SARASOTA BAY
Numeric Nutrient Criteria:
Task 1 - TN and TP Concentration and Loading Based Criteria

Letter Memorandum

Prepared for:

SARASOTA BAY ESTUARY PROGRAM
Restoring Our Bays

Sarasota Bay Estuary Program

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FOREWORD

This letter memo was produced in partial fulfillment of SBEP Contract 2011SBEP04 - Development of Numeric Nutrient Criteria for Sarasota Bay, Task 1.

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We wish to thank the partners of the Sarasota Bay Estuary Program (SBEP) for the numerous conversations providing direction and insight into concerns regarding numeric nutrient criteria establishment and appropriate methodology for developing the proposed criteria. We would particularly like to thank the following individuals who serve on the water quality subcommittee of the Technical Advisory Committee: Mark Alderson, Dr. Jay Leverone, Jack Merriam, Rob Brown, Lizanne Garcia, Kris Kaufmann, Veronica Craw, John Ryan, Gary Serviss, Amber Whittle, Pete Wenner, Charles Kovach, and Jon Perry.

EXECUTIVE SUMMARY

The Sarasota Bay Estuary Program (SBEP) has recommended numeric nutrient criteria for Sarasota Bay as segment-specific mean annual total nitrogen concentrations (Janicki Environmental, 2010). EPA has noted its intention to develop numeric criteria for estuarine TP concentrations. SBEP stakeholders have also requested that loading-based TN and TP criteria be developed. This document provides segment-specific TP criteria as well as TN and TP criteria expressed as loads.

Establishment of numeric nutrient criteria is dependent on an understanding of the limiting nutrient within the water body of concern. For Sarasota Bay, extensive data exist for evaluation of which nutrient, nitrogen or phosphorus, is limiting. Ambient water quality data strongly indicate that four of the SBEP segments are nitrogen limited while a fifth (Palma Sola Bay) displays some degree of co-limitation.

The following conclusions can be drawn from the analyses and results presented herein:

Nutrient Concentrations

- The relationships between segment TN concentrations and segment TP concentrations are not evident within any bay segment, and thus cannot be used to translate established TN concentration criteria to TP concentration criteria.

- The relationships between chlorophyll *a* concentrations and segment TP concentrations are not sufficient to derive TP concentration criteria based on established chlorophyll *a* thresholds.

- The Reference Period approach provides an internally consistent method for establishing concentration-based TP criteria. The following are the proposed numeric TP concentration criteria for the respective SBEP bay segments:

  - Palma Sola Bay 0.26 mg/L
  - Sarasota Bay 0.19 mg/L
  - Roberts Bay 0.23 mg/L
  - Little Sarasota Bay 0.21 mg/L
  - Blackburn Bay 0.21 mg/L

Nutrient Loadings

- On a monthly time scale, the relationships between either TN or TP loadings and chlorophyll *a* concentrations do not explain a significant proportion of the variability in the chlorophyll *a* concentrations to support development of loading-based numeric nutrient criteria based on these relationships in any bay segment.

- The relationships between TN and TP loadings and in-bay TN and TP concentrations do not provide a defensible approach for establishing loading-based numeric nutrient criteria in any bay segment.

- The Reference Period approach provides the most defensible method to define loading-based numeric nutrient criteria for the SBEP segments. The following are the proposed TN and TP loading-based criteria (thresholds) for the respective SBEP bay segments:

	TN Criteria	TP Criteria
– Palma Sola Bay	44.5 tons/yr	7.7 tons/yr
– Sarasota Bay	237.2 tons/yr	35.2 tons/yr
– Roberts Bay	250.8 tons/yr	48.8 tons/yr
– Little Sarasota Bay	49.5 tons/yr	8.9 tons/yr
– Blackburn Bay	71.0 tons/yr	11.6 tons/yr

1.0 Introduction and Objective

The Sarasota Bay Estuary Program (SBEP) has developed recommended numeric nutrient criteria for Sarasota Bay (Janicki Environmental, 2010a). The criteria are segment-specific (Figure 1) and are expressed as mean annual total nitrogen (TN) concentrations. The segment-specific TN concentrations are those commensurate with the segment-specific chlorophyll *a* thresholds, also described in Janicki Environmental (2010b).

The objective of this task is to develop segment-specific TP concentration criteria, and segment-specific TN and TP loading criteria to be recommended as numeric nutrient criteria by the SBEP. This will provide the U.S. Environmental Protection Agency (EPA) both concentration and loading criteria for TN and TP, as are currently being developed for Tampa Bay and Charlotte Harbor in addition to Sarasota Bay. This is in keeping with recognition of the importance of maintaining consistency with existing management goals, and specifically with the recent chlorophyll *a* thresholds developed for Sarasota Bay.

The following provides a discussion of nutrient limitation, description of the analyses completed and the results of each analysis, and the recommended TP numeric nutrient criteria, expressed as concentrations, and TN and TP loading criteria, for each of the five bay segments.

2.0 Nutrient Limitation

The establishment of numeric nutrient criteria depends upon knowledge of the nutrient most likely limiting in the waterbodies of concern. Three major factors control whether nitrogen or phosphorus is more likely to be limiting (National Research Council, 2000):

- the N:P ratio in external nutrient inputs;
- the preferential loss from the photic zone of nitrogen or phosphorus due to biogeochemical processes such as denitrification, sedimentation, or absorption of phosphorus; and
- the amount of nitrogen fixation.

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).

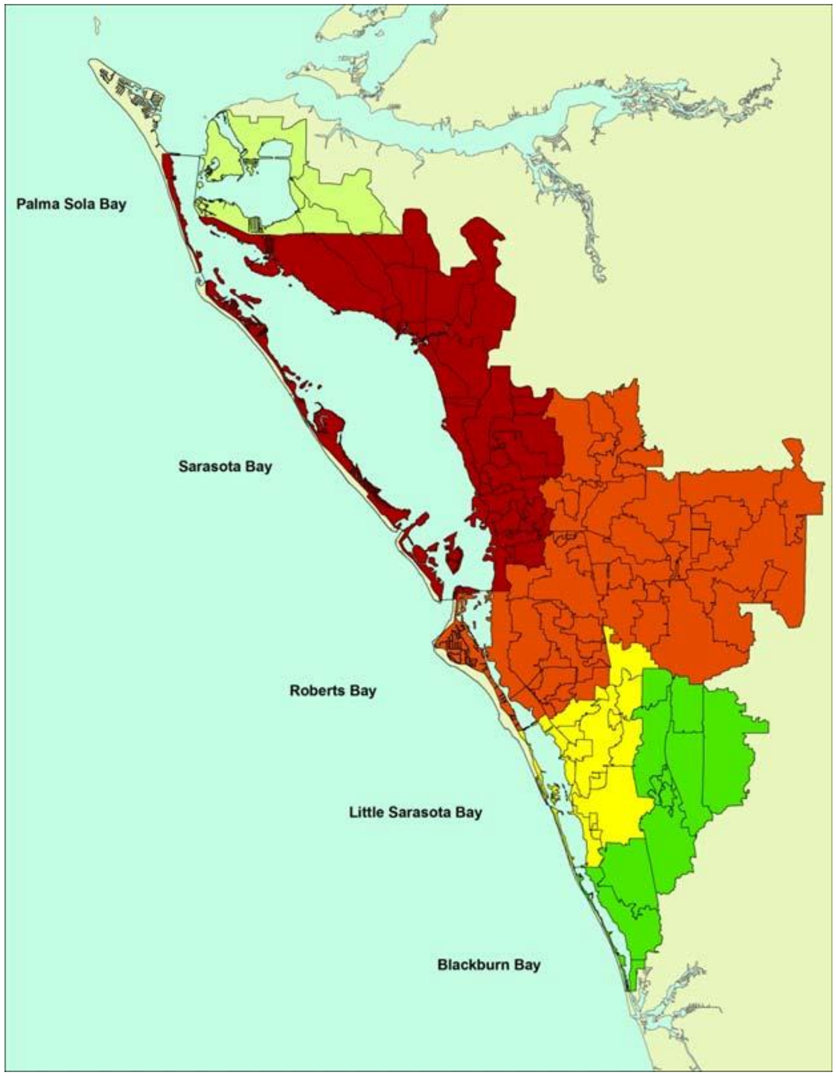


Figure 1. Sarasota Bay Estuary Program five bay segments.

Since nitrogen is considered the most likely limiting nutrient in estuarine systems, it has been identified as the primary nutrient of concern in estuarine ecosystems nationwide (Smith, 1984; NRC, 1993). As noted in Correll (1999), however, since estuaries are part of the transition zone between the open ocean and the phosphorus supplied from the land, it is possible that both phosphorus and nitrogen may be limiting in estuaries, dependent upon the time of year, location in the estuary, and nutrient supplies. Ryther and Dunstan (1971) noted the change from phosphorus limitation in freshwaters to nitrogen limitation in near-shore marine waters, although Hecky and Kilham (1988) indicated that the extent and severity of marine nitrogen limitation has not been conclusively determined, with other studies reporting estuarine phosphorus limitation in the spring and nitrogen limitation in the summer and fall (Fisher et al., 1992; Lee et al., 1996). Depending upon the relative rates of nitrogen and phosphorus supply, the limitation has been found to shift between nitrogen and phosphorus in coastal lagoons in the northeastern US (Taylor et al., 1995). It has also been documented that residence times play a significant role in determining the estuarine responses to nutrient loads ((Monson et al., 2002; Hagy et al., 2000; Borsuck et al., 2004; Boynton and Kemp, 2008).

2.1 Methods to Determine Limitation

There are two general methods that have been used to define which nutrient is limiting in a water body. They include:

- a method that depends upon ambient water quality data collected over a wide range of environmental conditions, and

- a method that involves experimental manipulation of nutrient conditions, either in the laboratory or *in situ*.

2.1.1 Ambient Water Quality Data Methods

This method depends upon a metric typically used to evaluate nutrient limitation: the nitrogen to phosphorus ratio (N:P ratio). The N:P ratio indicative of balanced conditions is typically taken to be 16:1 (molar), based on the work of Redfield (1934, 1958). This N:P ratio was based on the elemental composition of algae, under both laboratory and natural conditions. When N:P ratios are greater than 16:1 in a system, this is indicative of phosphorus limitation. However, there may be considerable variation in this ratio within an algal culture, dependent upon cell division status, light conditions, and precedent conditions (Correll, 1999; Correll and Tolbert, 1962; Terry et al., 1985).

Molar ratios of N:P are easily determined from water quality monitoring data. In freshwater systems, the N:P ratio is usually higher than 16:1, indicating that phosphorus is usually most limiting to primary production in these ecosystems (Schindler, 1977; Elser et al., 2007). This becomes evident by examining the concentrations of the forms of nitrogen and phosphorus that are available for algal uptake. Little if any dissolved inorganic phosphorus (DIP) is generally found in relatively productive freshwaters while measurable concentrations of dissolved inorganic nitrogen (DIN) remain.

Most marine systems are nitrogen limited because there are relatively low concentrations of dissolved inorganic nitrogen compared to dissolved phosphorus. Since Redfield's observations were published, research has shown that ratios from 10:1 to 20:1 for N:P are typically found in estuaries (Parsons et al., 1984). Howarth (1988) observed that the correlation between nitrogen and the primary production was better for estuaries that received nutrient concentrations with smaller N:P ratios than the one studied by Redfield. Several studies have led to the conclusion that estuaries receiving nutrient concentrations with high N:P ratios were limited by phosphorus and only those with low ratios are limited by nitrogen (Boynton et al., 1982). Boynton et al. (1982) and Howarth (1988) compiled data on the ratio of inorganic nitrogen to phosphorus in a variety of estuaries. Of the 27 studied by Howarth, 22 had N:P ratios below the Redfield ratio and may have been nitrogen limited. Because phytoplankton can assimilate some organic nutrient forms and all forms are relatively labile, it is useful to examine the ratio of total nutrient concentrations (TN:TP).

Reductions of nutrient levels in a water body will usually result in reduction in algal growth. Reducing phosphorus, however, will have no effect unless the reduction results in an N:P ratio greater than 16:1. Phosphorus would then become the limiting nutrient. In contrast, a reduction of nitrogen concentrations will result in a reduction of primary productivity when the ratio is less than 16:1. There are exceptions to this general rule. Some coastal areas are phosphorus limited due to strict phosphorus control measures or natural conditions and some freshwaters are nitrogen limited due to natural sources of phosphorus.

2.1.2 Experimental Methods

Experimental manipulation of nutrient conditions, either in the lab or *in situ,* typically involves nitrogen and phosphorus additions to either a test alga or a phytoplankton assemblage singularly and in combination. The responses to the additions determine the limiting nutrient. If growth is found only during nitrogen addition, nitrogen limitation is indicated. Conversely, if growth is found only during phosphorus addition, phosphorus limitation is indicated.

In situ methods have included:

- limnocorrals or bags in which nutrient additions are made and resultant growth responses are measured (Shapiro, 1980; Lynch and Shapiro, 1981; Havens and DeCosta, 1986; Perez et al., 1994);
- mesocosm studies in which water is collected and placed in separate containers or enclosures for application of separate treatments over multiple day time scales (Oviatt et al., 1986; Taylor et al., 1995); and
- whole-lake studies performed on entire lakes or portions of lakes separated by curtains (Schindler, 1974, 1975).

In Florida, as part of its TMDL process, the Florida Department of Environmental Protection (FDEP) attempts to identify the limiting nutrient(s) in impaired waterbodies. The TMDL for a specific waterbody specifies the maximum amount of the limiting nutrient that may enter the waterbody, with this limitation being defined with the aim of improving water quality. If the N:P ratio does not clearly suggest the limiting nutrient, TMDLs for both nitrogen and phosphorus are typically defined. The primary method for determining the limiting nutrient employed by the FDEP is use of existing water quality data to derive ambient N:P ratios, but more complicated methods, including field tests and laboratory algal growth potential bioassays, have been employed. Per FDEP guidelines, receiving waters with ratios less than 10:1 (molar) are considered nitrogen limited, ratios of greater than 30:1 (molar) indicate phosphorus limitation, and ratios of 10-30:1 (molar) indicate co-limitation (FDEP, 2002).

2.2 Confounding Factors

Determination of the limiting nutrient based solely on N:P ratios estimated from water quality data or from experimental uptake rates should be performed with consideration of potentially confounding effects. Algal cell interior N:P ratios and uptake rates may vary due to:

- cell division status (Correll and Tolbert, 1962),
- light intensity or light quality (Wynne and Rhee, 1986),
- light and temperature (Jahnke et al., 1986), and
- P deprivation and then subsequent availability (Sicko-Goad and Jensen, 1976).

Nutrient limitation in freshwaters, which are typically considered to be phosphorus limited, can vary seasonally. Summer nitrogen limitation in lakes can occur when photic zone inorganic nutrients are low (Elser et al., 1990). It has also been demonstrated that some estuaries show seasonal shifts in limitation (D'Elia et al., 1986; McComb et al., 1981; Conley, 2000). The best available information should be used to determine the limiting nutrient of a system before management decisions are made with the objective of improved water quality via nutrient load control.

2.3 Nutrient Limitation in Sarasota Bay

Nutrient limitation in the SBEP estuary has been examined using the N:P ratio method, with the results report in the following. The average TN:TP ratios for the segments of the SBEP, both by weight and molar, were determined based on ambient water quality data, and are presented in Table 1, with the years of data used for each segment provided in the table. The ratios were derived by first calculating the monthly ratio for each segment. The mean value of these monthly values within a year was calculated and the mean of these annual values was calculated. Annual mean TN values were lowest in Blackburn Bay (0.34 mg/L) and highest in Palma Sola Bay (0.65 mg/L). Annual mean TP values were lowest in Palma Sola Bay and Sarasota Bay (0.13 mg/L) and highest in Roberts Bay and Little Sarasota Bay (0.17 mg/L).

Table 1. Annual mean TN and TP concentrations and TN:TP in SBEP segments. Data provided by Manatee County Environmental Management Department and Sarasota County Water Resources Department.

Bay Segment	TN (mg/L)	TP (mg/L)	TN:TP (Weight)	TN:TP (Molar)
Palma Sola Bay (1996-2008)	0.65	0.13	9.0	20.0
Sarasota Bay (1998-2008)	0.35	0.13	3.1	6.9
Roberts Bay (1998-2009)	0.43	0.17	2.7	6.0
Little Sarasota Bay (1998-2009)	0.49	0.17	3.1	6.8
Blackburn Bay (1998-2009)	0.34	0.14	2.6	5.8

All segments except Palma Sola Bay have molar N:P ratios less than 10:1. According to the FDEP guidelines (FDEP, 2002), all segments except Palma Sola Bay would therefore be considered nitrogen-limited. Palma Sola Bay, with N:P ratio of 20:1, would be considered co-limited, as this ratio is between the 10:1 ratio indicating nitrogen limitation and the 30:1 ratio indicating phosphorus limitation.

It is important to recall that the nutrient that is most limiting can vary seasonally (Malone et al., 1996; Conley et al., 2009), so that areas that are generally nitrogen limited may by phosphorus limited at times. In addition to nutrient limitation, phytoplankton growth may also be light-limited during certain parts of the year (Pennock and Sharp, 1994).

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). Season-specific TN:TP ratios were also estimated (Table 2). These estimates continue further the conclusion that the SBEP system, with the exception of the Palma Sola Bay segment, is nitrogen-limited.

Table 2. Seasonal mean TN:TP ratios in SBEP segments. Data provided by Manatee County Environmental Management Department and Sarasota County Water Resources Department.

Bay Segment	Dry Season		Wet Season	
	TN:TP (Weight)	TN:TP (Molar)	TN:TP (Weight)	TN:TP (Molar)
Palma Sola Bay (1996-2008)	9.4	20.8	9.0	19.8
Sarasota Bay (1998-2008)	2.9	6.4	3.7	8.1
Roberts Bay (1998-2009)	2.6	5.7	2.9	6.5
Little Sarasota Bay (1998-2009)	2.8	6.3	3.6	7.9
Blackburn Bay (1998-2009)	2.4	5.3	3.1	6.8

3.0 Sarasota Bay TN and TP Criteria: Analyses and Results

Multiple analyses were completed in the evaluation of potential TN and TP criteria expressed as in-bay concentrations. The first set of analyses was performed to evaluate potential methods of deriving TP concentration criteria commensurate with the previously established TN concentration criteria and/or chlorophyll *a* thresholds. These include:

- examination of the relationships between TN and TP concentrations within each segment, following the rationale that the TN concentration criteria have already been developed (Janicki Environmental, 2010) and relationships between TN and TP concentrations could provided TP concentration criteria;

- examination of relationships between monthly TP concentrations with chlorophyll *a* concentrations, with the potential to derive TP concentration criteria based on chlorophyll *a* thresholds (Janicki Environmental, 2010); and
- application of a reference period approach to establishing TP concentration criteria.

Following selection of the most appropriate method for developing TP concentration criteria, additional analyses were completed in the evaluation of potential TN and TP criteria expressed as loadings to the bay segments, as requested by the SBEP. These include:

- examination of the relationships between chlorophyll *a* concentrations within each segment and TN and TP loadings to the segment, following the rationale that the chlorophyll *a* thresholds have already been developed (Janicki Environmental, 2010) and relationships between chlorophyll *a* and TN and TP loadings could provide TN and TP loading criteria;
- examination of relationships between monthly TN and TP concentrations with TN and TP loadings, respectively, with the potential to derive TP and TN loading criteria based on the selected TP concentration criteria (from results of analyses above) and the previously established TN concentration criteria (Janicki Environmental, 2010); and
- application of a reference period approach to establishing TN and TP loading criteria.

The data used in these analyses are defined in Attachments 1-4. The following describes these analyses and the results obtained.

3.1 Evaluation of Relationships Between In-bay TN and TP Concentrations

Since the current proposed TN criteria are expressed as concentrations (Janicki Environmental, 2010), the simplest method to propose TP criteria expressed as in-bay concentrations would be based on the potential relationships between in-bay TN and TP concentrations within each segment. If significant relationships are found between the TN concentrations and the TP concentrations, then the TP concentration criteria can be derived based on the TN concentration criteria already established.

Plots of monthly segment-specific TP concentrations as functions of TN concentrations were inspected, with TN and TP concentrations as functions of TN and TP loads, respectively, including various lag and cumulative load effects. Graphical results for each segment are provided in Attachment 1. The graphical representations of the relationships were then used to guide evaluation of relationships between TN and TP concentrations.

No relationships were found between TP concentrations and potential TN concentration that explained more than 24% of the variation in TP concentrations (Table 3). In Palma Sola Bay, the TN concentration explained only 3% of the variation in the log-transformed TP concentrations.

In Sarasota Bay, no relationships with TN concentrations explained any variation in TP concentrations. In Roberts Bay, the variation in TN concentration explained 24% of the variation in TP concentration. In Little Sarasota Bay, on 12% of the variation in TP concentrations was explained by the TN concentrations. In Blackburn Bay, 23% of the variation in monthly TP concentrations was explained by the variation in TN concentrations. There were significant relationships for Roberts Bay, Little Sarasota Bay, and Blackburn Bay, but the coefficients of determination (r^2) values were low indicating that TN concentrations are not a good predictor of TP concentrations.

Table 3. Best-fit regressions of monthly TP concentrations on TN concentrations.

Segment	Regression	p > F	r^2
Palma Sola Bay	-2.76 + 0.60*[TN]	0.10	0.03
Sarasota Bay	0.13 - 0.01*[TN]	0.7546	0.00
Roberts Bay	0.10 + 0.16*[TN]	<0.0001	0.24
Little Sarasota Bay	0.11 + 0.12*[TN]	<0.0001	0.12
Blackburn Bay	0.09 + 0.17*[TN]	<0.0001	0.23

3.2 Evaluation of Relationships Between Chlorophyll *a* and TP Concentrations

The second data analysis approach examined the potential relationships between chlorophyll *a* concentrations and TP concentrations in each segment. Chlorophyll *a* thresholds have been established by the SBEP. If significant relationships are found, then the these thresholds could be used to determine the corresponding TP concentrations for use as numeric nutrient criteria.

Monthly segment-specific chlorophyll *a* and TP concentrations were plotted. A series of variables based on the ambient TP concentrations, including various lag concentrations, was examined. Graphical results for each segment as scatter plots of chlorophyll *a* are provided in Attachment 2. The graphical representations of the relationships were then used to guide evaluation of relationships between chlorophyll *a* and TP concentrations that may explain the monthly variation in chlorophyll *a* concentrations.

No relationships were found between chlorophyll *a* and TP concentrations that explained more than 21% of the variation in chlorophyll *a* (maximum r^2 = 0.21) (Table 4). In Palma Sola Bay, the mean log-transformed two-month TP concentration explained 7% of the variation in log-transformed chlorophyll *a* concentrations. In Sarasota Bay, the mean three-month TP concentration explained 5% of the variation in log-transformed chlorophyll *a* concentrations. In Roberts Bay, the same-month TP concentration explained 21% of the variation in chlorophyll *a* concentrations. In Little Sarasota Bay, 6% of the variation in chlorophyll *a* concentrations was explained by the same-month TP concentration, and 19% of the variation in chlorophyll *a* concentrations in Blackburn Bay was explained by the same-month TP concentration.

Table 4. Best-fit regressions of monthly TP concentrations on chlorophyll a

concentrations.			
Segment	**Regression**	**p > F**	**r^2**
Palma Sola Bay	2.60 + 0.31*ln Mean 2-month TP Concentration	0.0045	0.07
Sarasota Bay	0.93 + 3.67*Mean 3-month TP Concentration	0.0155	0.05
Roberts Bay	-3.17 + 61.13*Mean TP Concentrations	<0.0001	0.21
Little Sarasota Bay	2.41 + 29.09*Mean TP Concentration	0.0035	0.06
Blackburn Bay	-0.55 + 39.51*Mean TP Concentration	<0.0001	0.19

The results of these analyses do not provide adequate evidence to support recommendations for TP concentration criteria based on the relationships between the chlorophyll *a* and TP concentrations.

3.3 Reference Period Concentration Criteria

The third approach to developing concentration-based numeric nutrient criteria for TP is the reference period approach. Segment-specific chlorophyll *a* **targets** (values at this level or below indicate desirable conditions) have been previously established. These targets were based on a 2001-2005 reference period. This period was deemed appropriate due to the seagrass coverage observed during this period (Janicki Environmental,. The SBEP also considered the year-to-year variability in chlorophyll *a* concentrations and arrived at segment-specific chlorophyll *a* **thresholds** (values above this level indicate undesirable conditions). The threshold was the sum of the chlorophyll a target and one standard deviation of the long-term chlorophyll *a* concentrations.

Following this approach, numeric nutrient criteria expressed as TP concentrations for the five bay segments were derived. Targets were based on 2001-2005 reference period data, and the standard deviations in each segment were based on the annual means. The TP concentration target, standard deviation, and threshold for each segment are provided in Table 5.

Table 5. TP targets and thresholds based on the Reference Period approach. The reference period was 2001-2005.

Segment	TP Target (mg/L)	Standard Deviation of Long-term Annual TP Concentrations	TP Threshold (mg/L)
Palma Sola Bay	0.13	0.13 (1996-2008)	0.26
Sarasota Bay	0.15	0.04 (1998-2008)	0.19
Roberts Bay	0.19	0.04 (1998-2009)	0.23
Little Sarasota Bay	0.18	0.03 (1998-2009)	0.21
Blackburn Bay	0.17	0.04 (1998-2009)	0.21

The proposed TN and TP concentration criteria are compared to the observed geometric mean annual TN and TP concentrations in Figures 2 through 6. The horizontal lines represent the proposed criteria.

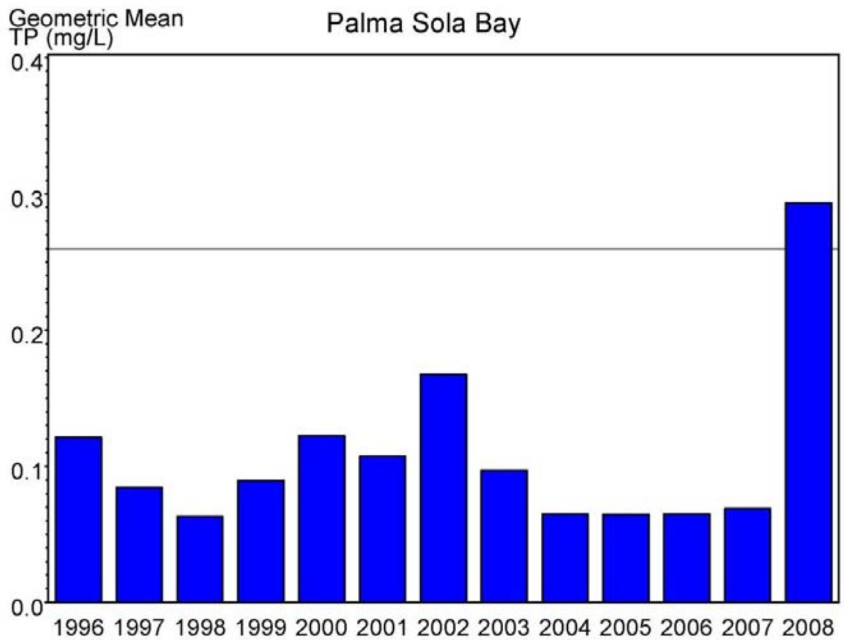


Figure 2. Comparison of proposed TP concentration criterion for Palma Sola Bay to the annual geometric mean TP concentrations from 1996 through 2008.

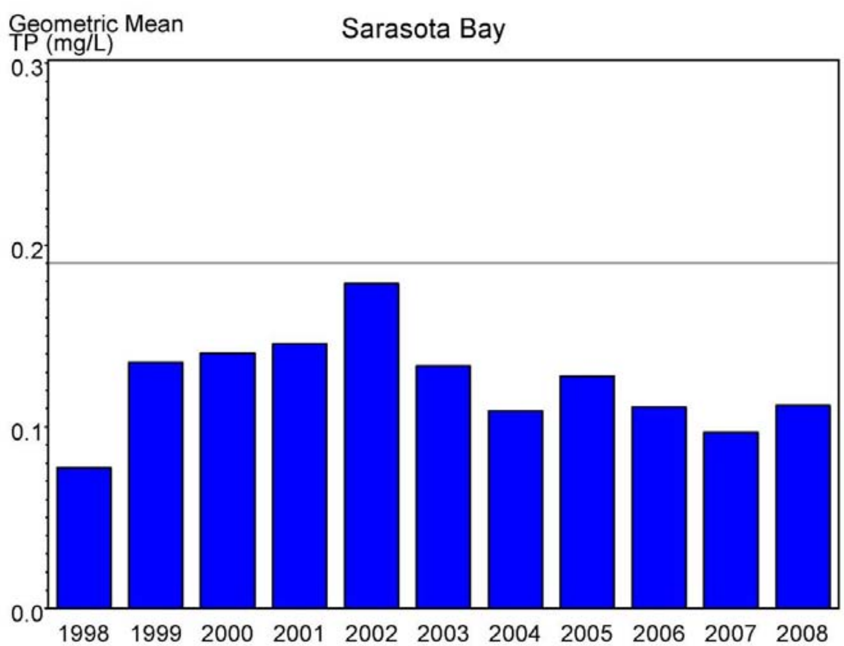


Figure 3. Comparison of proposed TP concentration criterion for Sarasota Bay to the annual geometric mean TP concentrations from 1996 through 2008.

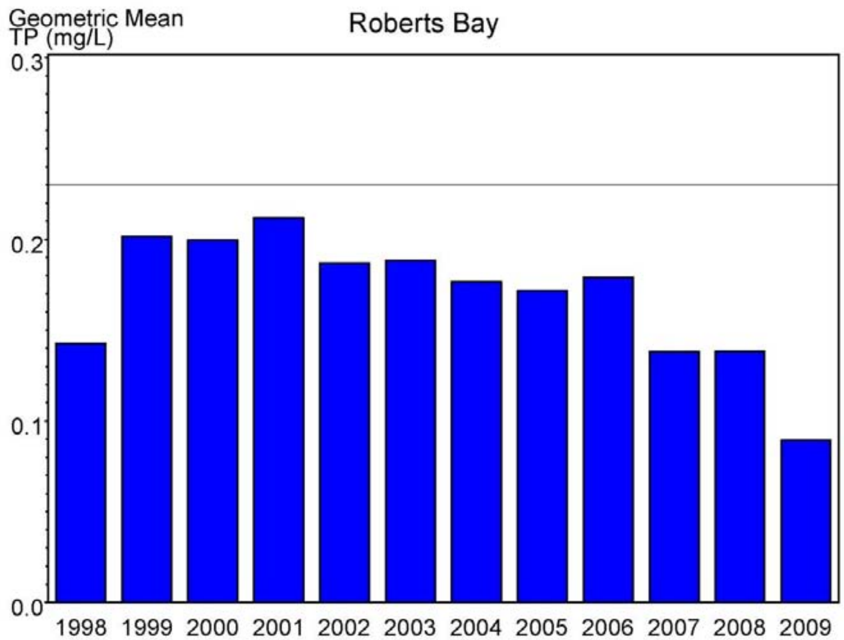


Figure 4. Comparison of proposed TP concentration criterion for Roberts Bay to the annual geometric mean TP concentrations from 1998 through 2009.

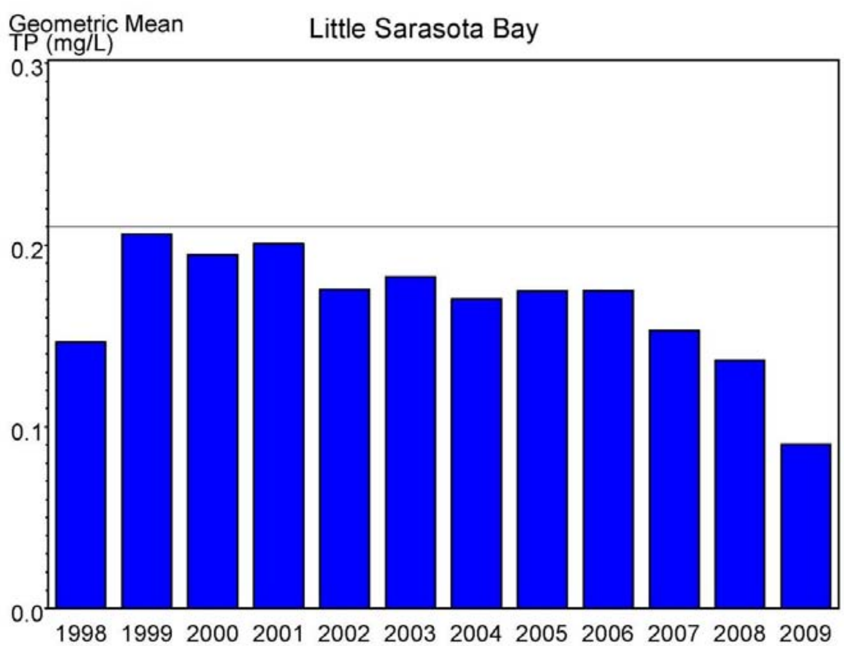


Figure 5. Comparison of proposed TP concentration criterion for Little Sarasota Bay to the annual geometric mean TP concentrations from 1998 through 2009.

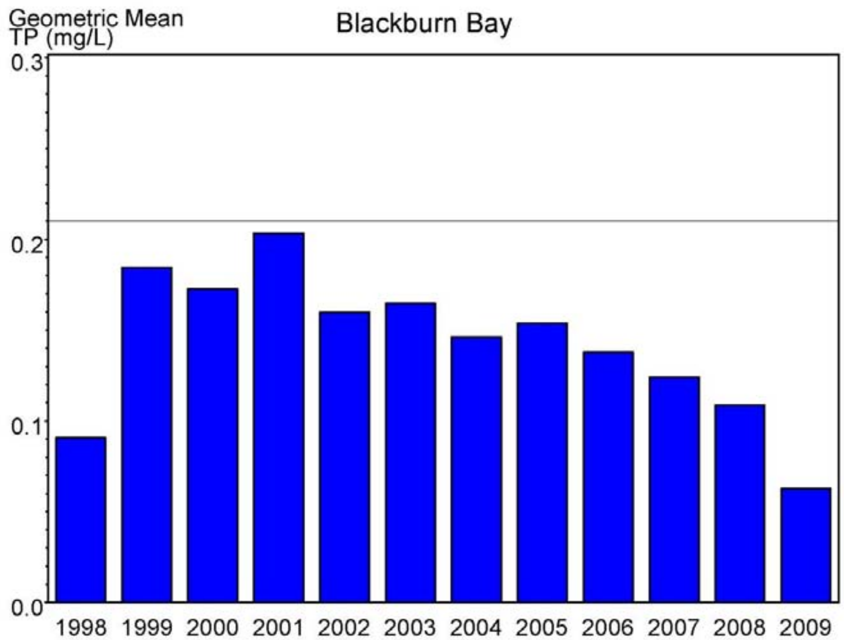


Figure 6. Comparison of proposed TP concentration criterion for Blackburn Bay to the annual geometric mean TP concentrations from 1998 through 2009.

3.4 Evaluation of Relationships Between TN and TP Concentrations and TN and TP Loadings

The simplest method to propose criteria expressed as loadings to bay segments is based on relationships between segment TN and TP concentrations and TN and TP loadings delivered to each segment. The current proposed TN concentration criteria and TP concentration criteria (reference period results described above) can be compared to TN and TP loadings to the segments. If significant relationships are found between the nutrient loads and their respective segment concentrations, then the proposed numeric nutrient criteria could be expressed as loadings. Monthly TN and TP concentrations for each segment were merged with monthly TN and TP loadings. Plots of these data were inspected, with TN and TP concentrations as respective functions of TN and TP loads, including various lag and cumulative load effects. Graphical results for each segment are provided in Attachment 3 (TN) and Attachment 4 (TP).

Table 6 shows the results for best-fit regressions for all segments for both TN and TP concentrations as a function of TN and TP loads, respectively. In Palma Sola Bay, no relationships were found between TN concentration and TN load that explained more than 9% of the variation in TN concentrations. Only 1% of the variations in TP concentrations in Palma Sola Bay were explained by TP load. In Sarasota Bay, no relationships were found that explained more than 16% of the variation between TN concentration and TN load, and only 1% of the variation in TP concentrations were explained by TP load. In Roberts Bay, 48% of the variation in segment TN concentrations was explained by the two-month cumulative TN load, and TP load explained 22% of the variation in TP concentration. In Little Sarasota Bay, the three-month cumulative TN load explained 45% of the variation in TN concentration, and the two-month cumulative TP load explained 3% of the variation in TP concentrations. In Blackburn Bay, 45% of the variation in TN concentrations was explained by the variation in three-month cumulative TN load, and the cumulative two-month TP loading explained 8% of the variation in TP concentrations.

Based on the limited relationships between the nutrient concentrations and nutrient loads to those segments, the results of these analyses do not provide adequate evidence to support recommendations for TN and TP loading criteria.

Table 6. Best-fit regressions of TN and TP concentrations on TN and TP loads, respectively.

Segment – Variable	Regression	p > F	r^2
Palma Sola Bay – [TN]	0.53 + 0.01*Cumulative 3-month TN Load	0.0050	0.09
Palma Sola Bay – [TP]	.09 - 0.01*ln Same Month TP Load	0.2358	0.01
Sarasota Bay – [TN]	-1.84 + 0.23* ln Cumulative 3-month TN Load	<0.0001	0.16
Sarasota Bay – [TP]	-2.21+0.05*ln Same Month TP Load	0.3745	0.01
Roberts Bay – [TN]	+ 0.01* Cumulative 2-month TN Load	<0.0001	0.48
Roberts Bay – [TP]	+ 0.01*Same Month TP Load	<0.0001	0.22
Little Sarasota Bay – [TN]	+ 0.02* Cumulative 3-month TN Load	<0.0001	0.45
Little Sarasota Bay – [TP]	+ 0.01*Cumulative 2-month TP Load	0.0622	0.03
Blackburn Bay – [TN]	+ 0.35* ln Cumulative 3-month TN Load	<0.0001	0.45
Blackburn Bay – [TP]	+ 0.02*Cumulative 2-month TP Load	0.0012	0.08

3.5 Evaluation of Relationships Between Chlorophyll *a* Concentrations and TN and TP Loads

A second method that could provide potential TN and TP criteria expressed as loadings to bay segments is based on relationships between segment chlorophyll *a* concentrations and TN and TP loads delivered to each segment. Chlorophyll *a* thresholds have been developed for the SBEP (Janicki Environmental, 2010), and may be used to derive loading criteria if appropriate relationships exist.

The relationships between monthly chlorophyll *a* concentrations and TN and TP loadings were examined, with graphical results provided in Attachments 5 (TN) and 6 (TP).

Table 7 shows the results for the best-fit regressions for all segments for monthly chlorophyll *a* concentrations as functions of both TN and TP loadings. No relationships were found between chlorophyll *a* and TN and TP loads that explained more than 41% of the variation in chlorophyll *a* (maximum r^2= 0.41) (Table 7). In Palma Sola Bay, the two-month TN and TP loadings explained 14% and 11%, respectively, of the variation in chlorophyll *a* concentrations. In Sarasota Bay, the two-month cumulative TN loads explained 32% of the variation in chlorophyll *a*, and the TP loadings explained 31% of the variation in chlorophyll *a* concentrations. In Roberts Bay, the cumulative two-month loads explained 41% (TN loading) and 39% (TP loading) of the variations in chlorophyll *a*. In Little Sarasota Bay, the cumulative two-month loading explained 37% (TN loading) and 35% (TP loading) of the variations in chlorophyll *a* concentrations. In Blackburn Bay, the cumulative two-month loading explained 35% (TN load) and 33% (TP Load) of the variations in chlorophyll *a* concentrations.

The results of these analyses do not provide adequate evidence to support recommendations for TN and TP loading criteria based on the relationships between chlorophyll *a* concentrations and TN and TP loadings in the bay segments.

Table 7. Best-fit regressions of monthly chlorophyll a concentrations on TN and TP loads (ton).

Segment – Variable	Regression	p > F	r^2
Palma Sola Bay – TN Load	5.03 + 2.64*ln Cumulative 2-month TN Load	<0.0001	0.14
Palma Sola Bay – TP Load	5.94 + 2.92* Cumulative 2-month TP Load	0.0006	0.11
Sarasota Bay – TN Load	2.48 + 0.09* Cumulative 2-month TN Load	<0.0001	0.32
Sarasota Bay – TP Load	3.75+2.37* ln Same Month TP Load	<0.0001	0.31
Roberts Bay – TN Load	+ 0.22* Cumulative 2-month TN Load	<0.0001	0.41
Roberts Bay – TP Load	+ 1.24*Cumulative 2-month TP Load	<0.0001	0.39
Little Sarasota Bay – TN Load	.80 + 0.82* Cumulative 2-month TN Load	<0.0001	0.37
Little Sarasota Bay – TP Load	+ 5.17*Cumulative 2-month TP Load	<0.0001	0.35
Blackburn Bay – TN Load	.05 + 0.47* Cumulative 2-month TN Load	<0.0001	0.35
Blackburn Bay – TP Load	+ 3.28*Cumulative 2-month TP Load	<0.0001	0.33

3.6 Reference Period TN and TP Loads as Nutrient Loading Criteria

Establishment of loading-based nutrient criteria should be consistent with the chlorophyll *a* and concentration-based TN and TP criteria already established for Sarasota Bay. The third approach to developing loadings-based numeric nutrient criteria for both TN and TP is the reference period approach. Based on the methods used for development of TP concentration criteria, loading targets and thresholds were developed. As with TP concentrations, the reference period was 2001-2005 . Because loading data are available through 2008, the period used to calculate the standard deviation was 1998-2008. These loading criteria (thresholds) are considered to be commensurate with reference period TP concentrations proposed as criteria above, and with the reference period chlorophyll *a* thresholds developed previously (Janicki Environmental, 2010a). The loading targets and standard deviations are presented in Table 8. By summing the target loads plus one standard deviation (Table 8), the loading criteria (thresholds) are obtatined. The loading criteria for TN and TP are presented in Table 9 based on the 2001-2005 reference period.

Table 8. Reference Period Loading-based TN and TP targets (2001-2005) and standard deviations (1998-2008).

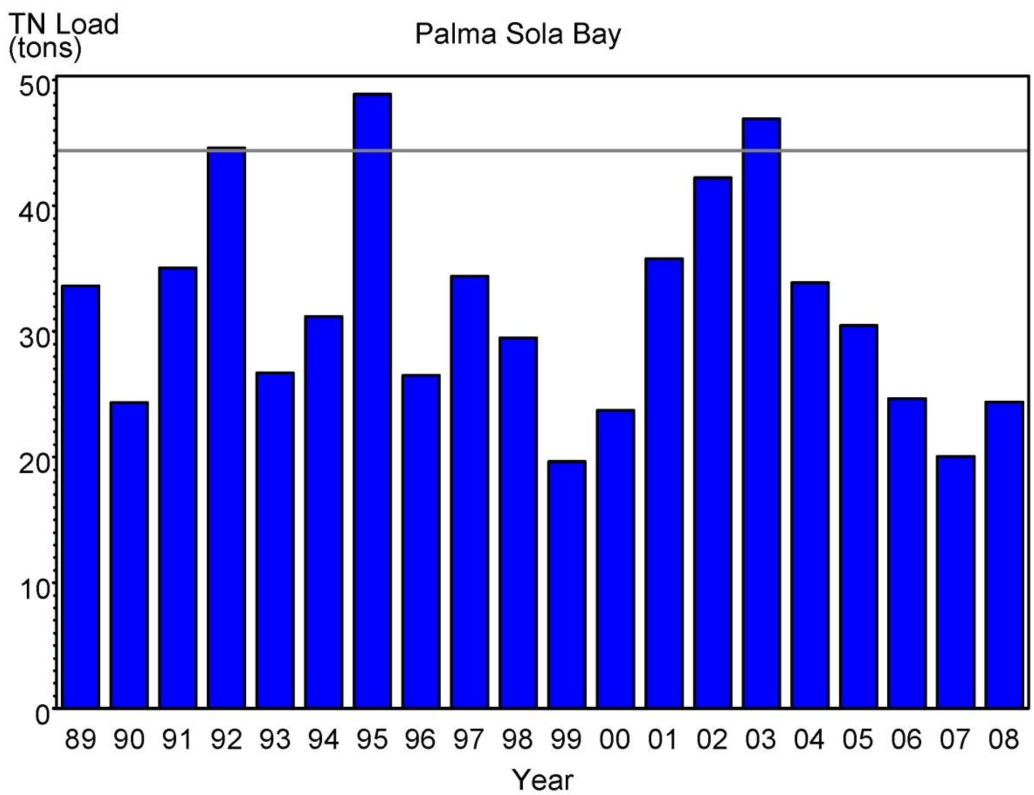
Segment	TP Target (tons/yr)	TP Standard Deviation	TN Target (tons/yr)	TN Stadard Deviation

		(tons/yr)		(tons/yr)
Palma Sola Bay	6.7	1.0	37.9	6.6
Sarasota Bay	31.8	3.4	215.3	21.9
Roberts Bay	42.4	6.4	213.3	37.5
Little Sarasota Bay	7.3	1.6	40.3	9.2
Blackburn Bay	9.3	2.3	55.4	15.6

Table 9. Reference Period Loading-based TN and TP criteria.

Segment	TP Load (tons/yr)	TN Load (tons/yr)
Palma Sola Bay	7.7	44.5
Sarasota Bay	35.2	237.2
Roberts Bay	48.8	250.8
Little Sarasota Bay	8.9	49.5
Blackburn Bay	11.6	71.0

The proposed TN and TP loading criteria are compared to the observed annual TN and TP loadings in Figures 7 through 11. The horizontal lines represent the proposed criteria.



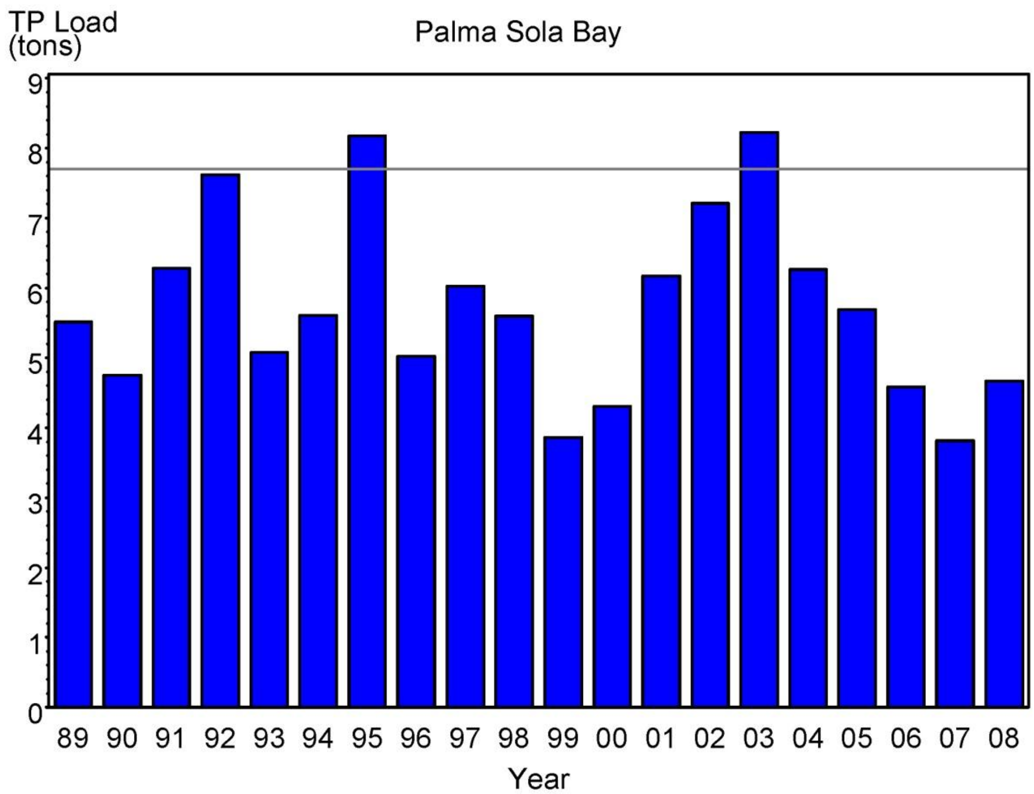
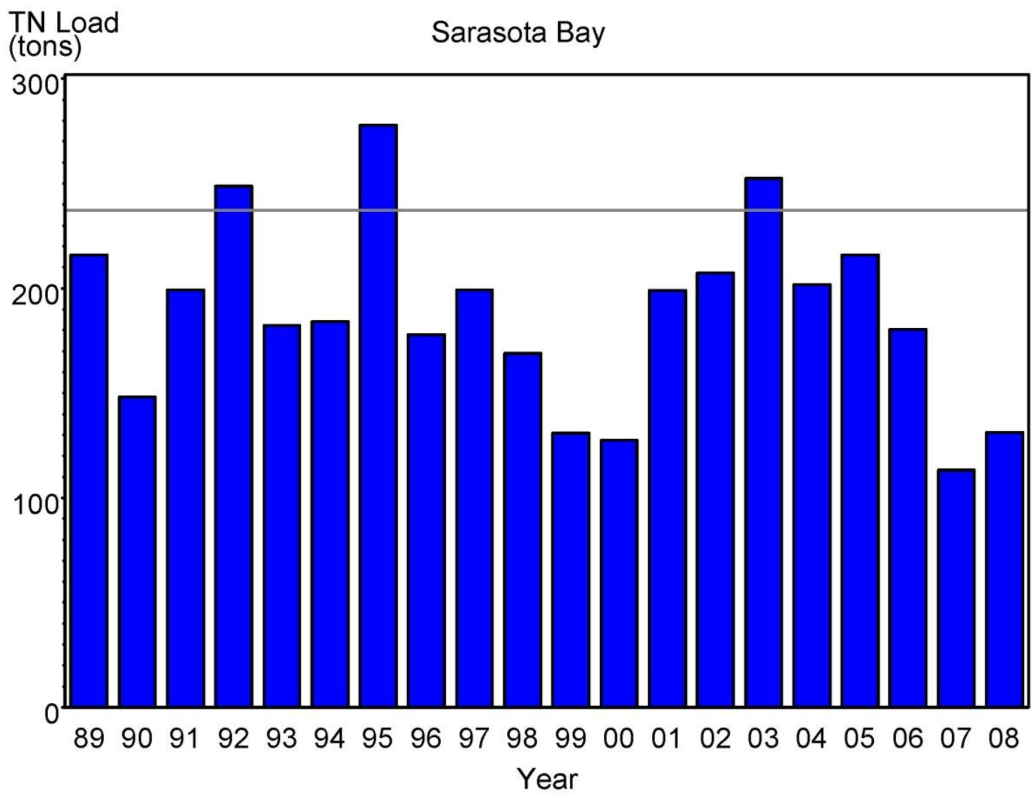


Figure 7. Comparison of proposed TN and TP load criterion for Palma Sola Bay to annual loads.



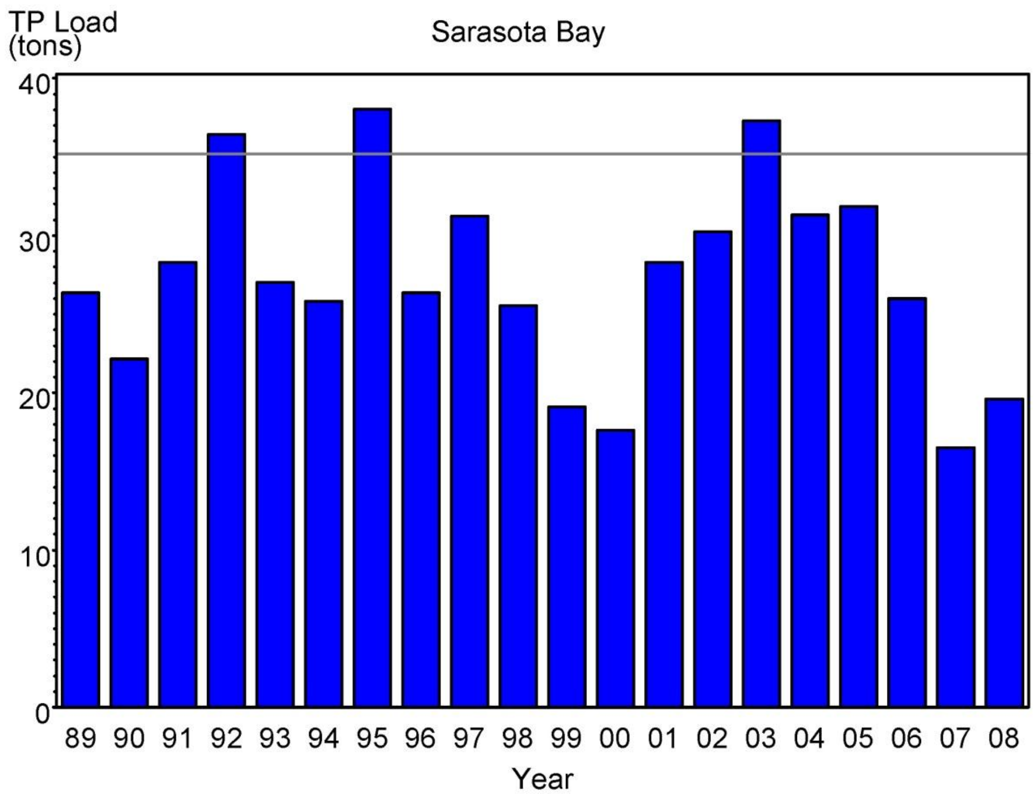
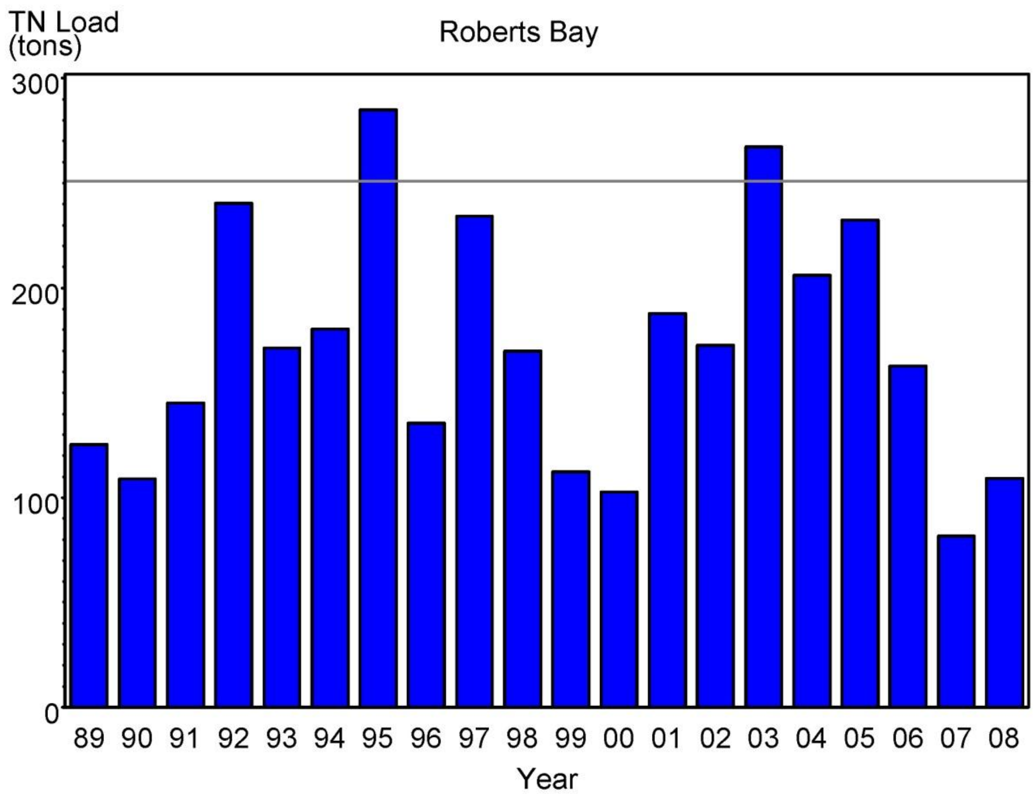


Figure 8. Comparison of proposed TN and TP load criterion for Sarasota Bay to annual loads.



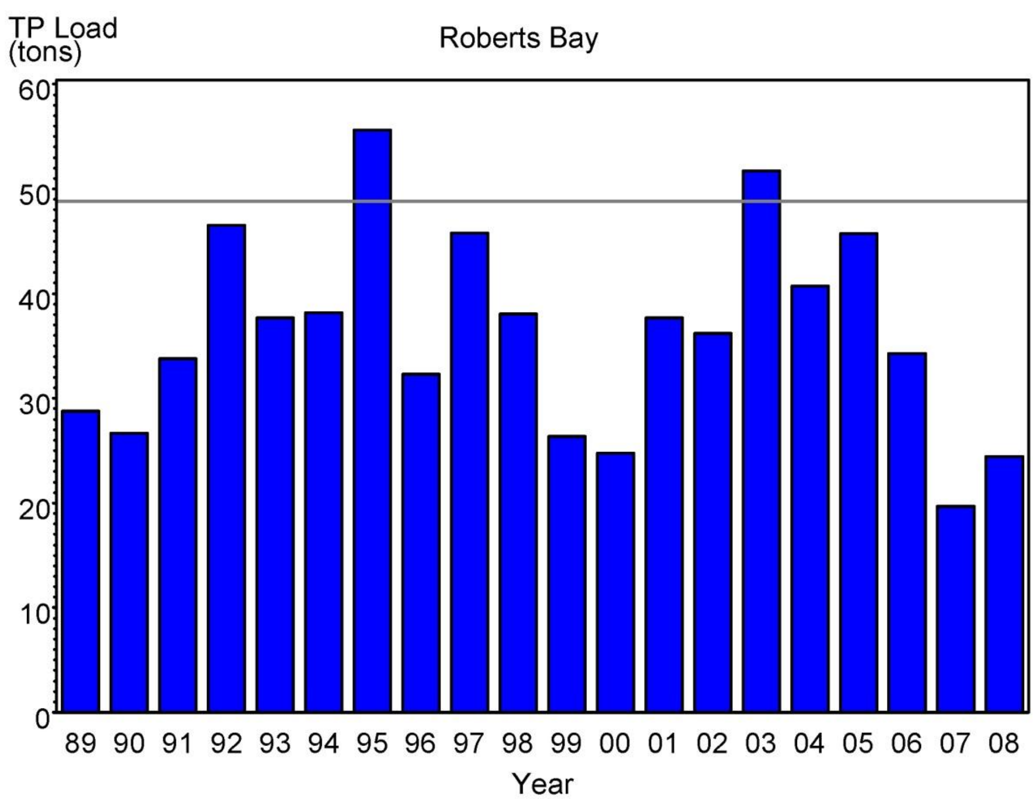
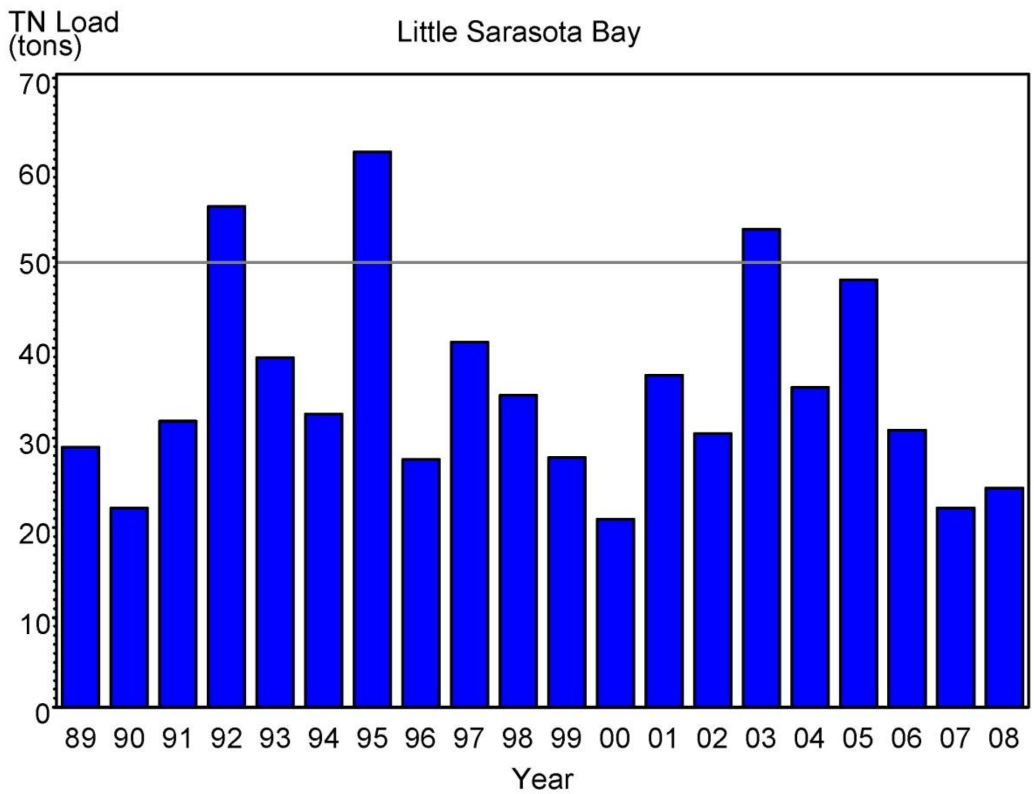


Figure 9. Comparison of proposed TN and TP load criterion for Roberts Bay to annual loads.



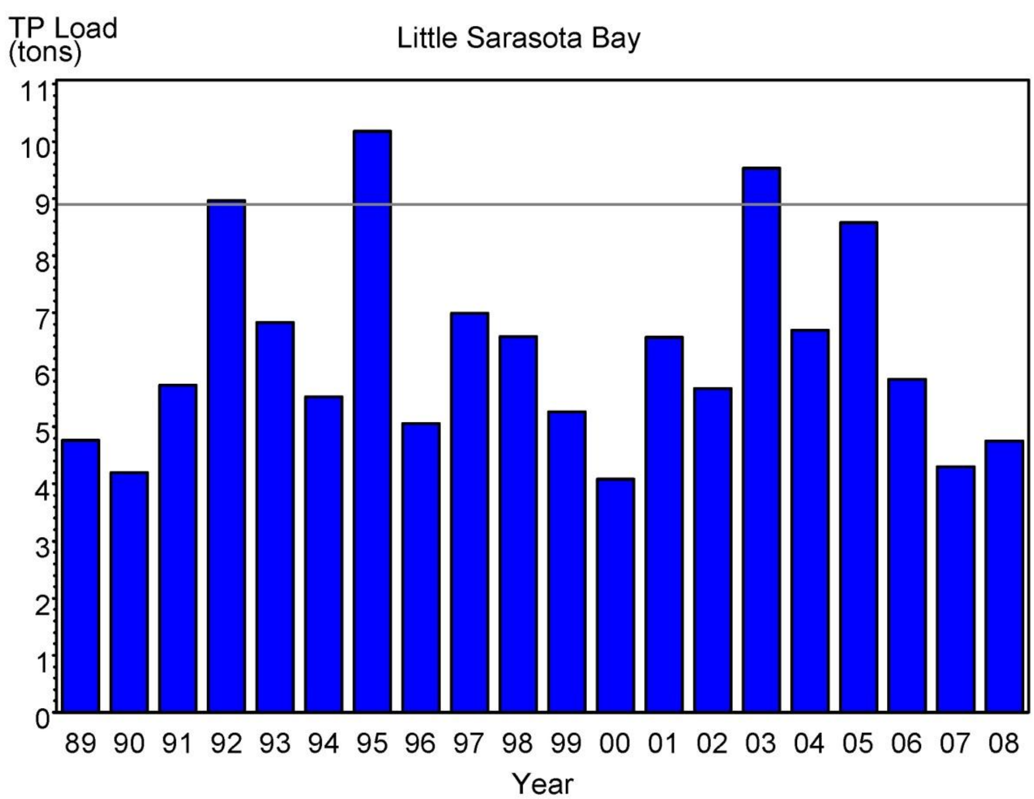
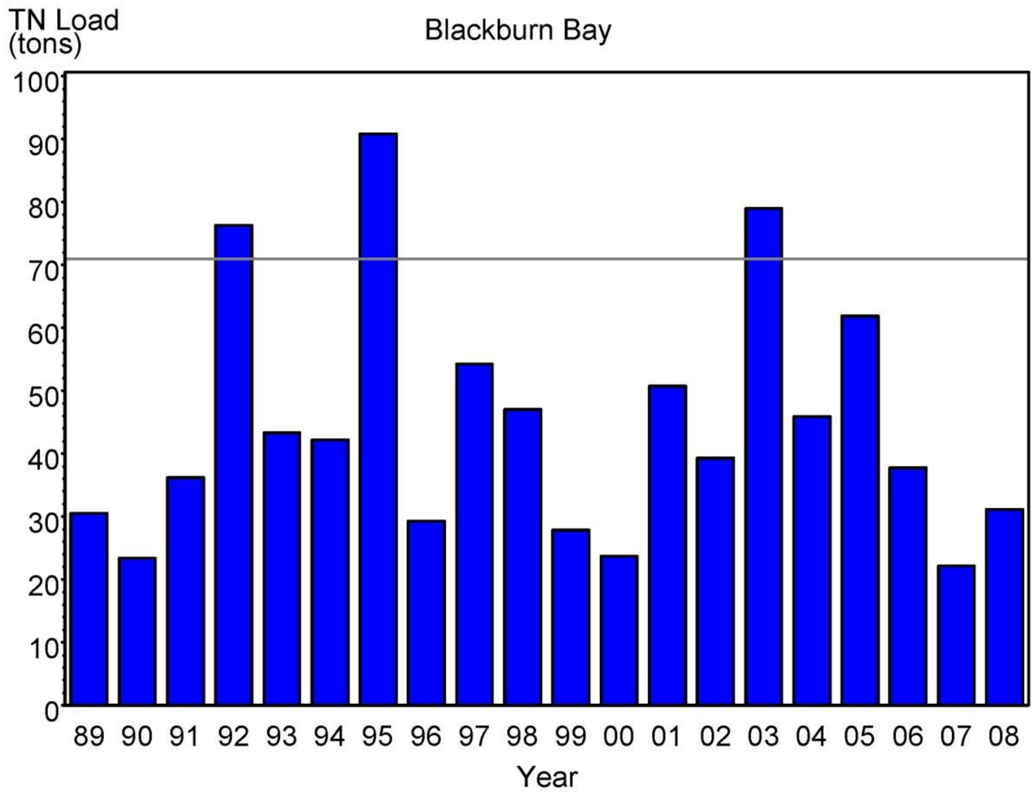


Figure 10. Comparison of proposed TN and TP load criterion for Little Sarasota Bay to annual loads.



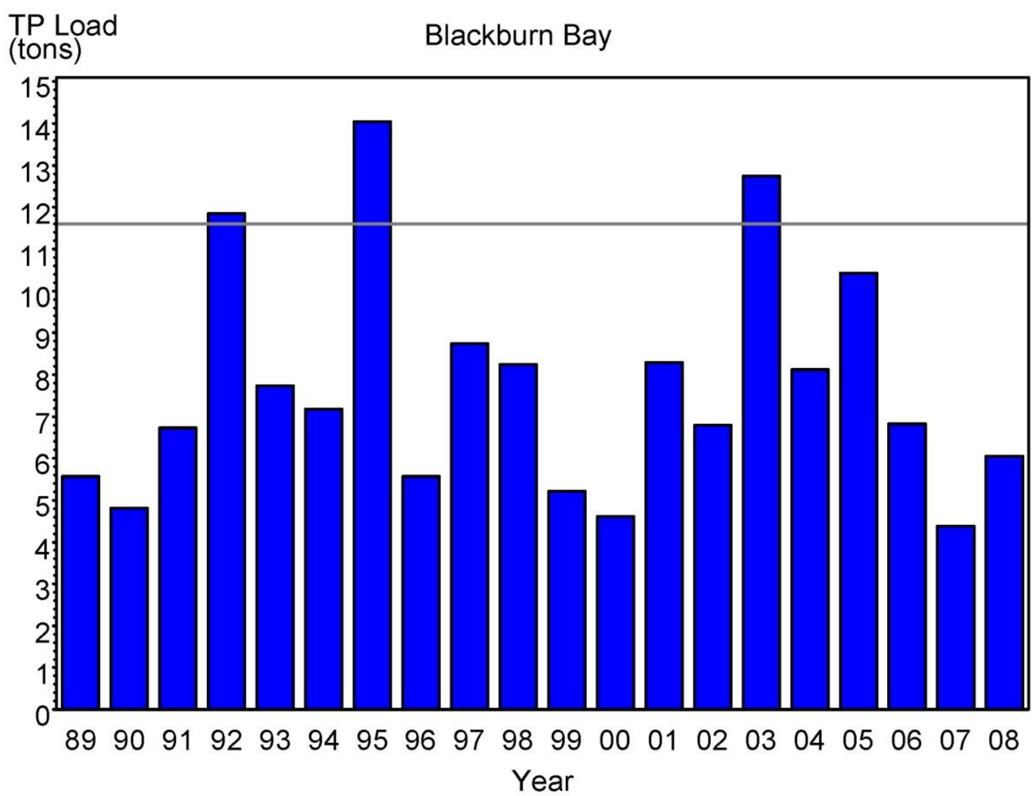


Figure 11. Comparison of proposed TN and TP load criterion for Blackburn Bay to annual loads.

4.0 Conclusions

The following conclusions can be drawn from the analyses and results discussed above:

- The SBEP has previously completed development of segment-specific TN concentration criteria and chlorophyll *a* thresholds.
- Sarasota Bay is largely nitrogen-limited as indicated by ambient TN:TP ratios, with the exception of Palma Sola Bay, where ratios indicate co-limitation.
- The relationships between segment TN concentrations and segment TP concentrations are not transparent, and thus cannot be used to translate established TN concentration criteria to TP concentration criteria.
- The relationships between chlorophyll *a* concentrations and segment TP concentrations are not sufficient to derive TP concentration criteria based on established chlorophyll *a* thresholds.
- The reference period approach provides an internally consistent method for establishing concentration-based TP criteria. The following are the proposed numeric TP concentration criteria for the SBEP bay segments:

– Palma Sola Bay	0.26 mg/L
– Sarasota Bay	0.19 mg/L
– Roberts Bay	0.23 mg/L
– Little Sarasota Bay	0.21 mg/L
– Blackburn Bay	0.21 mg/L

- On a monthly time scale, the relationships between either TN or TP loads and chlorophyll *a* concentrations do not explain a significant proportion of the variability in the chlorophyll *a* concentrations to support development of loading-based numeric nutrient criteria based on these relationships in any bay segment.
- The relationships between TN and TP loadings and in-bay TN and TP concentrations do not provide a defensible approach for establishing loading-based numeric nutrient criteria in any bay segment based on segment concentration criteria.
- The reference period approach provides the most defensible method to define loading-based numeric nutrient criteria (thresholds) for the SBEP segments. The following are the proposed TN and TP loading-based criteria for the SBEP bay segments:

	TN Criteria	TP Criteria
– Palma Sola Bay	44.5 tons/yr	7.7 tons/yr
– Sarasota Bay	237.2 tons/yr	35.2 tons/yr
– Roberts Bay	250.8 tons/yr	48.8 tons/yr
– Little Sarasota Bay	49.5 tons/yr	8.9 tons/yr
– Blackburn Bay	71.0 tons/yr	11.6 tons/yr

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