National Park Service
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South Florida Natural Resources Center
Everglades National Park

PROPOSED NUMERIC NUTRIENT CRITERIA FOR SOUTH FLORIDA ESTUARIES AND COASTAL WATERS

Prepared by the South Florida Natural Resources Center
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EXECUTIVE SUMMARY

Everglades National Park (ENP) has worked closely with the U.S. Environmental Protection Agency (EPA) and the Florida Department of Environmental Protection (FDEP) on the numeric nutrient criteria for south Florida estuaries and coastal waters. The National Park Service has three large units in south Florida that will be directly affected by the proposed criteria: Everglades National Park, Dry Tortugas National Park, and Biscayne National Park. These parks contribute immensely to the ecological resources of the state and local communities by providing invaluable habitat to multiple wildlife species, serving as a nursery to valued commercial species of fish and shrimp, and offering exceptional recreational opportunities to national and international visitors.

Recently, FDEP amended Chapters 62-302 and 62-303, F.A.C., and received approval from the Environmental Review Commission and ratification from the State House. These amendments limit the amount of nutrients in surface waters by setting numeric criteria. The park supports the State's effort to develop numeric nutrient criteria for surface waters but considers that certain changes to the criteria and methodology are necessary.

Below is a brief summary of the park's comments.

- Segments with elevated nutrient levels, by comparison to adjacent segments, should be considered unsuitable reference sites until further analysis of the data shows otherwise.
- A combination of statistical tests and analysis of ancillary nutrient data should be used to identify potentially nutrient-enriched segments. These segments must not be used as reference sites to develop criteria because their current nutrient levels already may be high enough to cause degradation of flora and fauna.
- The numeric nutrient criteria should include two limits. FDEP is proposing a single limit, which is an annual geometric mean not to be exceeded more than once in three consecutive years. The park is recommending that this limit be complemented with an annual geometric mean never to be exceeded. The purpose of the second limit is to avoid single, large exceedences—which are allowed by the first limit—capable of causing significant or even catastrophic adverse effects to the ecosystem.
- FDEP's TN, TP, and Chla proposed limits are consistently greater than ENP's proposed limits and, consequently, could be less protective of the ecosystem (see table 1 below).

Table 1. Comparison of 1-in-3 Years Annual Geometric Mean Limits

			FDEP 1:3L			ENP 1:3L		
WATERBODY	SYMBOL	SEGMENT NAME	mg/L		µg/L	mg/L		µg/L
			TP	TN	Chla	TP	TN	Chla
Biscayne Bay	CS	Card Sound	0.008	0.33	0.50	0.007	0.31	0.47
	MBS	Manatee Bay – Barnes Sound	0.007	0.58	0.40	0.007	0.58	**0.43**
	NCI	North Central Inshore	0.007	0.31	0.50	0.007	0.30	0.41
	NCO	North Central Outer-Bay	0.008	0.28	0.70	0.007	0.27	0.47
	NNB	Northern North Bay	0.012	0.30	1.70	0.007	0.29	0.47
	SCI	South Central Inshore	0.007	0.48	0.40	0.007	0.31	0.34
	SCM	South Central Mid-Bay	0.007	0.35	0.20	0.007	0.31	**0.31**
	SCO	South Central Outer-Bay	0.006	0.24	0.20	0.006	0.23	**0.24**
	SNB	Southern North Bay	0.010	0.29	1.10	0.007	0.28	0.47
Florida Bay	CFB	Central Florida Bay	0.019	0.99	2.20	0.018	0.97	2.19
	CL	Coastal Lakes	0.045	1.29	9.30	0.044	1.24	8.69
	ECFB	East Central Florida Bay	0.007	0.65	0.40	0.007	0.64	0.34
	NFB	Northern Florida Bay	0.010	0.68	0.80	0.010	0.66	0.78
	SFB	Southern Florida Bay	0.009	0.64	0.80	0.009	0.63	0.73
	WFB	Western Florida Bay	0.015	0.37	1.40	0.014	0.36	1.26
Florida Keys	BACB	Back Bay	0.009	0.25	0.30	0.009	0.25	0.30
	BACS	Backshelf	0.011	0.23	0.70	0.011	0.23	0.52
	LOWK	Lower Keys	0.008	0.21	0.30	0.008	0.20	**0.32**
	MAR	Marquesas	0.008	0.21	0.60	0.008	0.20	0.59
	MIDK	Middle Keys	0.007	0.22	0.30	0.007	0.22	**0.32**
	OFFS	Offshore	0.007	0.17	0.30	0.007	0.17	0.26
	UPPK	Upper Keys	0.007	0.18	0.20	0.007	0.17	**0.22**
Whitewater Bay - Ten Thousand Islands	BCK	Blackwater River	0.053	0.41	4.10	0.051	0.40	3.78
	CTZ	Coastal Transition Zone	0.034	0.61	3.90	0.033	0.60	3.78
	GI	Gulf Islands	0.038	0.44	3.40	0.038	0.44	3.36
	IWW	Inner Waterway	0.033	0.69	5.20	0.032	0.67	3.98
	MR	Mangrove Rivers	0.021	0.71	3.70	0.021	0.69	3.69
	PD	Ponce de Leon	0.024	0.52	3.00	0.023	0.51	2.76
	SRM	Shark River Mouth	0.022	0.75	2.20	0.021	0.73	2.14
	WWB	Whitewater Bay	0.026	0.82	4.10	0.026	0.79	3.98

Bold numbers indicate that ENP criterion is larger than FDEP criterion

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Introduction

The U.S. Environmental Protection Agency (EPA) and the State of Florida Department of Environmental Protection (FDEP) are developing numeric nutrient criteria for south Florida estuaries and coastal waters. These efforts are a result of legal action brought against EPA by Earthjustice in 2008. In 2009, EPA made a determination, under section 303(c)(4)(B) of the Clean Water Act, that the narrative nutrient criteria of Florida's existing lakes and flowing waters were not protective enough. EPA proposed to promulgate numeric criteria for existing lakes and flowing waters by 2010 and for estuaries by 2011. Most recently, EPA extended the deadlines to March 15 and November 15, 2012, to propose and finalize criteria, respectively. The federal criteria will apply unless the State adopts its own water quality standards addressing EPA determination. Everglades National Park (ENP) has been actively involved with FDEP and EPA in their efforts to develop nutrient criteria for south Florida. In this document, we propose numeric nutrient criteria for south Florida estuaries and coastal waters that are based on a two-part limit: (a) an annual geometric mean, not to be exceeded in any year, and (b) a 1-in-3 year annual geometric mean, not to be exceeded more than once in three consecutive years. This type of two-part test already is in use by FDEP for measuring compliance with the total phosphorus numeric criterion in the Everglades. The annual test would provide a compliance test in the short-term, and the 3-yr test would provide a more stringent test for the long term.

Urban and agricultural development in south Florida rapidly increased after the 1940s with the implementation of the Southern and Central Florida Project designed to provide flood control and water supply. During the following decades, water management decisions to support an increasing population and a growing farming community brought about extensive adverse impacts to Everglades ecology, including loss of habitat and changes in hydrology, which were manifested in declines in wading bird population, degradation of water quality, and eutrophication of fresh and marine environments. These problems were so pervasive that, in 1988, the Federal Government sued the State of Florida for water quality violations, which were settled by a Settlement Agreement in 1991, and a Consent Decree in 1992. In 1994, the State of Florida adopted the Everglades Forever Act, incorporating some aspects of the Consent Decree, and establishing a funding mechanism for water quality restoration. In 2003, a 10 µg/L total phosphorous criterion was established for the freshwater Everglades. Currently, the Federal Government and the State of Florida are engaged in an unprecedented effort at restoring the ecology and hydrology of the Everglades. These projects will bring changes to the quantity and quality of surface water discharges into the Everglades marshes and adjacent estuaries. Developing numeric nutrient criteria for both the fresh and estuarine systems is of upmost importance to guide the on-going restoration efforts, to assess the ecological significance of restoration projects, and to allow a sustainable, but balanced, development of the natural resources.

The purpose of the numeric nutrient criteria is to establish threshold limits that are protective of the ecosystems from unwanted eutrophication caused by anthropogenic influxes of nutrients from agricultural and urban runoff. These nutrient criteria will help Class II and Class III waters meet their designated use and Outstanding Florida Waters (OFWs) to maintain their healthy and well-balanced flora and fauna. FDEP is proposing numeric nutrient criteria for total phosphorus (TP), total nitrogen (TN), and chlorophyll-a (Chla) for Florida estuaries and coastal waters. Everglades National Park, the largest national park in south Florida, has a great interest in the outcome of the State and federal efforts to set nutrient criteria. We have examined and modified FDEP's numeric nutrient criteria method (FDEP, 2011) and are proposing an alternate methodology to develop nutrient criteria. While we introduced some desired changes, we strived at maintaining a significant level of compatibility with FDEP methodology.

In south Florida, there are six basins of special interest to us: Biscayne Bay (BB); Florida Bay (FB); Whitewater Bay-Ten Thousand Islands (WB-TT); Florida Keys (FK); Gulf Shelf (GS); and Pine Island Sound-Rookery Bay (PI-RB). We are proposing criteria for five of these basins. We excluded PI-RB from the analysis because it is outside the park's purview. All of these estuaries are complex systems where cause-and-effect relationships between nutrient enrichment and ecosystem responses have not been well-studied using research and monitoring specifically designed to address these relationships. Until recently, Florida International University (FIU), under contract with state and federal agencies, maintained an extensive water-quality monitoring network for south Florida estuaries and coastal waters. FIU's dataset includes 353 fixed stations and extends from 1989 to 2008 for some stations. We selected the 1995 to 2008 period, just as FDEP did, to carry out a water-quality analysis because this period was common to most stations.

METHOD

EPA recognizes that there are three useful methods for deriving marine numeric nutrient criteria: (a) reference conditions; (b) stressor-response relationships; and (3) water-quality simulation modeling. For south Florida, however, EPA is considering the reference conditions method with two approaches (EPA 2010). The objective of the reference conditions method is to maintain existing nutrient conditions that maintain a healthy, well-balanced flora and fauna. The two approaches are based on statistical analysis of the historical data and are discussed in EPA's Method and Approaches for Deriving Numeric Criteria for Nitrogen/Phosphorus Pollution in Florida's Estuaries, Coastal Waters, and Southern Inland Flowing Waters (EPA 2010). We concur and agree with EPA that the other methods are not viable for the systems in south Florida, mostly because of a lack of pertinent data.

FDEP and the park selected the reference conditions method based on a statistical approach (FDEP, 2011). In the park's approach, discussed below, we set numeric nutrient criteria equal to the upper 90th and 80th percentiles of the nutrient distribution data for waterbodies that currently meet their designated use or maintain a healthy, well-balanced ecosystem. For waterbodies that failed to meet their designated use and were considered potentially nutrient enriched, we set criteria equal to those

of a nearby reference site. We made a distinction between systems that had elevated nutrient levels caused by anthropogenic sources and systems that had naturally occurring elevated nutrient concentrations. For sites in the first group—potentially enriched—a reference site was used. We considered a site to be nutrient enriched if any of the three following conditions were met:

(1) the designated use was not met because of high nutrient concentrations,

(2) statistical tests demonstrate that nutrient concentrations were substantially higher than at neighboring sites, and

(3) there was additional evidence, mostly from nutrient-enrichment indicators, that when combined with local knowledge of the sites, supports the notion of nutrient enrichment.

For waterbodies that were considered potentially enriched, we selected a reference site that had similar water quality characteristics, was controlled by similar drivers, was within the same bay or estuary, was not nutrient enriched, and met its designated use.

An important drawback of this method is the apparent disconnect between criterion exceedence and expected adverse biological effects. Currently, there are no bioassay studies documenting cause-and-effect relationships from increased nutrients that can be used to set criteria. On the other hand, we expect that frequent exceedences of the criteria would cause adverse effects in the long-term because the system would not be able to assimilate the additional nutrient load. Thus, we believe than in the absence of such studies, the assumption that there will be long-term adverse biological effects due to frequent exceedences of the criteria is reasonable and prudent for the purpose of developing criteria. Many national and international studies have extensively documented the effects of nutrient enrichment in coastal systems, for example, Lapointe et al. (2002) described how increased nutrient concentrations resulted in algal blooms and seagrass die-off in Florida Bay and in a decline of coral reefs in the Florida Keys; Greening and Janicki, (2006) reviewed how changes in eutrophic conditions from decreased nitrogen loads resulted in visible water quality and habitat improvement in Tampa Bay; and Wang (2006) discussed how increasing nutrient levels in the Yangtze River have contributed to the eutrophication of the East China Sea.

Segmentation of Estuaries. In close coordination with the park, Florida International University (FIU) divided the six south Florida basins into smaller segments of similar geomorphologic, geochemical, and hydrologic characteristics to facilitate the nutrient criterion analyses (Briceño et al., 2011). The segmentation was based on a combination of Principal Component and Hierarchical Clustering analyses of multiple (from 8 to 13) water quality constituents and parameters. This segmentation, which was discussed with local scientists, was proposed to EPA and FDEP. Currently, both EPA and FDEP are basing their respective analysis on some variant of this segmentation. In our approach, Biscayne Bay was divided into nine segments, Florida Bay into six, the Florida Keys into seven, the Gulf Shelf into three, Whitewater Bay – Ten Thousand Islands into eight, and Pine Island Sound – Rookery Bay into six. These segments are shown in Figure 1 and listed in Table 1.

Estimation of Annual Geometric Means (AGM) and Standard Deviations. As is common with water quality data, nutrient concentrations were not distributed normally and the data required a transformation. We selected a logarithmic transformation of the concentrations to comply with normality requirements. The natural log-transformed values were averaged by year within each monitoring site to account for the within-year variability. These values became the annual geometric mean (AGM) for a site. Within each segment, the various sites' AGMs were averaged to estimate a segment's AGMs. By averaging the AGMs across sites, we accounted for spatial variability in a segment.

TABLE 1. Abbreviation and names of south Florida segments

Region	No.	Key	Segment
Biscayne Bay (BB)	1	NNB	Northern North Bay
	2	SNB	Southern North Bay
	3	NCO	North Central Outer-Bay
	4	NCI	North Central Inshore
	5	SCO	South Central Outer-Bay
	6	SCI	South Central Inshore
	7	SCM	South Central Mid-Bay
	8	CS	Card Sound
	9	MBS	Manatee Bay and Barnes Sound
Florida Bay (FB)	1	ECFB	East-Central Florida Bay
	2	NFB	Northern Florida Bay
	3	CL	Coastal Lakes
	4	CFB	Central Florida Bay
	5	SFB	Southern Florida Bay
	6	WFB	Western Florida Bay
Florida Keys (FK)	1	OFFS	Offshore
	2	BACB	Back Bay
	3	BACS	Back Shelf
	4	MAR	Marquesas
	5	UPPK	Upper Keys
	6	MIDK	Middle Keys
	7	LOWK	Lower Keys

Region	No.	Key	Segment
Gulf Shelf (GS)	1	IGS	Inner Gulf Shelf
	2	MGS	Middle Gulf Shelf
	3	OGS	Outer Gulf Shelf
White Water Bay -- Ten Thousand Ils. (WB-TI)	1	WWB	Whitewater Bay
	2	PD	Ponce de Leon
	3	SRM	Shark River Mouth
	4	MR	Mangrove River Zone
	5	CTZ	Coastal Transition Zone
	6	IWW	Inner Waterway
	7	GI	Gulf Island
	8	BLK	Blackwater River
Pine Is. -- Rookery Bay (PI-RB)	1	MARC	Marco Island
	2	NPL	Naples Bay
	3	CI	Collier Inshore
	4	EB	Estero Bay
	5	SCB	San Carlos Bay
	6	PINE	Pine Island Sound

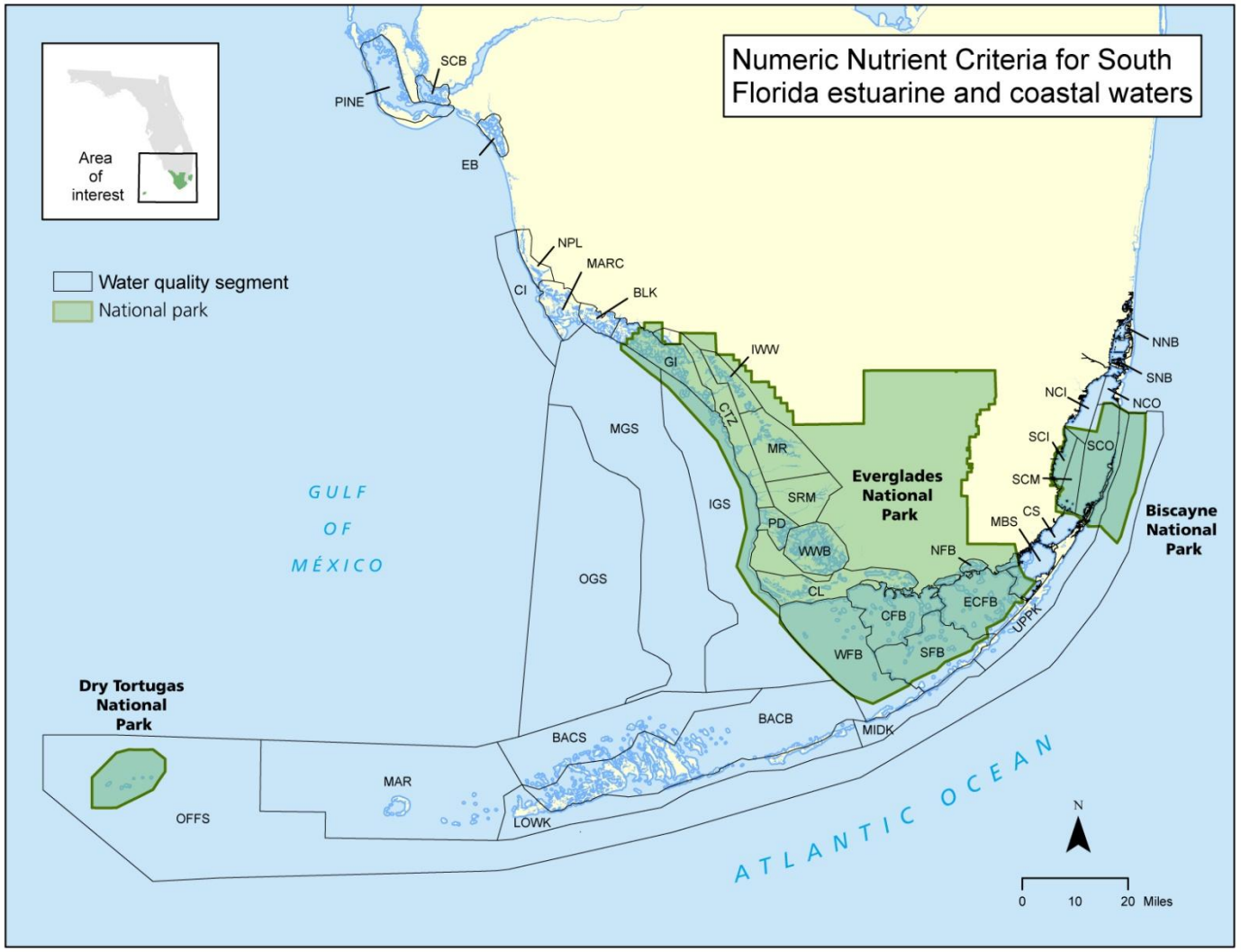


Figure 1. Division of south Florida estuaries and coastal waters into segments of similar geomorphologic, geochemical, and hydrologic characteristics.

Criteria Components. The FDEP's numeric nutrient criteria have three components, which are similar to ours: magnitude, duration, and frequency. The magnitude component defines the maximum allowable concentration; duration defines the maximum length of time the magnitude component can be safely exceeded; and frequency defines how often the magnitude component can be safely exceeded. The duration and frequency components of the criteria allow for some limited exceedences of the magnitude component to account for natural variability.

We are proposing that the numeric nutrient criteria be expressed as a two-part limit. Exceedence of either part would be considered an exceedence of the criteria. Following FDEP's methodology, we developed these limits using a binomial distribution and a low Type I error rate (FDEP, 2011). The binomial distribution was used to calculate the probability of exceedence of a given event in a specified number of trials. The Type I error (or false positive) was fixed to approximately 10% to limit the rate of falsely declaring an exceedence of the criteria when, in fact, the exceedence was due to chance or natural variability. In Table 2, we explore various scenarios: (a) the 1-year duration with no exceedences and (b) the 3-year duration with zero and one exceedence. The goal was to achieve a Type I error of 10% by adjusting the magnitude of the values in the column "Criterion", which represent the percentile of AGMs to be used as the criterion. For example, in the 3-year and 1 exceedence scenario, we selected the 80th percentile of AGMs, which had an exceedence probability of 0.2, to achieve a 10% rate for the Type I error. This means that there is a low probability, 1 in 10, of exceeding the criterion by chance alone.

Table 2. Binomial Test Results for Various Scenarios of Duration and Frequency of Exceedence

Duration Yrs	Exceedence No.	Criterion (Percentile)	Type I Error (%)
1	0	90	10.0
3	0	97	10.1
3	1	80	10.4

From these results, we selected two limits for the criteria, which are based on AGMs:

a. An Annual Limit (AL), never to be exceeded, and
b. A 1-in-3 Year Limit (1:3L), not to be exceeded more than once in three consecutive years.

We argue that criteria composed of a two-part limit (rather than one limit, as FDEP is currently advocating) are better suited to detect occurrences of extreme single events capable of causing severe damage to the ecosystem. Also, such a two-part limit consisting of two different compliance time periods (one is for one year, while the other is for three years), allows corrective measures to be considered in a shorter time frame. In the one-limit criterion case (FDEP's option), one exceedence of the criterion is allowed every three consecutive years, regardless of the magnitude of the exceedence. If

the exceedence of the criterion were by small margin, the adverse impacts might be small because the ecosystem might be able to assimilate the added nutrient load without causing adverse effects. If the exceedence of the criteria were by a large margin, however, the ecosystem wouldn't be able to assimilate the added nutrient load without adverse impacts. Depending on the severity of the exceedence, the response in the ecosystem could be extensive or even catastrophic. To avoid such scenarios, we propose that the 1-in-3 year limit be supplemented with an annual limit, as explained above. Criteria with two limits will continue to be easily implemented and add significantly more power to test for exceedences. The FDEP already has adopted, and the EPA has agreed with, a two-part criterion for the freshwater Everglades.

Potentially Nutrient-Enriched Segments. We conducted a Kruskal-Wallis Test of medians on a segment's AGMs to identify potentially nutrient-enriched segments. If the median of a segment was significantly different, above the 5% probability level, from the medians of other segments, we flagged the segment as potentially nutrient enriched. Segments that were found to be potentially enriched were not used as reference sites. Instead, we selected one of the unenriched segments, the one with the highest criterion, to be the reference site for the nutrient-enriched segment.

Computation of Limits. As discussed earlier, we designed the criteria to have two parts. These two parts were based on the 90th and 80th percentiles of the nutrient distribution data. Specifically, we calculated the percentiles using a function for normally distributed series with mean and standard deviation estimated from the segment's AGMs. For potentially enriched segments, the limits were set to that of a reference site. Below we discuss these limits and provide box plots of the segment's AGMs.

PROPOSED NUMERIC NUTRIENT CRITERIA

Biscayne Bay

Biscayne Bay (BB) is a shallow, well-mixed tropical lagoon. It has a 1978 designation as an Outstanding Florida Waters (OFW) and contains both the Biscayne Bay Aquatic Preserve and Biscayne National Park. The central and southern parts of the bay are surrounded by protected natural areas, including marine waters and lands managed by the State (John Pennekamp Coral Reef State Park, Bill Baggs Cape Florida State Park, and Biscayne Bay Aquatic Preserve) or the federal government (Florida Keys National Marine Sanctuary). The bay is located east of the Miami metropolitan area and is confined by a series of discontinued barrier islands that form the eastern boundary of the lagoon and offer limited connection to the Atlantic Ocean. In the western shore of the lagoon, several canals discharge freshwater, mostly from urban and agricultural runoff.

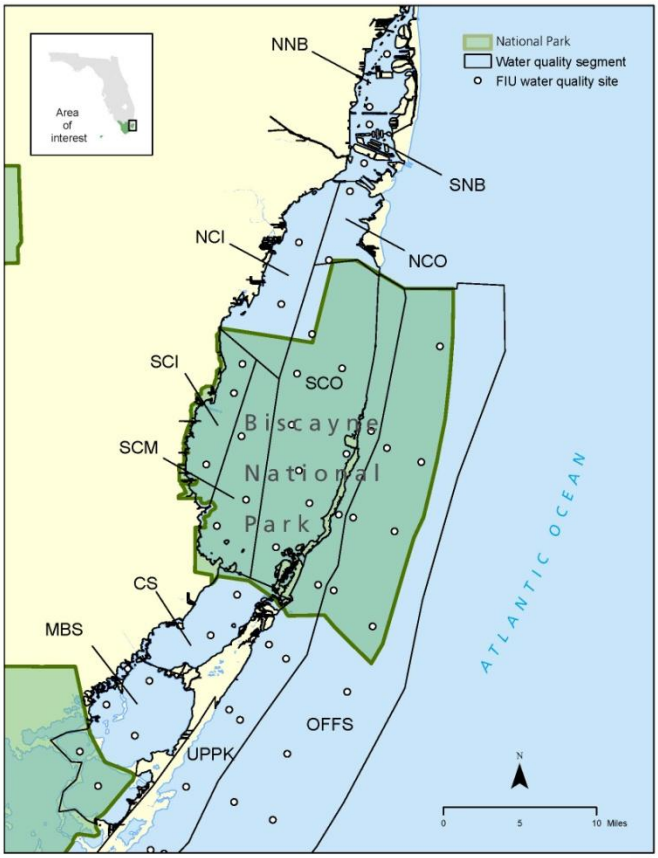
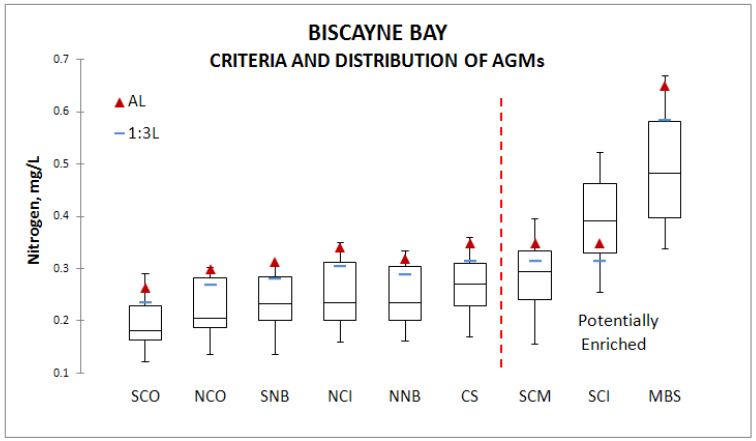


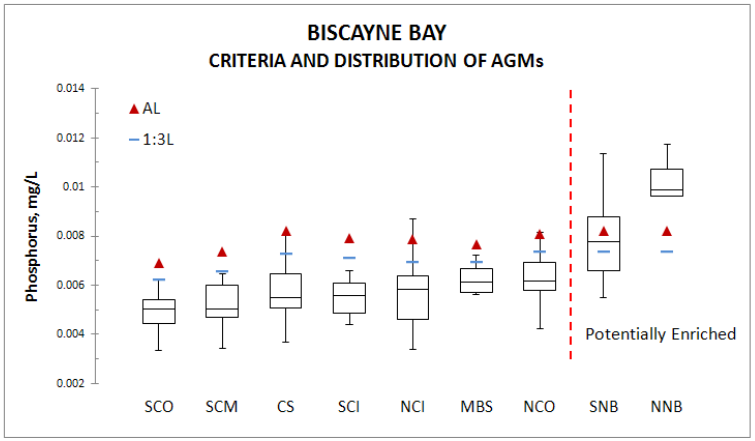
Figure 2. Biscayne Bay (BB) Segmentation for Nutrient Criteria Derivation.

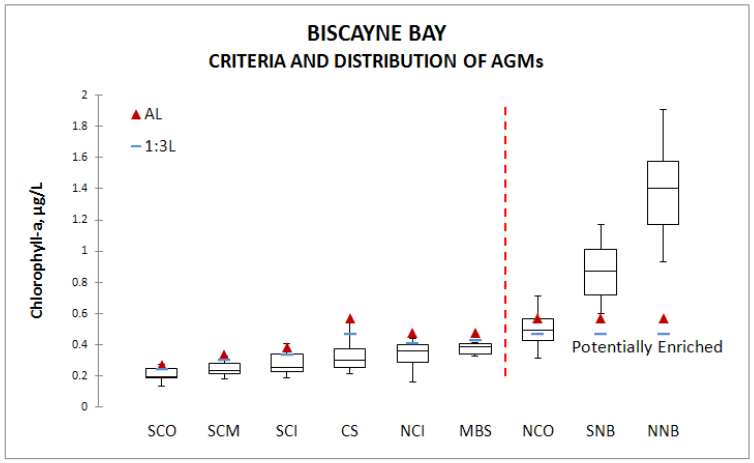
The Biscayne Bay drainage basin has been substantially impacted by industrial and urban development in the northern areas and by agricultural and, to a lesser extent, by urban development in the southern areas. Flood control structures have changed the timing and distribution of freshwater discharges to coastal marshes and to the bay from slow seepage to large, pulsed inflows. Alterations to the watershed and unnatural management of the hydrologic system have increased the nutrient load, which reaches the bay either directly as point discharges from canals or indirectly as seepage from the groundwater (Browder et al., 2005).

BB was subdivided into nine segments for deriving nutrient criteria (Fig. 2). The northern section of the bay has two segments: NNB and SNB; the middle section has five segments: NCI and SCI in the western side of the bay, SCM in the middle, and NCO and SCO in the ocean side; and the southern section has two segments: CS and MBS. The map also shows portions of the Florida Key's two most northern segments: OFFS and UPPK. Criteria and box plots of AGMs are shown in Figure 3.

Total Nitrogen. The median TN concentrations ranged from 0.2 to 0.49 mg/L, decreased from west to east, and were the highest in the middle section of the bay close to canals that drain agricultural fields. The criteria followed the concentration trend and were the lowest in segments closest to the ocean—SCO and NCO. The TN criteria ranged from 0.26 to 0.35 mg/L for the AL and from 0.23 to 0.31 mg/L for the 1:3L, excluding MBS. There were several segments identified as potentially enriched, located in the middle and southern sections of the bay: SCM, SCI, and MBS. The source of the nutrients in SCM and SCI is canal discharges from agricultural runoff, but the source of the nutrients in MBS is currently unknown. The nutrient levels in MBS were similar to those in eastern Florida Bay and appear to be from natural processes. Past and present anthropogenic impacts have altered Biscayne Bay's flora and fauna. There is also evidence that nutrient pollution from canal discharges has significantly impacted periphyton growth and benthic macroinvertebrate communities near the canal discharges (Szmant, 1987; Graves et al., 2005). From recent algal bloom events that have been attributed to road construction activities and hurricane impacts, it is clear that small increases in nutrient loads in the bay can result in significant, widespread biological impacts (Rudnick et al., 2006; Zhang et al., 2009).







BISCAYNE BAY NUMERIC NUTRIENT CRITERIA

SEGMENT	TN, mg/L		TP, mg/L		Chla, µg/L	
	AL	1:3L	AL	1:3L	AL	1:3L
CS	0.35	0.31	0.008	0.007	0.57	0.47
MBS	**0.65**	**0.58**	0.008	0.007	0.48	0.43
NCI	0.34	0.30	0.008	0.007	0.47	0.41
NCO	0.30	0.27	0.008	0.007	**0.57**	**0.47**
NNB	0.32	0.29	**0.008**	**0.007**	**0.57**	**0.47**
SCI	**0.35**	**0.31**	0.008	0.007	0.38	0.34
SCM	**0.35**	**0.31**	0.007	0.007	0.34	0.31
SCO	0.26	0.23	0.007	0.006	0.27	0.24
SNB	0.31	0.28	**0.008**	**0.007**	**0.57**	**0.47**

Criteria were rounded up

Bold numbers show potentially enriched segments

Figure 3. Biscayne Bay numeric nutrient criteria for TN, TP, and Chla. AL is the Annual Limit and 1:3L is the 1-in-3 Year Limit. The table provides the magnitude of the criteria with two decimal places for TN and Chla and three for TP.

Total Phosphorus. The median TP concentrations ranged from 0.005 to 0.010 mg/L and decreased from west to east but also have a strong north to south decreasing gradient. The northern segments of the bay, NNB and SNB, had the highest TP concentrations and were identified as potentially enriched. The TP criteria ranged from 0.007 to 0.008 mg/L for the AL and from 0.006 to 0.007 mg/L for the 1:3L.

Chlorophyll-a. The spatial distribution of Chla concentrations was similar to that of TP. The median Chla ranged from 0.2 to 1.41 µg/L and was highest in the northern segments: NCO, SNB, and NNB, which were identified as potentially enriched. The Chla criteria ranged from 0.27 to 0.57 µg/L for the AL and from 0.24 to 0.47 µg/L for the 1:3L.

Florida Bay

Florida Bay (FB) is a shallow, triangular-shaped estuary at the southern end of the Florida Peninsula, mostly within Everglades National Park and the Florida Keys National Marine Sanctuary. The bay is made up of multiple shallow basins that are enclosed by carbonate mud banks that limit circulation and connection to the Atlantic Ocean and Gulf of Mexico. Multiple ecosystems within Florida Bay provide valuable habit to endangered wading birds, crocodiles, sea turtles, and manatees, and other wildlife, and serve as a nursery for commercially important species (Hunt and Nuttle, 2007). Although there are some old, man-made canals that discharge into the bay, their flows aren't regulated by structures. Most of the freshwater inputs come from the Everglades marsh runoff, which have been drastically reduced over the past century. Diversion of the natural flows helped with flood control to support agricultural and urban development of south Florida. In the southeastern portion of the bay, adjacent to the Florida Keys, wastewater from septic tanks and treatment plants is the main anthropogenic source of nutrients to the bay. Nutrient budget estimates, however, suggest that the Gulf of Mexico is the major source of TP for the bay (Rudnick, 2010). Increased salinity, multiple-year droughts, reduced freshwater inflows, and man-made hydrologic alterations of the bay's watershed contributed to widespread seagrass die-offs, mass mortality of sponges, and occurrence of widespread phytoplankton blooms during 1987–91 and 2006–08. On-going restoration projects are focusing on delivering more freshwater to the bay to avoid such occurrences.

Florida Bay was divided into six segments (Fig. 4): NFB and ECFB in the eastern section of the bay, CFB and SFB in the middle section of the bay, WFB on the western section of the bay, and CL in the northern section of the bay straddling the center and western sections. The map also shows Biscayne Bay's two most southern segments: CS and MBS. Criteria and box plots of the AGMs are shown in Figure 5.

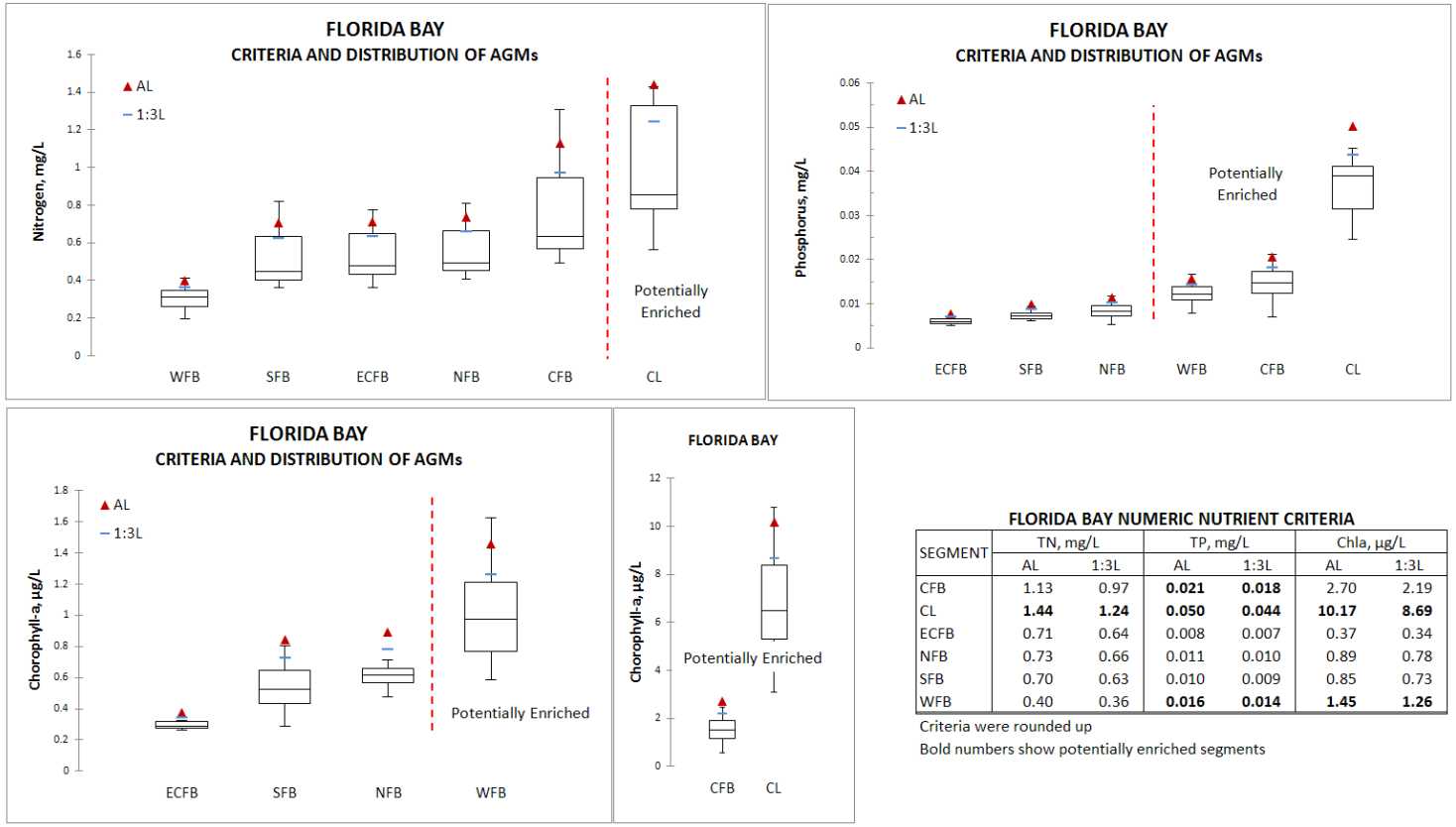
Total Nitrogen. The median TN concentrations ranged from 0.31 to 0.86 mg/L and decreased from east to west and also from north to south. Nutrient load estimates (Rudnick, 2010) indicate that groundwater contributions are 6 to 7 times larger than those from atmospheric, Gulf of Mexico, or other terrestrial inputs. The lowest

Figure 4. Florida Bay (FB) Segmentation for Nutrient Criteria Derivation.

concentrations and limits occurred in WFB and the highest in CL. The CL segment was identified as having elevated nutrient concentrations, which have been attributed to increased brackish groundwater discharges and saltwater intrusion (Frankovich et al., 2010). The TN criteria ranged from 0.40 to 1.44 mg/L for the AL and from 0.36 to 1.24 mg/L for the 1:3L.

Total Phosphorus. The median TP concentrations ranged from 0.006 to 0.039 mg/L and increased from east to west and from south to north. Nutrient load estimates (Rudnick, 2010) indicate that Gulf of Mexico inputs are 1.6 times larger than groundwater contributions and 4 to 5 times larger than those from atmospheric, terrestrial, or Keys' wastewater inputs, suggesting that the Gulf of Mexico and the Coastal Lake area are major sources of TP for Florida Bay. The increasing east-to-west gradient is opposite to that of TN. The CL segment and its two neighboring segments, WFB and CFB, were identified as having elevated nutrients. The source of the TP was attributed to natural processes (see TN and Chla sections). The TP criteria ranged from 0.008 to 0.050 mg/L for the AL and from 0.007 to 0.044 mg/L for the 1:3L.

Chlorophyll-a. The median Chla ranged from 0.29 to 6.5 mg/L and concentrations increased from east to west and from north to south in the Bay and from south to north along the Bay's western boundary with the Gulf Shelf, same as for TP. Diatom blooms in western Florida Bay have been linked to freshwater discharges from the Shark River watershed (Jurado et al., 2007) and phytoplankton blooms of cyanobacteria in the north central areas of the Bay to inflows from Taylor Slough, nitrogen fixation, and low turnover rates (Phlips and Badylak, 1996). The CL segment, located north of WFB and CFB, had exceedingly high Chla concentrations, 6 to 10 times higher than those of other segments. Both the CL and CFB segments were identified as having elevated Chla concentrations. The elevated nutrient levels have been associated with increased salinity (Frankovich et al., 2010). The criteria ranged from 0.37 to 10.17 µg/L for the AL and from 0.34 to 8.69 µg/L for the 1:3L.



FLORIDA BAY NUMERIC NUTRIENT CRITERIA

SEGMENT	TN, mg/L		TP, mg/L		Chla, µg/L	
	AL	1:3L	AL	1:3L	AL	1:3L
CFB	1.13	0.97	**0.021**	**0.018**	2.70	2.19
CL	**1.44**	**1.24**	**0.050**	**0.044**	**10.17**	**8.69**
ECFB	0.71	0.64	0.008	0.007	0.37	0.34
NFB	0.73	0.66	0.011	0.010	0.89	0.78
SFB	0.70	0.63	0.010	0.009	0.85	0.73
WFB	0.40	0.36	**0.016**	**0.014**	**1.45**	**1.26**

Criteria were rounded up

Bold numbers show potentially enriched segments

Figure 5. Florida Bay numeric nutrient criteria for TN, TP, and Chla. AL is the Annual Limit and 1:3L is the 1-in-3 Year Limit. The table provides the magnitude of the criteria with two decimal places for TN and Chla and three for TP.

Florida Keys

The Florida Keys (FK) is a chain of closely spaced islands extending 220 miles between the Gulf of Mexico and the Atlantic Ocean. The coastal and oceanic waters and submerged lands surrounding the FK form the Florida Keys National Marine Sanctuary. More than any of the other systems in south Florida, the Florida Keys is substantially impacted by external nutrient inputs from distant sources delivered by marine currents crisscrossing this archipelago (Lee et al., 2007). Other sources of nutrients are atmospheric deposition and local sources such as septic tanks, wastewater, and stormwater.

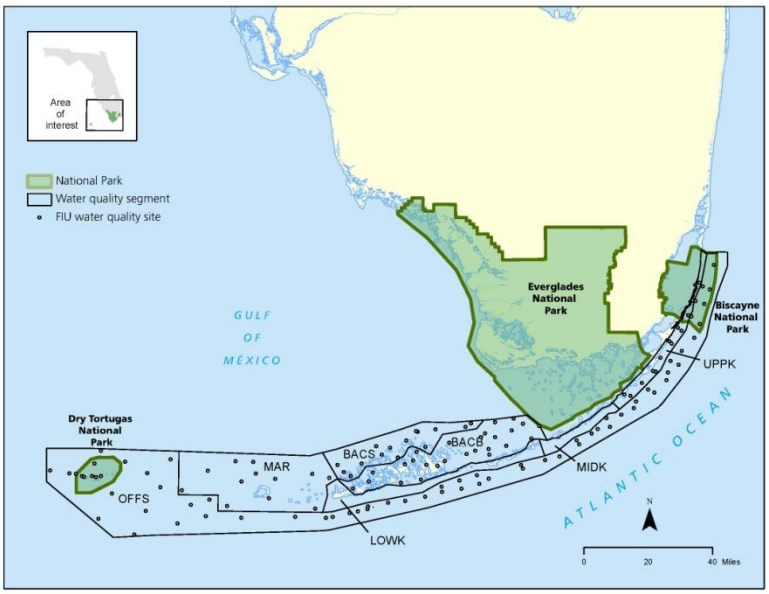
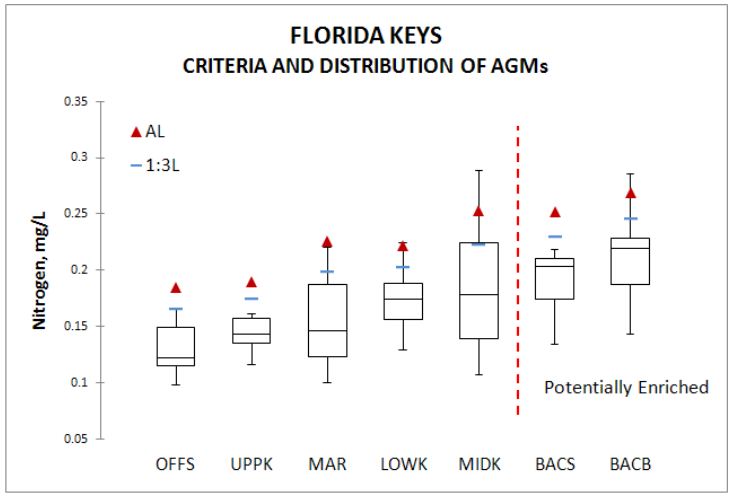
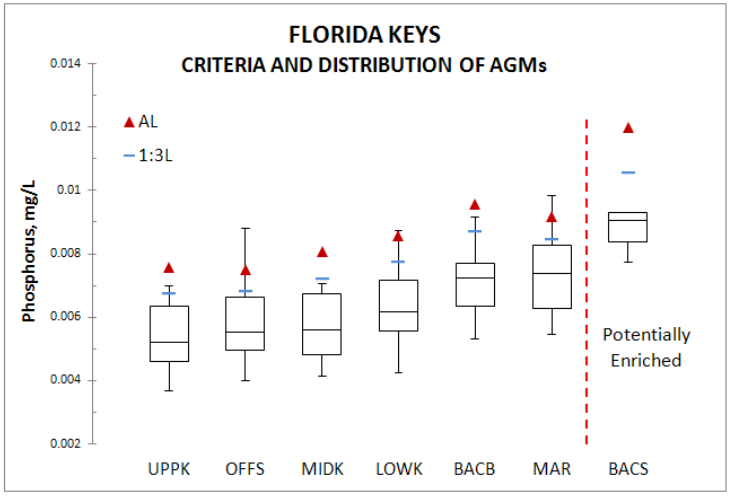


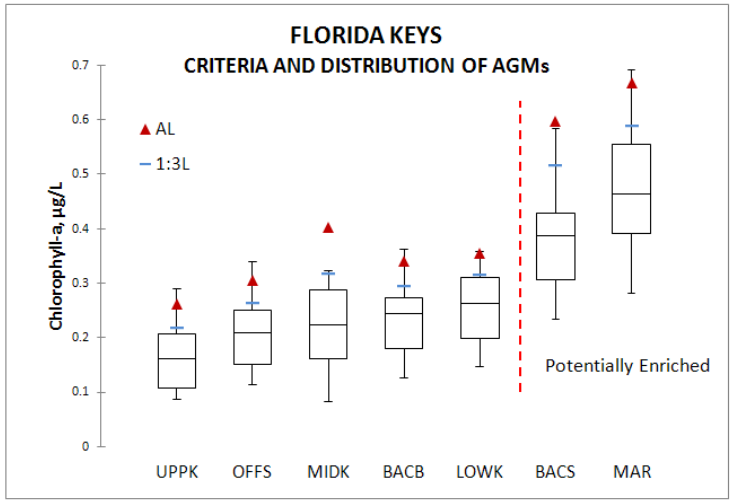
Figure 6. Florida Keys (FK) Segmentation for Nutrient Criteria Development.

The FK region was subdivided into seven segments (Fig. 6), which include the three traditional segments: UPPK, MIDK, LOWK; two segments on the Gulf side: BACS and BACB; one very long segment on the ocean side extending the entire length of the Florida Keys and including Dry Tortugas National Park: OFFS, and one segment that includes the Marquesas: MAR. Criteria and box plots of AGMs are shown in Figure 7.

Total Nitrogen. The median TN concentrations ranged from 0.12 to 0.22 mg/L and were the lowest of all coastal waters and estuaries in south Florida. Within the Florida Key segments, the OFFS and UPPK had the lowest concentrations and BACS and BACB had the highest. The TN concentrations in these two segments were significantly higher than those of the other segments and were marked as potentially nutrient enriched. Further examination of the nutrient concentrations in the adjacent Florida Bay and Gulf Shelf segments showed that there was a decreasing nutrient gradient towards the Florida Keys. In the absence of any other information, we hypothesized that the source of the elevated nutrient concentration in BACS and BACB were the adjacent segments in the Gulf Shelf and Florida Bay and not anthropogenic inputs from the Keys. It is important to note, however, that nutrients from land, mostly from stormwater runoff and septic tanks, may discharge into the sea via groundwater. In the ocean side of the Keys, by contrast, nutrients gradually decreased from inshore to offshore, suggesting that there was a net export of nutrients from the Florida Keys to the Atlantic Ocean. The TN criteria ranged from 0.18 to 0.27 mg/L for the AL and from 0.17 to 0.25 mg/L for the 1:3L.







FLORIDA KEYS NUTRIENT CRITERIA

SEGMENT	TN, mg/L		TP, mg/L		Chla, µg/L	
	AL	1:3L	AL	1:3L	AL	1:3L
BACB	**0.27**	**0.25**	0.010	0.009	0.34	0.30
BACS	**0.25**	**0.23**	**0.012**	**0.011**	**0.60**	**0.52**
LOWK	0.22	0.20	0.009	0.008	0.36	0.32
MAR	0.23	0.20	0.009	0.008	**0.67**	**0.59**
MIDK	0.25	0.22	0.008	0.007	0.40	0.32
OFFS	0.18	0.17	0.008	0.007	0.30	0.26
UPPK	0.19	0.17	0.008	0.007	0.26	0.22

Criteria were rounded up

Bold numbers show potentially enriched segments

Figure 7. Florida Keys numeric nutrient criteria for TN, TP, and Chla. AL is the Annual Limit and 1:3L is the 1-in-3 Year Limit. The table provides the magnitude of the criteria with two decimal places for TN and Chla and three for TP.

Total Phosphorus. The median TP concentrations ranged from 0.005 to 0.009 mg/L and were the lowest of all coastal waters and estuaries in south Florida. The UPPK and OFFS segments had the lowest concentrations and the BACS, MAR, and BACB segments the highest. The BACS segment was marked as potentially enriched, but the source of elevated TP appears to be the adjacent segments in the Gulf Shelf and Florida Bay (see TN section). The TP criteria ranged from 0.008 to 0.012 mg/L for the AL and from 0.007 to 0.011 mg/L for the 1:3L.

Chlorophyll-a. The media Chla concentrations ranged from 0.16 to 0.46 µg/L and was the lowest of all coastal waters and estuaries in south Florida. The UPPK and OFFS segments had the lowest concentrations and the BACS and MAR segments the highest. The distribution patterns of Chla appeared to be strongly influenced by the relatively elevated nutrient concentrations in adjacent Gulf Shelf and Florida Bay segments, as discussed previously. The Chla criteria ranged from 0.26 to 0.67 µg/L for the AL and from 0.22 to 0.59 µg/L for the 1:3L.

Gulf Shelf

The Gulf Shelf (GS), or more correctly, the Southwest Florida Shelf, is the southern extension of the West Florida Shelf. Circulation patterns in the Gulf Shelf are complex, vary seasonally, and respond to position and size of the Loop Current (Lee et al., 2002; Smith and Pitts, 2002). During most of the year, the water column in the Gulf Shelf is stratified with freshwater from the Everglades marshes and mangrove forest flowing offshore in the upper layers and higher salinity Gulf of Mexico water flowing toward shore in the lower layers (Lee, 2001). On-going oceanographic research shows that the Gulf Shelf basin, western Florida Bay, and the Lower and Middle Keys are strongly influenced by distant, upstream regions of the Gulf of Mexico and the Caribbean Sea (Lee et al., 2007). These distant influences must be carefully considered and evaluated when managing south Florida's coastal resources, including setting nutrient criteria.

For the purpose of developing nutrient criteria, the GS was divided into three segments, oriented from north to south and paralleling the costal line (Fig. 8): IGS near shore, MGS in the middle, and OGS farther offshore. Criteria and box plots of AGMs are shown in Figure 9.

Total Nitrogen. The median TN concentrations ranged from 0.17 to 0.22 mg/L and had a seaward decreasing trend. The TN criteria mimicked this pattern. There appeared to be a strong TN decreasing gradient from shore to sea associated with freshwater discharges from the Shark River watershed (Jurado et al., 2007), as discussed above. The TN criteria ranged from 0.24 to 0.32 mg/L for the AL and from 0.22 to 0.28 for the 1:3L.

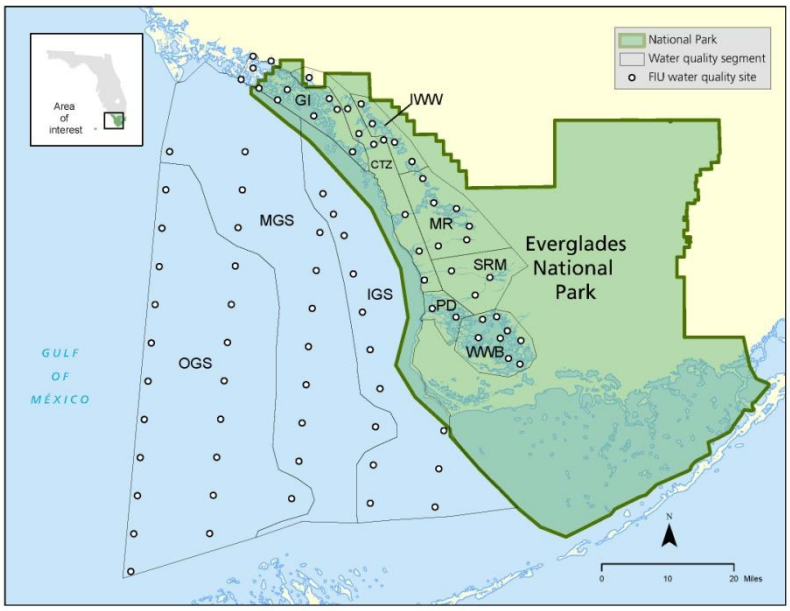


Figure 8. Gulf Shelf (GS) and Whitewater – Ten Thousand Island (WB-TI) Segmentation for Criteria Development.

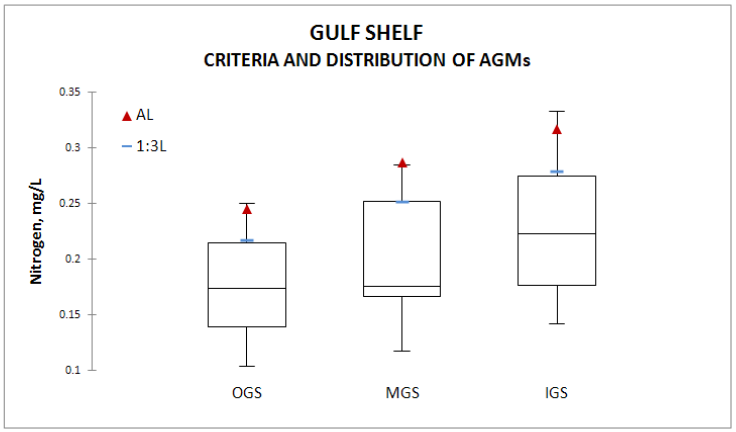
Total Phosphorus. The median TP concentrations ranged from 0.011 to 0.014 mg/L and were the lowest in the OGS segment, farthest from shore and highest in the IGS segment, closest to shore. Also there was a regional north-to-south gradient, with TP concentrations in WW-TT segments that were nearly double those in GS and more than triple those in FB. In GS, the TP criteria ranged from 0.014 to 0.018 mg/L for the AL and from 0.013 to 0.016 mg/L for the 1:3L.

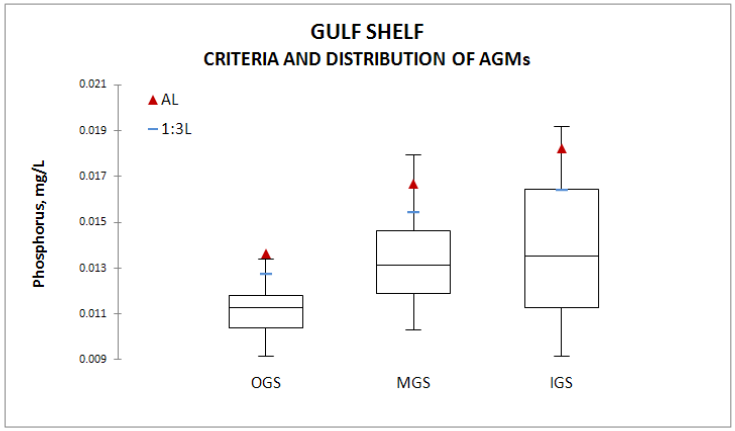
Chlorophyll-a. Chla concentrations had a similar distribution pattern as those of TN and TP. The median Chla ranged from 0.81 to 1.21 µg/L and was lowest in OGS, the segment farthest from shore, and was highest in MGS and IGS, the segments closest to shore. The MGS and IGS were marked as potentially enriched segments, but, in the absence of anthropogenic inputs, their source of nutrients appeared to be the Gulf of Mexico waters. The Chla criteria ranged from 1.07 to 1.57 µg/L for the AL and from 0.96 to 1.38 µg/L for the 1:3L.

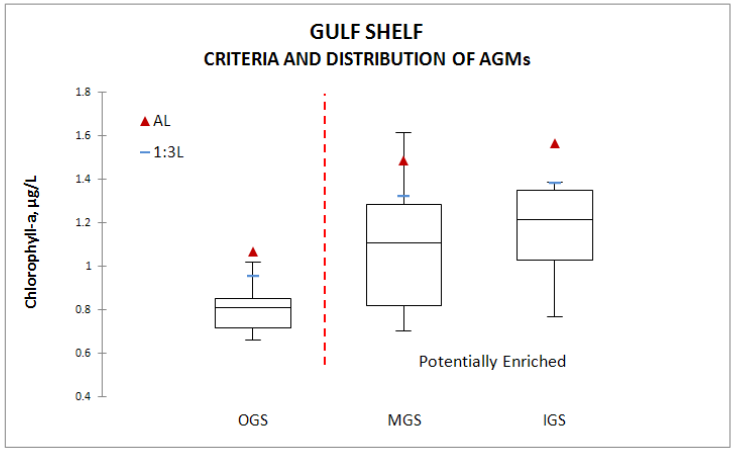
Whitewater Bay – Ten Thousand Islands

The Whitewater Bay – Ten Thousand Islands (WB-TI) region includes the chain of islands off the southwest Florida coast, south of Cape Romano, and extends south to include the coastal area of western Everglades National Park. This region represents the westernmost portion of the Everglades ecosystem and encompasses the largest mangrove forest in North America. The northern section of the Ten Thousand Islands is a National Wildlife Refuge and its lower section is part of Everglades National Park. Most of the area is largely undeveloped but channelization of the upper watershed has altered freshwater discharges and impacted water quality.

The WB-TI region was divided into eight segments that were mostly oriented parallel to the coast line (Fig. 8). The BLK, GI, CTZ, and IWW segments are downstream from the Big Cypress Swamp watershed and the MR, SRM, PD, and WWB segments are downstream from the Shark River watershed. Criteria and box plots of AGMs are shown in Figure 10.







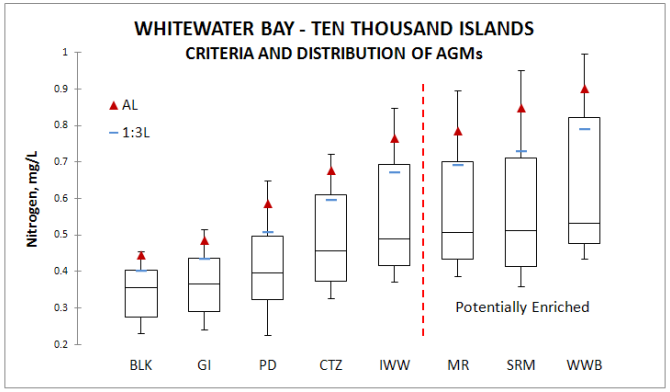
GULF SHELF NUMERIC NUTRIENT CRITERIA

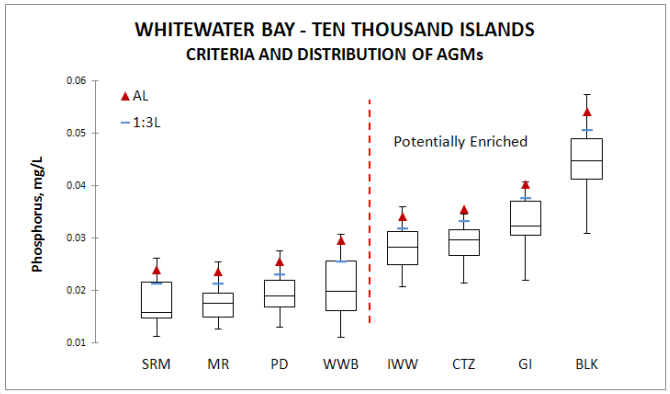
SEGMENT	TN, mg/L		TP, mg/L		Chla, µg/L	
	AL	1:3L	AL	1:3L	AL	1:3L
IGS	0.32	0.28	0.018	0.016	**1.57**	**1.38**
MGS	0.29	0.25	0.017	0.015	**1.49**	**1.32**
OGS	0.24	0.22	0.014	0.013	1.07	0.96

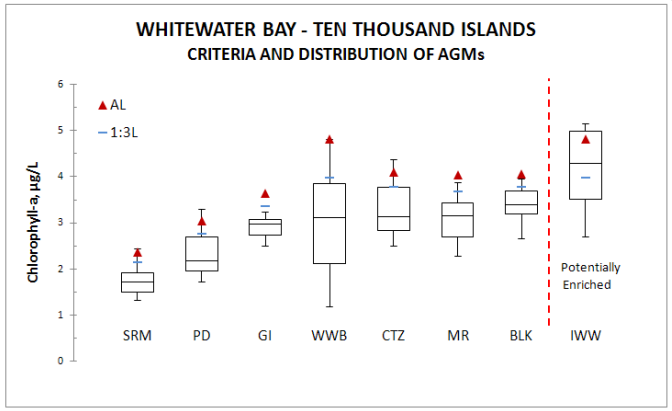
Criteria were rounded up

Bold numbers show potentially enriched segments

Figure 9. Gulf Shelf nutrient criteria for TN, TP, and Chla. AL is the Annual Limit and 1:3L is the 1-in-3 Year Limit. The table provides the magnitude of the criteria with two decimal places for TN and Chla and three for TP.







WHITEWATER BAY - TEN THOUSAND ISLANDS NUTRIENT CRITERIA

SEGMENT	TN, mg/L		TP, mg/L		Chla, µg/L	
	AL	1:3L	AL	1:3L	AL	1:3L
BLK	0.44	0.40	**0.054**	**0.051**	4.07	3.78
CTZ	0.68	0.60	**0.036**	**0.033**	4.09	3.78
GI	0.49	0.44	**0.040**	**0.038**	3.63	3.36
IWW	0.76	0.67	**0.034**	**0.032**	**4.82**	**3.98**
MR	**0.78**	**0.69**	0.024	0.021	4.03	3.69
PD	0.59	0.51	0.026	0.023	3.04	2.76
SRM	**0.85**	**0.73**	0.024	0.021	2.37	2.14
WWB	**0.90**	**0.79**	0.030	0.026	4.82	3.98

Criteria were rounded up

Bold numbers show potentially enriched segments

Figure 10. Whitewater Bay – Ten Thousand Islands nutrient criteria for TN, TP, and Chla. AL is the Annual Limit and 1:3L is the 1-in-3 Year Limit. The table provides the magnitude of the criteria with two decimal places for TN and Chla and three for TP.

Total Nitrogen. The median TN ranged from 0.36 to 0.53 mg/L and decreased from south to north. The TN criteria followed the same pattern. Marsh discharges from the Shark River watershed appeared to contribute to the elevated TN concentrations in WWB, SRM, and MR, which are closest to the terrestrial inputs. The elevated TN signature in the freshwater may come from agricultural runoff in the northern Everglades delivered to Everglades National Park by canals. The TN criteria ranged from 0.44 to 0.90 mg/L for the AL and from 0.40 to 0.79 for the 1:3L.

Total Phosphorus. TP concentrations had an opposite trend to that of TN. Median TP concentrations ranged from 0.016 to 0.044 mg/L and increased from south to north. TP concentrations were found to be elevated at IWW, CTZ, GI, and BLK. The source of the TP appeared to be located outside the area, mostly from urban areas located farther north along the coast and from the Gulf of Mexico. The nutrient criteria ranged from 0.024 to 0.054 mg/L for the AL and from 0.021 to 051 mg/L for the 1:3L.

Chlorophyll-a. Chla concentrations followed the TP trend. Median Chla concentrations ranged from 1.73 to 4.29 µg/L and were lowest in the southern end and highest in the northern end of the system. The Chla concentrations in IWW were elevated and this segment was identified as potentially enriched. The source of the nutrients appeared to be located outside this segment, mostly from areas farther north along the coast. The criteria ranged from 2.37 to 4.82 µg/L for the AL and from 2.14 to 3.98 µg/L for the 1:3L.

COMPARISON OF FDEP AND ENP's CRITERIA

FDEPs 1-in-3 Year Limits were similar in value but higher than ENP's proposed 1-in-3 Year Limits, with some important exemptions (Table 3). The similarity was expected because ENP's methodology was a modified version of FDEP's methodology (explained above). FDEP's criteria were higher because the limits were based on higher standard deviation values and computed from predicted intervals. The main discrepancy in criteria came from potentially nutrient enriched segments. FDEP's methodology failed to identify nutrient enriched segments and to recognize that existing nutrient conditions in these segments were elevated enough possibly to cause an imbalance in the flora and fauna of the aquatic ecosystem. ENP's methodology identified potentially enriched segments and excluded them from becoming reference sites (see discussion above).

Noticeable differences between FDEP's and ENP's 1-in-3 Year criteria were mostly identified for Chla in BB and FB. The segments with greater than 10 percent differences in criteria were:

- In Biscayne Bay:
    - TP: NNB and SNB. FDEP didn't identified these segments as potentially enriched even though their watersheds have been extensively developed into urban and commercial areas and water quality has been degraded
    - TN: SCI and SCM. FDEP didn't identify these segments as potentially enriched even though their watersheds have been extensively developed into agricultural fields and canal discharges are laden with nutrients

    - Chla: NCI, NCO, NNB, SCI, and SNB. FDEP didn't identify these segments as potentially enriched even though their watersheds have been extensively developed. These segments are impacted by canal delivery of urban runoff rich in TP or agricultural runoff rich in TN.

- In Florida Bay, discrepancies in Chla criteria were found at ECFB, SFB, and WFB. The differences could be associated with the methodology and the data. While ECFB could possibly have anthropogenic nutrient inputs from nearby terrestrial sources, SFB and WFB could not. These two segments are upstream and many miles away from potential Florida Key's anthropogenic sources.

- In the Florida Keys, discrepancies in Chla criteria were found at BACS and OFFS. The differences could be associated with the methodology and the data. We identified BACK as potentially enriched but concluded that the source of nutrients was the adjacent GS segments.

- In the Whitewater Bay –Ten Thousand Islands, discrepancies in Chla criteria were found at IWW. Again, the difference could be related to the methodology and data. We identified IWW as potentially enriched but concluded that the source of nutrients was urban development from farther north along the coast.

In a few cases, ENP's proposed criteria were higher than the FDEPs criteria. Those cases are shown as bold numbers in Table 3. We have not investigated these differences but speculated that may be related to the data, segmentation, and methodology.

CONCLUSIONS AND RECOMMENDATIONS

We have reviewed and analyzed FDEP's numeric nutrient criteria for south Florida estuaries and coastal waters and agreed with the overall approach. We also recognized that there are some necessary improvements and changes that needed to be implemented to FDEPs methodology. In order of importance, they are:

- Include a method for identifying potentially enriched segments by anthropogenic sources. Nutrient levels in these segments could be elevated enough to cause adverse effects to the aquatic biota. Consequently, these stations shouldn't be used as reference sites to set criteria. In our analyses, we identified several segments to be potentially enriched by anthropogenic sources; however, FDEP's analyses didn't. We strongly recommend that FDEP modify its analysis to include (a) a process to identify segments that should not be used as reference sites and (b) a process to identify and select alternate reference sites.

- Add a second part to the numeric nutrient criteria to avoid large exceedences that could cause catastrophic impacts on the ecosystem, and to provide an earlier (1 year instead of 3 years) warning of potential problems. The two parts we are recommending are:

    - the 1-in-3 year Limit (1:3L), not to be exceeded more than once in 3 years, and
    - the Annual Limit (AL), never to be exceeded.

- Base the limits on percentiles rather than on predictive intervals.

Simplify the analysis of variance, which appears to be unnecessarily complicated and may be incorrect. FDEP's analysis of variance, to estimate the true interannual standard deviation, included the interannual, spatial, and within-year variances. The first two variances, interannual and spatial, were estimated from annual geometric means, but the within-year variance was estimated from unaggregated values, which are larger than for annual or spatial averages. The estimation of both annual limits, 1:3L and AL, should be based on the standard deviation of a segment's AGM only.

For additional information, contact Dr. Joffre Castro at 305.224.4247 or at Joffre_Castro@nps.gov

Table 3. FDEP and ENP's 1-in-3 Year Criteria

			FDEP 1:3L			ENP 1:3L		
WATERBODY	SYMBOL	SEGMENT NAME	mg/L		µg/L	mg/L		µg/L
			TP	TN	Chla	TP	TN	Chla
Biscayne Bay	CS	Card Sound	0.008	0.33	0.50	0.007	0.31	0.47
	MBS	Manatee Bay – Barnes Sound	0.007	0.58	0.40	0.007	0.58	**0.43**
	NCI	North Central Inshore	0.007	0.31	0.50	0.007	0.30	0.41
	NCO	North Central Outer-Bay	0.008	0.28	0.70	0.007	0.27	0.47
	NNB	Northern North Bay	0.012	0.30	1.70	0.007	0.29	0.47
	SCI	South Central Inshore	0.007	0.48	0.40	0.007	0.31	0.34
	SCM	South Central Mid-Bay	0.007	0.35	0.20	0.007	0.31	**0.31**
	SCO	South Central Outer-Bay	0.006	0.24	0.20	0.006	0.23	**0.24**
	SNB	Southern North Bay	0.010	0.29	1.10	0.007	0.28	0.47
Florida Bay	CFB	Central Florida Bay	0.019	0.99	2.20	0.018	0.97	2.19
	CL	Coastal Lakes	0.045	1.29	9.30	0.044	1.24	8.69
	ECFB	East Central Florida Bay	0.007	0.65	0.40	0.007	0.64	0.34
	NFB	Northern Florida Bay	0.010	0.68	0.80	0.010	0.66	0.78
	SFB	Southern Florida Bay	0.009	0.64	0.80	0.009	0.63	0.73
	WFB	Western Florida Bay	0.015	0.37	1.40	0.014	0.36	1.26
Florida Keys	BACB	Back Bay	0.009	0.25	0.30	0.009	0.25	0.30
	BACS	Backshelf	0.011	0.23	0.70	0.011	0.23	0.52
	LOWK	Lower Keys	0.008	0.21	0.30	0.008	0.20	**0.32**
	MAR	Marquesas	0.008	0.21	0.60	0.008	0.20	0.59
	MIDK	Middle Keys	0.007	0.22	0.30	0.007	0.22	**0.32**
	OFFS	Offshore	0.007	0.17	0.30	0.007	0.17	0.26
	UPPK	Upper Keys	0.007	0.18	0.20	0.007	0.17	**0.22**
Whitewater Bay - Ten Thousand Islands	BCK	Blackwater River	0.053	0.41	4.10	0.051	0.40	3.78
	CTZ	Coastal Transition Zone	0.034	0.61	3.90	0.033	0.60	3.78
	GI	Gulf Islands	0.038	0.44	3.40	0.038	0.44	3.36
	IWW	Inner Waterway	0.033	0.69	5.20	0.032	0.67	3.98
	MR	Mangrove Rivers	0.021	0.71	3.70	0.021	0.69	3.69
	PD	Ponce de Leon	0.024	0.52	3.00	0.023	0.51	2.76
	SRM	Shark River Mouth	0.022	0.75	2.20	0.021	0.73	2.14
	WWB	Whitewater Bay	0.026	0.82	4.10	0.026	0.79	3.98

Bold numbers indicate that ENP criterion is larger than FDEP criterion

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