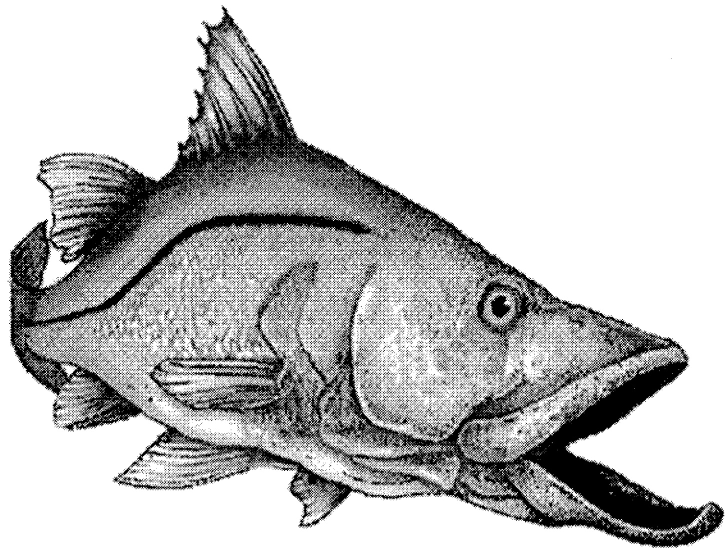
TECHNICAL MEMORANDUM NO. 12



INDIAN RIVER LAGOON WATER QUALITY MONITORING NETWORK: PROPOSED MODIFICATIONS

BY

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WATER QUALITY MONITORING NETWORK: PROPOSED MODIFICATIONS

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EXECUTIVE SUMMARY

This document describes and provides justification for proposed modifications to the water quality monitoring network (WQMN) in the Indian River Lagoon (IRL). The protection and maintenance of good water quality related to the re-establishment of a healthy seagrass ecosystem can best be accomplished through continued coordination among the WQMN agencies, and re-examination and refinement of the WQMN to meet current needs.

The IRL WQMN was established in 1988 and continues to operate through the cooperative efforts of the participating agencies: St. Johns River and South Florida Water Management Districts, Volusia County, Brevard County, Indian River County, and NASA (represented by their consultant, Dynamac, Inc.). The network presently consists of 150 fixed sampling stations that cover the entire length of the IRL system from New Smyrna Beach through Hobe Sound and including the Banana River Lagoon.

The proposed modifications to the network are intended to further focus its mission on (a) providing answers to specific questions related to the *long-term* management of *seagrass* and the *water quality* of its environment, (b) increasing the statistical power of the data collected (and, thus, the performance of the WQMN), (c) increasing the effectiveness of staff and laboratory resources, and (d) collecting complementary data for the calibration of the Pollution Load Reduction (PLR) Model. Furthermore, as management strategies are enacted to achieve pollution load reduction goals (PLRGs), the WQMN can help gauge their effectiveness in improving water quality necessary for seagrass recovery

Modifications to the WQMN would be in effect for up to three (3) years before re-evaluation. The proposed modifications are:

1) a substantial decrease in the number of fixed sampling stations;
2) the selection of existing sampling stations based on their proximity to seagrass measurement transects;

3) an increase in the sampling frequency at each station to three times per station during a tidal cycle each month (dropping back to one sampling per station per month after three years);

4) the inclusion of near-bottom nutrient samples to be collected at each station, at least once during a tidal cycle (~12 hr) each month, to help calibrate the PLR Model;

5) the measurement of the separate organic and inorganic fractions of total supended solids; and

6) the centralization of laboratory analyses to reduce potential analytical errors (which can occur when several laboratories are involved in a monitoring program).

By streamlining the WQMN as proposed, staff and laboratory resources will be used more effectively and place less budgetary demand on the participating agencies. The ultimate benefit will be a more cost-effective and efficient monitoring tool to measure the water quality of the seagrass environment.

INTRODUCTION

There is growing evidence that the *biological integrity* [1] of the Indian River Lagoon (IRL) has declined during the last 50 years. Increased anthropogenic activities have altered hydrologic and hydrodynamic patterns and increased the loading of pollutants, especially nutrients and suspended matter (Steward, *et al.*,1994). These changes are in the process of transforming the IRL from a macrophyte-based system to a phytoplankton or algal-based system. The most troubling indication of this transformation is the loss of seagrasses near urbanized areas, where water quality has apparently declined.

One of the mutual goals of the IRL Surface Water Improvement & Management (SWIM) and National Estuary programs is to attain and maintain a sufficient level of water and sediment quality to support a healthy, macrophyte based, estuarine lagoon ecosystem. The IRL water quality monitoring network (WQMN) is an invaluable management tool, with a mission to:

(1) characterize the IRL over the long term - assess the status and trends in estuarine water chemistry in relation to primary producers as indicators of biological integrity, especially seagrasses, the key macrophytes;

(2) identify problem areas (via indicators of biological integrity de-stabilization, i.e., some trend toward phytoplankton dominance over macrophytes);

(3) measure the effectiveness of management objectives and actions intended to remediate the problem areas;

(4) provide current information to re-direct or re-focus management plans; and

(5) provide accountability to the public by relating progress toward restoration and protection of the IRL.

This five-point mission of the WQMN is facilitated by close coordination of the participating WQMN agencies to ensure proper, quality-assured operation of the network, and *the periodic evaluation and modification of the network as necessary to meet current resource assessment needs.*

The WQMN was established in 1988 as a coordinated multi-agency project spanning the entire length (~155 miles) of the IRL system, from New Smyrna Beach through Hobe Sound (Figure 1a and b). The active participants of the network are the St. Johns River Water Management District (SJRWMD), South Florida Water Management

[1] Biological integrity: "... refers to a system's wholeness, including presence of all appropriate elements and occurrence of all processes at appropriate rates...refers to conditions under little or no influence from human actions;...high integrity reflects natural evolutionary and biogeographic processes." (Angermeier and Karr, 1994)

District (SFWMD), Volusia County, Brevard County, Indian River County, and NASA (represented by Dynamac, Inc.)[2]. These agencies collectively manage a total of 150 stations (nearly one station per Lagoon mile). The WQMN has generated useful information on the physical and chemical conditions of the IRL and its inferred relationship to the Lagoon's well-being or biological integrity.

However, the basic questions encountered when the current WQMN was designed was "what Lagoon resource(s) best represent or define the desired level of biological integrity, and what are the requisite water quality maintenance criteria?" These questions are difficult to answer because of the size and complexity of the IRL system. Nonetheless, sufficient progress has been made, in light of new information and scientific consensus, to warrant some modifications to the WQMN.

It is now generally accepted by the scientific and resource management establishment that seagrasses are a good indicator of biological integrity and health within the open waters of the IRL (Morris and Tomasko, 1993; Steward *et al.*, 1994). Seagrasses should be preserved or restored because they possess high value by providing habitat for an entire biological community, in addition to their value as primary producers (Morris and Tomasko, 1993). Sunlight availability or photosynthetically active radiation (PAR) is the limiting factor controlling the abundance and distribution of seagrasses in the IRL (Kenworthy and Haunert, 1991; Dennison *et al.*, 1993; Morris and Tomasko, 1993, Stevenson *et al.*, 1993). PAR is strongly influenced by those water quality characteristics that affect water transparency. Thus, the WQMN could more efficiently monitor the health of the IRL if it was further focused and strengthened in its ability to quantify PAR and those water quality constituents that attenuate PAR. By streamlining the WQMN to achieve this goal, staff and laboratory resources would be used more effectively and budgetary pressures on the WQMN participants would be eased as well. The ultimate benefit would be a more cost-effective and efficient monitoring tool to gauge the water quality of the seagrass environment.

RESOURCE MANAGEMENT QUESTIONS TO BE ADDRESSED BY THE WQMN

Specific resource management questions should be developed to re-focus the WQMN within the context of its mission and enable conversion of data into meaningful information regarding the interrelationship among water quality, PAR, and seagrass PAR requirements. The WQMN participant agencies have

[2] For more information on the WQMN, its current design details and sampling procedures, please refer to the IRL SWIM Plan (1994), Higman (1993), and the IRL WQMN Quality Assurance/Quality Control Manual, 1988 - 1990 (1991).

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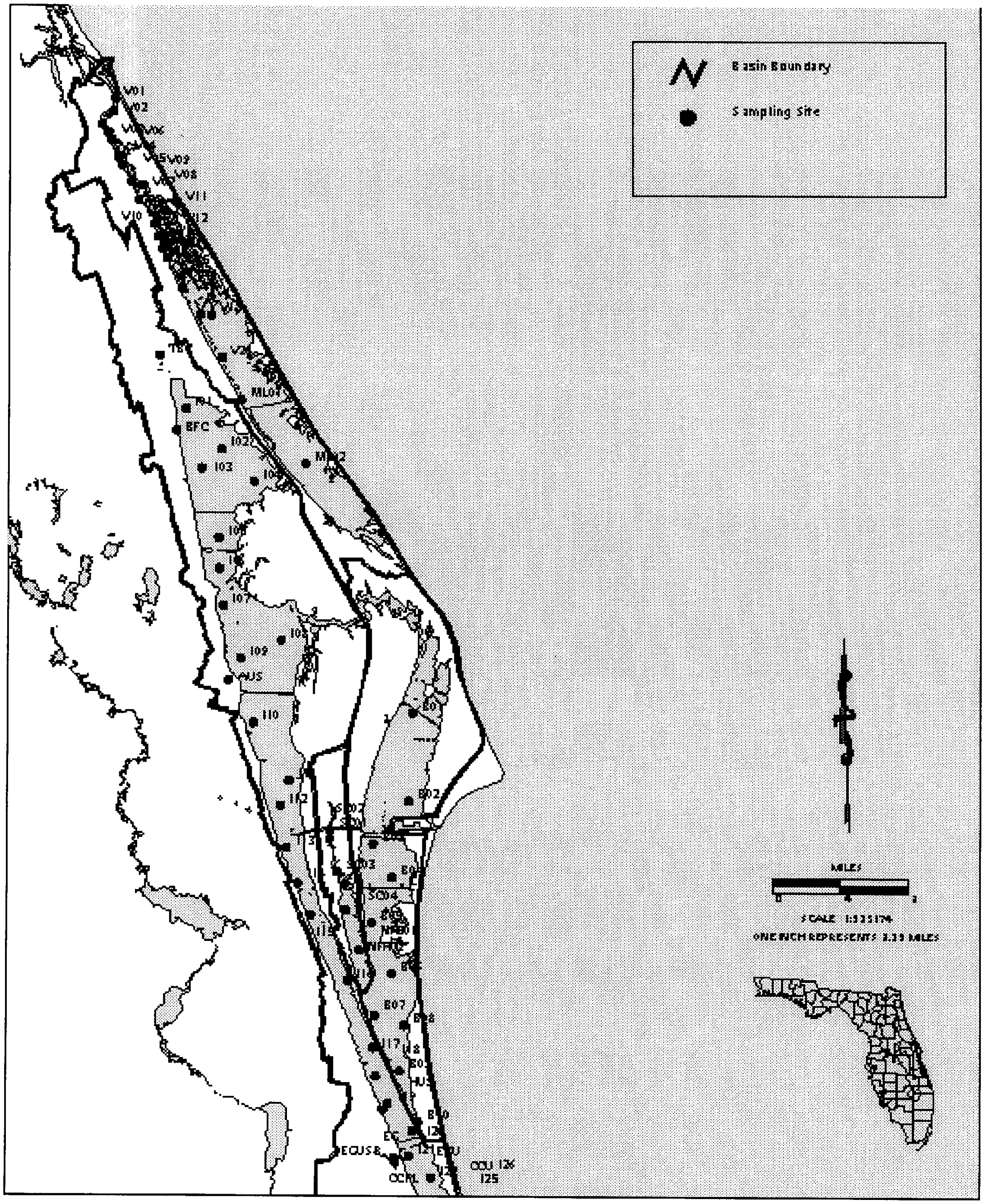

Figure 1a.
Water Quality Monitoring Sites
in the Indian River Lagoon
Source: SJRWMD, 1995

/LAGOONHOME/IRLPROJ/AMLS/lagoonhome/irlproj/maps/lagoon/lagoon_85x11_south.cmp (wat 12/05/95)

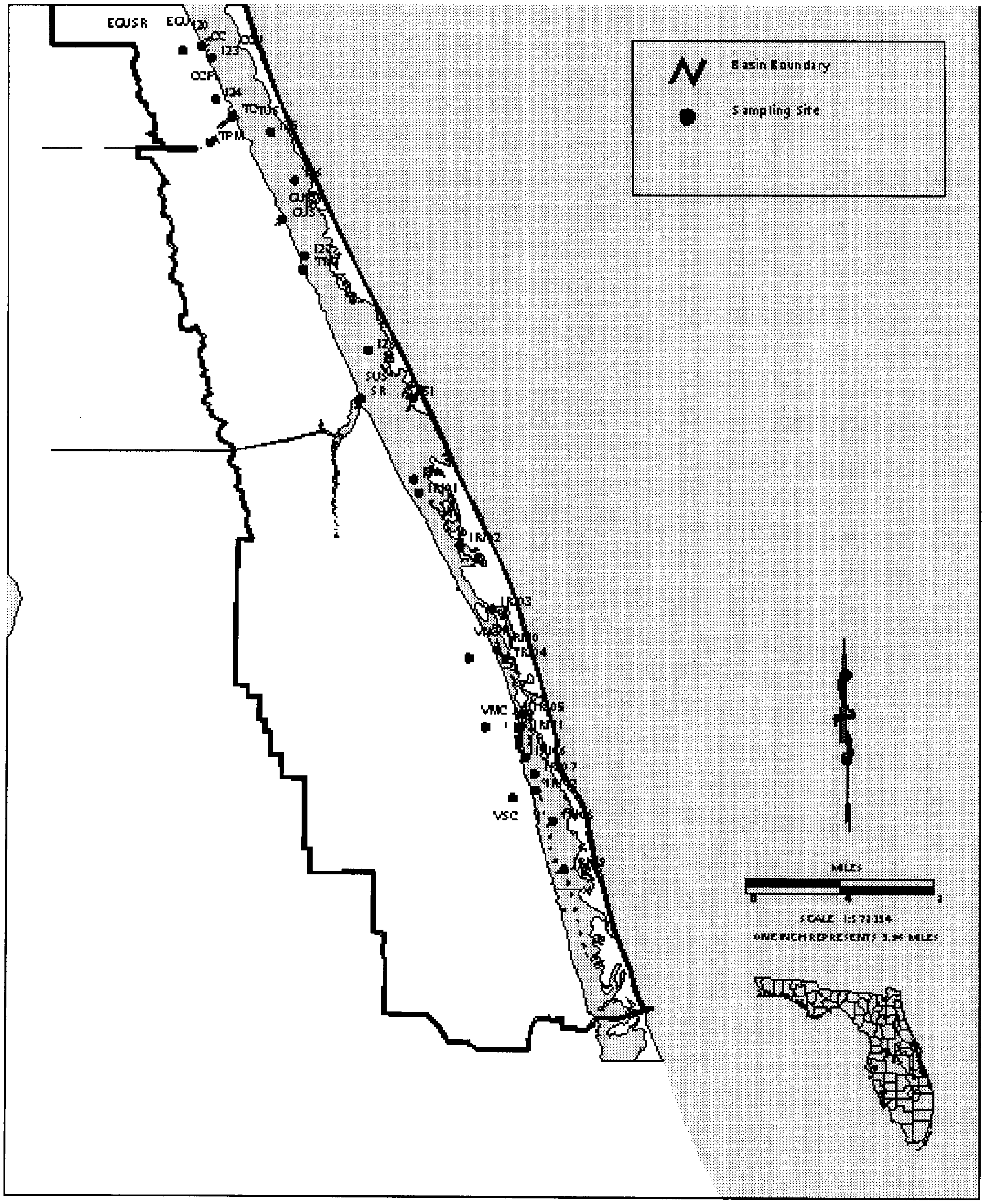

Figure 1b.
Water Quality Monitoring Sites
in the Indian River Lagoon
Source: SJRWMD, 1995

met (January 5 and 17, 1995; February 10, 1995) and offered a set of questions whose answers should be attempted by the network:

- What is the Lagoon-wide concentration gradient of the primary water quality constituents or variables that control water column PAR attenuation (*K*) and primary productivity?

- Generally, what constitutes good or poor water quality?

  What is good vs. poor would be based on water quality criteria for the IRL --

  Example 1: constituents and their maximum allowable concentrations related to some seagrass PAR requirement in the IRL (e.g., 25% of surface irradiance at 1.7 m depth).

  Example 2: nutrients and their maximum allowable concentrations related to microalgal biomass (e.g., microalgal biomass, expressed as chlorophyll a concentration, should not exceed the high standard deviation value of the wet season mean).

  Such criteria would be developed primarily by other research projects.

- Where is water quality considered poor (and where is it good)? What distinctions in water quality can be discerned between or among segments of the IRL (e.g., is there a statistical difference in water quality characteristics between the north and south segments of Banana River Lagoon)?

- In any specific segment of the IRL, is water quality declining or improving? If water quality is improving, is *K* showing a concomitant decrease? Have areas of demonstrated improvement been subjected to management actions (e.g., implementation of pollution load reduction goals via stormwater retrofits or other pollutant controls)?

- Is there a quantitative or statistical relationship between poor water quality areas, a certain high level of *K*, and poor seagrass coverage areas (and is the converse apparent for good areas)?

- Are there seasonality or other temporal patterns in water quality, lagoon-wide or per segment?

- Can the WQMN complement other programmatic work, especially the development of the PLR Model? For example, does the current network account for the major "attenuators" of PAR? What spatial and temporal density of sampling stations and events are adequate for the purpose of PLR Model calibration?

These questions provide guidance in the re-design of the WQMN with respect to what variables need to be measured, spatial and temporal sampling specifications, and analytical procedures. These and other re-design issues are addressed in the following sections.

PROPOSED MODIFICATIONS TO THE WQMN DESIGN

Synopsis

It is proposed that the five-point mission be preserved and the fundamental structure of the WQMN remain intact; i.e., a spatial array of strategically placed, fixed stations sampled at regular time intervals. Fixed stations sampled over the long term can provide a water quality baseline, yielding information on the spatial and temporal trends in water quality and the relationship between water quality and seagrass coverage. Seagrass coverage is being mapped every 1 to 3 years under a separate SJRWMD project (Virnstein and Morris, 1995; Steward et al., 1994).

The proposed modifications to the WQMN are intended to re-focus the mission of the network by (a) addressing the resource management questions posed above, (b) increasing the statistical power of the data collected (and, thus, the performance of the WQMN), (c) increasing the effectiveness of staff and laboratory resources, (d) providing complementary data for the calibration of the seagrass-based PLR Model and measuring the effectiveness of pollution load reduction strategies. Modifications to the WQMN would be in effect for up to three years before re-evaluation. The proposed modifications are:

1) a substantial decrease in the number of fixed sampling stations in the lagoon proper in Volusia, Brevard, and Indian River counties (24 lagoon stations and all 12 SJRWMD tributary stations retained, 50 lagoon stations deleted);

2) the selection of existing sampling stations based on their proximity to seagrass measurement transects managed by the SJRWMD (Virnstein and Morris, 1995);

3) an increase in the sampling frequency at each station to three times per station during a tidal cycle (~ 12 hr) each month (dropping back to 1 time per station per month after three years);

4) the inclusion of near-bottom nutrient samples, to be collected at each station at least once during a tidal cycle each month for 2 - 3 years to help calibrate the PLR Model; and

5) the measurement of the organic and inorganic fractions of total suspended solids.

6) a centralization of laboratory analyses to reduce potential analytical errors (which can occur when several laboratories are involved in a monitoring program);

Another result of the modifications would be a substantial long-term cost savings. The annual laboratory costs of the modified network that would serve the data needs of the PLR Model over the next three years would be comparable to that of the existing network. But, following the third year (1998), the frequency of sampling would substantially decrease as would the costs.

Regular data analysis and presentation of monitoring results should be as routine as the monitoring itself. They are important as a means to evaluate the WQMN's performance -- its ability to answer resource management questions and provide accountability to the public. Knowing the type of information to be presented and to whom it is presented determines the methods of data analysis and presentation. Green (1979) emphasized the importance of developing testable hypotheses during the design phase of environmental studies. The development of testable hypotheses and the selection of statistical methods are the first steps in evaluating the expected performance of the WQMN.

The Proposed Modifications -- Descriptions and Justifications

Number and Locations of Sampling Stations

The SJRWMD proposes a selective reduction in the number of sampling stations to eliminate statistically unnecessary sampling, resulting in a more efficient sampling effort in the IRL system. The stations that are retained will continue to provide information on the *long-term* spatial and temporal trends of the water quality and help discern the covariant or causal link between seagrass coverage (distribution/density) and water quality.

The decision to retain or delete stations was initiated with a sequence of statistical analyses of water quality data that served to group neighboring stations representing a Lagoon segment of relatively homogeneous water quality. Then, within each segment, one or two representative stations were selected based on proximity to seagrass monitoring transects and to prominent watershed impacts (e.g., wastewater treatment plants, significant tributary or stormwater inflows, inlets, etc.).

Statistical Analyses -- Segmentation. As an aid to the foregoing discussion, a schematic (Figure 2) is included that depicts the sequence of statistical tests used to determine segmentation (the number and placement of lagoon segments).

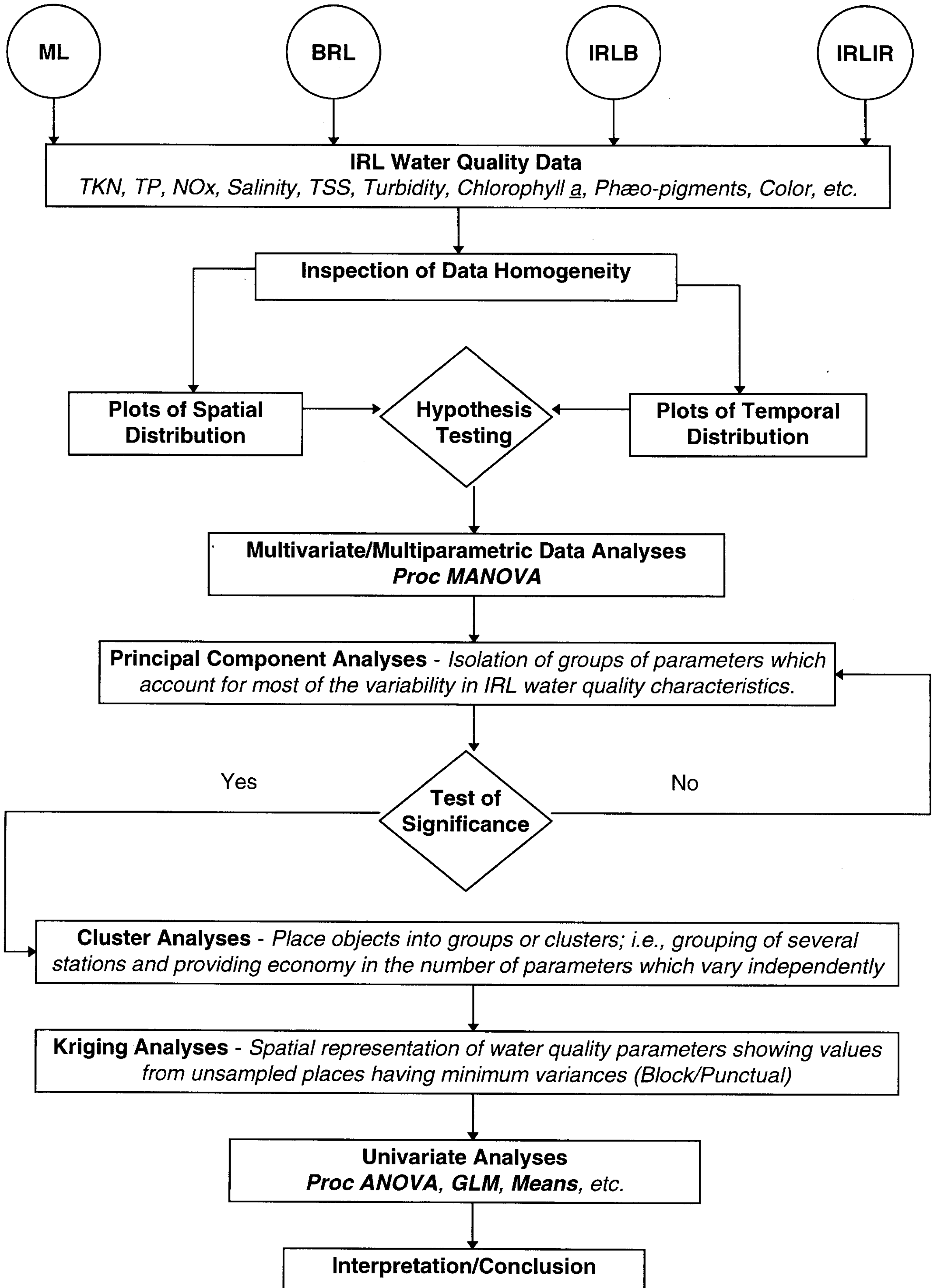

Figure 2. Flowchart of statistical tests for the segmentation of the Indian River Lagoon (ML-Mosquito Lagoon; BRL-Banana River Lagoon; IRLB-Indian River Lagoon-Brevard County; IRLIR-Indian River Lagoon-Indian River County).

First, the IRL Basin was treated as four separate reaches: Mosquito Lagoon (ML), Banana River Lagoon (BRL), Indian River Lagoon - Brevard County (IRL-B), and Indian River Lagoon - Indian River County (IRL-IR). Water quality variables that can affect seagrasses, and for which there are sufficient data, were selected to delineate reach segments. The water quality data for each reach were assumed to be normally distributed, and have independence of observation and homogeneity of variance over the period of record. Second, each reach was initially divided into segments based on a visual discrimination of water quality differences between station groupings aided by spatial and temporal data distribution plots. Then, multivariate analyses, including *Proc Manova* and *Principal Component Analysis*, served to accept or reject the segmentation hypotheses, as stated below.

1) ***Mosquito Lagoon***: (***Ho*** - null hypothesis; ***Ha*** - alternative hypothesis)

Ho : Total segments = 0
Ha : Total segments ≠ 0 (at least 3 segments based on visual discrimination)

Result: :Reject *Ho*; Mosquito Lagoon has 4 segments

2) ***Banana River Lagoon***:

Ho : Total segments = 0
Ha : Total segments ≠ 0 (at least 3 segments based on visual discrimination)

Result: Reject *Ho*: Banana River Lagoon has 3 segments

3) ***IRL-B*** (Brevard County)

Ho : Total segments = 0
Ha : Total segments ≠ 0 (up to 8 segments based on visual discrimination)

Result: Reject *Ho*: Indian River Lagoon (IRL-B) has 7 segments

4) ***IRL-IR*** (Indian River County)

Ho: Total segments = 0
Ha: Total segments ≠ 0 (at least 3 segments based on visual discrimination)

Result: Reject *Ho*: Indian River Lagoon (IRL-IR) has 3 segments

The accepted number of segments per reach is supported by the results of multivariate analyses -- *principal component* analysis, *cluster*, and *kriging* analysis. The variables selected for analyses were *salinity*, *DO*, *turbidity*, *Chlorophyll a*, *TP*, and *TKN*, with a 1987 - 1991 period of data record.

For each lagoon reach, *principal component* analysis of these data identified the principal variable(s) responsible for inter-segment variability. In Mosquito Lagoon, it was turbidity; in the Banana River Lagoon and IRL-B, it was salinity; and in the IRL-IR, it was both turbidity and salinity. The grouping of "like" stations or a segmenting of each of the lagoon reaches, based on principal component analysis, was confirmed by *cluster* and *kriging* analyses, and *univariate* analyses (Figures 2, 3a, 3b, 4a, 4b, 5a, 5b, 6a, 6b, 7a, and 7b). The location of the proposed segments above are shown in Figures 8, 9, 10, and 11. Table 1a provides descriptive information on each of the retained stations.

Further discussion of the statistics used to support the proposed segmentation is provided in Appendix B (Data Analyses and Summary Statistics; Tables B.2 to B.10).

Station Selection. Stations were selected within each segment based on their proximity to existing seagrass transects. Station selection was also based on major or representative land-based activities and resource features within the IRL Basin (e.g., wastewater treatment plants, inlets, tributary inflows from significant urban watersheds and relatively undeveloped watersheds). The closest existing water quality sampling stations to the SJRWMD seagrass transects were identified and tabulated in Table 1b.

Furthermore, sampling locations should be representative of the mean values of relevant variables for a particular averaging period. This is aided by *kriging* analysis, showing the spatial distribution of a variable or variables within the different lagoon segments (Figures 3b, 4b, 5b, 6b, and 7b).

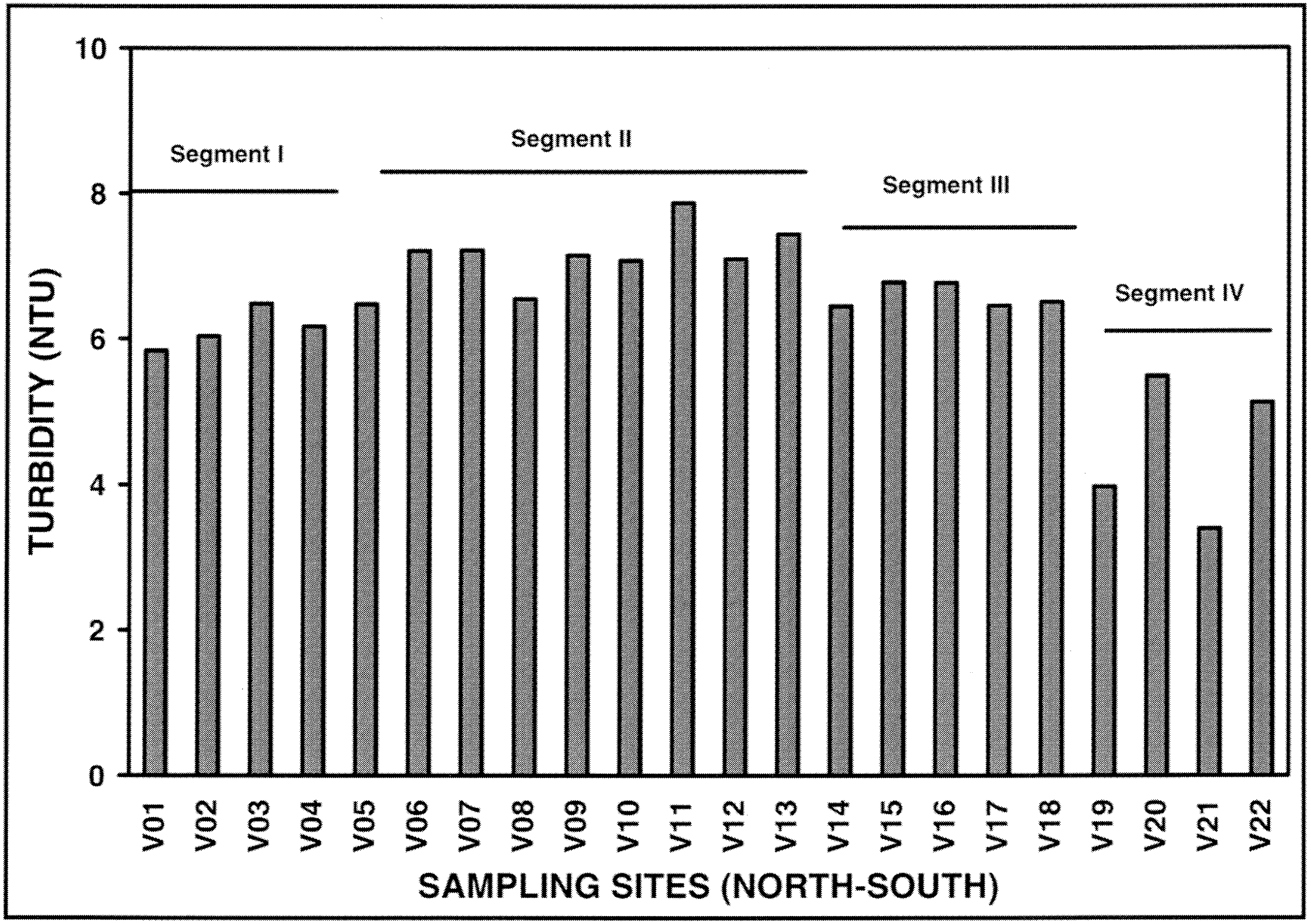

Figure 3a. Distribution of turbidity and proposed segments for the Mosquito Lagoon.

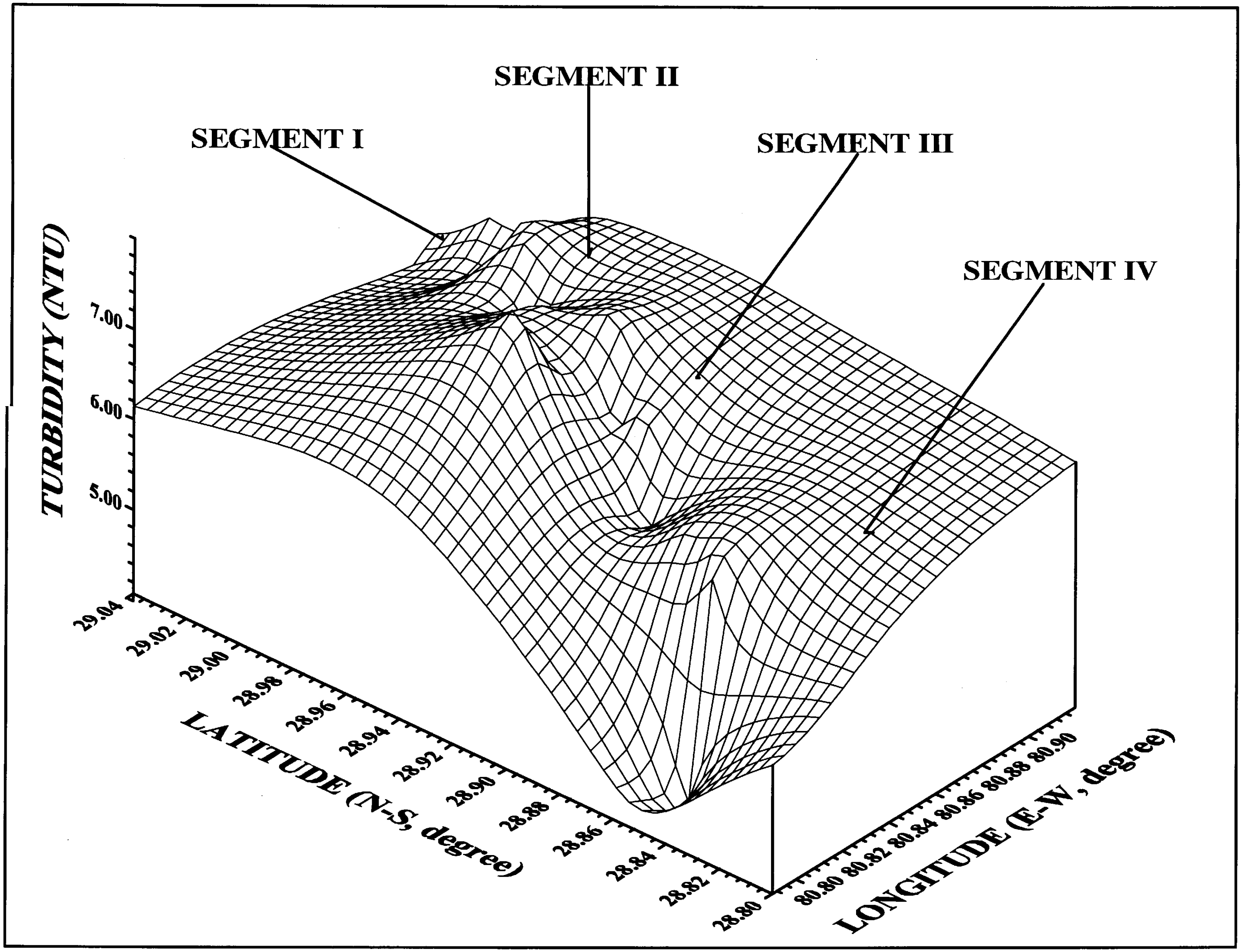

Figure 3b. 3-D representation of turbidity profile within the Mosquito Lagoon.

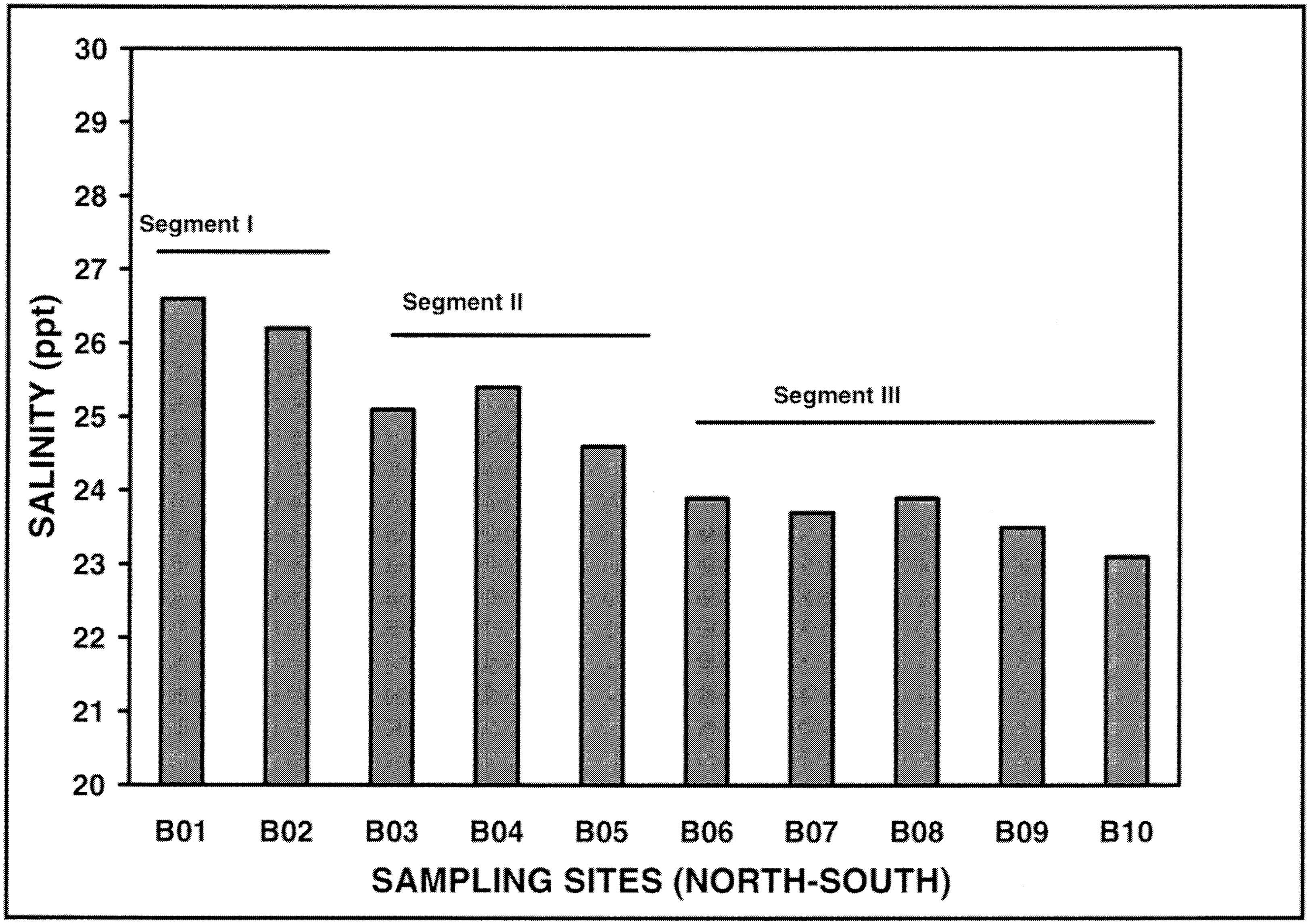

Figure 4a. Distribution of salinity and proposed segments for the Banana River Lagoon.

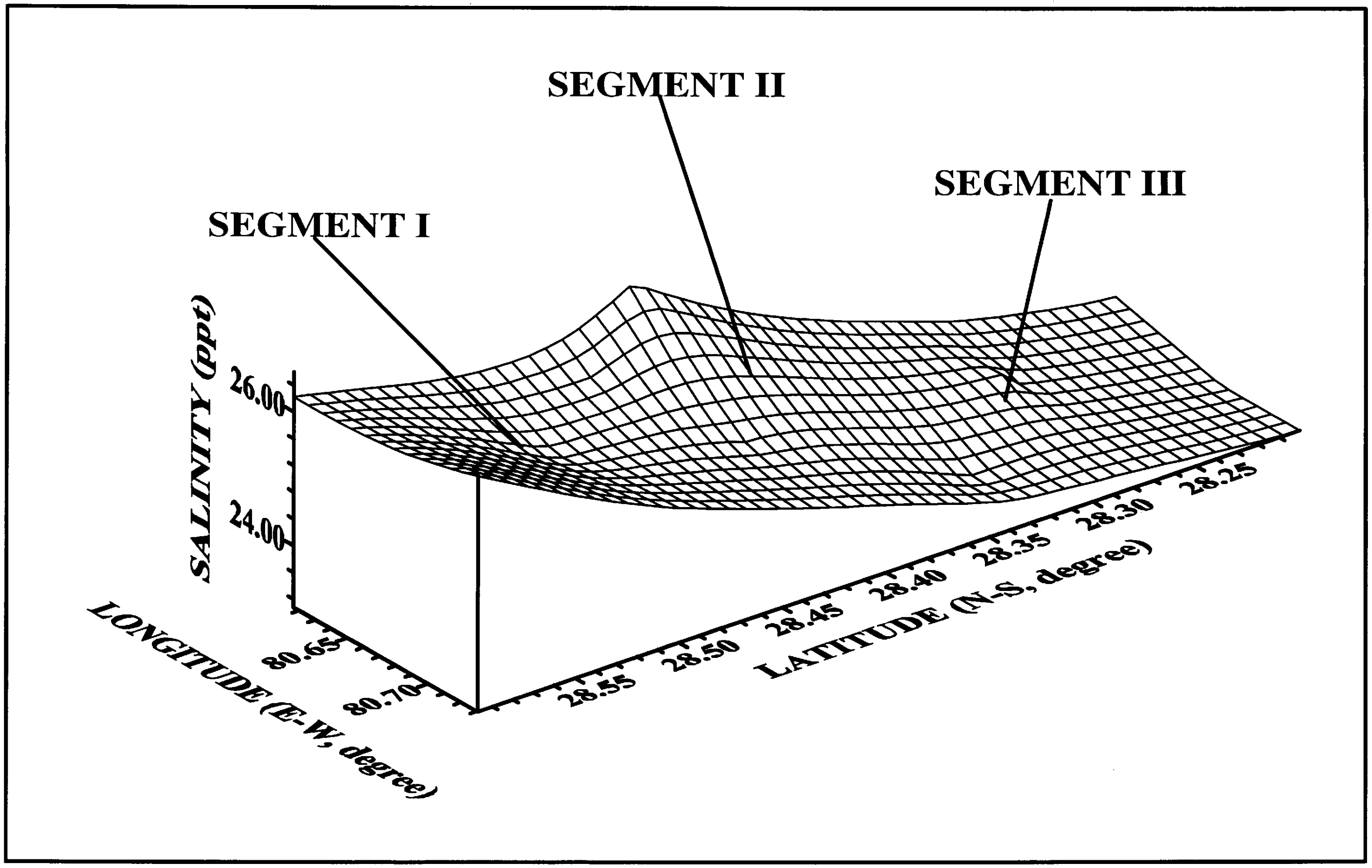

Figure 4b. 3-D representation of salinity profile within the Banana River Lagoon.

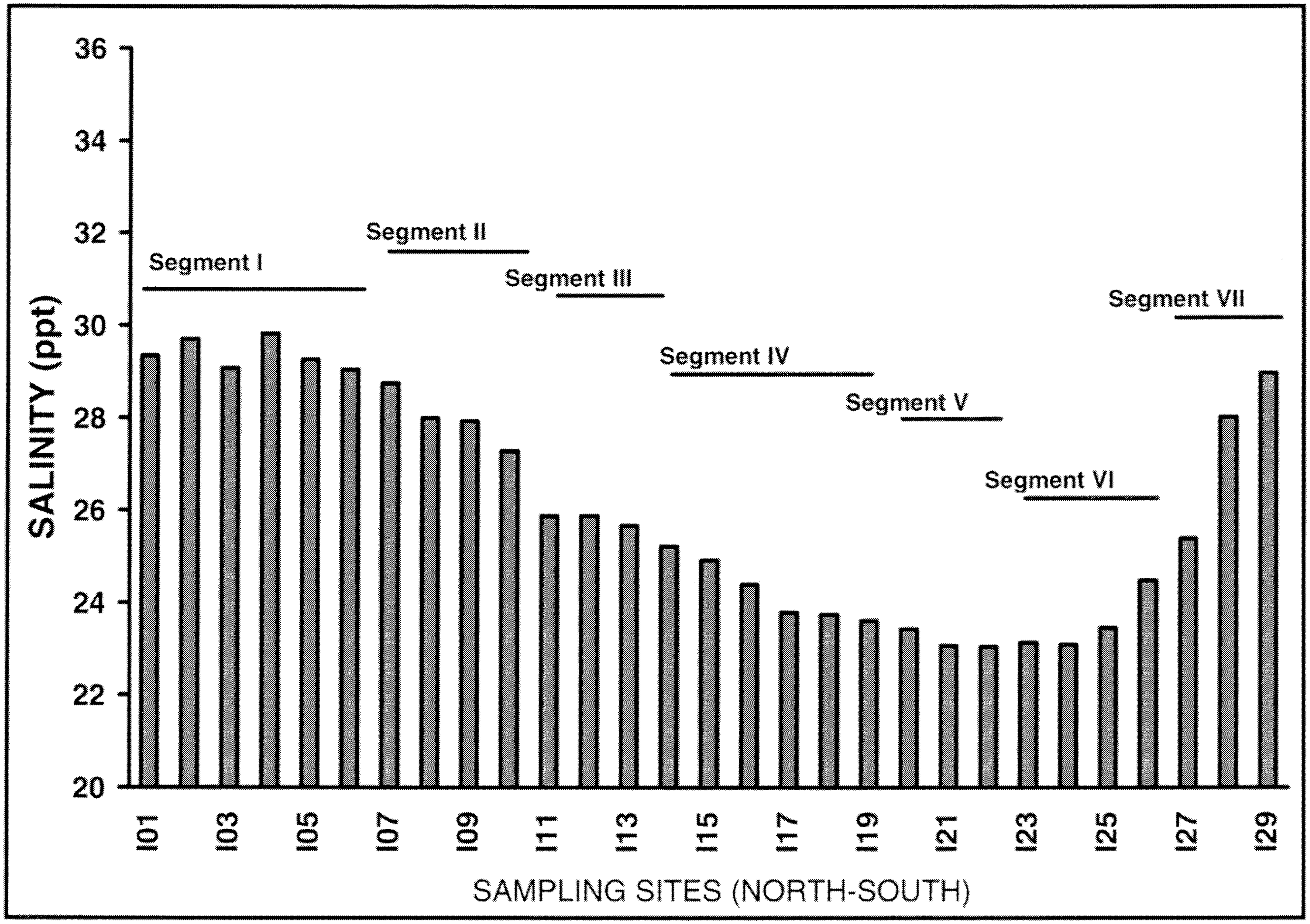

Figure 5a. Distribution of salinity and proposed segments for the Indian River Lagoon - Brevard County.

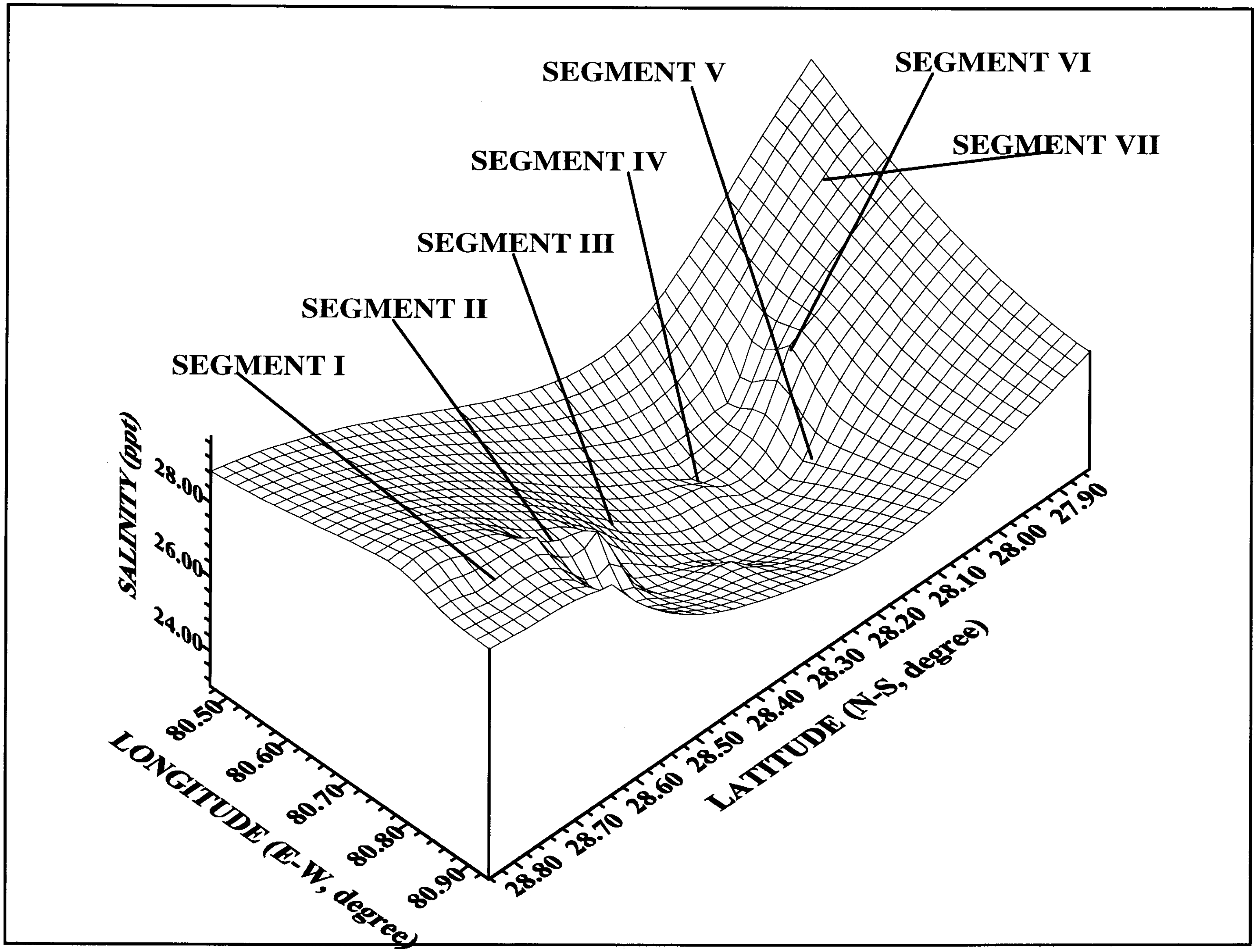

Figure 5b. 3-D representation of salinity profile within the Indian River Lagoon - Brevard County.

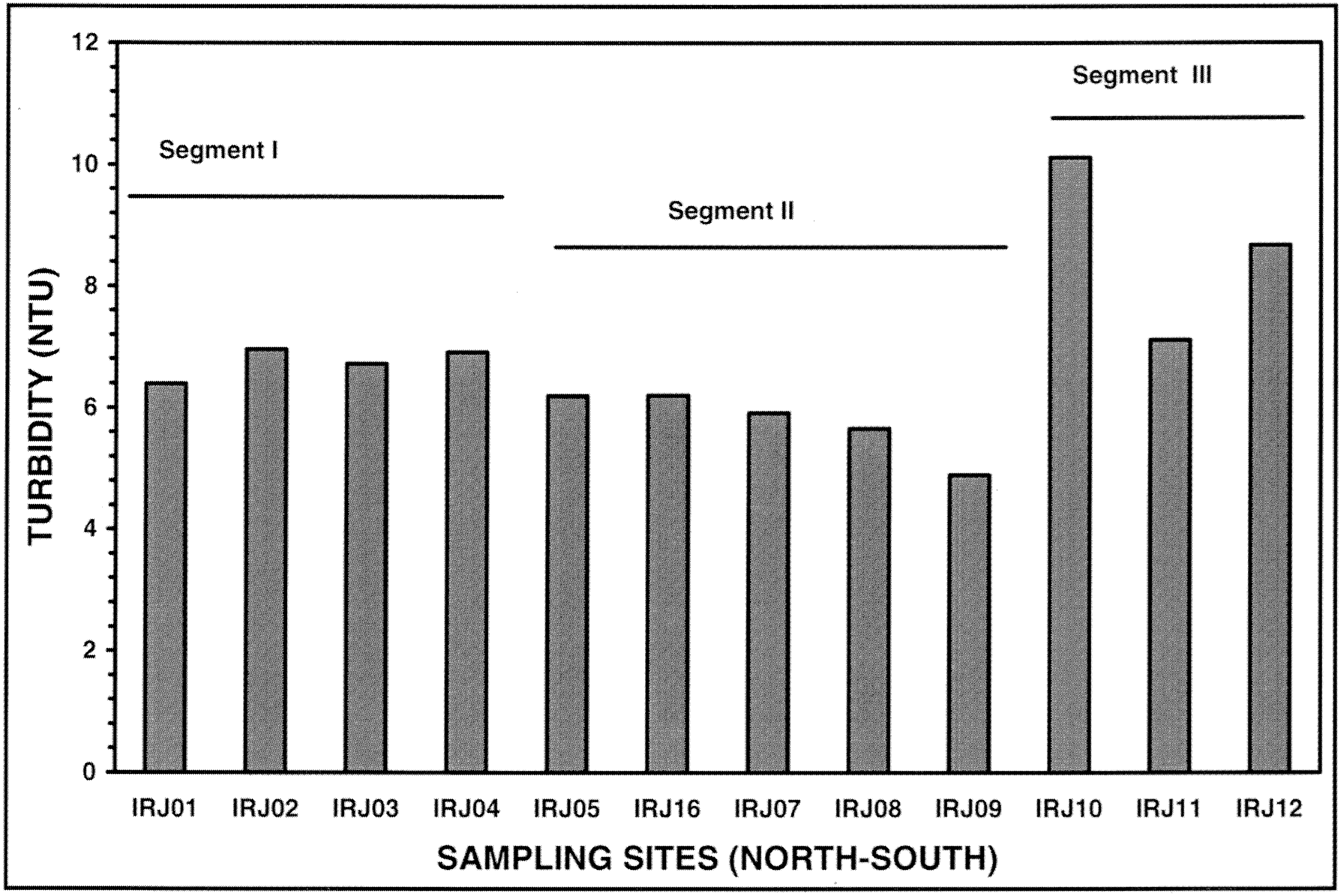

Figure 6a. Distribution of turbidity and proposed segments for the Indian River Lagoon (Indian River County).

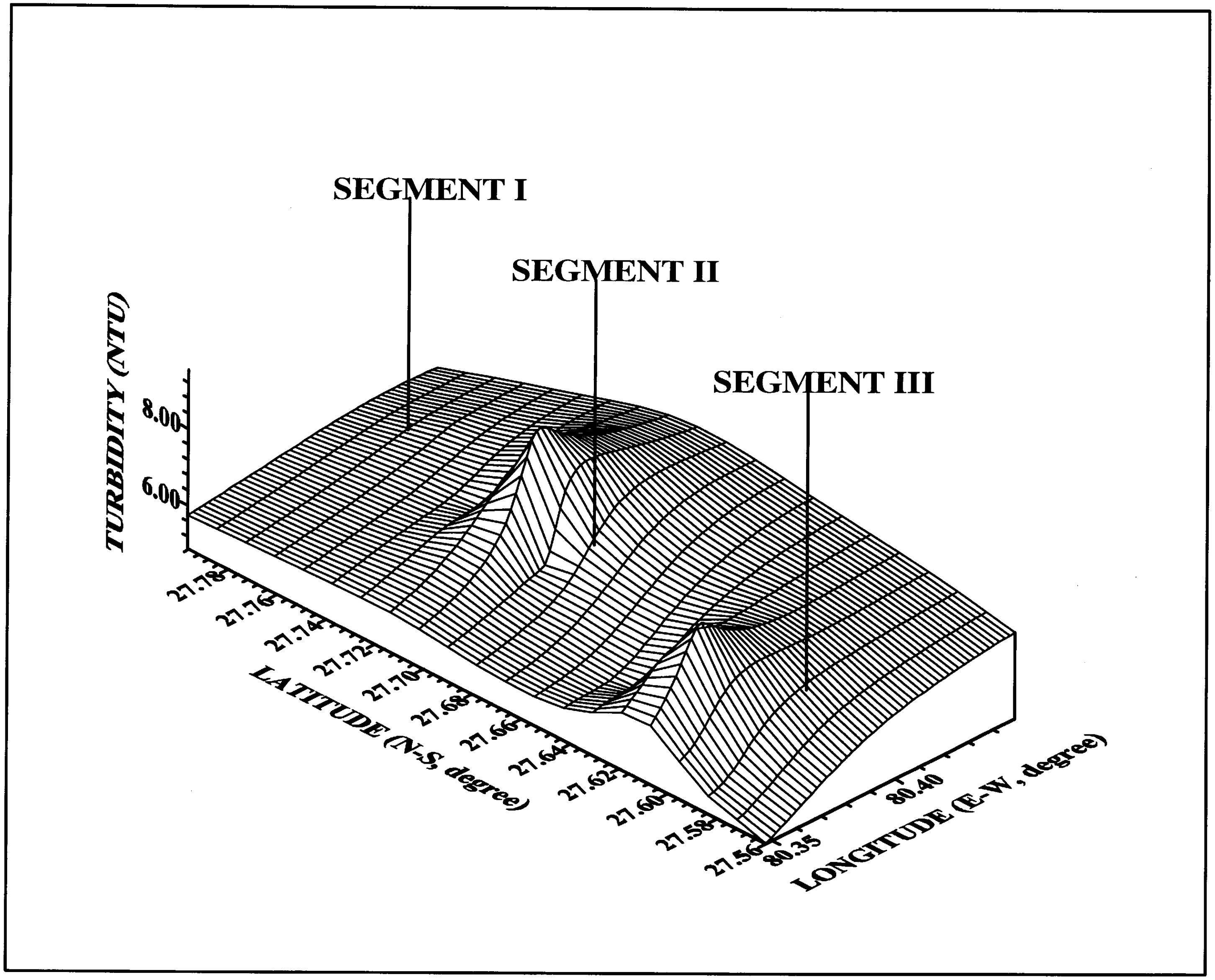

Figure 6b. 3-D representation of turbidity within the Indian River Lagoon - Indian River County.

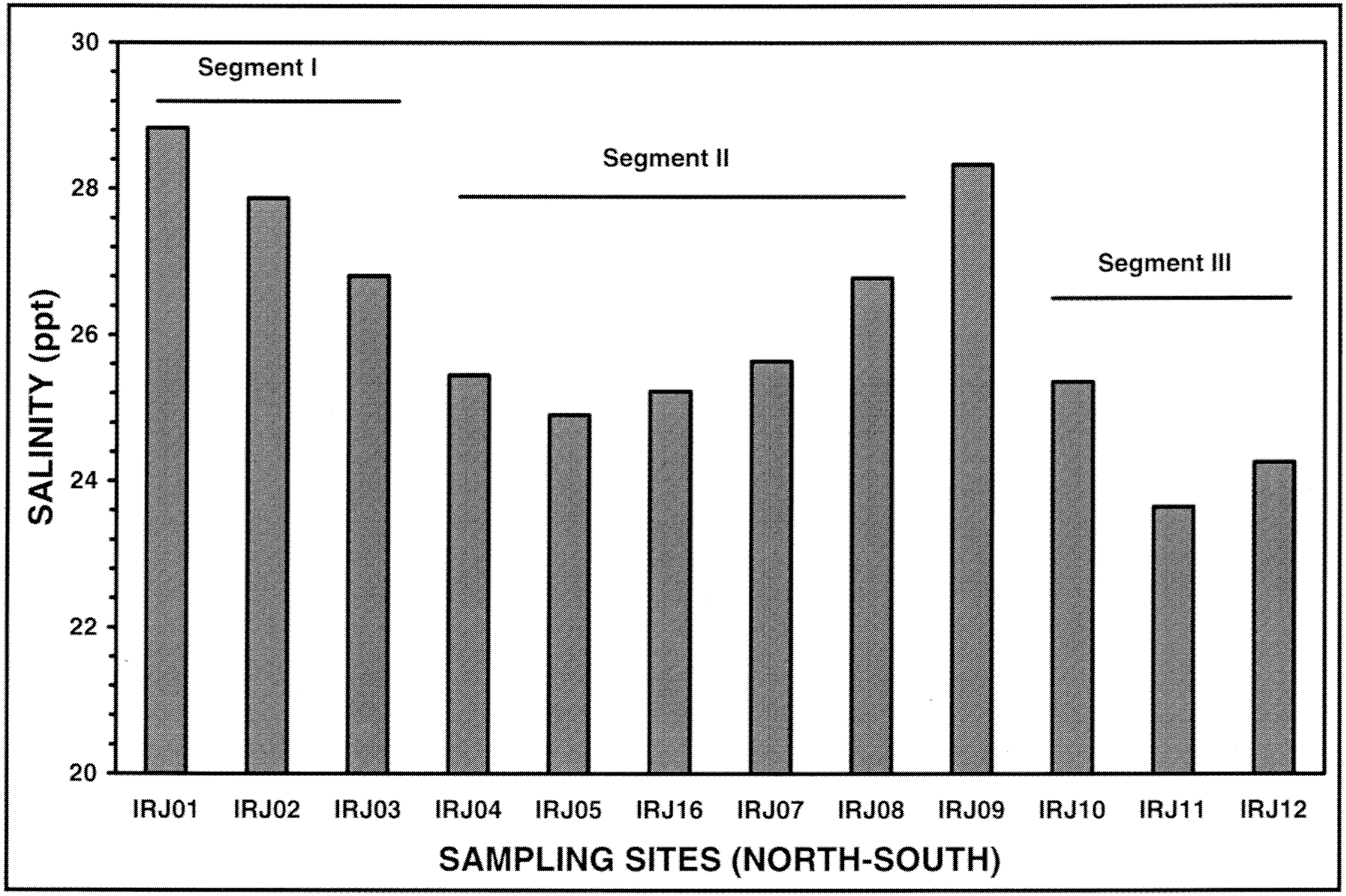

Figure 7a . Distribution of salinity and proposed segments for the Indian River Lagoon (Indian River County).

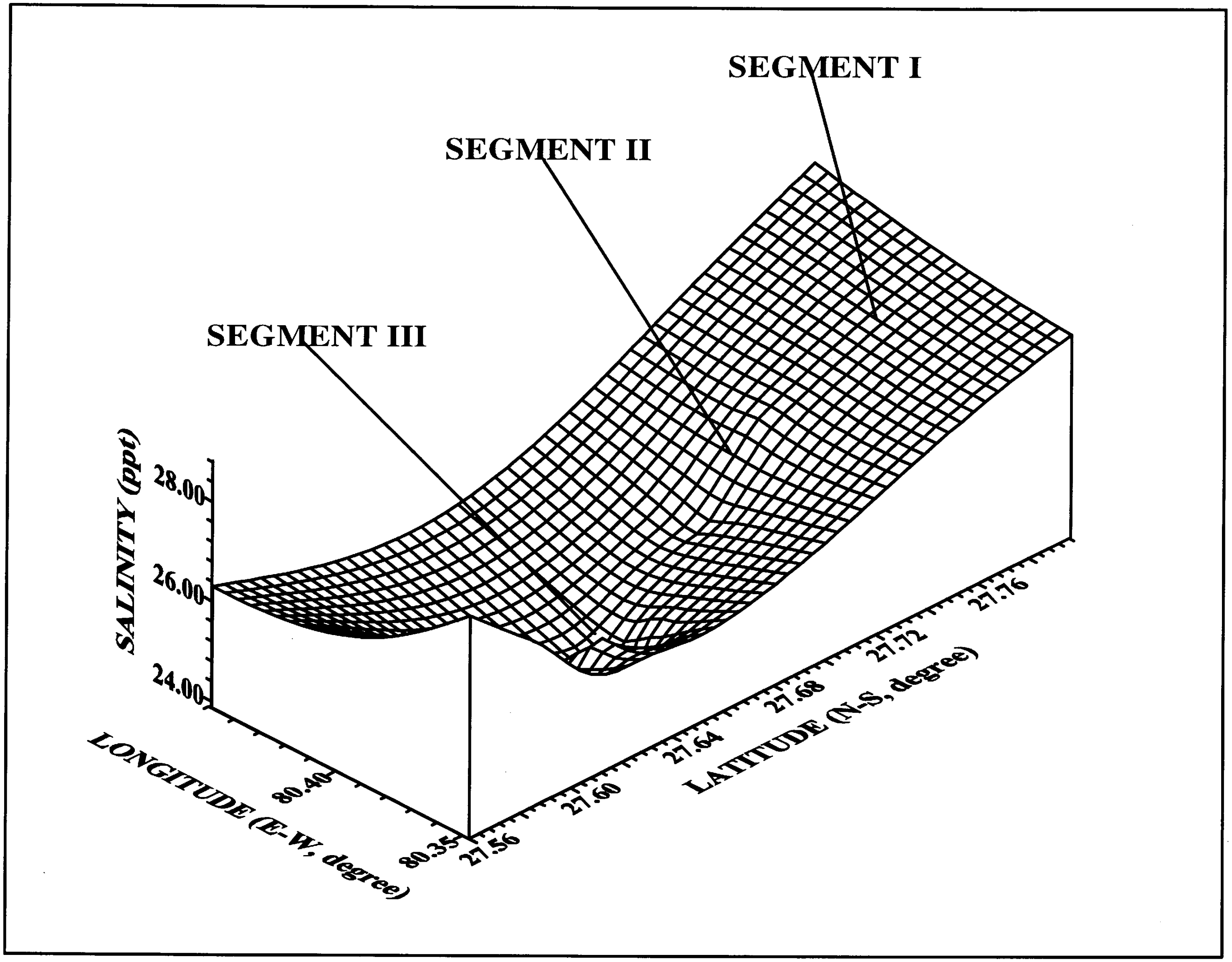

Figure 7b. 3-D representation of salinity profile within the Indian River Lagoon - Indian River County.

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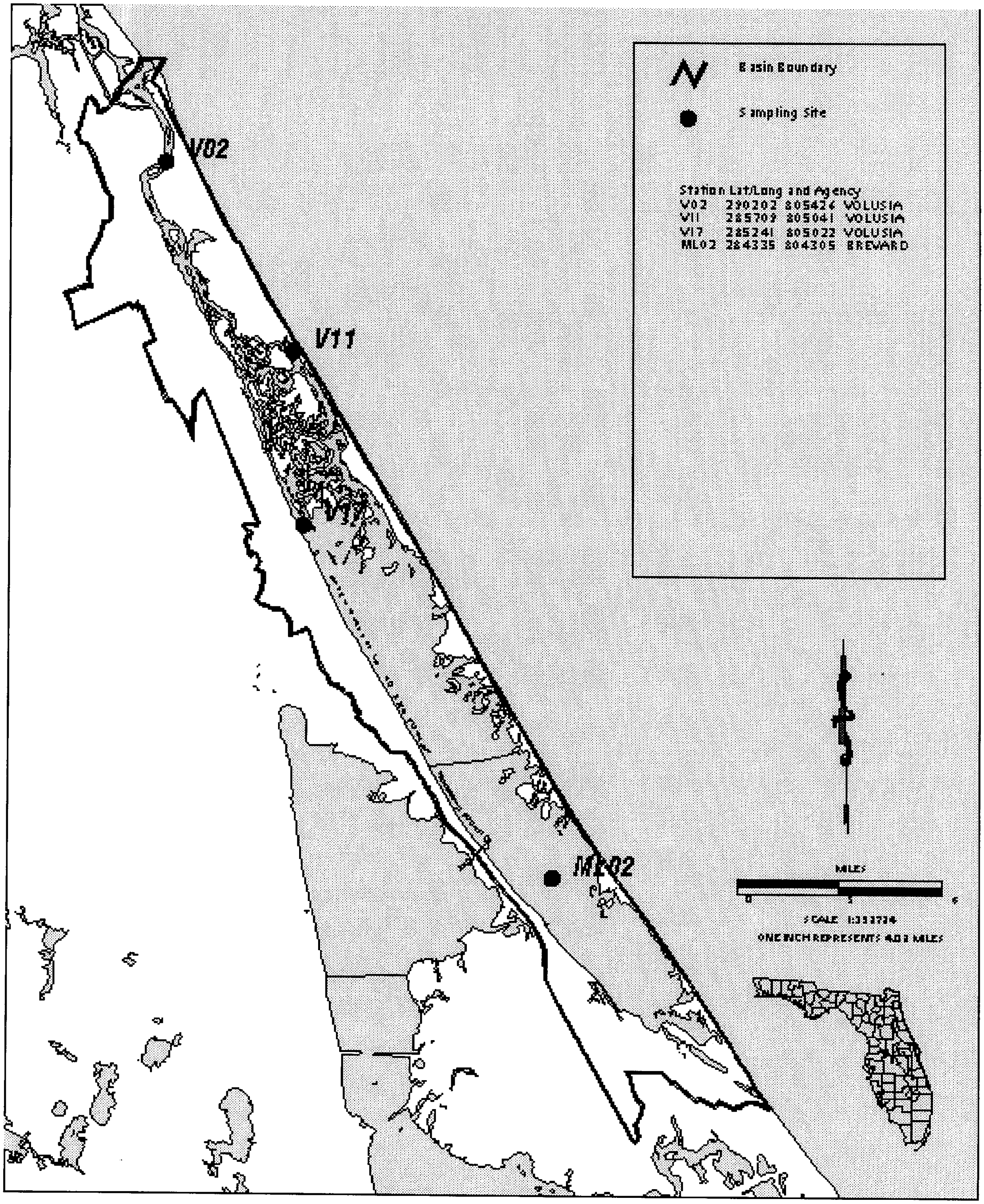

Figure 8.
Proposed Water Quality Monitoring Sites that
Would be Retained in the Mosquito Lagoon
Source: SJRWMD, 1995

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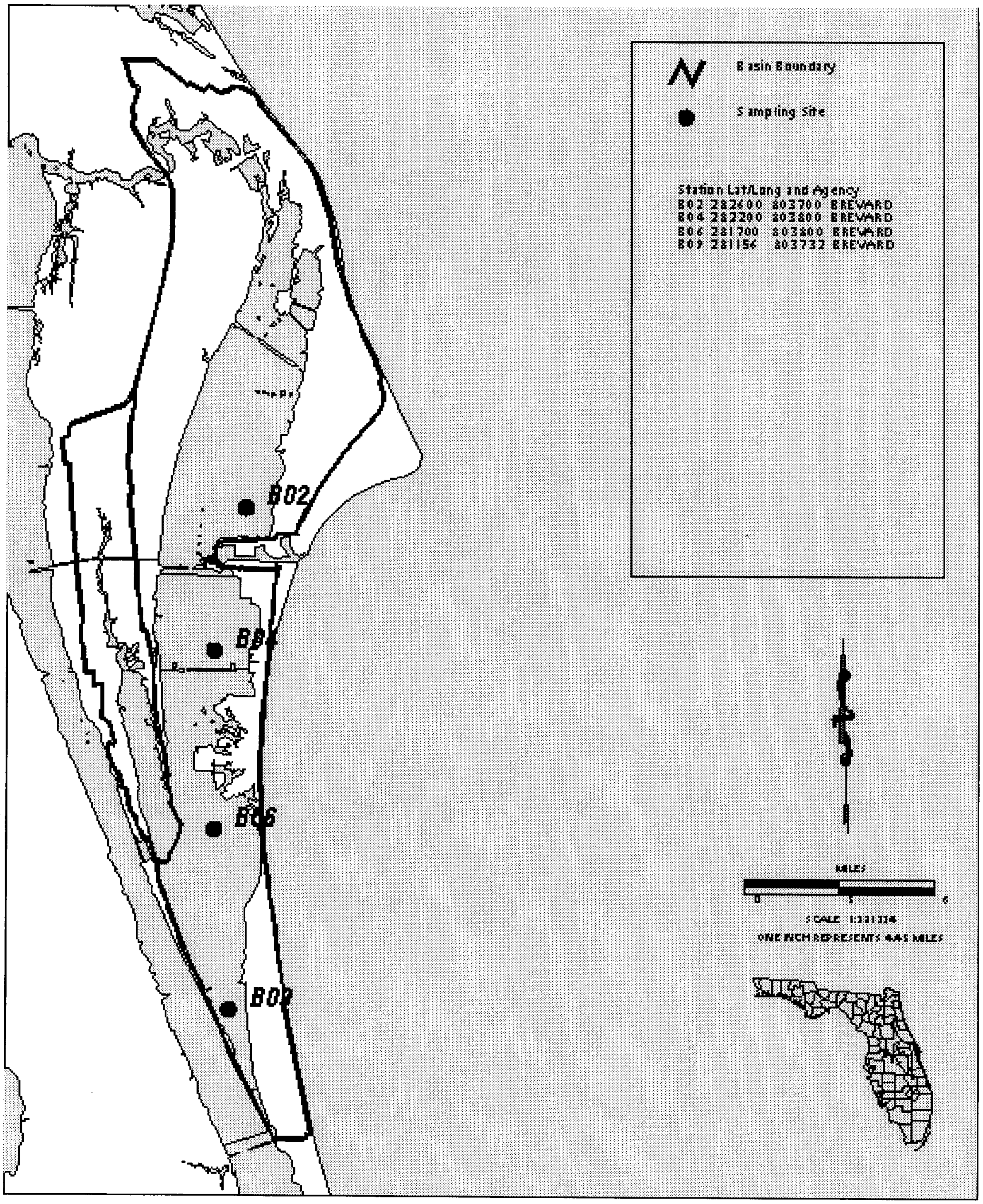

Figure 9.
Proposed Water Quality Monitoring Sites that
Would be Retained in the Banana River Lagoon
Source: SJRWMD, 1995

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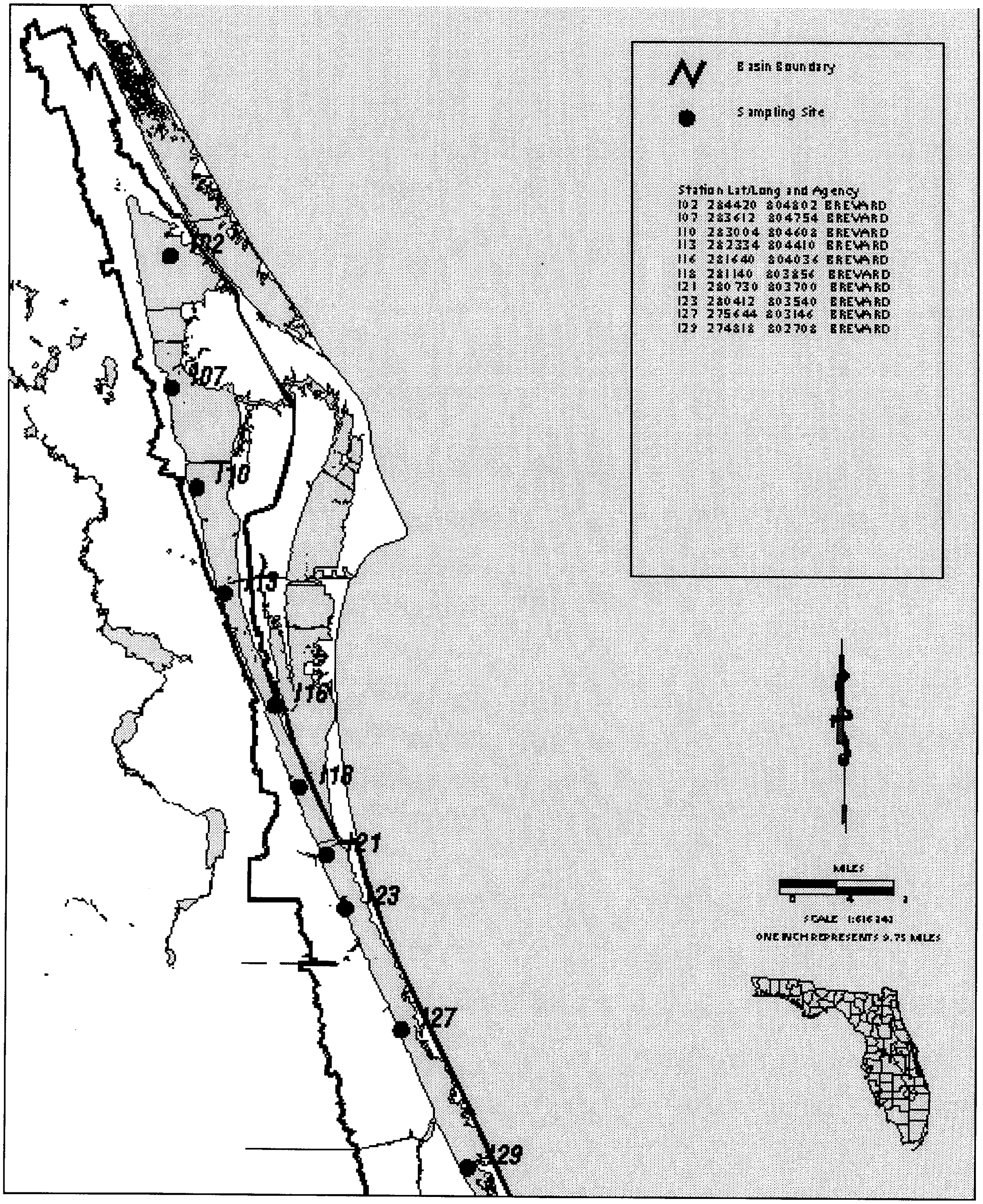

Figure 10.
Proposed Water Quality Monitoring Sites that Would be Retained in the Indian River Lagoon - Brevard County

Source: SJRWMD, 1995

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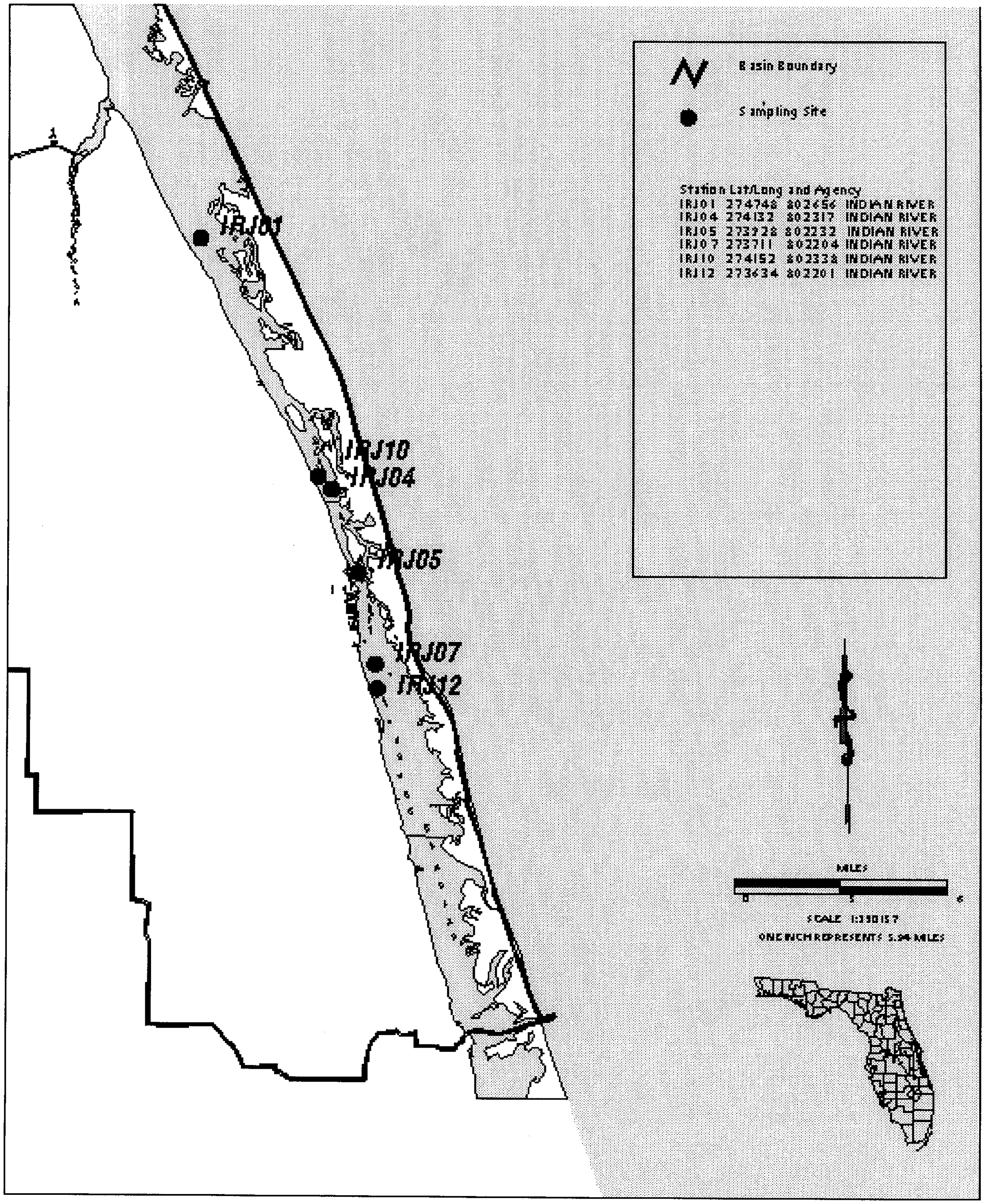

Figure 11.
Proposed Water Quality Monitoring Sites that Would be Retained in the Indian River Lagoon - Indian River County
Source: SJRWMD, 1995

Table 1a. Proposed Fixed Water Quality Stations for the Indian River Lagoon.

STATION ID	DESCRIPTION
V02	This station is located north of New Smyrna Beach and is receiving point discharge from the New Smyrna Beach STP, which is subject to the IRL Act and should end discharge in the near future
V11	Just east of Cedar Creek and west of Bethune Beach; close to seagrass transect # 1 (New Smyrna Beach)
V17	This station will represent water activities near Barlows Processing Plants and Oak Hill Dock
ML02	This station would give indications of what effects the Haulover Canal has on Mosquito Lagoon water quality (background information)
B02	This station was selected because of the influence from the Barge Canal and Port Canaveral. Ideal station to provide background water quality for the Banana River Lagoon
B04	This station will indicate a long term trend of water effluent input from Cape Canaveral Plant (WWTP) subject to IRL "No Discharge Act, 1990, FS) into the Banana River Lagoon. The increased development and nonpoint sources activities can be monitored and documented
B06	This station is retained to monitor the impact of Sykes Creek/Newfound Harbor on water quality in Banana River Lagoon
B09	This station is largely influenced by large marinas located between Pineda Causeway and the southern tip of Merritt Island; Monitor stormwater discharges from Indian Harbor Beach, Eau Gallie Yacht Club, and Anchorage); closer to seagrass transect # 17 (Banana River Lagoon - South Pineda)
I02	This station is located north of Titusville, will provide background level of water quality parameters
I07	This station was selected to measure increased nutrient levels caused, in part, by effluent discharges from the city of Titusville North Plant (subject to IRL "No Discharge Act, 1990); close to seagrass transect # 21 (South 406)
I10	This station is located between NASA Causeway and SR 528 to bracket the two power plants on the west side of the basin

STATION ID	DESCRIPTION
I13	This station is located in the northern half of the basin receiving nutrient input from effluent discharges (City of Cocoa, subject to IRL "No Discharge Act, 1990); close to seagrass transect # 25 (Southwest 528)
I16	Close to seagrass transect # 27 (Merritt Island- Honeymoon Lake); Approximately half the distance to the Pineda Causeway
I18	Located between the Pineda Causeway and the Eau Gallie Causeway; close to seagrass transect # 28 (South Pineda)
I21	This station will monitor impact of metro Melbourne and the Eau Gallie River on water quality in Melbourne area
I23	This station is located directly opposite of the mouth of Crane Creek; Crane Creek receives wastewater effluent from one of the city of Melbourne's WWTPs (subject to IRL "No Discharge Act, 1990); close to seagrass transect # 31 (Crane Creek)
I27	This station was selected to determine if the Grant area influences significant portion of the lagoon; Close to seagrass transect # 36 and 37 (Grant Farm Island)
I29	This station provide information on the influence of the Sebastian River and Inlet; close to seagrass transect # (Green Point)
IRJ01	This station will provide information on the septic outflow from the city of Sebastian; close to seagrass transect # 46
IRJ04	This sampling station will monitor the septic tank outflow and stormwater runoff from the Gifford area; close to seagrass transect # 50
IRJ05	This sampling site will monitor stormwater runoff from the north main canal, agricultural runoff from the western part of Vero Beach; close to seagrass transect # 51
IRJ07	This sampling station will monitor the stormwater runoff from the southern part of the Vero Beach; close to seagrass transect # 52
IRJ10	This station will provide information on the agricultural and stormwater runoff from the north section of the main canal; close to seagrass transect # 49
IRJ12	This station will provide information on the stormwater and agricultural runoff from the south relief canal; close to seagrass transect # 53

Table 1b. Seagrass Transects and Water Quality Stations in the IRL Basin.

Seagrass Transect ID	WQMN Station ID[1]	Distance (miles)	Action
-	V01		NA[2]
-	**V02**		***Retained***[3]
-	V03		NA
-	V04		NA
-	V05		NA
-	V06		NA
-	V07		NA
-	V08		NA
-	V09		NA
-	V10		NA
1	**V11**	0.5	***Retained***
2	V11	2.5	Deleted[3]
-	V12		NA
-	V13		NA
-	V14		NA
-	V15		NA
-	V16		NA
3	**V17**	1.0	***Retained***
-	v18		NA
4	V19	1.25	Deleted
-	V20		NA
-	ML01		NA
5	ML02	3.0	Deleted
6	**ML02**	0.5	***Retained***
7	ML02	5.5	Deleted
8, 9, 10, 11	B01	3.0	Deleted
-	**B02**		***Retained***[4]
12 & 13	B03	3.0	Deleted
13	**B04**	**1.0**	***Retained***
14	NFH01	2.0	Deleted
15	NFH02	0.75	Deleted
-	B05		NA
16	**B06**	1.0	***Retained***[4]
-	B07		NA
-	B08		NA
17	**B09**	**0.5**	***Retained***
18	I01	1.0	Deleted
-	**I02**		***Retained***[4]
-	I03		NA
19	I04	1.5	Deleted
-	I05		NA

Seagrass Transect ID	WQMN Station ID[1]	Distance (miles)	Action
20	I06	1.0	Deleted
21	**I07**	**0.5**	***Retained***
-	I08		NA
-	I09		NA
22	**I10**	**0.75**	***Retained***
-	I11		NA
-	I12		NA
23 & 24	I13	1.0	Deleted
25	**I13**	**0.5**	***Retained***
26	I14	0.75	Deleted
-	I15		NA
27	**I16**	**0.5**	***Retained***
-	I17		NA
28	**I18**	**0.75**	***Retained***
-	I19		NA
29	I20	1.5	Deleted
-	**I21**		***Retained***[4]
30	I22	1.25	Deleted
31	**I23**	**0.25**	***Retained***
32	I24	1.0	Deleted
33 & 34	I25	1.5	Deleted
35	I26	1.5	Deleted
37	**I27**	**0.5**	***Retained***
38	**I27**	**0.5**	***Retained***
-	I28		NA
45	**I29**	**0.25**	***Retained***
46	**IRJ01**	**0.5**	***Retained***
47 & 48	IRJ02	1.0	Deleted
-	IRJ03		NA
50	**IRJ04**	**0.25**	***Retained***
51	**IRJ05**	**0.25**	**Retained**
-	IRJ16		NA
52	**IRJ07**	**0.25**	***Retained***
54	IRJ08	1.0	Deleted
55	IRJ09	1.0	Deleted
49	**IRJ10**	**0.50**	***Retained***
-	IRJ11		NA
53	**IRJ12**	**0.25**	***Retained***

[1] *Closest existing WQM station to the existing seagrass transect*
[2] *NA - non applicable because no seagrass transect within the 2 miles radius*
[3] *Deleted - not selected for the revised water quality monitoring station*
[3] *Retained - selected for the revised water quality monitoring station*
[4] *Retained station because of other criteria*

Sample Number and Frequency

The sample number and frequency are important to periodically re-evaluate to maximize monitoring efficiency. A network is inefficient if the number of samples collected or the frequency of measurements is too low or too high. If the frequency is too low, the data generated may miss significant trends or fail to indicate the actual water quality condition. If the frequency is too high, it means that the information could have been derived, at a statistically significant level, from data collected at a lower frequency. Determining the optimum "sample size" can save effort and cost.

If all the changes in water quality of streams or estuaries were results of random variations, the appropriate frequency of sampling could be determined from purely statistical considerations. However, if water quality parameters exhibit a cyclic behavior, the sampling scheme must be selected to eliminate possible bias introduced by periodicity. Cyclic variations in IRL water quality could have a periodicity of a day, a month, a season or several years. Therefore, the frequency of measure as well as the number of samples required are important in order to capture significant trends in water quality.

For this evaluation of sample number and frequency, a *statistical power* analysis was employed. As a result of that analysis, the following is proposed: *three samplings per retained station during one tidal cycle each month over the next three years.*

The sample number and frequency can be statistically determined by addressing the question: how many samples must taken to indicate that if a "true" difference (δ) exists, it is significant at a specified significance level (α), with a desired probability that a significant difference will be found? The desired probability is the *power* (1-β) of the significance test. Furthermore, one must know how variable the data are by calculating the coefficient of variation (CV) of the historical data (Sokal and Rohlf, 1981).

The coefficient of variation (CV) for the IRL nutrient and TSS data (1987 -1991) is approximately 70. Because a reasonably moderate trend (difference) should be detected at a relatively high significance level, δ is set at 0.25 and α at 0.05, respectively (Figure 12). The power of the test, 1-β, or the probability that the trend will be detected was variously set between 0.70 and 0.85 to examine the range of sample numbers minimally required (Figure 12). It is proposed that, at a minimum, 108 samples per retained station over a three-year period is required to develop a statistically valid database for the IRL.

Three samples per station can be collected during a tidal phase each month for the next three years to obtain this sample size and capture any tidal or seasonal trends. This sample number and frequency would greatly complement the calibration of the PLR Model. After the three years, data will be evaluated for the appropriateness of monthly or some other sampling schedule.

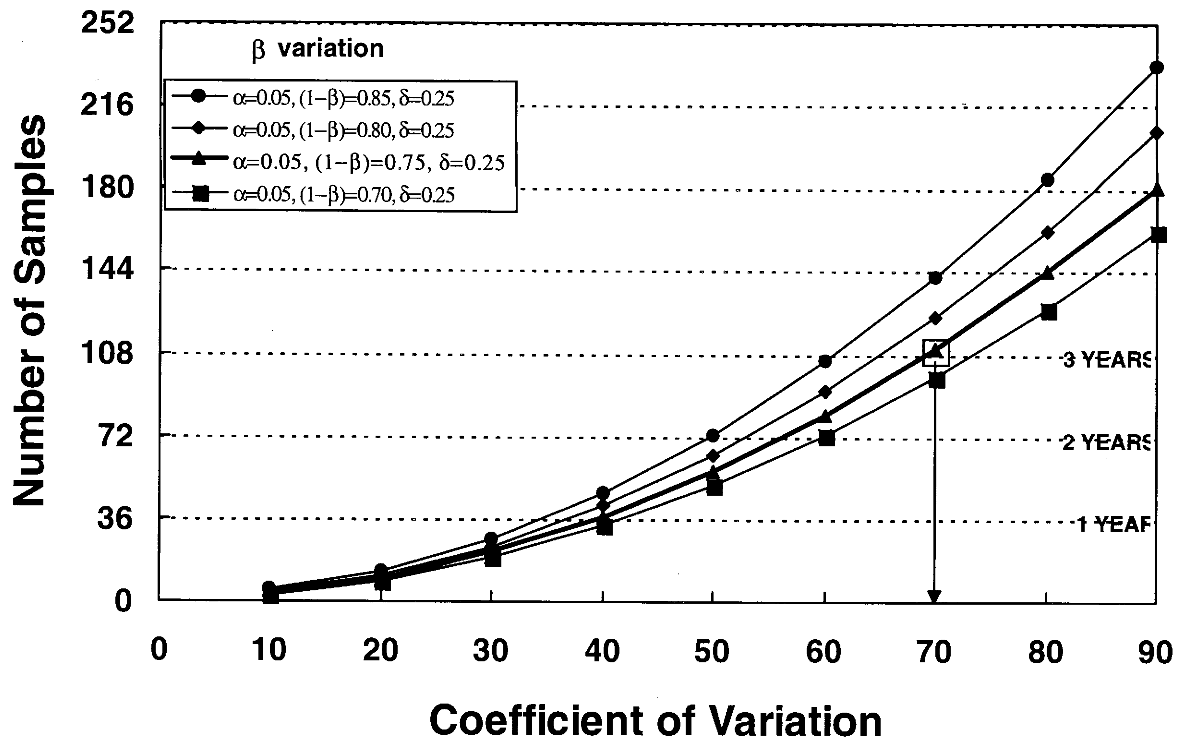

Figure 12. Statistical power analyses showing the relationship of the number of samples with the coefficient of variation, probability and statistical significance of water quality data for IRL.

Near-Bottom Sampling

Addition of near-bottom sampling will provide information on water column mixing and nutrient flux near the water-sediment interface. The primary goal of near-bottom sampling is to help quantify the carbon, nitrogen, and phosphorus fluxes in the IRL within the context of describing the role of bottom sediments as sinks or sources (internal loading) in the IRL. The PLR Model will be the means by which sediment flux of nutrients will be estimated and predicted. A knowledge of the nutrient budget (external + internal loadings), together with an understanding of the hydrodynamics of the estuary, via the PLR Model, is essential for developing technically defensible PLRGs.

It is recommended that at least one of the three samplings during the tidal cycle run include a near-bottom water grab sample (VanDoran sampler). Prior to and at the time of sampling, it is very important that there is minimal sediment disturbance. The station should be approached slowly, ideally with boat engine cut off as the boat is coasting into position, and then the anchor gently lowered. The sample should be taken as far away from any points of possible disturbance (anchor, engine, other sampling activities, etc.).

The recommended depth at which the near-bottom sample would be taken is 0.3 m above the bottom. The IRL database (1987 - 1991) reveals that the depth of the water column at most of the retained stations is usually more than 1.25 m. That is sufficient depth to collect both a near-surface sample (0.3 m from top) and near-bottom sample. If the water column depth is less than 1 m, no near-bottom sample will be taken; only the near-surface sample.

Organic and Inorganic Suspended Solids

Presently, the WQMN measures the concentration of "total" TSS (total suspended solids). It is proposed that the WQMN include the measurement of the organic and inorganic fractions of TSS. These data will be very helpful in the calibration of the PLR Model and may be necessary over the longer term.

It is not known which TSS fraction, inorganic or organic, contributes most to the water transparency or PAR attenuation problem. Knowing this is important because it can help determine the most cost-effective means for managing and monitoring TSS loadings. For example, if the inorganic fraction (e.g., silts and clays) contributes most to turbidity or PAR attenuation, then TSS load reduction strategies may emphasize soil erosion control in the uplands and muck removal in the Lagoon. Similarly, monitoring of the TSS fractions would be important to assess watershed management effectiveness.

Centralization of Laboratory Services

Each agency participating in the WQMN uses a different laboratory for chemical analyses. The WQMN agencies either have laboratory facilities in-house or use contract laboratories; and some agencies have changed contract laboratories as frequently as every year. This creates quality assurance and quality control (QA/QC) problems because each laboratory may use analytical methods or techniques that may differ somewhat from the overall WQMN QA/QC plan.

Split sampling has revealed significant discrepancies in analytical results for some variables among the laboratories used by the WQMN participants. Results of the split sampling analyses for TSS, chlorophyll a, and TP also showed large variability in the discrepancies over time (Figures 13- 15), precluding corrective adjustments to these data.

Utilization of a single laboratory or fewer laboratories by the WQMN agencies would ensure better quality assurance and control. Presumably, analytical errors and the magnitude of discrepancies would be reduced, and errors may be more readily detected and corrected.

Projected Budget of the Modified WQMN

Application of the proposed modifications to the WQMN (Volusia, Brevard, and Indian River counties only) will result in substantial cost savings for field operations and laboratory analyses over the *long term*. For example, Table 2 shows the cost comparison of laboratory analyses between the existing and the proposed WQMN for the IRL. The present WQMN on a monthly basis for the Banana River Lagoon (BRL), Indian River Lagoon-Brevard County (IRL-B), Indian River Lagoon-Indian River County (IRL-IR) and the Mosquito Lagoon (ML) have a total monthly samples of 190, 551, 228, and 418@ one sample per month, respectively. The number of samples in the modified WQMN with three (3) sampling frequencies per station during a tidal cycle per month for the BRL, IRL-B, IRL-IR, and the ML are 228, 513, 342, and 228, respectively. Between the existing and the modified WQMN, the total number of samples was reduced from 1387 to 1311. This total reduction in the number of samples is more or less equivalent to a cost reduction of $316.00 per month (or $3792.00 annual savings) for the WQMN.

Further cost reduction can be realized following the intensive tidal cycle sampling, if the frequency of sampling drops back to one (1) sampling per station per month. The total number monthly samples would then be reduced from 1311 to 437. And, this would mean a cost reduction of $3,634 per month (or $43,608 annual savings) based on the present approximate cost of the WQMN laboratory analyses.

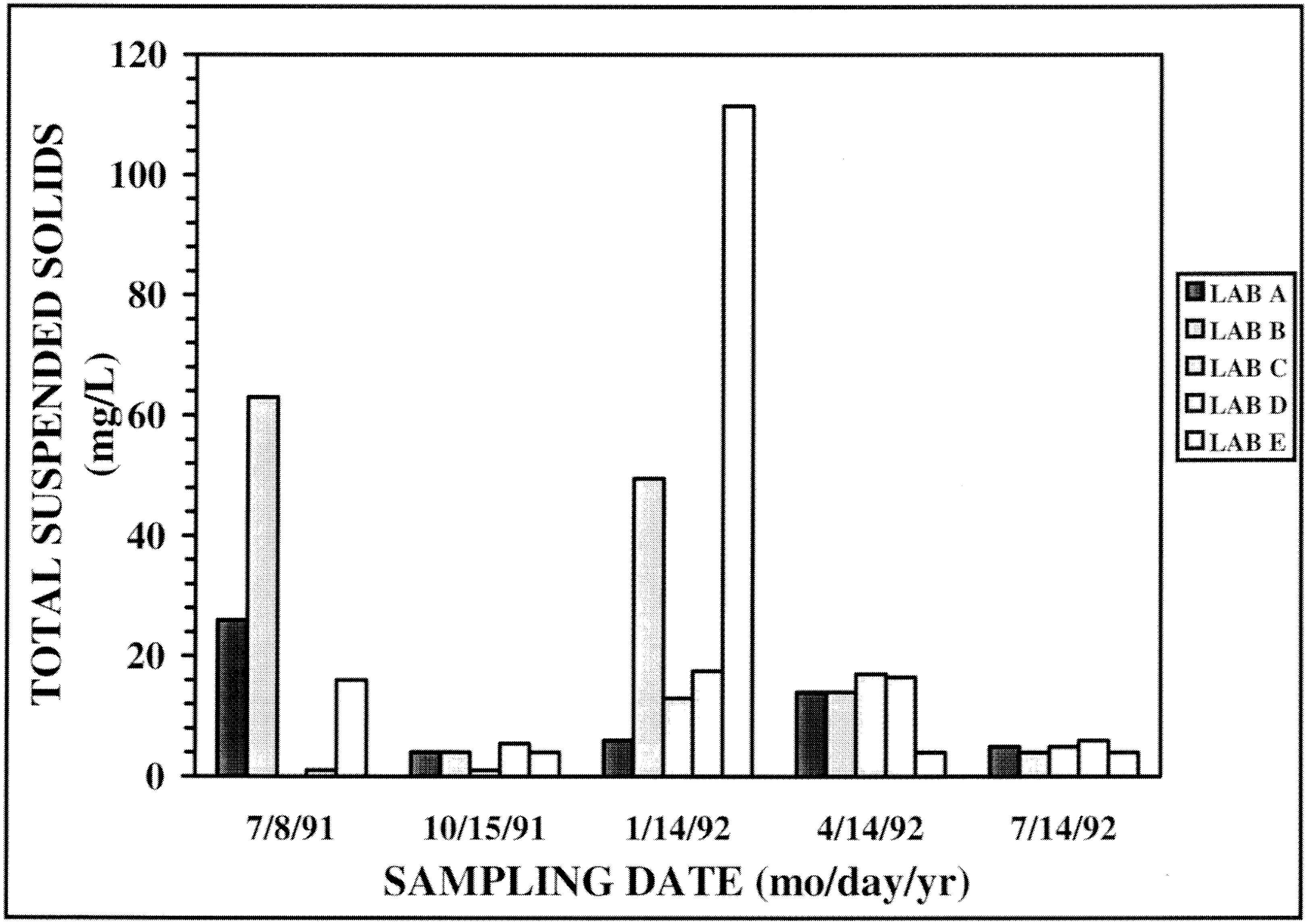

Figure 13. Comparative results of total suspended solids from different WQMN laboratories.

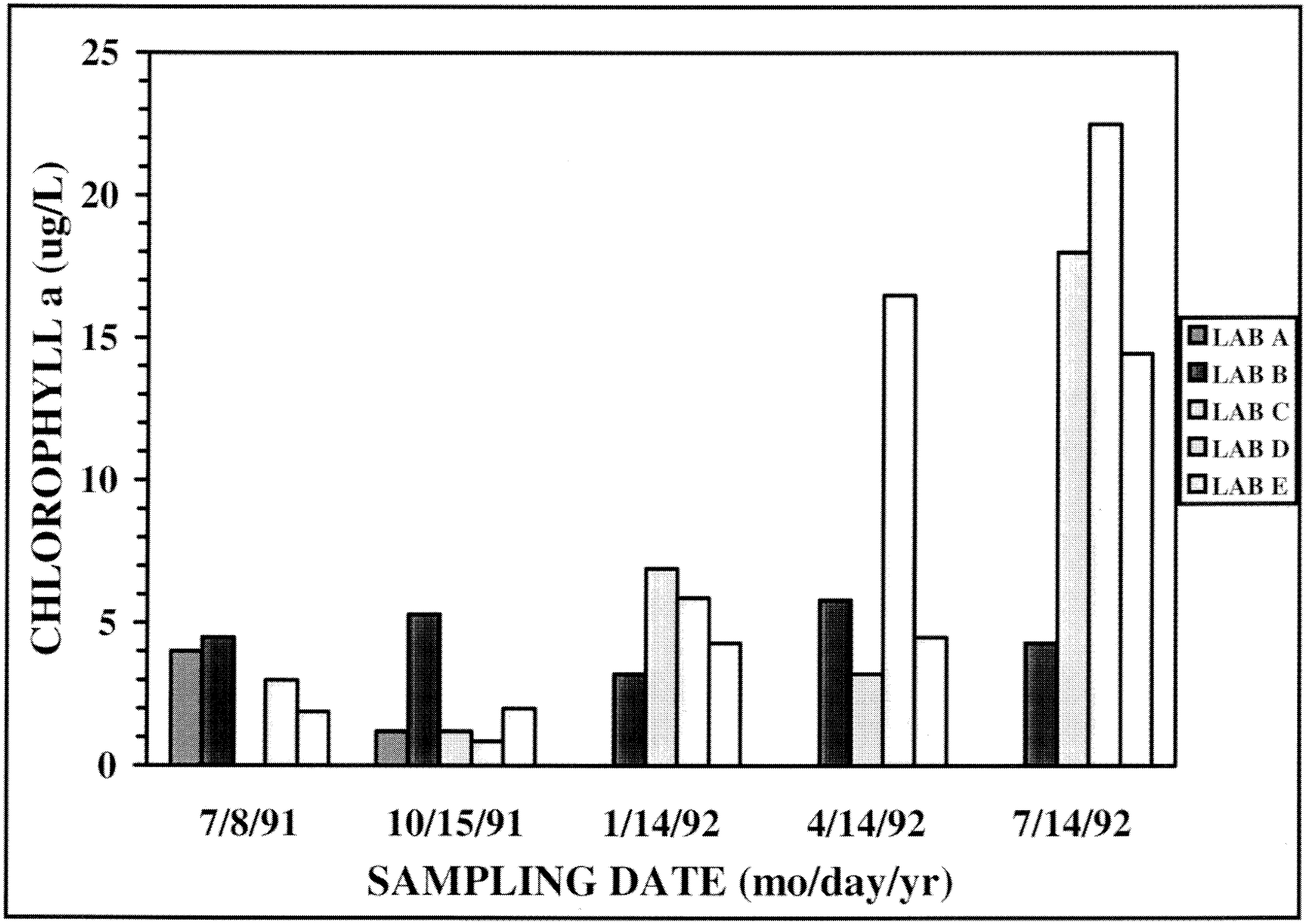

Figure 14. Comparative results of chlorophyll a analyses from different WQMN laboratories.

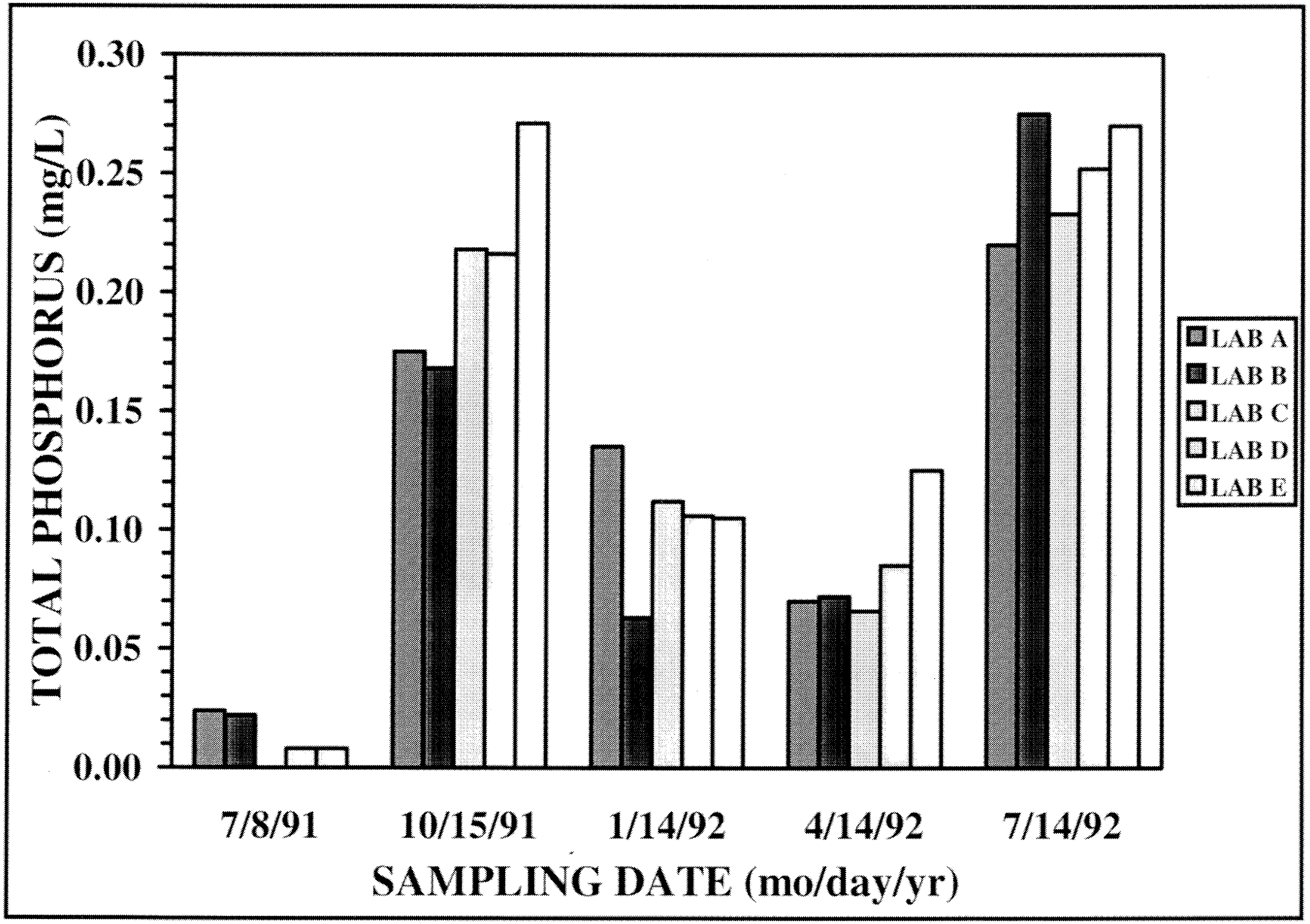

Figure 15. Comparative results of total phosphorus analysis from different WQMN laboratories.

Table 2. Cost comparison of laboratory analyses between the existing and proposed water quality monitoring network for the IRL.

I. BANANA RIVER LAGOON:

PARAM	COST[a]	NUMBER of SAMPLES			MONTHLY COST		
		EXWQM[b]	PWQMS1[c]	PWQMS2[d]	EXWQM[e]	PWQMS1[f]	PWQMS2[g]
Color	$3.00	10	12	4	$30.00	$36.00	$12.00
Turb	$3.00	10	12	4	$30.00	$36.00	$12.00
TDS	$6.00	10	12	4	$60.00	$72.00	$24.00
TSS(org)	$5.00	10	12	4	$50.00	$60.00	$20.00
TSS(inor)	$5.00	10	12	4	$50.00	$60.00	$20.00
Chlor	$5.00	10	12	4	$50.00	$60.00	$20.00
Cond	$5.00	10	12	4	$50.00	$60.00	$20.00
TOC	$4.00	10	12	4	$40.00	$48.00	$16.00
DOC	$4.00	10	12	4	$40.00	$48.00	$16.00
NOx	$4.00	10	12	4	$40.00	$48.00	$16.00
DNOx	$3.00	10	12	4	$30.00	$36.00	$12.00
NH4	$3.00	10	12	4	$30.00	$36.00	$12.00
DNH4	$3.00	10	12	4	$30.00	$36.00	$12.00
TKN	$5.00	10	12	4	$50.00	$60.00	$20.00
DTKN	$5.00	10	12	4	$50.00	$60.00	$20.00
PO4	$3.00	10	12	4	$30.00	$36.00	$12.00
DPO4	$3.00	10	12	4	$30.00	$36.00	$12.00
TP	$5.00	10	12	4	$50.00	$60.00	$20.00
DTP	$5.00	10	12	4	$50.00	$60.00	$20.00
TOTAL		**190**	**228**	**76**	**$790.00**	**$948.00**	**$316.00**

[a] Estimated costs of laboratory analyses per parameter based on the listings from Laboratory Services Division, SJRWMD

[b] Number of samples based on the existing number of sampling sites @ one sampling frequency per month

[c] Projected total number of samples based from the proposed WQMN @ three sampling frequency per month during the first three years of implementation

[d] Projected total number of samples based from the proposed WQMN @ one sampling frequency per month after the initial three years of implementation

[e] Monthly costs for the laboratory analyses of samples based on the existing water quality monitoring stations

[f] Projected monthly costs for the laboratory analyses of samples based on the proposed water quality monitoring stations @ three sampling frequency per month during the first three years of inplementation

[g] Projected monthly costs for the laboratory analyses of samples based on the proposed stations @ one sampling frequency per month after the initial (3 yrs)

II. INDIAN RIVER LAGOON - BREVARD COUNTY

PARAM	COST[a]	NUMBER of SAMPLES			MONTHLY COST		
		EXWQM[b]	PWQMS1[c]	PWQMS2[d]	EXWQM[e]	PWQMS1[f]	PWQMS2[g]
Color	$3.00	29	27	9	$87.00	$81.00.	$27.00
Turb	$3.00	29	27	9	$87.00	$81.00	$27.00
TDS	$6.00	29	27	9	$174.00	$162.00	$54.00
TSS(org)	$5.00	29	27	9	$145.00	$135.00	$45.00
TSS(inor)	$5.00	29	27	9	$145.00	$135.00	$45.00
Chlor	$5.00	29	27	9	$145.00	$135.00	$45.00
Cond	$5.00	29	27	9	$145.00	$135.00	$45.00
TOC	$4.00	29	27	9	$116.00	$108.00	$3600
DOC	$4.00	29	27	9	$116.00	$108.00	$3600
NOx	$4.00	29	27	9	$116.00	$108.00	$3600
DNOx	$3.00	29	27	9	$87.00	$81.00	$27.00
NH4	$3.00	29	27	9	$87.00	$81.00	$27.00
DNH4	$3.00	29	27	9	$87.00	$81.00	$27.00
TKN	$5.00	29	27	9	$145.00	$135.00	$45.00
DTKN	$5.00	29	27	9	$145.00	$135.00	$45.00
PO4	$3.00	29	27	9	$87.00	$81.00	$27.00
DPO4	$3.00	29	27	9	$87.00	$81.00	$27.00
TP	$5.00	29	27	9	$145.00	$135.00	$45.00
DTP	$5.00	29	27	9	$145.00	$135.00	$45.00
TOTAL		**551**	**513**	**171**	**$2291.00**	**$2133.00**	**$711.00**

III. INDIAN RIVER LAGOON - INDIAN RIVER COUNTY

PARAM	COST[a]	NUMBER of SAMPLES			MONTHLY COST		
		EXWQM[b]	PWQMS1[c]	PWQMS2[d]	EXWQM[e]	PWQMS1[f]	PWQMS2[g]
Color	$3.00	12	18	6	$36.00	$54.00.	$18.00
Turb	$3.00	12	18	6	$36.00	$54.00	$18.00
TDS	$6.00	12	18	6	$72.00	$108.00	$36.00
TSS(org)	$5.00	12	18	6	$60.00	$90.00	$30.00
TSS(inor)	$5.00	12	18	6	$60.00	$90.00	$30.00
Chlor	$5.00	12	18	6	$60.00	$90.00	$30.00
Cond	$5.00	12	18	6	$60.00	$135.00	$30.00
TOC	$4.00	12	18	6	$48.00	$72.00	$24.00
DOC	$4.00	12	18	6	$48.00	$72.00	$24.00
NOx	$4.00	12	18	6	$48.00	$72.00	$24.00
DNOx	$3.00	12	18	6	$36.00	$54.00	$18.00
NH4	$3.00	12	18	6	$36.00	$54.00	$18.00
DNH4	$3.00	12	18	6	$36.00	$54.00	$18.00
TKN	$5.00	12	18	6	$60.00	$90.00	$30.00
DTKN	$5.00	12	18	6	$60.00	$90.00	$30.00
PO4	$3.00	12	18	6	$36.00	$54.00	$18.00
DPO4	$3.00	12	18	6	$36.00	$54.00	$18.00
TP	$5.00	12	18	6	$145.00	$90.00	$30.00
DTP	$5.00	12	18	6	$60.00	$90.00	$30.00
TOTAL		**228**	**342**	**114**	**$948.00**	**$1422.00**	**$474.00**

IV. MOSQUITO LAGOON:

PARAM	COST[a]	NUMBER of SAMPLES			MONTHLY COST		
		EXWQM[b]	PWQMS1[c]	PWQMS2[d]	EXWQM[e]	PWQMS1[f]	PWQMS2[g]
Color	$3.00	22	12	4	$66.00	$36.00	$12.00
Turb	$3.00	22	12	4	$66.00	$36.00	$12.00
TDS	$6.00	22	12	4	$132.00	$72.00	$24.00
TSS(org)	$5.00	22	12	4	$110.00	$60.00	$20.00
TSS(inor)	$5.00	22	12	4	$110.00	$60.00	$20.00
Chlor	$5.00	22	12	4	$110.00	$60.00	$20.00
Cond	$5.00	22	12	4	$110.00	$60.00	$20.00
TOC	$4.00	22	12	4	$88.00	$48.00	$16.00
DOC	$4.00	22	12	4	$88.00	$48.00	$16.00
NOx	$4.00	22	12	4	$88.00	$48.00	$16.00
DNOx	$3.00	22	12	4	$66.00	$36.00	$12.00
NH4	$3.00	22	12	4	$66.00	$36.00	$12.00
DNH4	$3.00	22	12	4	$66.00	$36.00	$12.00
TKN	$5.00	22	12	4	$110.00	$60.00	$20.00
DTKN	$5.00	22	12	4	$110.00	$60.00	$20.00
PO4	$3.00	22	12	4	$66.00	$36.00	$12.00
DPO4	$3.00	22	12	4	$66.00	$36.00	$12.00
TP	$5.00	22	12	4	$110.00	$60.00	$20.00
DTP	$5.00	22	12	4	$110.00	$60.00	$20.00
TOTAL		**418**	**228**	**76**	**$1738.00**	**$948.00**	**$316.00**

[a] Estimated costs of laboratory analyses per parameter based on the listings from Laboratory Services Division, SJRWMD

[b] Number of samples based on the existing number of sampling sites @ one sampling frequency per month

[c] Projected total number of samples based from the proposed WQMN @ three sampling frequency per month during the first 3 years of implementation

[d] Projected total number of samples based from the proposed WQMN @ one sampling frequency per month after the initial three years of implementation

[e] Monthly costs for the laboratory analyses of samples based on the existing water quality monitoring stations

[f] Projected monthly costs for the laboratory analyses of samples based on the proposed water quality monitoring stations @ three sampling frequency per month during the first three years of implementation

[g] Projected monthly costs for the laboratory analyses of samples based on the proposed stations @ one sampling frequency per month after the initial (3 yrs) implementation of WQMN

EVALUATION OF WQMN PERFORMANCE

The cost of the IRL WQMN within the SJRWMD is substantial. In order to derive the most benefit from the network, it is essential to periodically evaluate its expected performance. This performance information will provide the basis for determining the feasibility of proposed sampling strategies and optimizing the overall monitoring effort. Initially, this evaluation will take place following a first year of sampling based on the modified network. The questions that will be addressed in the evaluation are:

1. Can the proposed sampling design meet the requirements of a long-term, ambient water quality monitoring program focused on the seagrass environment?

2. In the short term, can the WQMN meet the calibration needs of the PLR Model? Can the WQMN, in conjunction with other seagrass diagnostic projects and the PLR Model, establish better water quality targets for the IRL, and accurately measure IRL conditions relative to those targets?

3. How can the WQMN be further modified to ensure that the objectives or questions of the monitoring program are sufficiently addressed?

COMMUNICATION OF WQMN RESULTS

One of the objectives of the WQMN is to provide information on the IRL's water quality status and trends. Currently, the SJRWMD is preparing separate water quality reports on the IRL system: Mosquito Lagoon, Banana River Lagoon, and Indian River Lagoon - Brevard/Indian River counties. It is proposed that in the next two years, and biannually thereafter, report updates will be more narrow in scope; providing a status and trend assessment relative to seagrasses and relevant water quality targets. The reports are intended for agency resource managers and scientists, although a summary section should be included for the general public.

Summaries intended for general public consumption are very important for reasons of agency accountability, increasing awareness of the IRL, and engendering public support of IRL programs. In addition to preparing technical reports, non-technical summaries of one page or less can be included in an IRL newsletter published by the National Estuary Program through its Data and Information Management Strategies (DIMS) program.

OTHER ISSUES AND TASKS

Assuming that the proposed modification of the WQMN is accepted by the agencies participating in the network, the following issues should be discussed and resolved by consensus among the WQMN participants. These tasks are:

1. Modification of the QA/QC Plans for the WQMN based on the modification proposed above;
2. Uniformity or compatibility among agencies regarding data acquisition, management, and output formats;
3. Standard protocol for data analyses (e.g., determining central tendency, determining frequency that observed data exceeds a water quality target, detecting temporal and spatial trends)
4. Reports -- how should the data be presented and how often

CONCLUSION

The proposed modifications to the network are intended to further focus its mission on (a) providing answers to specific questions related to the *long-term* management of *seagrass* and the *water quality* of its environment, (b) increasing the statistical power of the data collected (and, thus, the performance of the WQMN), (c) increasing the effectiveness of staff and laboratory resources, and (d) collecting complementary data for the calibration of the PLR Model. Furthermore, as management strategies are enacted to achieve pollution load reduction goals, the WQMN can help gauge their effectiveness in improving water quality necessary for seagrass recovery .

Modifications to the WQMN would be in effect for up to three years before re-evaluation. The proposed modifications are:

1) a substantial decrease in the number of fixed sampling stations;

2) the selection of existing sampling stations based on their proximity to seagrass measurement transects;

3) an increase in the sampling frequency at each station to three times per station during a tidal cycle each month (dropping back to 1 sampling per station per month after three years);

4) the inclusion of near-bottom nutrient samples to be collected at each station, at least once during a tidal cycle (~12 hr) each month, to help calibrate the PLR Model;

5) the measurement of the separate organic and inorganic fractions of total supended solids; and

6) the centralization of laboratory analyses to reduce potential analytical errors (which can occur when several laboratories are involved in a monitoring program).

By streamlining the WQMN as proposed, staff and laboratory resources will be used more effectively and place less budgetary demand on the participating agencies. The ultimate benefit will be a more cost-effective and efficient monitoring tool to measure the water quality of the seagrass environment.

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APPENDIX

A. Summary of Actions

B. Data Analyses and Summary Statistics

C. Power of Test Analyses

A. SUMMARY OF ACTIONS FOR FIXED STATIONS IN THE IRL BASIN

Table A.1. Summary of actions taken for the fixed stations in the Indian River Lagoon system.

STATION	ACTION	STATION ID
I. MOSQUITO LAGOON		
V01	Deleted	
V02	***Retained***	**V02**
V03	Deleted	
V04	Deleted	
V05	Deleted	
V06	Deleted	
V07	Deleted	
V08	Deleted	
V09	Deleted	
V10	Deleted	
V11	***Retained***	**V11**
V12	Deleted	
V13	Deleted	
V14	Deleted	
V15	Deleted	
V16	Deleted	
V17	***Retained***	**V17**
V18	Deleted	
V19	Deleted	
V20	Deleted	
V21	Deleted	
V22	***Retained***	**ML02**
II. BANANA RIVER LAGOON		
B01	Deleted	
B02	***Retained***	**B02**
B03	Deleted	
B04	***Retained***	**B04**
B05	Deleted	
B06	***Retained***	**B06**
B07	Deleted	
B08	Deleted	
B09	***Retained***	**B09**
B10	Deleted	

STATION	ACTION	STATION ID
III. INDIAN RIVER LAGOON (Brevard County)		
I01	Deleted	
I02	***Retained***	**I02**
I03	Deleted	
I04	Deleted	
I05	Deleted	
I06	Deleted	
I07	***Retained***	**I07**
I08	Deleted	
I09	Deleted	
I10	***Retained***	**I10**
I11	Deleted	
I12	Deleted	
I13	***Retained***	**I13**
I14	Deleted	
I15	Deleted	
I16	***Retained***	**I16**
I17	Deleted	
I18	***Retained***	**I18**
I19	Deleted	
I20	Deleted	
I21	***Retained***	**I21**
I22	Deleted	
I23	***Retained***	**I23**
I24	Deleted	
I25	Deleted	
I26	Deleted	
I27	***Retained***	**I27**
I28	Deleted	
I29	***Retained***	**I29**
IV. INDIAN RIVER LAGOON (Indian River County)		
IRJ01	**Retained**	**IRJ01**
IRJ02	Deleted	
IRJ03	Deleted	
IRJ04	**Retained**	**IRJ04**
IRJ05	**Retained**	**IRJ05**
IRJ16	Deleted	
IRJ07	**Retained**	**IRJ07**
IRJ08	Deleted	
IRJ09	Deleted	
IRJ10	**Retained**	**IRJ10**
IRJ11	Deleted	
IRJ12	**Retained**	**IRJ12**

B. Data Analyses and Summary Statistics

Parametric and non-parametric methods can be used to analyze data. Unlike parametric methods, non-parametric methods do not require assumptions to be made about the data. The purpose of data analysis is to convert data into meaningful information. In order to quantify monitoring goals, appropriate statistical hypotheses must be expressed numerically.

Once the data are properly arranged, the data are ready to be explored and analyzed. The data analysis will provide the necessary information to determine which ***statistical test*** is appropriate to test the null hypothesis. The selection of a ***measure of central tendency*** (given below) for normal and skewed-log normal distribution or any ***statistical methodology*** is dependent upon: 1) what information is desired, 2) the characteristics of the data, and 3) the distribution of the data. It is wise to initially plot a data set before any statistical analysis is undertaken. Useful plots include ***data versus time, data versus distance***, ***histograms***, or ***normal probability***. The choice of statistical method or methods for the estimation of trends in water quality will depend upon:

1. ***the type of trend hypothesis to examine (step trend versus linear trend);***
2. ***the general category of statistical methods to employ (parametric versus non-parametric);***
3. ***the kind of water quality data to analyze (concentration versus flux); and***
4. ***various data manipulation choices (transformation, seasonality, principal component analysis, kriging).***

There are three assumptions regarding the use of statistics in water quality (Smith et al., 1982). These are:

1. ***Normally distributed observations;***
2. ***Independence of observations; and***
3. ***Homogeneity of variance over the period of record***

Normal Distribution. An assumption central to most parametric statistical test is that the data come from a population that exhibits a normal distribution. Graphical techniques, involving visual comparisons, could be used to provide qualitative information on the form of the underlying information (Montgomery and Reckhow, 1984). Two methods to test statistically the assumption of normality are the ***W-Test*** (Shapiro and Wilk, 1965), appropriate for sample size ≤ 50, and, for large samples (≥ 50), the ***Kolmogorov-Smirnov test*** (Siegel, 1956).

Independence of Observation. The independent, or random, sample assumption implies that in choosing a sample of observations, every possible combination of observations has an equal chance of being selected (Ponce, 1980). In an estuary or lake, an annual concentration of chosen water parameter or parameters will often depend on the concentration in the estuary or lake in a previous year, or years. This dependency is being referred to as autocorrelated data or serial correlation.

Homogeneity of Variance. A check of the homogeneity of variance may be undertaken by the testing the hypothesis, H_o: $\sigma_1^2 = \sigma_2^2 = \ldots \sigma_t^2$, where **t** is the number of treatments. Cochran (1947) described the consequence of violation of homogeneity of variance as a loss of efficiency in estimation of treatment effects. Cleveland and Kleiner (1975) discussed methods for testing homogeneity of variance. The precision of using one statistical procedure (parametric versus non-parametric) in preference to another should be based on considerations of power and efficiency of data analysis. ***Power*** is the probability of rejecting the null hypothesis given a particular type and magnitude of actual trend. ***Efficiency*** is a measure of error estimator. Table B.1 below shows a typical analysis of variance for balanced design applicable to estuarine water quality data analysis and interpretation in Indian River Lagoon system.

Table B.1. Analysis of variance for balanced design (parametric).

Sources of Variation	Degrees of Freedom	Sum of Squares	Expected Mean Square
Type of Lagoon (Banana River vs. Mosquito)	a-1	SS_{Type}	$\sigma_1^2 + d\sigma_2^2 + cd\sigma_3^2 + Q$
Individual Lagoon	a(b-1)	SS_{Lagoon}	$\sigma_1^2 + d\sigma_2^2 + cd\sigma_3^2$
Station within Lagoon	ab(c-1)	$SS_{Station}$	$\sigma_1^2 + d\sigma_2^2$
Sample within Station	abc(d-1)	SS_{Sample}	σ_1^2
Total	abcd-1		

Although water quality data, in general, violate independence, homogeneity, and normal distribution, the use of a balanced design analysis as shown in Table B.1 is still acceptable. Results of the balanced design analysis would certainly provide initial information that may lead to a more specific type of data trend analyses, i.e., parametric vs. non-parametric method. Hirsch et al. (1982) demonstrated that water quality data are commonly skewed. Non-parametric procedures can have significantly higher power or efficiency than parametric procedures in case there is substantial departure from normality. However, there is less confidence among water quality statisticians regarding effectiveness of non-parametric procedures for cases with minor departure from normality. The ***Monte Carlo*** and ***seasonal Kendal Tau*** test as suggested by Hirsch et al. (1982) are appropriate for the non-parametric trend analysis for monthly water quality. For more information for these tests, one may refer to technical papers (Hirsch et al., 1982, 1984, 1991; Montgomery and Rechow, 1984) published elsewhere.

Many ***time series*** of water quality data consist of a sequence of instantaneous concentration measurements and concurrent measurements of discharge. If discharge and concentrations are both available, then the choice can be between examining ***trends in concentration*** or ***trends in flux***. If the question is on the ambient water quality, then the concentration would certainly be an appropriate variable to evaluate for trend. However, if transport and storage of the water and its constituents is an important factor and the water has long residence time and exposure to chemicals by aquatic organisms, then flux may well be the appropriate variable to analyze.

Data Transformation and Multivariate Analysis. The analyses of water quality data from long-term fixed stations networks present a number of challenges. One feature that is common to a great deal of water quality data analysis is that they depart substantially from a normal distribution. Seasonal differences in the underlying distributions, presence of non-detectable values, or data that may be correlated in time and between constituents may further complicate data trend analyses because most water quality parameters can be classified into natural groups. Examples of such groupings are: common ions, nutrients, and trace metals. Since these groups are usually with common physico-chemical behavior and correlative relationships, **multivariate analysis** for their trend analysis may be desirable in most cases.

Principal Component Analysis (PCA). Principal components is an approach to multivariate analysis. It is an efficient method for discovering predominant patterns among a large number of variables. The applicability of this type of analysis is in the isolation of groups of parameters which account for most of the variability in estuarine water quality characteristics. The first step is to compute a **correlation matrix** . The second step is to find the principal components (**eigenvalues**) of the correlation matrix. The ***principal components*** are defined as the combination of variables which explain the greatest amount of variances and covariances in the correlation matrix. **PROC PRINCOMP** in Statistical Analysis System (SAS, 1988) computed the estimated **eigenvalues** for respective principal components. For the design of a multi-parameter surveillance system, like in the estuarine water quality monitoring, the PROC PRINCOMP provides valuable guidelines. It ranks the parameters in order of their importance. An example of principal component analysis using the SAS programming principles for water quality data trend analysis applicable to Indian River Lagoon system is given below.

```
Data = IndnRiv;
    Input Station Date Salinity TSS Turbidity TKN TP...Chloroa;
Proc Sort Data = IndnRiv;  By Station; By Date;

Title1 'Principal Component Analysis of WaterQual parameter in Indian River';
```

```
Proc PrinComp Data = IndnRiv cov out = Indiannew;
   Var Salinity TSS Turbidity TKN TP... Chloroa;

Proc Plot Data = Indiannew;
   Plot prin1*prin2 = Station;

Title2 'Analysis on Correlation Matrix'
Proc PrinComp out = Indiannew;
   Var Salinity TSS Turbidity TKN TP... Chloroa;
Proc Plot Data = Indiannew;
   Plot prin1*prin2 = Station;

Endsas;
```

Cluster Analysis. The **PROC CLUSTER** in SAS (SAS, 1988) is another helpful multivariate technique for examining water quality data from a long-term fixed station sampling. The purpose of cluster analysis (PROC CLUSTER) is to place objects into groups or clusters suggested by the data, such that objects in a given cluster tend to be similar. The applicability of this type of analysis is in grouping of several stations (spatial) or sampling frequency (temporal). This type of analysis may reveal through the ***clustering or grouping of stations*** that certain sampling sites are quite similar, thus, their number could be reduced to save time and money. Similarly, clustering or groupings of sampling frequency would likewise decrease the sampling frequency. The PROC CLUSTER provides economy in the number of parameters and isolates the parameters which vary independently and have to be included or excluded in any sampling scheme. Each observation begins in a cluster by itself. The two closest clusters are merged to form a new cluster replacing the two old clusters then merging is repeated until few clusters are left (SAS, 1988). An example of a ***PROC CLUSTER*** analysis procedure applicable to water quality data trend analysis is given below.

```
Data = IndnRiv;
   Input Station Date Salinity TSS Turbidity TKN TP...Chloroa;
Proc Sort Data = IndnRiv;
Title1 'Cluster Analysis For Salinity in Indian River Lagoon';

Proc Cluster Data = IndnRiv Method = Average Pseudo;
   Var Station;

Proc Tree;
Proc Cluster Data = IndnRiv  Method = Centriod Pseudo;
   Var Station;

Proc Tree;
Proc Cluster Data = IndnRiv Method = Twostage  K = 3;
   Var Station;
```

```
Proc Tree;
Proc Plot;
   Plot Station*salinity = Cluster / HPOS=86 VPOS=26;

Endsas;
```

Kriging. Kriging is a useful technique for spatial predictions that can be used for water quality data analysis and interpretation. It is a form of weighted local averaging. The applicability of this type of analysis on water quality monitoring data is in the spatial representation of water quality parameters showing values for unsampled places having minimum variance (Gamma Design, 1990; Matheron, 1963). A useful feature of kriging is that an error term (estimation variance) is calculated for each estimated value, providing a measure of the reliability of the interpolation.

If we want to the estimate values, **z***, for all the locations, $\mathbf{x_o}$, where values have not been measured, and that the estimation is assumed to be a linear combination of measured values, our initial kriging estimation is given in equation 1,

$$\mathbf{z^*(x_o) = \sum \lambda_i\, z(x_i) \qquad x = i \text{ to } N} \qquad [1]$$

in which **N** is the number of measured values, $\mathbf{z(x_i)}$ involved in the estimation, λ_i are the weights attached to each measured value, $\mathbf{z(x_i)}$ and **z*** is the estimator parameter. By taking $\mathbf{z(x_i)}$ as a realization of the random function $\mathbf{Z(x_i)}$ and assuming stationarity, the estimator **z***, becomes

$$\mathbf{Z^*(x_o) = \sum \lambda_i\, Z(x_i)} \qquad [2]$$

The kriging system (equation 2) can be written in matrix notation as

$$\mathbf{[C][\lambda] = [b]} \qquad [3]$$

with solution in the form

$$\mathbf{[\lambda] = [C]^{-1}[b]} \qquad [4]$$

in which **[C]** is the covariance matrix, or the kriging matrix in terms of covariance, $\mathbf{[C]^{-1}}$ is the inverse of **[C]**, **[λ]** is the matrix of unknown weighting factors. Suppose that N = 4, then the matrix **[C]** is then a ***5 x 5 matrix*** and can be written as

$$\mathbf{[C]} = \begin{bmatrix} c(x1, x1) & c(x1, x2) & c(x1, x3) & c(x1, x4) & 1 \\ c(x2, x1) & c(x2, x2) & c(x2, x3) & c(x2, x4) & 1 \\ c(x3, x1) & c(x3, x2) & c(x3, x3) & c(x3, x4) & 1 \\ c(x4, x1) & c(x4, x2) & c(x4, x3) & c(x4, x4) & 1 \\ 1 & 1 & 1 & 1 & 0 \end{bmatrix} \qquad [5]$$

$$[\boldsymbol{\lambda}] = \begin{bmatrix} \lambda 1 \\ \lambda 2 \\ \lambda 3 \\ \lambda 4 \\ -\mu \end{bmatrix} \qquad [6]$$

The value of **b** in equation 3 can be represented by the following matrix notation

$$[\mathbf{b}] = \begin{bmatrix} c(x1,\ x0) \\ c(x2,\ x0) \\ c(x3,\ x0) \\ c(x4,\ x0) \end{bmatrix} \qquad [7]$$

SUMMARY STATISTICS OF WATER QUALITY IN THE IRL BASIN

Table B.2. Summary statistics of water quality (turbidity) as a basis for segmentation in the Mosquito Lagoon.

Station	Turbidity (NTU)	Cluster[1]	Segment	Proposed Station
V01	5.84	***a***	**I**	Deleted
V02	6.04	***a***	**I**	**V02**
V03	6.49	***a***	**I**	Deleted
V04	6.17	***a***	**I**	Deleted
V05	6.48	***b***	**II**	Deleted
V06	7.21	***b***	**II**	Deleted
V07	7.22	***b***	**II**	Deleted
V08	6.55	***b***	**II**	Deleted
V09	7.15	***b***	**II**	Deleted
V10	7.08	***b***	**II**	Deleted
V11	7.87	***b***	**II**	**V11**
V12	7.10	***b***	**II**	Deleted
V13	7.44	***b***	**II**	Deleted
V14	6.45	***c***	**III**	Deleted
V15	6.78	***c***	**III**	Deleted
V16	5.77	***c***	**III**	Deleted
V17	6.46	***c***	**III**	**V17**
V18	6.51	***c***	**III**	Deleted
V19	3.97	***d***	**IV**	Deleted
V20	5.49	***d***	**IV**	Deleted
V21	3.39	***d***	**IV**	Deleted
V22	5.13	***d***	**IV**	**V22**

[1]Cluster or grouping of turbidity classes was generated using parametric techniques (SAS, 1988)

Other Basis For Creating Segments in the Mosquito Lagoon:

The four segments (**I**, **II**, **III**, and **IV**) created in the Mosquito Lagoon were also based on the results of the univariate analysis (Duncan's Multiple Range Tests) for DO, Chlorophyll a, and Turbidity data (SAS, 1988). These analyses assumed independence, homogeneity, and normal distribution. Results of the analyses are shown in Table B.3.

Table B.3. Mean salinity, DO, and chlorophyll a in the Mosquito Lagoon.

Station	**Salinity** (ppt)	**DO** (mg/L)	**Chlorophyll *a*** (µg/L)
V01	33.02a[1]	6.52abc	7.99a
V02	33.01a	6.49abc	8.29a
V03	33.98a	6.42abc	9.25a
V04	33.07a	6.45abc	8.82a
V05	33.03a	6.41abc	9.10a
V06	32.95a	6.81a	10.56a
V07	32.99a	6.82a	10.71a
V08	32.79a	6.79a	10.14a
V09	33.30a	6.79a	9.27a
V10	32.78a	6.66ab	10.74a
V11	33.11a	6.28bc	7.24a
V12	33.07a	6.53abc	8.85a
V13	32.88a	6.85a	8.51a
V14	32.53a	6.73a	10.11a
V15	32.62a	6.19c	8.56a
V16	32.53a	6.16c	7.52a
V17	32.68a	6.43abc	7.41a
V18	32.79a	6.51abc	8.07a
V19	32.84a	6.76a	4.73a
V20	32.78a	6.81a	6.76a
ML01	31.26a	6.46abc	6.67a
ML02	31.11a	6.57ab	6.64a

[1] *Mean values with common letter(s) are not significantly different at $p < 0.05$*

Table B.4. Summary statistics of water quality (salinity) as a basis for segmentation in the Banana River Lagoon.

Stations	Salinity (ppt)	Cluster[1]	Segment	Proposed Station
B01	26.6	***a***	**I**	**B02**
B02	26.2	***a***	**I**	Deleted
B03	25.1	***b***	**II**	Deleted
B04	25.4	***b***	**II**	**B04**
B05	24.6	***b***	**II**	Deleted
B06	23.9	***c***	**III**	**B06**
B07	23.7	***c***	**III**	Deleted
B08	23.9	***c***	**III**	Deleted
B09	23.5	***c***	**III**	**B09**
B10	23.1	***c***	**III**	Deleted

[1] *Cluster or grouping of salinity classes was generated using parametric techniques*

<u>Other Basis For Creating Segments in the Banana River Lagoon:</u>

The three segments (**I**, **II**, and **III**) created in the Banana River Lagoon were also based on the results of the univariate analysis (Duncan's Multiple Range Tests) for DO, Chlorophyll a, and Turbidity data (SAS, 1988). These analyses assumed independence, homogeneity, and normal distribution. Results of the analyses are shown in Table B.5.

Table B.5. Mean DO, chlorophyll a, and turbidity in the Banana River Lagoon.

Stations	DO (mg/L)	Chlorophyll a (μg/L)	Turbidity (NTU)
B01	6.42ab[1]	5.73d	3.98ab
B02	6.50ab	5.80d	3.69ab
B03	6.49ab	9.23cd	3.99ab
B04	6.82ab	9.18cd	5.03a
B05	6.30b	10.47bc	4.38ab
B06	6.72ab	16.78ab	4.72ab
B07	6.82ab	15.95ab	4.35ab
B08	6.99a	16.09ab	4.16ab
B09	6.81ab	13.22ab	3.24b
B10	6.28b	19.44a	4.64ab

[1] *Mean values with common letter(s) are not significantly different at $p < 0.05$*

Table B.6. Summary statistics of water quality (salinity) as a basis for segmentation in the Indian River Lagoon (Brevard County).

Station	**Salinity** (ppt)	**Cluster**[1]	**Segment**	**Proposed Station**
I01	29.34	***a***	**I**	Deleted
I02	29.70	***a***	**I**	**I02**
I03	29.07	***a***	**I**	Deleted
I04	29.82	***a***	**I**	Deleted
I05	29.26	***a***	**I**	Deleted
I06	29.04	***a***	**I**	**I06**
I07	28.75	***b***	**II**	Deleted
I08	27.99	***b***	**II**	Deleted
I09	27.93	***b***	**II**	Deleted
I10	27.28	***b***	**II**	**I10**
I11	25.88	***c***	**III**	Deleted
I12	25.88	***c***	**III**	Deleted
I13	25.66	***c***	**III**	**I13**
I14	25.22	***d***	**IV**	Deleted
I15	24.91	***d***	**IV**	Deleted
I16	24.39	***d***	**IV**	I16
I17	23.73	***d***	**IV**	Deleted
I18	23.74	***d***	**IV**	**I18**
I19	23.60	***d***	**IV**	Deleted
I20	23.43	***e***	**V**	Deleted
I21	23.07	***e***	**V**	**I21**
I22	23.05	***e***	**V**	Deleted
I23	23.14	***f***	**VI**	**I23**
I24	23.09	***f***	**VI**	Deleted
I25	23.45	***f***	**VI**	Deleted
I26	24.48	***f***	**VI**	Deleted
I27	25.38	***g***	**VII**	**I27**
I28	28.02	***g***	**VII**	Deleted
I29	28.97	***g***	**VII**	**I29**

[1]Cluster or grouping of salinity classes was generated using parametric techniques (SAS, 1988)

Other Basis For Creating Segments in the Indian River Lagoon (Brevard County):

The seven segments (**I**, **II**, **III**, **IV**, **V**, **VI**, and **VII**) created in the Indian River Lagoon were also based on the results of the univariate analysis (Duncan's Multiple Range Tests) for DO, Chlorophyll a, and Turbidity data (SAS, 1988). These analyses assumed independence, homogeneity, and normal distribution. The results of the analyses are shown in Table B.7.

Table B.7. Mean DO, chlorophyll a, and turbidity in the Indian River Lagoon (Brevard County).

Station	**DO** (mg/L)	**Chlorophyll a** (µg/L)	**Turbidity** (NTU)
I01	6.48g[1]	5.99d	2.11e
I02	6.67efg	7.98bcd	4.75abcde
I03	6.85defg	8.93bcd	3.00bcde
I04	6.60fg	8.76bcd	2.81de
I05	6.84defg	9.75abcd	3.15bcde
I06	7.03bcdef	10.08abcd	3.51bcde
I07	7.00bcdefg	11.06abcd	2.85de
I08	7.19abcdef	8.95bcd	2.13e
I09	7.20abcdef	7.26cd	3.08bcde
I10	6.90cdefg	11.15abcd	2.35e
I11	7.40abcd	9.70abcd	5.62ab
I12	7.10abcdef	12.24abcd	4.69abcde
I13	7.01bcdef	13.08abcd	5.15abcd
I14	7.25abcdef	17.13a	5.20abcd
I15	7.19abcdef	15.96ab	5.20abcd
I16	7.11abcdef	12.56abcd	5.58abc
I17	6.81defg	12.15abcd	4.22abcde
I18	6.82defg	14.16abc	3.15bcde
I19	6.88cdefg	13.54abcd	2.53de
I20	6.81defg	14.12abc	2.79de
I21	6.62fg	15.88ab	3.22bcde
I22	7.08bcdef	14.88abc	3.02bcde
I23	7.00bcdefg	14.52abc	2.95cde
I24	7.15abcdef	12.12abcd	3.06bcde
I25	7.25abcde	11.17abcd	2.54de
I26	7.68a	11.69abcd	3.15bcde
I27	7.47abc	13.52abcd	2.75de
I28	7.57ab	11.93abcd	4.17abcde
I29	7.56ab	10.18abcd	5.88a

[1] *Mean values with common letter (s) are not significantly different at $p < 0.05$*

Table B.8. Summary statistics of water quality (salinity) as a basis for segmentation in the Indian River Lagoon (Indian River County).

Station	Salinity (ppt)	Cluster[1]	Segment	Proposed Station
IRJ01	28.83	a	I	**IRJ01**
IRJ02	27.87	*a*	I	Deleted
IRJ03	26.81	*a*	I	Deleted
IRJ04	25.45	*b*	II	**IRJ04**
IRJ05	24.91	*b*	II	**IRJ05**
IRJ16	25.23	*b*	II	Deleted
IRJ07	25.64	*b*	II	**IRJ07**
IRJ08	26.78	*b*	II	Deleted
IRJ09	28.33			Deleted
IRJ10	25.36	*c*	III	**IRJ10**
IRJ11	23.65	*c*	III	Deleted
IRJ12	24.26	*c*	III	**IRJ12**

[1]Cluster or grouping of salinity classes was generated using parametric techniques (SAS, 1988)

Table B.9. Summary statistics of water quality (turbidity) as a basis for segmentation in the Indian River Lagoon (Indian River County).

Station	Turbidity (NTU)	Cluster[1]	Segment	Proposed Station
IRJ01	6.39	a	I	**IRJ01**
IRJ02	6.96	*a*	I	Deleted
IRJ03	6.72	*a*	I	Deleted
IRJ04	6.69	*b*	II	**IRJ04**
IRJ05	6.19	*b*	II	**IRJ05**
IRJ16	6.20	*b*	II	Deleted
IRJ07	5.91	*b*	II	**IRJ07**
IRJ08	5.66	*b*	II	Deleted
IRJ09	4.88			Deleted
IRJ10	10.11	*c*	III	**IRJ10**
IRJ11	6.13	*c*	III	Deleted
IRJ12	8.67	*c*	III	**IRJ12**

[1]Cluster or grouping of salinity classes was generated using parametric techniques

Other Basis For Creating Segments in the Indian River Lagoon (Indian River County):

The three segments (**I**, **II**, and **III**) created in the Indian River Lagoon (Indian River County) were also based on the results of the univariate analysis (Duncan's Multiple Range Tests) for DO, Chlorophyll a, and Turbidity data (SAS, 1988). These analyses assumed independence, homogeneity, and normal distribution. The results of the analyses are shown in Table B.10.

Table B.10. Mean DO, chlorophyll a, and TSS in the Indian River Lagoon (Indian River County).

Station	**DO** (mg/L)	**Chlorophyll a** (μg/L)	**TSS** (mg/L)
IRJ01	6.97a[1]	5.99d	39.52a
IRJ02	6.73ab	7.98bcd	34.59ab
IRJ03	6.51ab	8.93bcd	41.29a
IRJ04	6.33ab	13.80ab	32.59ab
IRJ05	6.19ab	13.96ab	36.97ab
IRJ16	6.39ab	15.34a	34.10ab
IRJ07	6.42ab	13.39ab	40.29a
IRJ08	6.23ab	9.13ab	2.13e
IRJ09	6.03b	7.45b	3.08bcde
IRJ10	6.59ab	12.97ab	2.35e
IRJ11	5.92b	9.26ab	5.62ab
IRJ12	6.01b	12.67ab	4.69abcde

[1] *Mean values with common letter (s) are not significantly different at $p < 0.05$*

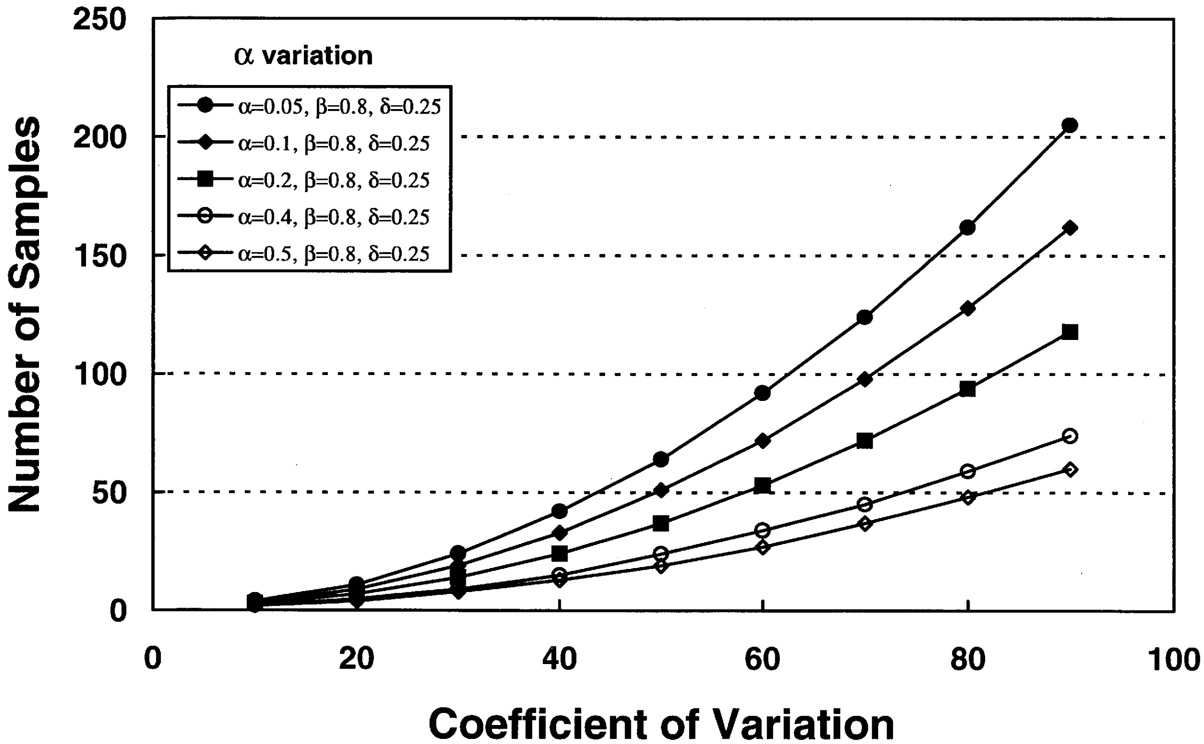

Figure C.1. Relationship of the number of samples with the coefficient of variation at varying levels of significance (α).

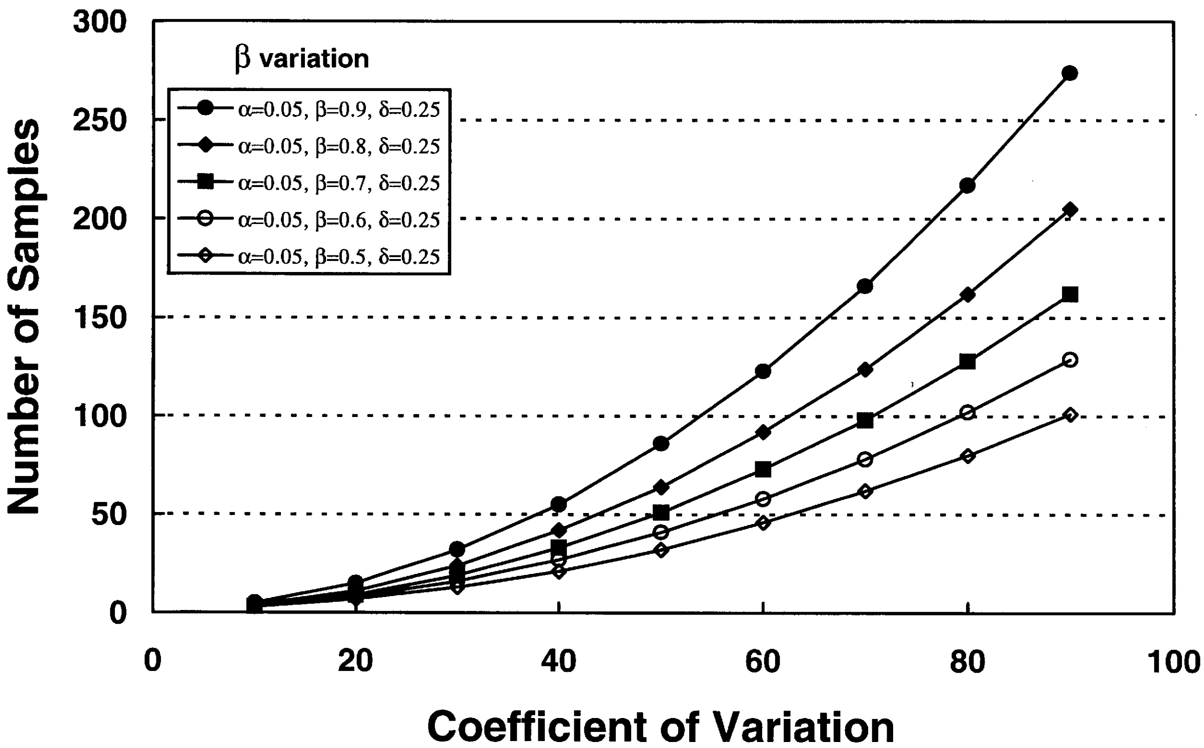

Figure C.2. Relationship of the number of samples with the coefficient of variation at varying levels of probability (β).

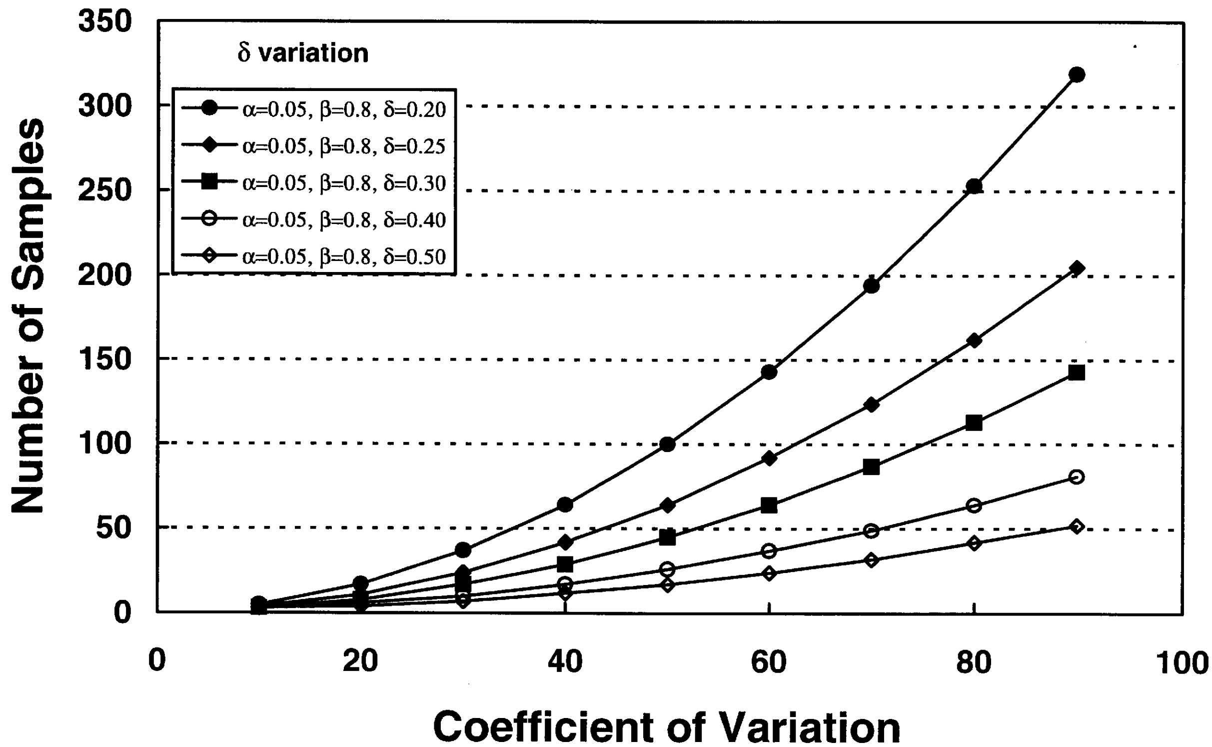

Figure C.3. Relationship of the number of samples with the coefficient of variation at varying levels of true difference (δ).