Numeric Nutrient Criteria for Lake Worth Lagoon

Division of Environmental Assessment and Restoration
Standards and Assessment Section
Florida Department of Environmental Protection
Tallahassee, FL 32399

July 2013

Table of Contents

Introduction and Numeric Nutrient Criteria (NNC) Development Approach

This report was prepared by the Florida Department of Environmental Protection (FDEP), in cooperation with local scientists and EPA, to support the development of site-specific interpretations of the narrative nutrient criteria for the Lake Worth Lagoon. Because of the diversity of Florida's marine systems, the Department has pursued an "estuary-specific" approach for Numeric Nutrient Criteria (NNC) development, where all existing information for each individual estuary was synthesized, and criteria were based on the ecological endpoints most relevant for a particular system. At a minimum, all of Florida's marine waters are currently designated to support "recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife" (Section 62-302.400, F.A.C.), although marine waters that are classified for shellfish harvesting have more stringent criteria for some (non-nutrient) parameters.

This NNC development effort consisted of numerically interpreting the long-standing narrative nutrient criteria to protect aquatic life use: "In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna" (Section 62-302.530, F.A.C.).

FDEP considered two main criteria development methods, including:

- the reference conditions approach (identifying times and areas where an estuarine segment was healthy and well balanced and establishing criteria to maintain community health); and
- a response-based approach (using modeling or empirical evidence to identify adverse nutrient effects and establishing criteria that would protect against the adverse effects and fully support a healthy community).

The reference conditions approach was the approach used to develop NNC in Lake Worth Lagoon.

System Description

The Lake Worth Lagoon is a 20-mile-long coastal estuary located in Palm Beach County (see Figure 1 of Appendix A). The lagoon averages approximately half a mile wide and has an average depth of 2 meters. Although the system historically was predominately fresh water, inlets dredged to the Atlantic Ocean converted Lake Worth into a high-salinity lagoon. It is the largest estuarine system in Palm Beach County, connected to the Atlantic Ocean by two permanent inlets, the Lake Worth Inlet and the South Lake Worth Lagoon Inlet. A barrier island separates the lagoon from the Atlantic Ocean. The Atlantic Intracoastal Waterway (ICW) traverses the entire length of this estuarine waterbody, with 8 bridges and causeways connecting the barrier island to the mainland. A complete description of the Lake Worth Lagoon, including physical, water quality, and biological information, is provided in Appendix A.

Method for Estuary Evaluation and Development of Numeric Nutrient Criteria

Overview

To develop NNC for the Lake Worth Lagoon estuarine system, FDEP systematically:

1. Compiled available water quality data, emphasizing Total Nitrogen (TN), Total Phosphorus (TP), chlorophyll *a*, Dissolved Oxygen (D), and Secchi depth;

2. Conducted quality assurance evaluations and data screening on any data to be used for criteria development**;**

3. Established estuary segmentation based on areas of relative homogeneity (*e.g.*, salinity, hydrology, system morphology, etc.);

4. Evaluated areas on the 303(d) list of impaired waters and excluded data from stations that were in **W**ater**b**ody **Id**entification units (WBIDs) verified as impaired for the years that were impaired if the reference conditions approach was being considered;

5. Established biological endpoints, which if achieved, would indicate that an estuarine segment was meeting its designated use during a particular time period;

6. Evaluated achievement of the biological endpoints using the screened data and established a time period during which the reference conditions approach was appropriate (if the reference conditons approach was not appropriate, a response-based approach was pursued); and

7. Conducted a statistcial analysis of the TN, TP, and chlorophyll *a* data associated with the reference conditions period, and established criteria for TN, TP, and chlorophyll *a*.

These steps are described in more detail below.

Segmentation

FDEP proposes a segmentation scheme (Figure 1) very similar to that proposed by EPA in the Technical Support Document for U.S. EPA's Proposed Rule for Numeric Nutrient Criteria for Florida's Estuaries, Coastal Waters, and South Florida Inland Flowing Waters, (Volume 1 Estuaries [DCN 1-1498] 2012). FDEP adjusted EPA's proposed North Lake Worth Lagoon segment slightly to include an additional open water area at its northern boundary. The North segment was also adjusted to exclude residential canals to the west. The North segment's southern boundary was moved to the Flagler Memorial Bridge (approximately 600m north of EPA's boundary) to take into consideration segmentation developed by Palm Beach County. The only other deviation from EPA's proposed segmentation for Lake Worth Lagoon was the exclusion of approximately 3.5 miles of the Intracoastal Waterway that EPA included as part of the South Lake Worth Lagoon segment. FDEP will address criteria for this area in a report to the Governor and Legislature that is due August 1, 2013.

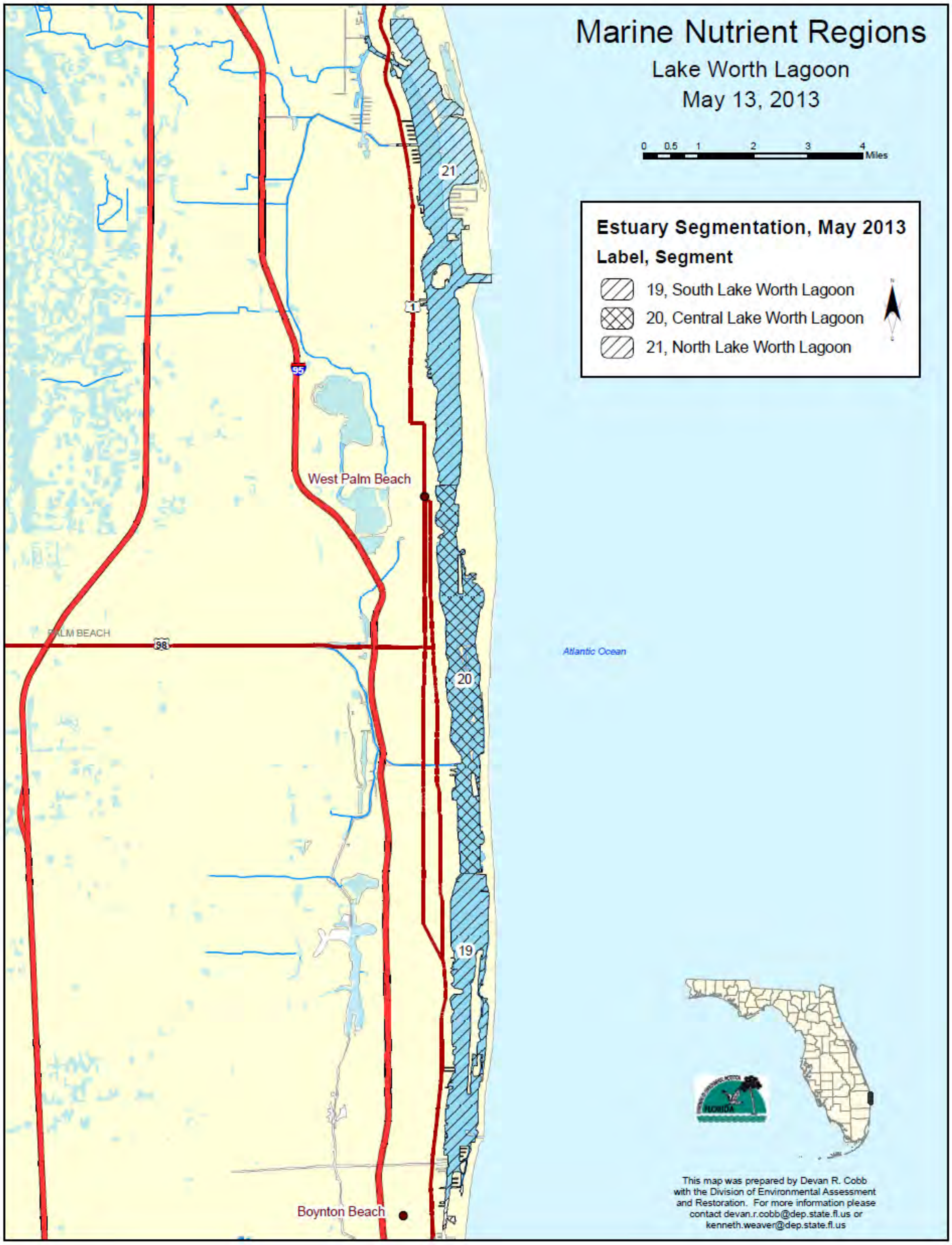


Figure 1. Lake Worth Lagoon segmentation.

Waters on the 303 List

FDEP reviewed the 303(d) listing status for all WBIDs within estuary segments based on the current federally approved 303(d) list of impaired waters and all subsequent listing or de-listing actions taken by FDEP according to the FDEP Impaired Waters Rule (IWR; Chapter 62-303, Florida Administrative Code [F.A.C.]). Table 1 contains the 303(d) listing status of WBIDs within the Loxahatchee River Estuary that have been on one of the 303(d) lists for either nutrients or Dissolved Oxygen (DO). FDEP generally plans to develop Total Maximum Daily Loads (TMDLs) for waters that have been verified as impaired for nutrients or DO, and the TMDLs will serve as a site-specific interpretation of the narrative nutrient criterion for these waters. However, FDEP concluded that the reference condition approach was valid for developing NNC for some estuarine systems that included areas with impairments, including:

1. Waters that were subsequently delisted;
2. Waters that were listed for DO but have subsequently been determined to meet the recently revised marine DO criterion (see "Dissolved Oxygen" section of this report);
3. Waters that were listed for DO but have subsequently been determined to be naturally low in DO; and
4. Waters listed for historic chlorophyll *a* but which do not have a statistically significant increasing trend in chlorophyll.

After examining the data specific for an impaired WBID, FDEP sometimes determined that none of the data from the WBID were appropriate for the reference condition approach. In these cases, only data from unimpaired WBIDs comprising the remainder of the NNC estuary segment were used for criteria development.

If FDEP determined the reference approach was appropriate for a waterbody that was listed as impaired, FDEP did not use data from the years when the waterbody (WBID) was considered impaired. Years or data were included or excluded based on the following decision criteria:

1. For a WBID on the 1998 303(d) list for nutrients and subsequently delisted to Category 3B, FDEP calculated the annual geometric mean (AGM) chlorophyll *a* for all years prior to 1998. If the AGM was less than 11 µg/L for a given year, then data from those years were included. For years when the AGM was greater than 11 µg/L, the Department excluded data from that year and the preceding year in criteria calculation. The Department initially only excluded the data for the specific years exceeding 11 ug/L, which is consistent with the Impaired Waters Rule (Chapter 62-303, F.A.C.) assessment process that assesses individual years for impairment. However, the Department decided to also exclude data from the preceding year as a conservative measure to ensure that antecedent nutrient conditions did not contribute to the observed elevated chlorophyll a levels. Observed lag times between nutrient loading and resultant algal growth are generally less than three months in Florida estuaries, but EPA (2013) found that at some Florida estuary stations, a preceding year's TN concentration may have a small influence (coefficient value ~0.1) on the following year's chlorophyll *a* concentration.

It should be noted that, for the 1998 303(d) list, estuaries were assessed as impaired for nutrients using the Trophic State Index (TSI) for lakes minus 10 units. During the development of the IWR, the IWR Technical Advisory Committee and Department acknowledged that applying the lakes TSI to estuaries was too simplistic, and the Department contracted with Janicki Environmental to develop a nutrient impairment threshold for estuaries (11 ug/L), which was supported by the TAC, and subsequently approved by the ERC and EPA as a change to Florida's water quality standards.

2. For a WBID listed as impaired for nutrients based on mean chlorophyll *a* > 11 µg/L under the IWR assessment methodology and subsequently delisted by FDEP, FDEP excluded any year for which the WBID exceeded the chlorophyll *a* threshold, as well as the preceding year, from criteria calculations.
3. For a WBID listed as impaired for nutrients based on an increase in chlorophyll *a* of 50% over historical levels under the IWR assessment methodology, FDEP conducted a Mann's one-sided, upper-tail test for trend (with a 95% confidence interval) for chlorophyll *a* over the period of record. If no increasing trend was detected, then all years were included in criteria calculations. If an increasing trend was detected, then the years in which the chlorophyll was significantly increasing were excluded from criteria calculations. It should be noted that the IWR provision that listed waters based on a greater than 50% increase in chlorophyll a over historical minimums for two consecutive years was deleted from the IWR and replaced with a more robust trend assessment using the Mann's one-sided, upper-tail test for trend. This change was made as part of the Nutrient Standards rulemaking adopted in December 2011 and approved by EPA in November 2012.

For a WBID on the 303(d) list for DO for any listing cycle (including 1998[1]), FDEP determined whether or not the WBID would have been verified impaired under the revised marine DO saturation criterion (see "Dissolved Oxygen" section of this report) for the relevant cycle (8 years were used rather than 7.5). If the DO saturation criterion was met for a given assessment cycle, then data from that cycle were included, and data were not included in criteria calculation if the DO saturation criterion was not met. For 1998 listings, FDEP assessed the impairment status under the revised criteria for the following 8-year time periods, as applicable: 1973-1980, 1981-1988, and 1989-1996. These checks were all conducted following provisions in the IWR for daily DO assessment. If any value at a given site and time was less than 2 mg/L, then the 25th percentile of all values measured at that site and time was used as the value for that site and time. Results obtained during a single day were averaged for the assessment.

There are five WBIDs in the Lake Worth Lagoon area that either are currently or have been on the EPA 303(d) list of impaired waters for nutrient-related impairment (Table 1). The Lake Worth region was assessed according to the FDEP Impaired Waters Rule (IWR; Chapter 62-303, Florida Administrative Code [F.A.C]) in 2012, and only a subset of those WBIDs were determined by FDEP to be impaired due to

[1] In addition to using the old DO criteria, the assessment methodology for the 1998 303(d) list relied on a direct assessment of the percent exceedances of the criteria, and listed estuaries if more than 10% of the DO measurements for a WBID were below 4 mg/L. In acknowledgement that this simplified methodology results in a very high error rate, the IWR TAC recommended use of the Binomial Method so that minimum confidence levels could be incorporated into the assessment. The Binomial Method was subsequently adopted into the IWR, and approved by the ERC and EPA, and endorsed by the National Academy of Sciences.

nutrients. The following text describes how each WBID impairment was handled according to the criteria above. Table 1 shows each listing, the checks conducted to address the listing, and the data use decision. Figures 2 and 3 show the Lake Worth Lagoon NNC segments and WBID boundaries.

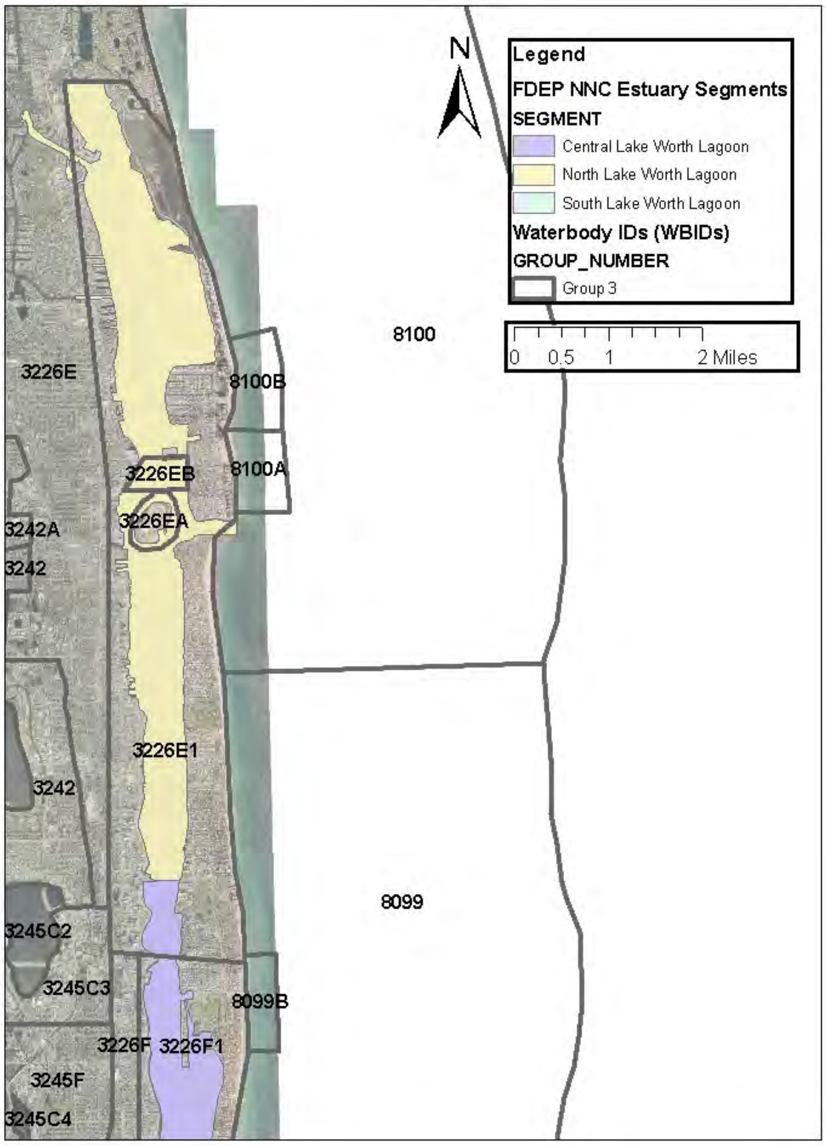


Figure 2. NNC Estuary segments and WBID boundaries for the northern half Lake Worth Lagoon (FDEP, 2013).

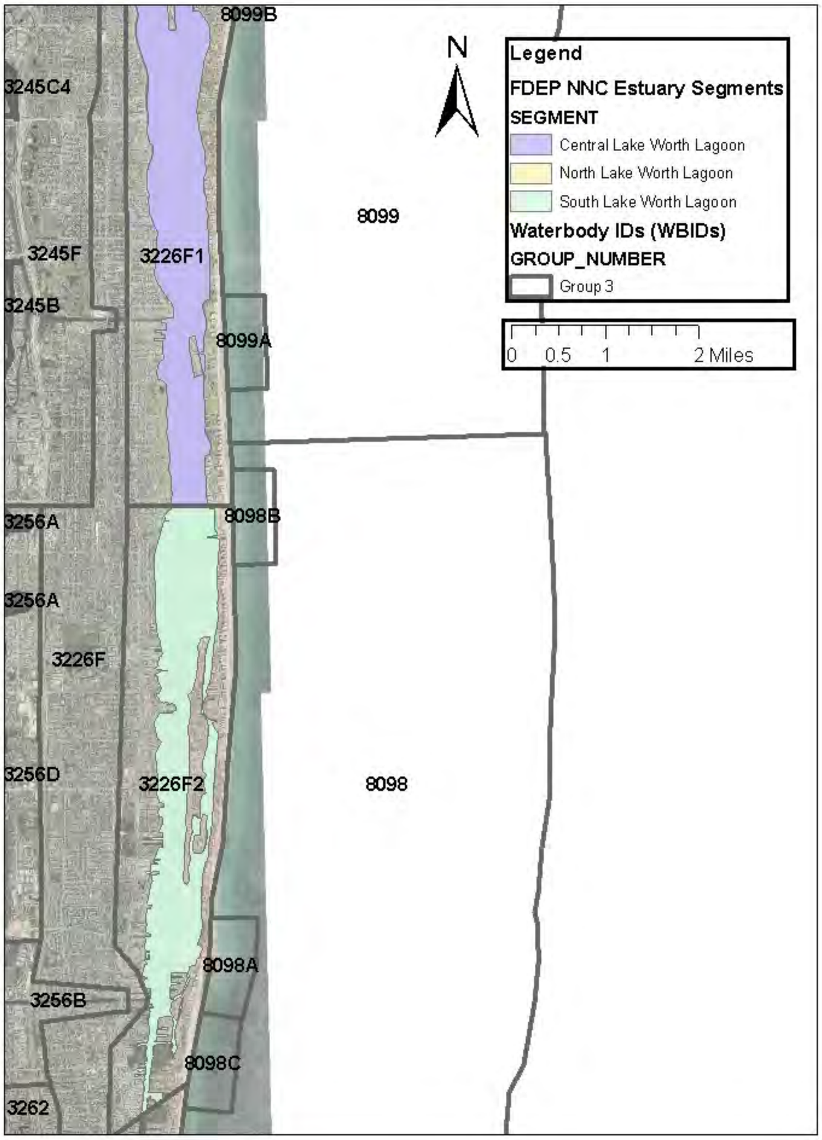


Figure 3. NNC Estuary segments and WBID boundaries for the southern half Lake Worth Lagoon (FDEP, 2013).

<u>Northern Lake Worth Lagoon (WBID 3226E1) and the ICWW north of Lake Worth Lagoon (WBID 3226E)</u>

The Northern Lake Worth Lagoon WBID (3226E1) was created in Cycle 1 (2002) and was previously a part of WBID 3226E, which was on the 1998 303(d) list for DO. EPA accepted the delisting for the ICWW north of Lake Worth Lagoon (WBID 3226E) in Cycle 2 (2010), but Northern Lake Worth Lagoon (WBID 3226E1) was not delisted at the same time that WBID 3226E was delisted because the 1998 listing was not carried over at the time the WBID was split. In Cycle 3, if the data still supports the non impairment, FDEP will delist this Northern Lake Worth Lagoon (WBID 3226E1) from the 303(d) list. Additionally, the ICWW north of Lake Worth Lagoon (WBID 3226E) was not impaired under the revised DO criteria for the 1998 listing cycle. Northern Lake Worth Lagoon (WBID 3226E1) is not impaired for DO (Cycle 1 and Cycle 2), and was also not impaired under the revised DO criteria for the 1998 listing cycle. No data was excluded from Northern Lake Worth Lagoon or the ICWW north of Lake Worth Lagoon during calculations of the NNC.

ICWW above Pompano (WBID 3226F)

This WBID is not in an NNC estuary segment.

Central Lake Worth Lagoon (WBID 3226F1) and Southern Lake Worth Lagoon (WBID 3226F2)

Central and Southern Lake Worth Lagoon (WBIDs 3226F1 and 3226F2) were created in Cycle 1 and were previously part of WBID 3226F, which was on the 1998 303(d) list for nutrients and DO. The current chlorophyll assessments of Central Lake Worth Lagoon (WBID 3226F1) and Southern Lake Worth Lagoon (WBID 3226F2) do not show any annual average chlorophylls >11 ug/L. Southern Lake Worth Lagoon (WBID 3226F2) was not impaired under the revised DO criteria for the 1998 listing cycle, however Central Lake Worth Lagoon (WBID 3226F1) was impaired under the revised DO criteria for the 1998 listing cycle (1973-1980). No data was excluded from Southern Lake Worth Lagoon (WBID 3226F2) during calculations. Data from 1973-1980 were excluded from Central Lake Worth Lagoon (WBID 3226F1) during criteria calculations.

Table 1. EPA and FDEP Impairment considerations.

WBID	Estuary Segment	DO 303(d) Listing Events	DO Checks Conducted	Nutrient 303(d) Listing Events	Nutrient Checks Conducted	Data Use Decision
3226E	Small part of Northern Lake Worth Lagoon	1998: Listed 2010: Delisted to Category 2	The WBID was not impaired under the revised DO criteria for the 1998 listing cycle.	No listings	N/A	No data were excluded based on 303(d) listings.
3226E1	Northern and small part of Central Lake Worth Lagoon	1998: Listed	The WBID used to be part of WBID 3226E. The revised WBID was not impaired under the revised DO criteria for the 1998 listing cycle.	No listings	N/A	No data were excluded based on 303(d) listings.
3226F1	Central Lake Worth Lagoon	1998: Listed	The WBID used to be part of WBID 3226F. The revised WBID was impaired under the revised DO criteria for	1998: Listed	The WBID used to be part of WBID 3226F. No chlorophyll *a* AGMs were >11 µg/L.	Data from 1973-1980 were excluded based on 303(d) DO listing.

			the 1998 listing cycle (1973-1980).			
3226F2	Southern Lake Worth Lagoon	1998: Listed	The WBID used to be part of WBID 3226F. The revised WBID was not impaired under the revised DO criteria for the 1998 listing cycle.	1998: Listed	The WBID used to be part of WBID 3226F. No chlorophyll *a* AGMs were >11 µg/L.	No data were excluded based on 303(d) listings.

WBID	Estuary Segment	Comments
3226F	Central and Southern Lake Worth Lagoon	WBID not in NNC estuary segment.

Assessment of Biological Endpoints

Based on input from EPA (2012), FDEP evaluated whether each estuarine segment attained the biological endpoints that EPA used to develop the NNC that they proposed in November 30, 2012. EPA's proposal included the following endpoints, which if met demonstrate protection of healthy, well balanced communitites:

- Site-specific seagrass depth (Z_c) and water clarity (K_d) targets to **achieve 20% of surface light at the mean depth of the deep edge of seagrass beds**, relative to mean sea level, based on historic or recent seagrass coverages (where applicable, as proposed by EPA 2012, Hagy in press, and also Hagy personal communication), using Secchi depth measurements. If EPA did not propose depth targets for a given segment, FDEP considered the presence of stable seagrass beds at the deepest points of the segments as evidence that 20% of surface light was reaching the bottom. In addition to this EPA-recommended endpoint, FDEP also evaluated the areal extent of seagrass beds in the system over time to determine if they were stable or increasing;

- A chlorophyll *a* target to prevent nuisance algal blooms (**not to exceed 20 µg/L >10% of the time based on annual data**); and

- Dissolved Oxygen (DO) targets to protect aquatic life (**assessment against the recently revised marine DO criteria, including a minimum allowable daily average DO saturation of 42%, which must be met at least 90 percent of the time based on annual assessments of the data**).

Submersed Aquatic Vegetation (SAV or Seagrasses)

SAV are "foundational" taxa (ecologically important species with a strong role in structuring communities) that may be harmed by anthropogenic reductions in transparency caused by excess algal production. SAV provides valuable habitat for many other estuarineestuarine organisms. Therefore, maintenance of SAV coverage within estuaries is an important indicator of designated use support. One mechanism by which SAV loss can occur is reduced water clarity. Reduced clarity can result from increases in colored dissolved organic matter (often measured as color), turbidity caused by suspended particles, or phytoplankton biomass (indicated by chlorophyll *a*), or a combination of these elements. Increased nutrient loading can cause an increase in algal biomass and non-pigmented organic particulates (a component of the total suspended matter). These are the principal means by which excess nutrients cause reduced clarity. SAV loss can also occur due to physical disruption from hurricanes, dredging, boat traffic, and excess freshwater.

Most estimates of seagrass coverage and density, and the proposed colonization depth targets, are based on interpretation of aerial photography. Estimates of coverage are subject to various sources of error, including quality and scale of the imagery, differences between photointerpreters, and different habitat classification schemes (Carlson and Madley 2007). Most photointerpretation projects include efforts to classify seagrasses as continuous or patchy, and those categories are not always judged consistently between interpretation efforts. Tomasko *et al.* (2005) quantified error in total SAV areal coverage estimates among three photo-interpreters for five aerial photos of SAV beds, and found a mean coefficient of variation of 1.9%. More recently, integrated spatial and spectral processing techniques have allowed investigators to estimate seagrass coverages based on satellite imagery with accuracy that is fairly comparable to photointerpretation (Baumstark *et al.* 2012). Attempts to compare total seagrass coverage or colonization extent must account for differences between the data sources (Carlson and Madley 2007), which FDEP did on an estuary specific basis.

Site-Specific Seagrass Colonization Depth (Z_c) and Water Clarity (K_d) Targets

EPA (2012) and Hagy (in press) proposed seagrass colonization depth targets for Central Lake Worth Lagoon (0.77 m) and Northern Lake Worth Lagoon (0.95 m) based on 2007 aerial photography. FDEP provided EPA with 2001 aerial photography as well, which EPA analyzed according to the same methodology as the 2007 aerials. Using the 2001 aerials, EPA was able to develop a depth target of 0.78 m for the Southern Lake Worth Lagoon segment (Hagy, personal communication). Additionally, the depth target for the Central Lake Worth Lagoon segment developed using the 2001 aerials was deeper (1.17 m) than that using the 2007 aerials (Hagy, personal communication). FDEP used the deeper of the two targets for assessing water clarity in Central Lake Worth Lagoon. Table 2 gives the depth target, which aerial it was based on, and the corresponding secchi depth target by segment.

As proposed by EPA (2012), FDEP calculated a Secchi depth target (SD_{target}) from the depth target (D_{target}) as follows:

$$SD_{target} = \frac{1.44}{-ln(0.2)} D_{target}$$

Table 2. SAV depth targets with corresponding secchi depth target by segment.

Segment	**Depth Target (D_{target}) (in meters)**	**Secchi Depth Target**

		(SD_{target}) (in meters)
Northern Lake Worth Lagoon	0.95 (2007 aerial)	0.85
Central Lake Worth Lagoon	1.17 (2001 aerial)	1.05
Southern Lake Worth Lagoon	0.78 (2001 aerial)	0.7

FDEP compared annual average Secchi depth results with the Secchi depth target (SD_{target}) to identify years in which water clarity supported seagrass depth targets (Tables 3-5).

FDEP examined all available SD data in the Impaired Waters Rule Database (IWR) Run 47 database and additional data obtained from the South Florida Water Management District, after removal of SD values that were greater than 10 meters. If the Secchi disk was visible on bottom (VOB) and the bottom depth was greater than SD_{target}, the bottom depth was used as the SD because the SD was known to exceed the target. If SD was VOB but the bottom depth was less than SD_{target}, then the bottom depth was not used because it is not known whether or not the SD would have exceeded the target. The dataset was also visually inspected for erroneous values, which were removed.

FDEP calculated the annual average SD as the arithmetic mean of daily segment means per year. FDEP then calculated the upper 90% confidence interval (C.I.) of the mean (upper C.I. = arithmetic mean + t*(stdev/sqrt[n]) where t = the T distribution for the SD population at alpha = 0.1) for years with at least four samples. If the 90% C.I. SD (or annual average for years with <4 samples) for a segment was deeper than the SD_{target}, then the segment was considered to achieve the target of 20% surface light available on bottom for seagrass support for that year.

The annual average Secchi depth (SD) measurement achieved the EPA depth to seagrass colonization target (Zc) in Northern, Central, and Southern Lake Worth Lagoon for 16, 12, and 11 years, respectively (Tables 3-5).

SAV Areal Coverage and Density

Areal extent and categorical density of SAV were also analyzed (see the section, "Seagrass Background and Current Status" of Appendix A). FDEP investigators evaluated all available map interpretations conducted by SAV researchers to determine if SAV coverage has become more or less extensive through time, taking into consideration mapping differences among years, and if those gains or losses are likely related to nutrients.

SAV coverage in Lake Worth Lagoon has varied over time, and although current SAV coverage is higher than that observed in the 1970s, it is still lower than 1940s levels. However, the cause for the loss in SAV coverage has been linked to dredge-and-fill activities, extreme salinity fluctuations, and turbidity/sedimentation (see the section, "Seagrass Background and Current Status" of Appendix A). Because the depth to seagrass targets are routinely achieved where they have been established in Lake Worth Lagoon, and because the chlorophyll *a* target (< 10% exceeding 20 ug/L) is also routinely achieved throughout the system, it suggests that the above factors, and not nutrients, are responsible for seagrass losses.

Chlorophyll a

Chlorophyll *a* is an indicator of phytoplankton biomass and can reflect the integrated effects of many ecological factors, including nutrient loading. Increased phytoplankton biomass, expressed as increased chlorophyll *a* concentrations, is the mechanism by which anthropogenic nutrient enrichment can cause excess organic matter and reduced water clarity, leading to ecosystem changes such as SAV loss. As an indicator, chlorophyll *a* responds to increased or excess nutrient loading, is relevant to the biological health of an estuary, and is practical to measure.

The Department analyzed available chlorophyll *a* data to determine if chlorophyll *a* concentrations exceeded 20 µg/L in more than 10% of the measurements for each year (EPA 2012). For each segment and year, FDEP calculated the proportion of chlorophyll *a* samples for that year that were greater than 20 µg/L. If chlorophyll *a* in a given estuary segment did not exceed 20 µg/L in more than 10% of the measurements, the segment was considered to attain the designated use with respect to chlorophyll *a* for that year.

FDEP used the IWR Run 47 database and additional data obtained from the South Florida Water Management District to assess the frequency of chlorophyll *a* concentrations > 20 µg/L. For T or U qualified data, one half of the value was used (see Table 7 for Qualifier Codes). Chlorophyll *a* results less than 1 µg/L were set to 1 µg/L. FDEP excluded data with fatal qualifier codes (rcode or xcode): H, J, K, N, O, Q, Y, and ?. FDEP used corrected chlorophyll *a* data if they were available, and uncorrected chlorophyll *a* if corrected data were not available.

Chlorophyll *a* concentrations achieved the target for 17 years, 16 years, and 13 years in Northern, Central, and Southern segments of Lake Worth Lagoon, respectively (Tables 3-5).

Dissolved Oxygen

Nutrient enrichment potentially may cause reductions in DO concentrations and changes in the DO regime through increased respiration from plants (algae or macrophytes) and decomposition of organic material produced from excess nutrients. DO concentrations below water quality criteria can also occur naturally in Florida estuaries in association with water column stratification or naturally high organic matter levels associated with wetland inputs.

FDEP determined whether or not each estuary segment achieved the recently revised marine DO criterion (Rule 62-302.533 (1),F.A.C.), which is expressed as percent saturation rather than mg/L. The new criteria includes three different parts:

1. The daily average percent DO saturation shall not be below 42 percent saturation in more than 10 percent of the values;
2. The seven-day average DO percent saturation shall not be below 51 percent more than once in any twelve week period; and

3. The 30-day average DO percent saturation shall not be below 56 percent more than once per year.

However, there were insufficient DO data to meet the data sufficiency requirements in Rules 62-302.533(2)(b) and (c), F.A.C., to calculate 7-day and 30-day average DO values, and only the daily average percent DO saturation was assessed. To be conservative, the Department assessed whether the daily average criterion was attained in each year, rather than over the period of record or over the typical Impaired Waters Rule assessment period of 7.5 years.

If DO was collected at multiple depths at a given station and time, the average of the values was used to assess achievement with the 42% saturation criterion unless any of the individual DO values were less than 2 mg/l, in which case the lower 25th percentile of the measured values was used. These DO provisions were approved by the Environmental Regulation Commission (ERC) in April, 2013. If an estuary segment complied with the 42% saturation target during a given year, it was considered to attain the designated use with respect to DO for that year. For estuary segments that did not attain the current DO criteria, the Department assessed whether the low DO was due to natural conditions. If the DO could not be demonstrated to be caused by natural processes, the segment would be considered to not achieve the DO target for that year.

Development of the new criteria followed the USEPA Virginian Province method (EPA 2000), which is based on laboratory dose-response data similar to the approach routinely used to set criteria for toxics (Stephan *et al.* 1985). The EPA Virginian Province methodology represents a synthesis of current knowledge regarding biological responses to hypoxic stressors in aquatic ecosystems. This approach considers the response to both continuous and cyclic exposures to low DO levels to derive criteria that are protective of aquatic life. To apply this method in Florida, adjustments were made to include the most sensitive taxa found in Florida waters, while excluding those taxa that do not occur in the state. The 26 species used in the calculation of the concentration based Criterion Minimum Concentration (CMC) for Florida waters exhibited LC_{50}s that ranged from 6 to 33 percent saturation. The four most sensitive species are *Menidia beryllina* (inland silverside), *Trachinotus carolinus* (pompano), *Cynoscion nebulosus* (spotted seatrout), and *Harengula jaguana* (scaled sardines), with LC_{50}s ranging from 25 to 33 percent saturation. The Final Acute Value (FAV) calculated in accordance with the Virginian Province methodology, using the four most sensitive species, is 31 percent saturation. A CMC of 42% saturation was then calculated by multiplying the FAV by the average LC_5/LC_{50} ratio of 1.35 to adjust the result to allow a maximum of five percent of the organisms to be affected. Consequently, the revised marine DO criteria prohibits DO in marine waters from falling below 42% saturation in more than 10% of the samples, unless the low DO is demonstrated to be a natural phenomenon.

Minimum DO concentrations resulting from the revised DO saturation criteria (42% saturation) for Florida's marine waters over the range of expected water temperatures are shown in Figure 4.

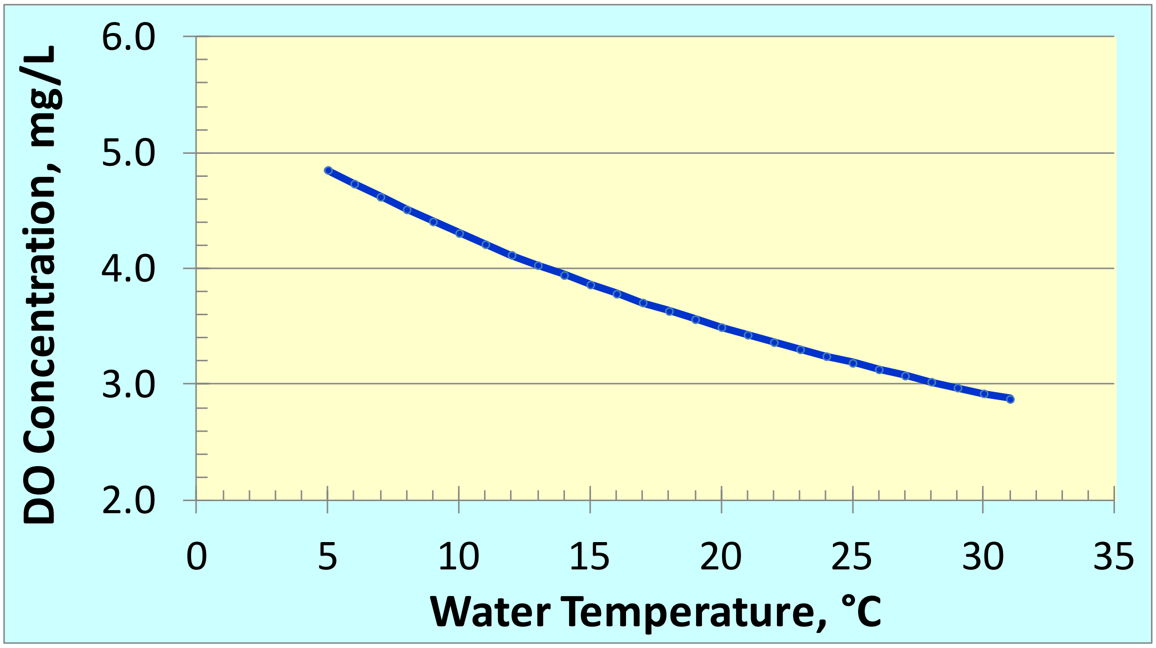


Figure 4. Minimum DO concentrations resulting from the revised 42 percent DO saturation criterion for Florida's marine waters over the range of expected water temperatures using a salinity of 15 ppt.

Additional information on the recently approved DO criteria for both fresh and marine waters is found in *Technical Support Document for the Derivation of Dissolved Oxygen Criteria to Protect Aquatic Life in Florida's Fresh and Marine Waters*" (DEP-SAS-001/13), dated March 2013. The document provides a comprehensive scientific description on the complete criteria and their derivation and application.

FDEP used the IWR Run 47 database and additional data obtained from the South Florida Water Management District to assess daily DO percent saturation. For T or U qualified data, one half of the value was used. FDEP excluded data with fatal qualifier codes (rcode or xcode): H, J, K, N, O, Q, Y, and ?.

The revised DO saturation criterion was achieved in all years with available DO data in Northern, Central, and Southern segments of Lake Worth Lagoon (Tables 3-5).

Results of Evaluation of Water Quality and Achievement of Biological Endpoints

Evaluations of the achievement of seagrass depth, chlorophyll *a*, and DO targets in Lake Worth Lagoon segments for each year with sufficient data are shown in Tables 3-5, while Table 6 provides the years when all year targets were met per segment. If any endpoint failed, the year was not included in the reference period. If data were not available to assess one of the endpoints for a given year, but that endpoint passed for all other years and the other endpoint(s) passed for that year, the year was included in the reference period.

Table 3. Achievement of Seagrass Depth target, chlorophyll a target, and DO target in Northern Lake Worth Lagoon (1201). A dash (-) indicates a target could not be assessed due to insufficient data.

Year	DO proportion <42% saturation	DO Target Achieve-ment	Proportion Chl-a > 20 ug/L	Chl-a Target Achieve-ment	Annual Average (or if available Upper 90th C.I.) Secchi	Depth Target Achieve -ment (0.85m)	Included in Reference Period
1969	0	Pass	-	-	-	-	-
1970	0	Pass	-	-	-	-	-
1971	-	-	-	-	-	-	-
1975	0	Pass	-	-	-	-	-
1976	0.05	Pass	-	-	-	-	-
1977	0	Pass	-	-	-	-	-
1979	0	Pass	-	-	-	-	-
1980	0.11	Fail	-	-	-	-	-
1981	0.08	Pass	-	-	-	-	-
1982	0	Pass	-	-	-	-	-
1983	0	Pass	-	-	-	-	-
1984	0	Pass	0	Pass	1.41	Pass	Yes
1985	0	Pass	-	-	1.44	Pass	Yes
1986	0	Pass	-	-	-	-	-
1987	0	Pass	-	-	-	-	-
1988	0	Pass	-	-	-	-	-
1989	0	Pass	-	-	2.11	Pass	Yes
1990	0	Pass	-	-	1.85	Pass	Yes
1991	0	Pass	-	-	-	-	-
1992	0	Pass	-	-	-	-	-
1993	0	Pass	0	Pass	2.38	Pass	Yes
1994	0	Pass	0	Pass	2.29	Pass	Yes
1995	0	Pass	0	Pass	2.44	Pass	Yes
1999	-	-	-	-	-	-	-
2000	0	Pass	0	Pass	2.10	Pass	Yes
2001	0	Pass	0	Pass	-	-	Yes
2002	0	Pass	0	Pass	4.27	Pass	Yes
2003	0	Pass	0	Pass	-	-	Yes
2004	0	Pass	0	Pass	-	-	Yes
2005	0	Pass	0	Pass	-	-	Yes
2006	0	Pass	0	Pass	1.40	Pass	Yes
2007	0	Pass	0	Pass	2.04	Pass	Yes
2008	0	Pass	0.01	Pass	1.54	Pass	Yes
2009	0	Pass	0	Pass	1.38	Pass	Yes
2010	0	Pass	0	Pass	1.48	Pass	Yes
2011	0	Pass	0	Pass	1.45	Pass	Yes
2012	0	Pass	0	Pass	1.43	Pass	Yes

Table 4. Achievement of Seagrass Depth target, chlorophyll a target, and DO target in Central Lake Worth Lagoon (1202). A dash (-) indicates a target could not be assessed due to insufficient data. A 'No' in the "Included in Reference Period" column indicates that one of the targets failed for that year.

Year	DO proportion <42% saturation	DO Target Achieve-ment	Proportion Chl-a > 20 ug/L	Chl-a Target Achieve-ment	Annual Average (or if available Upper 90th C.I.) Secchi	Depth Target Achieve -ment (1.05m)	Included in Reference Period
1969	0	Pass	-	-	-	-	-
1970	0	Pass	-	-	-	-	-
1971	-	-	-	-	-	-	-
1981	0	Pass	-	-	-	-	-
1982	-	-	-	-	-	-	-
1983	0	Pass	-	-	-	-	-
1984	0	Pass	0	Pass	1.10	Pass	Yes
1985	0	Pass	-	-	0.87	Pass	-
1986	0	Pass	-	-	-	-	-
1987	0	Pass	-	-	-	-	-
1988	0	Pass	-	-	-	-	-
1989	0	Pass	-	-	0.80	Pass	-
1990	0	Pass	-	-	0.85	Pass	-
1991	0	Pass	-	-	-	-	-
1992	0	Pass	-	-	-	-	-
1993	0	Pass	0	Pass	2.36	Pass	Yes
1994	0	Pass	0	Pass	2.16	Pass	Yes
1995	0	Pass	0	Pass	2.59	Pass	Yes
2000	0	Pass	0	Pass	0.45	Fail	No
2001	0	Pass	0	Pass	-	-	-
2002	0	Pass	0.07	Pass	-	-	-
2003	0	Pass	0.50	Fail	-	-	-
2004	0.08	Pass	0	Pass	-	-	-
2005	0	Pass	0.07	Pass	-	-	-
2006	0	Pass	0	Pass	-	-	-
2007	0.03	Pass	0	Pass	1.71	Pass	Yes
2008	0.04	Pass	0.07	Pass	1.24	Pass	Yes
2009	0	Pass	0	Pass	1.46	Pass	Yes
2010	0	Pass	0.02	Pass	1.46	Pass	Yes
2011	0	Pass	0	Pass	1.55	Pass	Yes
2012	0	Pass	0	Pass	1.45	Pass	Yes

Table 5. Achievement of Seagrass Depth target, chlorophyll a target, and DO target in Southern Lake Worth Lagoon (1203). A dash (-) indicates a target could not be assessed due to insufficient data.

Year	DO proportion <42% saturation	DO Target Achieve-ment	Proportion Chl-a > 20 ug/L	Chl-a Target Achieve-ment	Annual Average (or if available Upper 90th C.I.) Secchi	Depth Target Achieve-ment (0.70m)	Included in Reference Period
1969	0	Pass	-	-	-	-	-
1970	0	Pass	-	-	-	-	-
1971	-	-	-	-	-	-	-
1973	0	Pass	-	-	-	-	-
1975	0	Pass	-	-	-	-	-
1980	0	Pass	-	-	-	-	-
1981	0	Pass	-	-	-	-	-
1982	0	Pass	-	-	-	-	-
1983	0	Pass	-	-	-	-	-
1984	0	Pass	0	Pass	1.45	Pass	Yes
1985	0	Pass	-	-	1.39	Pass	Yes
1986	0	Pass	-	-	-	-	-
1987	0	Pass	-	-	-	-	-
1988	0	Pass	-	-	-	-	-
1989	0	Pass	-	-	2.44	Pass	Yes
1990	0	Pass	-	-	1.69	Pass	Yes
1991	0	Pass	-	-	-	-	-
1992	0	Pass	-	-	-	-	-
1993	0	Pass	-	-	-	-	-
1994	0	Pass	-	-	-	-	-
1995	0	Pass	-	-	-	-	-
2000	0	Pass	0	Pass	1.47	Pass	Yes
2001	0	Pass	0	Pass	-	-	Yes
2002	0	Pass	0.10	Pass	-	-	Yes
2003	0.05	Pass	0	Pass	-	-	Yes
2004	0	Pass	-	-	-	-	-
2005	0.06	Pass	0	Pass	-	-	Yes
2006	0	Pass	0.05	Pass	-	-	Yes
2007	0	Pass	0.02	Pass	1.63	Pass	Yes
2008	0.01	Pass	0.05	Pass	1.41	Pass	Yes
2009	0	Pass	0	Pass	1.54	Pass	Yes
2010	0	Pass	0.03	Pass	1.48	Pass	Yes
2011	0	Pass	0.04	Pass	1.45	Pass	Yes
2012	0	Pass	0.04	Pass	1.34	Pass	Yes

Table 6. Summary of the years achieving all Three Targets per Segment in Lake Worth Lagoon.

Northern Lake Worth Lagoon	Central Lake Worth Lagoon	Southern Lake Worth Lagoon
1984	1984	1984
1985	1993	1985
1989	1994	1989
1990	1995	1990
1993	2007	2000
1994	2008	2001
1995	2009	2002
2000	2010	2003
2001	2011	2005
2002	2012	2006
2003		2007
2004		2008
2005		2009
2006		2010
2007		2011
2008		2012
2009		
2010		
2011		
2012		

Approach for Criteria Development

FDEP found that all of the above biological targets were achieved during the years shown in Table 6, which supports the application of a Reference Period Approach for development of NNC in the segments of Lake Worth Lagoon during those years (see Appendix A for additional evidence of aquatic life designated use support). Therefore, FDEP used the Reference Condition approach with data from reference years (Table 6) to calculate numeric nutrient criteria. Data sufficiency was determined individually for TN, TP, and Chlorophyll *a* (described below).

Methodology for Calculating Criteria

Data Sets, Data Screening for Calculating Criteria

FDEP used the TN, TP, and chlorophyll *a* data from the IWR Run 47, as well as, from the South Florida Water Management District (SFWMD). FDEP excluded data with fatal qualifier codes (rcode or xcode): H, J, K, N, O, Q, Y, and ?, and used one half the reported value for data with the T or U qualifier. (See Table 7 for qualifier code descriptions.) Data that were flagged within the IWR database as not useable for Verified Listing purposes were excluded from criteria calculations and target evaluations. The useable data are denoted by an entry of "y" in the "epa" field of the IWR database, while unusable data are denoted by "n." Data were flagged as unusable if they were collected under conditions that were not representative of the waterbody, or if there were concerns about the quality of the data based on audit findings, non-standard procedures, or fatal qualifier codes described above.

Table 7. Data qualifier table.

H	Value based on field kit determination; results may not be accurate. This code shall be used if a field screening test (i.e., field gas chromatograph data, immunoassay, vendor-supplied field kit, etc.) was used to generate the value and the field kit or method has not been recognized by the Department as equivalent to laboratory methods.
J	Estimated value. A “J” value shall be accompanied by a detailed explanation to justify the reason(s) for designating the value as estimated. Where possible, the organization shall report whether the actual value is estimated to be less than or greater than the reported value. A “J” value shall not be used as a substitute for K, L, M, T, V, or Y, however, if additional reasons exist for identifying the value as an estimate (e.g., matrix spiked failed to meet acceptance criteria), the “J” code may be added to a K, L, M, T, V, or Y. Examples of situations in which a “J” code must be reported include: instances where a quality control item associated with the reported value failed to meet the established quality control criteria (the specific failure must be identified); instances when the sample matrix interfered with the ability to make any accurate determination; instances when data are questionable because of improper laboratory or field protocols (e.g., composite sample was collected instead of a grab sample); instances when the analyte was detected at or above the method detection limit in a blank other than the method blank (such as calibration blank or field-generated blanks and the value of 10 times the blank value was equal to or greater than the associated sample value); or instances when the field or laboratory calibrations or calibration verifications did not meet calibration acceptance criteria.
K	Off-scale low. Actual value is known to be less than the value given. This code shall be used if:
	1. The value is less than the lowest calibration standard and the calibration curve is known to be non-linear; or
	2. The value is known to be less than the reported value based on sample size, dilution.
	This code shall not be used to report values that are less than the laboratory practical quantitation limit or laboratory method detection limit.
N	Presumptive evidence of presence of material. This qualifier shall be used if:
	1. The component has been tentatively identified based on mass spectral library search; or
	2. There is an indication that the analyte is present, but quality control requirements for confirmation were not met (i.e., presence of analyte was not confirmed by alternative procedures).
O	Sampled, but analysis lost or not performed.
Q	Sample held beyond the accepted holding time. This code shall be used if the value is derived from a sample that was prepared or analyzed after the approved holding time restrictions for sample preparation or analysis.
Y	The laboratory analysis was from an improperly preserved sample. The data may not be accurate.
?	Data are rejected and should not be used. Some or all of the quality control data for the analyte were outside criteria, and the presence or absence of the analyte cannot be determined from the data.
T	Value reported is less than the laboratory method detection limit. The value is reported for informational purposes only and shall not be used in statistical analysis.
U	Indicates that the compound was analyzed for but not detected. This symbol shall be used to indicate that the specified component was not detected. The value associated with the qualifier shall be the laboratory method detection limit. Unless requested by the client, less than the method detection limit values shall not be reported (see “T” above).

A summary of the Run 47 dataset and SFWMD data is shown in Table 8, indicating that there is extensive spatial and temporal coverage for Lake Worth Lagoon segments.

Table 8 provides the number of data points, the number of samples by season, and the number of sample years per segment used for criteria calculations. Data did not always meet the annual data sufficiency requirements for the annual geometric mean approach for all parameters in all segments. (See the section below called "Statistical Method and Proposed Criteria" for more information on criteria approach sufficiency requirements.) Chlorophyll *a* in the Central Lake Worth Lagoon segment fell short of the minimum of eight years; therefore, the criterion was derived as a sample maximum value not to be exceeded in more than 10% of samples. In Table 8, the first Segment Year count represents the total number of years used to derive the criterion, while the value in parentheses is the number of years that met annual data sufficiency requirements for the annual geometric mean calculation. This additional information is provided for informational purposes, only.

Table 8. Number of data points that passed screening for quality assurance, target achievement, and lack of impairment for each segment of Lake Worth Lagoon. Sample sizes are summarized as the total number of samples, by calendar season (quarter), and the number of segment years used to calculate the criteria.

Segment	Parameter	Total Samples	Seasonal Sample Count 1	Seasonal Sample Count 2	Seasonal Sample Count 3	Seasonal Sample Count 4	Segment Years
North Lake Worth Lagoon	Chl-a	596	164	148	148	136	10
North Lake Worth Lagoon	TN	607	158	170	149	130	14
North Lake Worth Lagoon	TP	661	177	175	165	144	16
Central Lake Worth Lagoon	Chl-a	317	89	83	70	75	6(6)[1]
Central Lake Worth Lagoon	TN	286	78	74	65	69	8
Central Lake Worth Lagoon	TP	308	76	81	74	77	8
South Lake Worth Lagoon	Chl-a	557	141	132	140	144	9
South Lake Worth Lagoon	TN	558	146	137	138	137	10
South Lake Worth Lagoon	TP	551	145	136	137	133	9

1. Data did not meet annual data sufficiency requirements; therefore, criteria were derived as a sample maximum value not to be exceeded in more than 10% of samples. The first Segment Year count represents the total number of years used to derive the criterion, while the value in parentheses is the number of years that met annual data sufficiency requirements annual geometric mean calculation.

Statistical Method and Components of the Proposed Criteria

To be applied consistently and to provide an appropriate level of protection, water quality criteria need to include magnitude, frequency, and duration components. The magnitude is a measure of how much of a pollutant may be present in the water without an unacceptable adverse effect. Duration is a measure of how long a pollutant may be above the magnitude, and frequency relates to how often the magnitude may be exceeded without adverse effects. It is preferable to derive the magnitude component of a criterion through a cause-effect relationship (such as that measured through toxicity testing). The magnitude would then be set at a level that would protect a majority of the sensitive aquatic organisms inhabiting the system. Absent sufficient data to demonstrate a cause-effect relationship, the magnitude may be set at a level designed to maintain the current data distribution, accounting for natural temporal variability, assuming the current conditions are protective of the designated uses of the waterbody. Since a criterion derived based on the existing data distribution has no direct link to any observed cause-and effect relationship, it is assumed that maintaining the current data distribution will preserve the uses associated with that distribution.

The frequency and duration components of the criteria are best established as additional descriptors of the reference condition data distribution. Specifically, these components should be part of a statistical test designed to determine whether the long-term distribution of data has shifted upward from the reference distribution. This test would then be used to determine whether future monitoring data are consistent with the magnitude (long-term average) defined by the reference dataset. It is critical to account for the natural variability surrounding the magnitude expression and to control for statistical errors. The magnitude component can be set at the long-term central tendency (geometric mean) of the distribution, while the frequency and duration components describe how often and by how much nutrient concentrations can be above the central tendency while still being consistent with the reference distribution. The methods for deriving the magnitude, frequency and duration components of numeric nutrient criteria are described briefly below. More details concerning the statistical approaches used can be found in the document, *Overview of FDEP Approaches for Nutrient Criteria Development in Marine Waters*.

Magnitude

The magnitude component represents a level of nutrients demonstrated to be protective of the designated use. For the "Reference Period" approach, the magnitude can be interpreted as the central tendency of the baseline distribution and may be set at a level that represents a long-term average condition of that distribution. For the "Reference Period" approach, the Department proposes establishing the magnitude as an annual geometric mean, not to be exceeded more than once over a three- year period.

The objective of this magnitude component is to maintain the long-term average concentration at the level observed in the baseline data set. Exceedance of the one magnitude component more than once in a three-year period would provide strong evidence that the waterbody nutrient levels had increased above the baseline distribution.

Frequency and Duration

To provide a consistent and appropriate level of protection, the duration and frequency components of the criteria must be consistent with the derivation of the magnitude component. While the magnitude component of the criteria was derived based on a long-term geometric mean concentration, it is not practical to assess compliance with the criteria on the same long-term basis. Instead, a statistical test can be developed to allow the application of the criteria on a shorter-term basis. For the criteria to be protective, the duration component of the criteria (*e.g*., single sample maximum, annual geometric mean) must be linked to the response time frame of the sensitive endpoint. Short-term averaging periods (*e.g.,* 1 to 30 days) would be appropriate for nutrient criteria where a sufficiently robust cause-effect relationship has demonstrated that a eutrophic response occurs over such time frames. If, however, such a short-term response cannot be demonstrated, or there is no indication of use impairment, then longer averaging periods should be considered.

For example, since the relationship between nutrient and chlorophyll *a* response in Florida lakes was extremely weak, with a much more robust relationship found when data were evaluated based on annually averaged log-transformed data, FDEP and EPA used an averaging period of a year to assess the enrichment in Florida lakes with the criteria being expressed as an annual geometric mean. Likewise, the nutrient criteria for estuaries will be assessed annually. Since the duration and frequency components of the criteria must be consistent with the derivation of the magnitude component to provide a consistent and appropriate level of protection, the long-term geometric mean target cannot simply be applied as an annual mean. Doing so would result in unacceptably high Type I failure rate (identifying a healthy system as being impaired), since approximately 50% of the individual years can be expected to be above the long-term mean. Therefore, the long-term target must be adjusted to allow for the application to a shorter duration with an acceptable Type I error rate of no more than 10%.

This assessment of the Type I error rate is related only to addressing the null hypothesis that future monitoring data are equivalent to the baseline distribution. This Type I error does not take into account the possibility that a higher nutrient threshold would be fully protective of the use. The Type I error rate, for the current application, may be defined as the rate of incorrectly concluding that the mean of (future) monitoring data is greater than the baseline or reference long-term mean condition identifying. Type I statistical errors result in the management decision error to incorrectly list a healthy waterbody as impaired.

An annual target concentration with an approximate 10% Type I error rate for a given frequency can be derived by appropriately accounting for the annual variability above the mean. This annual target concentration can be derived as an upper percentile of the distribution of the annual geometric mean concentrations. Previous proposals by EPA have used 3-year assessment periods to express the magnitude and duration nutrient criteria components. Assuming a 3-year assessment period, it can be statistically determined that using the 80th percentile of the annual geometric means from the long-term dataset with a frequency and duration of no more than once during the 3-year period will achieve the targeted 10% error rate**.** Therefore the proposed criteria will be applied such that the 80th percentile of the annual geometric mean concentrations cannot be exceeded in more than 1 out of 3 years.

Summary of the Proposed Criteria

For a "reference conditions" dataset, the Department considered several potential ways to express the NNC. The Department's selected approach is to set the magnitude as an annual geometric mean maximum established at the upper 80 percent prediction limit of the spatially averaged annual geometric means, with a frequency and duration of no more than 1 annual geometric mean exceeding the limit in a 3-year period. This approach requires 8 years of appropriate data to confidently calculate, which is available for the Northern and Southern segments of Lake Worth Lagoon (Table 8).

FDEP proposes an alternative for segments that have less than 8 years of data (as is the case for the chlorophyll criterion in Central Lake Worth Lagoon). The alternative is a single sample value not to be exceeded in more than 10% of the samples. This is calculated as an upper 90% prediction limit on the individual samples where there are at least 30 total samples. Table 8 shows the number of chlorophyll samples in Central Lake Worth Lagoon, as well as, the number of years those samples span. There were many more than 30 samples available to calculate criteria based on an upper 90% prediction limit over several years.

The proposed limits for each segment, for the protection of a healthy, well-balanced aquatic community in each Lake Worth Lagoon segment, are provided in Table 9. To demonstrate achievement of the criteria expressed as an annual geometric mean, the limits must not be exceeded more than once in any three year period. The criteria expressed as a single sample value must not be exceeded in more than 10% of samples over the period of assessment.

Table 9. Proposed numeric nutrient criteria for Lake Worth Lagoon segments, including TP, TN, and Chlorophyll a.

North Lake Worth Lagoon Segment	Existing Long-Term Geometric Mean	Maximum Annual Geometric Mean Criterion (1-in-3 year exceedance rate)
TP (mg/L)	**0.030**	**0.044**
TN (mg/L)	**0.33**	**0.54**
Chl *a* (µg/) (corrected)	**2.4**	**2.9**

Central Lake Worth Lagoon Segment	Existing Long-Term Geometric Mean	Maximum Annual Geometric Mean Criterion (1-in-3 year exceedance rate)
TP (mg/L)	**0.043**	**0.049**
TN (mg/L)	**0.54**	**0.66**
	Existing Long-Term Geometric Mean	**Single Sample Criterion (Not to be exceeded**

		>10% of time)
Chl *a* (µg/) (corrected)	**4.2**	**10.2**

South Lake Worth Lagoon Segment	Existing Long-Term Geometric Mean	Maximum Annual Geometric Mean Criterion (1-in-3 year exceedance rate)
TP (mg/L)	**0.037**	**0.050**
TN (mg/L)	**0.42**	**0.59**
Chl *a* (µg/) (corrected)	**4.7**	**5.7**

Literature Cited

Baumstark, R, B. Dixon, P. Carlson, D. Palandro, and K. Kolasa. 2012. Alternative spatially enhanced integrative techniques for mapping seagrass in Florida's marine ecosystem. International Journal of Remote Sensing 34: 1248-1264.

Carlson, P. and K. Madley. 2007. Statewide Summary for Florida. In: L. Handley, D. Altsman, and R. DeMay (Eds.), *Seagrass status and trends in the northern Gulf of Mexico: 1940–2002* (U.S. Geological Survey Scientific Investigations Report 2006-5287 and U.S. Environmental Protection Agency 855-R-04-003, pp. 99-114).

EPA. 2000. Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras. Environmental Protection Agency, Office of Water, Washington D.C. PA-822-R-00-012.

EPA. 2012. Technical Support Document for U.S. EPA's Proposed Rule for Numeric Nutrient Criteria for Florida's Estuaries, Coastal Waters, and South Florida Inland Flowing Waters, Volume 1 Estuaries [DCN 1-1498].

FDEP. 2013. Technical Support Document for the Derivation of Dissolved Oxygen Criteria to Protect Aquatic Life in Florida's Fresh and Marine Waters. DEP-SAS-001/13. 230 pp.

Hagy, J. 2013. Seagrass Depth of Colonization in Florida Estuaries. In press.

Hagy, J. 2013. Alternate Lake Worth Lagoon depth targets based on 2001 aerials. Personal communication.

Stephan, C.E., D.I. Mount, D.J. Hansen, G.H. Gentile, G.A. Chapman, and W.A. Brungs. 1985. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. National Technical Information Service Publication No.: PB85-227049.

Tomasko, D.A., C.A. Corbett, H.S. Greening, and G.E. Raulerson. 2005. Spatial and temporal variation in seagrass coverage in Southwest Florida: assessing the relative effects of anthropogenic nutrient load reductions and rainfall in four contiguous estuaries. Marine Pollution Bulletin 50: 797-805.

Appendix A. Geographical, Biological, and Water Quality Information in Support of Establishing Numeric Nutrient Criteria for Lake Worth Lagoon

The information given in this appendix is provided as supplemental information about water quality in and the biological health of the Lake Worth Lagoon. While data used in the analyses presented in this appendix may have been used for NNC development, they were not the sole data source. The Department used data from the Impaired Waters Rule (IWR) database as well as data collected by Palm Beach County (available from the South Florida Water Management District's database DBHYDRO) when performing the target checks presented in the main document and when calculating numeric nutrient criteria for Lake Worth Lagoon.

Geographic and Physical Description

The Lake Worth Lagoon is a 20-mile-long coastal estuary located in Palm Beach (Figure 1). The lagoon averages approximately half a mile wide and has an average depth of 2 m (although some dredged areas reach up to 10 m in depth). Table 2 gives additional physical description of the lagoon. Although the system historically was predominately fresh water, inlets dredged to the Atlantic Ocean converted Lake Worth into a high-salinity lagoon. It is the largest estuarine system in Palm Beach County, connected to the Atlantic Ocean by two permanent inlets, the Lake Worth Inlet and the South Lake Worth Lagoon Inlet. A barrier island separates the lagoon from the Atlantic Ocean. The Atlantic Intracoastal Waterway (ICW) traverses the entire length of this estuarine waterbody, with 8 bridges and causeways connecting the barrier island to the mainland.

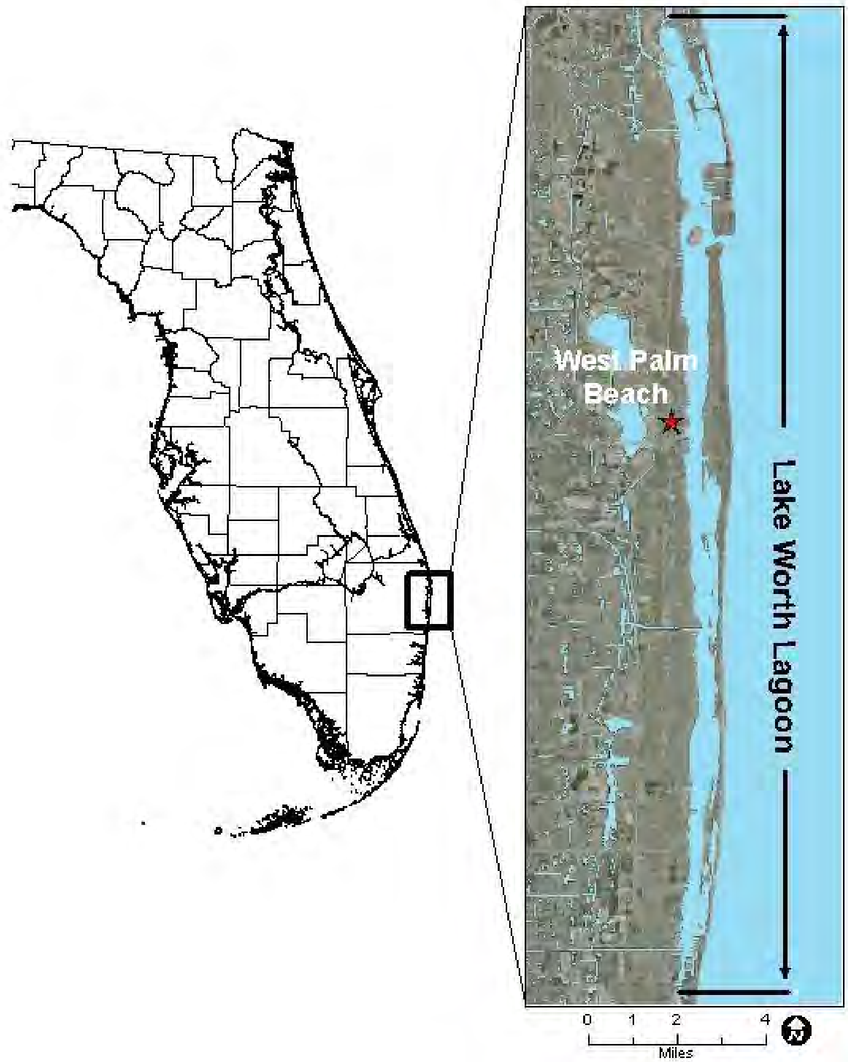


Figure 1. Location of Lake Worth Lagoon, Palm Beach County, Florida.

The watershed of the lagoon includes the communities of North Palm Beach, Lake Park, Riviera Beach, Palm Beach Shores, West Palm Beach, Palm Beach, South Palm Beach, Lake Worth, Lantana, Hypoluxo, Manalapan, Boynton Beach, Ocean Ridge, and unincorporated Palm Beach County. Currently, the Lake Worth Lagoon receives drainage from an area of approximately 450 square miles. Major freshwater inflows from the watershed are discharged to the estuary from regional canals: the Earman River (C-17) Canal, which discharges to the north or upper segment of the lagoon; the West Palm Beach Canal (C-51), which discharges to the central segment; and the Boynton Beach Canal (C-16), which discharges to the southern segment. These canals discharge significant volumes of fresh water that contain nutrients, suspended and dissolved organic matter, and other contaminants that may affect the flora and fauna of the lagoon (Crigger *et al.* 2005). Altered hydrology, fishing and boating pressure, and the loss of natural habitat are also major stressors.

Human activities over the past 100 years, including the construction of permanent inlets; the dredging and filling of wetlands along the shoreline; channel dredging; wastewater discharges; and the construction of sea walls, canals, causeways, and marinas have adversely the Lake Worth Lagoon's habitat. Today, 81% of the shoreline is bulkheaded, and much of the stormwater from the urbanized watershed is not fully treated prior to discharging to the lagoon. During the 1950s, an estimated 10 million gallons per day (MGD) of untreated sewage were discharged in the lagoon, resulting in high bacterial and nutrient concentrations. By 1970, 7 major wastewater treatment plants had been constructed, discharging 18.49 MGD of secondary treated sewage effluent. The volume was reduced to 2.98 MGD by 1984 (U.S. Environmental Protection Agency [EPA]), and currently 14 wastewater treatment package plants operate in the Ocean Ridge (FDEP 2007). Two package plants have direct surface water discharges to the Lake Worth Lagoon. The remaining 12 domestic facilities dispose of secondary wastewater via land applications (ponds, drain fields, injection wells, etc.) (PBCERM and FDEP 1998).

Table 2. Physical characteristics of the Lake Worth Lagoon.

Physical Characteristic	Value	Source
Estuarine surface area (acres)	4,045 acres	PBCERM
pH (standard units [SU])	Average 7.54	FDEP
Mean depth (m)	2 m	PBCERM
Temperature (°C)	20° C to 32° C	Florida Atlantic University (FAU) Harbor Branch
Salinity and salinity zones (practical salinity units [psu])	.~20 average (range is + or -10) Highly correlated to discharge at (C-51)	FAU Harbor Branch

Lake Worth Lagoon Segmentation

The Lake Worth Lagoon is divided into three segments (north, central, and south) based on hydrologic factors, including water quality, circulation, and physical characteristics (Figure 2).

Lake Worth Lagoon North (LWN)

This segment includes waters north of the Flagler Memorial Bridge in West Palm Beach. Lake Worth Inlet (also referred to as Palm Beach Inlet) is the largest inlet and primary source of ocean water in the LWN and it is also the primary outlet for fresh water. The flushing provided by the inlet results in generally good water quality that supports seagrass beds and a marine population of fish and shellfish. The C-17 Canal serves as the primary freshwater source in this segment of the lagoon, just south of Munyon Island, on the west side of the ICW in north Palm Beach. The largest amount of mangroves in the Lake Worth Lagoon is located here. There are extensive seagrass beds in this area of the lagoon, located in and around John D. MacArthur Beach State Park, Peanut Island, and south of Peanut Island, primarily along the western shores of the ICW (PBCERM 2006).

Located within this section of the LWN is the Port of Palm Beach (PPB) District, the 4th busiest port in Florida. Entrance and access to the port are gained through the Lake Worth Inlet, where a channel 300 feet wide and 33 to 35 feet deep at mean low water (MLW) is maintained for vessel access.

Lake Worth Lagoon Central (LWC)

This segment includes waters from the Flagler Memorial Bridge to Lake Worth Bridge. It ranges anywhere from a few hundred feet to nearly three-quarters of a mile across, with depths up to 25 feet. The central lagoon is characterized primarily by single-family residences with armored shorelines, a sand and muck bottom with less seagrass coverage, and scattered mangrove islands. The C-51 Canal is the major source of fresh water to the LWC.

Lake Worth Lagoon South (LWS)

The south segment includes waters between Lake Worth Bridge and the Boynton Beach Bridge at Ocean Avenue. The South Lake Worth Inlet (otherwise known as Boynton Inlet) is 130 feet wide by 9 to 12 feet deep. It was initially opened in 1927 to increase circulation and improve water quality. In addition to abundant seagrass beds and mangroves, the LWS also contains Boynton (C-16) Canal, which is the primary source of freshwater discharges in this segment.

Figure 2. Lake Worth Lagoon segmentation as determined by the Palm Beach County Department of Environmental Resources Management.

Biological Summary of Region

More than 70% of all commercial and recreational fish species depend on coastal estuaries at some stage of their life cycle (Harris *et al.* 1983). An extensive survey, inventory, and analysis of existing natural resources, literature, and data for the lagoon were compiled in the *Lake Worth Lagoon Natural*

Resources Inventory and Enhancement Study (PBCERM 1990). The following sections summarize information on seagrass beds, oyster reefs, and mangrove communities.

Seagrass Background and Current Status

Seagrass beds are highly productive and ecologically important habitats within south Florida's estuaries and coastal lagoons. They are also nursery grounds for the juveniles of a variety of finfish and shellfish of commercial and recreational fishing value. Their roots and rhizomes stabilize sediments, promote the sedimentation of particles, inhibit the resuspension of sediments, and maintain an active environment for nutrient recycling. Seagrass blades provide a substrate on which epiphytes can attach, providing a valuable food source for aquatic herbivores. Seagrasses may be more important to the food web as source of detritus rather than as a source for direct herbivory. Detritus is an important food source for deposit feeders, providing polychaetes, amphipods, isopods, ophiuroids, some gastropods, and mullet with much of their nutrition. Seagrasses are also important because they are the primary food source for the Florida manatee and green sea turtles (PBCERM and FDEP 1998).

The loss of seagrasses has been documented worldwide and has been attributed to transparency reductions due to eutrophication and to the physical alteration of shorelines and habitats. Declines have been correlated with a reduction in available light due to an increase in phytoplankton, epiphytic, or macroalgal growth (Bortone 2000). Light limitation reduces the depth to which seagrass can grow, thus reducing the overall areal extent of seagrass beds. The protection of seagrass is a management priority for the Lake Worth Lagoon, as specified in the 1998 Lake Worth Lagoon Management Plan, Palm Beach County Comprehensive Plan–Coastal Management Element (Section 376.121, Florida Statutes—Liability for Damage to Natural Resources) and the federal Endangered Species Act protecting listed species of seagrass. This report presents the results of historical seagrass surveys in 1940, 1975, 1990, and 2001 to provide a baseline and a benchmark for the development of a seagrass restoration model (Braun 2006).

The earliest seagrass survey for the Lake Worth Lagoon, conducted in 1940, identified 4,271 acres of seagrass (PBCERM and FDEP 1998) (Table 3). In 1975, a resource inventory found that only 161 acres of seagrass remained in the lagoon. While there is uncertainty about the accuracy of the methods used, this indicates a substantial loss of seagrass since 1940. The loss was hypothesized to result from extensive dredging-and-filling activities, sewage disposal outfalls that directly discharged to the lagoon, and changes in salinity (PBCERM 1998). In 1990, the natural resource inventory performed by Dames & Moore and PBCERM included detailed surveys that provided the most complete information to date. The survey indicated that there were 2,110 acres of seagrass, or approximately half of the extent of seagrass in 1940. Note that there was a substantial increase (1,949 acres) compared with the results of the 1975 survey (Braun 2006).

The most recent assessment of seagrass beds was conducted in 2001, using true color aerial photographs (Figure 3). The total coverage of seagrass beds was 1,626 acres, or approximately 22% of the total area in the lagoon (PBCERM 2002). The coverage varies throughout the three segments of the lagoon. Specifically, 69.7% of the seagrass in the Lake Worth Lagoon is in the northern segment of the lagoon (1,134 acres), with 11.8% in the central segment (300 acres) and 18.5% in the southern segment (192 acres). The overall seagrass coverage within each of the segments is 33.5% in the north, 9% in the central, and 17% in the south (Braun 2006) (Table 4). Although the methods of analysis were markedly different for the 1990 and 2001 surveys, there appears to be a potential loss of seagrass coverage over the 11-year period. This assessment did not include extensive ground truthing (verification); therefore, sparse seagrass beds, or those located in areas with poor water visibility, were not mapped.

Table 3. Summary of seagrass coverage in the Lake Worth Lagoon found in the four studies (1940, 1975, 1990, and 2001).

- = Empty cell/no data
*Arbitrary date reflects conditions prior to intense urbanization; conditions allow for maximum coverage of seagrass.
**Acres is the maximum possible area of seagrass given pre-World War II conditions.
***Due to gross differences in survey methods, these values should only be used to indicate an order–of-magnitude change.

Year	Seagrass (acres)	% Change from Most Recent Previous Assessment***
1940*	**4,271****	**-**
1975	**161**	**-96%**
1990	**2,110**	**1,210%**
2001	**1,626**	**-23%**

Table 4. Coverage results of 2001 seagrass mapping in Lake Worth Lagoon.

Lake Worth Lagoon Segment	2001 Seagrass (acres)	Segment (acres)	% Seagrass Cover
North	**1,134**	**3,386**	**33.50%**
Central	**192**	**2,102**	**9%**
South	**300**	**1,747**	**17%**
Totals	**1,626**	**7,235**	**22%**

One of the requirements for seagrass growth is availability of light, along with proper salinity, sediment type, and nutrient regime. PBCERM staff assembled existing datasets to determine the distribution of seagrass by depth using the seagrass coverage from 2001, and bathymetry data from 2003 (PBCERM 2003). Approximately 92% of the seagrass in the north segment is present at depths of -2.0 to -6.0 feet national geodetic vertical datum (NGVD), with an average depth of -5.0 feet NGVD.

In the central segment of the lagoon, which contains only 192 acres of seagrass, the majority of seagrass is found at depths between -3.0 to -5.0 feet NGVD, with an average depth of -4.4 feet NGVD.

Finally, the average depth of seagrass in the south segment is -3.4 feet NGVD. Sediment smothering continues to be an issue in this area of Lake Worth Lagoon.

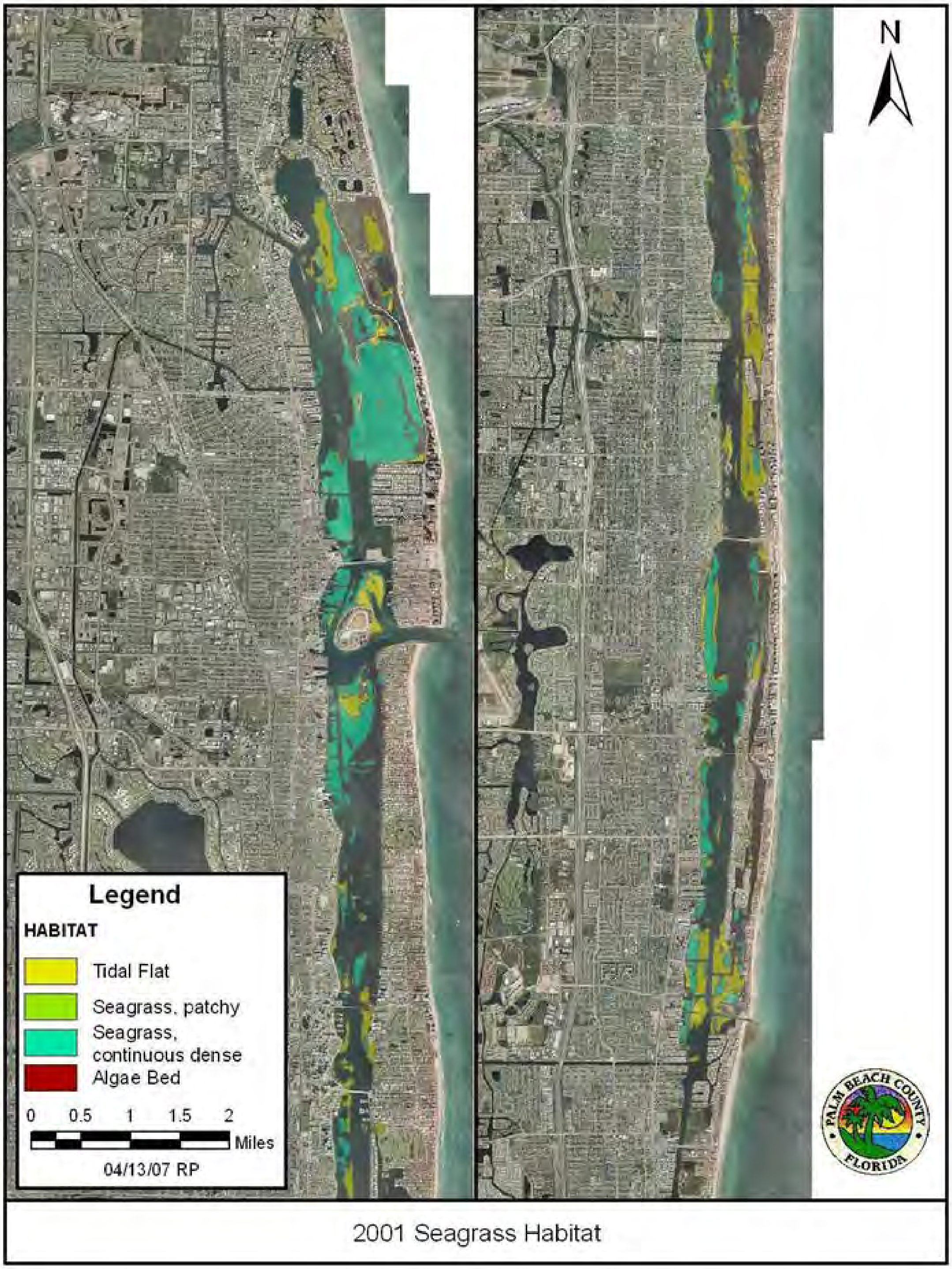


Figure 3. Seagrass coverage from 2001 seagrass mapping project.

Fixed Transect Seagrass Surveys

Since 2000 (except during 2006), PBCERM has conducted annual monitoring along 9 transects running perpendicular to the length of the Lake Worth Lagoon. These transects were located in areas where the lagoon bottom increased in depth by 1 to 2 feet within 50 to 100 feet of the edge of an existing seagrass bed. The areas selected were chosen for their proximity to construction projects funded by the Lake Worth Lagoon Partnership Grant (LWLPG) Program or other habitat improvement project. As clarity in the lagoon improves, seagrass beds are expected to expand to greater depths and increase in density and diversity. Five years of surveys have shown fluctuation in seagrass cover and no obvious pattern of increase or decrease until the hurricanes of 2004. After the significant hurricane damage, the survey conducted in June 2005 showed a major decrease in seagrass cover in most areas of the lagoon. This loss is believed to be due to increased turbidity caused by the hurricanes, freshwater discharges from Lake Okeechobee, and burial/scour from wave action. The least impacted areas were shallow sites and sites closer to inlets where water quality was least affected (PBCERM 2005a).

Oyster Reefs

Oysters form an important part of a healthy estuarine ecosystem, but their ecological function and significance remain underappreciated and understudied (Coen *et al.* 1999a). Individual oysters filter 4 to 34 liters of water per hour, removing phytoplankton, particulate organic carbon, sediments, pollutants, and microorganisms from the water column. These processes result in greater light penetration immediately downstream of an oyster bed, thus promoting the growth of submerged aquatic vegetation. Although oysters assimilate the bulk of the organic matter that they filter, the remainder is deposited on the bottom, where it provides food for benthic organisms.

Furthermore, the oyster's ability to form large biogenic reefs (Coen *et al.* 1999b) qualifies it as a keystone species. Oysters, and the complex three-dimensional reef structure they form, attract numerous species of fish and invertebrates (Comprehensive Everglades Restoration Plan [CERP] 2007). However, excessive freshwater discharges from drainage canals may alter an ecologically appropriate range of salinity conditions, adversely affecting oyster populations. Water management and dredging practices have had major impacts on the presence of oysters and SAV within the Lake Worth Lagoon estuaries (CERP 2006).

A monitoring program currently conducted by the Florida Fish and Wildlife Conservation Commission (FWCC) found several natural oyster reefs in the Lake Worth Lagoon (Figure 4). Although the oyster bars were healthy, the areal extent of natural oyster reefs in the lagoon was very limited (about 5 acres). The FWCC also found oysters on dock pilings and seawalls throughout the area, as well as on limestone riprap at the Snook Islands Natural Area. These findings imply that the population in the lagoon is not recruitment limited but instead limited by the availability of suitable substrate. The distribution of oysters in the Lake Worth Lagoon is confined primarily to the intertidal zone, with the densest concentrations found in the central segment of the lagoon. This area contains a rocky “spine” east of the ICW channel, most of which is intertidal. The majority of natural oyster reefs in the lagoon are located on this rocky spine; however, much of the area is impacted by sediment deposits, which inhibit oyster colonization. The accumulation of muck on available substrate or nearby areas makes the substrate unsuitable for oyster larval settlement and thus for the recruitment and growth of larval oysters (CERP 2007a). In addition, the accumulated muck may also impact DO concentrations, making the area/substrate unsuitable for larval settlement and growth (CERP 2007a).

Expanding the areal extent of oyster reefs in the Lake Worth Lagoon is an objective of CERP’s Restoration Coordination and Verification (RECOVER) Project for the Lake Worth Lagoon. While projects implemented in the C-51 Basin as part of CERP will affect freshwater discharges and consequently sedimentation and salinity, it is very difficult to quantify predicted impacts on oyster colonization. Adding suitable material to provide additional substrate, on the other hand, provides direct and measurable results. PBCERM has identified over 185 acres of potentially suitable habitat for oyster reef enhancement in the central zone of the lagoon. Other areas in the estuary might also be suitable for reef creation; however, those areas have not yet been identified.

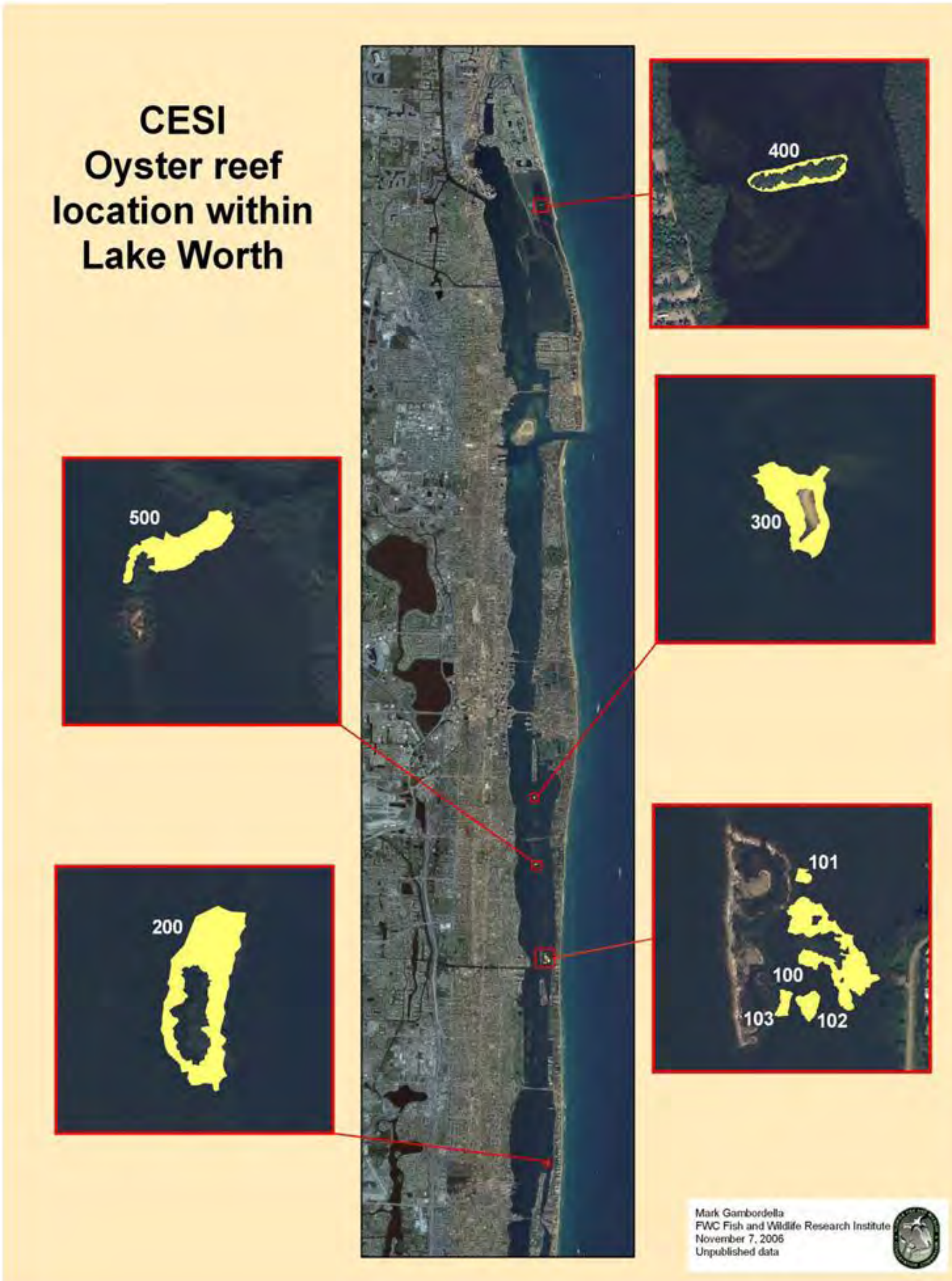


Figure 4. Currently mapped natural oyster reefs in the Lake Worth Lagoon (courtesy of Mark Gambordella, Critical Ecosystem Studies Initiative [CESI], FWCC).

Mangrove Communities and Shoreline Characteristics

Mangroves serve very important functions in the ecology of south Florida. They have a key ecological role as nursery grounds and as physical habitat for a wide variety of vertebrates and invertebrates. They recycle nutrients and contribute to the nutrient mass balance of estuarine ecosystems. Mangrove leaves, wood, roots, and detrital material provide essential food chain resources and provide habitat for many wildlife, including mammals, birds, reptiles, amphibians, and arthropods. Mangroves have a special ecological function for endangered species, threatened species, and species of special concern. They also serve as storm buffers, as their roots stabilize shorelines and fine substrates, reducing potential turbidity and enhancing water clarity.

In 2003, PBCERM initiated a study (PBCERM 2004b) to expand the 1990 resource baseline inventory by Palm Beach County and Dames and Moore by including the entire ICW and updating the data. One of the goals of this new study was to map and inventory mangrove communities and shoreline characteristics countywide, and to provide trend analyses between 1985 and 2001. The inventory data were categorized by the following shoreline characteristics: seawall, seawall with riprap, riprap revetment, exotic woody vegetation, mangrove swamp, and developed unarmored. True color aerial photographs of the Lake Worth Lagoon, the Loxahatchee River, and the entire ICW were acquired in 2001 for these mapping purposes. From 1985 to 2001, the percent of shoreline converted from natural to an armored condition in the Lake Worth Lagoon increased from 79% to 87%. Countywide, mangroves showed a slight increase from 1985 (657 acres) to 2001 (669 acres), a 2% increase. In the Lake Worth Lagoon, mangrove stands also increased about 2%, from 273 acres in 1985, to 278 acres in 2001.

It should be noted that the 1985 aerial photographs were taken at a resolution of 1:58,000, which is much less accurate than the scale of 1:10,000 used for the 2001 aerial photographs. In addition, 2 different types of photography were used for the maps. The larger scale for the older maps made data interpretation more difficult, and the results were never ground-truthed. Also, a minimum mapping unit of 2 acres was used in 1985 compared with 0.25 acres for the 2001 aerials. Therefore, these results should be used with caution and with the recognition that they are appropriate for depicting gross changes only.

Several conclusions and recommendations were drawn from this study. The results show a substantial shift in shoreline characteristics toward greater armoring as a result of development. This is expected to negatively affect fisheries and wildlife, such as fish, birds, and benthic invertebrates that use shallow, natural estuarine shorelines and beaches. Although the amount of armoring increased 19% countywide, the increase in riprap facing the armoring that provides some habitat value showed a 267% increase. Shorelines with just riprap (no seawall) increased by 44%; this stabilization method provides more habitat value than a vertical bulkhead. There appeared to be a slight increase in mangrove acreage that is most likely attributable to large-scale restoration projects and some mitigation projects.

Many habitat enhancement projects have been completed since the 2001 aerials were taken and this countywide study was performed. Approximately 184 acres of habitat have been restored (see Figures 5 and 6 for a comparison).

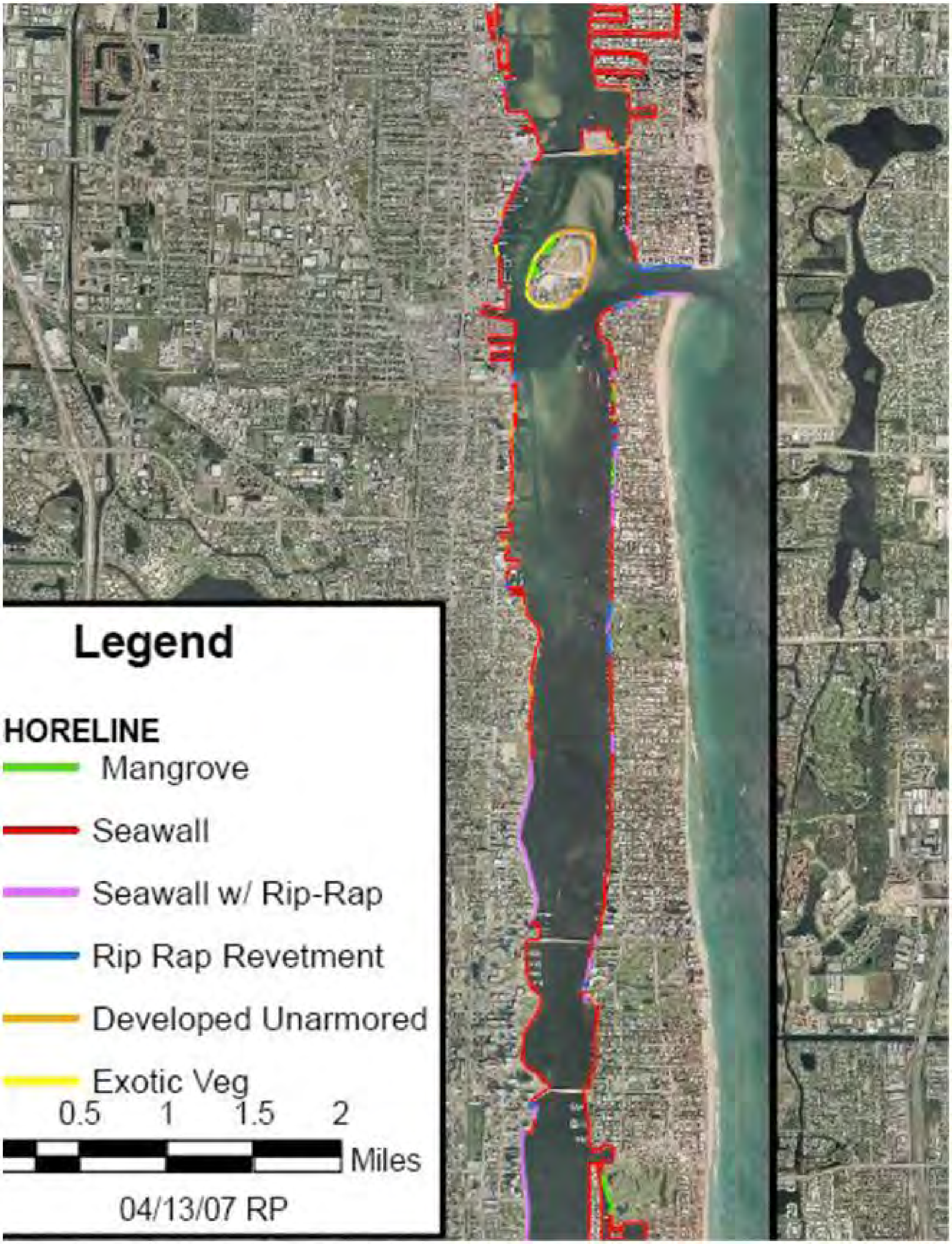


Figure 5. Map of shoreline habitat in 1985.

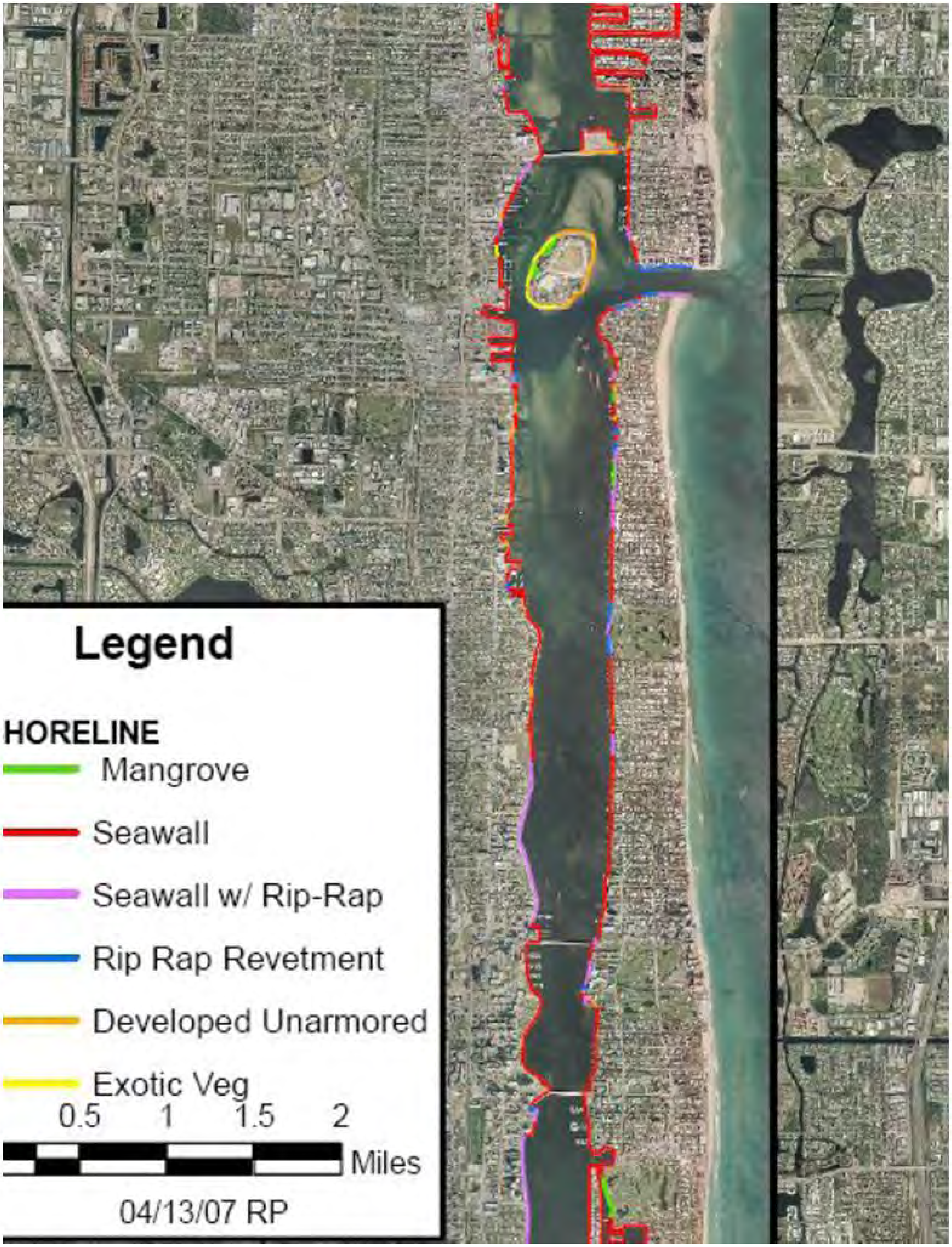


Figure 6. Map of shoreline habitat in 2001.

Water Quality of the Lake Worth Lagoon

Main Water Quality Issues

At present, water quality within the estuarine coastal areas of the Lake Worth Lagoon is highly variable. Generally, water quality is best in the vicinity of the tidal inlets, where tidal flushing and enhanced circulation occurs, but since World War II, water quality within the lagoon has been significantly affected by various drainage, dredging, and development projects. These projects have significantly altered the timing, distribution, quality, and quantity of fresh water that enters the coastal waterways. Water quality issues associated with stormwater or freshwater discharges to the Lake Worth Lagoon include low levels of DO from two tributaries (C-51 and C-17), nutrients, metals (copper, zinc, and lead), elevated bacterial levels, and turbidity (FDEP 2003).

Large volumes of freshwater discharges into the lagoon, primarily through the C-17, C-51, and C-16 Canals, cause extreme salinity fluctuations in the Lake Worth Lagoon. Many aquatic organisms, such as oysters and seagrasses, are unable to tolerate excessive freshwater inflows, which sometimes occur over relatively short periods following large rainfall events. Adult oysters typically occur in a salinity range between 10 and 30 parts per thousand (ppt), but they tolerate a range of 2 to 40 ppt (Gunter and Geyer 1995). Excessive freshwater inflows over a short time period can cause a sudden drop in salinity that can lead to significant mortality in the oyster population, and decreased growth, reproduction, and spat recruitment (CERP 2007a). Salinity fluctuations also affect seagrasses. Montague and Ley (1993) found that SAV biomass, including seagrasses, was directly proportional to salinity, with biomass decreasing as salinity variation increased (CERP 2007b). The canal discharges also have a significant suspended sediment load, which may smother SAV and oyster habitats.

Water Quality Monitoring Network

The Lake Worth Lagoon monitoring network has undergone several revisions since 1991, with stations added or discontinued, and there are few stations with relatively long datasets. Originally, the Lake Worth Lagoon Water Quality Monitoring Program consisted of 20 sampling stations in the 3 segments of the lagoon (north, central, and south) sampled monthly. Of these 10 original stations, 8 were located within the Lake Worth Lagoon proper, and 2 fixed stations were located at South Florida Water Management District (SFWMD) control structures or within tidally influenced canal confluences.

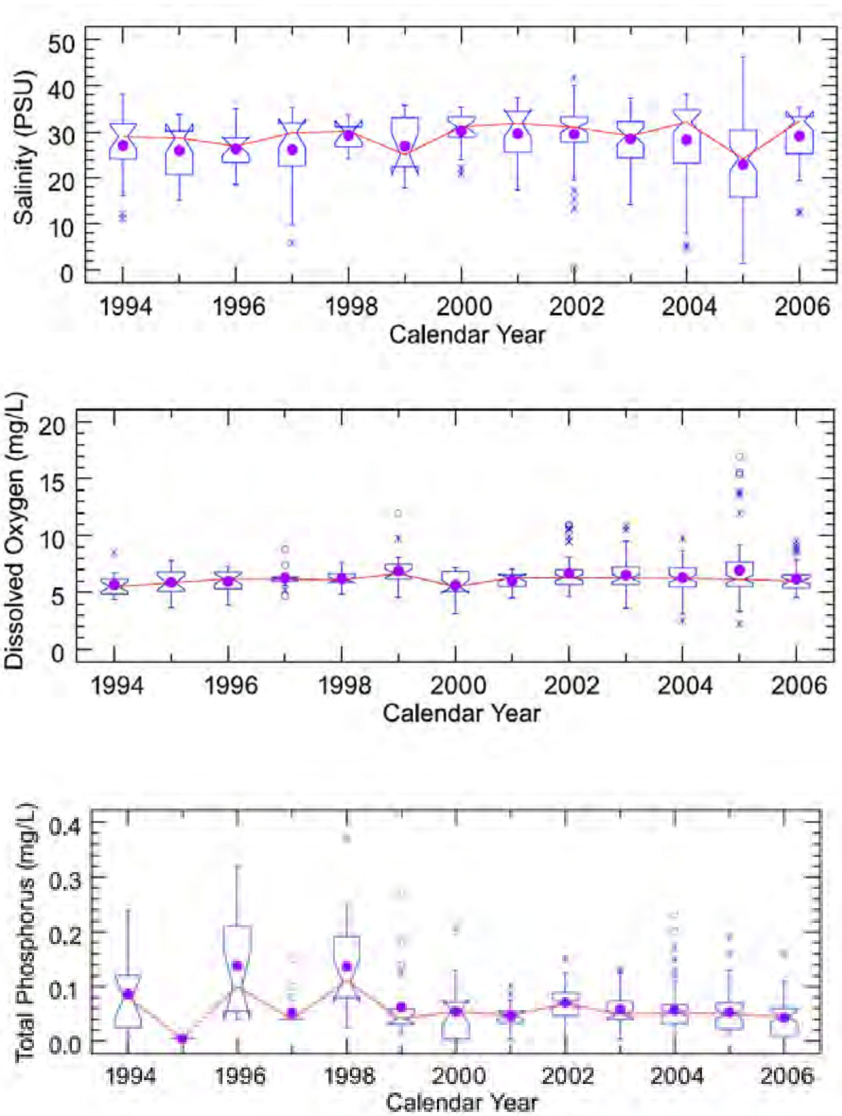
Twelve new stations have been added to the monitoring network (implemented in October 2007), for a total of 22 sites (Figure 7). Parameters analyzed monthly at the stations include DO, pH, salinity, total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH4), nitrite-nitrate nitrogen (NOx), total phosphorus (TP) and orthophosphorus (OPO4), turbidity, and chlorophyll *a*. Several metals, including arsenic (As), copper (Cu), cadmium (Cd), and lead (Pb) are also collected. Additionally, 5 high-frequency *in situ* sondes (multiparameter sampling units) are deployed to augment the monitoring network.

The SFWMD analyzed the water quality data using data retrieved from STORET, the hydrometeorologic database maintained by FDEP, and the PBCERM database. Samples taken before 1994 were collected irrespective of tidal cycle, and consequently samples before 1994 were excluded from the analysis. Data from 2001 to 2006 were also analyzed separately because there is higher confidence in data collected after 2001.

Figure 7. Lake Worth Lagoon sampling site locations and future monitoring locations.

Water Quality Results

The water quality data are presented in time series statistical box plots (Figure 8). Summary statistics for key parameters of interest such as nutrients, chlorophyll *a*, and DO are not available due to an issue with providing the raw data from the Lake Worth Lagoon Initiative database. Both monthly and yearly means were calculated and assessed to evaluate relationships between parameters and temporal trends. When multiple samples were collected within a given month, arithmetic means were calculated. Trends were evaluated using the nonparametric Seasonal Kendall Trend test, using the 12 months as individual seasons.



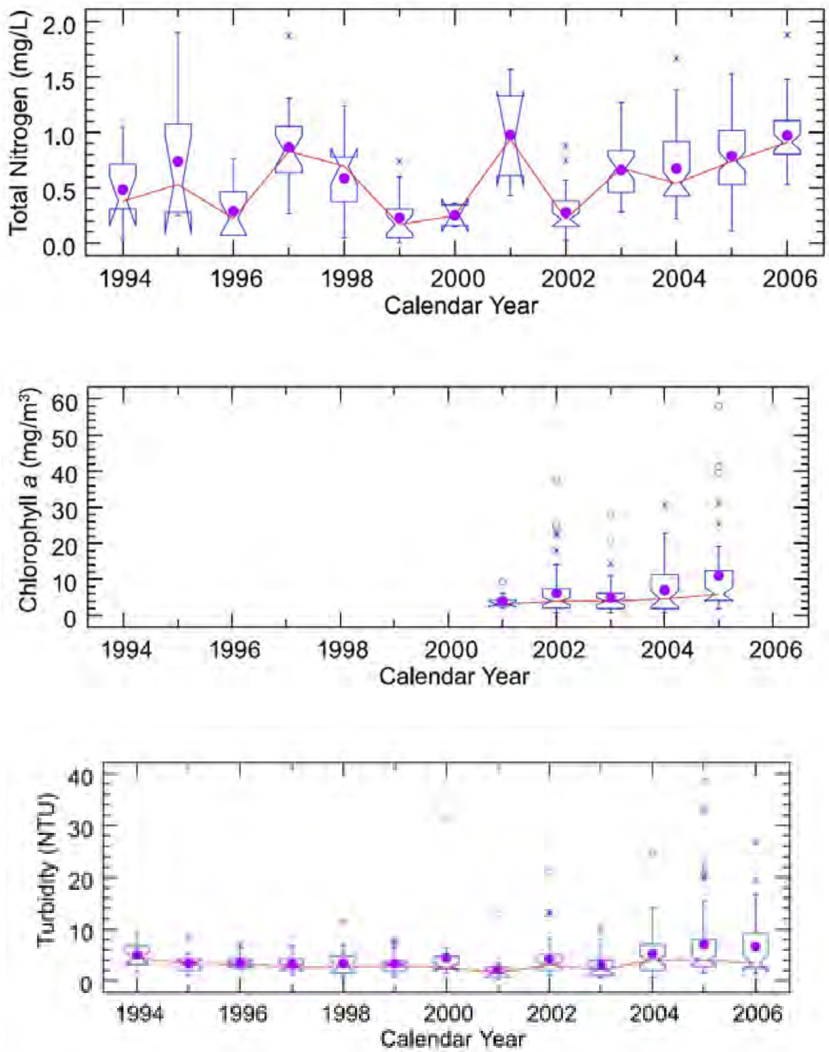


Figure 8. Box plots of salinity, DO, TP, TN, chlorophyll a, and turbidity in the Lake Worth Lagoon, 1994–2006.

As shown in Figure 8, salinity levels were dynamic. Salinity values are highly affected by canal freshwater inputs. During extreme storms, significant salinity reductions occur throughout the system.

DO was not a parameter of concern in the Lake Worth Lagoon, with mean and median concentrations of 5.8 and 6.0 mg/L, respectively. The surface water quality criteria for Class III marine waters (4.0 mg/L minimum and daily average of 5.0 mg/L) was met consistently, with a few exceptions.

The mean and median concentrations of TP were 0.138 and 0.067 mg/L, respectively, for the period of record (1994 to 2006). Mean and median TP concentrations from 2000 to 2006 were significantly lower, calculated to be 0.061 and 0.057 mg/L, respectively, and some of the higher values in the 1994 to 1999 dataset may not be valid (including a TP value of 22 mg/L).

The mean and median concentrations of TN from 1994 to 2006 were 0.83 and 0.72 mg/L, respectively. A statistically significant increase in TN was observed from 2002 to 2006, and may have resulted from the active hurricane season in 2004 and 2005.

The mean and median chlorophyll *a* levels for 2001 to 2006 were 4.4 and 3.2 µg/L, respectively. High chlorophyll *a* values (near 30 µg/L) were observed after hurricanes, when salinities in the estuary approached 1 PSU.

Mean and median turbidity concentrations were 4.6 and 3.1 NTU, respectively, although turbidity approached 40 NTU on occasion. Turbidity exhibited an increasing trend lagoon-wide from 2001 to 2006 that could potentially be related to high tropical storm/hurricane activity in this period.

Because the C-51 Canal plays a pivotal role in the water quality of the lagoon and is a focus of restoration efforts, the pair of water quality monitoring sites immediately above and below the canal mouth (Stations LWL 9 and LWL 11) were also assessed to better examine the effect of canal discharges. TN, TP, turbidity, salinity, and chlorophyll *a* at Stations LWL 9 and 11 were significantly related to discharges from the C-51 Canal at the S-155 structure (Table 5). TN and turbidity were significantly higher near the C-51 Canal. Salinity showed an inverse relationship with TN ($N=427$, $\rho=-0.555$, $P<0.001$), TP ($N=639$, $\rho=-0.261$, $P<0.001$), and turbidity ($N=691$, $\rho=-0.309$, $P<0.001$), suggesting that C-51 Canal discharges resulted in increases in these constituents. These effects were more pronounced as the distance to the C-51 Canal mouth decreased. DO, pH, or temperature were not found to be related to discharges from the canal (CERP 2007).

Table 5. Basic statistics of water quality constituents from the two sites adjacent to the canal mouth (adapted from CERP 2007a).

NTU = Nephelometric turbidity units
mg/L = Milligrams per liter

Statistic	Turbidity	Chlorophyll *a*	TN
Number of cases	**101**	**98**	**86**
Minimum	**.50 NTU**	**.82 µg/L**	**.15 mg/L**
Maximum	**16.00 NTU**	**59.15 µg/L**	**1.67 mg/L**
Mean	**6.24 NTU**	**9.60 µg/L**	**.77 mg/L**
Median	**6.00 NTU**	**6.30 µg/L**	**.76 mg/L**
25th percentile	**4**	**3.2**	**0.51**
75th percentile	**8**	**12.3**	**0.99**

References

Anderson, K. L., J. E. Whitlock, and V. J. Harwood. 2005. Persistence and differential survival of fecal indicator bacteria in subtropical waters and sediments. 2005. *Appl. Environ. Microb. 71:3041–3048.*

Applied Technology and Management, Inc. 1995. *Lake Worth Inlet management plan.*

Archaeological and Historical Conservancy and Sea System Corp. 1994. *A Phase I archaeological and historical assessment of Munyon Island, Palm Beach County, FL.*

Bonadonna, L., R. Briancesco, M. Ottaviani, and E. Veschetti. 2002. Occurrence of Cryptosporidium oocysts in sewage effluents and correlation with microbial, chemical and physical water variables. *Environ. Monit. Assess. 75:241–252.*

Bortone, S.A. 2000. *Seagrasses: Monitoring, ecology, physiology, and management.* Boca Raton, FL: CRC Press.

Braun, R.A. 2006. Modeling a seagrass restoration target for an urbanized Florida estuary. *2006 ESRI international user conference proceedings.*

Byappanahalli, M. N., and R. S. Fujioka. 1998. Evidence that tropical soil environment can support the growth of *Escherichia coli*. *Water Sci. Technol. 38:171–174.*

Byappanahalli, M. N., D. A. Shively, M. B. Nevers, M. J. Sadowsky, and R. L. Whitman. 2003. Growth and survival of *Escherichia coli* and enterococci populations in the macro-alga Cladophora (*Chlorophyta*). *Fems Microbiol. Ecol. 46:203–211.*

Coastal Planning and Engineering, Inc. 1998. *South Lake Worth Inlet management plan.*

Coen, L. D., M. W. Luckenbach, and D. L. Breitberg. 1999a. The role of oyster reefs as essential fish habitat: A review of current knowledge and some new perspectives. *American Fisheries Society Symposium 22: 438-454.*

Coen, L. D., D. M. Knott, E. L. Wenner, N. H. Hadley, A. H. Ringwood, and M. Y. Bobo. 1999b. Intertidal oyster reef studies in South Carolina: Design, sampling and experimental focus for evaluating habitat value and function. *In:* M.W. Luckenbach, R. Mann, and J. A. Wesson (Eds.), *Oyster reef habitat restoration: A synopsis and synthesis of approaches* (Proceedings from the symposium, Williamsburg, Virginia, April 1995, pp. 133-158).

Crigger, D.K., G.A. Graves, and D.L. Fike. 2005. Lake Worth Lagoon conceptual ecological model. *Wetlands 25(4): 943–954.*

Clean Water Fund (CWF). 2006. *Are we still wading in waste?* 2006 Florida sewage overflow follow-up report. Prepared by the Clean Water Fund.

Comprehensive Everglades Restoration Plan. 2006. *Restoration Coordination and Verification Program (RECOVER) system status report. Northern estuaries module.* U.S. Army Corps of Engineers, Jacksonville District, Jacksonville, FL, and South Florida Water Management District, West Palm Beach, FL.

———. 2007a. *Restoration Coordination and Verification Program (RECOVER), Northern estuaries oyster habitat performance measure.* System-wide performance measure documentation sheet. Revised February 28, 2007. U.S. Army Corps of Engineers, Jacksonville District, Jacksonville, FL, and South Florida Water Management District, West Palm Beach, FL.

———. 2007b. *Restoration Coordination and Verification Program (RECOVER), Northern estuaries submerged aquatic vegetation assessment.* System-wide performance measure documentation sheet. Revised February 27, 2007. U.S. Army Corps of Engineers, Jacksonville District, Jacksonville, FL, and South Florida Water Management District, West Palm Beach, FL.

Florida Department of Environmental Protection. 2003. *Water quality status report: Lake Worth Lagoon–Palm Beach Coast.* Tallahassee, FL: Division of Water Resource Management.

———. 2004. *Letter to Palm Beach County Department of Environmental Resources Management*, *September 15, 2004.*

———. 2007. *South Florida Water Quality Protection Program.* Available: http://www.dep.state.fl.us/southeast/WRMEP/wqpp/wqpp.htm.

Gunter, G., and R.A. Geyer. 1955. Studies of fouling organisms in the northeastern Gulf of Mexico. *Publ. Inst. Mar. Sci. Univ. Tex. 4(1):39-67.*

Hamrick, J.M. 1992. *A three-dimensional environmental fluid dynamics computer code: Theoretical and computational aspects.* College of William and Mary, Virginia Institute of Marine Science, Special Report 317.

Hamrick, J.M., and T.S. Wu. 1996. *Computational design and optimization of the EFDC/HEM3D Surface Water Hydrodynamic and Eutrophication Models. Computational methods for the Next Generations Environmental Models.* U.S. Environmental Protection Agency (EPA), National Environmental Supercomputer Center.

Harris, B., K.D. Haddad, R.A. Steinger, and J.A. Huff. 1983. *Assessment of fisheries habitat: Charlotte Harbor and Lake Worth.* Tallahassee, FL: Florida Department of Natural Resources.

Harwood, V. J., A. D. Levine, T. M. Scott, V. Chivukula, J. Lukasik, S. R. Farrah, and J. B. Rose. 2005. Validity of the indicator organism paradigm for pathogen reduction in reclaimed water and public health protection. *Appl. Environ. Microb. 71:3163–3170.*

Ishii, S., W. B. Ksoll, R. E. Hicks, and M. J. Sadowsky. 2006. Presence and growth of naturalized *Escherichia coli* in temperate soils from Lake Superior watersheds. *Appl. Environ. Microb. 72:612–621.*

Jeng, H. W. C., A. J. England, and H. B. Bradford. 2005. Indicator organisms associated with stormwater suspended particles and estuarine sediment. *J. Environ. Sci. Heal. A 40:779–791.*

Ksoll, W. B., S. Ishii, M. J. Sadowsky, and R. E. Hicks. 2007. Presence and sources of fecal coliform bacteria in epilithic periphyton communities of Lake Superior. *Appl. Environ. Microb. 73:3771–3778.*

Lemarchand, K., and P. Lebaron. 2003. Occurrence of Salmonella spp. and Cryptosporidium spp. in a French coastal watershed: Relationship with fecal indicators. *Fems Microbiol. Lett. 218:203–209.*

Lietz, A.C., and E. Debiak. 2005. *Development of rating curve estimators for suspended-sediment concentration and transport in the C-51 Canal based on surrogate technology, Palm Beach County, Florida, 2004-05.* U.S. Geological Survey.

Lund, V. 1996. Evaluation of E-coli as an indicator for the presence of Campylobacter jejuni and Yersinia enterocolitica in chlorinated and untreated oligotrophic lake water. *Water Res. 30:1528–1534.*

MacDonald, D. D. 1994. *Approach to the assessment of sediment quality in Florida coastal waters.* Tallahassee, FL: Florida Department of Environmental Protection.

National Research Council. 1985. *Committee on oil in the sea: Inputs, fates, and effect.* Washington DC: National Academy Press.

Palm Beach County. 1989. *Palm Beach County comprehensive plan.* As amended in October 2002 (Ordinance 2002-51) and December 2004 (text amendment staff report, amended round 04-2).

———. *Palm Beach County mangrove and seagrass mapping project.* 2007, Final report prepared by Avineon, Inc.

———. 2003. *National Pollutant Discharge Elimination System (NPDES) Program.* Available: http://www.pbconpdes.org.

Palm Beach County Department of Environmental Resources Management (PBCERM). 1992. *Estuarine natural resources inventory and resource enhancement study.*

———. 2002. *Lake Worth Lagoon seagrass mapping project.*

———. 2003. *Lake Worth Lagoon bathymetric survey.* Prepared by Morgan and Eklund, Inc.

———. 2004a. *Lake Worth Lagoon pollutant load reduction determination.* Prepared by Miller Legg.

———. 2005a. *Seagrass monitoring in Lake Worth Lagoon.* Final report prepared by Applied Technology and Management, Inc.

———. 2005b. *Preliminary evaluation of dredge hole depressions in Lake Worth Lagoon: Habitat utilization by fishes and macrobenthos.* Final report prepared by the Florida Fish and Wildlife Conservation Commission (FWCC) Fish and Wildlife Research Institute (FWRI). Tequesta, FL.

———. 2006. *Palm Beach County manatee protection plan.* Final report prepared by the Catanese Center for Urban and Environmental Solutions, Florida Atlantic University (FAU). Ecological Associates, Inc.

———. 2007. *Lake Worth Lagoon Partnership Grant Program—10 years of restoration, 1998–2007.*

Palm Beach County Department of Environmental Resources Management and Dames and Moore. 1990. *Lake Worth Lagoon natural resources inventory and resource enhancement study.*

Palm Beach County Department of Environmental Resources Management and Florida Department of Environmental Protection, Southeast District. 1998. *Lake Worth Lagoon management plan.*

———. 2003. *Lake Worth Lagoon monitoring project, final report.*

Port of Palm Beach. 2006. *Port of Palm Beach master plan 2005–2015.* Report prepared by CH2M HILL, The Four Gates Company, and John C. Martin Associates.

Rees, G., K. Pond, K. Johal, S. Pedley, and A. Rickards. 1998. Microbiological analysis of selected coastal bathing waters in the UK, Greece, Italy and Spain. *Water Res. 32:2335–2340.*

Smith, S.K., and J.M. Nogle. 2002. Projects of Florida population by county, 2001–2030. University of Florida Bureau of Economic and Business Research. *Florida Population Studies 35 (2), Bulletin 132.*

Solo-Gabriele, H. M., M. A. Wolfert, T. R. Desmarais, and C. J. Palmer. 2000. Sources of *Escherichia coli* in a coastal subtropical environment. *Appl. Environ. Microb. 66:230–237.*

Souza, V., M. Rocha, A. Valera, and L. E. Eguiarte. 1999. Genetic structure of natural populations of Escherichia coli in wild hosts on different continents. *Appl. Environ. Microb.65:3373–3385.*

Tomasello, R. 1996. *Lake Worth hydrodynamic salinity model.* Consulting Engineers, Inc. and Coastal Planning and Engineering.

Topp, E., M. Welsh, Y. C. Tien, A. Dang, G. Lazarovits, K. Conn, and H. Zhu. 2003. Strain-dependent variability in growth and survival of *Escherichia coli* in agricultural soil. *Fems Microbiol. Ecol. 44:303–308.*

Trefry, J.H., R. P. Trocine, S. Metz, N. Iricanin, and N-C. Chen. 1989. *Particulate nutrient and metal investigations in the Turkey Creek watershed.* Final report to the St. Johns River Water Management District. Special Publication SJ 90-SP2. Florida Institute of Technology, Melbourne, FL 32901.

Trefry, J.H., S. Metz, R. P. Trocine, N. Iricanin, D. Burnside, N-C. Chen, and B. Webb. 1990. *Final report to the St. Johns River Water Management District.* Special Publication SJ 90-SP3. Florida Institute of Technology, Melbourne, FL 32901.

Whitman, R. L., D. A. Shively, H. Pawlik, M. B. Nevers, and M. N. Byappanahalli. 2003. Occurrence of *Escherichia coli* and enterococci in *Cladophora* (*Chlorophyta*) in nearshore water and beach sand of Lake Michigan. *Appl. Environ. Microb. 69:4714–4719.*

Appendix B: Data Quality Assessment of the LAKEWATCH Program in the Lake Worth Lagoon 1993 – 2002

By FDEP Water Quality Standards Program

Introduction

This document summarizes the Data Quality Assessment conducted for data included in the IWR Run 47 from LAKEWATCH from 1993 to 2002. The criteria used for this assessment are provided in the DEP Quality Assurance (QA) Rule (Rule 62-160.670, FAC, Data Validation by the Department), which is consistent with the EPA guidance document (QA-G8), *Guidance on Environmental Data Verification and Data Validation* (EPA 2002). Information sources for assessment findings included laboratory SOPs, peer reviewed literature, the DEP QA archive for the University of Florida(UF)/IFAS/Department of Fisheries and Aquatic Sciences Comprehensive QA Plan (CompQAP) 910157, and an interview with the laboratory director (Mark Hoyer, 4/30/13) and the laboratory's chemist (Claude Brown, 9/4/12-9/5/12). Because these data were initially collected for research purposes and FDEP did not oversee the projects through the years, FDEP reviewed the field and lab procedures for the program, and conducted two data comparisons between data produced by the LAKEWATCH lab and the FDEP lab. In addition, the FDEP Quality Assurance staff are working through the process to approve several alternative procedures used by the LAKEWATCH lab. An assessment of how the field and lab procedures meet FDEP requirements is provided in the first portion of this document, and results of data comparisons are described in the second portion.

QA and Data Validation Process

Pursuant to the Quality Assurance (QA) Rule, Chapter 62-160, Florida Administrative Code, FDEP has the authority to conduct audits in support of program-specific use of data (see Rule 62-160.650, F.A.C., Field and Laboratory Audits). DEP staff may audit sampler performance at the time of sample collection and visit laboratories to assess analytical operations. For both on-site audits and off-site records audits, documentation is inspected for conformance with requirements found in the QA Rule, the DEP SOPs, and the NELAC/TNI standards. Regulated parties and contractors, as well as consultants, local governments and DEP work units, are all subject to audits, and must provide all information necessary to reconstruct sampling events and laboratory analyses. FDEP may require corrective action responses for specific findings reported as the result of audits.

The QA Rule also authorizes FDEP to verify and validate data used by its programs for specific usability assessments (see Rule 62-160.670, F.A.C., Data Validation by the Department). This assessment includes evaluation of sample collection, preservation and handling; laboratory certification, analysis methodology, analytical sensitivity, instrument calibration and quality control; and attainment of any specific data quality objectives identified for the project or program. Data records are evaluated for completeness and internal linkage by tracking specific samples through the record set to reconstruct the sampling and/or analytical process that produced the sample results. Further detail about the usability assessment process is provided in the FDEP document, "Process for Assessing Data Usability", DEP-EA-001/07, which is incorporated into the QA Rule requirements.

While the QA Rule provides the authority to conduct audits and perform data validations, the FDEP Quality Assurance staff, due to resource limitations, typically only perform or assist with audits and data validations at the request of FDEP program or project managers, or when specific concerns about data generators or data sets otherwise arise. Other work units in FDEP may also perform audits for specific usability purposes. At the conclusion of audits or data validations, FDEP auditors may also make recommendations as to the usability of the audited data for specific purposes (e.g., usability recommendations for the use of analyte-specific data from designated timeframes for the assessment of waterbodies under the Impaired Waters Rule may be provided to the FDEP Watershed Assessment Section).

For the LAKEWATCH data quality review, FDEP staff conducted phone interviews and met with project and lab staff to learn about methods, procedures, and quality control measures. By these means, FDEP conducted a process audit for LAKEWATCH data production. FDEP did not conduct field, lab, or records audits.

Findings

These data were originally generated by UF parties for research purposes, and not for numeric nutrient criteria development or impaired waters assessment. However, the following findings of data quality procedures provide reasonable assurance that the specified data generated during the indicated data periods of record meet FDEP data quality objectives for use in the development of numeric nutrient criteria.

FDEP did not request a data package because of the extremely short timeframe for numeric nutrient criteria development. Reconstruction of sampling and analysis events was performed by interviewing the LAKEWATCH laboratory director (Mark Hoyer, 4/30/13), who is involved with the collection, analysis, staff training, and quality control procedures associated with the entity. Assessment of these secondary-use data is therefore limited to a review of the quality assurance planning and guidance documents in effect at the time of sample collection and laboratory analysis, as corroborated by the above interviews. The DEP QA rule criteria listed at 62-160.670 (Data Validation by the Department) were used as a guide for the secondary-use review. The following sections contain detailed information about field and lab methods, as well as quality control activities.

Integrity of Samples

Samplers fill out a data sheet with sampling information and unique observations pertinent to the waterbody on that day, including waterbody name and location (lat-long), date, county, station identifier, weather conditions, etc. This field sheet is maintained with the samples and included during delivery of the samples to the laboratory, where the information is transferred to the Laboratory Information Management System (electronic spreadsheets) and maintained throughout all laboratory processing, and later, is archived. This is consistent with QA rule requirements.

Sample Collection Procedures

All samplers are trained to follow DEP sampling SOPs (although there are modified preservation methods and holding times for nutrients), followed by an internal audit to demonstrate proficiency. LAKEWATCH volunteers collect direct grab samples in plastic sample bottles that are acid-washed in the lab and rinsed in the field before sample collection. Samples for TN and TP are placed in ice, chlorophyll *a* samples are filtered in the field immediately after sample collection, and then TN and TP samples and chlorophyll *a* filters are frozen upon receipt by the lab.

One modification from the DEP SOPs is the use of freezing as a sample preservation method for total nitrogen (TN) and total phosphorus (TP). DEP SOP FS 1000 requires TN and TP samples to be acidified and then analyzed within 28 days. For LAKEWATCH, samples are frozen and then analyzed within five months. Canfield *et al*. (2002) showed that freezing was equivalent to acidification as a preservation method for TN and TP. The laboratory compared TP and TN results from 125 water samples that were frozen and held up to 150 days with results from 125 water samples that were preserved according to DEP SOPs. All statistical tests showed that freezing was an equivalent means of preserving samples (Canfield *et al.* 2002). An additional sample comparison between the LAKEWATCH lab and the FDEP Tallahassee lab supported that conclusion (see second part of this document). FDEP Quality Assurance staff are preparing the documentation for approval of this alternative preservation method as used by the LAKEWATCH laboratory, as limited use approvals, under Chapter 62-160.220, F.A.C. (anticipated approval during summer 2013).

Analyses Procedures

Analysis for TN, TP, and chlorophyll *a* for LAKEWATCH are conducted in the lab overseen by Dr. Dan Canfield and Mr. Mark Hoyer. The quality assurance procedures for these labs were approved by FDEP for the years 1994-2000 under Comprehensive QA Plan (CompQAP) 910157 for the University of Florida (UF)/IFAS/Department of Fisheries and Aquatic Sciences. FDEP ended the requirement for CompQAP approval in 2002. Updates to lab methodology for TN and TP are available in the Florida LAKEWATCH SOP, for which the most recent version is dated February 2013 (LAKEWATCH 2013).

Total Phosphorus

Samples are digested using an autoclave and a persulfate digestion following the methods of Menzel and Corwin (1965). For sample oxidation, 25 ml of sample are placed in a labeled, screw-capped test tube, and 4 ml of oxidizing reagent (5.2 g potassium persulfate dissolved per 100 ml DI water) is added. Tubes are then capped, inverted, and autoclaved at 15 psi at 121 C for 30 minutes. Pressure is brought down slowly and samples are allowed to cool to room temperature before measurement of TP is made. All blanks, standards, and samples are treated in the same way.

The following standards are made according to current standard methods (APHA 2005) to develop an absorbance versus TP concentration curve used in calculating concentrations of samples based on absorbance: blanks and known concentrations of phosphorus at 0.005, 0.01, 0.05, 0.1, 0.2, 0.4, and 0.6 mg/L. TP stock solution is made from Hach phosphorus standard solution Certified ACS (KH2PO4). TP standards are generated from 10 mL of Hach standard dissolved in 1000 ml DI water, giving a concentration of 10mg/L TP stock, which are used to make the various known concentrations.

TP concentrations are measured with the colormetric procedures of Murphy and Riley (1962). Sample absorbance is determined at a wavelength of 882 nm after being inoculated with 4 ml of mixed coloring reagent. Mixed coloring reagent is composed of 5N sulfuric acid, ammonium molybdate, ascorbic acid, and antimony potassium tartrate. Sample absorbance is determined using a Perkin-Elmer Lambda 2 dual beam spectrophotometer with 50 mm Hellman cylindrical (16 mL) reference and sample cells. Readings outside the calibration range are brought back into range by re-pouring original samples and diluting with deionized water for reanalysis.

Total Nitrogen

Samples are prepared using an autoclave with a persulfate digestion and then nitrate-nitrogen is determined with second derivative spectroscopy (D'Elia et al. 1977; Simal et al. 1985; Wollin 1987; Crumpton et al. 1992; Bachmann and Canfield 1996). This method was approved by FDEP for use by the Canfield lab in 1991 (Appendix 2 of the CompQAP).

For sample oxidation, ten ml of sample are placed in a labeled, screw-capped test tube, and 1.5 ml of oxidizing reagent (6.0 g low-nitrogen potassium persulfate dissolved per 100 ml 1.5 N sodium hydroxide) is added to each tube. Tubes are capped, inverted, and autoclaved at 15 psi at 121 C for 30 minutes. Pressure is brought down slowly and samples are allowed to cool to room temperature before measurement of nitrate nitrogen is made. All blanks, standards, and samples are treated in the same way. For measurement of nitrate nitrogen, all blanks, standards, and samples are acidified to $pH < 2.0$ with 0.2 ml of concentrated sulfuric acid per 10 ml sample prior to measurement.

LAKEWATCH uses a Perkin-Elmer Lambda 25 dual beam spectrophotometer with 10 mm, 3.0 mL, Suprasil quartz windows spectrophotometer reference and sample cells. Project COAST also uses a UV Windlab software program that scans from 190 nm to 290 nm looking for a peak absorbance around 220 nm.

The following standards are made according to current standard methods (APHA 2005) to develop an absorbance versus TN concentration curve to use in calculating concentrations of samples based on absorbance: 3 blanks, 3 sets of known concentrations of N at 0.1, 0.25, and 0.5 mg/L, and 2 sets of known concentrations 0.75, 1.0, 1.5, and 2.0 mg/L. TN stock solution is made from urea standard stock Certified ACS (NH2CONH2). TN standards are generated from 1072 g urea dissolved in 1000 ml DI water giving a concentration of 50 mg/L urea stock used to make the various known concentrations. Averaged values are determined from the multiple sets of known concentrations to generate the linear regression. Readings outside the calibration range are brought back into range by re-pouring original samples and diluting with deionized water for reanalysis.

Chlorophyll a

Chlorophyll *a* analyses are conducted in the LAKEWATCH lab following Method SM10200 H.2. (APHA 2005) with the heated ethanol extraction method (Sartory and Grobbelaar 1984).

For chlorophyll analysis, filters are removed from desiccant storage bottles and sorted by county, waterbody, date, and station. Laboratory Technicians examine the condition of sample filters and desiccant, and look for any missing label information or discrepancies. They ensure that samples were frozen before analysis and that the analytical instruments are functioning properly. Notes are taken and forwarded to the laboratory Chemist/Manager to be stored in file folders for later reference. Similar to TP and TN, the procedures for chlorophyll involve creating a spreadsheet of results used to track individual filter results through the laboratory.

After spreadsheets are prepared, individual filters are placed in sequentially numbered screw cap centrifuge tubes used for chlorophyll extraction. Eight mL of 90% ethanol is pipetted into each tube and then capped. Each tube is inspected to make sure the entire filter is covered with ethanol. One rack of tubes is placed in hot water bath at 78° C and timed for 5 minutes after reaching temperature. The rack of samples is removed and wrapped in a dark bag and allowed to stand for 24 hours before reading absorbance on a spectrophotometer (Sartory and Grobbelarr 1984). Before centrifuging samples, filters are removed and samples are centrifuged for 20 min at 2,000 rpm to separate the filtrate from any precipitate. Ethanol method blanks are routinely analyzed. After samples are centrifuged, an aliquot of 3.2 ml of sample is transferred to a glass screw capped test tube with the corresponding number label. This sample is used to determine the absorbance readings at 750 nm and 664 nm. The sample is then poured back into the glass tube and recapped. After the entire set of samples has been measured, 100 μL of 0.1 N HCL is pipetted into the first test tube, a 90 second timer is started, and the contents of the acidified sample are poured into the cuvette and placed into the holding cell in the spectrophotometer. After the timer goes off, the acidified sample is used to determine absorbance readings at 750 nm and 665 nm to determine chlorophyll a in the presence of pheophytin.

LAKEWATCH uses a Hitachi Digilab U-2810 double-beam spectrophotometer that can use either 1 cm or 4 cm path length cuvette sample cells. UV Solutions software (Hitachi) is used to manage the data and perform calculations for chlorophyll analysis (including absorbance values for both unacidified [664 nm] and acidified [665 nm] samples). All test measurements and chlorophyll readings are printed and stored. LAKEWATCH began correcting for phaeophytin in 2012.

Pheophytin corrected chlorophyll concentrations are calculated using standard methods (Method 10200 H; A.P.H.A. 2005). Calculated concentrations are evaluated based on data sheets and lab notes in hard copy files related to status of samples received. This check is to ascertain if sample filters were not in approved desiccant, or if there is any extenuating reason to flag results. Concentrations are entered into the data file.

The procedures are sound and consistent with the intent of the QA rule, especially considering the paired sample comparison below. The hot ethanol pigment extraction is not currently on the FDEP list of approved preparation procedures for chlorophyll *a* analysis; however, FDEP Quality Assurance staff are in the process of approving that alternative method as a limited use approval under Chapter 62-160.330, F.A.C. (anticipated approval during summer 2013).

Quality Control Measures

The LAKEWATCH laboratory routinely calibrates instruments for nutrient analyses with a series of standards, and conducts a calibration/verification for every 40 samples processed. Spiked samples and blanks are analyzed every 40 samples processed to determine analyte recovery (accuracy) and ensure that artificial contamination is not present. Measurement repeatability (precision) is assessed by running duplicates. For the chlorophyll spectrophotometer, a Wavelength Accuracy Test, a Baseline Flatness Test, and a Spectrum Bandwidth Test are conducted prior to running each batch of samples. Additionally, samples are individually evaluated to determine if they are within three standard deviations of historic measurements, and are reanalyzed if they exceed this threshold. Method Detection Limits have been determined for TP and TN, with MDLs of 1.3 µg/L and 34 µg/L, respectively. The chlorophyll MDL is 1 ug/L. These quality control measures are consistent with QA rule requirements.

Data qualifiers have historically not been used in the LAKEWATCH laboratories. Their approach is to re-analyze samples if results are outside of expected ranges, based on historical data, or if instrument calibration drifts by more than 10% (LAKEWATCH 2013). The MDLs are sufficiently low that results are rarely below it, so there is likely a small proportion of data that need to be qualified. Statistical summaries of COAST (a marine program for which TN and TP analyses are conducted in the LAKEWATCH lab) datasets were comparable to other datasets (see later sections of this Appendix), so the overall effect of missing qualifiers was determined to be negligible.

Calibration and Verification

As required by the QA Rule and standards cited therein, instruments for nutrient analyses are calibrated with a series of known standards to ensure instrument response is correlated with the standards at a coefficient of determination of > 0.995. Every 40 samples, a known standard is run as a sample to verify the calibration relationship has not drifted. If the instrument drift is greater than 10%, all samples in that batch are reanalyzed.

Documentation

All processes, including field procedures, sample preparation, sample analyses, data calculations, quality control checks, and corrective action are documented and the records have been retained since 2002. Some records (e.g., field sheets) are available as hard copies, but many records are available as computer files. The records enable linking all results to field collection information, such as sampling date, station, sampler, and analyte. Before 2002, procedures were done in accordance with the FDEP-approved CompQAP. This is consistent with QA rule requirements.

LAKEWATCH Lab and FDEP Paired Sample Comparison

Predominantly Marine Comparison

FDEP conducted a comparison sampling analysis between its laboratory in Tallahassee and the labs used by Project COAST, a marine sampling program directed by the University of Florida. The LAKEWATCH lab analyses the TN and TP samples for Project COAST, so those portions of that comparison were used as part of the quality demonstration for marine LAKEWATCH data. In the LAKEWATCH program, volunteers collect samples and the samples may be frozen for up to five months, whereas the COAST samples are collected by professional staff and are frozen for up to two months. Canfield *et al*. (2002) and Hoyer *et al.* (2012) showed that sample collection by volunteers and analysis after a 2-5 month period of freezing yielded statistically similar results to sample collection strictly following DEP SOPs.

Grab samples were collected in duplicate by FDEP Coastal and Aquatic Managed Areas (CAMA) staff at ten sites at each of the following systems: Withlacoochee Estuary, Crystal River Estuary, and Homosassa Estuary (CAMA staff typically collect samples for these systems in cooperation with Project COAST). Samples were collected from Crystal River on 7/20/10, Homosassa on 7/22/10, and from Withlacoochee on 7/27/10. Duplicate samples were collected such that one sample set was treated as usual, with samples sent to the Project COAST labs at the University of Florida (UF), and one sample set was preserved per FDEP SOPs and sent to the FDEP Central Laboratory in Tallahassee for analysis (where TN was calculated as the sum of NO_{2+3} and TKN). TN and TP analyses for Project COAST are conducted by the LAKEWATCH Lab.

FDEP performed regressions between FDEP and COAST results for each analyte using an orthogonal fit (equal variance model) because it adjusts for variability in both dependant and independent variables; it is equivalent to the non-standardized first principal component line. This analysis approach is valid because distributions of FDEP and COAST values have similar variances for all analytes (Table 1). FDEP also compared COAST and FDEP results as paired samples using the two-tailed paired t-test for TN and TP. For these tests, FDEP used the full dataset with results as reported, and again after removing stations for which the FDEP result was less than the method detection limit (MDL) because FDEP MDLs are higher than COAST MDLs for all analytes. The relative percent difference (RPD) for each sample pair was calculated as the difference between the two results divided by the average of the two results. The RPD is commonly used in labs to evaluate results of duplicate analyses. All statistics were conducted with JMP software, and $p < 0.05$ was considered statistically significant.

Results of the regressions between COAST and FDEP indicated very similar results between entities, with correlation coefficients of 0.79 and 0.92 for TN and TP, respectively (Table 1, Figures 1 and 2). Paired t-tests indicated no significant difference between datasets for TN or TP (Table 2).

For 21 of the 28 sample pairs for which TP was greater than the MDL (FDEP results), the RPD for TP was less than or equal to the acceptable lab duplicate limit of 20 percent (FDEP 2008), and the remaining seven had RPD values ≤ 49%. For 24 of the 30 sites for which TKN was greater than the MDL (FDEP results), the RPD for TN was less than or equal to the acceptable lab duplicate limit of 20 percent, and RPD values for the remaining six sites were ≤ 44%.

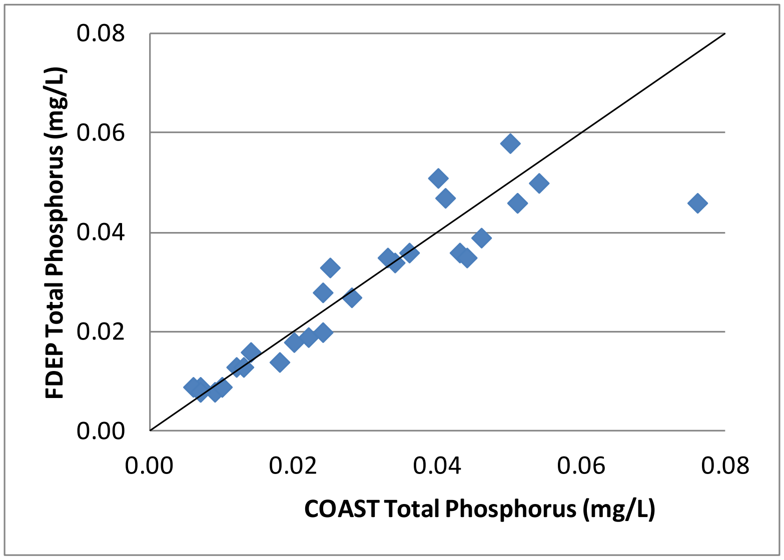


Figure 1. Relation between Total Phosphorus concentrations collected and analyzed by Florida Department of Environmental Protection (FDEP) methods and Total Phosphorus concentrations collected by Project COAST and analyzed by the LAKEWATCH Lab. Data are from 30 predominantly marine sites sampled in July 2010. The solid line represents the 1:1 line.

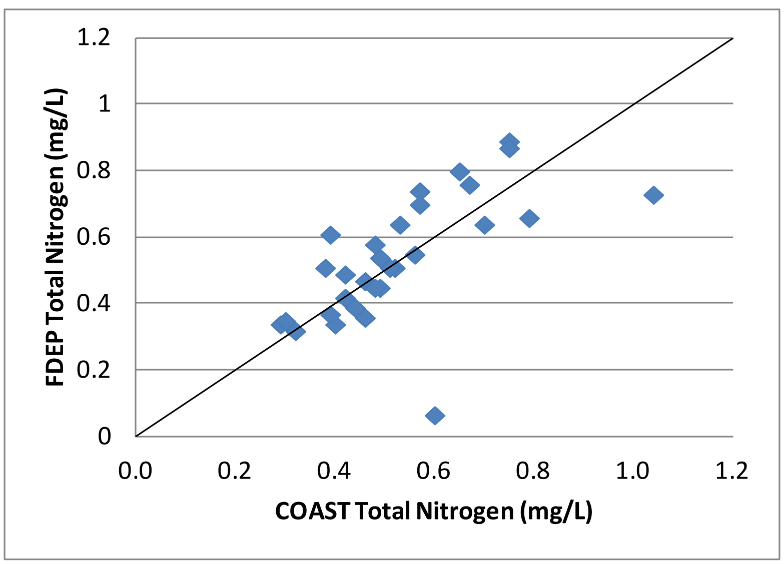


Figure 2. Relation between Total Nitrogen concentrations collected and analyzed by Florida Department of Environmental Protection (FDEP) methods and Total Nitrogen concentrations collected by Project COAST and analyzed by the LAKEWATCH Lab. Data are from 30 predominantly marine sites sampled in July 2010. The solid line represents the 1:1 line.

Table 1. Results of regression analysis with orthogonal fit comparing LAKEWATCH (UF) and Florida Department of Environmental Protection (DEP) lab results for total nitrogen (TN) and total phosphorus (TP).

Analyte	Mean UF	Mean DEP	Std Dev UF	Std Dev DEP	Correlation Coefficient	Intercept	Slope	95% Confidence Interval of Slope

					(Pearson's r)			
TN (µg/L)	527	555	164	165	0.79	-24	0.99	0.73-1.35
TP (µg/L)	28.5	27.3	18.1	15.9	0.92	-2.98	1.15	0.98-1.36

Table 2. Results of paired t-tests comparing LAKEWATCH (UF) and Department of Environmental Protection (DEP) lab results for total nitrogen (TN) and total phosphorus (TP). Sample pairs for which DEP results were below the detection limit were not included in these tests.

	N	Mean Value_UF	Mean Value_DEP	Mean Difference	Std. Error Difference	t-statistic	Probability (2-tailed)
TN (µg/L)	30	527	555	-28	19	-1.44	0.1597
TP (µg/L)	28	30.0	28.7	1.3	1.39	0.95	0.3514

Predominantly Fresh Comparison

FDEP also conducted a comparison sampling analysis between its laboratory in Tallahassee and the LAKEWATCH lab at LAKEWATCH lakes. For the LAKEWATCH component, this comparison involved volunteer samplers and the longer freezing times, but was for a fresh water matrix.

Between September and November 2011, FDEP biologists and LAKEWATCH volunteers sampled 27 Florida lakes across a gradient of nutrient concentrations. FDEP and LAKEWATCH collected surface water samples from the same lake on the same day, with FDEP obtaining three replicate samples from one station and LAKEWATCH samplers sampling three stations spatially on each lake. FDEP personnel collected samples for total phosphorus (TP), total Kjeldahl Nitrogen (TKN), nitrite+nitrate nitrogen (NO_2-N+NO_3-N), and chlorophyll *a* (both uncorrected and corrected for phaeophytin) concentrations. LAKEWATCH volunteers collected samples for TP, total nitrogen (TN), and chlorophyll *a* (uncorrected for phaeophytin). FDEP's TKN and NO_2-N+NO_3-N were added together for comparison to LAKEWATCH's total nitrogen values. See Hoyer *et al* (2012) for a full description of methods and results.

LAKEWATCH field collections and laboratory analyses followed the methods of LAKEWATCH (2013). FDEP field methods followed FDEP field SOPs (http://www.dep.state.fl.us/water/sas/sop/sops.htm). FDEP laboratory methods followed FDEP internal lab SOPs (http://www.dep.state.fl.us/labs/library/lab_sops.htm).

Results of the comparison between LAKEWATCH and FDEP indicated very similar results between entities, with coefficients of determination (R^2) of 0.97, 0.90, and 0.97 for TP, TN, and chlorophyll *a*, respectively (Figures 3-5; Hoyer et al. 2012). Paired t-tests indicated no significant difference between datasets for TN or chlorophyll *a*, but showed a significant but small difference of 1 µg/L for TP (Hoyer et al. 2012).

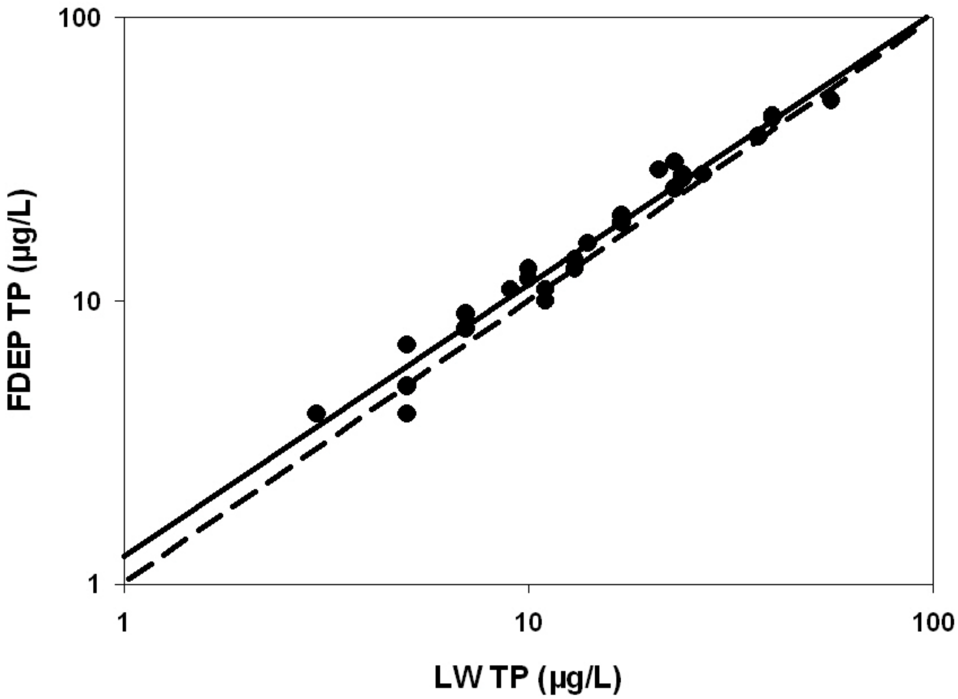


Figure 3. Relation between total phosphorus concentrations collected and analyzed by Florida Department of Environmental Protection (FDEP TP) personnel and total phosphorus concentrations collected and analyzed by Florida LAKEWATCH (LW TP). Data are from 27 Florida lakes sampled between September and December 2011. The linear regression line is solid and the dashed line represents the 1:1 line. (from Hoyer et al. 2012)

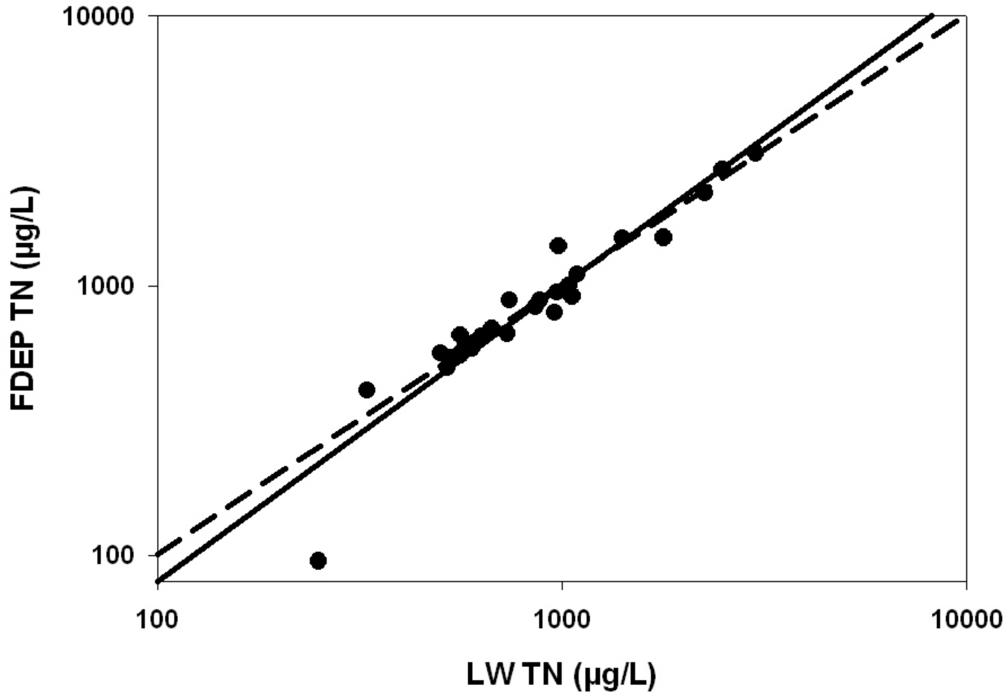


Figure 4. Relation between total nitrogen concentrations collected and analyzed by Florida Department of Environmental Protection (FDEP TN) personnel and total nitrogen concentrations collected and analyzed by Florida LAKEWATCH (LW TN). Data are from 27 Florida lakes sampled between September and December 2011. The linear regression line is solid and the dashed line represents the 1:1 line. (from Hoyer et al. 2012)

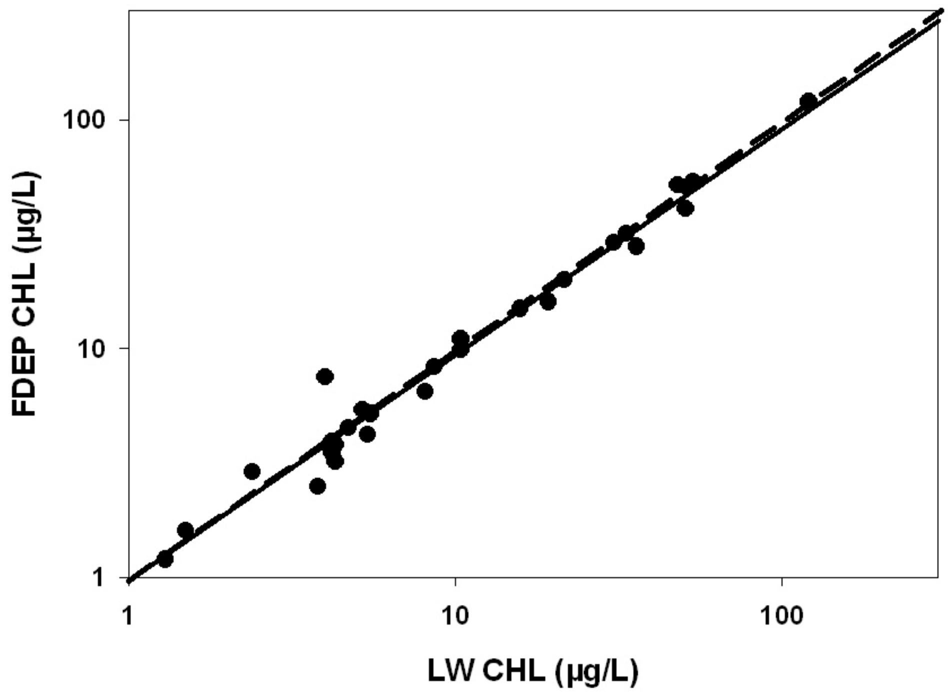


Figure 5. Relation between uncorrected chlorophyll concentrations collected and analyzed by Florida Department of Environmental Protection (FDEP CHL) personnel and uncorrected chlorophyll concentrations collected and analyzed by Florida LAKEWATCH (LW CHL). Data are from 27 Florida lakes sampled between September and December 2011. The linear regression line is solid and the dashed line represents the 1:1 line. (from Hoyer et al. 2012)

Regional and Temporal Comparisons with Predominantly Marine LAKEWATCH Lab Results (Project COAST Data)

To further evaluate the LAKEWATCH lab analyses for TN and TP, FDEP compared water chemistry results from Project COAST with results from concurrent sampling by other entities that follow FDEP QA requirements. There are some differences in sample collection methodologies between Project COAST and LAKEWATCH, as described earlier in this appendix, but the lab analyses for TN and TP are conducted in the same lab. Although these comparisons do not represent samples collected from the exact same locations at the exact same time, similar concentrations and ranges over many years of data collection provides reasonable assurance to FDEP that the COAST data are comparable to other data collected per FDEP QA guidelines. FDEP calculated annual geometric means and standard errors for TN and TP, and determined whether or not the means and errors for the COAST datasets overlapped with those of the other data providers. Results from the dataset pairs are presented here.

Weeki Wachee River

FDEP and COAST regularly monitor the Weeki Wachee River near the head spring. Available data from both programs for the Weeki Wachee River (freshwater spring run) were plotted over time to compare data that were collected and analyzed by different entities but from approximately the same locations. The FDEP Weeki Wachee at Brooksville site is a Trend Network site that is sampled monthly by FDEP. Project COAST site Weeki Wachee-1 is located in the same stretch of the river, approximately 860 meters upstream from the TV site (Figure 6). FDEP TN was calculated as the sum of nitrate+nitrite and total Kjeldahl nitrogen. Annual geometric mean TN and TP for the TV and COAST sites are statistically comparable, based on overlapping error bars, for most years (Figures 7 and 8).

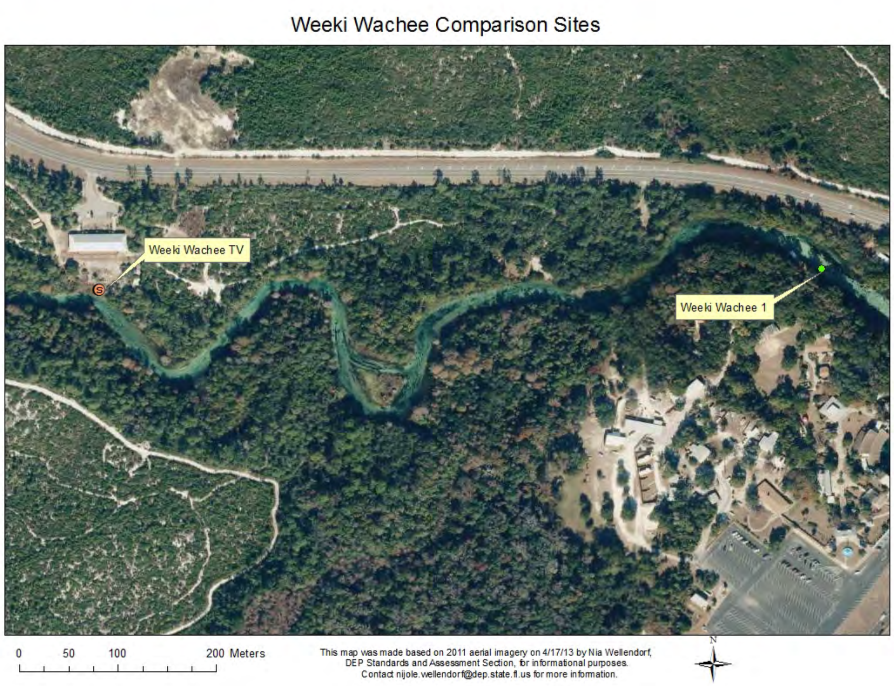


Figure 6. Sampling locations for FDEP Weeki Wachee Near Brooksville Trend Variability (TV) site and Project COAST Weeki Wachee-1 site near the head spring of the Weeki Wachee River.

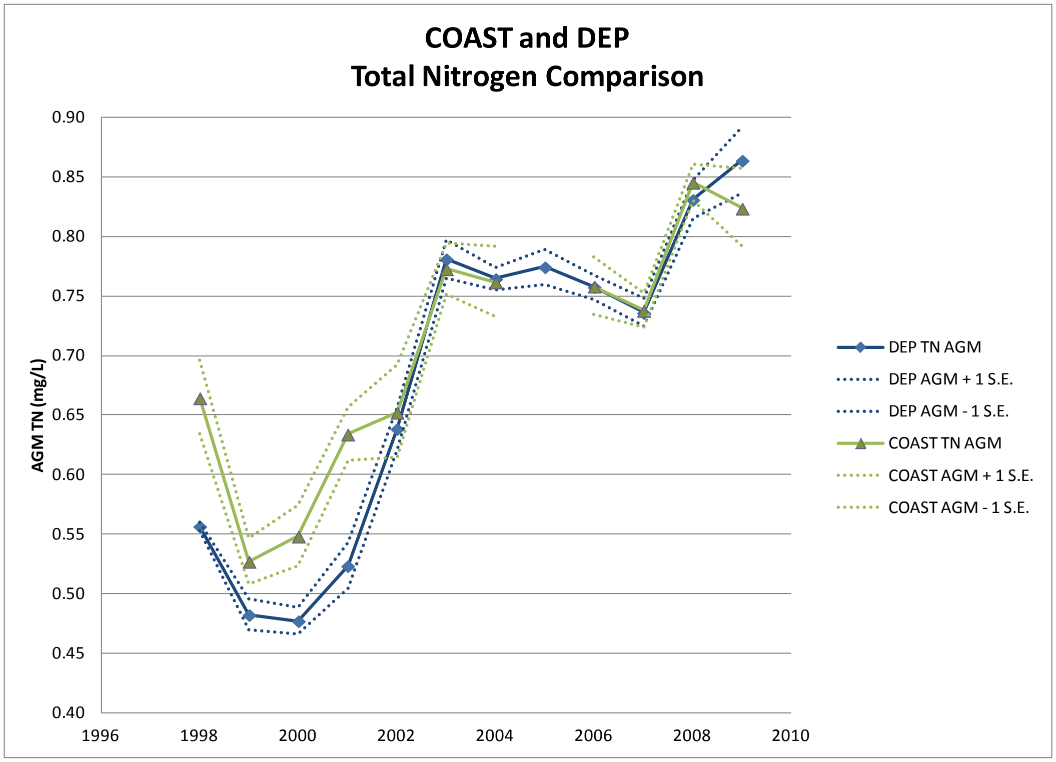


Figure 7. Comparison of annual geometric mean (AGM) +/- one standard error (S.E.) for COAST TN data and FDEP Trend Variability TN data from the Weeki Wachee River.

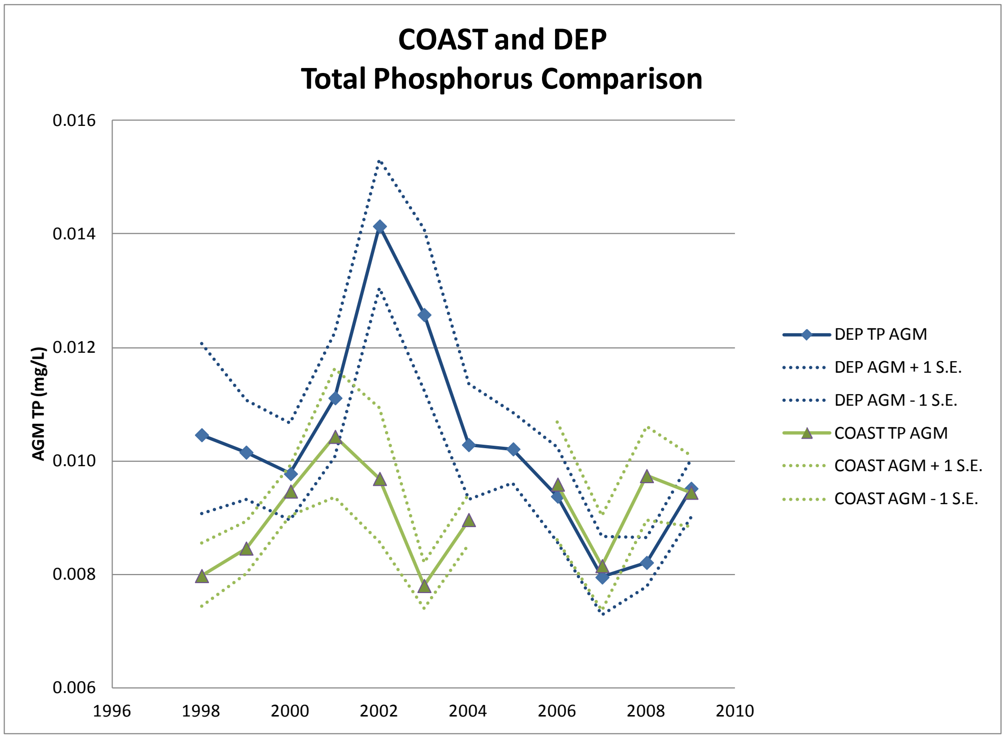


Figure 9. Comparison of annual geometric mean (AGM) +/- one standard error (S.E.) for COAST TP data (COAST TP) and FDEP Trend Variability TP data (DEP TP) from the Weeki Wachee River.

Suwannee River Estuary

The Suwannee River Water Management District (SRWMD) monitored water quality in the Suwannee Estuary for a period of time during which Project COAST monitored the Suwannee Estuary, and the SRWMD site SRE070C1 was located approximately 1,000 meters from the COAST Suwannee-4 site (Figure 10). Monthly data were available for the COAST station from 1997 to 2007. For Site SRE070C1, data were collected monthly from October 1995 until September 1999, then bimonthly from October 2001 until October 2010 (with 2 missing sampling events in 2007). For the SRWMD, lab analysis of TP and TN were conducted by two different labs which were both NELAC certified for those analytes, but which had different method detection limits for nitrogen species. SRWMD TN was calculated as the sum of nitrate+nitrite and total Kjeldahl nitrogen. Annual geometric mean TN and TP for the SRWMD and COAST sites are statistically comparable, based on overlapping error bars, for most years (Figures 11 and 12). Some differences are expected and may be due to differences in sampling frequency between entities.

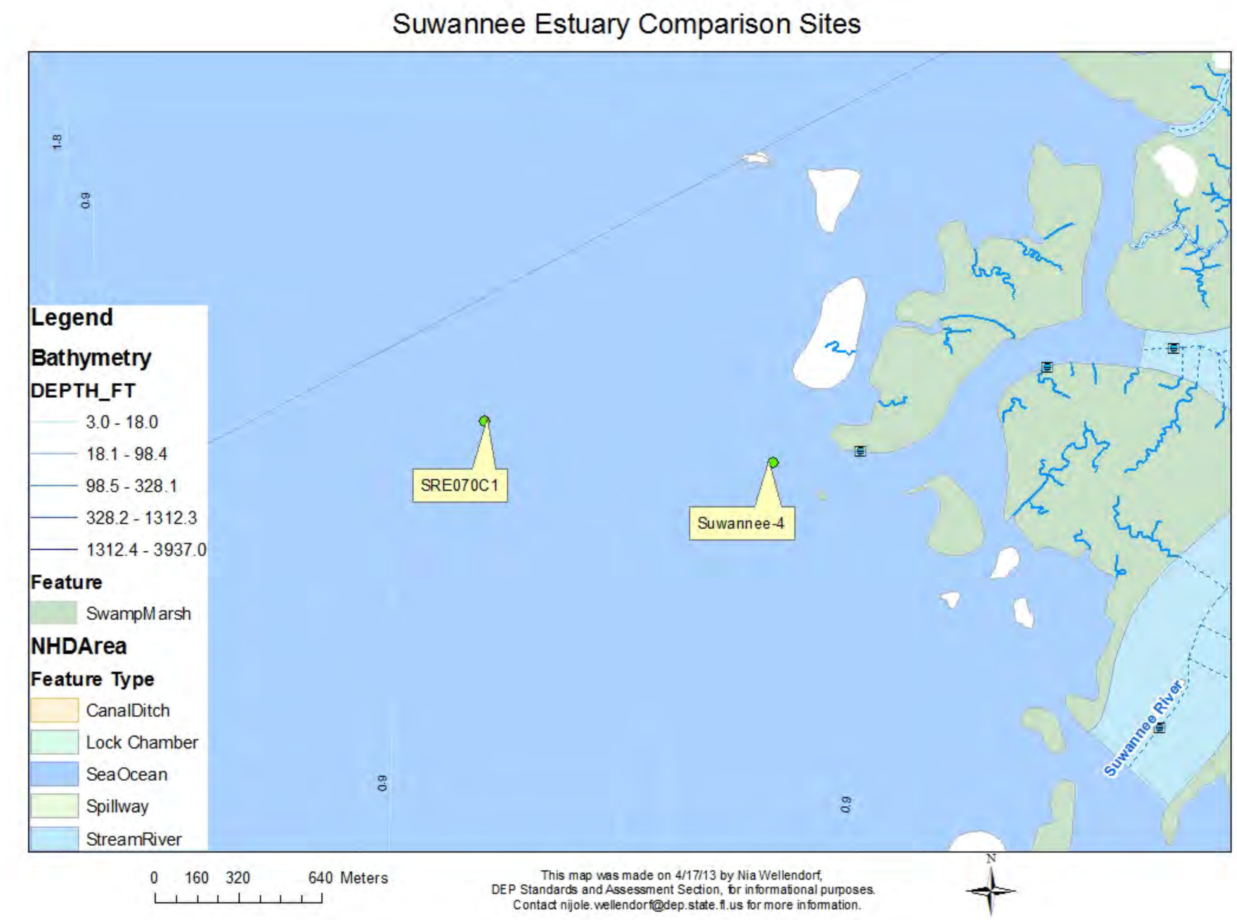


Figure 10. Sampling station locations for the SRWMD SRE070C1 site and Project COAST Suwannee-4 site near the mouth of the Suwannee River in Dixie County.

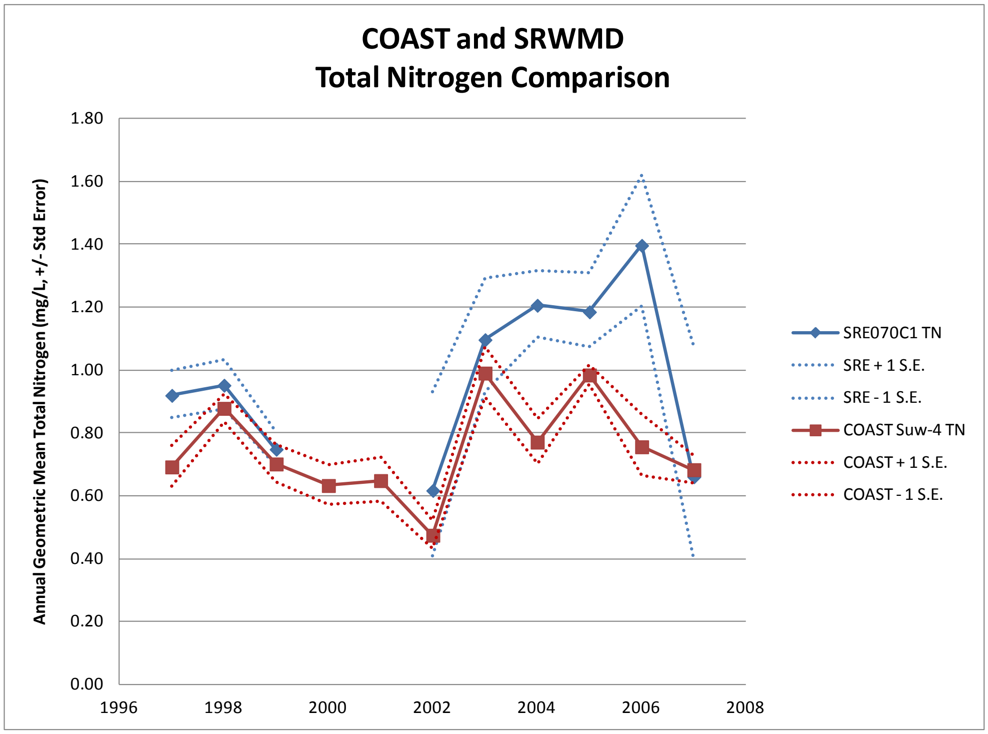


Figure 11. Comparison of annual geometric mean (AGM) +/- one standard error (S.E.) for COAST TN data (COAST TN) and SRWMD TN data (SRE TN) from the Suwannee River Estuary.

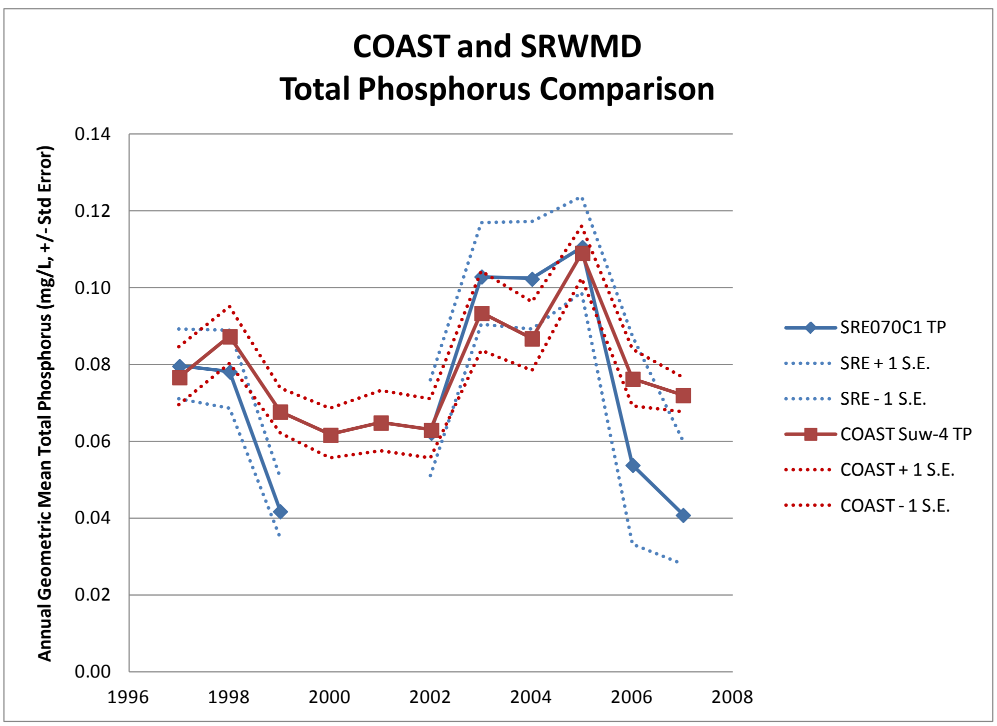


Figure 12. Comparison of annual geometric mean (AGM) +/- one standard error (S.E.) for COAST TP data (COAST TP) and SRWMD TP data (SRE TP) from the Suwannee River Estuary.

Chassahowitzka River Estuary

Mote Marine Lab (MML) conducted a study in the Chassahowitzka River Estuary during several years in which the Project COAST also collected water quality data. Mote Marine Lab station MML-18 and COAST Chassahowitzka-10 were located within 1000 m of each other (Figure 13). Annual geometric mean TN results for the MML and COAST sites are statistically comparable, based on overlapping error bars, for most years (Figure 14). A comparison was not possible between sampling entities for TP because most MML results were below their MDL, and the FDEP MDL is lower than the MML MDL.

The Southwest Florida Water Management District (SWFWMD) monitors stations along the Chassahowitzka River. Data for Station CV5 were collected approximately bimonthly from February 2006 until December 2008, and then from February 2010 to October 2011. Lab analysis of TP, TN, and phaeophytin-corrected chlorophyll *a* were conducted by the SWFWMD laboratory in Brooksville, which is NELAC certified for these analytes. Station CV5 (STORET 20022) is approximately 740 meters upstream from COAST station Chassahowitzka-4 in the tidal portion of the Chassahowitzka River that passes through salt marshes before opening up to the Gulf (Figure 13). Only three years of overlapping data were available for comparisons, but annual geometric mean TN and TP results for the SWFWMD and COAST sites are statistically comparable for those years, based on overlapping standard errors for annual geometric means (Figures 15 and 16).

Figure 13. Sampling station locations for the SWFWMD CV-5 site and Project COAST Chassahowitzka-4 site, and for Mote Marine Lab's Site 18 and Project COAST Chassahowitzka-10 site, near the mouth of the Chassahowitzka River in Citrus County.

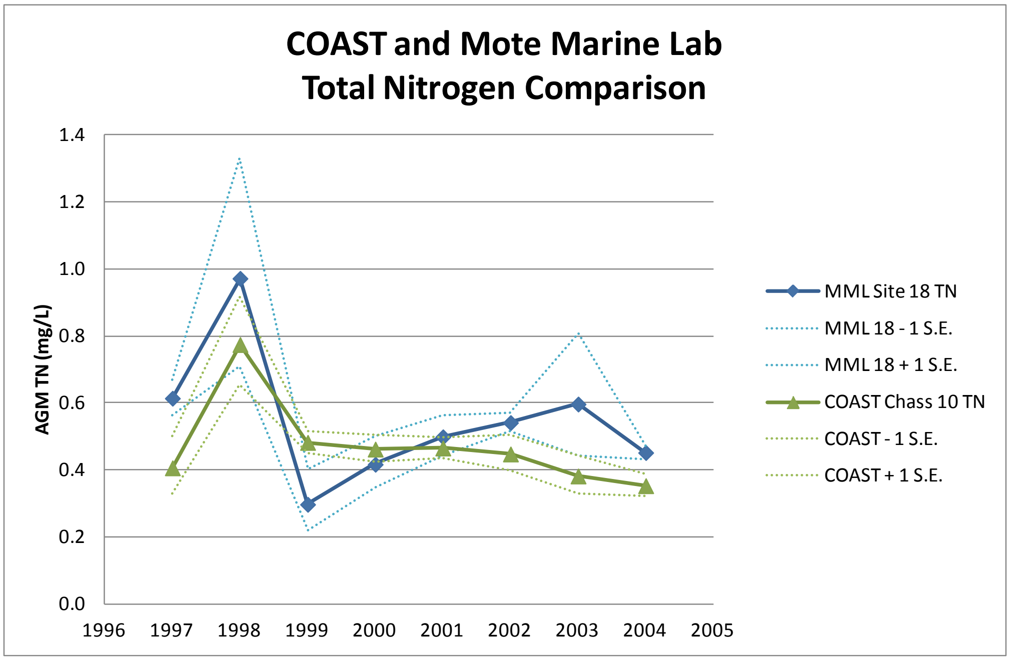


Figure 14. Comparison of annual geometric mean (AGM) +/- one standard error (S.E.) for COAST TN data (COAST Chass 10 TN) and Mote Marine Lab TN data (MML Site 18 TN) from the Chassahowitzka River Estuary.

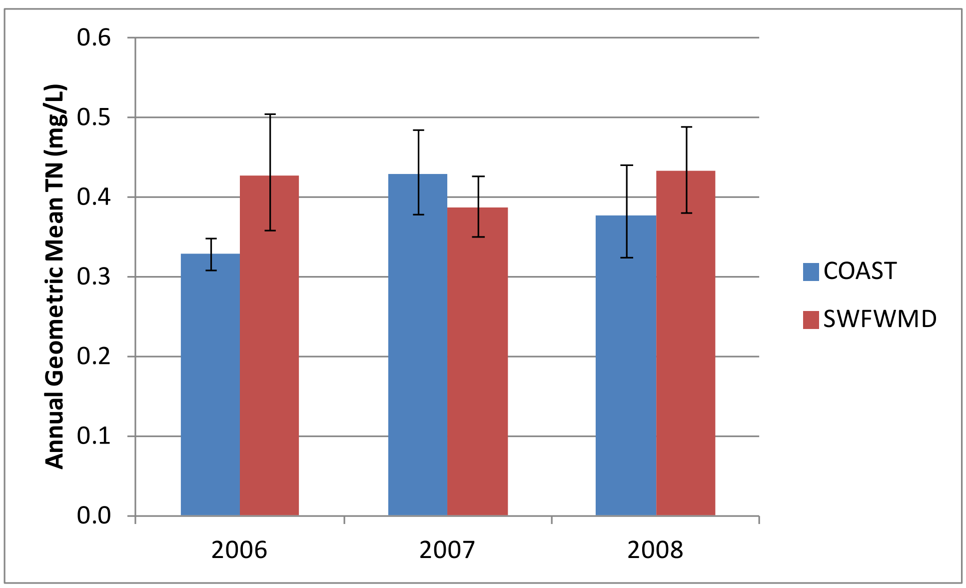


Figure 15. Comparison of annual geometric mean (AGM) +/- one standard error (S.E.) for COAST TN data and SWFWMD TN data from the Chassahowitzka River Estuary.

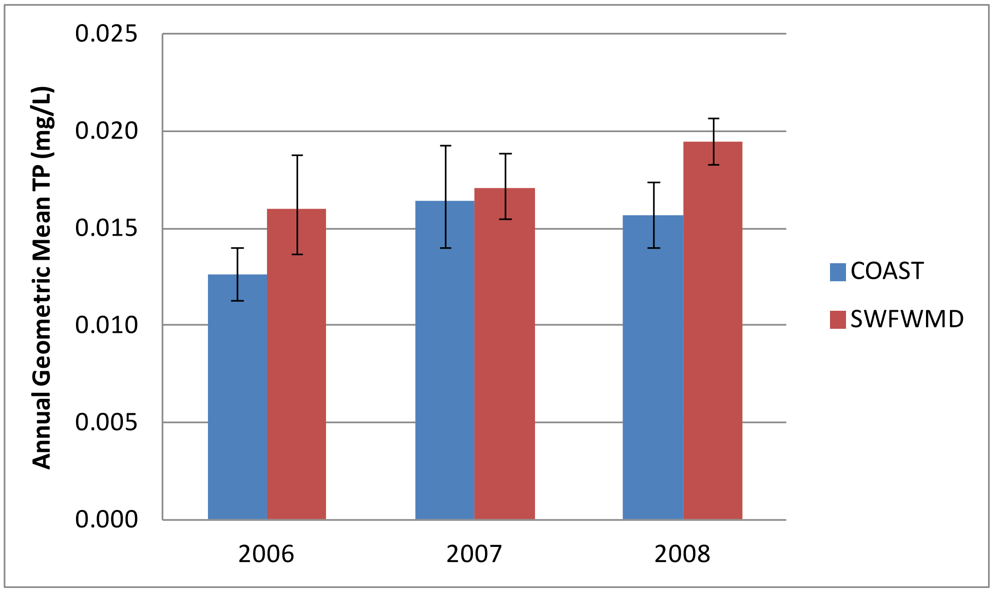


Figure 16. Comparison of annual geometric mean (AGM) +/- one standard error (S.E.) for COAST TP data and SWFWMD TP data from the Chassahowitzka River Estuary.

References Cited

APHA (American Public Health Association) 2005. Standard Methods for the Examination of Water and Wastewater 21st Edition. Baltimore, Maryland. United Book Press, Inc.

Bachmann, R.W., and D.E. Canfield, Jr. 1996. Use of an alternative method for monitoring total nitrogen concentrations in Florida lakes. *Hydrobiologia 323: 1-8.*

Canfield, D.E., Jr., C.E. Brown, R.W. Bachmann, and M.V. Hoyer. 2002. Volunteer lake monitoring: Testing the reliability of data collected by the Florida LAKEWATCH program. *Lake and Reservoir Mgmt 18: 1-9.*

Crumpton, W.G., T.M. Isenhart, and P.D. Mitchell, 1992. Nitrate and organic N analyses with second derivative spectroscopy. *Limnology and Oceanography 37:907-913.*

D'Elia, C.F., P.A. Steudler and N. Corwin. 1977. Deermination of total nitrogen in aqueous samples using persulfate digestion. *Limnology and Oceanography 22: 760-764.*

Hoyer, M.V., N. Wellendorf, R. Frydenborg, D. Bartlett, D.E. Canfield. 2012. A comparison between professionally (Florida Department of Environmental Protection) and volunteer (Florida LAKEWATCH) collected trophic state chemistry data in Florida*. Lake and Reservoir Management 28:277-281.*

LAKEWATCH. 2013. Florida LAKEWATCH Water Chemistry Field Sampling and Laboratory Protocols. Florida LAKEWATCH, Fisheries and Aquatic Sciences, School of Forest Resources and Conservation/IFAS, University of Florida. February 2013.

Menzel, D.W. and N. Corwin, 1965. The measurement of total phosphorus in seawater based on the liberation of organically bound fractions by persulfate oxidation. Limnology and Oceanography 10:280-282.

Murphy, J. and J.P. Riley, 1962. A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta 27:31-36.

Sartory, D.P. and J.U. Grobbelarr, 1984. Extraction of chlorophyll a from freshwater phytoplankton for spectrophotometric analysis. Hydrobiologia 114:117-187.

Simal, J., M.A. Lage, and I. Iglesias. 1985. Second derivative ultraviolet spectroscopy and sulamic acid method for determination of nitrates in water. *J. Assoc. Off. Anal. Chem*. *68:962-964.*

Wollin, K.M. 1987. Nitrate determination in surface waters as an example of the application of UV derivative spectroscopy to environmental analysis. *Acta Hydrochemica Hydrobiologia 15:459-469.*