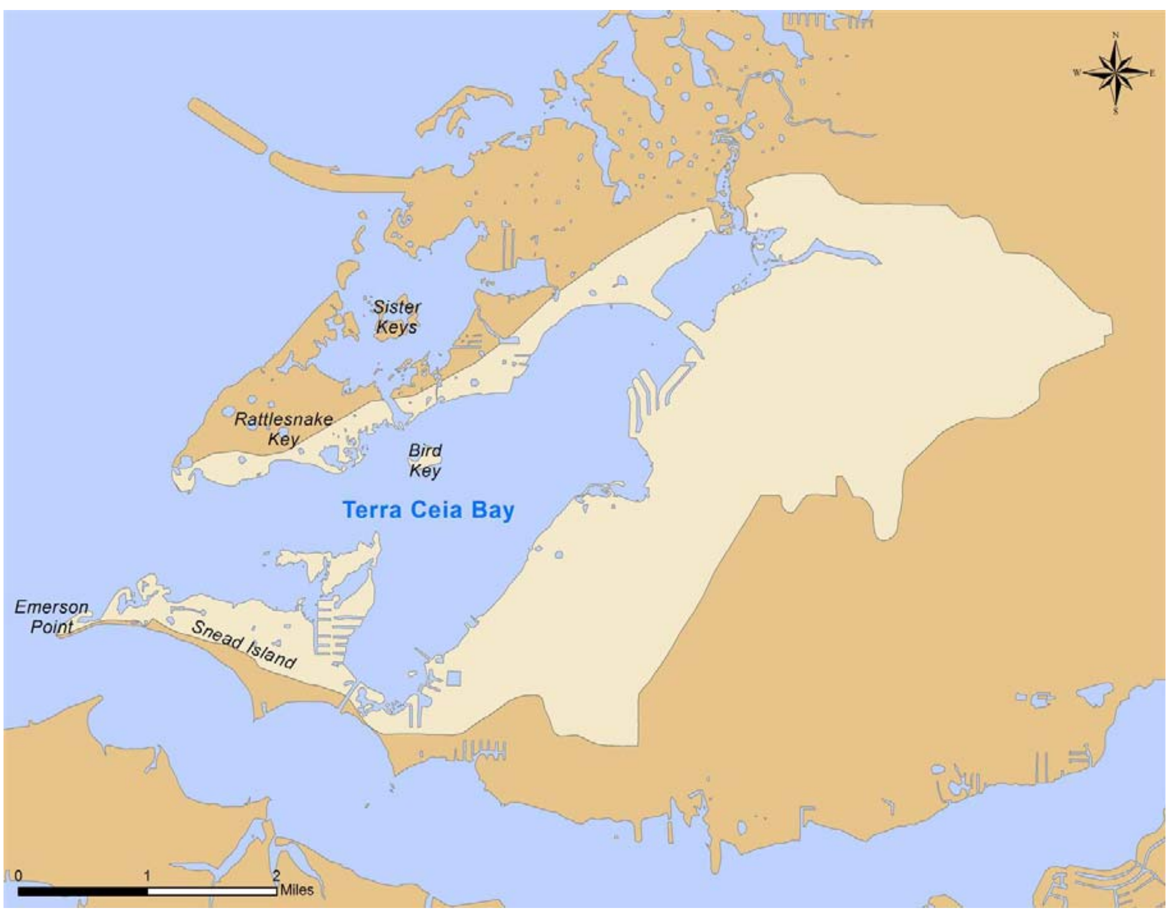

Figure 3-1. Terra Ceia Bay segment.

A causeway for US19 crosses the bay to the north. The short open-water span on the causeway restricts tidal flows between the north and south portions of the bay. The bay exchanges tidal waters with Lower Tampa Bay through a wide pass at its mouth. Extensive mangrove forests bound the estuary to its west. Mangrove islands include Rattlesnake Key, Bird Key, Sister Keys, and Little Bird Key. Terra Ceia Bay is separated from the Manatee River to the south by Snead Island, although a canal through the island allows some interflow between the river and estuary.

The 13.8 mi^2 watershed is a mix of urban (52% in 2005) – mainly residential - and agriculture (34%) including both intensive agriculture and range/pasture. Wetlands comprise about 8% of the watershed and forest/open land the remainder. The watershed of Terra Ceia Bay is only 1.7 times the size of the water surface of Terra Ceia Bay, a very small watershed to receiving water body ratio. Major roadways I-275, US19, and US41 all intersect within the watershed. Although over half of Terra Ceia Bay's shoreline is lined with mangroves, there is significant waterfront development, including dredge and fill residential finger canals, on the north and east shores, and on Snead Island to the south. Several trailer parks and a portion of the city of Palmetto are located in the watershed. The city of Palmetto discharges treated wastewater to the surface water of Terra Ceia Bay and to reuse. In recent years the amount of reuse has been increasing and the amount of treated wastewater that is discharged to surface waters has been decreasing.

3.1 Seagrass Targets

As discussed in Section 2.2, seagrass targets have been developed for the segments of Tampa Bay. However, chlorophyll *a* targets were not developed for Terra Ceia Bay during the initial target development given the scarcity of data at that time (Janicki and Wade, 1996; Janicki et al., 1995). In this section, estimates of recent seagrass acreages are examined relative to the seagrass target for Terra Ceia Bay.

3.1.1 Temporal Distribution of Seagrass

Seagrass acreages in Terra Ceia Bay have been stable since 1990. Seagrasses have been above the 1950-Nonrestorable area and just below target levels (as determined in Janicki et al., 1995), though a slight decline was observed between 1992 and 2001 (Figure 3-2). Little change in seagrass coverage has been observed over the period of record. In 2010, the seagrass extent in Terra Ceia Bay was less than 5% below the seagrass target.

3.2 Temporal Variability in Ambient Water Quality and Nutrient Loadings

Water clarity in Terra Ceia Bay improved between 1998 and 2006 with increases in annual average Secchi disc depth from 1.1 m to 2.4 m over that time period (Figure 3-3). Since 2007, annual average Secchi disc depths have remained consistent at 1.7-1.8 m.

Average annual TN concentrations in Terra Ceia Bay ranged from 0.5-1.0 mg/L between 1998 and 2010 (Figure 3-4). Prior to 2003, TN concentrations average 0.65-1.0 mg/L, but following a peak in 2001, concentrations appear to have declined and have averaged between 0.5-0.6 mg/L during most recent years.

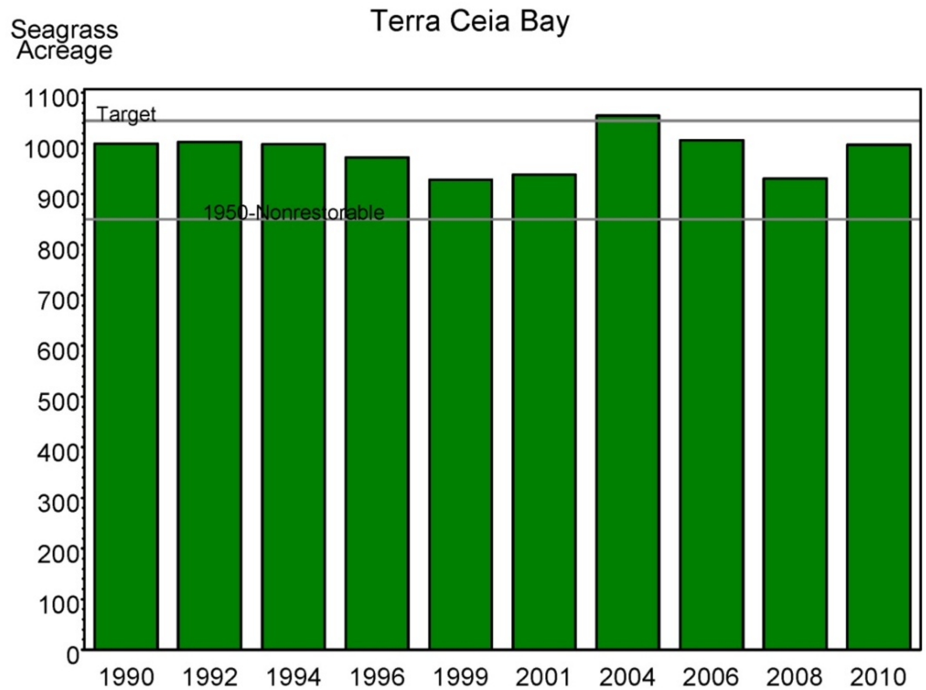

Figure 3-2. Extent of seagrasses during recent surveys in Terra Ceia Bay. The reference lines indicate the seagrass target and the 1950s acreage minus any nonrestorable areas for this bay segment.

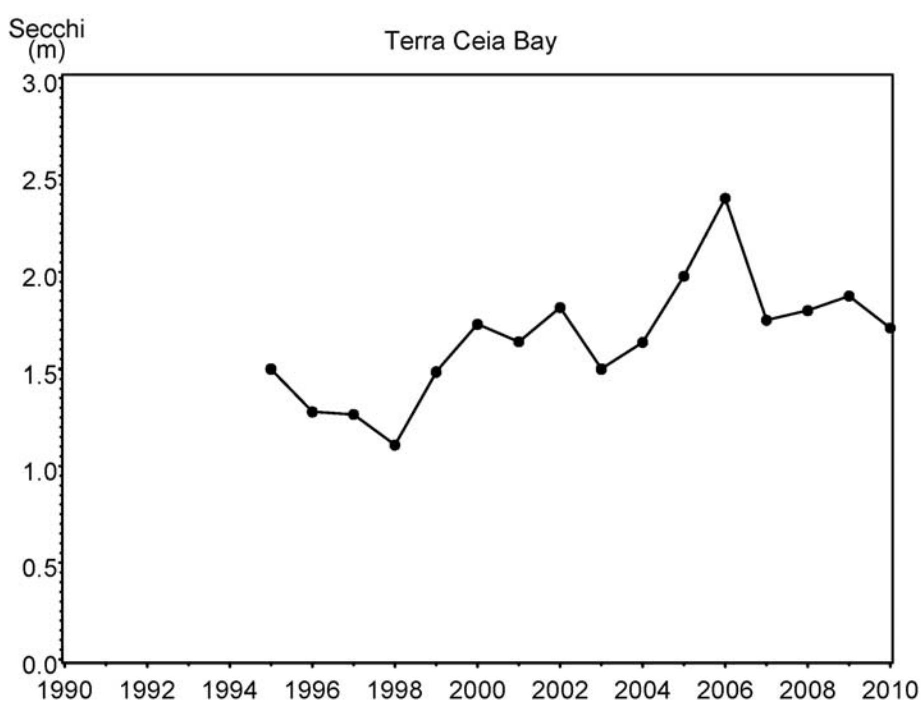

Figure 3-3. Annual average Secchi disc depth in Terra Ceia Bay.

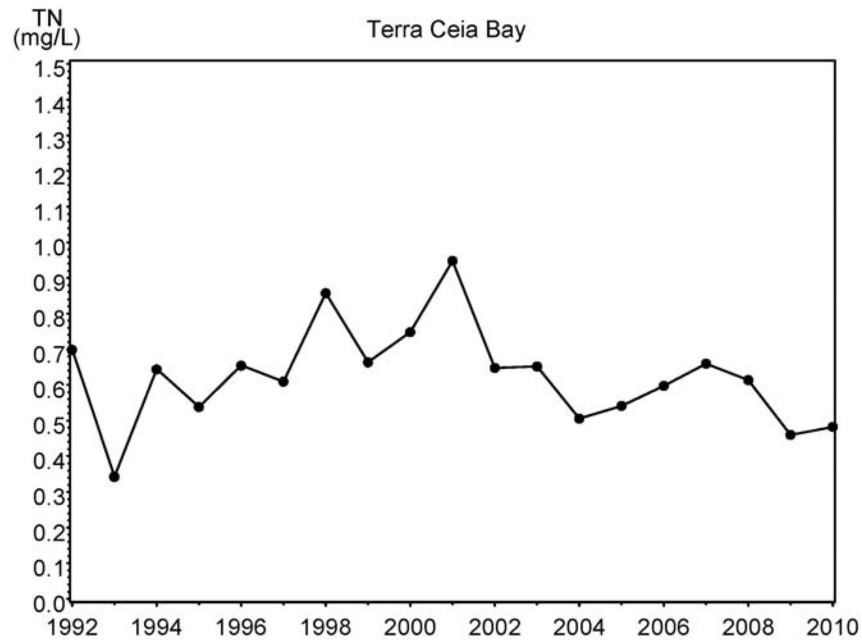

Figure 3-4. Annual average TN concentration in Terra Ceia Bay.

Annual average chlorophyll *a* concentrations in Terra Ceia Bay were highly variable between 1990 and 2010 (Figure 3-5). The highest annual average was nearly 15 µg/L in 2003 Recent chlorophyll *a* levels (2005-2010) were lower and more consistent than any time period between 1990 and 2010 with a maximum just over 6 µg/L in 2005 and a steady decline to 4 µg/L in 2010. Based on the temporal trends observed, there is no clear relationship between nutrients, chlorophyll *a* concentrations, and water clarity in Terra Ceia Bay.

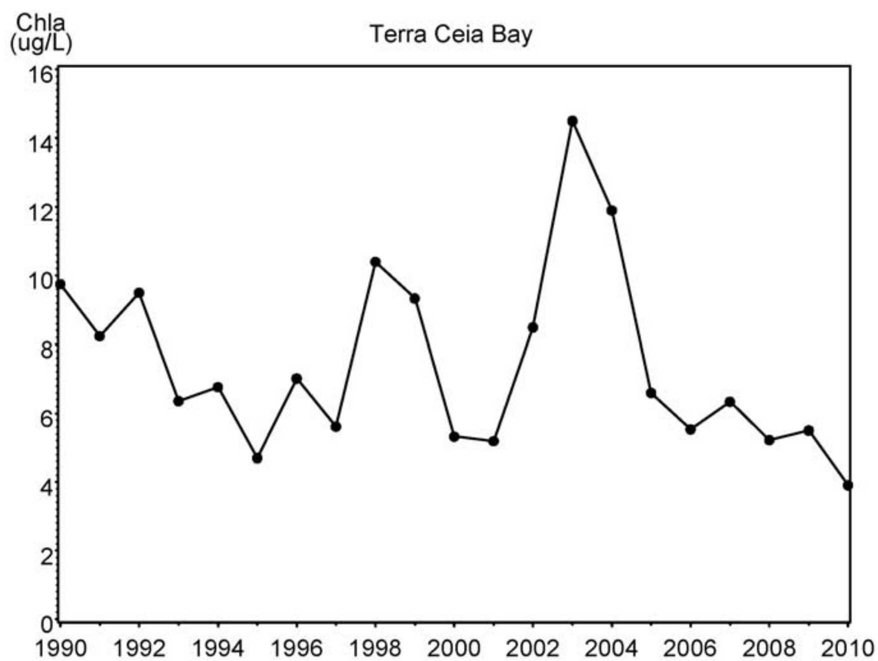

Figure 3-5. Annual average chlorophyll *a* concentration in Terra Ceia Bay.

Nutrient loads to Terra Ceia Bay varied from 17-65 tons/year for TN loads (Figure 3-6). Nutrient loads were relatively stable over the period of record with no indication of an increasing or decreasing trend from 1989-2007. Between 2004 and 2007, TN loads in Terra Ceia Bay ranged from 20-35 tons/year.

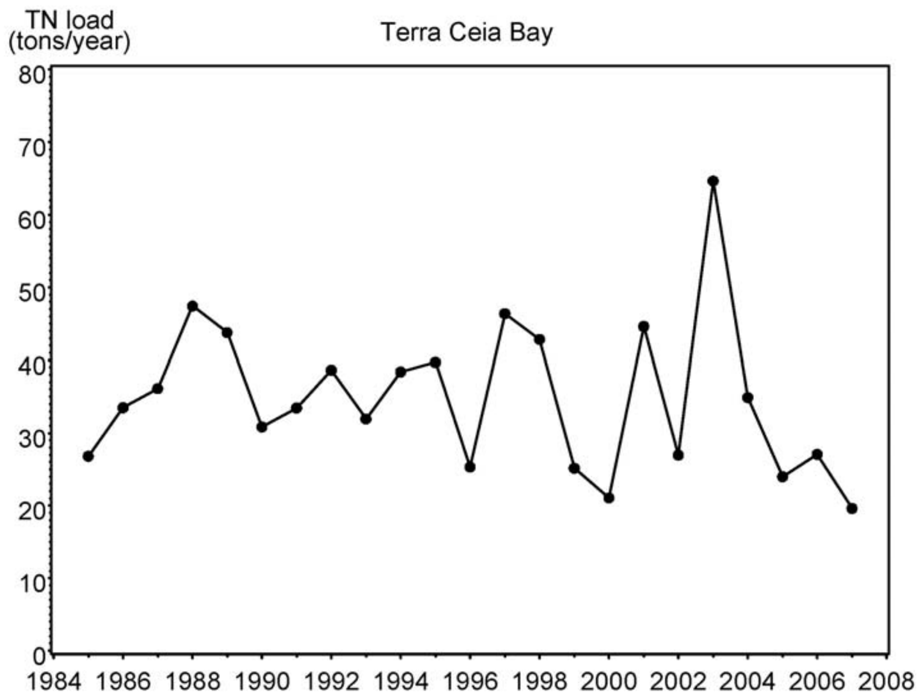

Figure 3-6. Annual TN load in Terra Ceia Bay.

3.3 Empirical Relationships between Chlorophyll *a* and Light Attenuation

Previous work by Dixon and Leverone (1995) determined that the minimum light requirement for turtle grass (*Thalassia testudinum*) is 20.5% of incident subsurface light. An estimate of subsurface light as a fraction of incident light can be obtained using Beer's law, with the relationship dependent upon the diffuse attenuation due to water quality constituents (chlorophyll a, turbidity, color) (Janicki and Wade, 1996). The diffuse attenuation coefficient, K_D, can be approximated by a factor divided by Secchi disc depth (Giesen et al., 1990). For this analysis, concurrently measured light attenuation data (from light sensors) and Secchi disk data, for 1991-2010 in Boca Ciega Bay and 2005-2010 in Terra Ceia Bay and Manatee River, were multiplied to provide a sample-specific estimate of the "Giesen factor". For a given segment, the median of these factor values was chosen to represent the Giesen factor. This factor was combined with the Secchi disc data from all samples to derive a diffuse light attenuation coefficient for all samples. Using Beer's law, this K_D allowed estimation of the depth to which 20.5% of subsurface irradiant light penetrated (Z). The relationship between mean monthly chlorophyll *a* concentration and Z and between chlorophyll *a* concentration and Secchi disc depth for Terra Ceia Bay are shown in Figures 3-7 and 3-8. In Terra Ceia Bay, chlorophyll a explained 13% of the variation in Z and 12% of the variation in Secchi depth.

3.4 Proposed Chlorophyll *a* Target and Threshold

In order to propose chlorophyll *a* targets and thresholds, it was necessary to delineate the historical depth distribution for seagrasses in each bay segment. To do this, historical seagrass data were examined to determine their spatial extent and depth distribution during 1950 (Janicki and Wade, 1996). Based on the cumulative frequency of depths at which seagrasses were observed, a target depth was identified as the depth above which 95% of all seagrasses historically occurred in each bay segment. This depth was used to provide a baseline from which to assess more recent water quality and clarity data. A cumulative frequency distribution plot of historical seagrass depths in Terra Ceia Bay is presented in Figure 3-9. Historically, 95% of seagrass habitat in Terra Ceia Bay was found at depths up to 1.8 m. Therefore, 1.8 m is the potential depth target that could be used to develop the chlorophyll *a* target for Terra Ceia Bay.

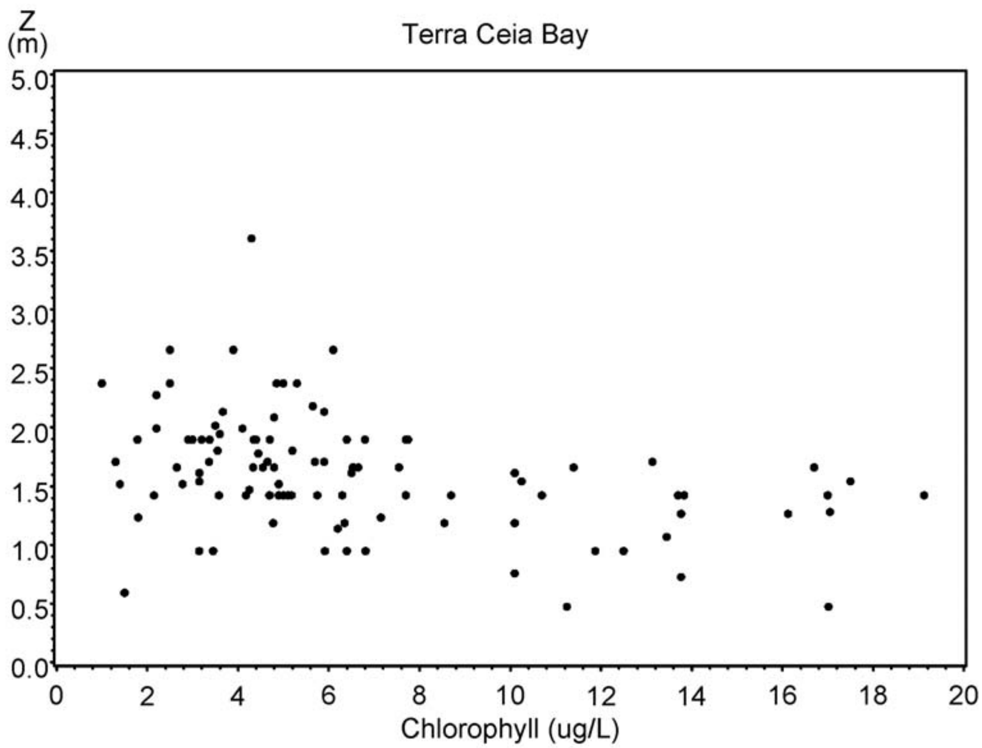

Figure 3-7. Empirical relationship between chlorophyll *a* concentration and Z (depth at which 20.5% of irradiant light is available for seagrass) in Terra Ceia Bay.

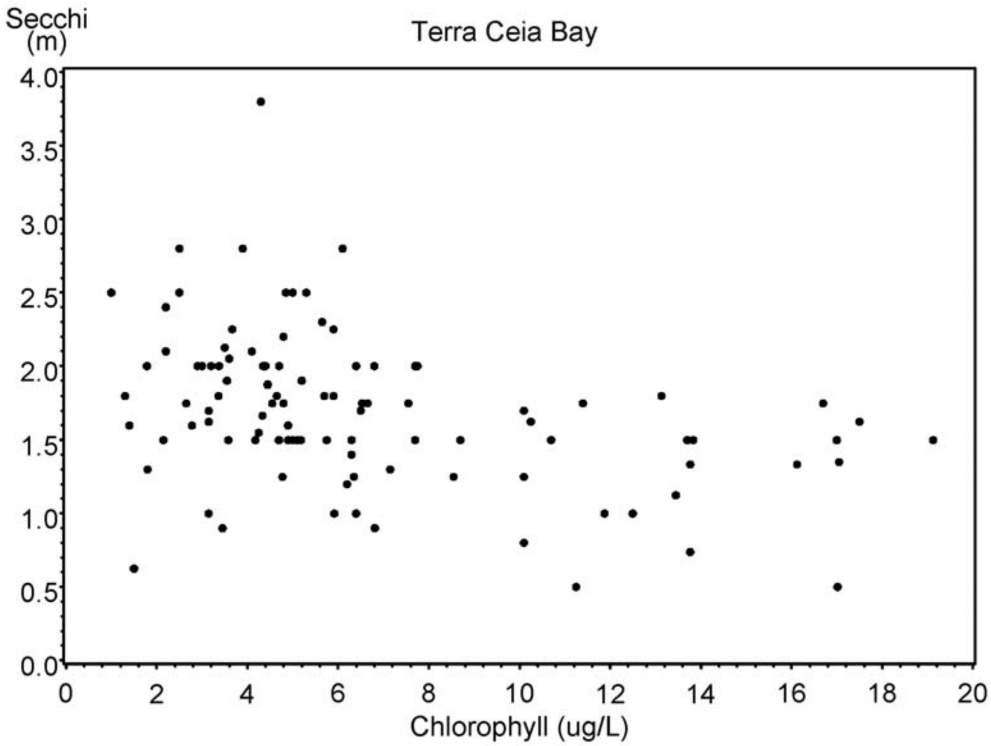

Figure 3-8. Empirical relationship between chlorophyll *a* concentration and Secchi disc depth in Terra Ceia Bay

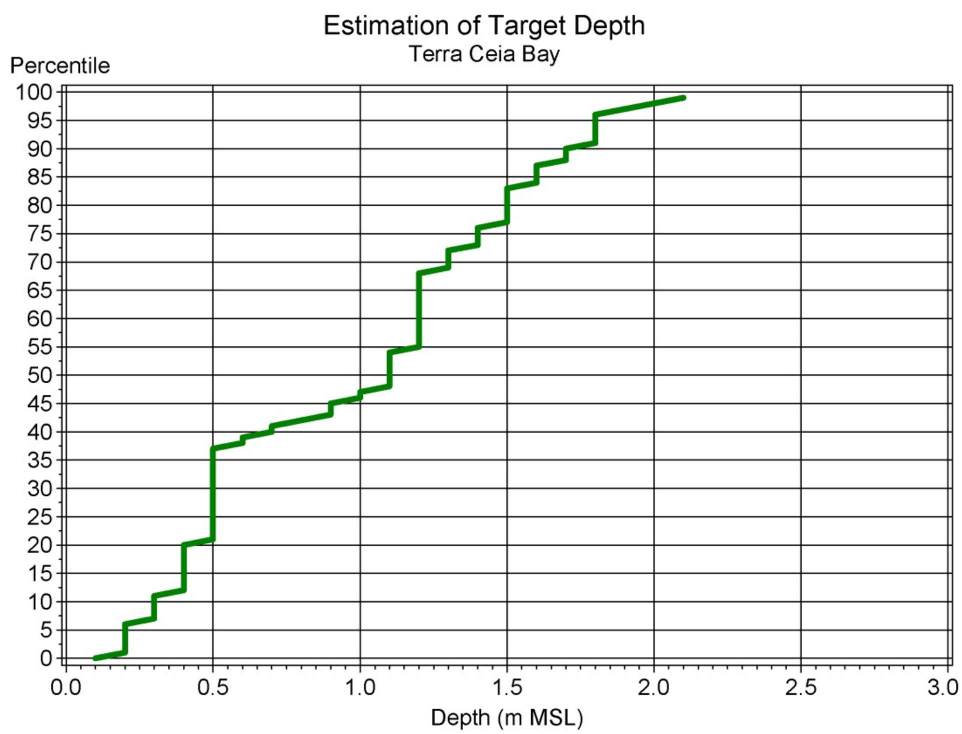

Figure 3-9. Cumulative depth distribution of seagrass in Terra Ceia Bay during the historical period (1950). The chlorophyll *a* target was derived from the depth target of 1.8 m, which was the estimated depth at which 95% of seagrass occurred historically.

One method that can be employed to obtain a chlorophyll target is to develop a quantitative relationship between chlorophyll *a* and light attenuation. Although a statistically significant relationship was identified between chlorophyll *a* and light attenuation in Terra Ceia Bay, this relationship left a considerable amount of variability unexplained. Therefore, a reference period approach was used to develop the chlorophyll *a* target and threshold for Terra Ceia Bay. This is consistent with the methodology of Janicki and Wade (1996), who examined both the stressor response approach and the reference period approach to develop chlorophyll *a* thresholds for the main segments of Tampa Bay.

In Janicki and Wade (1996), the reference period (1992-1994) was selected as it represented a period during which stable or increasing seagrass coverage existed in the segments of Tampa Bay. The reference period for Terra Ceia Bay (1992-1994) was selected because it is representative of a period when water quality (TN, TP, and chlorophyll *a*) and seagrasses were stable and water clarity was increasing (Figure 3-3). The annual arithmetic mean chlorophyll *a* concentration during the reference period (target) is 7.5 µg/L. Following the approach developed by Janicki and Wade (1996), an allowance was made to account for natural variability in the system. The threshold was calculated by summing the target (arithmetic mean for the reference period) plus two standard errors, resulting in a chlorophyll *a* threshold of 8.7 µg/L. Comparison of the proposed threshold with observed chlorophyll *a* concentrations during the period of record (Figure 3-10) indicates that chlorophyll *a* concentrations have not exceeded the threshold since the 2003-2004 period.

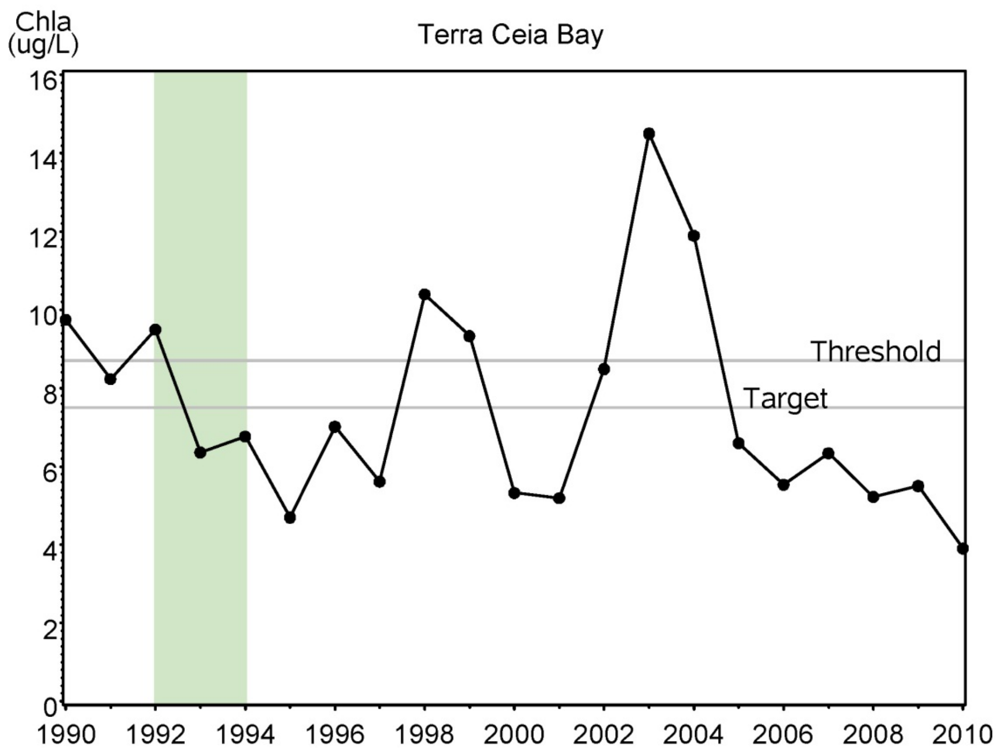

Figure 3-10. Annual average chlorophyll *a* concentration in Terra Ceia Bay. The reference lines represent the proposed chlorophyll *a* target and threshold based on the reference period approach. The reference period is shaded.

3.5 Empirical Relationships Between Chlorophyll *a* and Nutrients

Figure 3-11 depicts the relationship between log transformed TN concentrations and log transformed chlorophyll *a* concentrations for Terra Ceia Bay. Only 18% of the variation in chlorophyll *a* concentrations was explained by TN concentrations.

Additional relationships were investigated between TN loads and chlorophyll *a* concentrations. Though this relationship was significant (Figure 3-12), the majority of the variation was left unexplained. TN loads accounted for 11% of the variation in chlorophyll *a* in Terra Ceia Bay. Though this relationship was significant, the low R^2 values makes it impractical for management decisions as the vast majority of the variation is left unexplained.

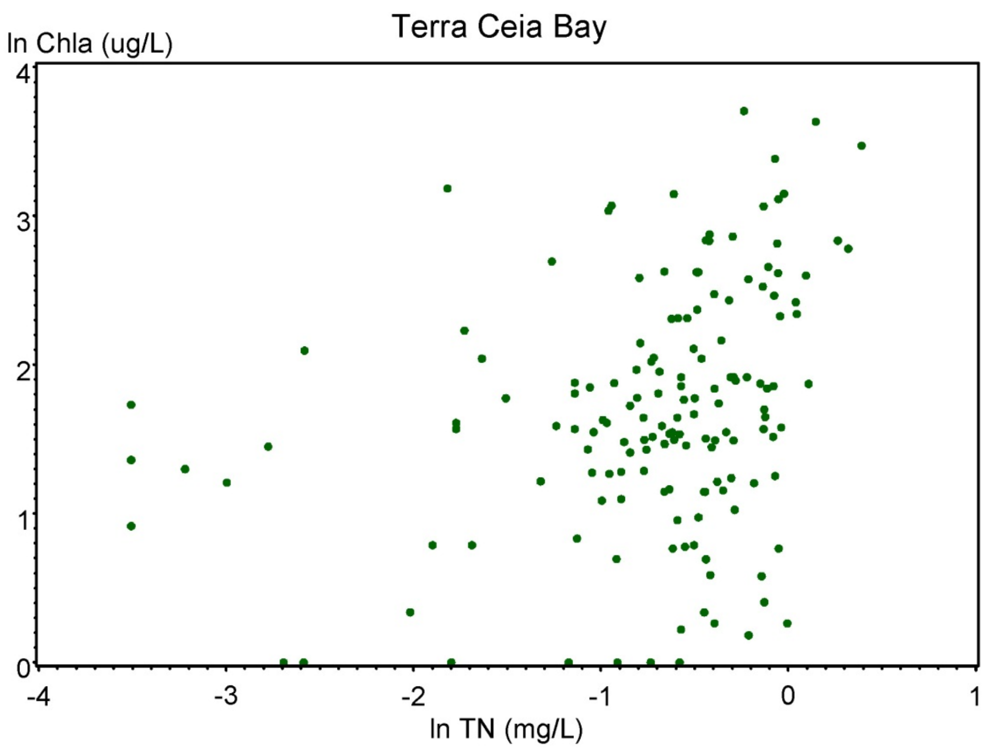

Figure 3-11. Empirical relationship between ln(chlorophyll *a*) concentration and ln(TN concentration) in Terra Ceia Bay.

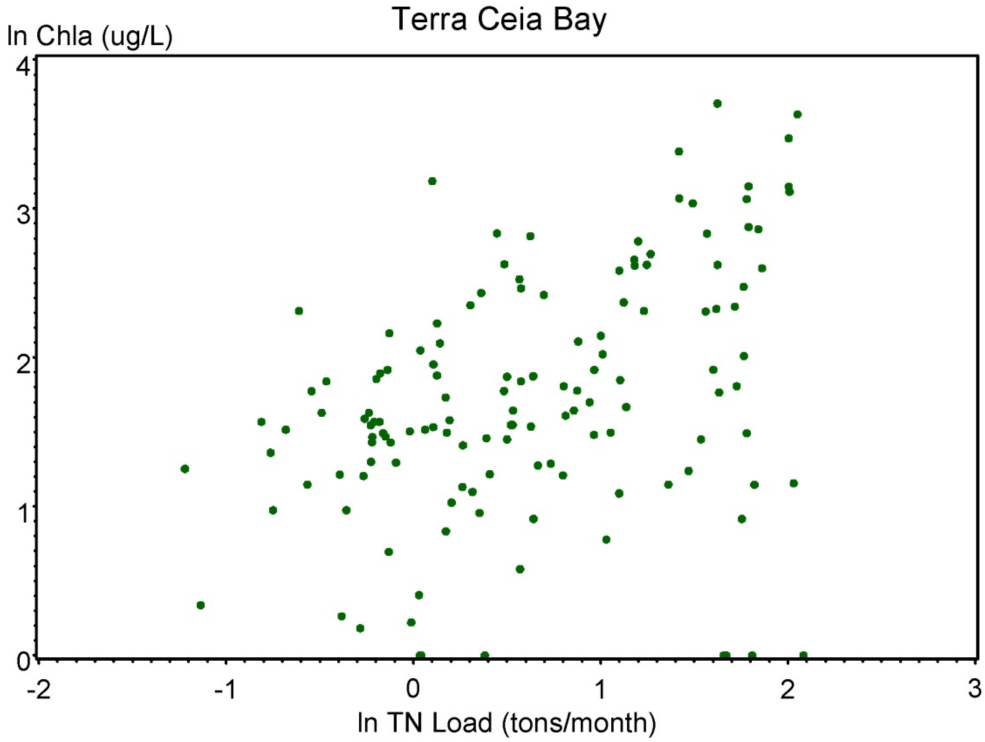

Figure 3-12. Empirical relationship between chlorophyll *a* concentration and TN load in Terra Ceia Bay.

3.6 Recommended Loading- and Concentration-Based Nutrient Criteria

Attempts were made to develop statistically defensible relationships between monthly chlorophyll *a* concentrations and potential explanatory variables, including nutrients concentrations and loads. In addition to same-month nutrient concentrations and loads, numerous transformations and lags of these variables were also investigated. However, because of the lack of robust statistical relationships between chlorophyll *a* concentrations and TN loads or concentrations, the reference period approach was used to calculate the TN criteria for Terra Ceia Bay. The concentration criterion was calculated by taking the average of the annual geometric means during the reference period (1992-1994) plus the standard deviation of the annual geometric means for the period of record. This is consistent with the methodology employed in Janicki Environmental (2010a) to develop nutrient concentration criteria for the four main segments of Tampa Bay. The reference period was selected because it is representative of a period when water quality (TN, TP, and chlorophyll *a*) and seagrasses were stable and water clarity was increasing (Figure 3-3). The proposed TN concentration criterion for this bay segment is 0.69 mg/L based on the reference period approach. Average annual TN concentrations in Terra Ceia Bay have exceeded this proposed threshold in only three years over the past two decades, but have remained below the threshold since 2002 (Figure 3-13).

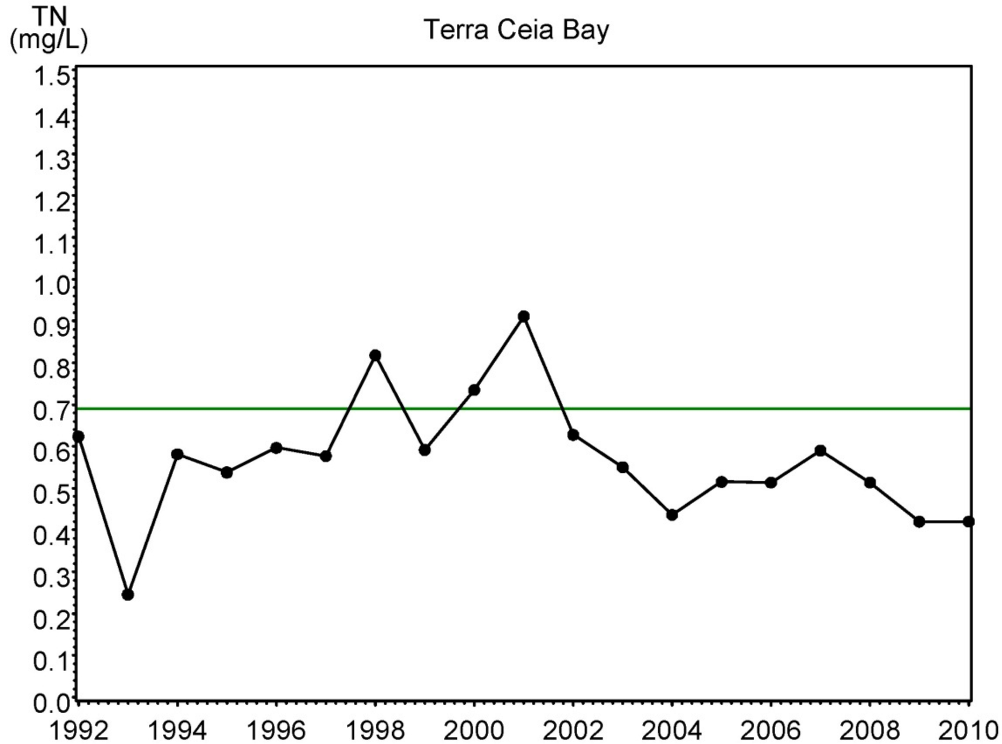

Figure 3-13. Annual geometric mean TN concentration in Terra Ceia Bay. The reference line represents the proposed concentration-based TN criterion for the reference period.

The proposed TN load target for Terra Ceia Bay is the average annual load for the 1992-1994 reference period (36 tons/year). This reference period is consistent with the reference period that was used in the Tampa Bay total maximum load. Average annual TN loads have exceeded the proposed target in nine of the previous 23 years with the most recent exceedence occurring in 2003 (Figure 3-14). This presents an interesting paradox as the segment is not meeting its loading targets though seagrass and water quality have been stable or improving. This same issue was identified during target development for the four main bay segments of Tampa Bay.

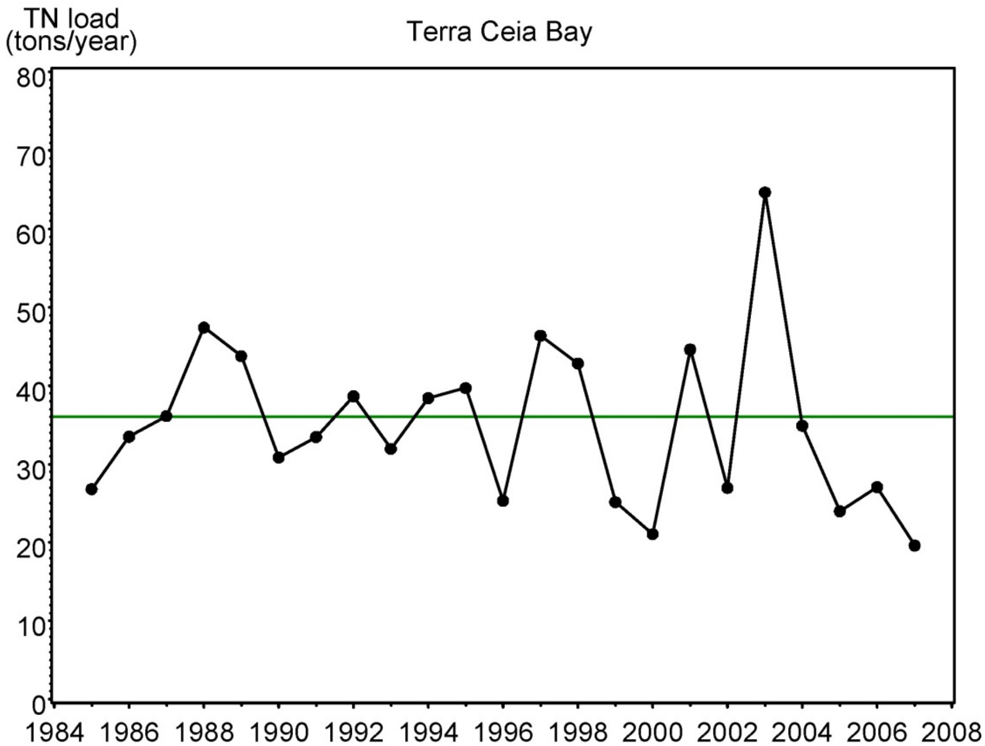

Figure 3-14. Annual TN load in Terra Ceia Bay. The reference line represents the proposed loading-based TN target for the reference period.

During the development of the 2009 Reasonable Assurance (TBNMC, 2010b), the TBNMC investigated the temporal trends in TN loading for the four main segments of Tampa Bay. While the chlorophyll *a* thresholds were being met, the TN loading targets were exceeded in some years in the four main segments of Tampa Bay. 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 were also considered, along with the annual TN loads to establish TN loading thresholds for each segment.

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. The TN delivery ratio for Terra Ceia Bay based on the 1992-1994 reference period is 1.10 tons TN per million cubic meters of freshwater delivered. Analysis of the time series plot of the annual TN delivery ratio for Terra

Ceia Bay (Figure 3-15) reveals that the TN threshold (i.e., the TN delivery ratio) been exceeded five times, but has not been exceeded since 1995. This result is consistent with the picture of stable or improving water quality and seagrasses in Terra Ceia Bay.

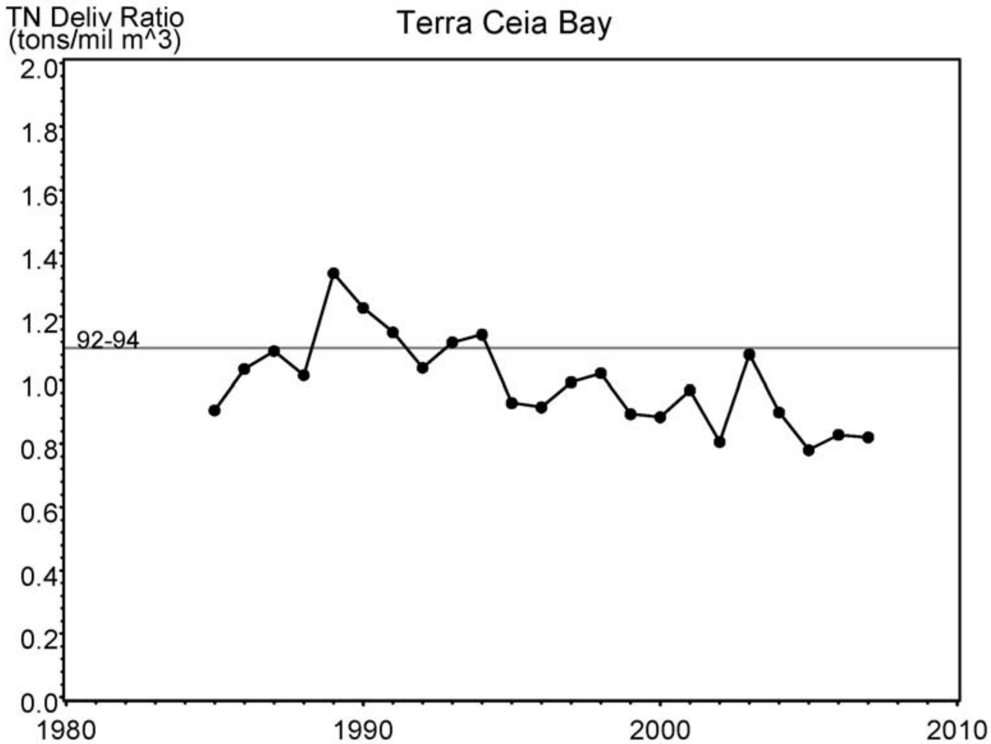

Figure 3-15. Annual TN load delivery ratio in Terra Ceia Bay. The reference line represents the proposed loading-based TN criterion for the reference period.

4.0 Manatee River

In this section, the development of numeric nutrient criteria for Manatee River is presented, including:

- a general description of the watershed,
- a summary of seagrasses, including the seagrass target
- a description of water quality and loadings,
- a description of empirical relationships between chlorophyll *a* and light attenuation,
- the proposed chlorophyll *a* target,
- a description of empirical relationships between chlorophyll *a* and nutrients, and
- the recommended nutrient criteria.

The Manatee River is located at the mouth of Tampa Bay (Figure 4-1). The river has a surface area of approximately 21 mi^2 and discharges into Lower Tampa Bay. The river is dammed approximately 24 miles upstream of its mouth to create Lake Manatee (Figure 4-1), a public water supply. Flows are tidally-influenced from the river mouth upstream to the dam. The river is broad, over one-half mile wide, in its most downstream reach and then transforms into a braided channel with small interconnected flow paths surrounded by wetlands up to the dam.

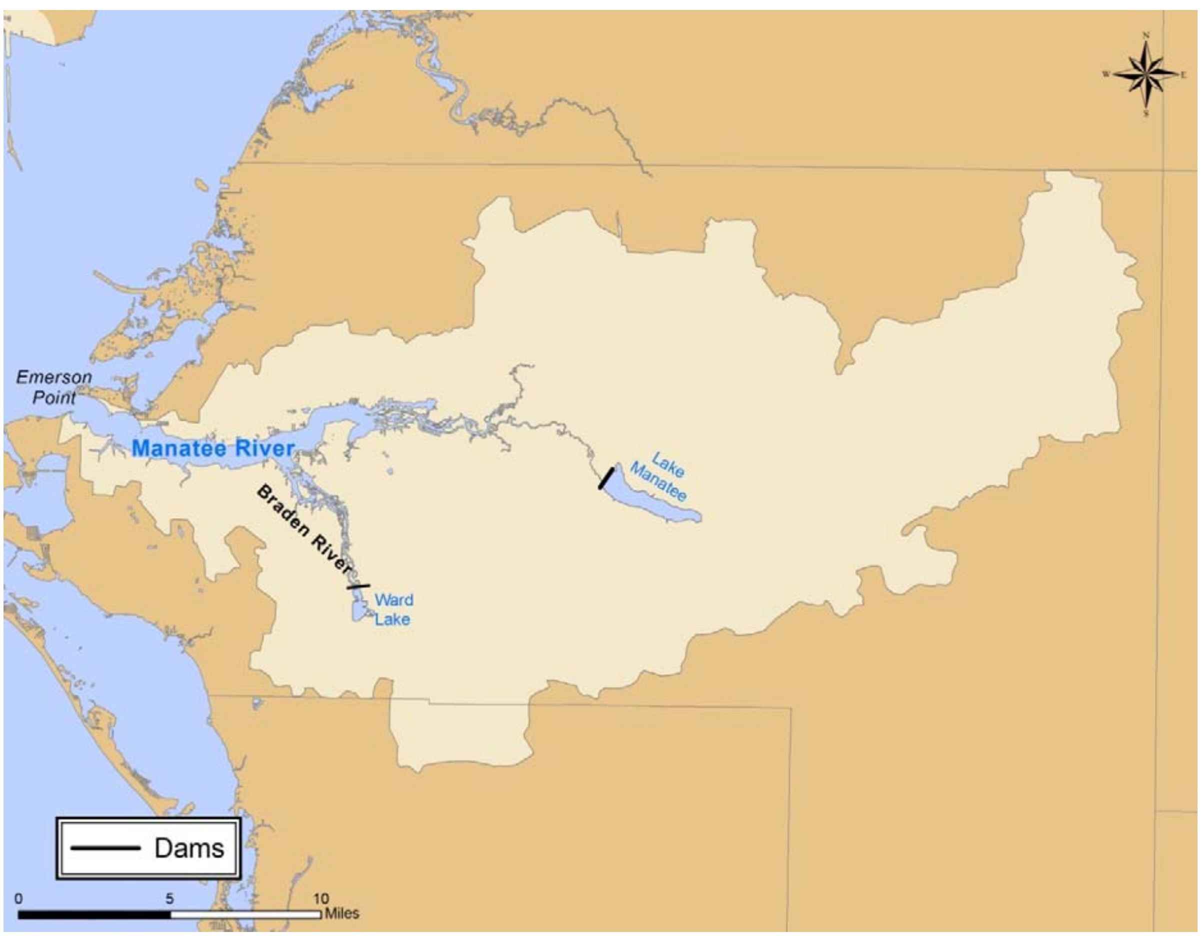

Figure 4-1. Manatee River segment.

The Manatee River has 18 named tributaries. Among the largest are Gamble Creek and Wares Creek. The largest tributary is the Braden River, which discharges to the Manatee River about 8 miles upstream from Tampa Bay. The Braden River is also dammed for potable water supply, creating Ward Lake.

The 322 mi^2 Manatee River watershed has historically been in agricultural use with the exception of the cities of Bradenton and Palmetto to the west, and smaller inland communities such as Parrish and Duette. Much of the eastern half of the watershed still supports agricultural activities but significant urban development, mainly residential, has occurred in the western watershed during the past two decades. Urban development in the watershed upstream of the dam is restricted by Manatee County's reservoir watershed protection rules. Land use in 2005 was 51% agricultural (including intensive agriculture and range/pasture), 20% urban, 16% wetlands and open freshwater, 10% forest and open land, and 2% mining. The city of Bradenton discharges treated wastewater to the surface water of Manatee River and to reuse. In recent years the amount of reuse has been increasing and the amount of treated wastewater that is discharged to surface waters has been decreasing. An industrial facility, Tropicana North America, historically discharged to the surface waters of Manatee River. Over the last decade the facility has gone to zero surface water discharge under typical operating conditions.

The Manatee River segment is unique to the Tampa Bay estuarine management areas; and therefore, careful consideration of other factors that contribute to the expression of nutrient-related responses will need to be considered during implementation. For instance, timing and delivery of loads to this segment should be a practical consideration for both TMDL and minimum flow development for the segment as it relates to the highly regulated loads from the dammed portions of the Manatee and Braden rivers.

4.1 Seagrass Targets

As discussed in Section 2.1, seagrass targets have been developed for the segments of Tampa Bay (Janicki et al., 1995). However, chlorophyll *a* targets were not developed for Manatee River during the initial target development because of a scarcity of data at the time (Janicki and Wade, 1996; Janicki et al., 1995). In this section, estimates of recent seagrass acreages are examined relative to the seagrass target for Manatee River.

4.1.1 Temporal Distribution of Seagrass

Seagrass coverage as determined from aerial photography has been limited to the area downstream of the Braden River. Seagrass acreages in the Manatee River were stable during the 1990s (Figure 4-2). From 2006 to 2010, the seagrass extent in this bay segment was well above the seagrass target (as determined in Janicki et al., 1995) and approximately twice that recorded during the 1990s.

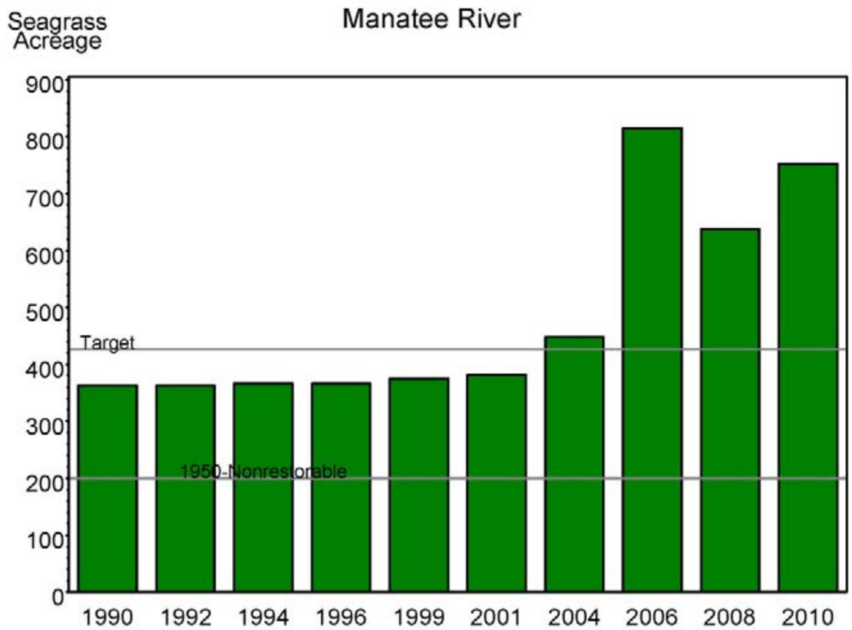

Figure 4-2. Extent of seagrasses during recent surveys in Manatee River. The reference lines indicates the seagrass target and 1950s acreage minus any nonrestorable areas for this bay segment.

4.2 Temporal Variability in Ambient Water Quality and Nutrient Loadings

Water clarity has steadily improved in the Manatee River from 1998 to 2010. Annual average Secchi disc depths during this time increased from 1.0 m to just below 1.9 m with a slight decrease in 2009 and 2010 when Secchi disc depths were 1.7-1.8 m (Figure 4-3).

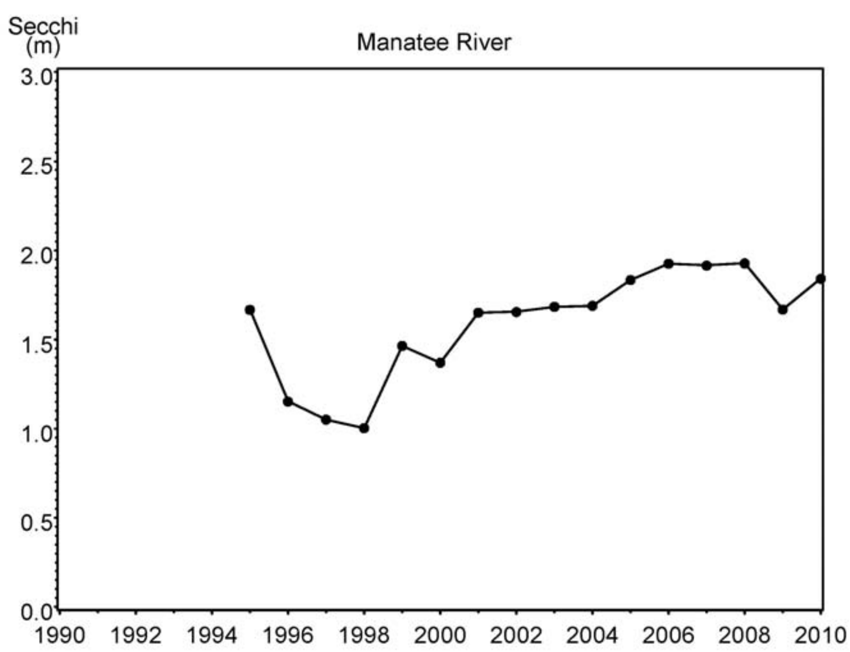

Figure 4-3. Annual average Secchi disc depth in Manatee River.

Temporal trends in TN concentrations in the Manatee River are shown in Figure 4-4. Between 1998 and 2003, annual average TN concentrations fluctuated widely from 0.6 mg/L to nearly 1.1 mg/L. TN concentrations have been relatively constant at just below 0.5 mg/L between 2006 and 2010. Peak TN concentrations were observed in 1994, 1998, 2001 and 2005.

Annual average chlorophyll *a* concentrations in the Manatee River were highly variable over time (Figure 4-5). The highest annual average was observed in 1992 (slightly over 15 μg/L), but chlorophyll *a* concentrations declined over the next nine years to a near low of 5 μg/L in 2001. Prior to 1995, chlorophyll *a* concentrations fluctuated between 10 and 15 μg/L, but were generally between 5 and 10 μg/L over the remaining 16 years.

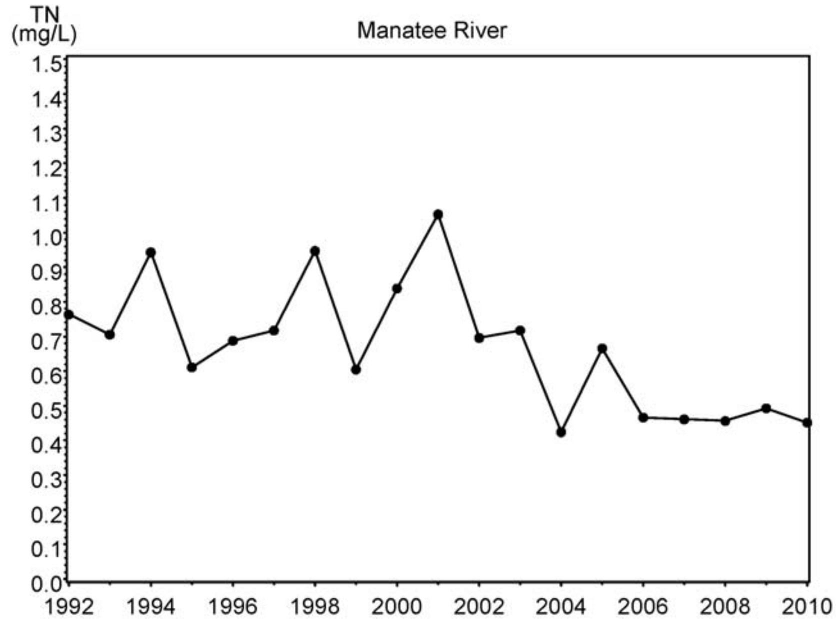

Figure 4-4. Annual average TN concentration in Manatee River.

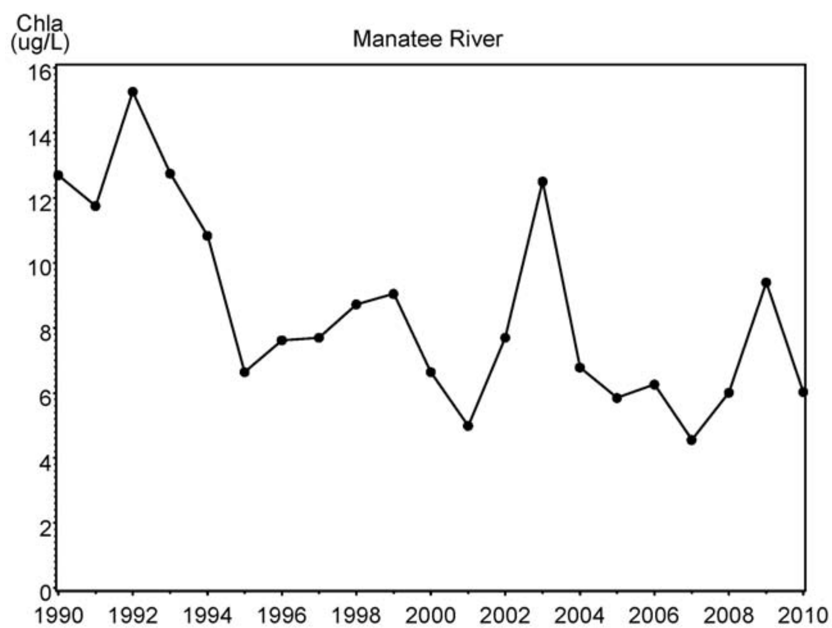

Figure 4-5. Annual average chlorophyll *a* concentration in Manatee River.

TN loads to the Manatee River ranged between 200 tons/year and 1,450 tons/year with considerable year-to-year variation, i.e., three-fold changes in TN loadings in consecutive years (Figure 4-6). Peak nutrient loads were estimated for 2003 when TN loads were 1,450 tons/year, in contrast to 2004-2007 when loads were considerably lower (<800 tons/year TN).

Both nutrient loads and concentrations appeared to co-vary over time however there was very little covariation between nutrients and chlorophyll *a* concentrations, except during the peak nutrient loadings of 1998 and 2003. Improved water clarity in the Manatee River, despite peak nutrient loadings, appears to be related to improved water quality in terms of reduced nutrient concentrations and lower chlorophyll *a* levels in this bay segment.

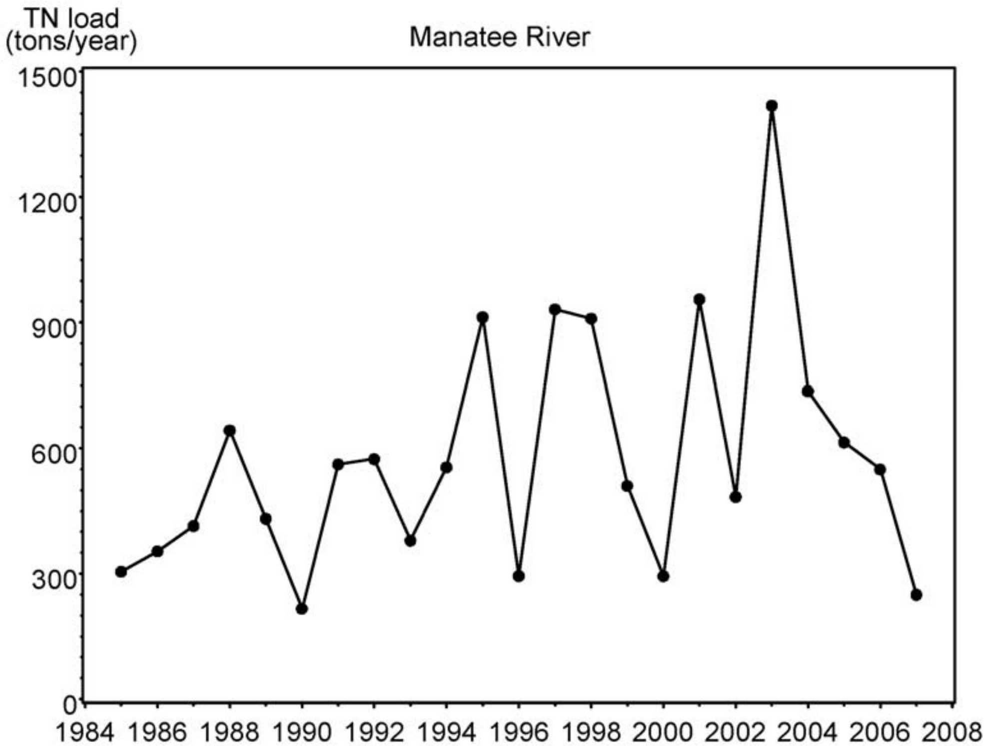

Figure 4-6. Annual TN load in Manatee River.

4.3 Empirical Relationships between Chlorophyll *a* and Light

Previous work by Dixon and Leverone (1995) determined that the minimum light requirement for turtle grass (*Thalassia testudinum*) is 20.5% of incident subsurface light. An estimate of subsurface light as a fraction of incident light can be obtained using Beer's law, with the relationship dependent upon the diffuse attenuation due to water quality constituents (chlorophyll a, turbidity, color) (Janicki and Wade, 1996). The diffuse attenuation coefficient, K_D, can be approximated by a factor divided by Secchi disc depth (Giesen et al., 1990). For this analysis, concurrently measured light attenuation data (from light sensors) and Secchi disk data, for 1991-2010 in Boca Ciega Bay and 2005-2010 in Terra Ceia Bay and Manatee River, were multiplied to provide a sample-specific estimate of the "Giesen factor". For a given segment, the median of these factor values was chosen to represent the Giesen factor. This factor was combined with the Secchi disc data from all samples to derive a diffuse light attenuation coefficient for all samples. Using Beer's law, this K_D allowed estimation of the depth to which 20.5% of subsurface irradiant light penetrated (Z).The relationship between mean monthly chlorophyll *a* concentration and Z, and between chlorophyll *a* concentration and Secchi disc depth for the Manatee River are shown in Figures 4-7 and 4-8. In this bay segment, the relationship between chlorophyll *a* and Z explained 17% of the variation in chlorophyll.

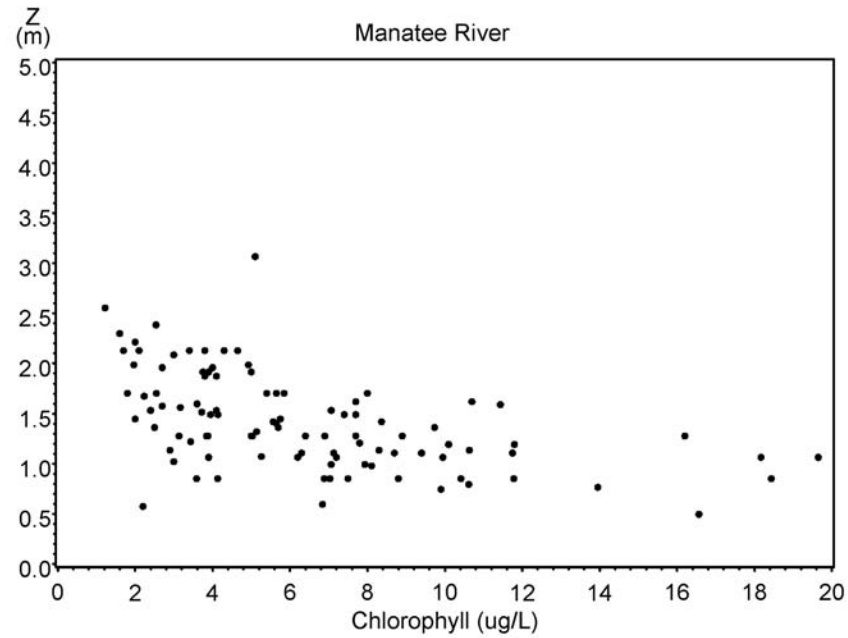

Figure 4-7. Empirical relationship between chlorophyll *a* concentration and Z (depth at which 20.5% of irradiant light is available for seagrass) in Manatee River.

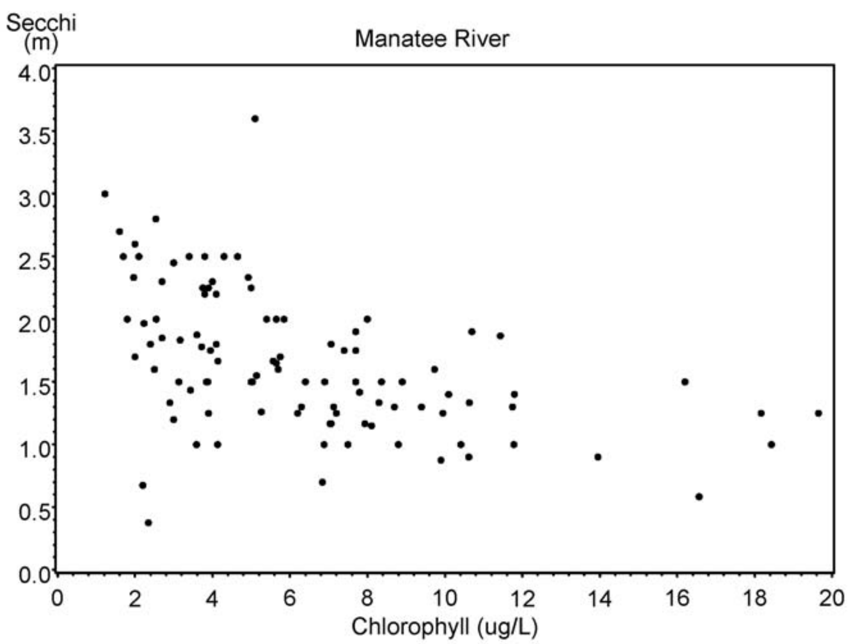

Figure 4-8. Empirical relationship between chlorophyll *a* concentration and Secchi disc depth in Manatee River.

4.4 Proposed Chlorophyll *a* Target

In order to propose chlorophyll *a* targets and thresholds, it was necessary to delineate the historical depth distribution for seagrasses in each bay segment. To do this, historical seagrass data were examined to determine their spatial extent and depth distribution during 1950 (Janicki and Wade, 1996). As discussed above, seagrasses have been limited to the area downstream of the Braden River in estimates based on aerial photography. Based on the cumulative frequency of depths at which seagrasses were observed, a target depth was identified as the depth above which 95% of all seagrasses historically occurred in each bay segment. This depth was used to provide a baseline from which to assess more recent water quality and clarity data. Figure 4-9 illustrates the cumulative frequency distribution for historical seagrass depths in Manatee River. Historically, 95% of seagrass habitat in Manatee River was found at depths up to 1.5 m. Therefore, 1.5 m is the potential depth target that could be used to develop the chlorophyll *a* target for Manatee River.

As discussed in Section 3.4, quantitative relationships were investigated between chlorophyll *a* concentrations and light attenuation. Although a statistically significant relationship was identified between chlorophyll *a* and light attenuation in Manatee River, this relationship left a considerable amount of variability unexplained. Therefore, a reference period approach was used to develop the chlorophyll *a* target and threshold for Manatee River.

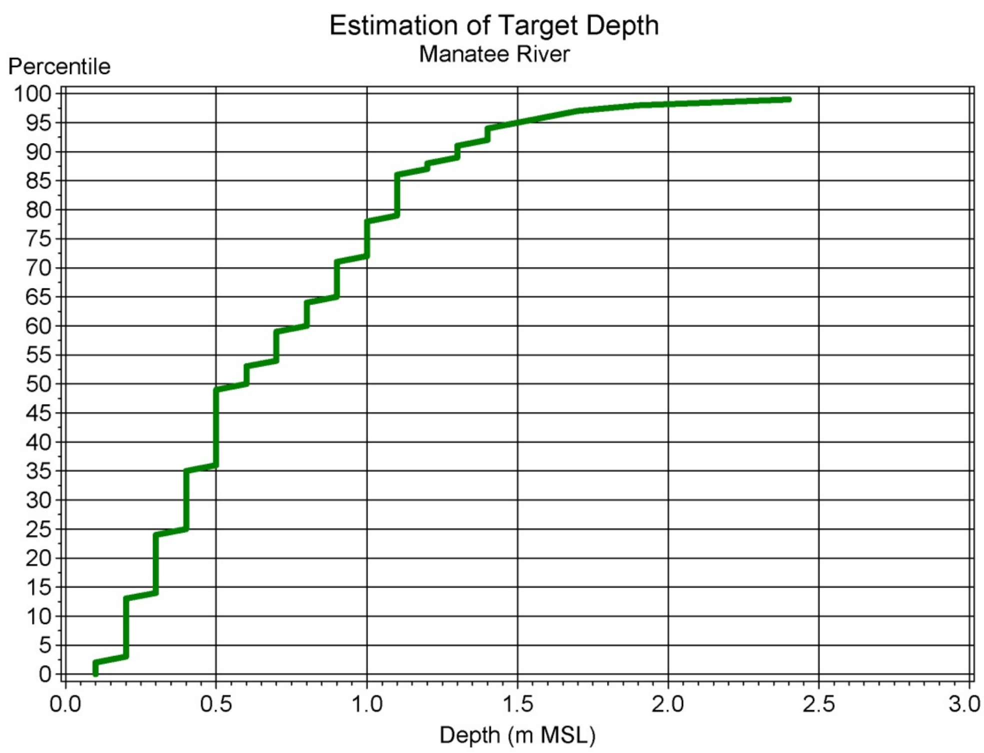

Figure 4-9. Cumulative depth distribution of seagrass in Manatee River during the historical period (1950). The chlorophyll *a* target was derived from the depth target of 1.5 m, which was the estimated depth at which 95% of seagrass occurred historically.

Important changes to loadings to the Manatee River system have occurred since the early 1990s, including the cessation of discharges from the Tropicana North America facility and the increased reuse of wastewater from City of Bradenton facility. Therefore, the selection of a more recent reference period was appropriate as it is representative of more recent water quality conditions in the segment. This is supported by inspection of the chlorophyll record (Figure 4-5), which shows high values during the early 1990s likely associated with discharges from a facility under consent order. Using the approach of Janicki and Wade (1996), the reference period that was selected for Manatee River was 2003-2007. The reference period was selected because it is representative of a period when water quality conditions (TN, TP, chlorophyll a, and water clarity) and seagrasses were stable or improving.

The water quality conditions commensurate with seagrass presence are those conditions found downstream of the mouth of the Braden River (water quality stations identified in Figure 2-2), as this is the only area where seagrasses are delineated based on the aerial photography. Therefore, only water quality data from those sites downstream of the Braden River were used in development of chlorophyll and nutrient concentration targets and thresholds. This must be accounted for when performing compliance assessment, which should use data only from these sites for comparison to targets and thresholds.

The mean chlorophyll *a* concentration (target) during the reference period is 7.3 µg/L. Following the approach developed by Janicki and Wade (1996), an allowance was made to allow for the natural variability in the system. The threshold was calculated by summing the target (mean for the reference period) plus two standard errors. Based on this approach, the chlorophyll *a* threshold for Manatee River is 8.8 µg/L. Comparison of the proposed threshold with observed chlorophyll *a* concentrations during the period of record (Figure 4-10) indicates eight exceedences, but only two years have exceeded the threshold since 2000.

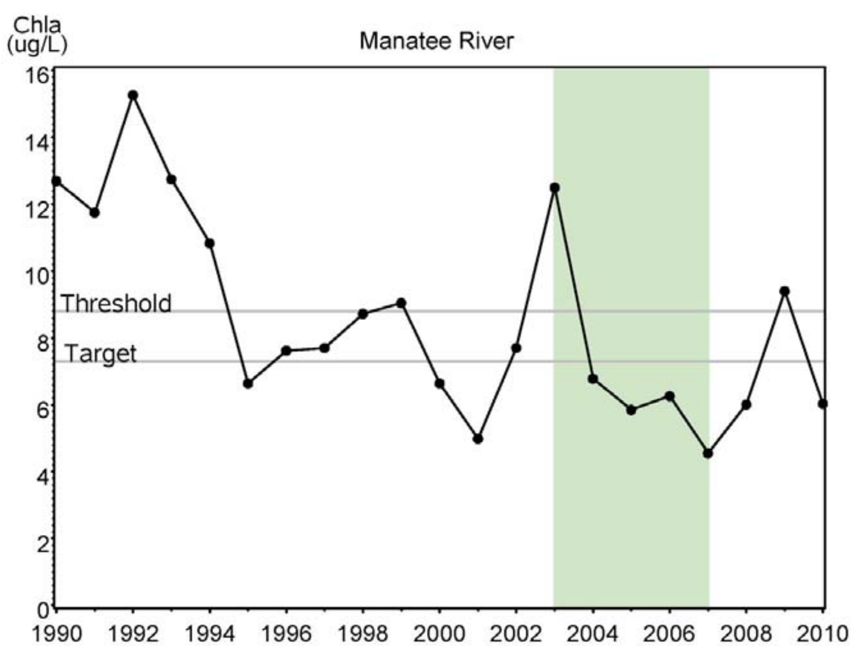

Figure 4-10. Annual average chlorophyll *a* concentration in Manatee River. The reference line represents the proposed chlorophyll *a* target and threshold based on the reference period approach. The reference period is highlighted.

4.5 Empirical Relationships between Chlorophyll *a* and Nutrients

The relationships between TN concentrations and chlorophyll *a* concentrations for the Manatee River are shown in Figure 4-11. Only 25% of the variation in chlorophyll *a* concentrations in this bay segment was explained by TN concentrations.

Similar to the poor relationships between chlorophyll *a* and TN concentrations in Manatee River, TN loads and chlorophyll *a* concentrations were significantly related, but left the majority of the variation unexplained (Figures 4-12). TN loads accounted for 22% of the variation in chlorophyll As the Manatee River is a highly managed system, it is not surprising to see that these relationships are weak. Because of the lack of defensible relationship between chlorophyll *a* concentration and TN load in Manatee River, the reference period approach was used to estimate the TN load target.

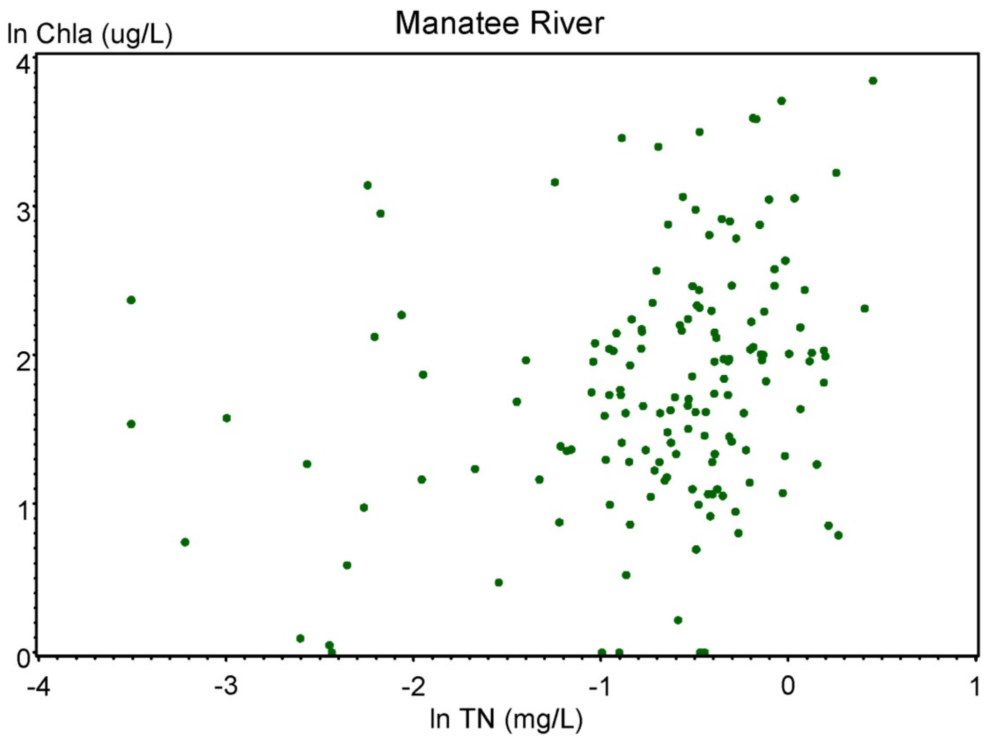

Figure 4-11. Empirical relationship between ln(chlorophyll *a*) concentration and ln(TN concentration) in Manatee River.

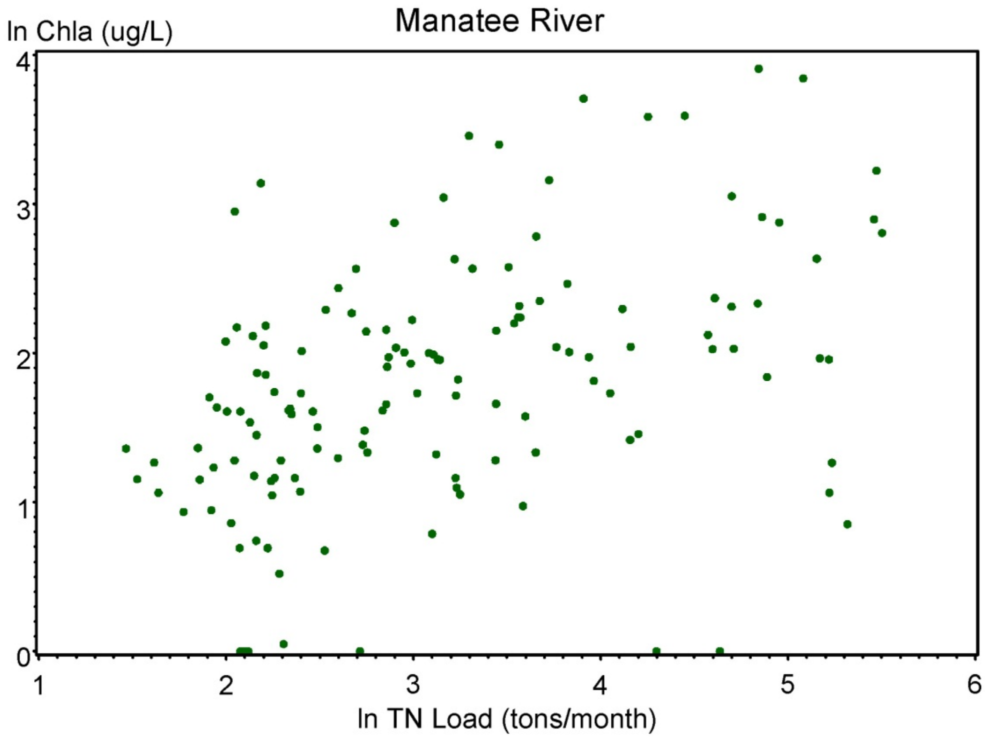

Figure 4-12. Empirical relationship between ln(chlorophyll *a*) concentration and ln(TN load) in Manatee River.

4.6 Recommended Loading- and Concentration-Based Nutrient Criteria

Attempts were made to develop statistically defensible relationships between monthly chlorophyll *a* concentrations and potential explanatory variables, including nutrients concentrations and loads. In addition to same-month nutrient concentrations and loads, numerous transformations and lags of these variables were also investigated. However, because of the lack of robust statistical relationships between chlorophyll *a* concentrations and TN loads and concentrations, the reference period approach was used to calculate the TN criteria for Manatee River. The concentration criterion was calculated by summing the annual average during the reference period (2003-2007) plus the standard deviation for the period of record. The reference period was selected because it is representative of a period when water quality (TN, TP, and chlorophyll a) and seagrasses were stable and water clarity was increasing (Figure 4-3). The proposed TN concentration criterion for this bay segment is 0.65 mg/L based on the reference period approach. Average annual TN concentrations in Manatee River have exceeded this proposed threshold in only three years over the past two decades, but have remained below the threshold since 2002 (Figure 4-13).

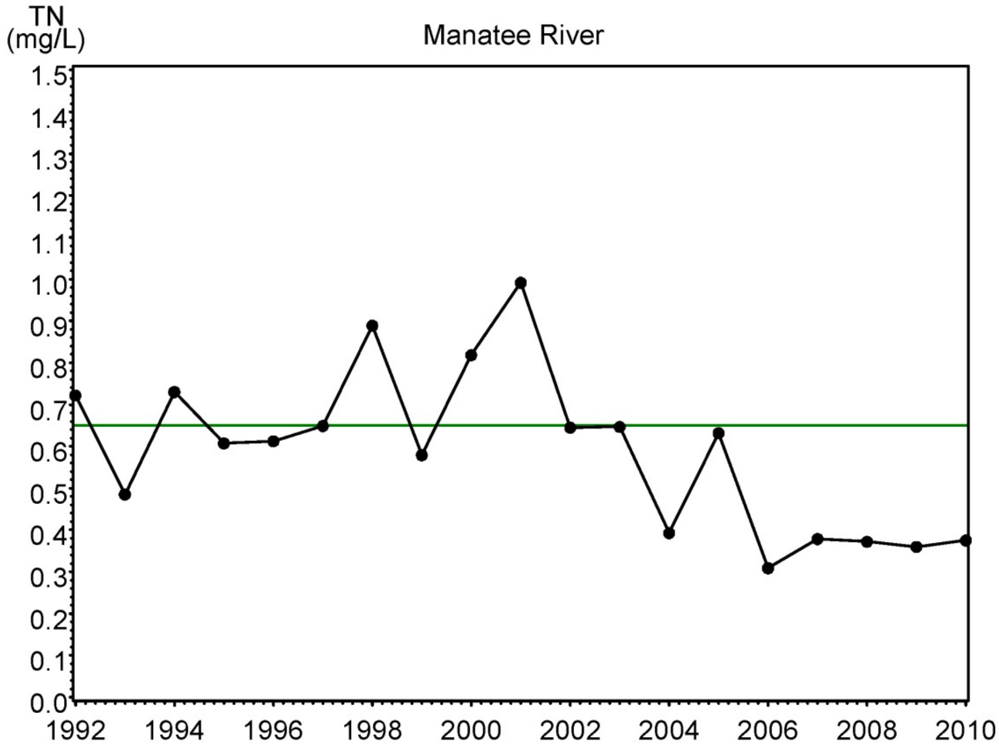

Figure 4-13. Annual geometric mean TN concentration in Manatee River. The reference line represents the proposed concentration-based TN criterion for the reference period.

As discussed above, inspection of seagrass and water quality data supported the finding that the 2003-2007 period is a better choice as a reference period than 1992-1994. However, loadings from the 2003-2007 period are substantially higher than those from the 1992-1994 period. Therefore, to be consistent with the RA, 1992-1994 was selected as the reference period for setting loading targets. Therefore, it is expected that the TN loading target will be protective of not only the Manatee River segment, but of the Lower Tampa Bay segment as well.

The proposed TN load target for Manatee River is the average annual load for the 1992-1994 reference period (503 tons/year). Average annual TN loads have regularly exceeded the proposed target in the 23 years of loading estimates, with the most recent exceedence occurring from 2003-2006 (Figure 4-14).

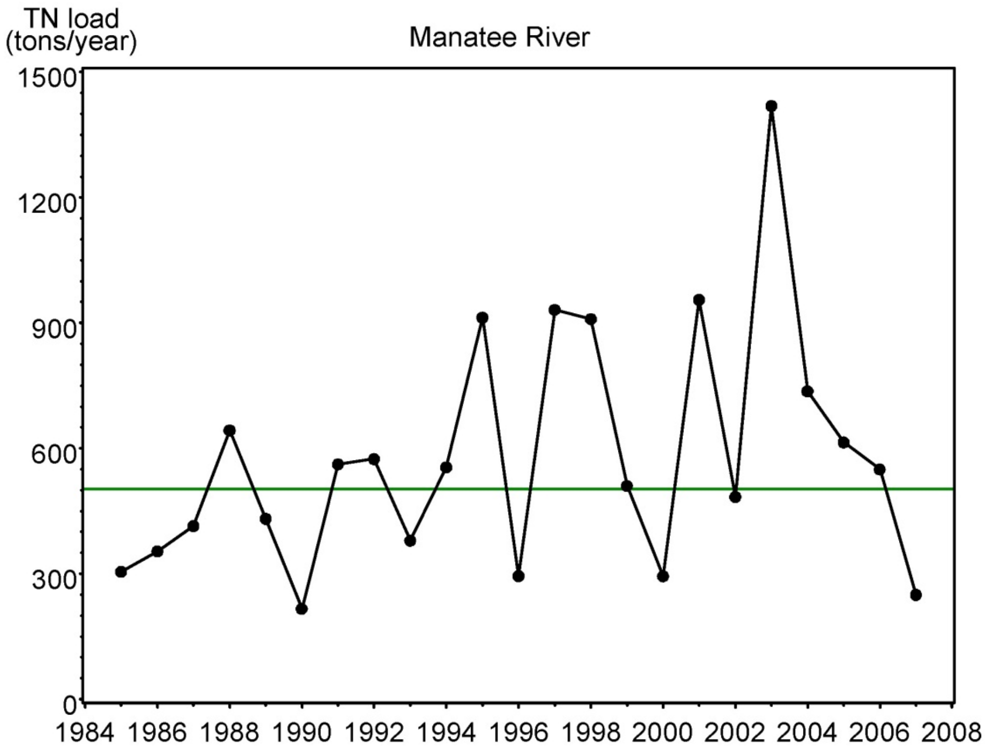

Figure 4-14. Annual TN load in Manatee River. The reference line represents the proposed loading-based TN target for the reference period.

As discussed in Section 3.6 for Terra Ceia Bay, analysis of loading targets revealed exceedences although water quality and seagrasses were stable or improving. Therefore, 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. The TN delivery ratio for Manatee River based on the 2003-2007 reference period is 1.80 tons TN per million cubic meters of freshwater delivered. Analysis of the time series plot of the annual TN delivery ratio for Manatee River (Figure 4-15) reveals that the TN threshold (i.e., the TN delivery ratio) has been exceeded 1 time out of 23 years. This result is consistent with the improvements in water quality and seagrasses in Manatee River.

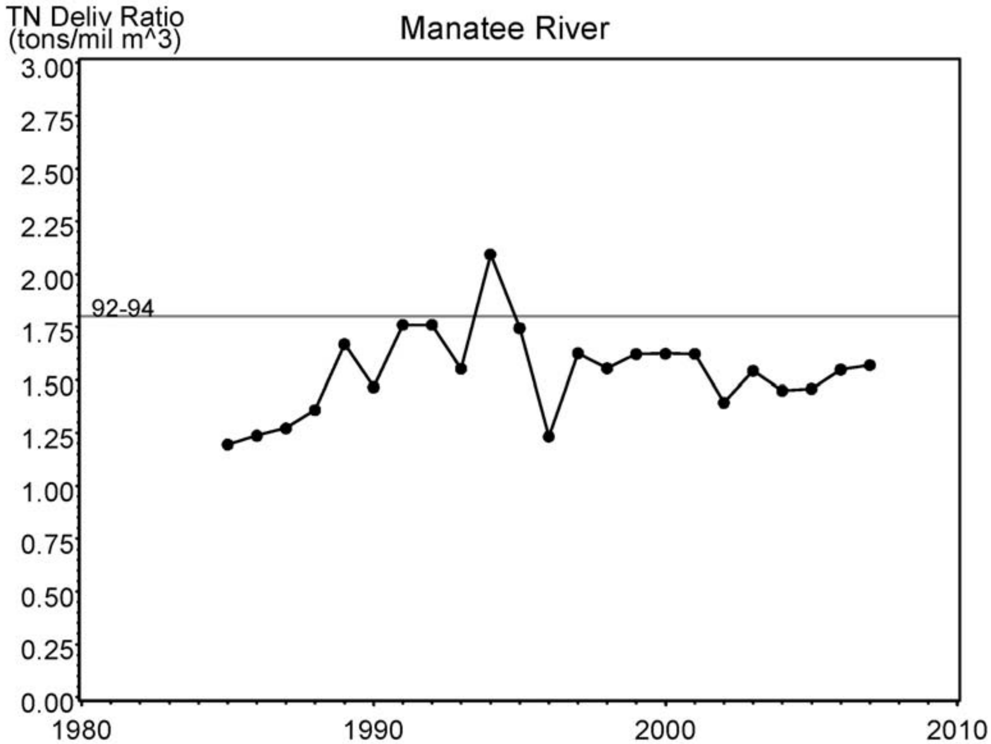

Figure 4-15. Annual TN load delivery ratio in Manatee River. The reference line represents the proposed loading-based TN criterion for the reference period.

5.0 Boca Ciega Bay

Boca Ciega Bay is a 36 mi^2 open-water segment of the Tampa Bay estuary system and is located between the southern tip of Pinellas County and barrier islands separating the bay from the Gulf of Mexico (Figure 1-1). It is bounded to the northwest by Clearwater Harbor at "The Narrows" and to the southeast by Mullet Key and a line of mangrove islands and sand bars that extend to the mainland at Pinellas Point. Although the southern-most portions of the bay do have high rates of interflow with Lower Tampa Bay, tidal flows through The Narrows at the north end of the bay are very restricted. Water also passes between the bay and gulf through several inlets, including Bunces Pass just north of Mullet Key, Pass-a-Grille Channel farther north, Blind Pass at Treasure Island, and John's Pass, the northern-most conveyance. The bay is shallow with much of the southern portion 2 feet deep or less with only isolated pockets of water more than 5 feet deep. The Intracoastal Waterway (ICW) bisects the bay and has a design depth of 6 feet.

The area of the Boca Ciega Bay watershed is approximately 92 mi^2 and, except for Mullet Key (Pinellas County's Ft. DeSoto Park) and isolated small mangrove islands (Indian Key, Whale Key, Cow and Calf Key, and others) is totally urbanized (86% of the total watershed area in 2005). Coastal wetlands comprise about 5% of the watershed area. Limited freshwater inflows are from tributaries Bear Creek, Clam Bayou Drain, Cross Canal, Lake Seminole Outfall and the Seminole Bypass Canal. There are no major sources of freshwater inflow to the bay. The watershed extends into historically- submerged areas through extensive dredge and fill developments, mainly residential with finger canals, that were constructed between the 1950s and 1970s. These created uplands not only reduce the bay bottom area but also greatly restrict circulation in the bay. Although water quality in the northern portions of the bay suffers from low circulation rates and pollutant loading from urban runoff, the southern bay with its better circulation and lower runoff supports significant seagrass meadows. The western side of the barrier islands faces the Gulf of Mexico and supports extensive recreational beaches. The Ft. DeSoto beaches are regularly listed among the best in the country.

While seagrass target development looked at Boca Ciega Bay as a whole and is therefore managed as a whole, recent work for Pinellas County to evaluate circulation in Boca Ciega Bay revealed differences in the northern and southern portions of the bay. The study indicated that water in the northern portion of Boca Ciega Bay (Figure 5-1) exchanged with the Gulf of Mexico primarily through Johns Pass and Blind Pass, so that the southern portion of Boca Ciega Bay (Figure 5-2) exchanges with Lower Tampa Bay and the Gulf of Mexico (Levy, 2009). The analysis of water quality that follows lends support to this delineation as water quality differences between Boca Ciega Bay north and south are apparent.

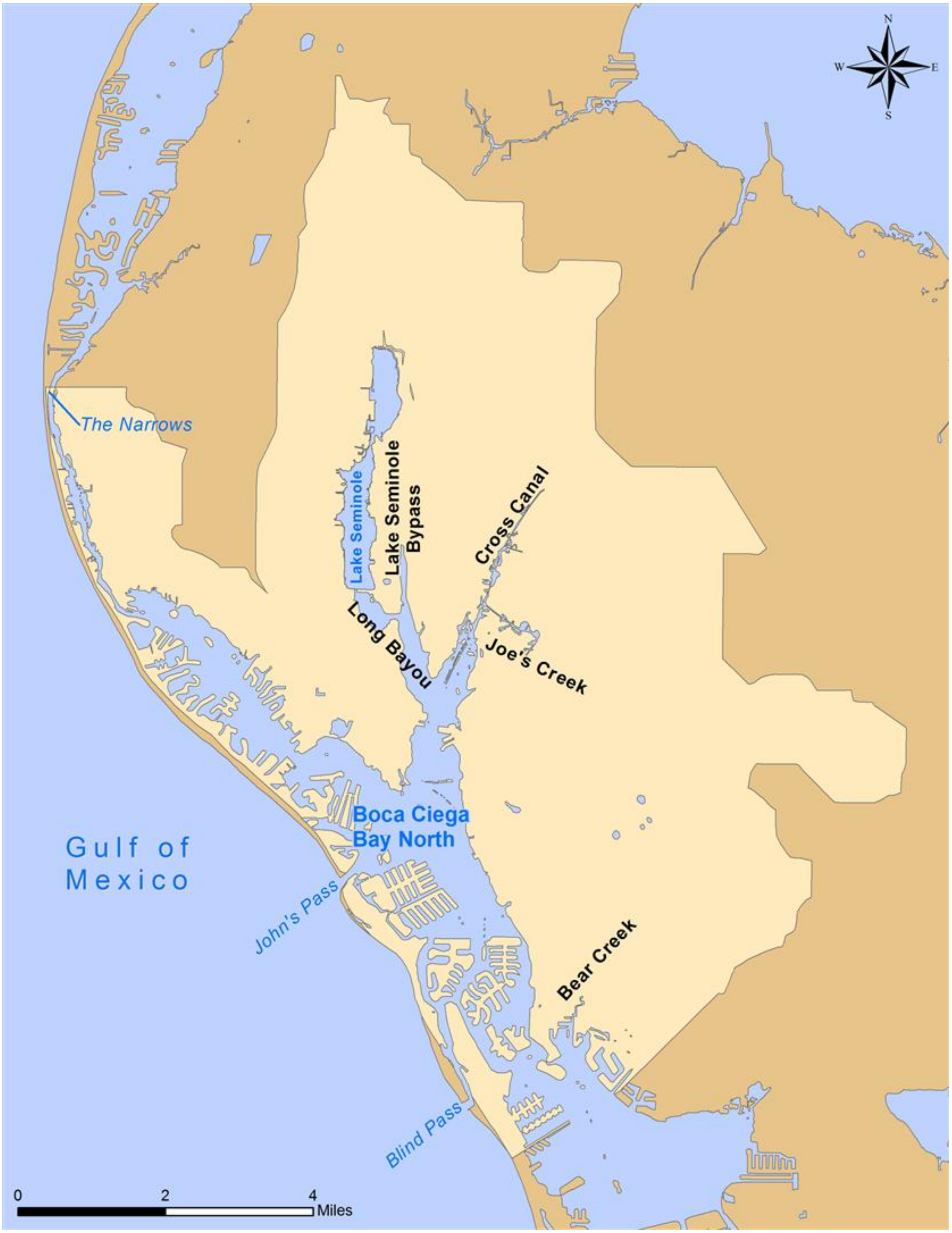

Figure 5-1. Boca Ciega Bay North segment.

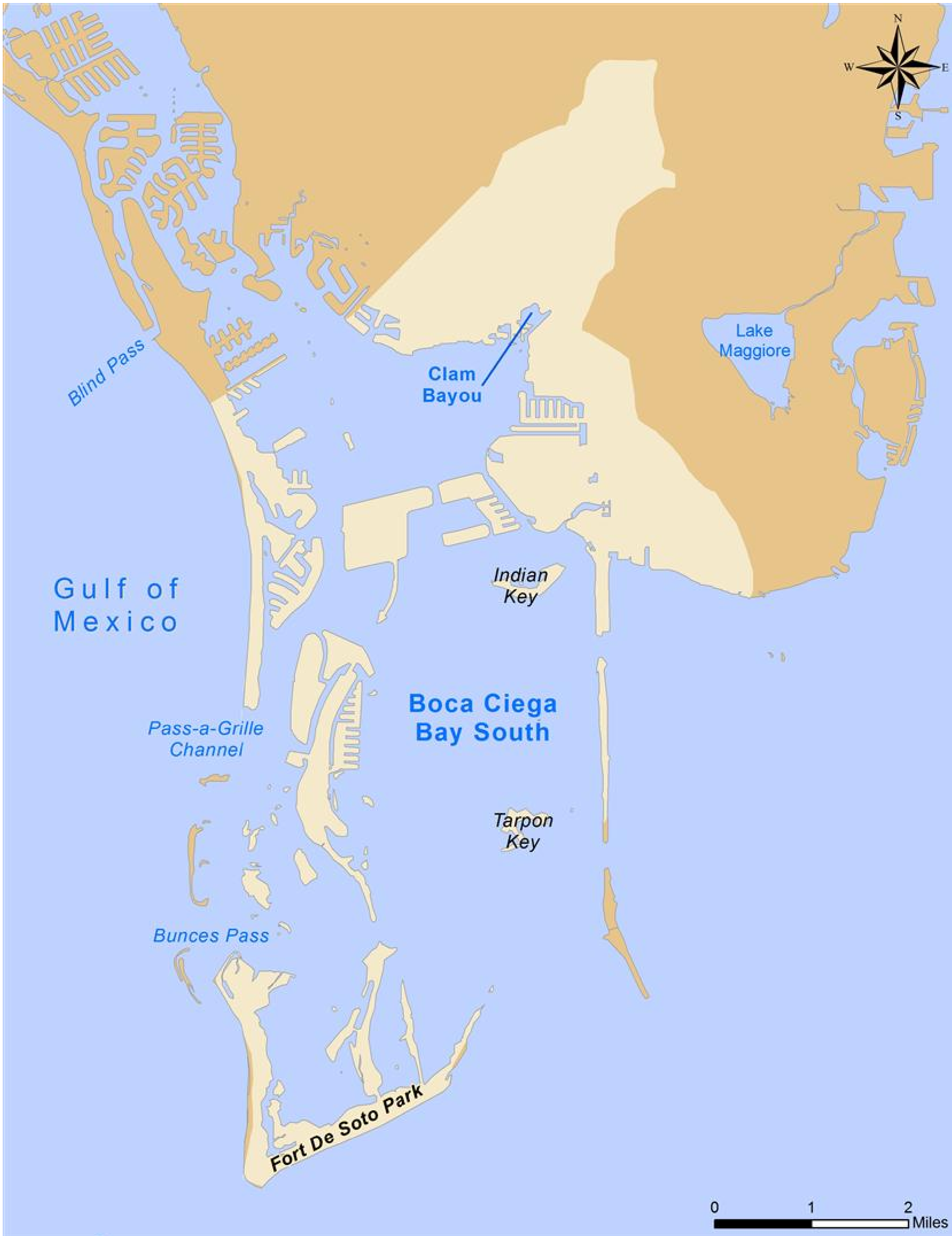

Figure 5-2. Boca Ciega Bay South segment.

5.1 Boca Ciega Bay North

In this subsection, the development of numeric nutrient criteria for Boca Ciega Bay North is presented, including:

- a summary of seagrasses, including the seagrass target
- a description of water quality and loadings,
- a description of empirical relationships between chlorophyll *a* and light attenuation,
- the proposed chlorophyll *a* targets,
- a description of empirical relationships between chlorophyll *a* and nutrients, and
- the recommended nutrient criteria.

5.1.1 Seagrass Targets

As discussed in Section 2.1, seagrass targets have been developed for the segments of Tampa Bay. However, as discussed in Section 3.1, chlorophyll *a* targets were not developed for Boca Ciega Bay during the initial target development because of insufficient data at the time (Janicki and Wade, 1996; Janicki et al., 1995). In this section, estimates of recent seagrass acreages are examined relative to the seagrass target for Boca Ciega Bay North.

5.1.1.1 Temporal Distribution of Seagrass

Seagrasses in Boca Ciega Bay North are presently just over 1,300 acres, with only half of the historical extent remaining due to dredge and fill activities in the 1950s and 1960s. The areal extent has increased since 1990 and has been relatively stable since 2006 during which time estimates have been above the seagrass target (as determined by Janicki et al., 1995).

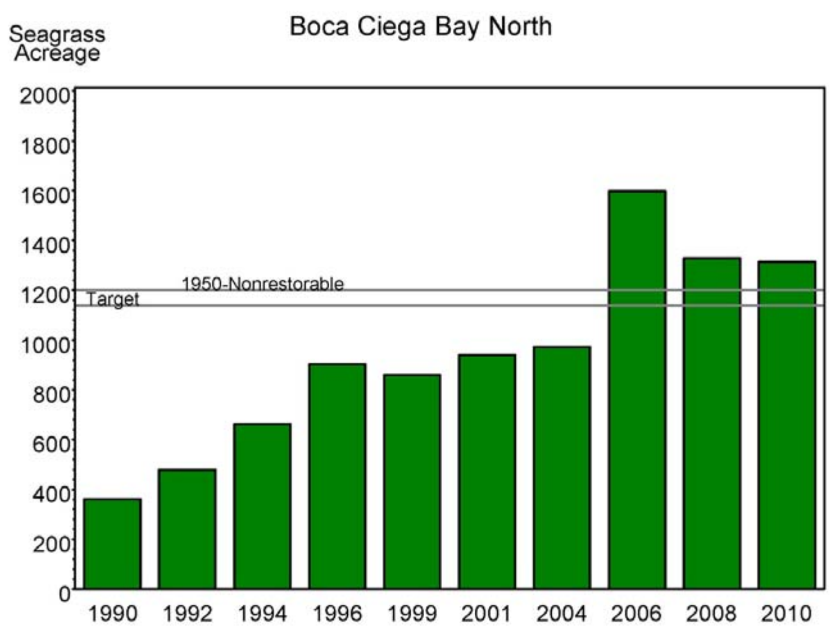

Figure 5-3. Extent of seagrasses in recent surveys in Boca Ciega Bay North. The reference lines indicate the seagrass target and 1950s acreage minus any nonrestorable areas for this bay segment.

5.1.2 Temporal Variability in Ambient Water Quality and Nutrient Loadings

Examination of water quality and clarity data from 1996-2010 indicates relatively stable conditions in Boca Ciega Bay North. Data used to determine segment Secchi disc depth were first filtered to remove any data where Secchi disc depth was greater than or equal to the bottom depth. Annual average Secchi disc depth fluctuated between 1.0 m and 1.5 m over the period of record (Figure 5-4). Water clarity was greatest in 2005 when annual average Secchi disc depth was 1.5 m.

TN concentrations in Boca Ciega Bay North were stable over the same time period. Annual average TN concentrations in this bay segment fluctuated between 0.4 and 0.6 mg/L but remained relatively consistent over time (Figure 5-5). Peak TN concentrations were observed in 1997, 2001, 2005 and 2009.

Annual average chlorophyll *a* concentrations in Boca Ciega Bay North ranged from 5.5-10 μg/L between 1991 and 2010 (Figure 5-6). Peak concentrations in 1997-98 and 2004-05 tend to coincided with elevated rainfall and associated TN loads (Figure 5-7). Interannual variation in chlorophyll *a* concentrations was relatively low (4 μg/L during the time period examined).

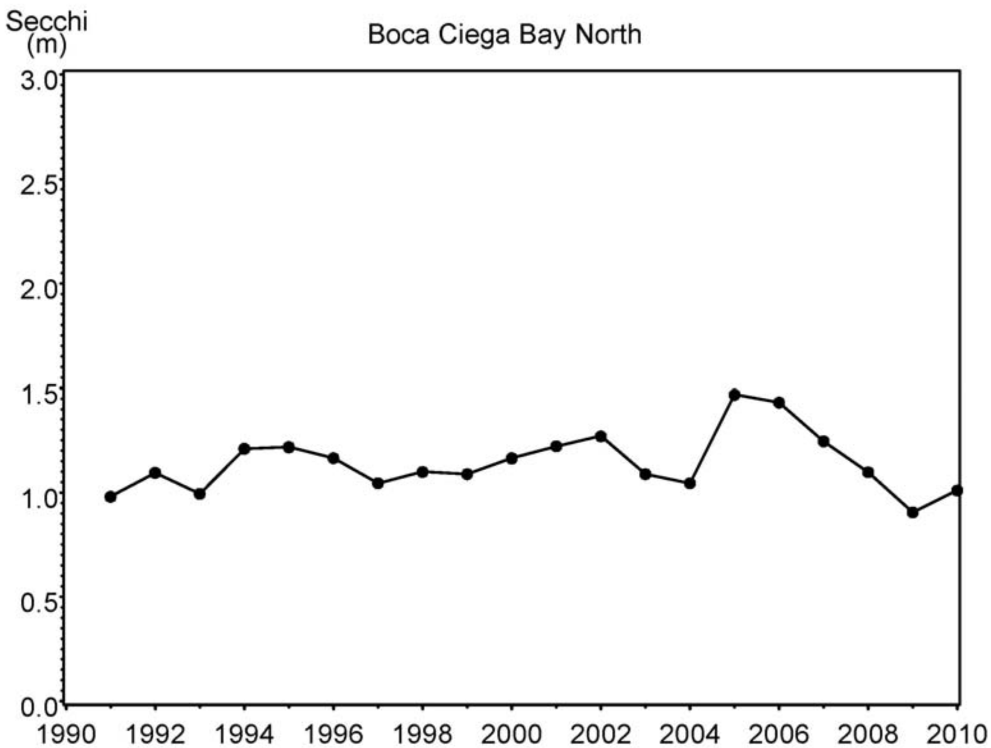

Figure 5-4. Annual average Secchi disc depth in Boca Ciega Bay North.

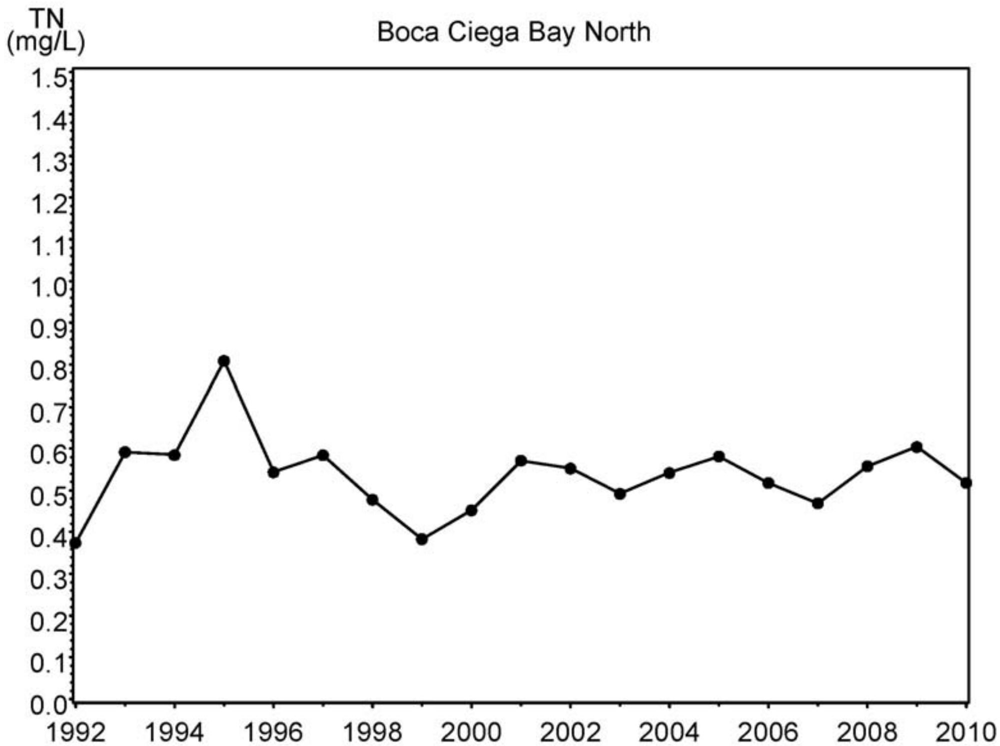

Figure 5-5. Annual average TN concentration in Boca Ciega Bay North.

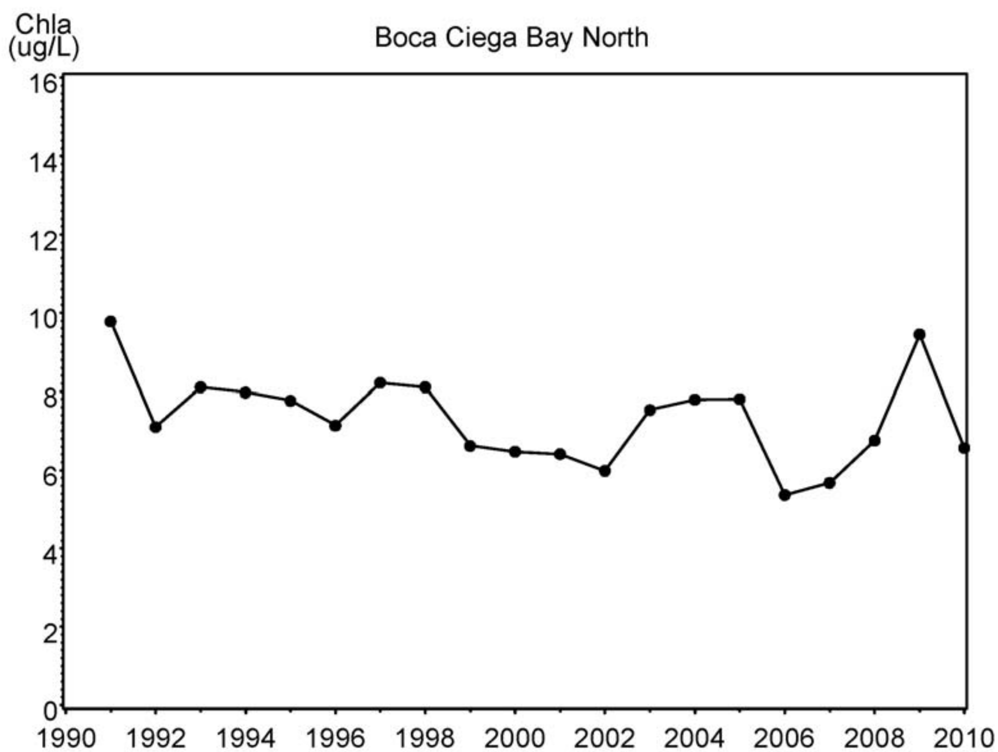

Figure 5-6. Annual average chlorophyll *a* concentration in Boca Ciega Bay North.

Nutrient loads were available for the period 1985 through 2007 based on previous work for the TBEP and FDEP. Nutrient loads in Boca Ciega Bay North were highly variable over the period of record as the loads are primarily driven by rainfall and associated nonpoint source runoff (Figure 5-7). Total nitrogen loads fluctuated between 75 tons/year and nearly 425 tons/year with the largest variation occurring during consecutive years (Figure 5-7), generally in keeping with annual variation in rainfall to the watershed. Between 2004 and 2007, TN loads ranged from just under 150 tons/year to approximately 325 tons/year.

It should be noted that an FDEP consent order signed in January 2002 required the Pinellas County South Cross Bayou water reclamation facility to cease discharging treated wastewater to deep well injection. The consent order was the result of the potential migration of injected effluent into the overlying aquifer, although that aquifer is not a potable water source. Without the ability to discharge to deep well injection, the facility was compelled to only discharge to surface waters or reuse. Following the signing of the consent order, Pinellas County completed a $143 million renovation of the South Cross facility in 2003. Starting in February 2002, treated effluent that would have been discharged to deep well injection was discharged to surface waters. This action resulted in an increase in point source pollutant loads to Boca Ciega Bay North. The impact of this decision can be seen clearly in Figures 5-7, where loads of TN were higher in the period 2003-2004. Though part of the increase in loads in 2003-2004 is due higher rainfall and associated nonpoint source runoff, surface water loads from South Cross Bayou were also higher during that time. During the 1999-2001 period, loads from the South Cross facility ranged from 11-16 tons TN. After the consent order, loads from the facility increased to around 60 tons TN in the 2003-2004 period. Since the peak in 2003-2004, TN loads from the South Cross facility have been declining as Pinellas County moves forward with its goal of 100% reuse for the South Cross facility.

5.1.3 Empirical Relationships between Chlorophyll *a* and Light

Previous work by Dixon and Leverone (1995) determined that the minimum light requirement for turtle grass (*Thalassia testudinum*) is 20.5% of incident subsurface light. An estimate of subsurface light as a fraction of incident light can be obtained using Beer's law, with the relationship dependent upon the diffuse attenuation due to water quality constituents (chlorophyll a, turbidity, color) (Janicki and Wade, 1996). The diffuse attenuation coefficient, K_D, can be approximated by a factor divided by Secchi disc depth (Giesen et al., 1990). For this analysis, concurrently measured light attenuation data (from light sensors) and Secchi disk data, for 1991-2010 in Boca Ciega Bay and 2005-2010 in Terra Ceia Bay and Manatee River, were multiplied to provide a sample-specific estimate of the "Giesen factor". For a given segment, the median of these factor values was chosen to represent the Giesen factor. This factor was combined with the Secchi disc data from all samples to derive a diffuse light attenuation coefficient for all samples. Using Beer's law, this K_D allowed estimation of the depth to which 20.5% of subsurface irradiant light penetrated (Z). The relationship between mean monthly chlorophyll *a* concentration and light attenuation, Z, and between chlorophyll *a* concentration and Secchi disc depth for Boca Ciega Bay North are shown in Figures 5-8 and 5-9. In this bay segment, light attenuation explained 22% of the variation in chlorophyll *a* concentration.

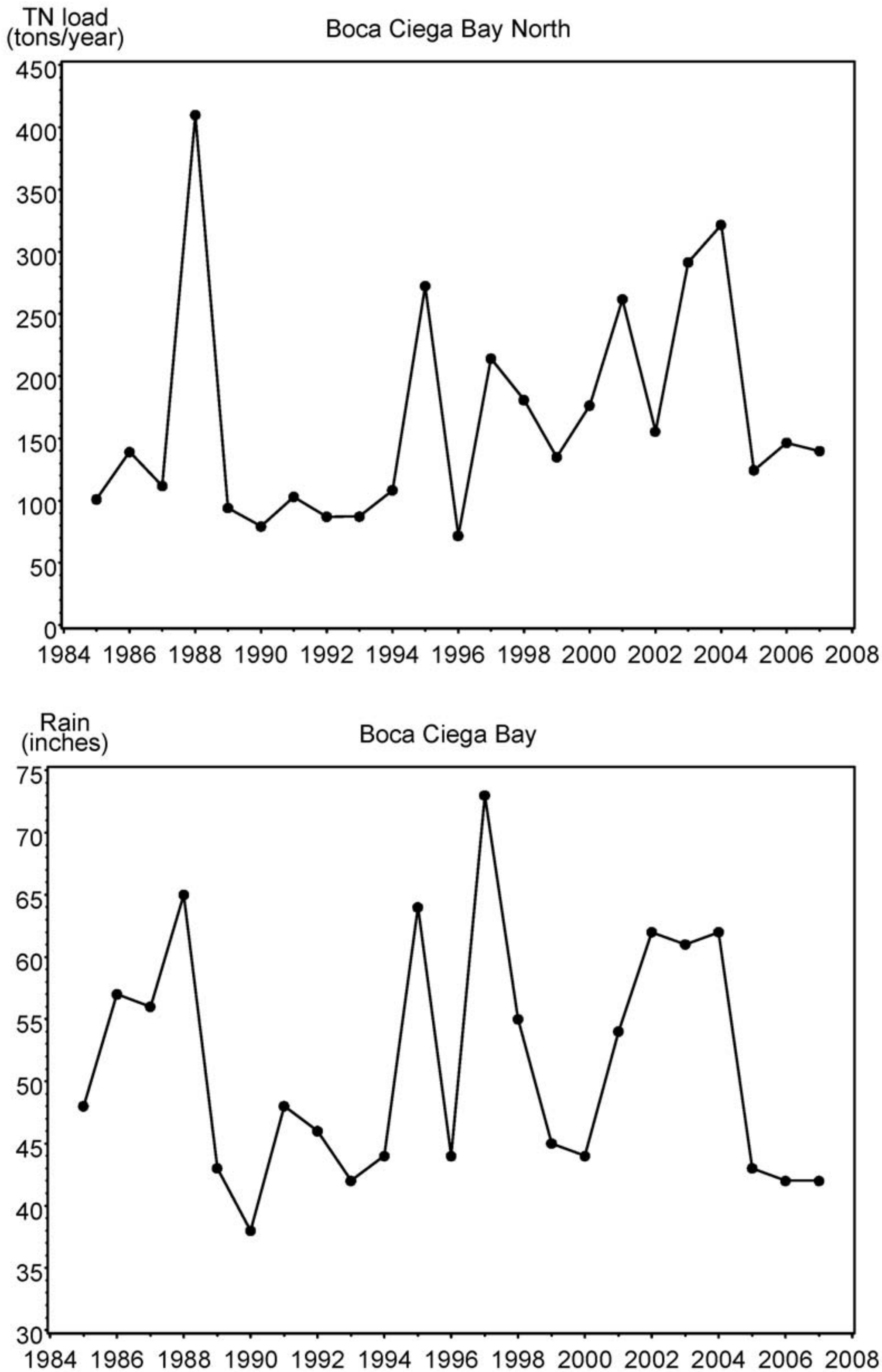

Figure 5-7. Annual TN load in Boca Ciega Bay North (top panel) and rainfall to Boca Ciega Bay watershed (bottom panel).

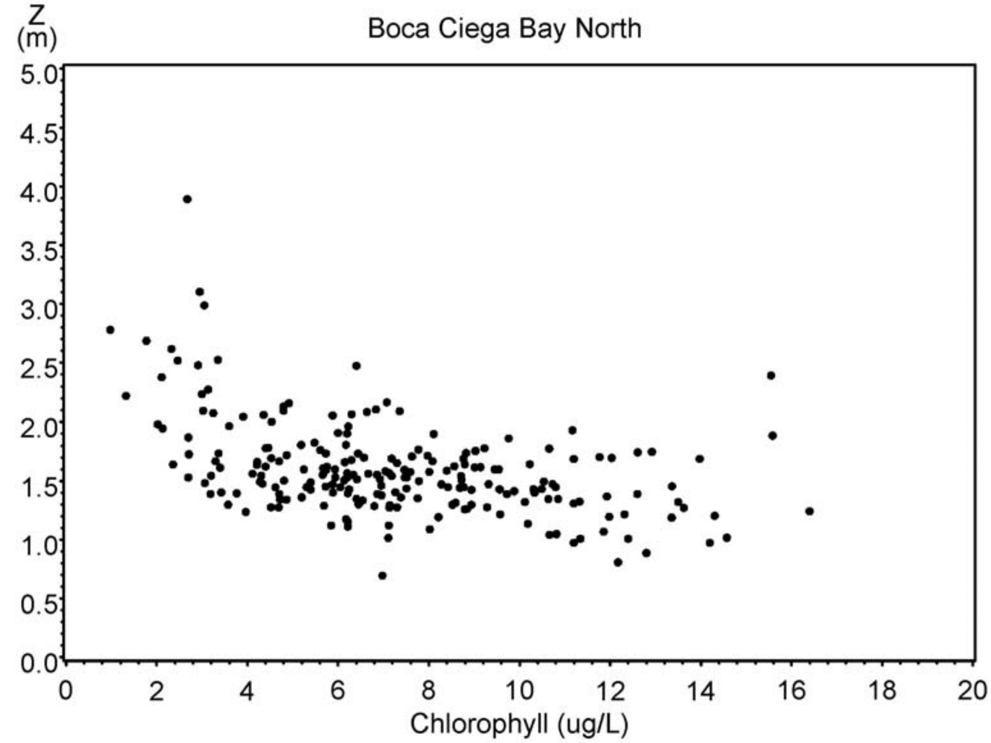

Figure 5-8. Empirical relationship between chlorophyll *a* concentration and Z (depth at which 20.5% of irradiant light is available for seagrass) in Boca Ciega Bay North.

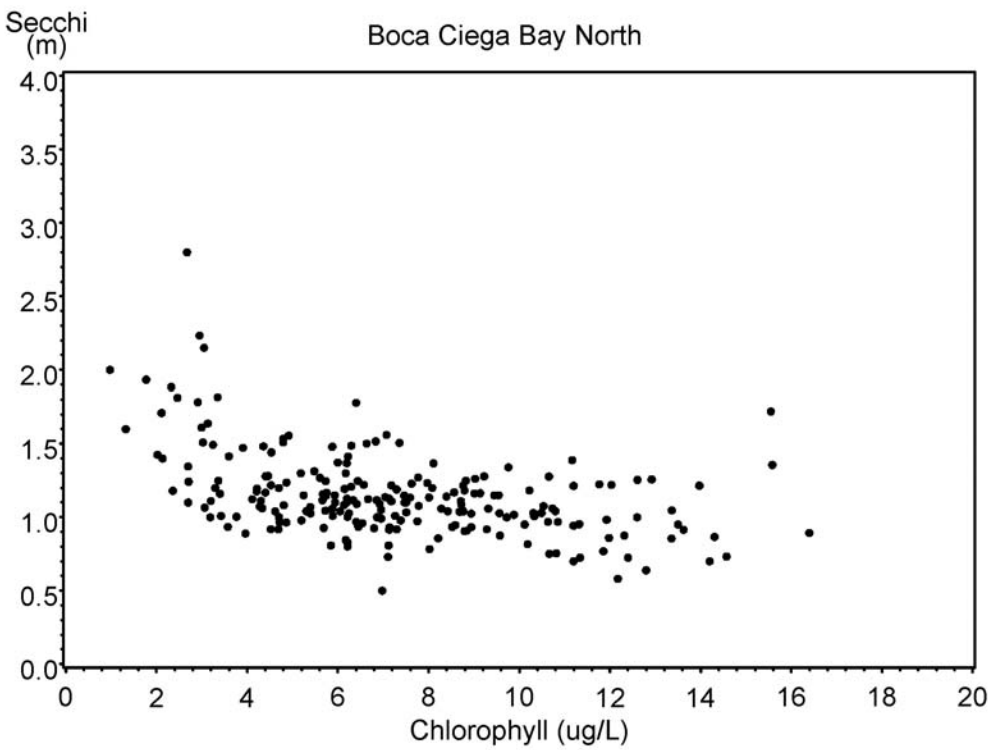

Figure 5-9. Empirical relationship between chlorophyll *a* concentration and Secchi disc depth in Boca Ciega Bay North.

5.1.4 Proposed Chlorophyll *a* Target and Threshold

In order to propose chlorophyll *a* targets and thresholds, it was necessary to delineate the historical depth distribution for seagrasses in each bay segment. To do this, historical seagrass data were examined to determine their spatial extent and depth distribution during 1950 (Janicki and Wade, 1996). Based on the cumulative frequency of depths at which seagrasses were observed, a target depth was identified as the depth above which 95% of all seagrasses historically occurred in each bay segment. This depth was used to provide a baseline from which to assess more recent water quality and clarity data. The cumulative depth distribution of seagrasses estimated for the historical period is shown in Figure 5-10. Based on the historical extent of seagrasses in Boca Ciega Bay North, a potential depth target of 1.7 m could be used to ensure that 95% of all seagrasses existed at depths receiving sufficient light for growth (i.e., ≤1.7 m).

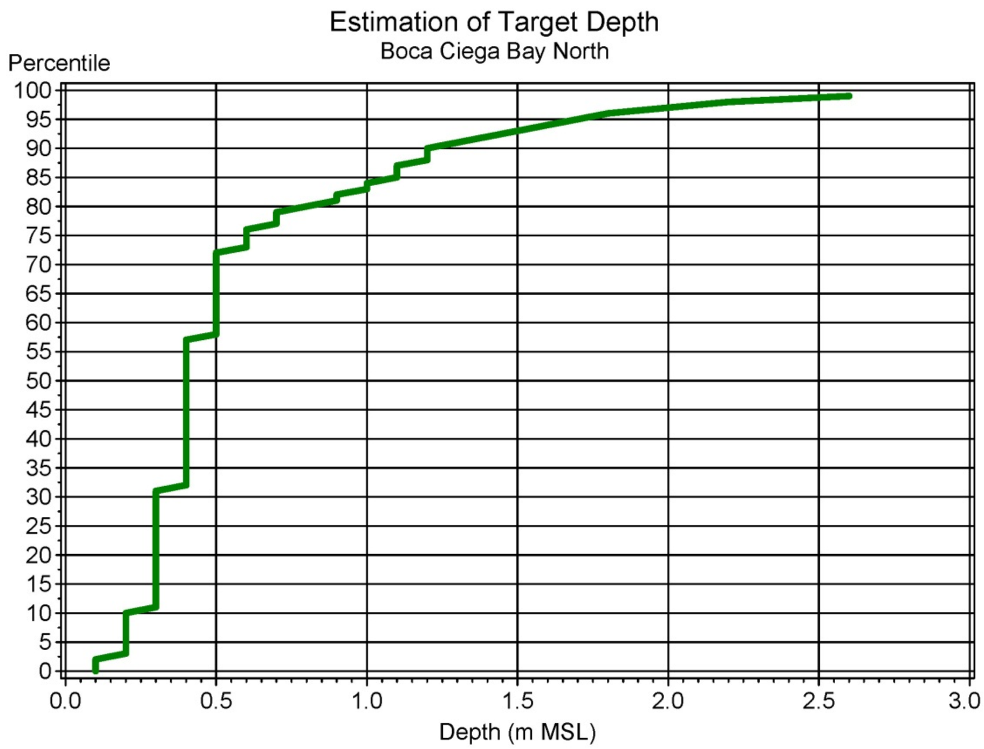

Figure 5-10. Cumulative depth distribution of seagrass in Boca Ciega Bay North during the historical period (1950). The chlorophyll *a* target was derived from the depth target of 1.7 m, which was the estimated depth at which 95% of seagrass occurred historically.

Although a statistically significant relationship was identified between chlorophyll *a* and light attenuation in Boca Ciega Bay North, this relationship left the majority (>75%) of the variability unexplained. Therefore, a reference period approach was used to develop the chlorophyll *a* target and threshold for Boca Ciega Bay North.

As discussed in Section 3.4, this is consistent with the methodology of Janicki and Wade (1996). Using the same approach, the reference period that was selected for Boca Ciega Bay was 1992-1994. The reference period was selected because it is representative of a period when water quality and water clarity were stable and seagrasses (Figure 5-3) were increasing. This is consistent with the four main bay segments of Tampa Bay. The mean chlorophyll *a* concentration (target) during the reference period is 7.7 µg/L. Following the approach developed by Janicki and Wade (1996), an allowance was made to allow for the natural variability in the system. The threshold was calculated by summing the target (mean for the reference period) plus one standard deviation, which results in a chlorophyll *a* threshold of 8.3 µg/L. Comparison of the chlorophyll *a* threshold with observed chlorophyll *a* concentrations during the period of record (Figure 5-11) indicates that chlorophyll *a* concentrations have been below the threshold during the majority of years, having only exceeded the chlorophyll *a* threshold in 1991 and 2009.

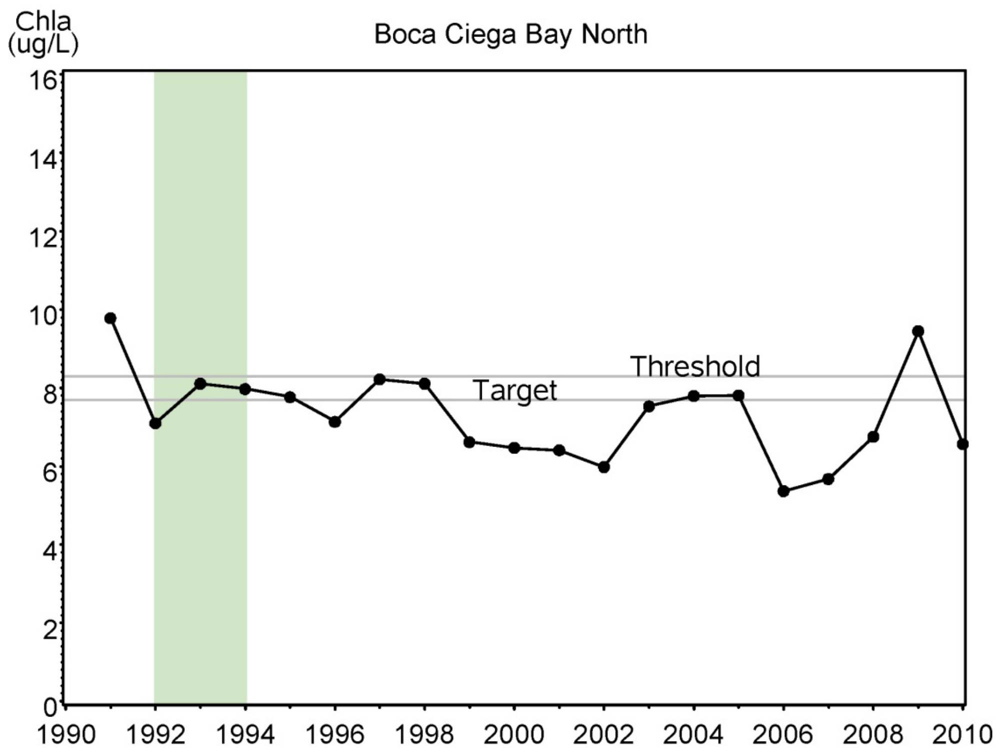

Figure 5-11. Annual average chlorophyll *a* concentration in Boca Ciega Bay North. The reference lines represent the proposed chlorophyll *a* target and threshold based on the reference period approach. The reference period is highlighted.

5.1.5 Empirical Relationships between Chlorophyll *a* and Nutrients

The relationship between TN concentrations and chlorophyll *a* concentration is shown in Figure 5-12. Total nitrogen concentrations accounted for only 14% of the variation in chlorophyll *a* concentrations in Boca Ciega Bay North.

The relationship between TNloads and chlorophyll *a* concentrations is shown in Figures 5-13. TN loads accounted for a small amount of the variation in chlorophyll *a* (21%).

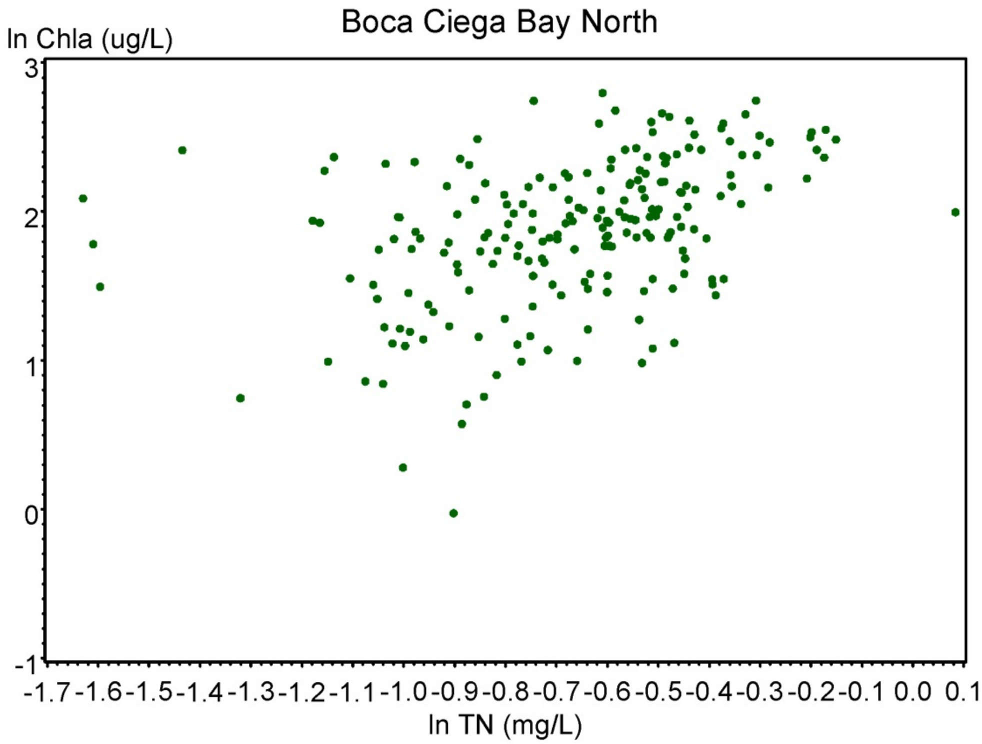

Figure 5-12. Empirical relationship between ln(chlorophyll *a*) concentration and ln(TN concentration) in Boca Ciega Bay North.

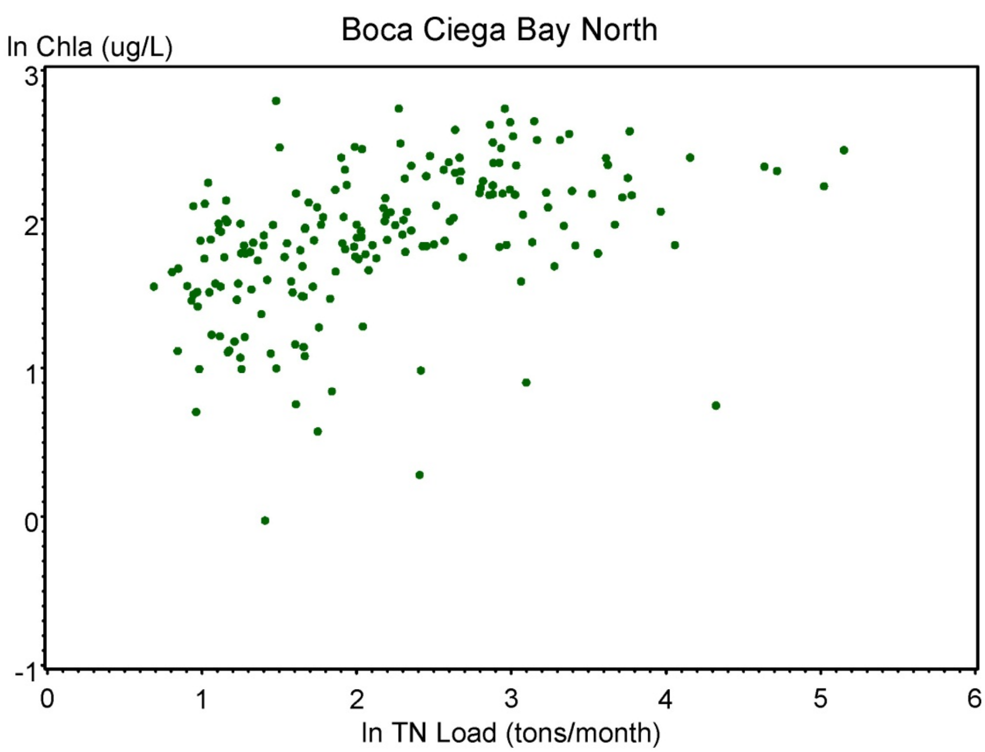

Figure 5-13. Empirical relationship between ln(chlorophyll *a*) concentration and ln(TN load) in Boca Ciega Bay North.

5.1.6 Recommended Loading- and Concentration-Based Nutrient Criteria

Because of the lack of robust statistical relationships between chlorophyll *a* concentrations and TN concentrations, the reference period approach was used to calculate the TN concentration criterion for Boca Ciega Bay North. The criterion was calculated by summing the annual average during the reference period (1992-1994) plus the standard deviation for the period of record. This method is consistent with the method used to develop TN concentration criterion for the four main segments of Tampa Bay (Janicki Environmental, 2010a). The reference period was selected because it is representative of a period when water quality and water clarity were stable and seagrasses (Figure 5-3) were increasing. The proposed TN concentration criterion for this bay segment is 0.57 mg/L based on the reference period approach. Average annual TN concentrations in this segment have remained below this proposed threshold during the majority of years during the past two decades, with exceedences in 1995 and 2009 (Figure 5-18). Using the same approach, the proposed TP concentration criterion for Boca Ciega Bay North is 0.11 mg/L. This threshold has not been exceeded during the period of record analyzed for this study (Figure 5-14).

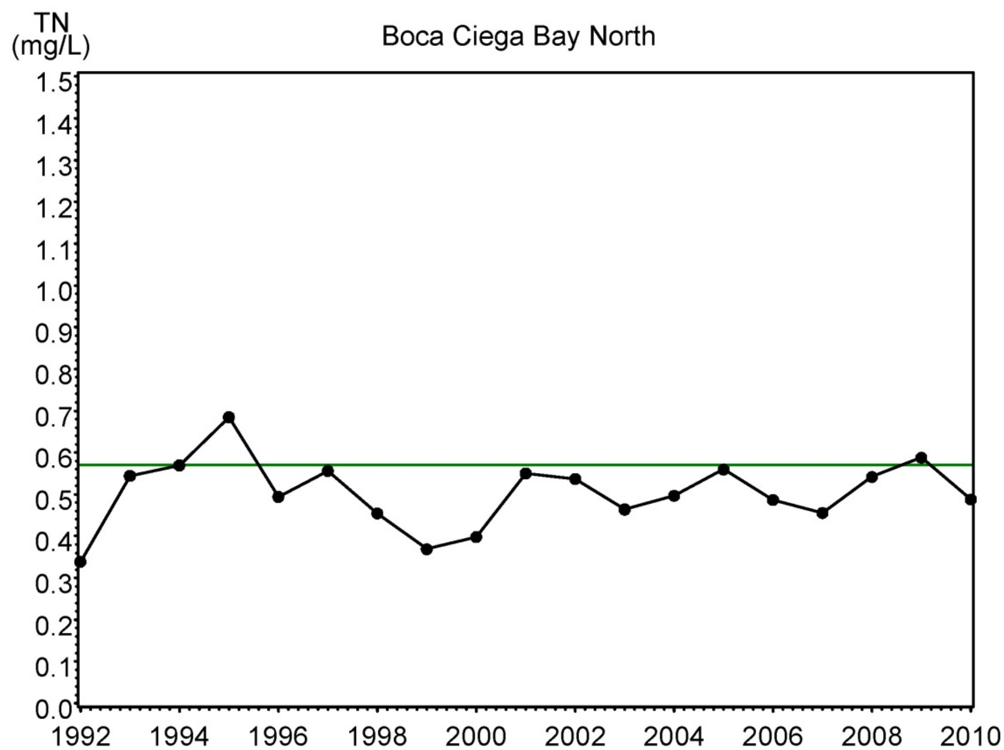

Figure 5-14. Annual geometric mean TN concentration in Boca Ciega Bay North. The reference line represents the proposed concentration-based TN criterion for the reference period.

Based on the reference period approach, the proposed TN load target for Boca Ciega Bay North is 94 tons/year. Average annual TN loads have exceeded the proposed TN load target in the majority of the previous 23 years because the 1992-1994 period had low TN loads relative to the period after 1994 (Figure 5-15).

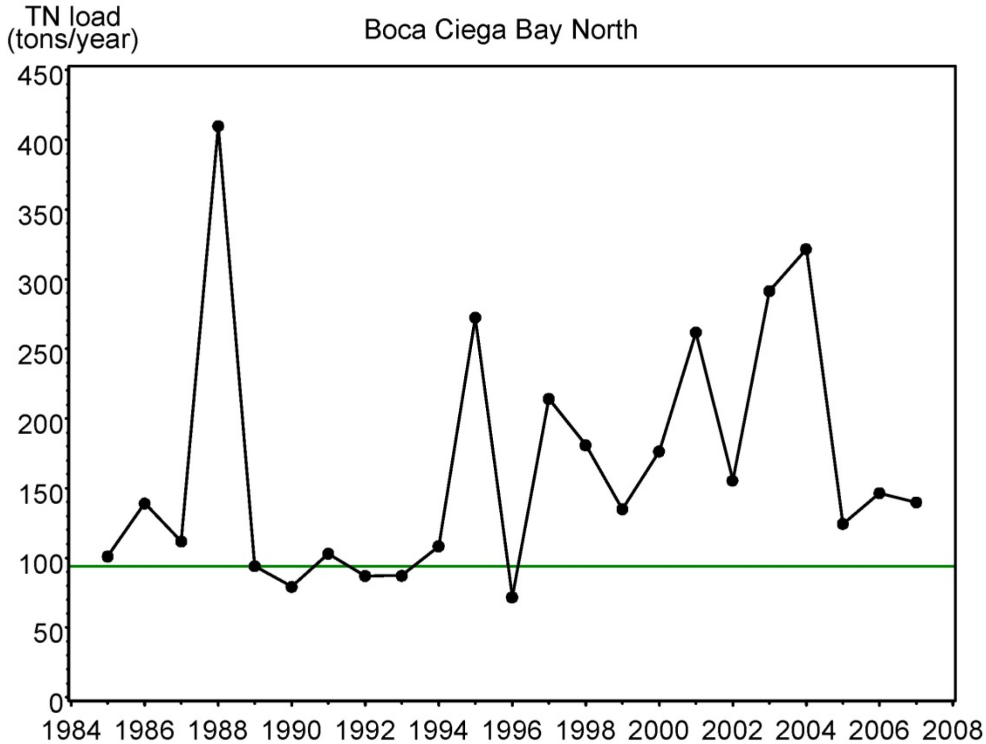

Figure 5-15. Annual TN load in Boca Ciega Bay North. The reference line represents the proposed loading-based TN target for the reference period.

As discussed in Section 3.6 for Terra Ceia Bay, analysis of loading targets revealed exceedences in Boca Ciega Bay North although water quality and seagrasses were stable or improving. This is also the case in Boca Ciega Bay North. Although in Boca Ciega Bay North, this is a result of the reference period loads (1992-1994) being lower than the loads since 1994. 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. The TN delivery ratio for Boca Ciega Bay North based on the 1992-1994 reference period is 1.54 tons TN per million cubic meters of freshwater delivered. Analysis of the time series plot of the annual TN delivery ratio for Boca Ciega Bay North (Figure 5-16) reveals that the TN threshold (i.e., the TN delivery ratio) has been exceeded ten times out of 23 years. However, no exceedences occurred between 2005 and 2007, when seagrasses exceeded the seagrass target for Boca Ciega Bay North.

Most notably, the TN delivery ratios have not changed significantly in Boca Ciega Bay North since the reference period, as the watershed is built out and the TN loads are dominated by nonpoint source runoff. It should also be noted that the South Cross Bayou water reclamation facility was required by FDEP to move from deep well injection of treated wastewater to surface water discharge to the estuary in January, 2002. This resulted in an increase in point source TN loads to Boca Ciega Bay North. The effect on the TN delivery ratio has been minimal as the TN concentration of treated wastewater is very similar to that found in nonpoint source runoff.

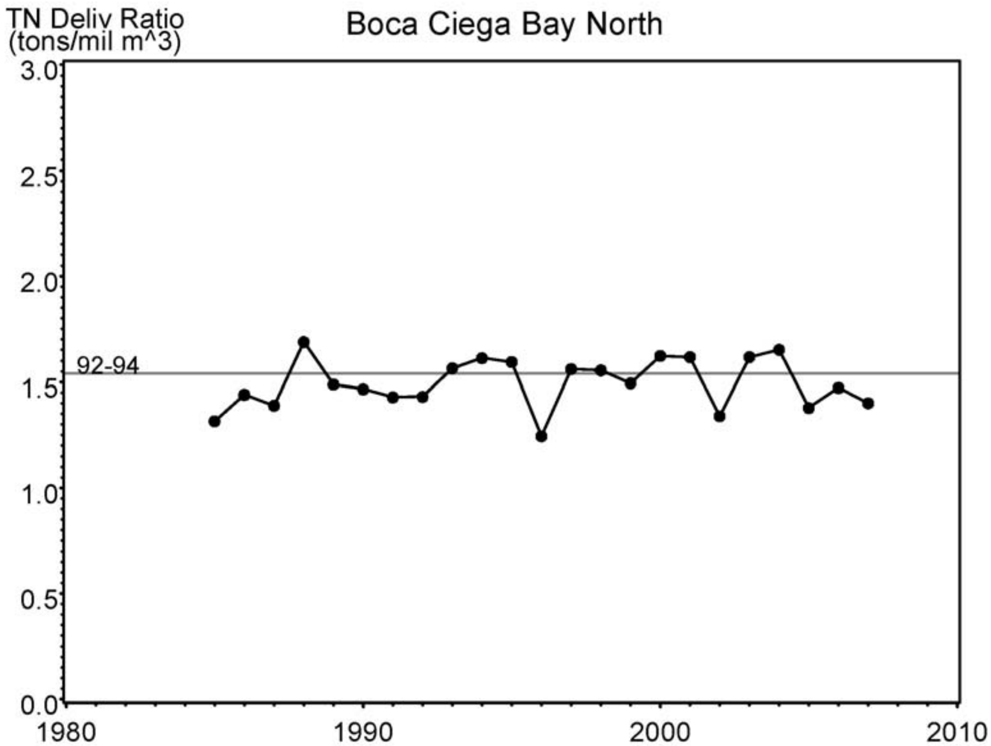

Figure 5-16. Annual TN delivery ratio in Boca Ciega Bay North. The reference line represents the proposed loading-based TN criterion for the reference period.

5.2 Boca Ciega Bay South

In this subsection, the development of numeric nutrient criteria for Boca Ciega Bay South is presented, including:

- a summary of seagrasses, including the seagrass target
- a description of water quality and loadings,
- a description of empirical relationships between chlorophyll *a* and light attenuation,
- the proposed chlorophyll *a* targets,
- a description of empirical relationships between chlorophyll *a* and nutrients, and
- the recommended nutrient criteria.

5.2.1 Seagrass Targets

As discussed in Section 5.1.1, seagrass targets have been developed for the segments of Tampa Bay. However, chlorophyll *a* targets were not developed for Boca Ciega Bay because of insufficient data at the time (Janicki and Wade, 1996; Janicki et al., 1995). In this section, estimates of recent seagrass acreages are examined relative to the seagrass target for Boca Ciega Bay South.

5.2.1.1 Temporal Distribution of Seagrass

Seagrasses in Boca Ciega Bay South historically covered close to 9,000 acres. From 2004 to 2006 the seagrass extent reached the target (based on Janicki et al., 1995) and has since been maintained at or just below this point (Figure 5-17).

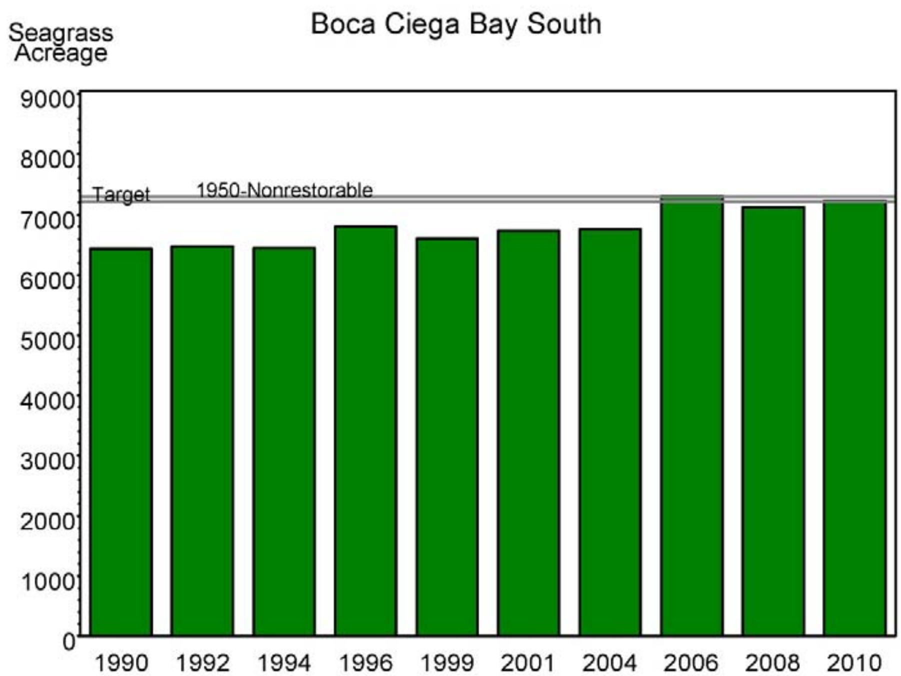

Figure 5-17. Extent of seagrasses during recent surveys in Boca Ciega Bay South. The reference lines indicate the seagrass target and 1950s acreage minus any nonrestorable area for this bay segment.

5.2.2 Temporal Variability in Ambient Water Quality and Nutrient Loadings

Annual average water clarity in Boca Ciega Bay South was better than that observed in Boca Ciega Bay North, with Secchi disc depths ranging from approximately 0.2 m to nearly 1.0 m deeper in Boca Ciega Bay South during any given year (Figure 5-18). As with the northern segment, water clarity in Boca Ciega Bay South was consistent from 1996 through 2004 and fluctuated slightly between 1.3 m and 1.6 m. From 2005 to 2010, clarity improved to almost 1.8 m during four of the most recent six years and never averaged less than 1.5 m depth. Since 1997, water quality has remained relatively stable in Boca Ciega Bay South with slight improvement in clarity.

TN concentrations were relatively stable in Boca Ciega Bay South from 1996-2010 (Figure 5-19). Annual average TN concentrations ranged from 0.3 to 0.5 mg/L during this time period and except for slightly higher concentrations since 2004, have been consistent since 1996. Peak years were observed in 2001, 2004 and 2009.

Chlorophyll *a* concentrations in Boca Ciega Bay South declined from 9 µg/L in 1991 to just over 4 µg/L in 1997 and then remained relatively consistent, fluctuating between 4 and 6 µg/L through 2010 (Figure 5-20). Until 1997, peak chlorophyll *a* concentrations were observed every other year, but became less frequent in more recent years. Peak chlorophyll *a* concentrations in 2001, 2005 and 2009 coincided with peak TN concentrations in 2001, 2004 and 2009. As observed in Boca Ciega Bay North, variation in chlorophyll *a* concentration was relatively low over time (4 µg/L).

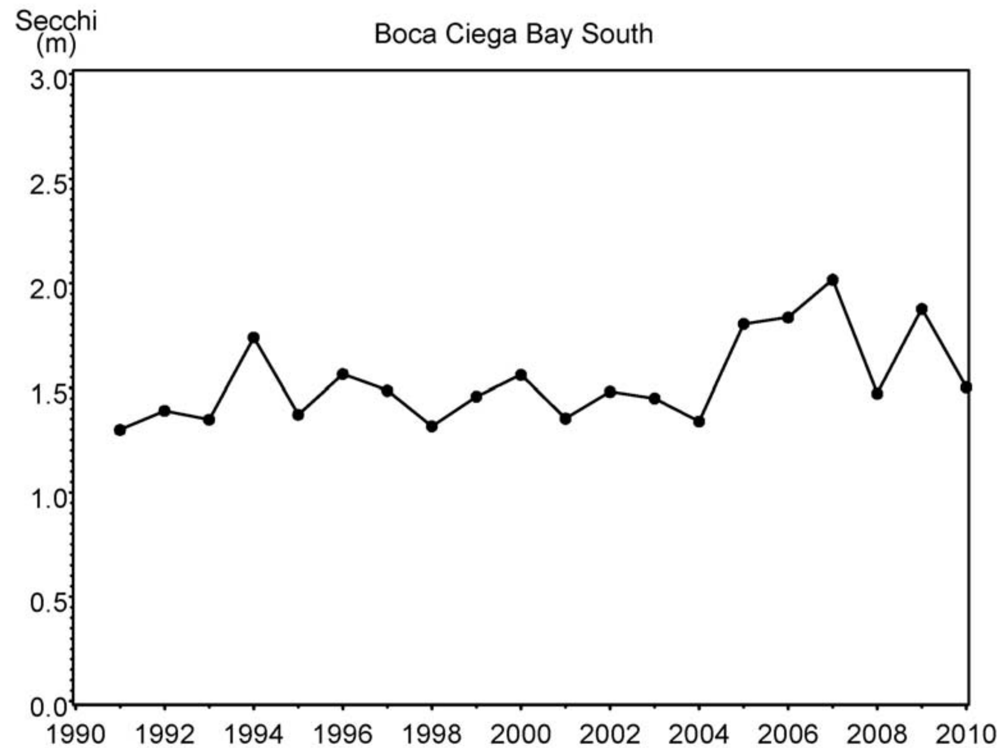

Figure 5-18. Annual average Secchi disc depth in Boca Ciega Bay South.

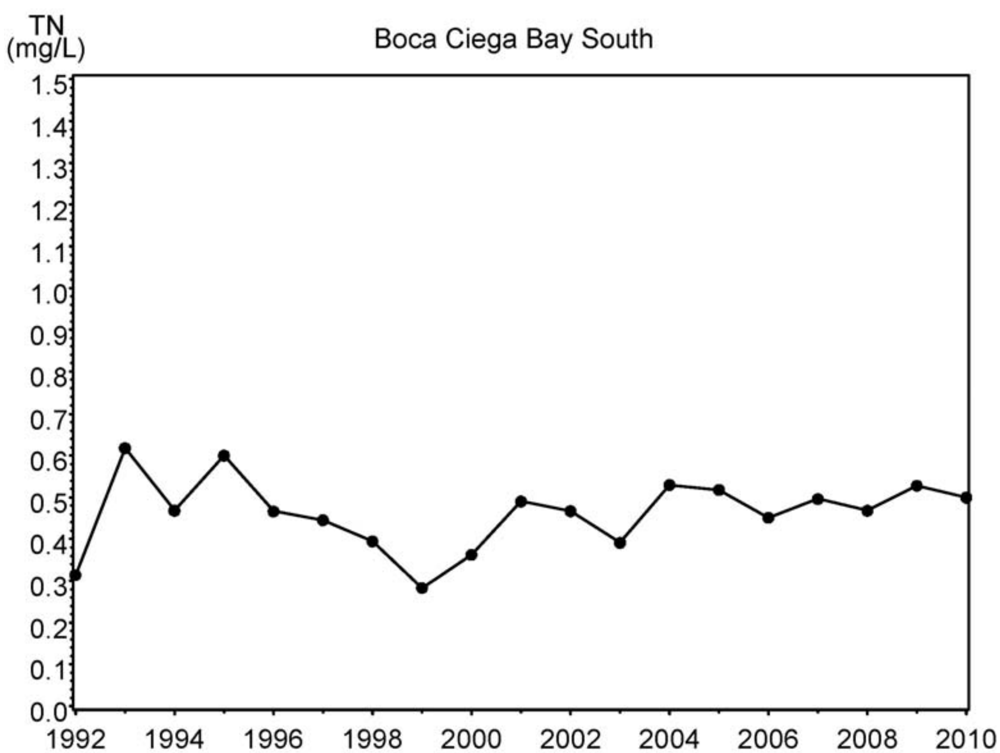

Figure 5-19. Annual average TN concentration in Boca Ciega Bay South.

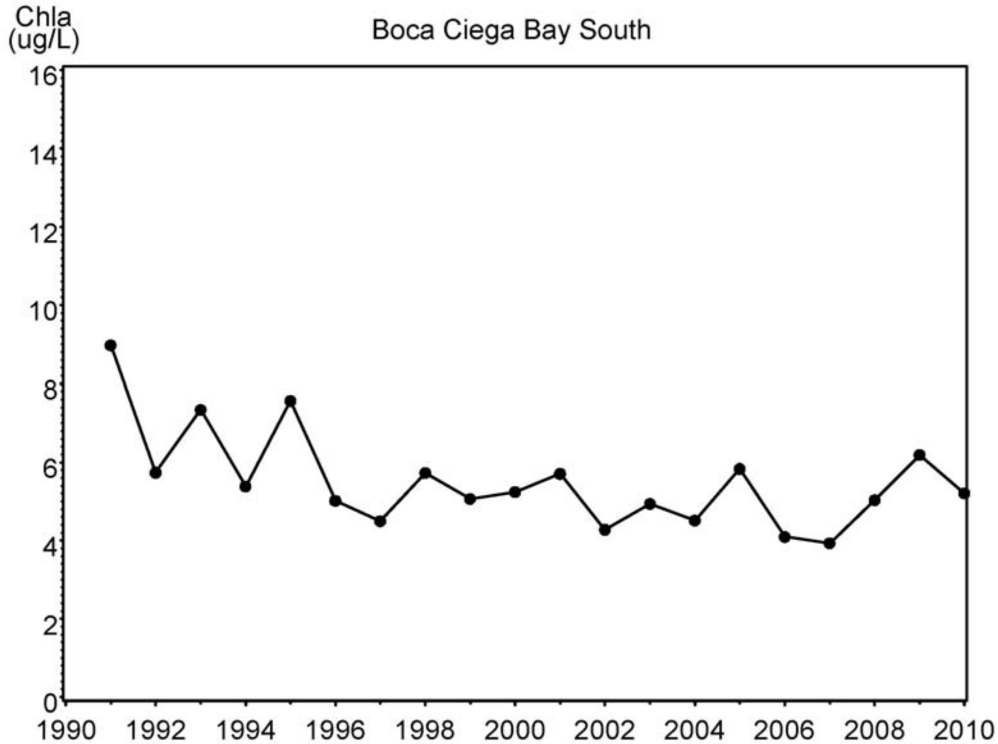

Figure 5-20. Annual average chlorophyll *a* concentration in Boca Ciega Bay South.

Nutrient loads in Boca Ciega Bay South were not as variable as those estimated for the northern segment, with TN loads ranging from approximately 50 tons/year to just over 125 tons/year (Figure 5-21). TN loads in Boca Ciega Bay South were generally half that observed for the northern segment, and in contrast to Boca Ciega Bay North, appeared to decline over the period of record. Between 2004 and 2007, annual TN loads were approximately 50 tons/year, except in 2004 when loads were 85 tons/year.

Nutrient concentrations and loadings to Boca Ciega Bay South coincided with one of the highest annual average chlorophyll *a* concentrations observed during the period of record, although this peak in chlorophyll *a* in 1995 was not substantially higher than most years. Since 2004, nutrient levels and chlorophyll *a* concentrations in Boca Ciega Bay South have been relatively constant, except for TN loads, which declined from 2003 to the lowest levels observed during the period of record. Following the decline in TN loads, improved water clarity was observed, despite relatively stable chlorophyll *a* concentrations.

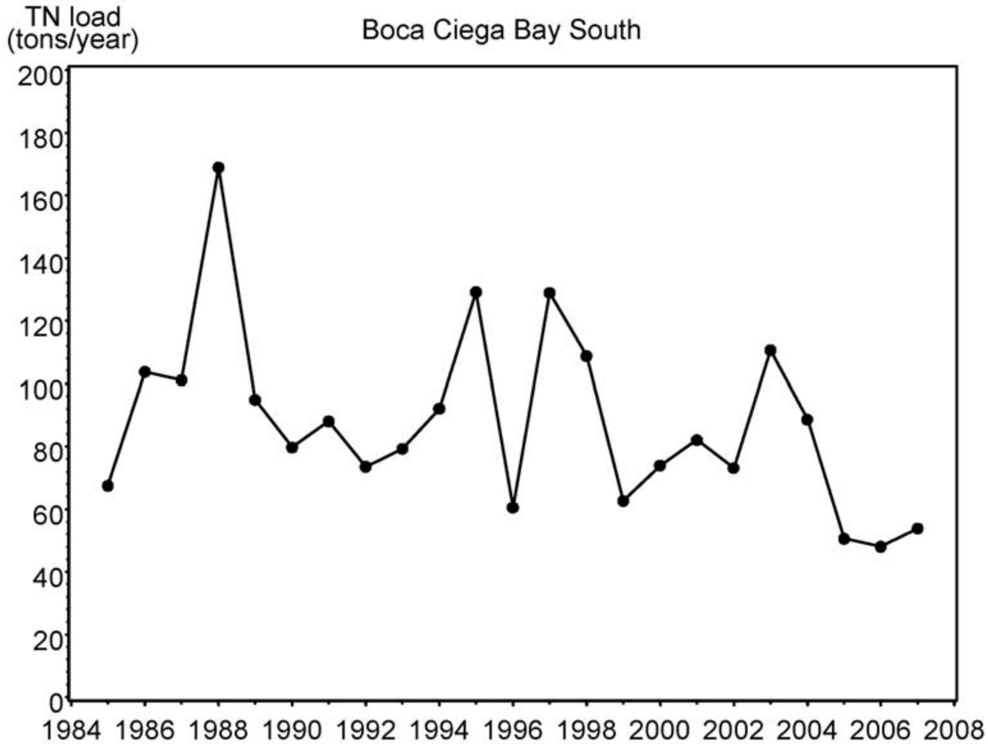

Figure 5-21. Annual TN load in Boca Ciega Bay South.

5.2.3 Empirical Relationships between Chlorophyll *a* and Light

Previous work by Dixon and Leverone (1995) determined that the minimum light requirement for turtle grass (*Thalassia testudinum*) is 20.5% of incident subsurface light. An estimate of subsurface light as a fraction of incident light can be obtained using Beer's law, with the relationship dependent upon the diffuse attenuation due to water quality constituents (chlorophyll a, turbidity, color) (Janicki and Wade, 1996). The diffuse attenuation coefficient, K_D, can be approximated by a factor divided by Secchi disc depth (Giesen et al., 1990). For this analysis, concurrently measured light attenuation data (from light sensors) and Secchi disk data, for 1991-2010 in Boca Ciega Bay and 2005-2010 in Terra Ceia Bay and Manatee River, were multiplied to provide a sample-specific estimate of the "Giesen factor". For a given segment, the median of these factor values was chosen to represent the Giesen factor. This factor was combined with the Secchi disc data from all samples to derive a diffuse light attenuation coefficient for all samples. Using Beer's law, this K_D allowed estimation of the depth to which 20.5% of subsurface irradiant light penetrated (Z). The relationship between mean monthly chlorophyll *a* concentration and light attenuation, Z, and between chlorophyll *a* concentration and Secchi disc depth for Boca Ciega Bay South are shown in Figures 5-22 and 5-23. In this bay segment, light attenuation explained 13% of the variation in chlorophyll *a*.

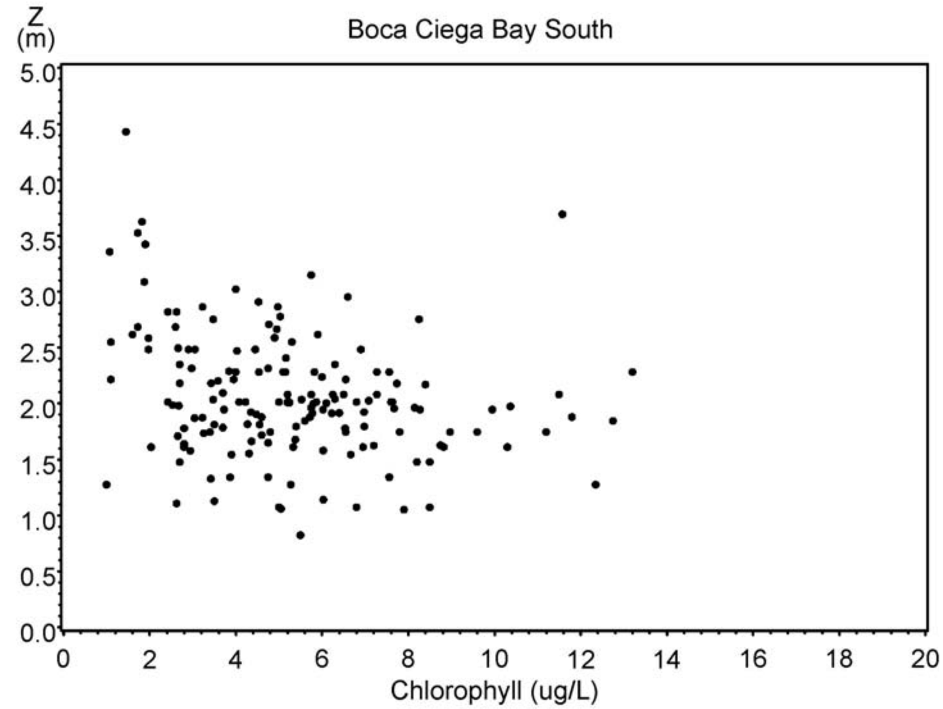

Figure 5-22. Empirical relationship between chlorophyll *a* concentration and Z (depth at which 20.5% of irradiant light is available for seagrass) in Boca Ciega Bay South.

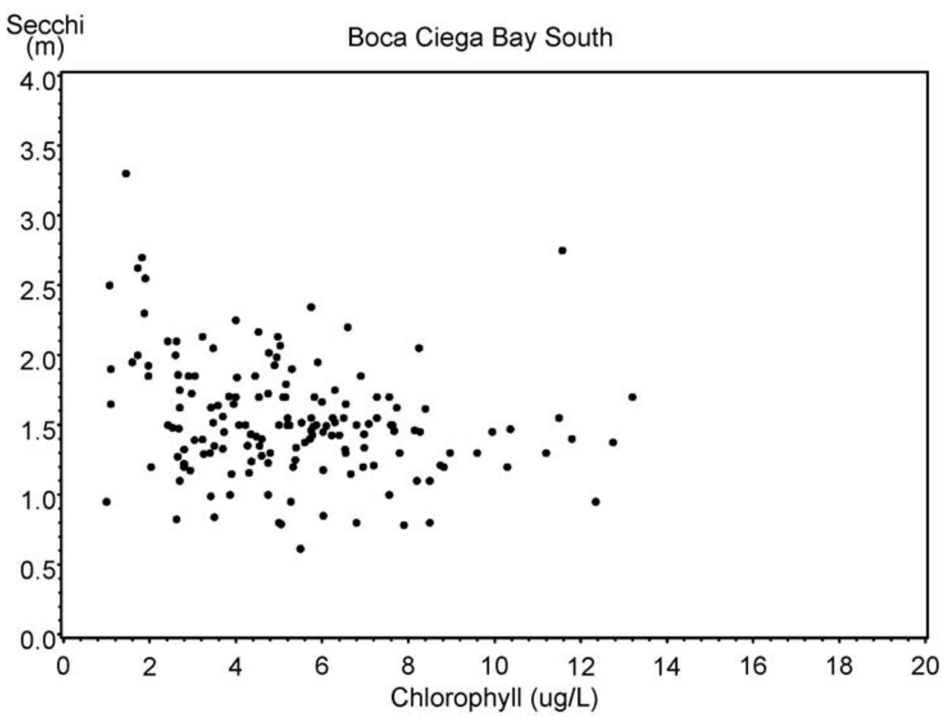

Figure 5-23. Empirical relationship between chlorophyll *a* concentration and Secchi disc depth in Boca Ciega Bay South.

5.2.4 Proposed Chlorophyll *a* Target and Threshold

The historical frequency distribution of seagrasses in Boca Ciega Bay South is shown in Figure 5-24. Based on this distribution, the depth target required for restoration of seagrasses to historical levels is 2.8 m.

Although a statistically significant relationship was identified between chlorophyll *a* and light attenuation in Boca Ciega Bay South, this relationship left a considerable amount (>85%) of variability unexplained. Therefore, a reference period approach was used to develop the chlorophyll *a* target and threshold for Boca Ciega Bay South. As discussed in Section 3.4, this is consistent with the methodology of Janicki and Wade (1996). Using the same approach, the reference period that was selected for Boca Ciega Bay was 1992-1994. The reference period was selected because it is representative of a period when water quality and water clarity were stable or improving and seagrasses (Figure 5-17) were increasing. The mean chlorophyll *a* concentration (target) during the reference period is 6.2 µg/L.

Following the approach developed by Janicki and Wade (1996), an allowance was made to allow for the natural variability in the system. The threshold was calculated by summing the target (mean for the reference period) plus two standard errors, resulting in a chlorophyll *a* threshold of 6.7 µg/L. Comparison of the proposed threshold with chlorophyll *a* trends during the period of record (Figure 5-25) indicates that chlorophyll *a* concentrations have exceeded the threshold during only three years and have not exceeded the proposed threshold since 1996.

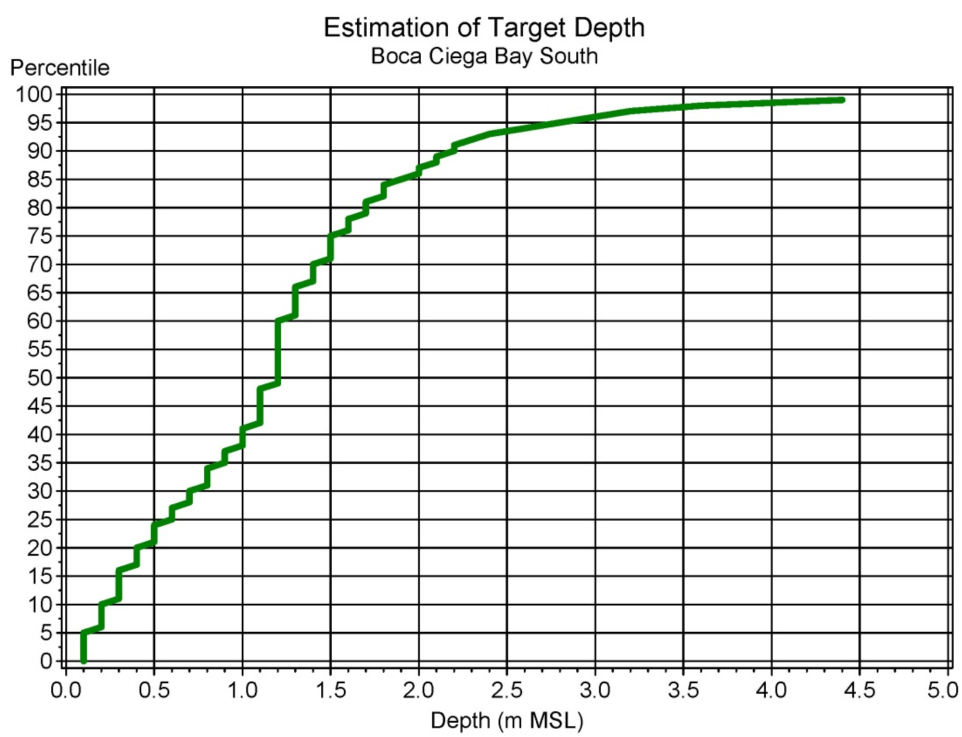

Figure 5-24. Cumulative depth distribution of seagrass in Boca Ciega Bay South during the historical period (1950). The chlorophyll *a* target was derived from the depth target of 2.8 m, which was the estimated depth at which 95% of seagrass occurred historically.

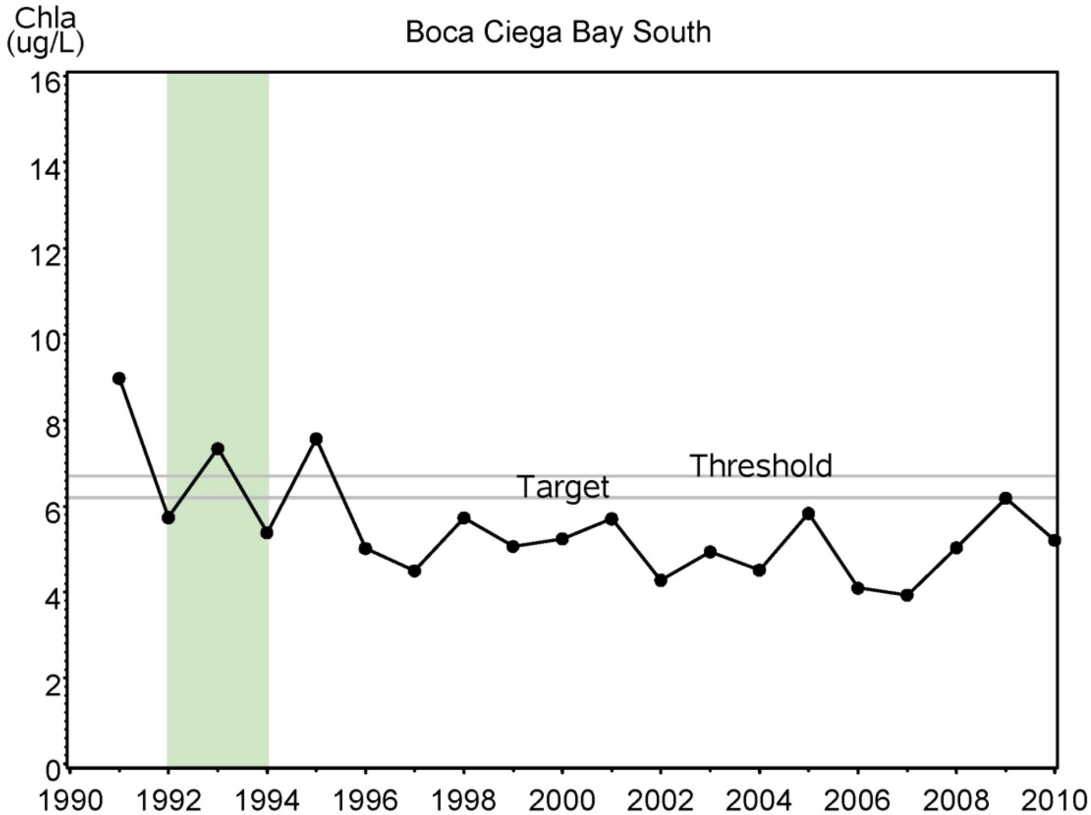

Figure 5-25. Annual average chlorophyll *a* concentration in Boca Ciega Bay South. The reference line represents the proposed chlorophyll *a* threshold based on the reference period approach.

5.2.5 Empirical Relationships between Chlorophyll *a* and Nutrients

The relationship between TN concentrations and chlorophyll *a* concentration for Boca Ciega Bay South is shown in Figures 5-26. Approximately 7% of the variation in chlorophyll *a* concentration in this bay segment was explained by TN concentration.

The relationship between TN loads and chlorophyll *a* concentration is shown in Figure 5-27. Total nitrogen loads accounted for only 15% of the chlorophyll *a* variation in Boca Ciega South.

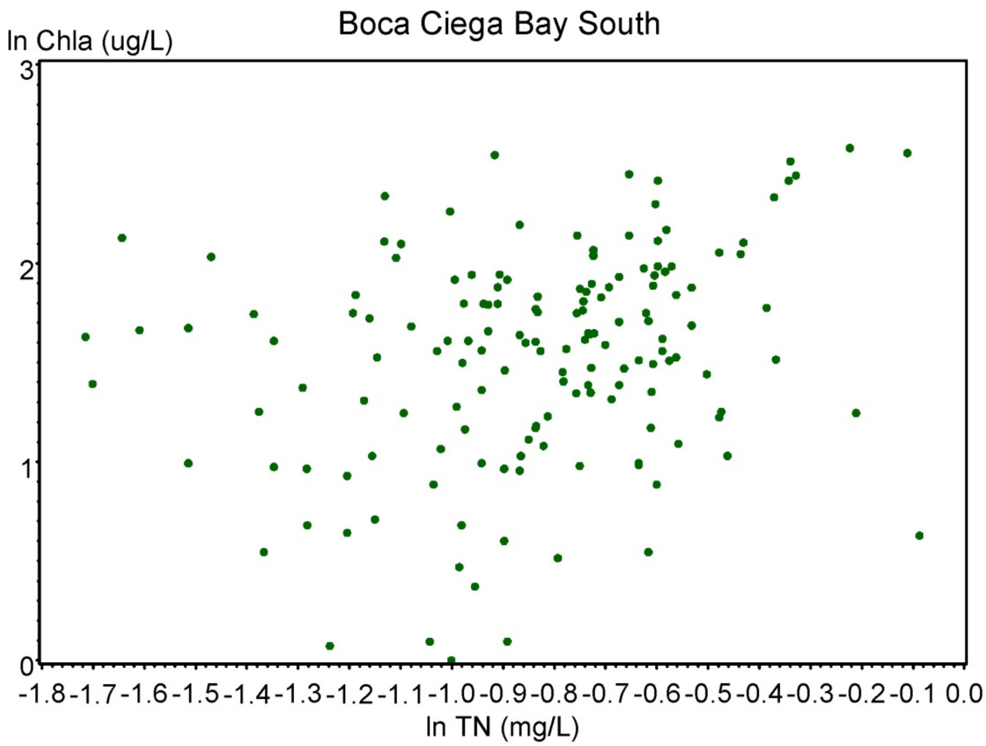

Figure 5-26. Empirical relationship between ln(chlorophyll *a* concentration) and ln(TN concentration) in Boca Ciega Bay South.

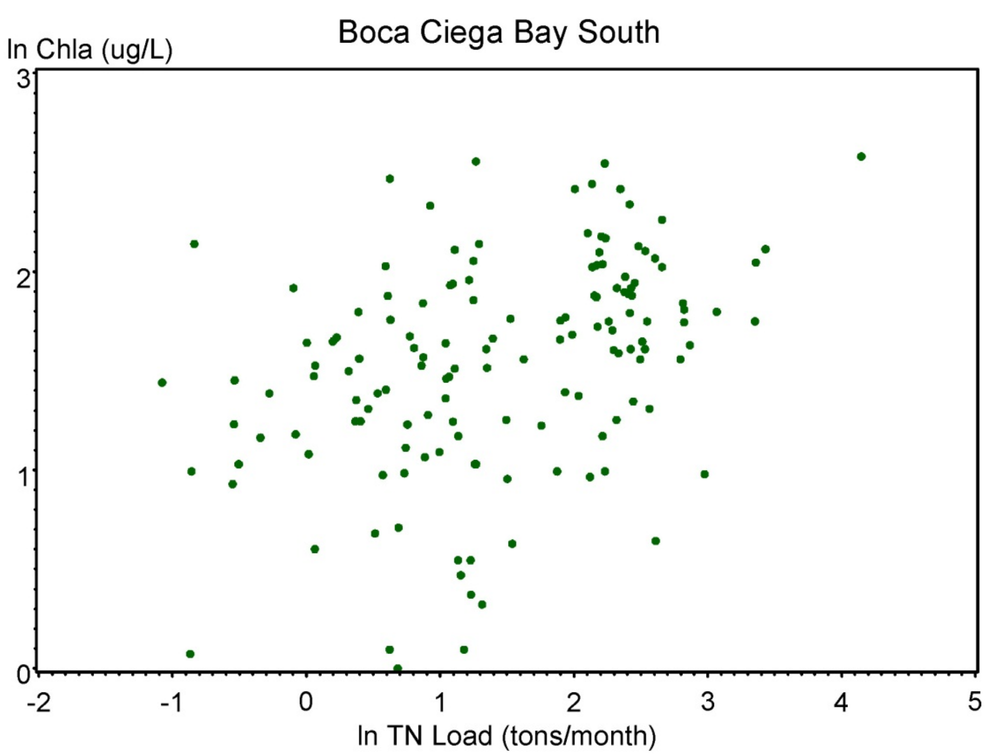

Figure 5-27. Empirical relationship between ln(chlorophyll *a* concentration) and ln(TN load) in Boca Ciega Bay South.

5.2.6 Recommended Loading- and Concentration-Based Nutrient Criteria

Because of the lack of robust statistical relationship between chlorophyll *a* concentrations and TN concentrations, the reference period approach was used to calculate the TN concentration criterion for Boca Ciega Bay South. The criterion was calculated by summing the annual average during the reference period (1992-1994) plus the standard deviation for the period of record. The reference period was selected because it is representative of a period when water quality and water clarity were stable or improving and seagrasses (Figure 5-17) were increasing. The proposed TN concentration criterion for this bay segment is 0.54 mg/L based on the reference period approach. Average annual TN concentrations in Boca Ciega Bay South have exceeded this proposed threshold only twice over the past two decades, with the most recent occurrence in 1995 (Figure 5-28).

The recommended TN load target for Boca Ciega Bay South is 82 tons/year, based on the reference period approach. Average annual TN loads have exceeded the proposed target in eleven of the previous 19 years with the most recent exceedences occurring in 2003-2004 (Figure 5-29).

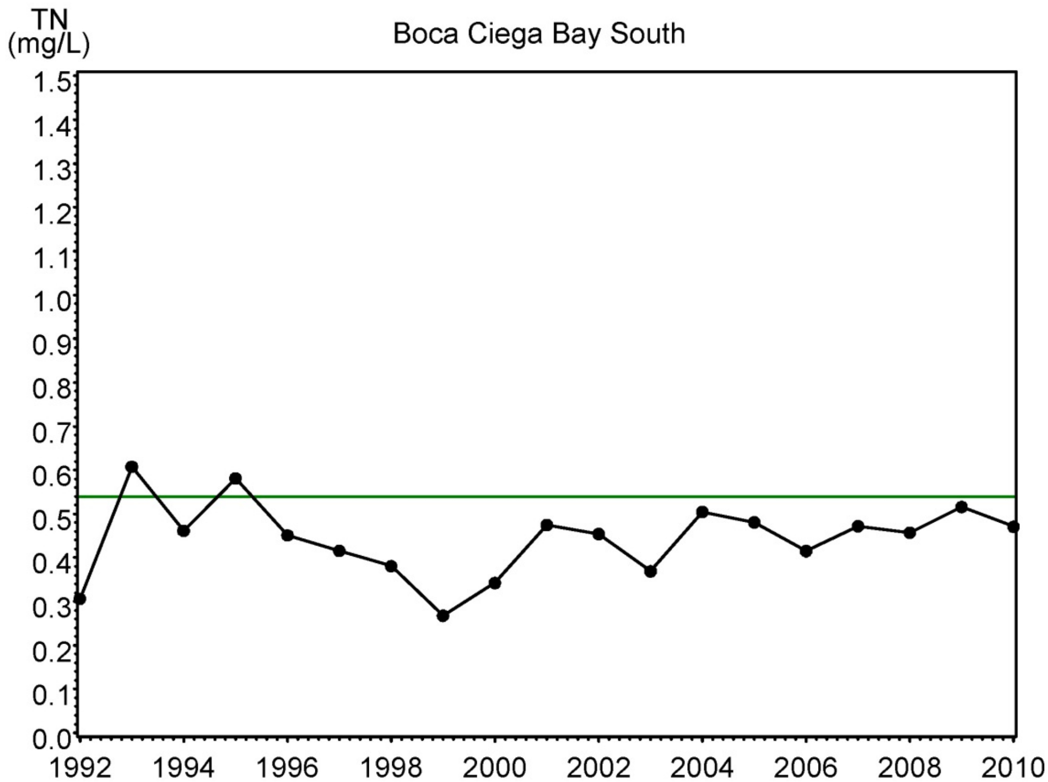

Figure 5-28. Annual average TN concentration in Boca Ciega Bay South. The reference line represents the proposed concentration-based TN criterion for the reference period.

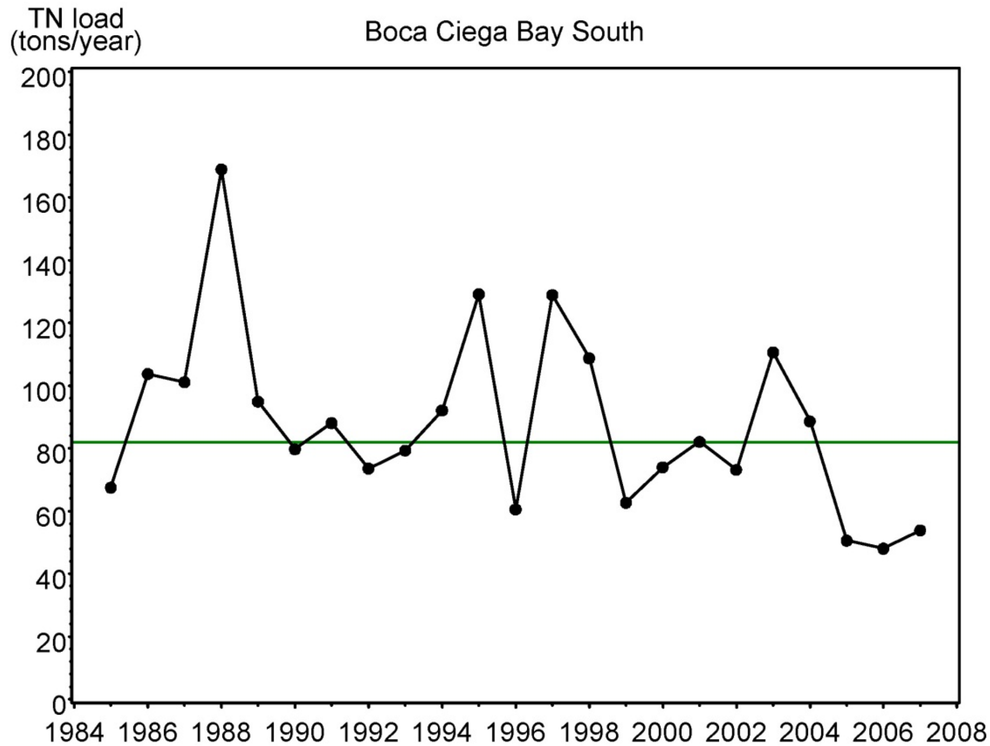

Figure 5-29. Annual TN load in Boca Ciega Bay South. The reference line represents the proposed loading-based N target for the reference period.

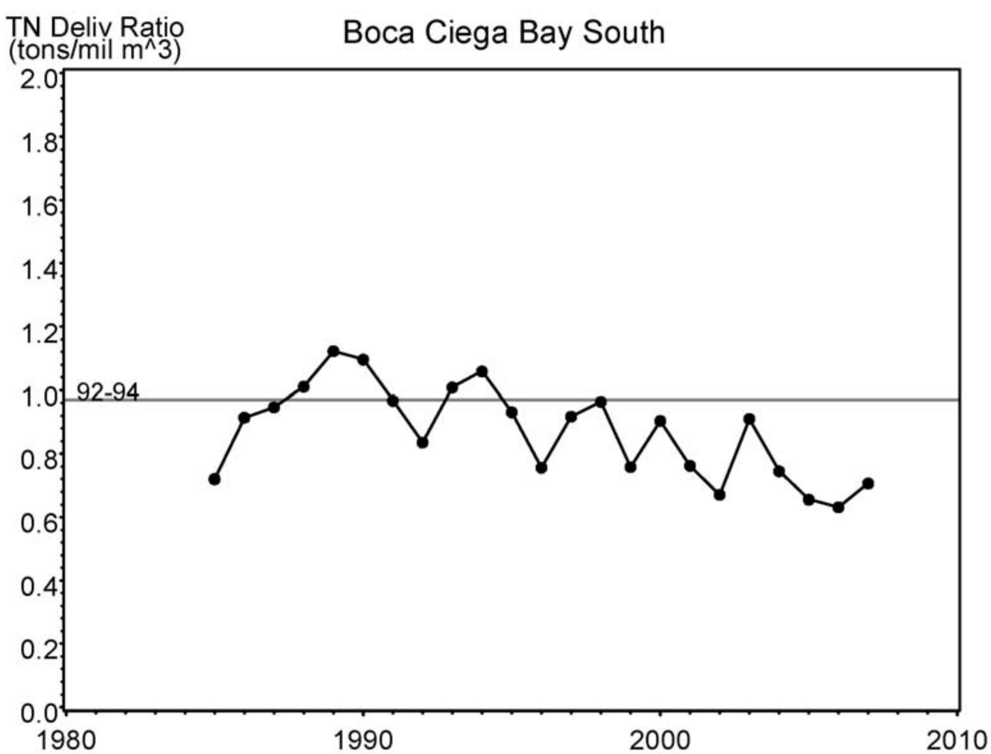

Figure 5-30. Annual TN delivery ratio in Boca Ciega Bay South. The reference line represents the proposed loading-based TN criterion for the reference period.

As discussed in Section 3.6 for Terra Ceia Bay, analysis of loading targets revealed exceedences although water quality and seagrasses were stable or improving. This is also the case in Boca Ciega Bay South. 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. The TN delivery ratio for Boca Ciega Bay South based on the 1992-1994 reference period is 0.97 tons TN per million cubic meters of freshwater delivered. Analysis of the time series plot of the annual TN delivery ratio for Boca Ciega Bay North (Figure 5-30) reveals that the TN threshold (i.e., the TN delivery ratio) has been exceeded five times out of 23 years, but not since 1995. Also, there is a definite trend of decreasing TN delivery ratios over time.

6.0 Conclusions

The TBEP and the TBNMC have recommended numeric nutrient criteria to EPA for the four main stem segments of the bay (Tampa Bay Nitrogen Management Consortium, 2010). These criteria are specific to the bay segments of Tampa Bay and are expressed as annual TN loads. Despite the commonly held view that phosphorus is not limiting in Tampa Bay, criteria for TP loads have also been recommended to EPA. EPA has noted its intention to express the numeric nutrient criteria for Tampa Bay as TN and TP concentrations as well. Therefore, segment-specific TN and TP concentrations were developed (Janicki Environmental, 2010a). This is in keeping with recognition of the importance of maintaining consistency with existing management goals and specifically with the recent load allocations to comply with the existing TMDL for Tampa Bay.

Based on the analyses presented herein for Boca Ciega Bay, Terra Ceia Bay, and Manatee River, segment-specific targets and thresholds are summarized below. ***The recommended numeric nutrient criteria for these segments are the TN load thresholds provided. Concentration-based TN thresholds have also been developed commensurate with these TN load thresholds, should it be necessary to establish TN criteria as concentrations. It is strongly recommended that criteria be set only for TN, given that the system is nitrogen limited.*** However, if TP criteria are required, potential TP criteria are provided in Appendix 1.

- Terra Ceia Bay
  - Seagrass target = 1,045 acres
  - Depth target = 1.8 m
  - Chlorophyll *a* threshold = 8.7 μg/L
  - Based on a reference period approach,
    - TN load target = 36 tons/year
    - TN load threshold = 1.10 tons/million m^3
    - TN concentration criterion = 0.69 mg/L

- Manatee River
  - Seagrass target = 427 acres
  - Depth target = 1.5 m
  - Chlorophyll *a* threshold = 8.8 μg/L
  - Based on a reference period approach,
    - TN load target = 503 tons/year
    - TN load threshold = 1.80 tons/million m^3
    - TN concentration criterion = 0.65 mg/L

- Boca Ciega Bay North
    - Seagrass target = 1,140 acres
    - Depth target = 1.7 m
    - Chlorophyll *a* threshold = 8.3 μg/L
    - Based on a reference period approach,
        - TN load target = 94 tons/year
        - TN load threshold = 1.54 tons/million m^3
        - TN concentration criterion = 0.57 mg/L

- Boca Ciega Bay South
    - Seagrass target = 7,220 acres
    - Depth target = 2.8 m
    - Chlorophyll *a* threshold = 6.3 μg/L
    - Based on a reference period approach,
        - TN load target = 82 tons/year
        - TN load threshold = 0.97 tons/million m^3
        - TN concentration criterion = 0.54 mg/L

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APPENDIX 1.
Alternative Criteria Expressed in Terms of TP Loads and Concentrations

The recommended numeric nutrient criteria for these segments are the TN load thresholds provided. Concentration based TN thresholds have also been developed commensurate with these TN load thresholds, should it be necessary to establish TN criteria as concentrations. It is strongly recommended that criteria be set only for TN, given that the system in nitrogen limited. However, if TP are required, potential TP criteria are presented here.

1.0 Terra Ceia Bay

In this section, development of TP criteria is presented for Terra Ceia Bay.

1.1 Temporal Variability in Ambient Water Quality and Nutrient Loadings

During most years, TP concentrations were between 0.15 and 0.2 mg/L, but peaks were observed in 1998, 2007, and 2008 when concentrations reached 0.34 – 0.41 mg/L (Figure 1-1). There did not appear to be a close relationship between TN and TP concentrations in this bay segment.

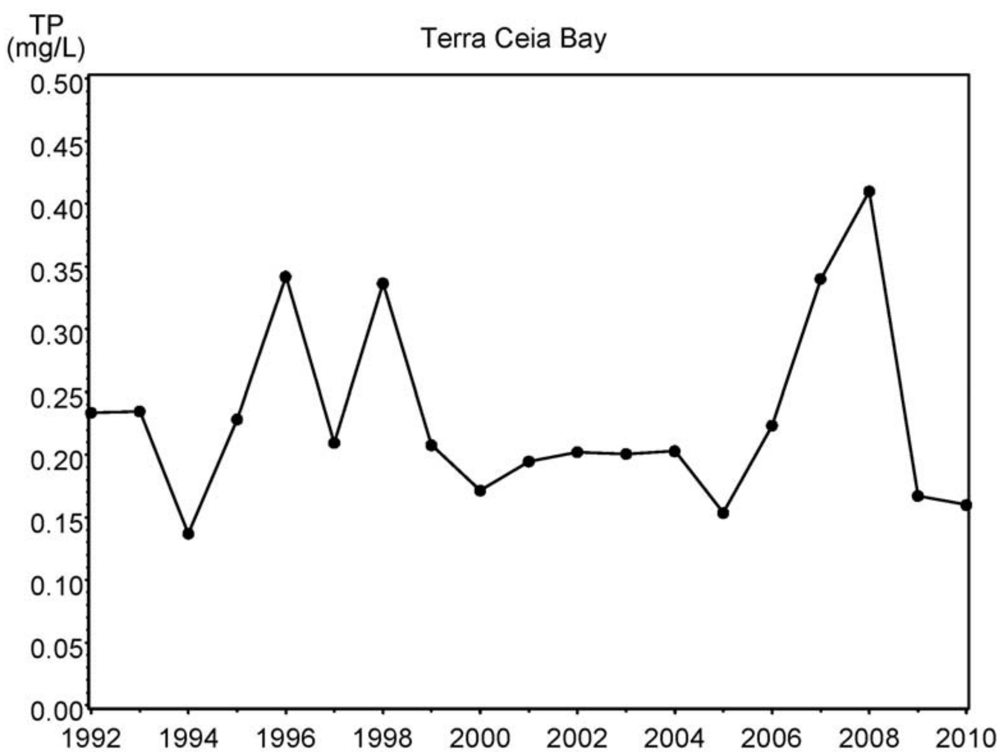

Figure 1-1. Annual average TP concentration in Terra Ceia Bay.

TP loads to Terra Ceia Bay varied from approximately 2 to 9 tons/year (Figure 1-2). Nutrient loads were relatively stable over the period of record with no indication of an increasing or decreasing trend from 1989-2007. Between 2004 and 2007, TP loads ranged from 1.7-5.5 tons/year.

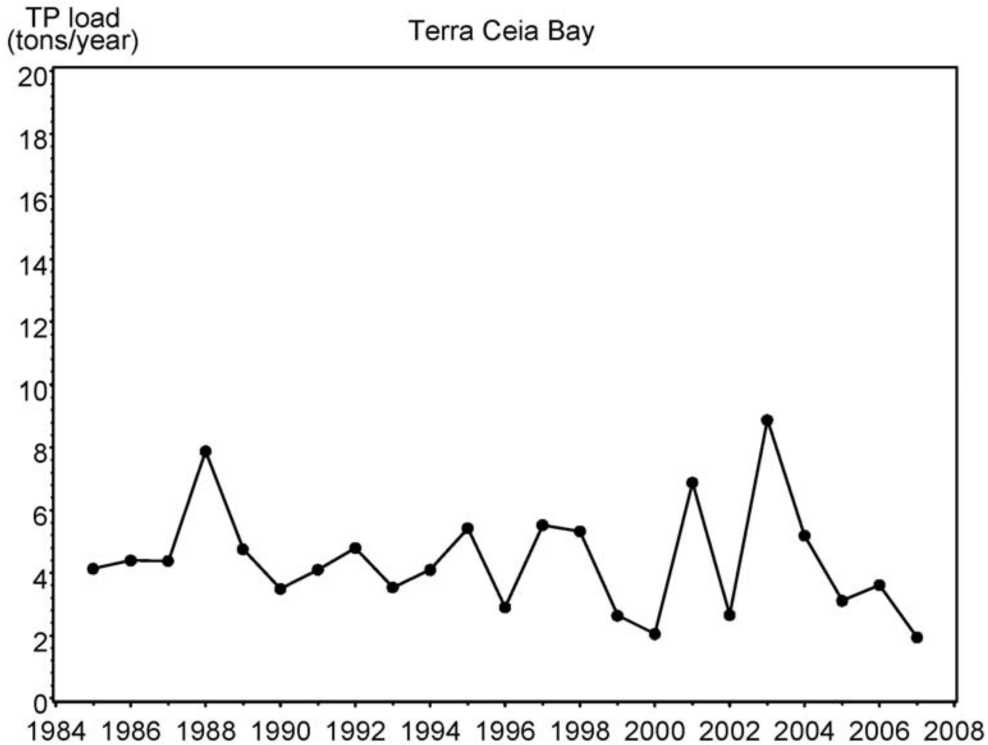

Figure 1-2. Annual TP load in Terra Ceia Bay.

1.2 Empirical Relationships Between Chlorophyll *a* and Nutrients

Figure 1-3 depicts the relationships between log transformed TP concentrations and log transformed chlorophyll *a* concentrations for Terra Ceia Bay. Only 17% of the variation in chlorophyll *a* concentrations was explained by TP concentrations.

Additional relationships were investigated between nutrient loads and chlorophyll a concentrations. Though these relationships were significant (Figures 1-4), the majority of the variation was left unexplained. TP loads accounted for 11% of the variation in chlorophyll *a* in Terra Ceia Bay. Though these relationships were significant, their low R^2 values make them impractical for management decisions as the vast majority of the variation is left unexplained.

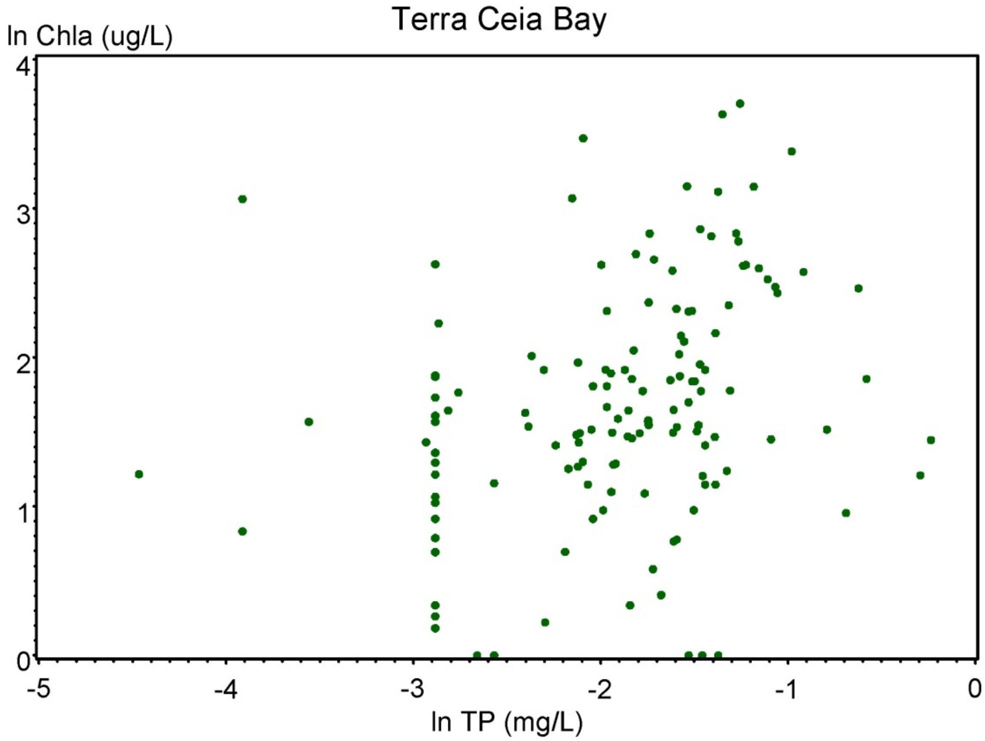

Figure 1-3. **Empirical relationship between ln(chlorophyll *a*) concentration and ln(TP concentration) in Terra Ceia Bay.**

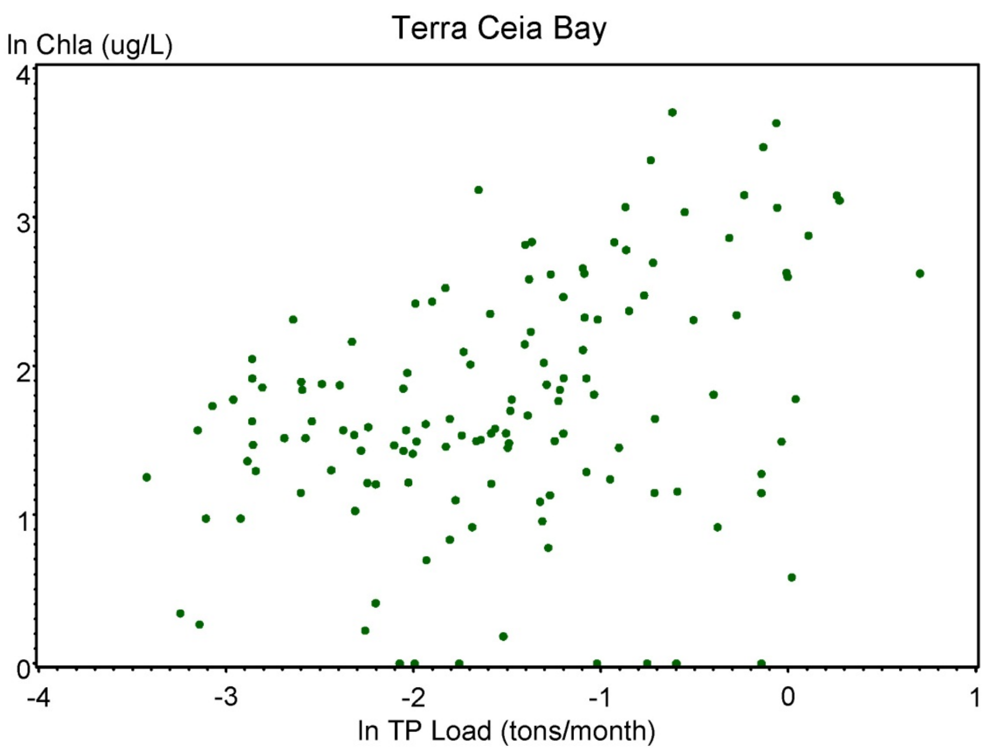

Figure 1-4. **Empirical relationship between chlorophyll *a* concentration and TP load in Terra Ceia Bay.**

1.3 Recommended Loading- and Concentration-Based Nutrient Criteria

Attempts were made to develop statistically defensible relationships between monthly chlorophyll *a* concentrations and potential explanatory variables, including nutrient concentrations and loads. In addition to same-month nutrient concentrations and loads, numerous transformations and lags of these variables were also investigated. However, because of the lack of robust statistical relationships between chlorophyll *a* concentrations and nutrient loads or concentrations, the reference period approach was used to calculate the TP criteria for Terra Ceia Bay. The concentration criterion was calculated by taking the average of the annual geometric means during the reference period (1992-1994) plus the standard deviation of the annual geometric means for the period of record. This is consistent with the methodology employed in Janicki Environmental (2011a) to develop nutrient concentration criterion for the four main segments of Tampa Bay. The reference period was selected because it is representative of a period when water quality (TN, TP, and chlorophyll *a*) and seagrasses were stable and water clarity was increasing. Although the system has been determined to be nitrogen limited, EPA has expressed its desire to develop numeric nutrient criteria for both TN and TP, regardless of which nutrient is limiting. Therefore, using the same approach as was used for TN, the proposed TP concentration criterion for Terra Ceia Bay would be 0.20 mg/L. This threshold has been exceeded during six years since 1992, with the last exceedences occurring in 2006-2008 (Figure 1-5).

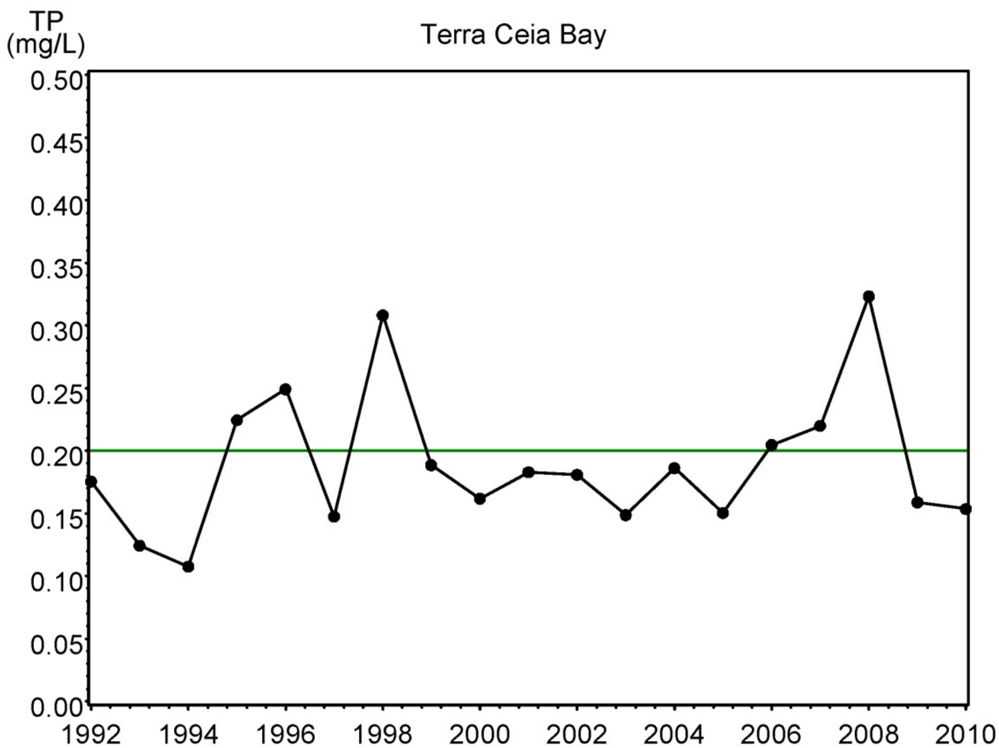

Figure 1-5. Annual geometric mean TP concentration in Terra Ceia Bay. The reference line represents the proposed concentration-based TP criterion for the reference period.

The reference period approach resulted in a proposed TP load target for Terra Ceia Bay of 4 tons/year. Assessment of TP loading to Terra Ceia Bay since 1989 indicates that the proposed threshold has been exceeded during 14 years and most recently in 2004 (Figure 1-6). This presents an interesting paradox as the segment is not meeting its loading targets though seagrass and water quality have been stable or improving. This same issue was identified during target development for the four main bay segments of Tampa Bay.

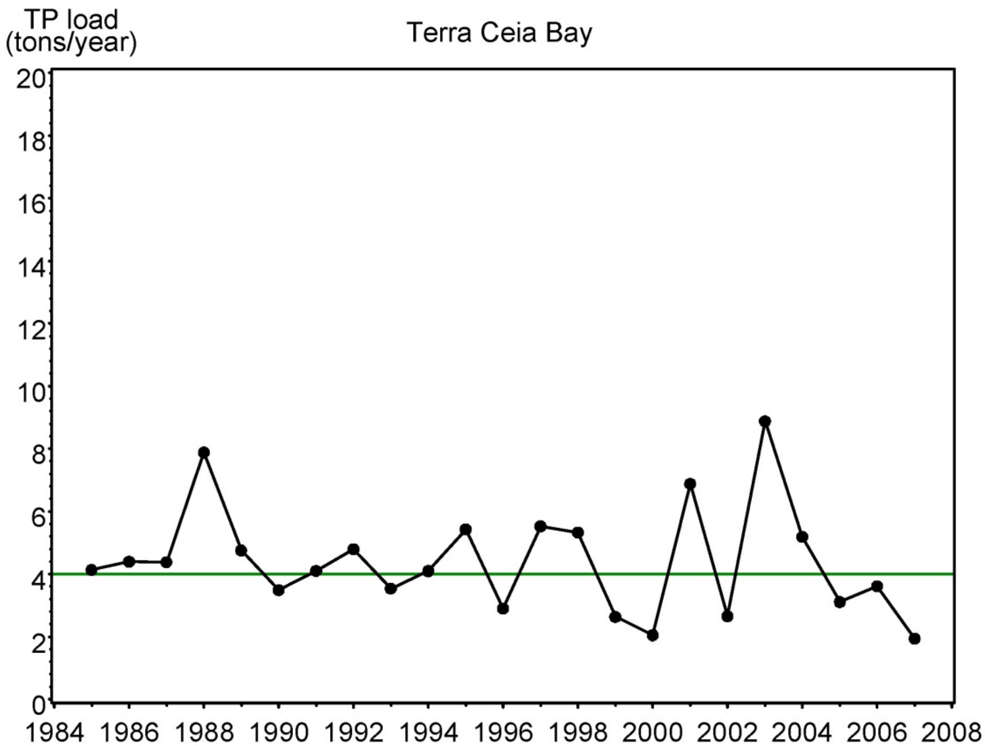

Figure 1-6. Annual TP load in Terra Ceia Bay. The reference line represents the proposed loading-based TP target for the reference period.

During the development of the 2009 Reasonable Assurance (TBNMC, 2010b), the TBNMC investigated the temporal trends in TN loading for the four main segments of Tampa Bay. While the chlorophyll *a* thresholds were being met, the TN loading targets were exceeded in some years in the four main segments of Tampa Bay. 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 were also considered, along with the annual TN loads to establish TN loading thresholds for each segment.

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. Although the system has been determined to be nitrogen limited, EPA has expressed its desire to develop numeric nutrient criteria for both TN and TP, regardless of which nutrient is limiting. Therefore, the TP load threshold (i.e., the TP delivery ratio) was calculated for the reference period. The TP load threshold for Terra Ceia Bay for the 1992-1994 reference period would be 0.14 tons TP per million cubic meters of freshwater delivered. Analysis of the time series plot of the annual TP delivery ratio for Terra Ceia Bay (Figure 1-7) reveals that the TP threshold (i.e., the TP delivery ratio) has been exceeded 13 times out of 23 years. This result is inconsistent with the fact that water quality and seagrasses in Terra Ceia Bay have been stable or improving during this time period. As the system is nitrogen limited, it is strongly recommended not to develop and implement the TP load threshold.

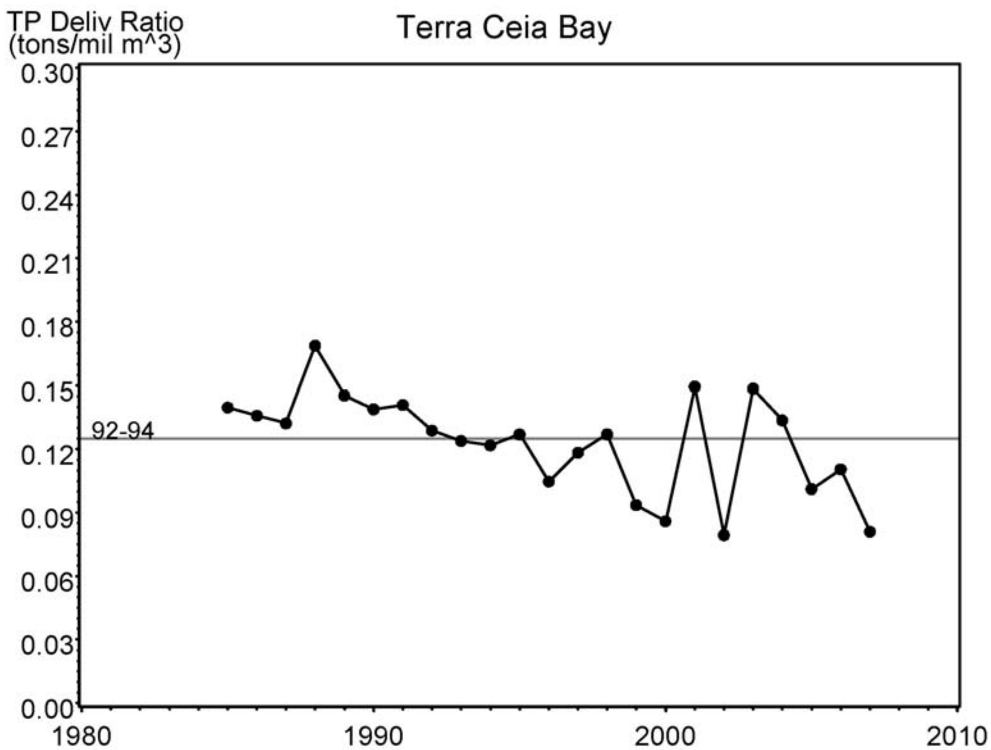

Figure 1-7. Annual TP load delivery ratio in Terra Ceia Bay. The reference line represents the proposed loading-based TP criterion for the reference period.

2.0 Manatee River

In this section, development of TP criteria is presented for Manatee River.

2.1 Temporal Variability in Ambient Water Quality and Nutrient Loadings

Temporal trends in TP concentrations in the Manatee River are shown in Figures 2-1. Peak TP concentrations were observed in 1994, 1998, 2001 and 2005. For TP concentrations, a decreasing trend in the annual average was observed between 1998 and 2006 as TP concentrations declined from 0.32 mg/L (the highest annual average observed) to approximately 0.17 mg/L. In recent years (2006-2010), TP concentrations fluctuated between 0.15 mg/L and 0.30 mg/L.

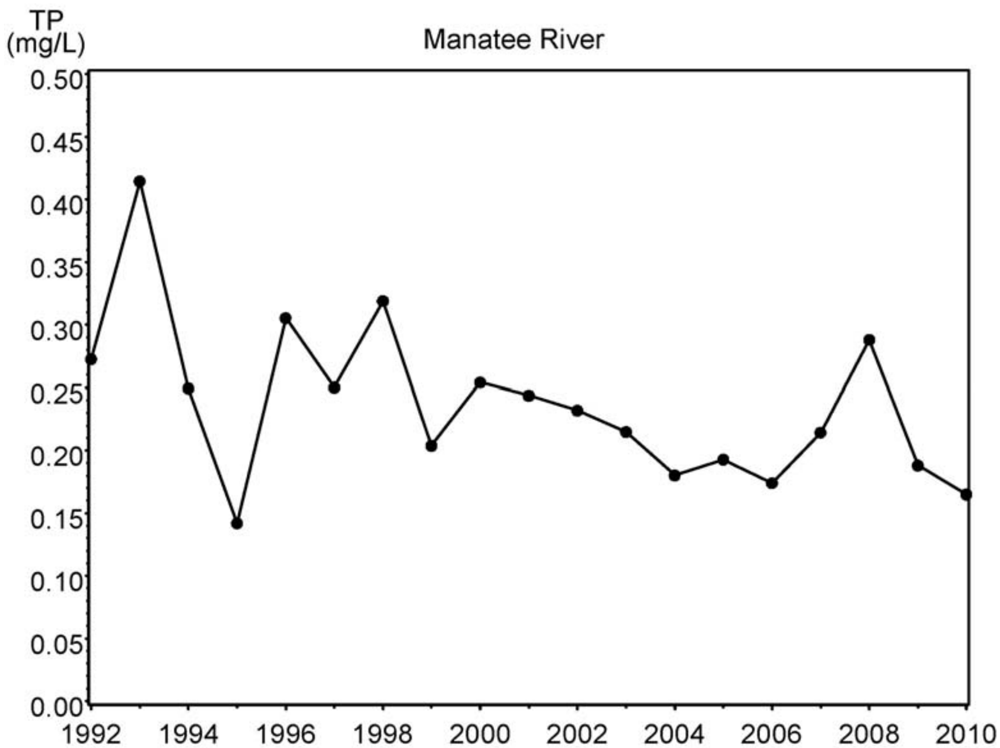

Figure 2-1. Annual average TP concentration in Manatee River.

TP loads ranged from approximately 50 tons/year to 350 tons/year, with two- to three-fold differences in loadings from one year to the next (Figure 2-2). Peak nutrient loads were estimated for 2003 when TP loads were 350 tons/year, in contrast to 2004-2007 when loads were considerably lower (<175 tons/year for TP).

Both nutrient loads and concentrations appeared to co-vary over time; however there was very little covariation between nutrients and chlorophyll *a* concentrations, except during the peak nutrient loadings of 1998 and 2003. Improved water clarity in the Manatee River, despite peaks in nutrient loadings, appears to be related to improved water quality in terms of reduced nutrient concentrations and lower chlorophyll *a* levels in this bay segment.

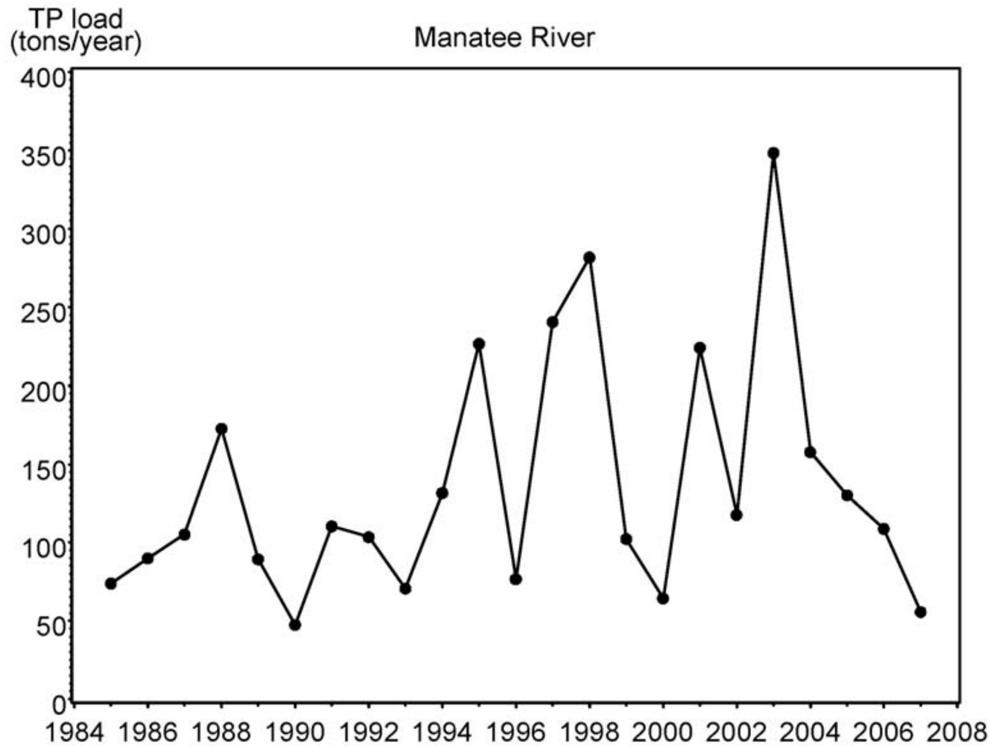

Figure 2-2. Annual TP load in Manatee River.

2.2 Empirical Relationships between Chlorophyll *a* and Nutrients

The relationships between TP concentrations and chlorophyll *a* concentrations for the Manatee River are shown in Figure 2-3. Only 29% of the variation in chlorophyll *a* concentrations in this bay segment was explained by TP concentrations.

Similar to the poor relationships between chlorophyll *a* and nutrient concentrations in Terra Ceia Bay, TP loads and chlorophyll *a* concentrations were significantly related, but left the majority of the variation unexplained (Figures 2-4). TP loads accounted for 20% of the variation in chlorophyll. As the Manatee River is a highly managed system, it is not surprising to see that these relationships are weak. Because of the lack of defensible relationship between chlorophyll *a* concentration and TP load in Manatee River, the reference period approach was used to estimate the TP load target.

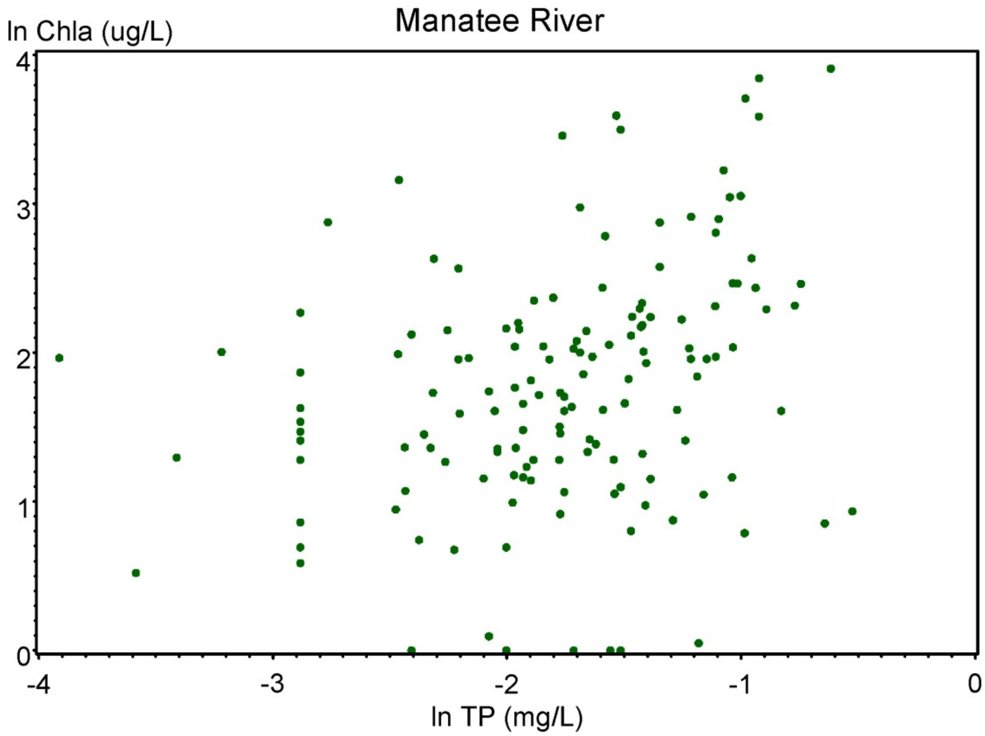

Figure 2-3. **Empirical relationship between ln(chlorophyll *a*) concentration and ln(TP concentration) in Manatee River.**

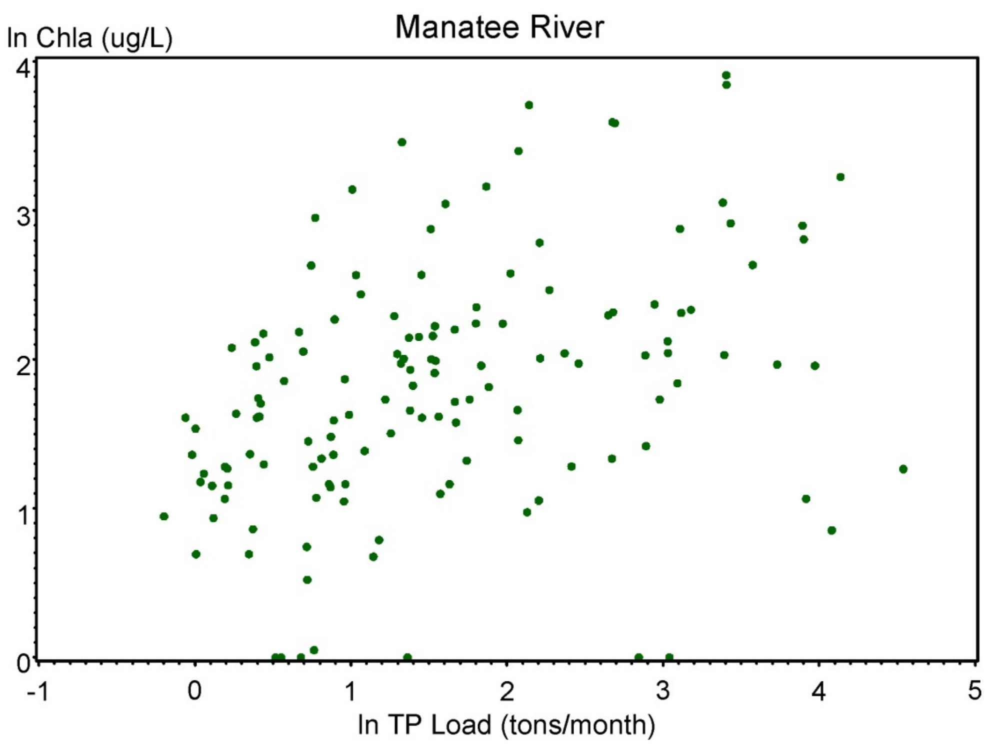

Figure 2-4. **Empirical relationship between ln(chlorophyll *a*) concentration and ln(TP load)in Manatee River.**

2.3 Recommended Loading- and Concentration-Based Nutrient Criteria

Attempts were made to develop statistically defensible relationships between monthly chlorophyll *a* concentrations and potential explanatory variables, including nutrient concentrations and loads. In addition to same-month nutrient concentrations and loads, numerous transformations and lags of these variables were also investigated. However, because of the lack of robust statistical relationships between chlorophyll *a* concentrations and TP loads and concentrations, the reference period approach was used to calculate the TP criteria for Manatee River. The concentration criterion was calculated by summing the annual average during the reference period (2003-2007) plus the standard deviation for the period of record. The reference period was selected because it is representative of a period when water quality (TN, TP, and chlorophyll a) and seagrasses were stable and water clarity was increasing. Though the segment was determined to be nitrogen limited, EPA has expressed a desire to develop criteria for both nitrogen and phosphorus, regardless of which nutrient is limiting. Therefore, the proposed TP concentration criterion for Manatee River would be 0.20 mg/L based on the reference period approach. This threshold has been exceeded often prior to 2003, but only once since 2003 (Figure 2-5).

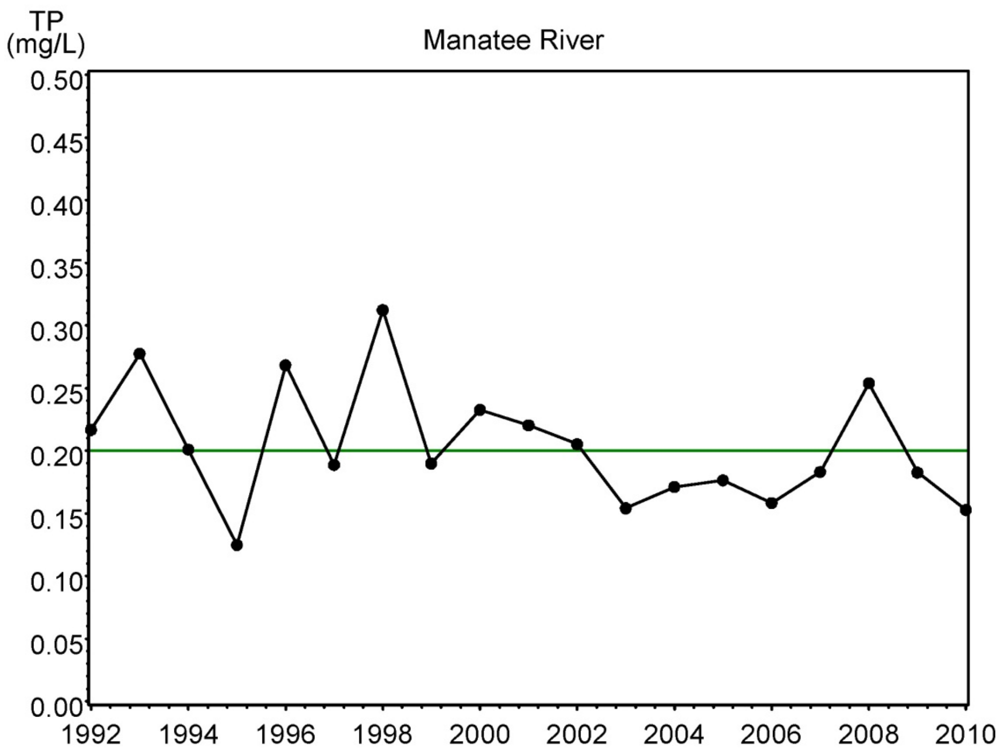

Figure 2-5. Annual geometric mean TP concentration in Manatee River. The reference line represents the proposed concentration-based TP criterion for the reference period.

As discussed above, inspection of seagrass and water quality data supported the finding that the 2003-2007 period is a better choice as a reference period than 1992-1994. However, loadings from the 2003-2007 period are substantially higher than those from the 1992-1994 period. Therefore, to be consistent with the RA, 1992-1994 was selected as the reference period for setting loading targets. Therefore, it is expected that the TP loading target will be protective of not only the Manatee River segment, but of the Lower Tampa Bay segment as well.

As discussed previously, the EPA has stated its desire to develop criteria for both TN and TP, regardless of which nutrient is limiting. Given this directive, the proposed TP load target for Manatee River would be 102 tons/year based on the reference period approach. Assessment of TP loading to Manatee River since 1985 indicates that the proposed threshold has been exceeded regularly during the period of record, with the most recent exceedence from 2001-2006 (Figure 2-6).

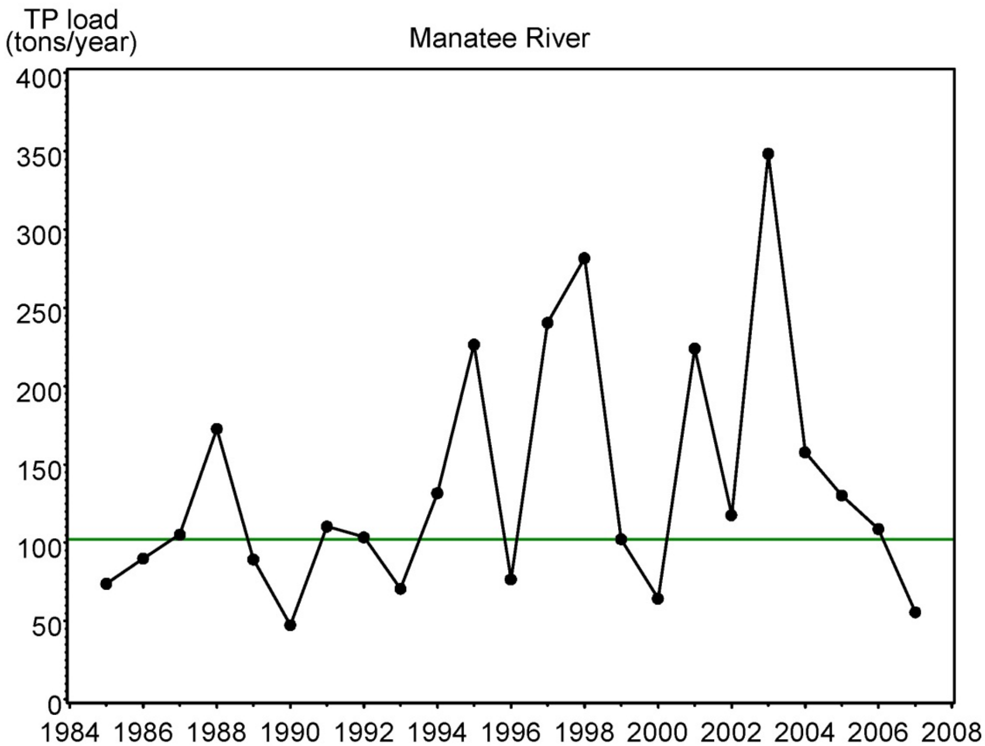

Figure 2-6. Annual TP load in Manatee River. The reference line represents the proposed loading-based TP target for the reference period.

As discussed in Section 1.3 for Terra Ceia Bay, analysis of loading targets revealed exceedences although water quality and seagrasses were stable or improving. Therefore, 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. Although the system has been determined to be nitrogen limited, EPA has expressed its desire to develop numeric nutrient criteria for both TN and TP, regardless of which nutrient is limiting. Therefore, the TP load threshold (i.e., the TP delivery ratio) was calculated for the reference period. The TP load threshold for Manatee River for the 1992-1994 reference period would be 0.37 tons TP per million cubic meters of freshwater delivered. Analysis of the time series plot of the annual TP delivery ratio for Manatee River (Figure 2-7) reveals that the TP threshold (i.e., the TP delivery ratio) has been exceeded six times out of 23 years. As discussed in Section 2.1, the Manatee River segment is clearly nitrogen limited. Therefore, it is strongly recommended not to implement a TP load threshold for the Manatee River.

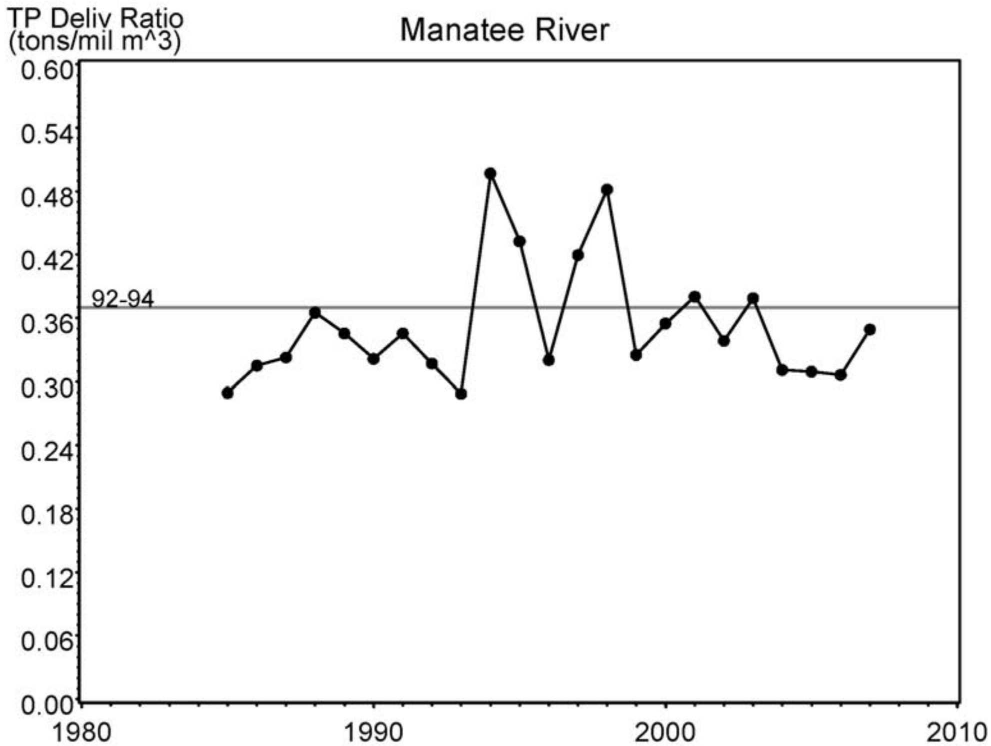

Figure 2-7. Annual TP load delivery ratio in Manatee River. The reference line represents the proposed loading-based TP criterion for the reference period.

3.0 Boca Ciega Bay

3.1 Boca Ciega Bay North

In this section, development of TP criteria is presented for Boca Ciega Bay North.

3.1.1 Temporal Variability in Ambient Water Quality and Nutrient Loadings

TP concentrations in Boca Ciega Bay North were stable over the period of record. Annual average TP concentrations ranged between 0.04 and 0.12 mg/L and were highest in 1992, but declined through 2000 when the lowest annual concentration was recorded (Figure 3-1). Between 2000 and 2010, peak TP concentrations were observed to be about 0.06-0.07 mg/L, but the non-peak years were typically not less than 0.05 mg/L.

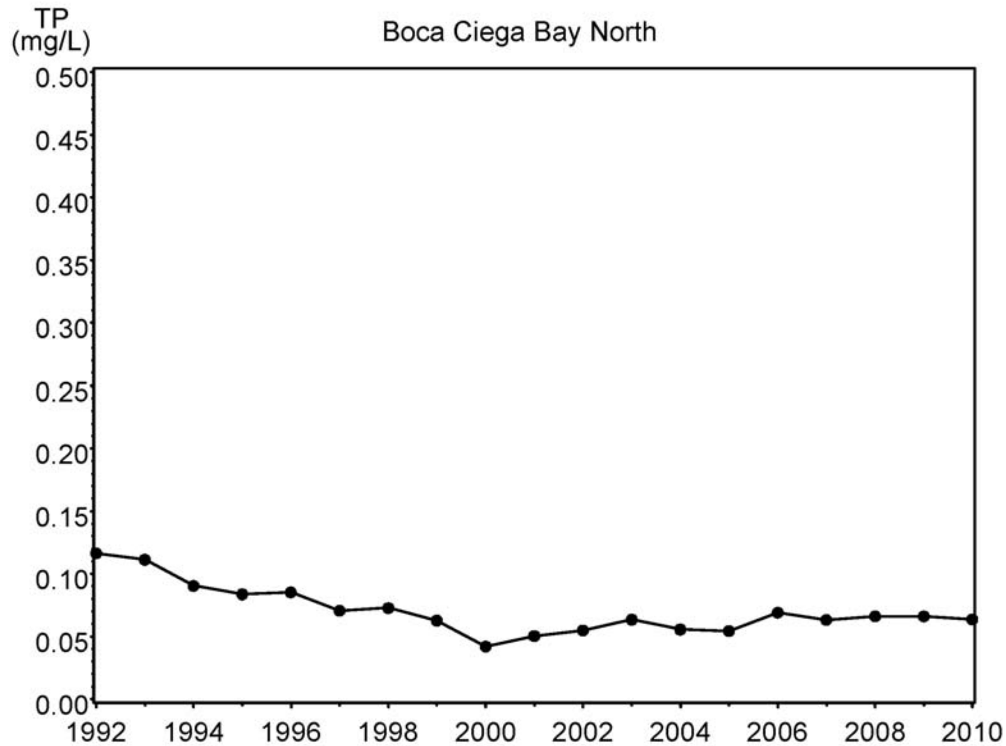

Figure 3-1. **Annual average TP concentration in Boca Ciega Bay North.**

Nutrient loads were available for the period 1985 through 2007 based on previous work for the TBEP and FDEP. TP loads in Boca Ciega Bay North were highly variable over the period of record as the loads are primarily driven by rainfall and associated nonpoint source runoff (Figure 3-2). TP loads ranged from approximately 10 tons/year to 65 tons/year (Figure 3-2). TP loads exhibited peaks in 1988, 1995, 2001, and 2003-2004.

It should be noted that an FDEP consent order signed in January 2002 required the Pinellas County South Cross Bayou water reclamation facility to cease discharging treated wastewater to deep well injection. The consent order was the result of the potential migration of injected effluent into the overlying aquifer, although that aquifer is not a potable water source. Without the ability to discharge to deep well injection, the facility was compelled to only discharge to surface waters or reuse. Following the signing of the consent order, Pinellas County completed a $143 million renovation of the South Cross facility in 2003. Starting in February 2002, treated effluent that would have been discharged to deep well injection was discharged to surface waters. This action resulted in an increase in point source pollutant loads to Boca Ciega Bay North. The impact of this decision can be seen clearly in Figure 3-2, where loads of TP were higher in the period 2003-2004. Though part of the increase in loads in 2003-2004 is due higher rainfall and associated nonpoint source runoff, surface water loads from South Cross Bayou were also higher during that time. During the 1999-2001 period, loads from the South Cross facility were up to 0.3 tons TP. After the consent order, loads from the facility increased to around 30 tons TP in the 2003-2004 period. Since the peak in 2003-2004, TP loads from the South Cross facility have been declining as Pinellas County moves forward with its goal of 100% reuse for the South Cross facility.

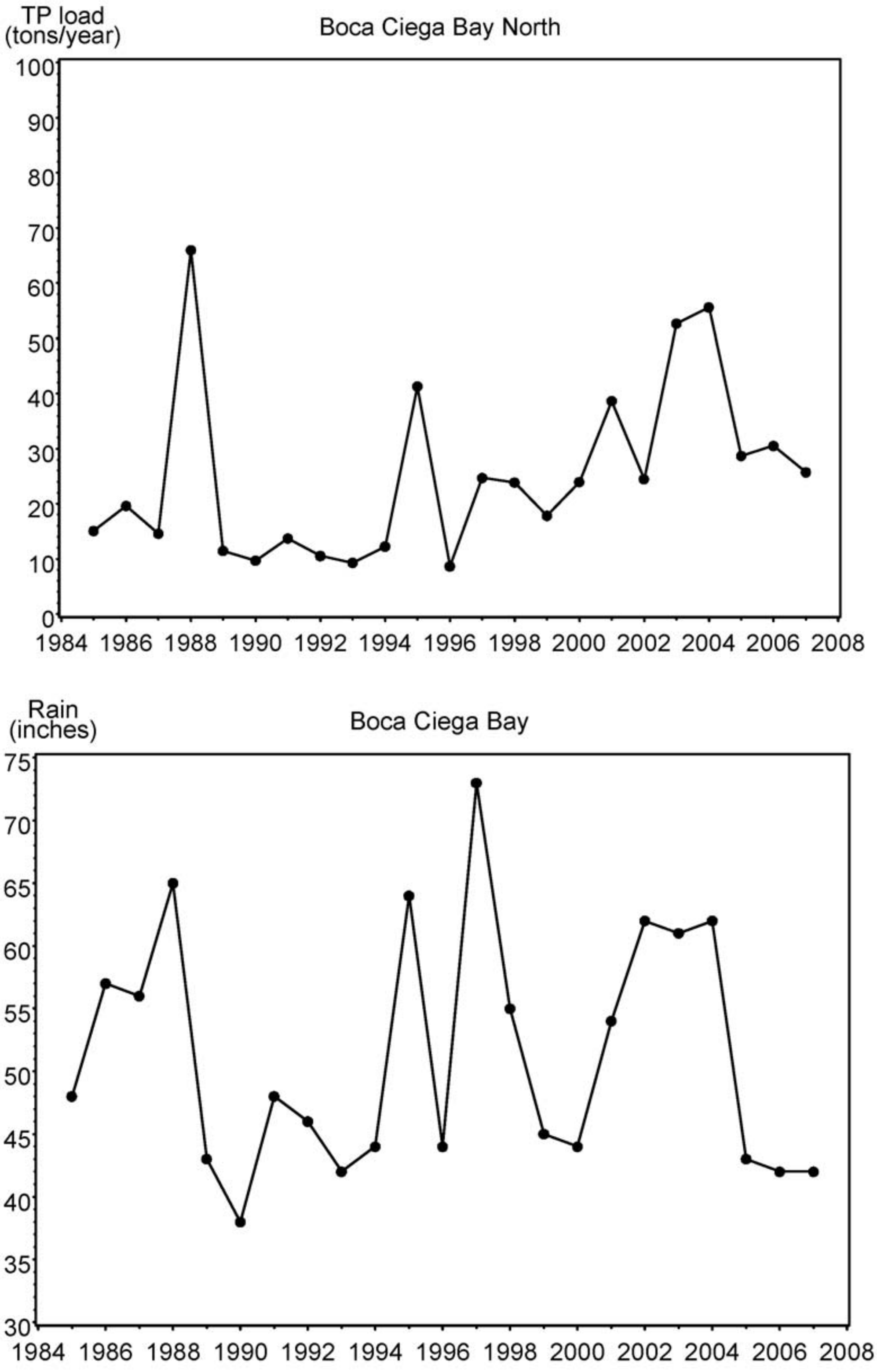

Figure 3-2. Annual TP load in Boca Ciega Bay North (top panel) and rainfall to Boca Ciega Bay watershed (bottom panel).

3.1.2 Empirical Relationships between Chlorophyll *a* and Nutrients

The relationships between TP concentrations and chlorophyll *a* concentration are shown in Figure 3-3. TP concentrations explained 11% of the variation in chlorophyll *a* concentrations. The relationships between TP loads and chlorophyll *a* concentrations are shown in Figure 3-4. TP loads accounted for a little of the variation in chlorophyll *a* (15%).

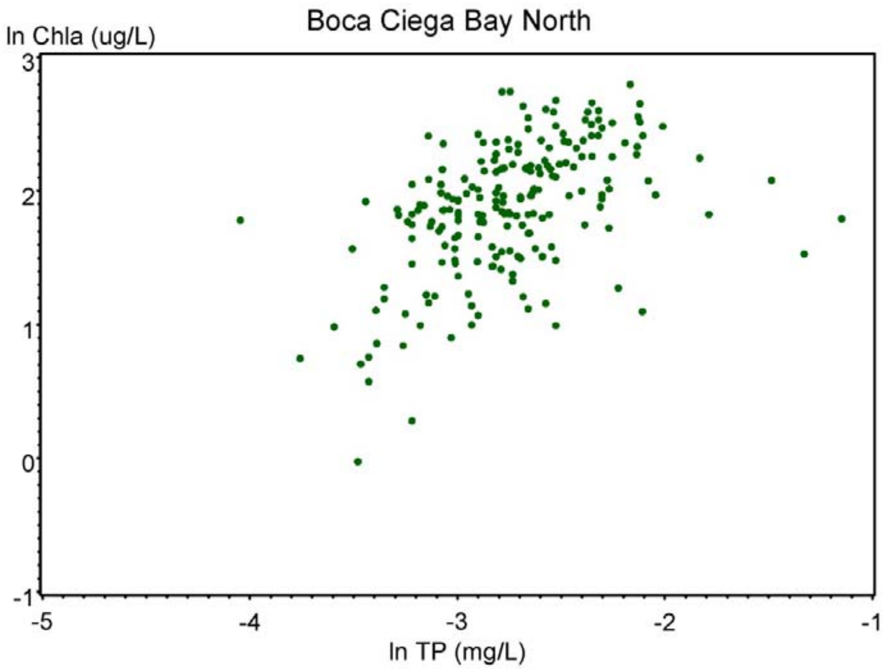

Figure 3-3. Empirical relationship between ln(chlorophyll *a*) concentration and ln(TP concentration) in Boca Ciega Bay North.

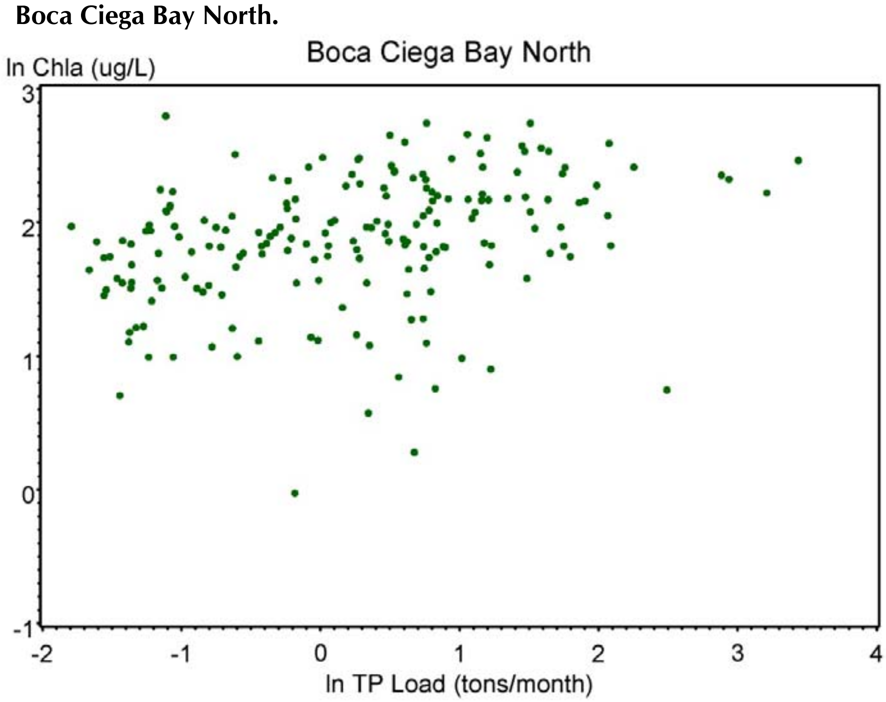

Figure 3-4. Empirical relationship between ln(chlorophyll *a*) concentration and ln(TP load) in Boca Ciega Bay North.

3.1.3 Recommended Loading- and Concentration-Based Nutrient Criteria

Because of the lack of robust statistical relationships between chlorophyll *a* concentrations and TP concentrations, the reference period approach was used to calculate the TP concentration criterion for Boca Ciega Bay North. The criterion was calculated by summing the annual average during the reference period (1992-1994) plus the standard deviation for the period of record. This method is consistent with the method used to develop TN and TP concentration criteria for the four main segments of Tampa Bay (Janicki Environmental, 2011a). The reference period was selected because it is representative of a period when water quality and water clarity were stable and seagrasses were increasing. The proposed TP concentration criterion for this bay segment is 0.11 mg/L based on the reference period approach. This threshold has not been exceeded during the period of record analyzed for this study (Figure 3-5).

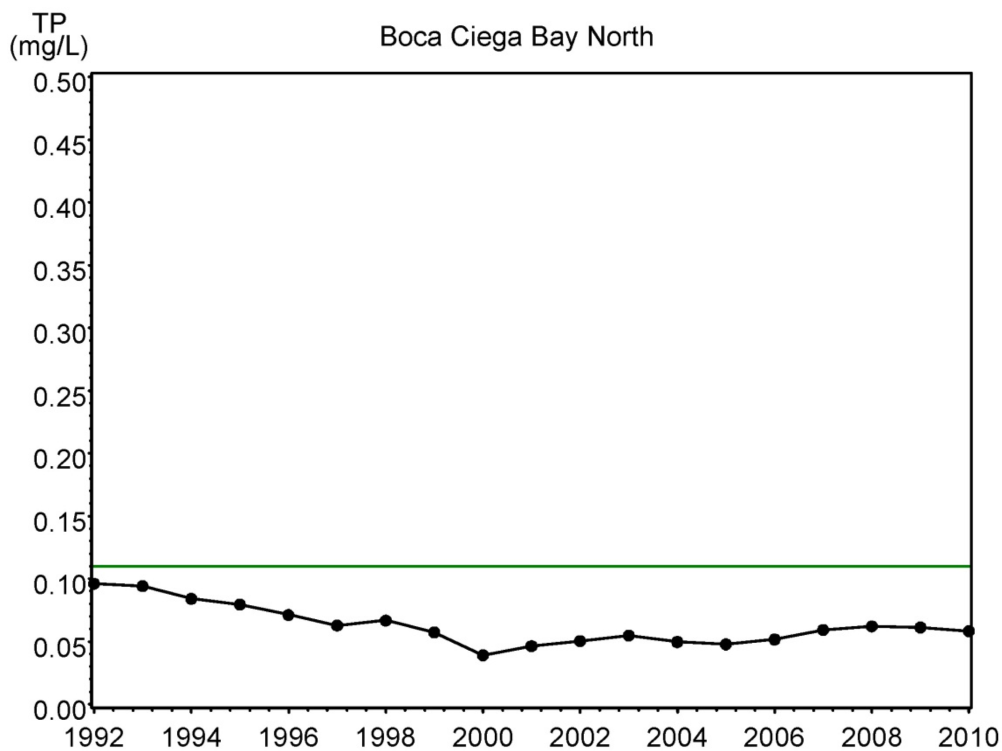

Figure 3-5. Annual geometric mean TP concentration in Boca Ciega Bay North. The reference line represents the proposed concentration-based TP criterion for the reference period.

The reference period approach resulted in a proposed TP load target for Boca Ciega Bay North of 11 tons/year. Assessment of TP loading to Boca Ciega Bay North since 1989 indicates that the majority of years have been above the proposed threshold (Figure 3-6).

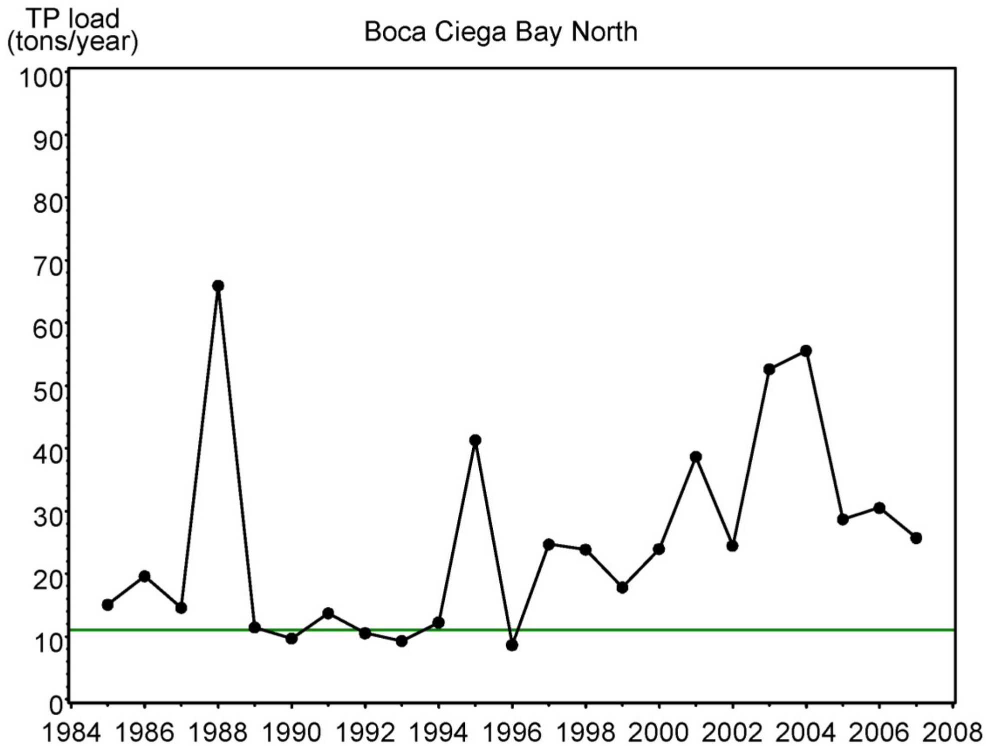

Figure 3-6. Annual TP load in Boca Ciega Bay North. The reference line represents the proposed loading-based TP target for the reference period.

As discussed in Section 1.3 for Terra Ceia Bay, analysis of loading targets revealed exceedences in Terra Ceia Bay North although water quality and seagrasses were stable or improving. This is also the case in Boca Ciega Bay North. Although in Boca Ciega Bay North, this is a result of the reference period loads (1992-1994) being lower than the loads since 1994. 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. Although the system has been determined to be nitrogen limited, EPA has expressed its desire to develop numeric nutrient criteria for both TN and TP, regardless of which nutrient is limiting. Therefore, the TP load threshold (i.e., the TP delivery ratio) was calculated for the reference period. The TP load threshold for Boca Ciega Bay North for the 1992-1994 reference period is 0.18 tons TP per million cubic meters of freshwater delivered. Analysis of the time series plot of the annual TP delivery ratio for Boca Ciega Bay North (Figure 3-7) reveals that the TP threshold (i.e., the TP delivery ratio) has been exceeded in the majority of the 23 years. This result is inconsistent with the fact that water quality and seagrasses in Boca Ciega Bay North have been stable or improving during this time period, but is consistent with nitrogen limitation in Boca Ciega Bay North, so that increases in the TP delivery ratio do not result in deteriorating water quality conditions in Boca Ciega Bay North.

The TP delivery ratios have increased within the last decade, which is attributable to the discharge of treated wastewater from the South Cross Bayou water reclamation facility. As discussed above, the facility was required by FDEP to move from deep well injection of treated wastewater to surface water discharge to the estuary in January, 2002. This resulted in an increase in point source TP loads to Boca Ciega Bay North. The effect on the TP delivery ratio has been significant as the TP concentration of treated wastewater is higher than that found in nonpoint source runoff, and the TP load from this point source is a large contributor to the TP load for the segment, more than 50% in 2005. However, since 2005 less surface water loading has occurred as reuse has increased, and the TP loading ratio has declined.

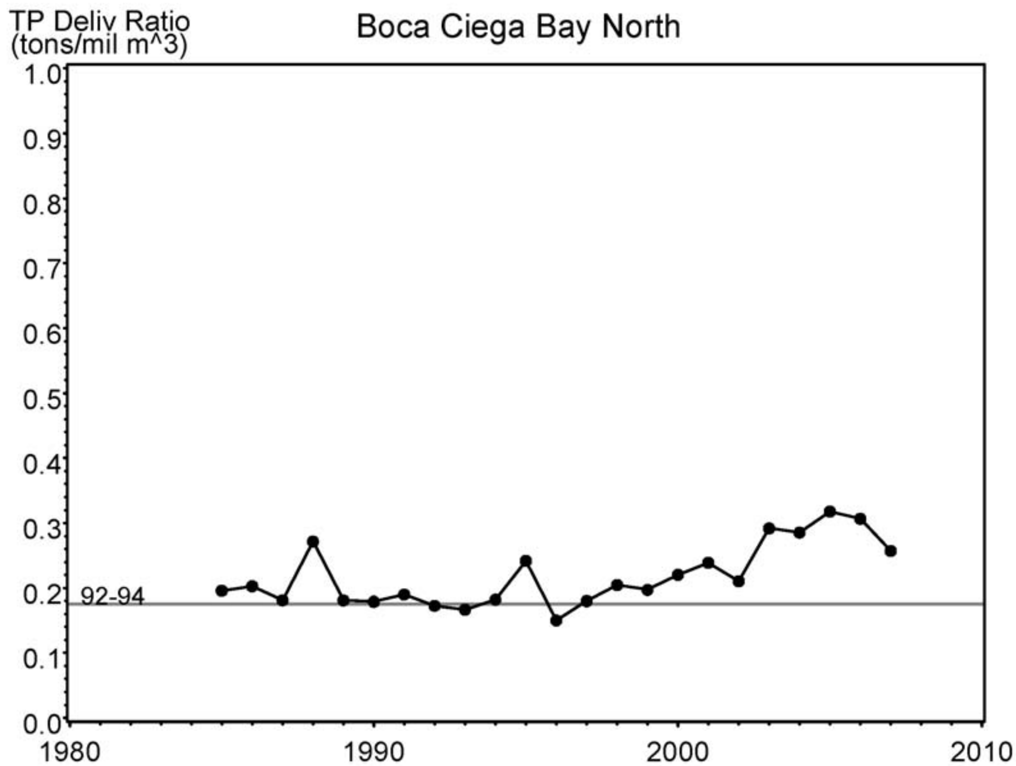

Figure 3-7. Annual TP delivery ratio in Boca Ciega Bay North. The reference line represents the proposed loading-based TP criterion for the reference period.

3.2 Boca Ciega Bay South

In this section, development of TP criteria is presented for Boca Ciega Bay South.

3.2.1 Temporal Variability in Ambient Water Quality and Nutrient Loadings

TP concentrations were relatively stable in Boca Ciega Bay South from 1996-2010 (Figure 3-8). As with the northern bay segment, annual average TP concentration was highest in the early 1990s From 1996 to 2000, TP concentrations declined from 0.10 mg/L to 0.05 mg/L after which less variation was observed (i.e., 0.05-0.07 mg/L from 2000-2010). Peak annual average TP concentrations were recorded in 1993 and 1996.

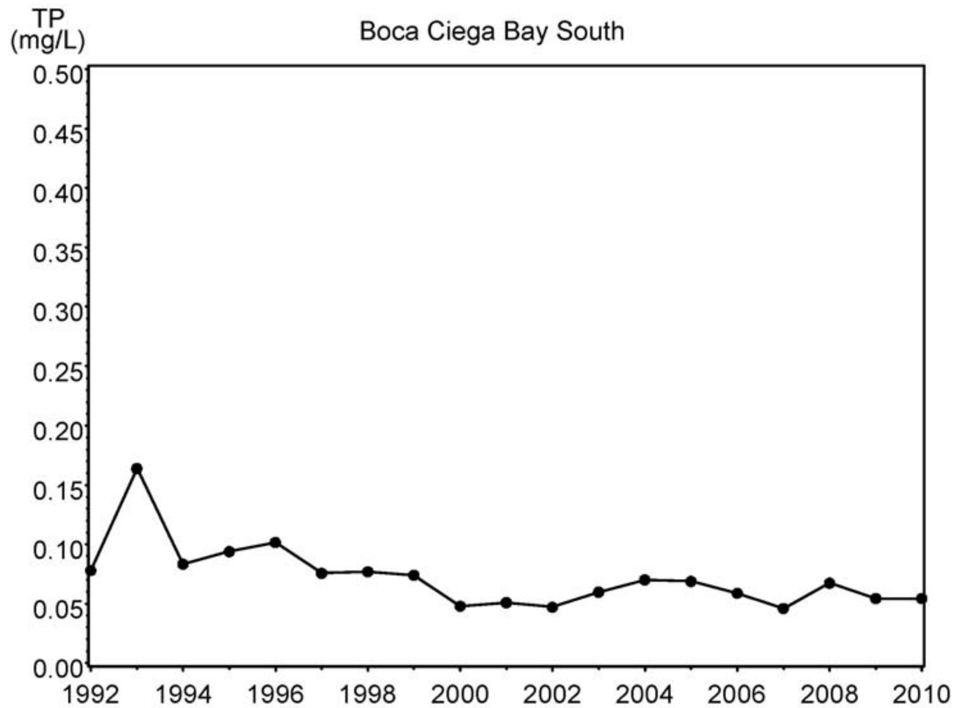

Figure 3-8. Annual average TP concentration in Boca Ciega Bay South.

Nutrient loads in Boca Ciega Bay South were not as variable as those estimated for the northern segment, with TP loads ranging from 3 to 22 tons/year (Figure 3-9). TP loads were relatively consistent and rarely exceeded 10 tons/year. Between 2004 and 2007, annual TP loads were approximately 3 to 10 tons/year.

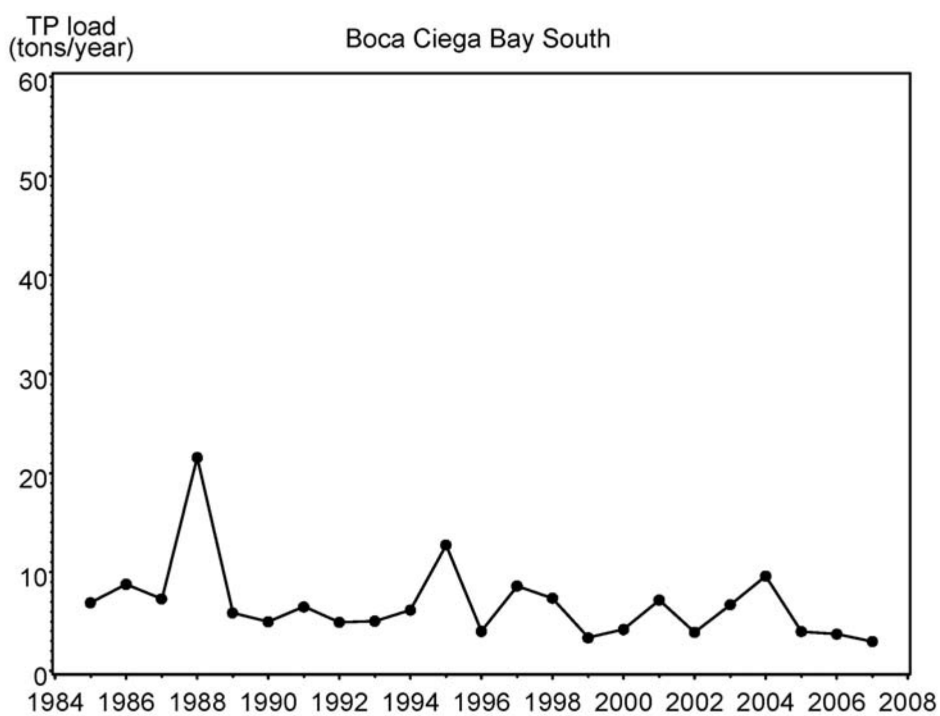

Figure 3-9. Annual TP load in Boca Ciega Bay South.

3.2.2 Empirical Relationships between Chlorophyll *a* and Nutrients

The relationship between TP concentrations and chlorophyll *a* concentration for Boca Ciega Bay South is shown in Figure 3-10. Approximately 13% of the variation in chlorophyll *a* concentration in this bay segment was explained by TP concentration. The relationship between TP loads and chlorophyll *a* concentration is shown in Figure 3-11. Total phosphorus loads accounted for only 14% of the chlorophyll *a* variation in Boca Ciega South.

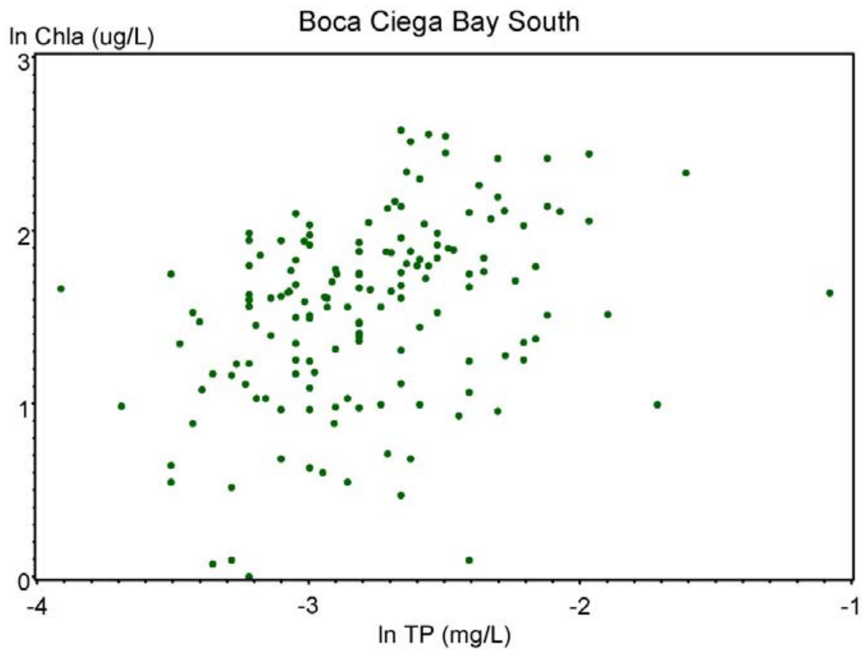

Figure 3-10. Empirical relationship between ln(chlorophyll *a* concentration) and ln(TP concentration) in Boca Ciega Bay South.

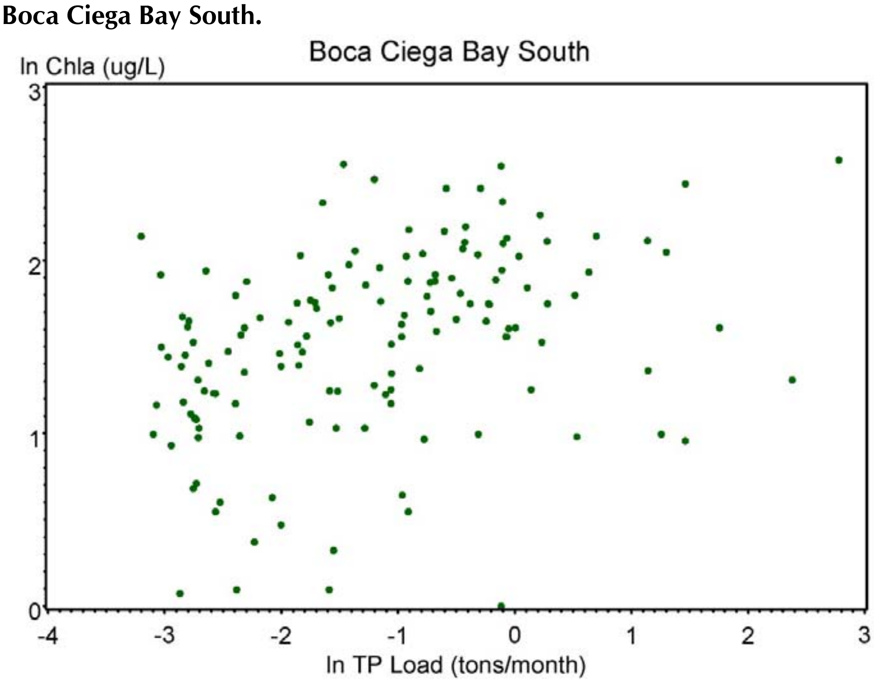

Figure 3-11 Empirical relationship between ln(chlorophyll *a* concentration) and ln(TP load) in Boca Ciega Bay South.

3.2.3 Recommended Loading- and Concentration-Based Nutrient Criteria

Because of the lack of robust statistical relationships between chlorophyll *a* concentrations and TP concentrations, the reference period approach was used to calculate the TP concentration criterion for Boca Ciega Bay South. The criterion was calculated by summing the annual average during the reference period (1992-1994) plus the standard deviation for the period of record. The reference period was selected because it is representative of a period when water quality and water clarity were stable or improving and seagrasses were increasing. The proposed TP concentration criterion for this bay segment is 0.12 mg/L. This threshold has been exceeded only once since 1992 (Figure 3-12).

The reference period approach resulted in a proposed TP load target for Boca Ciega Bay South of 5 tons/year. Assessment of TP loading to Boca Ciega Bay South since 1989 indicates that the proposed target has been exceeded numerous times (Figure 3-13).

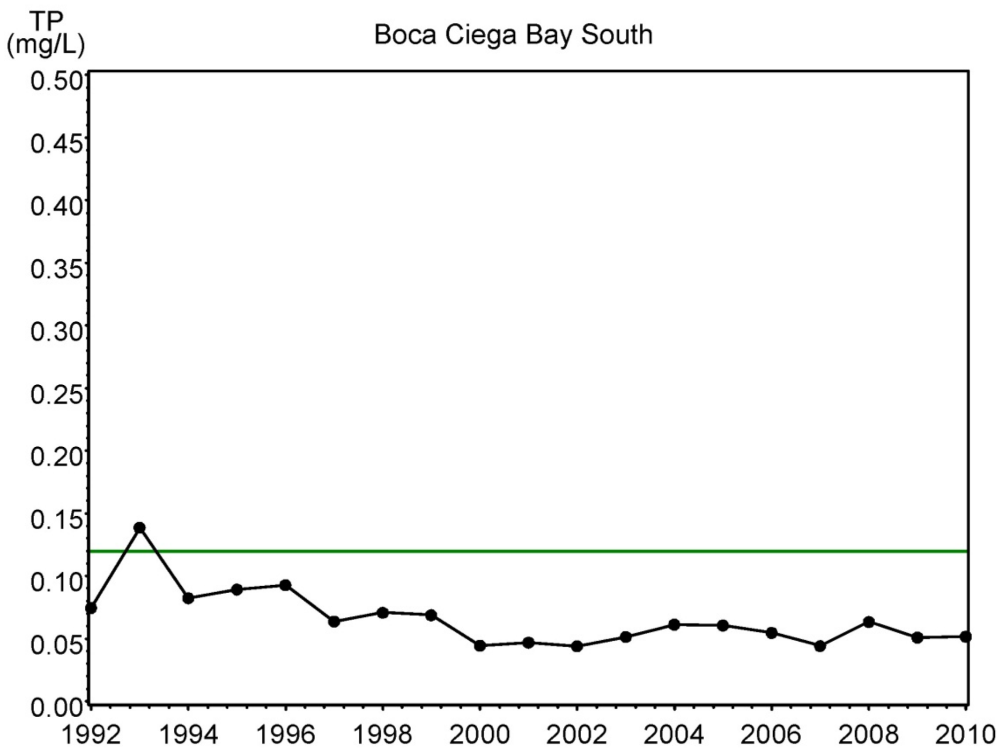

Figure 3-12. Annual average TP concentration in Boca Ciega Bay South. The reference line represents the proposed concentration-based TP criterion for the reference period.

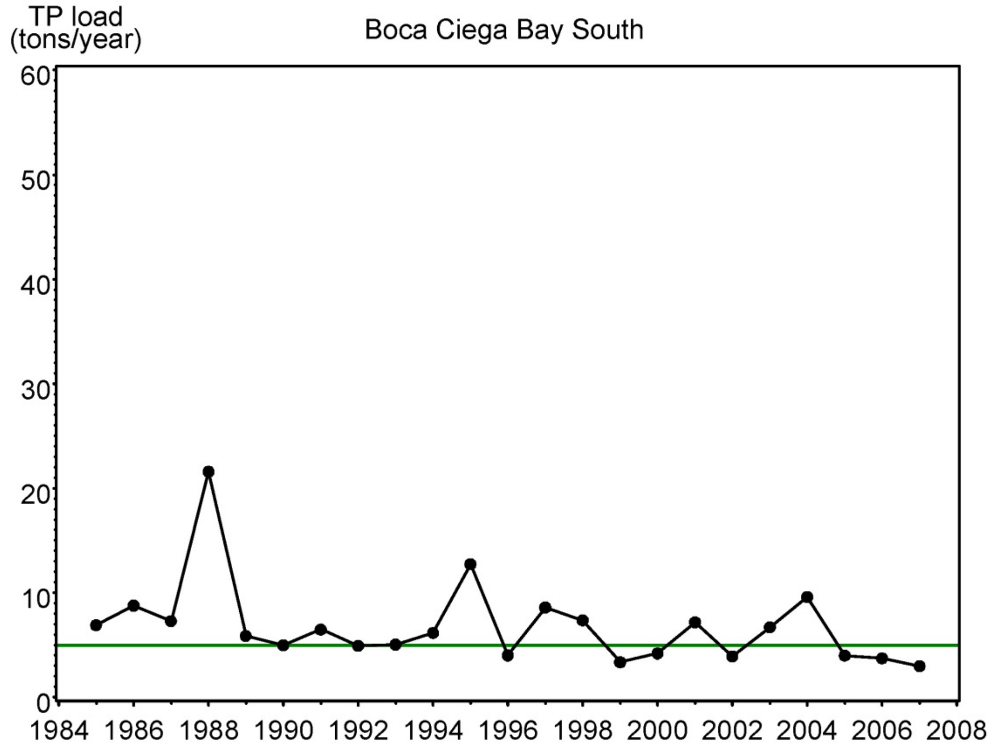

Figure 3-13. **Annual TP load in Boca Ciega Bay South. The reference line represents the proposed loading-based TP target for the reference period.**

As discussed previously for the other segments, analysis of loading targets revealed exceedences although water quality and seagrasses were stable or improving. This is also the case in Boca Ciega Bay South. 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 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. The TP load threshold for Boca Ciega Bay South for the 1992-1994 reference period is 0.06 tons TP per million cubic meters of freshwater delivered. Analysis of the time series plot of the annual TP delivery ratio for Boca Ciega Bay South (Figure 3-14) reveals that the TP threshold (i.e., the TP delivery ratio) has been exceeded in the eleven of the 23 years, and only twice since 2000.

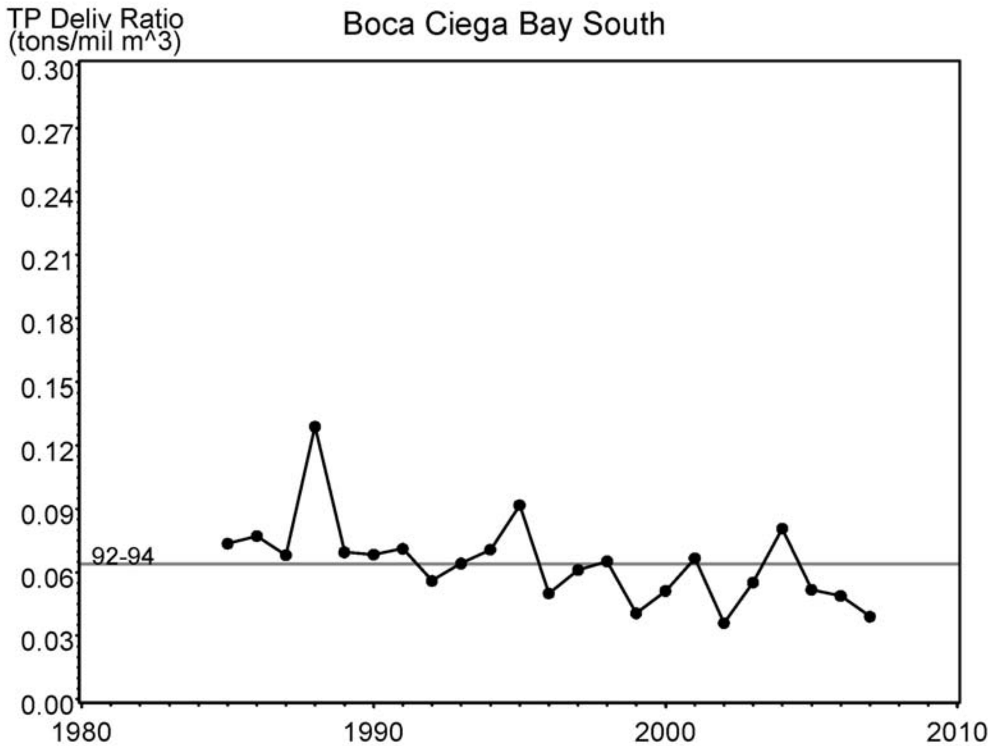

Figure 3-14. Annual TP delivery ratio in Boca Ciega Bay South. The reference line represents the proposed loading-based TP criterion for the reference period.