Setting pollutant loading targets for the Indian River and Banana River lagoons based on loadings vs. seagrass depth limit relationships

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INTRODUCTION

Background

In many estuaries, including the Indian River and Banana River (IRBR) lagoons, the depth distribution of seagrass is largely a function of downwelling light, which is affected by water transparency. By reducing the loadings of pollutants that diminish water transparency and attenuate light, the potential for further seagrass coverage at depth increases. The major pollutants of concern in the IRBR system are total suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP)[1] (Steward et al. 2003a; Hanisak 2001).

Two levels of seagrass restoration depth targets have been proposed. The first level is the mapped 1943 coverage for IRBR (46,031 acres), the greatest lagoon-wide seagrass coverage of any single mapping year available up to 2001 (the other mapping years are 1986, 1989, 1992, 1994, 1996, and 1999). However, the 1943 seagrass depth limits serve only as intermediate, not full, restoration targets because 1943 was not an un-impacted year with respect to seagrass growing conditions (Virnstein and Morris 2000). In fact, several segments have had more coverage in recent mapping years than in 1943 (e.g., segment IR4 had greater coverage in 1986 than in 1943, as did segments BR1-2, BR3-5, IR5, IR8, and IR21 in 1999; and IR13 and IR14-15 in 1996; see Figure 1 for map of IRL segments).

The second target level is the full restoration depth target. This target is based on the union of all the mapped seagrass coverages available from 1943 to 1999, which encompassed every lagoon bottom area where seagrass had been mapped (Steward et al. 2005). The deep-edge boundary delineating this union coverage is considered the full restoration depth-limit target for seagrass. Both the intermediate (1943) and full restoration (union coverage) depth-limit targets were established for each IRBR segment. For much of the IRBR, the 1943 depth target is shallower than the restoration target (using median depth target values) by an average of -0.2 m or -15%.

Following the establishment of the depth targets, we proceeded to determine the prerequisite pollutant load limits. With respect to meeting the intermediate (1943) depth targets, it's assumed that by meeting 1943 loading rates, water transparency would improve sufficiently to enable seagrass expansion to the 1943 depth coverage (Steward and Green 2003; Steward et al. 2003a). U.S. EPA adopted this approach in 2003 in its development of draft Total Maximum Daily Loads (TMDLs) for the IRBR estuaries (U.S. EPA, Region 4, 2003).

Subsequent analyses in 2003 utilized linear regression models that quantified the variability of seagrass depth limits as a function of pollutant load (lb/ac/yr). The seagrass depth limits were represented as percent departures from the full restoration, depth-limit targets. The regression models provided statistical support to EPA's 2003 draft TMDLs (Steward et al. 2003b). These system-wide linear regressions showed that the application of 1943 loads as load limits could achieve not only the 1943 depth limits in most segments, but could achieve about 85% of the full restoration depth targets.

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[1] Either nutrient can be limiting in the Indian River Lagoon system. P is typically limiting in the northern portion of the system, N in the southern portion, although both nutrients are generally in surplus (Phlips et al., 2002).

INDIAN RIVER & BANANA RIVER (IRBR) Sub-lagoons and Segments

For this study, the IRBR estuary includes the Indian River Lagoon (IRL) just north of Ft. Pierce Inlet, and Banana River. The IRBR sub-lagoons are the North IRL, Central IRL, and Banana River

Setting Segment Boundaries

Several factors were considered in setting segment boundaries. The primary factor is the presence of causeway bridges (13) that cross the IRBR between Titusville and Vero Beach. There were apparent differences in seagrass coverage patterns between several segment pairs separated by causeways. Large island groupings, cuspate spits, and major tributaries were also considered in setting boundaries. Final segmentation was based on spatial analyses of water quality data -- principal component analysis (PCA), cluster and kriging analyses. PCA identified the principal variables -- turbidity and salinity -- responsible for inter-segment variability. The grouping of seagrass segments with similar water quality was performed through cluster and kriging analyses of turbidity and salinity (Sigua et al. 1996). The final outcome was an IRBR system divided into 15 segments as shown here.

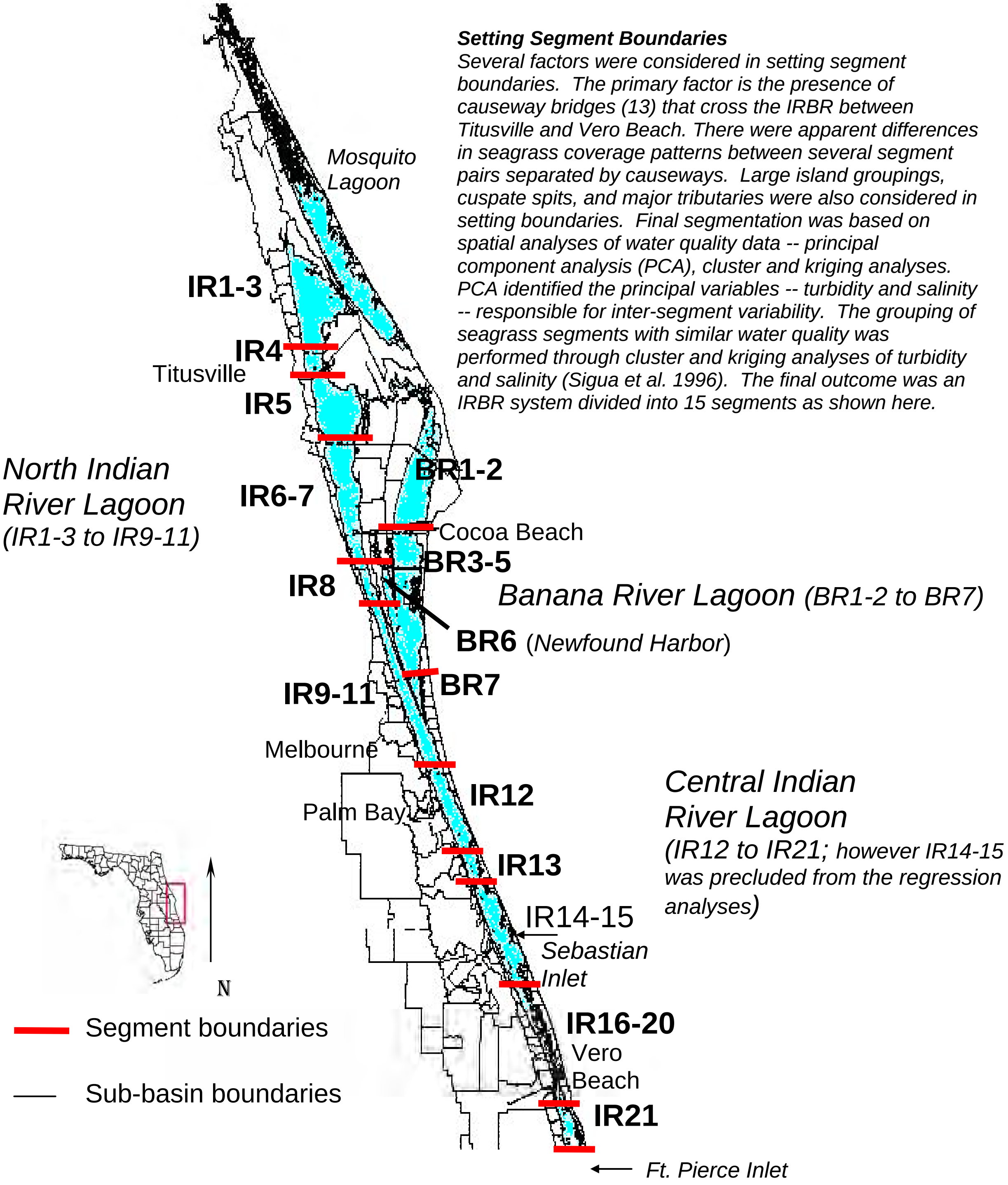

Figure 1. Segmentation of the Indian River and Banana River (IRBR) Lagoon System (South Indian River Lagoon not shown)

From 2004 through 2006, we further revised and applied the regression analyses as described below.

- Surface run-off pollutant load estimates were slightly modified due to the re-calibration of the Pollutant Load Screening Model (PLSM). Load estimates were revised for 1943, 1996 and 1999 and newly developed for 2001. Except for 1943, the load estimates included run-off loads plus point-source loads from NPDES permitted facilities[2]. The Florida Department of Environmental Protection (FDEP), Tallahassee, provided the NPDES facility flow and concentration data that were used to calculate point-source loads, but not before FDEP's Central District (Orlando) Office reviewed those data against the original file data (monthly operating reports) and corrected any errors.

  For 1943, only the run-off load estimates were used because there are no point-source data for that year and we assumed that any amount of point-source loading during 1943 was not significant. The revised regression models were developed for the IRBR as a whole as well as for each sub-lagoon: North Indian River Lagoon (IRL), Central IRL, and Banana River Lagoon.

- The loading data were log-transformed and then regressed against depth limits, which, as before, were represented as percent departures from the depth-limit targets (see **METHODS**, p. 6). Log-transforming the load data resulted in normally distributed data sets and is scientifically supported by the fact that the relationship between loading rates and seagrass depth limits is exponential (and not linear as suggested by the earlier regression models in Steward et al. 2003b). The exponential relationship between downwelling light and water quality variables that scatter and absorb light is well established (Kirk 1983; Davies-Colley et al. 1993; and Gallegos and Kenworthy 1996) and, thus, a similar relationship has been shown to exist between the loadings of the water transparency constituents and seagrass depths as mediated by light.

- As a check on the PLSM results, another model, Hydrologic Simulation Program-Fortran or HSPF, was used to generate load estimates for the same years listed above. The HSPF model generally confirmed the PLSM-estimated annual loads. But, the annual PLSM loads generally produced better regression statistics than HSPF loads based on the determinant coefficient (R^2) and significance (p value) for all parameters and sub-lagoons (except for annual TP loads in the North IRL); thus, the PLSM-based regression models were predominant in setting annual load targets. For setting seasonal load targets for the sub-lagoons, PLSM and HSPF loads were used nearly equally.

- Seasonality (wet and dry seasons) was also evaluated and it appears there is statistical merit in considering seasonal load limits.

- For the revised Central IRL regression models (annual and seasonal), segments IR12 and IR13A were combined, creating a new and enlarged IR12 (consequently, we re-labeled IR13B as IR13). Combining the two segments was justified given the statistical similarity in water quality between them and the apparent influence that discharges from Turkey Creek, which is in IR12, can have on IR13A immediately to the south.

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[2] NPDES is National Pollutant Discharge System (managed by EPA). The NPDES facilities included in the point-source load estimation are domestic wastewater treatment plants and reverse osmosis plants that discharge continuously or intermittently to the IRBR system.

- Early during the revision process, the District and EPA held a methods review meeting with FDEP [3]. As a result of that meeting, it was decided that load limits or TMDLs calculated from the revised regression models be based on a -10% departure (shoreward) from the full restoration, depth-limit target (i.e., allowing for a higher load limit compared to one based on the full restoration, depth-limit target). The basis for the 10% departure is related to Florida's water transparency standard (Chapter 62-302.530, Florida Administrative Code), which states that the "depth of the compensation point for photosynthetic activity [as it relates to seagrass depth limits in this case] shall not be reduced by more than 10% as compared to the natural background value." Natural background is defined as "…the condition of the waters [specifically water transparency in this case] in the absence of man-induced alterations based on the best scientific information available…" (Ch. 62-302.200(14), F.A.C.).

Purpose

The purpose of this paper is fourfold:

(1) to utilize the better of the two regression models (PLSM or HSPF-based) per sub-lagoon to determine new loading targets for TN, TP, and TSS that can be considered in the development of TMDLs, both annual and seasonal, and the corresponding annual pollutant load reduction goals (PLRGs).

(2) to compare the new loading targets to EPA's 2003 draft TMDLs (U.S.EPA, Region 4, 6/30/03) and to the District's revised 1943 loading estimates (6/25/04). Because the average 1943 seagrass depth limit is –15% of the full restoration depth target, we were interested to see how well the revised 1943 pollutant loads compare with the regression-calculated loads that are intended to meet –10% of the full restoration depth target.

(3) to allocate TMDLs among segments and to further evaluate that allocation between surface runoff sources and point sources (NPDES facilities)

(4) to present a case for an implicit margin of safety (MOS) in the development of TMDLs for the IRBR system; but also to present a statistical approach using the regression models to determine an explicit MOS.

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[3] Comments were received during an April 21, 2004 teleconference meeting between FDEP staff (Daryll Joyner, Wayne Magley), District staff (Joel Steward and Whitney Green), and EPA staff and consultant (Drew Bartlett, Dan Scheidt, David Melgaard, Molly Davis, and Tetra Tech's Frank Metzler).

METHODS

Sub-lagoons and Segments

Large spatial variability is a major characteristic of the IRBR and is well documented with respect to biology and hydrography (Gilmore 1977; St. Johns River and South Florida Water Management Districts 1987; Virnstein 1990; and Steward et al. 2005). The Indian River and Banana River lagoons are geographically, morphometrically, and hydrodynamically distinct (Fig. 1). The Central IRL differs from the North IRL and Banana River with respect to inlet proximity and average flushing rates (Christian 2004; Sheng 1997). The entire area of the Central IRL is within 28 km of either Sebastian Inlet or Ft. Pierce Inlet, much closer to the inlets than the North IRL and Banana River[4] (Fig. 1). Consequently, the average flushing rate in the Central IRL is ~10 times higher than in the North IRL, and ~15 times higher than in Banana River sub-lagoon (Christian 2004).

The North IRL, Central IRL, and Banana River sub-lagoons were further divided into segments (Fig. 1). Initially, segment boundaries were located at the 13 causeway bridges that span the IRL system where disruptions in hydrodynamic circulation patterns have either been observed or presumed to exist (Evink 1980), and where changes in seagrass coverage patterns were apparent (Virnstein et al. 2003). Variability among those segments was then assessed with respect to turbidity and salinity, the water quality parameters with the greatest spatial variability as determined by principal component analysis. Contiguous segments were aggregated if no significant turbidity and salinity differences were found between them (via kriging and cluster analysis by Sigua et al. 1996). As a result, 15 segments in the IRBR were established.

Seagrass Depth-Limit and Pollutant Loading Data

Segment-specific data sets comprising seagrass depth limits and pollutant loads (TN, TP, and TSS) were generated for those years when both types of data were sufficiently available. There were 4 years that qualified: 1943, 1996, 1999, and 2001.

Seagrass Depth-Limit Data: Seagrass depth limits were determined from depth measurements obtained from a 1996 bathymetric data set developed by Coastal Planning & Engineering, Inc. (1997). Depth measurements closest to a segment's seagrass deep-edge boundary were selected using a set of rules that served to capture only the appropriate bathymetric data and exclude other data that could create erroneous depth limits (e.g., near or within dredged areas and the shallow edges of seagrass beds; Steward et al. 2005). A large number of measurements were used. The number of depth points averaged 295 per segment, ranging from 76 measurements in the smallest segment, BR7, to 628 in one of the largest segments, IR16-20.

The 1996 depth measurements were used to estimate the depth limits of seagrass for all mapping years, including 1943. No sea-level-rise correction was applied (i.e., a subtraction of 0.1 m from the MWL-adjusted depths based on NOAA water level measurements from Mayport, Florida) because sea-level rise has been roughly offset by the rate of sedimentation estimated for the IRBR. Sedimentation rates range from ~1 mm/yr in sandy sediments (Martin et al. 2004), the dominant substrate in the IRBR, to 2 -10 mm/yr in organic-enriched sediments (Trefry et al. 1990). These rates indicate that the bottom elevation of the IRBR has been generally keeping pace with sea-level rise. There have been some localized changes in bottom elevations by dredge and fill activities (e.g., navigational channels and dredge spoil islands), but these areas

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[4] There is a navigational channel from Banana River to the ocean at Port Canaveral, but this opening is controlled and intermittent, and hardly affects hydrodynamic flushing.

are lost to potential seagrass colonization and were excluded from the determination of depth limits.

For the purpose of performing the regression analyses, the percent departure of the seagrass depth limit from the full restoration, depth-limit target depth was used. The percent departure was calculated per segment for each mapping year (1943, 1996, 1999, and 2001). The seagrass depth targets are described in Steward et al. (2005).

Pollutant Loading Data: TN, TP, and TSS loading estimates were calculated per segment per year by summing surface runoff loads and point-source loads. Not all segments include point-source loads; therefore, in those segments, only runoff loads are accounted for in the pollutant load estimates. The total pollutant load per segment was calculated as an areal load rate (lb/ac/year or season) and then log-transformed for the regression analyses.

The runoff loading data were generated using the PLSM and HSPF models that were calibrated against observed rainfall-runoff loading conditions in several IRL watersheds (Green and Steward 2003; CDM 2003; Adkins et al. 2004). Separate PLSM and HSPF model outputs were generated for each segment for each of the 4 years. Each year's model run incorporated its own contemporaneous rainfall and land use (L.U.) data in the following manner:

1943: 1942/43 rainfall (gage) data were used with 1943 L.U. data
1996: 1995/96 rainfall (gage) with 1995 L.U.
1999: 1998/99 rainfall (gage) with 2000 L.U.
2001: 2000/01 rainfall (Doppler) with 2000 L.U.

Point-source loading data were obtained from FDEP's NPDES facility database (flows and concentrations) to calculate annual and seasonal loads. The NPDES facilities considered in this study are listed below (Table 1).

TABLE 1. The major NPDES facilities that discharge to the IRBR

North IRL Segments	**NPDES Facility**	**Facility Type**	**Mean Annual Loads* (2000 – 2005, lb/yr)**		
			TN	**TP**	**TSS**
IR6-7	Cocoa, J. Sellers	Domestic WWTP	6,148	575	441
IR8	Rockledge	Domestic WWTP	0	0	0
IR9-11	Melbourne	Reverse Osmosis	6,558	96	0
		North IRL Total	12,706	671	441
Central IRL Segments					
IR12	South Beaches (BCUD)	Domestic WWTP	415	77	554
IR12	Melbourne Grant St.	Domestic WWTP	44	2	24
IR14-15	Barefoot Bay	Domestic WWTP	123	19	87
IR16-20	Vero Beach	Domestic WWTP	12,993	1,064	1,947
IR16-20	Vero Beach	Reverse Osmosis	2,419	536	0
IR16-20	Indian R. County, Hobart	Reverse Osmosis	2,123	46	0
IR16-20	West Regional, IRCUD	Domestic WWTP	1,422	84	1,642
IR16-20	Indian R. County South	Reverse Osmosis	3,795	103	0
		Central IRL Total	23,335	1,931	4,253
Banana R. Segment					
BR3-5	Cape Canaveral	Domestic WWTP	1,475	161	2,035
BR3-5	Cocoa Beach	Domestic WWTP	13,652	2,622	2,042
		Banana R. Total	15,128	2,783	4,077

***** Mean annual loads are calculated from 2000 – 2005 period of record obtained from FDEP. Please note that the actual annual loads (1995/96, etc.) were used in the regression models, not the mean annual loads.

The time periods selected for the regression analyses were the same as for the runoff load calculations (1995/96, 1998/99, 2000/01) save for 1942/43. There are no 1942/43 point-source data, so only run-off load estimates were used for that year. Regardless, any amount of point-source loading during 1942/43 was assumed to be relatively negligible and would have no bearing on the regression results.

Regression Analyses (loading rates vs. seagrass depth limits)

Loading limits or targets (lb/ac) for TN, TP, and TSS were determined for the IRBR estuary using regression analyses that relate areal loading rates (log-transformed) to percent departure from seagrass depth targets (as shown in Figure 2).

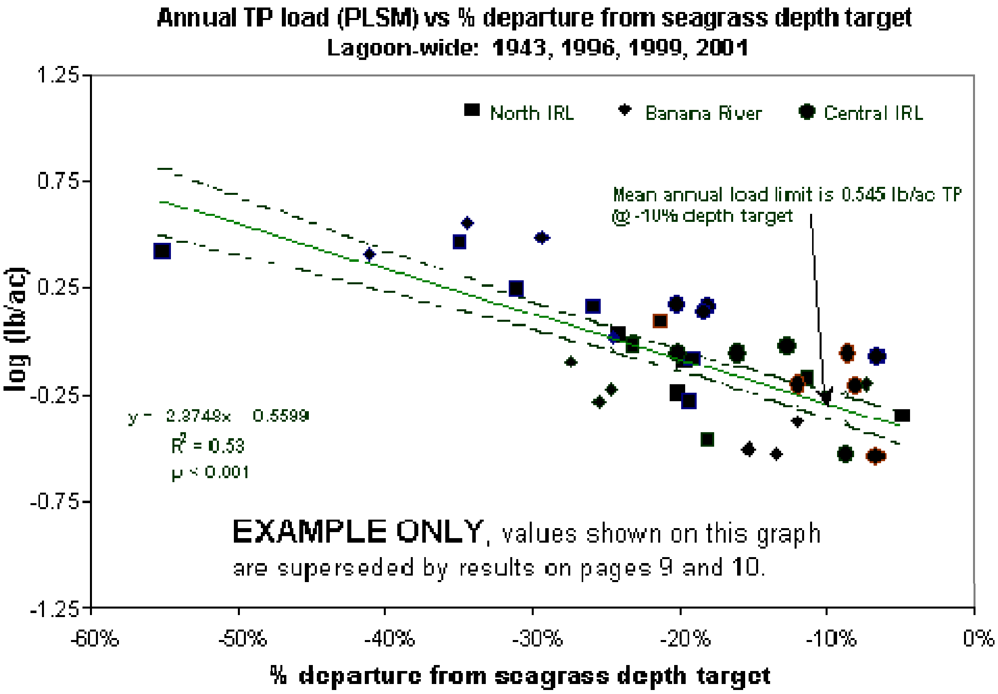

Figure 2. **An example of a loading (TP) vs. seagrass depth regression plot along with its correlation and significance statistics, and the 80% confidence interval (----). The predicted mean annual loading targets are based on the -10% departure from the seagrass depth target.**

These semi-log regression analyses utilize data from all the segments except the Sebastian Inlet segment, IR14-15. The Sebastian segment was precluded from the regression analyses because its hydraulic flushing rate (measured in days) far exceeds the rates of the other segments (measured in months). The higher flushing rate in the Sebastian segment significantly reduces the impact that pollutant loads have on seagrass coverage in contrast to the apparent impact observed elsewhere in the IRBR estuary.

There were two types of loading data used to develop two separate sets of semi-log regression analyses. One set of analyses took advantage of the loading estimates generated by the PLSM[5], while the other set used loading estimates generated by the HSPF model[6]. Both loading models

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[5] Description of the PLSM and its use in estimating loading rates and developing loading targets are found in Green and Steward (2003).

[6] Description of the HSPF and its use in estimating loading rates are found in Adkins et al. (2004).

provide comparable annual loading estimates for the IRBR system (Green and Steward 2003); nonetheless, there were sufficient differences between the PLSM and HSPF results so that one or the other provided a stronger regression outcome for a given sub-lagoon or pollutant. Hence, the stronger of the two sets of regressions, based on their correlation and significance statistics (R^2 and p values), was the one selected for determining the final loading *targets*. The PLSM loads generally produced better regression statistics than HSPF loads and were predominant in setting the annual load targets. The HSPF-estimated loads for TP produced the better set of regression statistics for the North IRL and, thus, dictated the annual TP loading target for that sub-lagoon.

The loading limits or targets are based on the –10% departure from the seagrass depth limit target as recommended by FDEP (see ***Background***, p. 3). To obtain loading target values (lb/ac/year or season), the log-transformed loading rates must be back-transformed. However, by simply taking the inverse log of the *y*-axis loading rate, the result *under*estimates the true mean value derived from the regression equation. This happens because the distribution of back-transformed *y*-values based upon *x*-values is no longer normal (Helsel and Hirsch 1992). To obtain a more accurate estimate of the mean value, we used a nonparametric method described by Duan (1983) as “smearing.” This method uses the mean of the regression residuals (expressed in their original units) as a multiplier applied to the regression line value. So, for any back-transformed relationship to *x*, the value of *y* is derived from the following equation:

$$\hat{y} = f^{-1}[b_o + b_1 * \log(\mathrm{x})] * \frac{\sum f^{-1}(e_i)}{n}$$

in which,

e_i = residual errors

f^{-1} = inverse function of the transformation

$b_o + b_1 * \log(\mathrm{x})$ = regression line equation

n = sample size

Areal loading target values, corrected as shown above, are presented for the IRBR as a whole (i.e., the Indian River and Banana River sub-lagoons combined) and for each major sub-lagoon separately: North IRL, Central IRL, and Banana River Lagoon. The annual loading targets are compared to the EPA’s 2003 draft TMDLs (U.S. EPA, Region 4, 6/30/03) and to the estimated1943 loading rates for the IRBR. The annual loading targets (lb/ac/yr) are calculated as total load allocations (or TMDLs, lb/yr) and as load reductions (or PLRGs, lb/yr) per sub-lagoon, which are then distributed among segment watersheds. We also present for consideration either an implicit and explicit margin of safety to determine final TMDLs. Finally, we evaluate the load allocations between surface runoff sources and point sources (NPDES facilities) and between wet and dry seasons.

RESULTS and DISCUSSION

Lagoon-wide Analysis

The Lagoon-wide loading limits were calculated from the PLSM regression models because the PLSM loads produced slightly better regression statistics (R^2 and p values) than HSPF loads. The Lagoon-wide, mean annual loading limits predicted to meet a –10% departure from the depth targets are ≤3.33 lb/ac/yr TN, ≤0.545 lb/ac/yr TP, and ≤56.3 lb/ac/yr TSS (Table 1).

Sub-Lagoon Analyses

Regression analyses were performed for each of the sub-lagoons: North IRL, Central IRL, and Banana River Lagoon. As with the Lagoon-wide loading limits, the sub-lagoon loading limits were also based on the –10% departure from seagrass depth targets. The sub-lagoon analyses generally yielded stronger correlation statistics than the Lagoon-wide analysis. Also, in contrast to a Lagoon-wide analysis, a sub-lagoon analysis should generate more realistic loading targets because it better reflects land use and rainfall characteristics specific to the sub-lagoon and its constituent segments. Consequently, it is recommended that the sub-lagoon loading limits be favored over the Lagoon-wide loading limits in the establishment of loading targets or TMDLs. The results of the sub-lagoon analyses are presented in Table 2 and further summarized below.

TABLE 2. Predicted mean annual loading targets for watershed runoff + major point sources at –10% departure from the seagrass depth target

Lagoon-wide (Indian R. and Banana R. lagoons combined; excludes Sebastian segment IR14-15; PLSM-based regression plots are in Appendix A)			
PLSM regressions	**TN lb/ac/yr**	**TP lb/ac/yr**	**TSS lb/ac/yr**
2005 regression models: 1943, ’96, ’99, & ’01 data	**3.33** $R^2 = 0.49$ $p < 0.001$	**0.545** $R^2 = 0.53$ $p < 0.001$	**56.3** $R^2 = 0.47$ $p < 0.001$
North IRL (regression plots are in Appendix B)			
PLSM regressions	**TN (lb/ac/yr)**	**TP (lb/ac/yr)**	**TSS (lb/ac/yr)**
2005 regression models: 1943, ’96, & ’99 data	**2.88** $R^2 = 0.43$, $p = 0.006$		**45.1** $R^2 = 0.50$, $p = 0.002$
HSPF regression			
2005 model revisions: 1943, ’96, & ’99 data		**0.368** $R^2 = 0.47$, $p = 0.003$	
Central IRL (excludes Sebastian segment IR14-15; regression plots are in Appendix C)			
PLSM regressions	**TN (lb/ac/yr)**	**TP (lb/ac/yr)**	**TSS (lb/ac/yr)**
2005 regression models: 1996, ’99, 2001 data	**2.89** $R^2 = 0.88$, $p < 0.001$	**0.570** $R^2 = 0.66$, $p = 0.001$	**56.8** $R^2 = 0.66$, $p = 0.001$
Banana River Lagoon (regression plots are in Appendix D)			
PLSM regressions	**TN (lb/ac/yr)**	**TP (lb/ac/yr)**	**TSS (lb/ac/yr)**
2005 regression models: 1943,’96, ’99 data	**2.18** $R^2 = 0.74$, $p = 0.001$	**0.374** $R^2 = 0.72$, $p = 0.001$	**43.3** $R^2 = 0.61$, $p = 0.004$

North IRL: The correlation and significance statistics favor the PLSM regression models for TN and TSS, whereas mean annual TP loading limits are better predicted using the HSPF regression model; thus, the mean annual loading targets are ≤2.88 lb/ac/yr TN, ≤0.368 lb/ac/yr TP, and ≤45.1 lb/ac/yr TSS.

Central IRL: The PLSM loads provide much better regression statistics than HSPF loads. Consequently, PLSM regression models were used to calculate the mean annual loading targets for the Central IRL: ≤2.89 lb/ac TN, ≤0.570 lb/ac TP, and ≤56.8 lb/ac.

Banana R. Lagoon: Again, the PLSM regressions present a stronger set of regression statistics than do the HSPF regressions; thus, the mean annual loading targets for Banana R. Lagoon are ≤2.18 lb/ac TN, ≤0.374 lb/ac TP, and ≤43.3 lb/ac/yr TSS.

Comparison of the mean annual load targets with U.S. EPA's 2003 draft TMDLs (6/30/2003) and the estimated 1943 loads (6/25/04)

The mean annual load targets for the North and Central IRL and Banana R. Lagoon were compared to EPA's 2003 draft TMDLs (nonpoint + point-source loads) and to the estimated 1943 loadings (Table 3).

TABLE 3. Sub-lagoon mean annual loading targets compared to U.S. EPA's 2003 draft TMDLs and the estimated 1943 loadings*

	TN (lb/ac/yr)	TP (lb/ac/yr)	TSS (lb/ac/yr)
North Indian River Lagoon			
Mean annual loading targets (refer to Table 2 above)	***2.88***	***0.368***	***45.1***
U.S. EPA's 2003 draft TMDLs (from Tables 11 & 12 in U.S. EPA, 2003)	**2.58**	**0.395**	**N.A.**
Estimated 1943 loadings (SJRWMD, PLSM, 6/25/04)	**2.6**	**0.42**	**26**
Central Indian River Lagoon			
Mean annual loading targets (refer to Table 2 above)	***2.89***	***0.570***	***56.8***
U.S. EPA's 2003 draft TMDLs (from Tables 11 & 12 in U.S. EPA, 2003)	**5.61**	**0.620**	**N.A.**
Estimated 1943 loadings (SJRWMD, PLSM, 6/25/04)	**4.7**	**0.57**	**38**
Banana River Lagoon			
Mean annual loading targets (refer to Table 2 above)	***2.18***	***0.374***	***43.3***
U.S. EPA's 2003 draft TMDLs (calculated from values in Tables 11& 12, U.S. EPA, 2003)	**2.68**	**0.312**	**N.A.**
Estimated 1943 loadings (SJRWMD, PLSM, 6/25/04)	**2.5**	**0.33**	**20**

***** PLSM-estimated 1943 loadings (lb/yr) for TN, TP, and TSS per sub-lagoon and segment are in Appendix E.

For North IRL overall, there is fair agreement between the TN and TP loading targets and EPA's 2003 nutrient TMDLs. For the Central IRL, the loading target and the 2003 TMDL for TP are quite close, but the TN target is 48% lower than the 2003 TN TMDL. For the Banana R. Lagoon, the TN target is 17% lower and the TP target is 20% higher than the 2003 draft TMDLs (Table 3).

The annual nutrient loading targets are fairly comparable to the 1943 annual loading estimates (revised 6/25/04), except for the Central IRL TN target. The seagrass depth limits in 1943 represent an average departure of –15% from the full restoration depth limit target (-17% in IRL North, -16% in IRL Central, and –14% in the Banana River Lagoon). Since an average departure of –15% does not differ much from a –10% departure (which serves as the basis for the loading targets), it is reasonable to expect the 1943 loading estimates to be fairly close to the loading targets. Again, the exception is the Central IRL where the 1943 TN load is considerably higher than its target. We believe that the Central IRL was “load-impacted” in 1943 given that nearly all inter-basin diversion canals were in place (except C-54), Sebastian Inlet was closed, and there was an appreciable increase in land development since the 1920s (more so in Central IRL than in the other sub-lagoons).

Conversely, the TSS loading targets are higher than the 1943 TSS loading estimates for all the sub-lagoons. The regression analyses indicate that a sub-lagoon could absorb a mean annual TSS load at a considerable level above its 1943 load estimate and yield a seagrass coverage that, on average, extends to –10% of the full restoration depth target. This conclusion, however, may be misleading considering the fact that it is the “fines” fraction (silts and clays) of the TSS load that contributes most to light attenuation. Unfortunately, the monitoring and modeling of “fines” as a discrete parameter has not been done and cannot be assessed in this study.

Application of Regression Model Loading Targets and Current (2000) Loadings Toward the Development of TMDLs and PLRGs per segment

We are proposing the application of the regression models’ loading targets toward the development of TMDLs and PLRGs. The District’s intent, as stated in the IRL SWIM Plan, is to establish PLRGs that are consistent with TMDLs (Steward et al. 2003a); that is, PLRGs should be the amount of load reduction required to satisfy the total load allocation or TMDL.

Total load allocations or TMDLs: The EPA and the State of Florida are required to develop TMDLs for water bodies identified by the state as not meeting designated uses or standards (Clean Water Act, 40 CFR Part 130; Section 403.067, Florida Statutes). A TMDL is arithmetically expressed as follows:

$$\text{TMDL} = (\Sigma WLA + \Sigma LA) - MOS$$

in which,

ΣWLA = cumulative wasteload allocations assigned to point sources (NPDES permitted facilities)

ΣLA = cumulative load allocations assigned to non-point anthropogenic sources and natural background sources.

MOS = margin of safety, which accounts for the uncertainty about the relationship of the pollutant load and the targeted resource (e.g., water quality and seagrasses in the IRBR).

We solved for the total annual load allocations for TN, TP, and TSS ($\Sigma WLA + \Sigma LA$, lb/yr) per sub-lagoon by multiplying the areal loading targets (lb/ac/yr) derived from the regression models (see Table 2) to their corresponding sub-lagoon drainage area (acres). The total annual load allocations are presented in comparison to the current loading estimates per sub-lagoon (Table 4). This comparison provides a general idea of the magnitude of load reduction needed to meet the total load allocations.

TABLE 4. Comparison between current total loads (nonpoint + point-source) and this study's proposed total load allocations (nonpoint + point-source).

(NOTE: In the IRBR overall, point-source loads only account for ≤2% of the total, current external loads, whereas nonpoint surface runoff accounts for >70%.)

Sub-lagoon (basin acres)	**Current loads (lb/yr), nonpoint + point-source**			**Proposed total load allocations (lb/yr), nonpoint + point-source** also expressed as % *reduction* of current total loads					
	TN	**TP**	**TSS**	**TN**		**TP**		**TSS**	
North IRL (135,384)	**589,119***	**94,178****	**12,683,573***	**389,906***	34%	**49,821****	47%	**6,105,822***	52%
Central IRL (284,180)	**1,819,397***	**310,938***	**29,560,326***	**821,282***	55%	**161,983***	48%	**16,141,450***	45%
Banana R. Lagoon (51,389)	**304,244***	**57,764***	**9,030,627***	**112,029***	63%	**19,220***	67%	**2,225,155***	75%

***** PLSM-estimated nonpoint loads. The current nonpoint loads were based on 2000 land-use coverage and 30-year mean annual rainfall. The current point-source loads were based on 2000-2005 mean annual loads from the NPDES facilities listed in Table 1. The sum-total, mean annual point-source loads in the North IRL are 12,706 lb/yr TN, 671 lb/yr TP, and 441 lb/yr TSS; in the Central IRL: 23,335 lb/yr TN, 1,931 lb/yr TP, and 4,253 lb/yr TSS; and in the Banana R. Lagoon: 15,128 lb/yr TN, 2,783 lb/yr TP, and 4,077 lb/yr TSS.

****** HSPF-estimated nonpoint loads. The current nonpoint loads (HSPF) were based on 2000 land-use coverage and 9-year mean annual rainfall (1995 – 2003). The current point-source loads are the same as described above.

A sub-lagoon's total load allocation was further distributed among its segments according to the following steps.

1. A reasonable WLA per sub-lagoon needs to be established. For this study we chose the mean annual point-source load (2000 – 2005 period of record) from the NPDES facilities listed in Table 1.
2. A sub-lagoon's mean annual point-source load or WLA was subtracted from its *total* load allocation (nonpoint + point-source loads). The result is the sub-lagoon's *nonpoint* load allocation (LA).
3. A sub-lagoon's LA was then distributed among its segments based on the relative percent contributions of each segment toward the sub-lagoon's current (c. 2000) nonpoint load.
4. Finally, for any segment that contains point-source loads (i.e., contains any of the NPDES facilities listed in Table 1), its mean annual point-source load or individual WLA was added to its distributed LA.

These steps provide a segment-specific *total* load allocation or TMDL (MOS notwithstanding); along with a segment-specific LA (nonpoint load allocation) and WLA. Two examples of this segment allocation method are provided below. Segment allocations for all IRBR segments are presented in Table 5.

> *Example 1 -- Segment BR7*: Banana R. Lagoon's mean annual point-source load for TN is 15,128 lb/yr, which serves as that sub-lagoon's WLA. Subtracting that amount from Banana R. Lagoon's total TN load allocation (112,029 lb/yr, Table 5) results in 96,901 lb/yr TN, which is the nonpoint load allocation (LA) for the sub-lagoon. Under current (c. 2000) conditions, segment BR7's nonpoint TN loading is ~14.32% of Banana R. Lagoon's current nonpoint TN loading[7]. Multiplying this percentage by the sub-lagoon's LA yields a distributed LA for BR7 of ~13,880 lb/yr TN. Because there are no point sources in BR7 (i.e., no NPDES facilities), BR7's WLA = 0, and BR7's LA becomes its *total* TN load allocation (Table 5).

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[7] Current loading estimates per segment for TN, TP, and TSS (PLSM and/or HSPF-calculated) are in Appendix E.

> *Example 2 – Segment BR3-5*: Perform the first two steps as described above. Under current conditions, BR3-5's current nonpoint TN loading is ~25.49% of Banana R. Lagoon's current nonpoint TN loading. Multiplying this percentage by the sub-lagoon's LA yields a distributed LA for BR3-5 of 24,702 lb/yr TN. Because all point-source loads in Banana R. Lagoon are discharged to BR3-5, that segment receives 100% of the mean annual point-source load or WLA (15,128 lb/yr TN). Consequently, the total TN load allocation to BR3-5 is 24,702 lb/yr + 15,128 lb/yr or 39,830 lb/yr (Table 5).

For the other sub-lagoons, North and Central IRL, the mean annual point-source load was distributed among the multiple segments that contain NPDES facilities. That distribution was simply based on the current average (2000-2005) distribution of point-source loads among those NPDES segments.

TABLE 5. Segment distribution of sub-lagoon total load allocations (nonpoint + point-source) and corresponding load reductions

IRBR sub-lagoons and segments	Total load allocations (lb/yr)			Load reductions (lb/yr) under average current conditions Current load – load allocation		
	TN	TP	TSS	TN	TP	TSS
North IRL	**389,906**	**49,821**	**6,105,822**	**199,213**	**44,357**	**6,577,751**
IR1-3	**88,322**	**7,307**	**699,601**	**46,646**	**6,594**	**753,730**
IR4	**13,574**	**2,331**	**263,835**	**7,169**	**2,104**	**284,248**
IR5	**82,358**	**10,711**	**1,275,310**	**43,497**	**9,666**	**1,373,979**
IR6-7	**81,993***	**10,361***	**1,129,177***	**40,056***	**8,832***	**1,216,066***
IR8	**15,894***	**2,322***	**287,124***	**8,394***	**2,096***	**309,338***
IR9-11	**107,765***	**16,789***	**2,450,775***	**53,451***	**15,065***	**2,640,390***
Central IRL	**821,282**	**161,983**	**16,141,450**	**998,115**	**148,955**	**13,418,877**
IR12	**226,361***	**42,376***	**5,259,468***	**282,571***	**39,364***	**4,373,028***
IR13	**27,896**	**4,010**	**313,590**	**34,893**	**3,733**	**260,766**
IR14-15**	**323,757***	**62,791***	**4,908,181***	**404,819***	**58,420***	**4,081,322***
IR16-20	**237,793***	**51,584***	**5,468,574***	**268,984***	**46,301***	**4,544,406***
IR21	**5,475**	**1,222**	**191,637**	**6,848**	**1,137**	**159,355**
Banana R. Lagoon	**112,029**	**19,220**	**2,225,155**	**192,215**	**38,544**	**6,805,472**
BR1-2	**42,828**	**6,176**	**752,320**	**84,954**	**14,484**	**2,305,141**
BR3-5	**39,830***	**7,879***	**772,419***	**49,001***	**11,948***	**2,354,231***
BR6	**15,489**	**2,907**	**420,696**	**30,724**	**6,817**	**1,289,030**
BR7	**13,882**	**2,258**	**279,720**	**27,536**	**5,295**	**857,072**

***** Segment allocations and reductions account for the distributed mean annual point-source loads. In the case of BR3-5, its load allocation and reduction accounts for the entire mean annual point-source load for the Banana R. sub-lagoon.

****** IR14-15 is the Sebastian segment precluded from the regression analyses because of its much greater flushing rate (due to its close proximity to Sebastian Inlet) as compared to other IRL segments. This reason for preclusion could also be used to argue for some upward adjustment of the load allocation to IR14-15. Other factors outside the scope of this study would need to be considered to determine what the level of adjustment could be.

The load allocation and reduction analyses above indicate that the IRBR and its seagrass resource would be well served by primarily addressing surface runoff and, secondarily, point sources (NPDES facilities). Atmospheric and groundwater sources of loads were considered in the analyses, but the results of stepwise regression analyses indicate that atmospheric loadings do not independently provide any significant contribution to the regression analyses at a confidence level, $\alpha = 0.15$. (Furthermore, there is no practical way under federal or state TMDL programs to control atmospheric sources.) Groundwater load estimations are available only as system-wide extrapolations and, as such, could not be incorporated into the stepwise regressions. However, it is believed that the groundwater contribution would be similarly insignificant because it constitutes less than 5% of the total external TN load to the IRBR (Belaineh 2005).

Actually, like the atmospheric contribution, point sources do not significantly contribute to the regression models either (via step-wise regression results) given that point-sources presently comprise only ~2% of the annual external nutrient loading to the IRBR overall (Steward et al. 2003). As long as the point-source loads are maintained at present levels (near the 2000 – 2005 mean annual), then seagrass depth targets could be achieved by solely limiting surface runoff loads, which constitute 70% or more the current external load to the IRBR.

Nonetheless, there are two reasons why point-source loads were included in the regression models and must be considered in a load allocation process. First, as previously discussed, the development of a numeric TMDL requires both nonpoint-source load allocations (ΣLA) and point-source allocations (ΣWLA). Therefore, the regression analyses, from which a TMDL can be derived, should account for those two types of loads. Second, we believe that the WLAs specified in current facility permits are excessively high and should be substantially reduced. The regression analyses in this study provide an objective means toward determining reasonable WLA levels.

Over the past decade, NPDES facilities have achieved significant reductions in their nutrient loadings to the IRL; however, their permitted WLAs allow for much higher loadings. For some facilities, their permitted WLAs presently allows them to discharge nutrient loads that are more than an order of magnitude above what they currently discharge. We propose that a WLA should more closely approximate the facility's mean annual point-source load to best achieve seagrass depth targets. If a WLA is set higher than the mean annual, then further, compensatory reductions in nonpoint-source loads would need to be established to meet the total load allocation. Any argument that calls for reductions in nonpoint loads beyond what the regression models indicate in order to establish a higher WLA should carefully consider the increased technical challenges and costs required to manage the additional runoff loads.

Consideration of an implicit and explicit MOS: The development of a numerical TMDL must consider or address a MOS (Clean Water Act, 40 CFR 130.2). The MOS accounts for the uncertainty about the relationship between a pollutant load and the condition of the water body, or in the case of the IRBR estuary, the seagrass depth limit.

The sub-lagoon and segment load allocations in Table 5 can serve as the TMDLs for the IRBR system if the MOS is considered to be implicit. A case could be made for an implicit MOS given that the sub-lagoon loading targets (lb/ac/yr) generally approximate the 1943 loads, except for TSS (Table 3). Also, Sebastian Inlet, as an important flushing mechanism for the system, was not present in 1943, but is present today as a maintained channel.

An explicit MOS can be statistically defined as the lower limit of a specified confidence interval (CI) that is calculated about the regression line (e.g., an 80% CI is shown in Fig. 2 and in the regression plots in the appendices). By application of an explicit MOS, we assume that by lowering an initial load target (i.e., the mean annual derived from the regression line), the certainty of meeting a seagrass target is increased. But, for the sake of reasonableness, a limit on the lower target needs to be decided. The CI provides a statistical context in making that decision. The CI represents some level of probability that the *true* mean annual load is not outside the upper or lower limit of that interval. Of course, it's the lower limit (LL) of a specified CI that would be used to set the new (and lower) load target. For example, if a 66% CI is chosen, then its LL value becomes the new load target with a 66% probability that the true mean annual load is not lower.

We do not recommend a specific CI; we'll leave that decision to EPA or FDEP if either agency adopts this approach. But, as a way to facilitate that decision, we present in Table 6 the LL values of 3 alternative CIs (50%, 66%, and 80%) in comparison with the mean annual load targets from Table 2.

TABLE 6. Example results of the regression confidence interval (CI) approach used to define an explicit MOS in the development of TMDLs

For each parameter and sub-lagoon, the lower-limit values relative to the 50%, 66%, and 80% CI are presented in comparison to the mean values derived from the regression line. All lb/yr values represent possible total load allocations or TMDLs.

	TN (lb/ac/yr)	TN (lb/yr)	TP (lb/ac/yr)	TP (lb/yr)	TSS (lb/ac/yr)	TSS (lb/yr)
North IRL						
***Mean** annual load allocations* (lb/ac/yr from Table 2)	***2.88***	***389,906***	***0.368***	***49,821***	***45.1***	***6,105,822***
50% LL	***2.22***	***300,233***	***0.266***	***36,012***	***30.3***	***4,103,712***
66% LL	***2.07***	***280,275***	***0.247***	***33,440***	***27.7***	***3,751,055***
80% LL	***1.93***	***261,291***	***0.228***	***30,868***	***25.2***	***3,411,679***
Central IRL						
***Mean** annual load allocations* (lb/ac/yr from Table 2)	***2.89***	***821,282***	***0.570***	***161,983***	***56.8***	***16,141,450***
50% LL	***2.65***	***753,077***	***0.482***	***136,975***	***47.5***	***13,498,550***
66% LL	***2.59***	***736,026***	***0.464***	***131,860***	***45.7***	***12,987,026***
80% LL	***2.48***	***704,768***	***0.438***	***124,471***	***43.8***	***12,447,104***
Banana R. Lagoon						
***Mean** annual load allocations* (lb/ac/yr from Table 2)	***2.18***	***112,029***	***0.374***	***19,220***	***43.3***	***2,225,155***
50% LL	***1.68***	***86,218***	***0.277***	***14,242***	***25.9***	***1,329,323***
66% LL	***1.57***	***80,872***	***0.258***	***13,276***	***23.4***	***1,202,281***
80% LL	***1.45***	***75,542***	***0.237***	***12,179***	***20.7***	***1,063,758***

If a confidence interval LL value (lb/ac/yr) is adopted as an explicit MOS to determine a sub-lagoon TMDL, one can simply follow steps 1 – 4, page 12, to calculate *segment* TMDLs.

Load reductions or PLRGs: PLRGs are defined as "estimated numeric reductions in pollutant loadings needed to preserve or restore…receiving bodies of water…" [Chapter 62-40.210(18) Florida Administrative Code]. The State of Florida has directed its water management districts to establish PLRGs as part of a SWIM Plan or other plans or as a basin rule. PLRGs are intended to address excessive *nonpoint* loads, particularly from older stormwater management systems, which were constructed before the adoption of Chapter 62-25, F. A. C., Regulation of Stormwater Discharge. To emphasize that intent, FDEP and the water management districts often refer to PLRGs as *stormwater* PLRGs. PLRGs should be inextricably linked to TMDLs, which limit both nonpoint and point-source discharges (Chapter 62-40, F. A. C.). The link between PLRGs and TMDLs is an important management strategy and, as stated in the IRL SWIM Plan, both types of loading targets for the IRL system are predicated on the relationship between seagrass coverage and loadings of nutrients and TSS (Steward et al. 2003a).

A PLRG can be defined as the difference between a current, nonpoint load and a nonpoint load allocation. The load reduction values in Table 5 basically represent that difference and can serve as the PLRGs for each of the IRBR segment under current conditions.

To ensure that TMDLs are not exceeded in the future, it is important to plan for the higher level of load reduction that will be necessary under build-out development conditions. Therefore, PLRGs that are established based on current loads would need to be modified sometime in the future as development proceeds. Build-out loads were PLSM-estimated for each of the segments[8] by using build-out land use data obtained from the counties via their comprehensive growth management databases (and the current 30-yr mean annual rainfall). These build-out load estimates, along with the load allocations, can be and have been translated into design parameters for surface water projects whose purpose is to provide sufficient load reduction to meet TMDLs well into the future.

For example, segment BR3-5 has an estimated build-out, nonpoint load of 86,324 lb/yr TN. Build-out planning for that segment may need to consider a nonpoint load reduction of 61,622 lb/yr TN[9] to ensure that BR3-5's nonpoint load allocation (LA) of 24,702 lb/yr TN will be met. By achieving that nonpoint load reduction (61,622 lb/yr) and by fully complying with the WLA established for BR3-5 (i.e., 15,128 lb/yr TN for this study), then BR3-5's TMDL of 39,830 lb/yr TN (implicit MOS) should be satisfied under build-out conditions. If we assume that the NPDES facilities in segment BR3-5 can comply with the WLA today and into the future, then agencies can focus on managing surface runoff and the increase in runoff loads as growth continues. Today, BR3-5's nonpoint load reduction or PLRG for TN is estimated to be 33,873 lb/yr (the total load reduction in Table 5 less 15,128 lb/yr from point sources). But tomorrow (build-out), it could nearly double (~62,000 lb/yr). Source-control projects being designed today need to keep the future in mind.

Consideration of Seasonal Loading Limits

The loading rate vs. seagrass depth-limit relationship was evaluated seasonally for each sub-lagoon. Two types of regression models were evaluated. One type accounted for nonpoint loads only and the other type accounted for both nonpoint and point-source loads. The wet-season months of August through October and the dry-season months of February through April were chosen for this evaluation. In the IRBR basin, the August through October period, on average, captures the more intense storms of the year; and February through April is in the middle of the dry season (Knowles 1995). The point-source loads were calculated from the same period of record as the runoff loads: August – October and February – April in each of the year-periods: 1995/96, 1998/99, and 2000/01.

The seasonal regressions yielded good correlations, except for the Central IRL's dry season, which showed such a poor correlation ($R^2 = 0.1$) that it was not given further consideration. Exclusive of the Central IRL dry season, the regressions statistics are summarized as follows:

1. Nonpoint loads only, wet and dry season: *$p \leq 0.010$; R^2_{TN} values of 0.41 to 0.71, R^2_{TP} values of 0.44 to 0.71, and R^2_{TSS} values of 0.48 to 0.65.*
2. Nonpoint + point-source loads, wet and dry season: *$p \leq 0.012$; R^2_{TN} values of 0.41 to 0.82; R^2_{TP} values of 0.44 to 0.72; and R^2_{TSS} values of 0.48 to 0.62.* The nonpoint + point-source regression plots are provided in Appendix F.

Seasonal load allocations were determined for the sub-lagoons and are presented in Table 7. This seasonal analysis can be used to apportion the annual load allocation by wet and/or dry season. Regardless of whether TMDLs are imposed as seasonal targets or not, a maximum limit on a seasonal load, particularly on the wet-season load, can prove useful in the design of runoff storage/treatment projects to help ensure annual TMDLs are met.

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[8] Build-out loading estimates (lb/yr, PLSM) per sub-lagoon and segment for TN, TP, and TSS are in Appendix E.

[9] 86,324 lb/yr $_{\text{build-out}}$ – (39,830 lb/yr $_{\text{total load allocation or TMDL, Table 5}}$ – 15,128 lb/yr $_{\text{NPDES load, Table 1}}$) = 61,622 lb/yr TN$_{\text{load rdctn.}}$

TABLE 7. Mean seasonal load allocations per sub-lagoon
The nonpoint (NP) + point-source (P) regression plots are provided in Appendix F.

	TN (lb/ac)		TP (lb/ac)		TSS (lb/ac)	
WET Season (Aug. – Oct.)	NP only	NP + P	NP only	NP + P	NP only	NP + P
North IRL	0.98	**1.07**	0.100	**0.127**	10.7	**10.7**
Central IRL**	1.68	**1.64**	0.280	**0.272**	30.8	**30.2**
Banana R. Lagoon	0.70	**0.75**	0.109	**0.114**	13.3	**13.3**
DRY Season (Feb. – Apr.) *						
North IRL	0.32	**0.32**	0.057	**0.057**	5.8	**5.8**
Banana R. Lagoon	0.13	**0.14**	0.023	**0.024**	2.9	**3.1**

* Dry-season load allocations for the Central IRL were not considered because of poor correlation statistics.

**Non-point + point-source load allocation rates are lower as a result of removing a statistical outlier, which shifted the slope of the regression line.

The three-month wet season load allocation represents a large portion of the annual allocation in the Lagoon system. For example, Banana R. Lagoon's wet-season TN load allocation of 38,542 lb (51,389 acres x 0.75 lb/ac TN) is 34% of that sub-lagoon's annual allocation or TMDL of 112,029 lb. In contrast, Banana R. Lagoon's dry-season TN load allocation is only 6% of its annual TN load allocation.

CONCLUSIONS

The annual loading regression models indicate that nutrient loads account for 43% to 88% of the variability in the depth distribution of IRBR seagrass, and TSS loads explain about 50% to 66% of that variability. The light-attenuating effects of TSS and nutrients (indirectly via algal concentrations) probably explain this relationship. The regression models also predict the TN, TP, and TSS loading limits per sub-lagoon that should help restore seagrass coverage to target depths (Tables 2, and 4 - 8). The loading targets (lb/ac/yr) or allocations (lb/yr) presented in tables 2 and 5, respectively, can be considered the TMDLs with an implicit margin of safety. However, the degree of probability that a seagrass depth-limit target is met, can be increased by applying a lower loading limit derived from a regression model's confidence interval. Consequently, that lower limit explicitly defines a margin of safety as well as a TMDL.

Even though point-source loads presently constitute a small (~2%) contribution toward the IRBR basin's total external nutrient load, the permitted WLAs for several NPDES facilities are much higher (in some cases, an order-of-magnitude higher) than their actual annual loads and exceed the segment load allocations predicted by the regression models. The WLAs should be revised to more closely approximate what the facilities presently discharge. Otherwise, the major focus of TMDLs and PLRG implementation should be directed toward non-point, surface-water drainages that provide the lion's share of the nutrient and TSS loads to the estuary.

Finally, there are two resource management challenges made apparent by this study:

1. In situations where the WLA dictates the magnitude of the LA (in order to meet the total allocation or TMDL), it is important to keep in mind that the higher the WLA that is established, the higher the burden to meet a lower nonpoint load allocation. It could cost more to reduce a nonpoint load (land cost, construction, etc.) than to reduce an equivalent point-source load at an existing wastewater treatment facility.
2. Nonpoint source-control projects should be designed to treat build-out loads to ensure that TMDLs will be met in the future. The PLRGs that are cited in this document are subject to change according to what final TMDLs are established, and whether load reductions are based on a current condition or some future condition.

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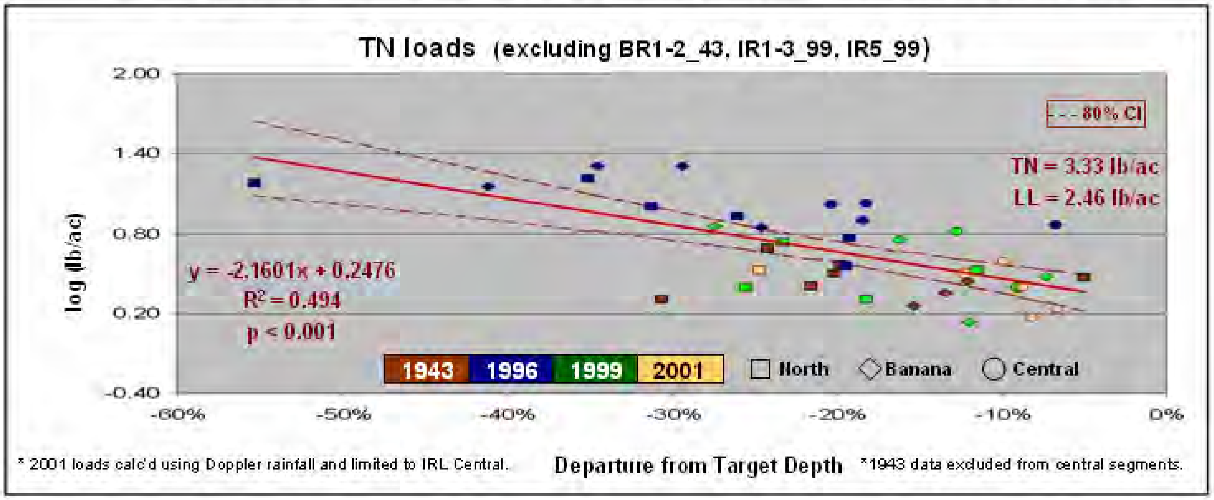
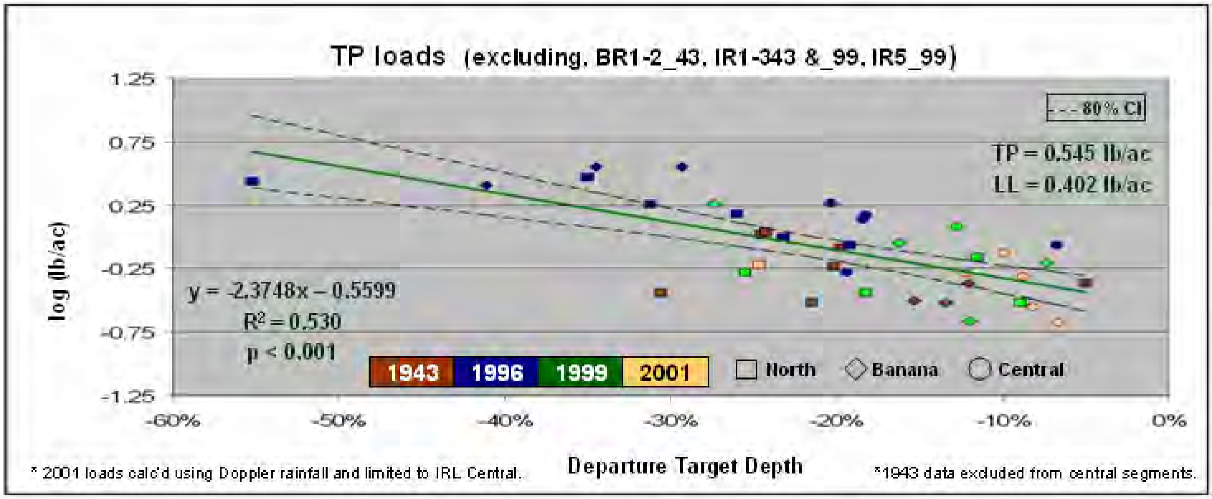
APPENDIX A. Lagoon-wide annual runoff & point-source loads (PLSM) vs. % departure from seagrass depth-limit targets: 1943*, 1996, 1999, 2001*



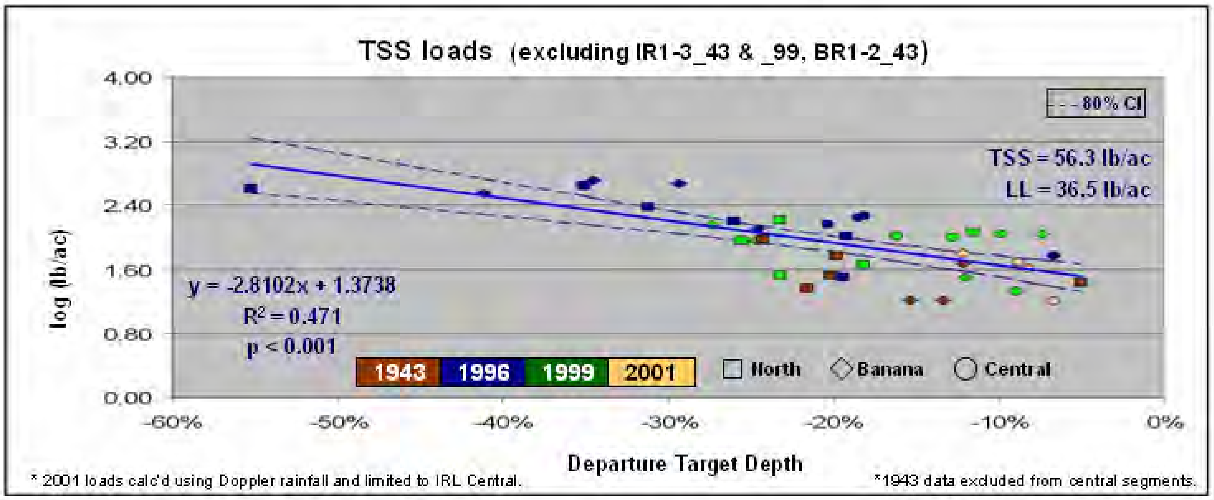
* 2001 loads calc'd using Doppler rainfall and limited to IRL Central.

*1943 data excluded from central segments.



* 2001 loads calc'd using Doppler rainfall and limited to IRL Central.

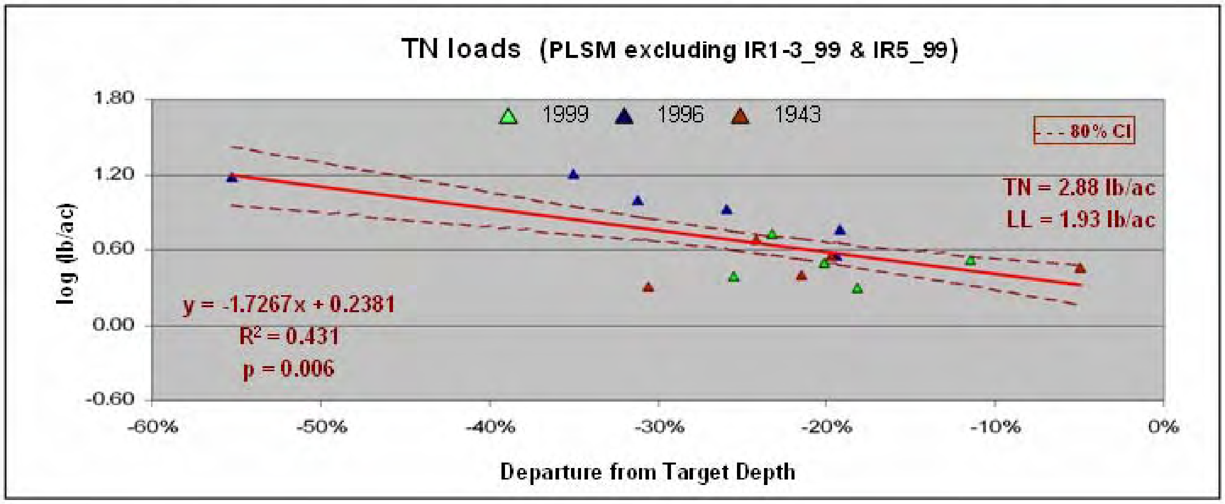
*1943 data excluded from central segments.

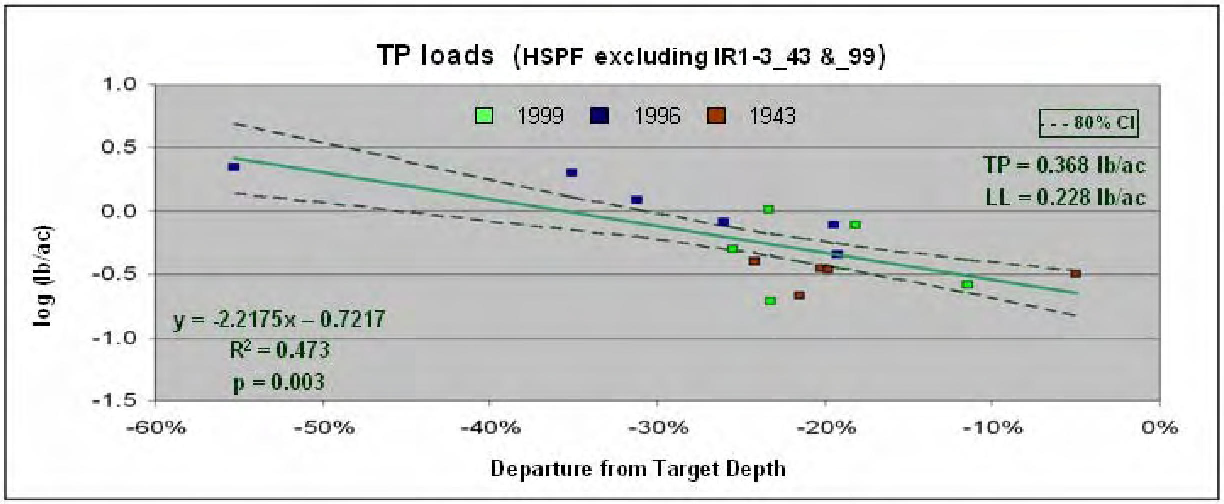


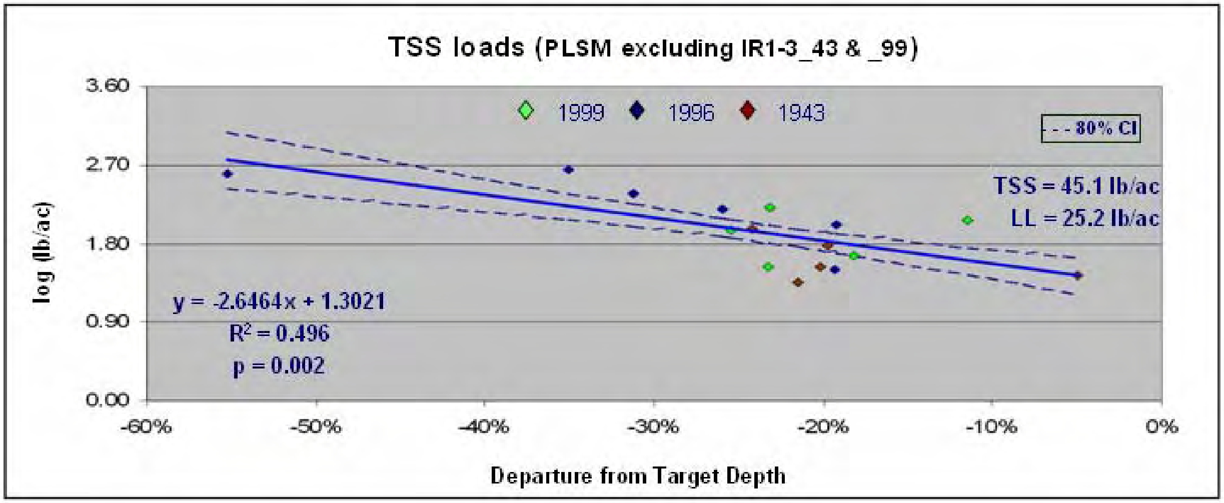
* 2001 loads calc'd using Doppler rainfall and limited to IRL Central.

*1943 data excluded from central segments.

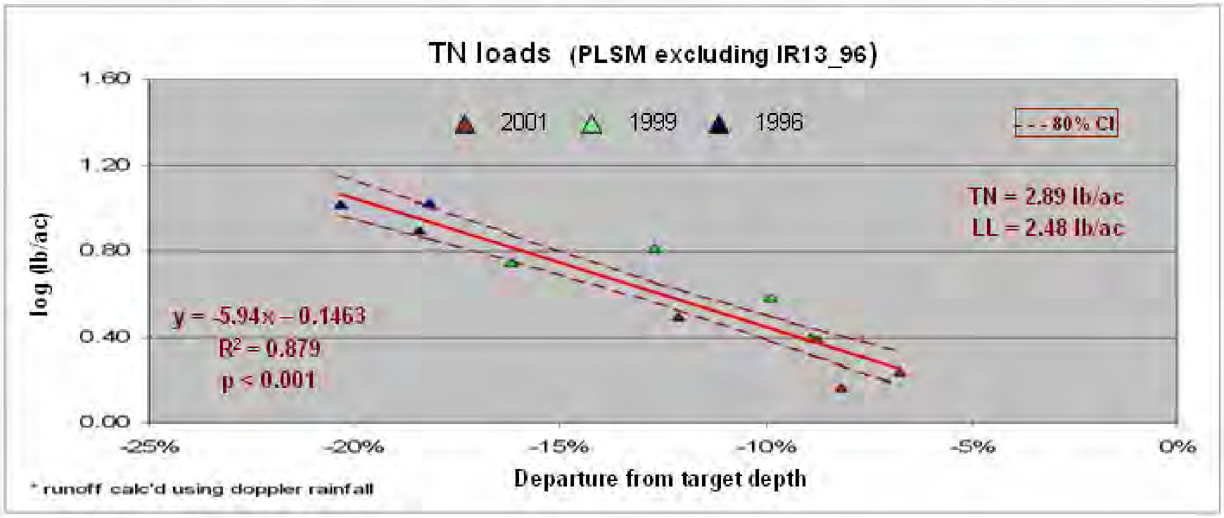
APPENDIX B. North IRL annual runoff & point-source loads vs. % departure from seagrass depth-limit targets: 1943, 1996 & 1999

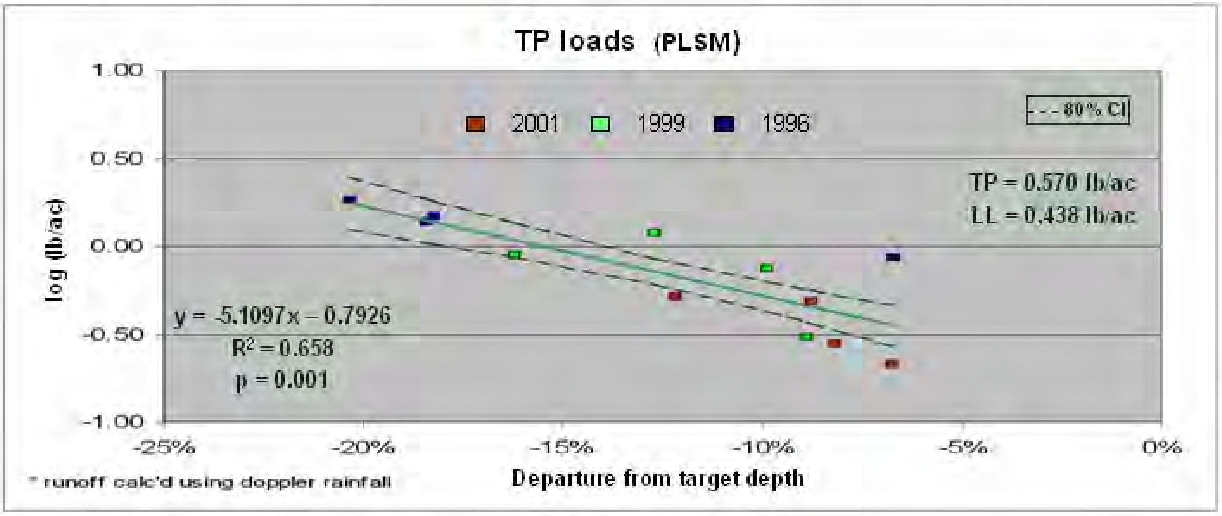


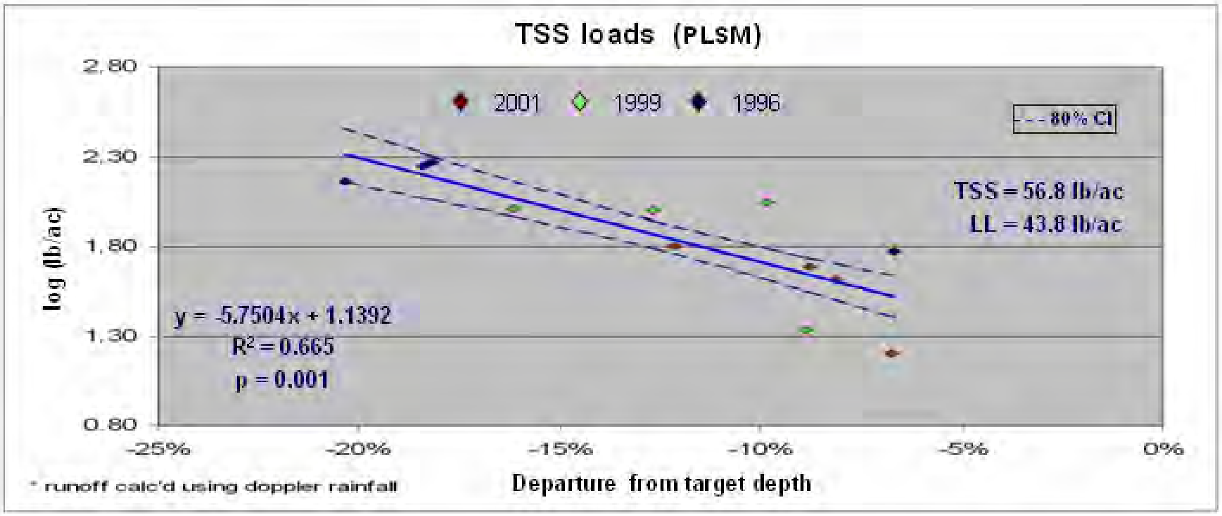




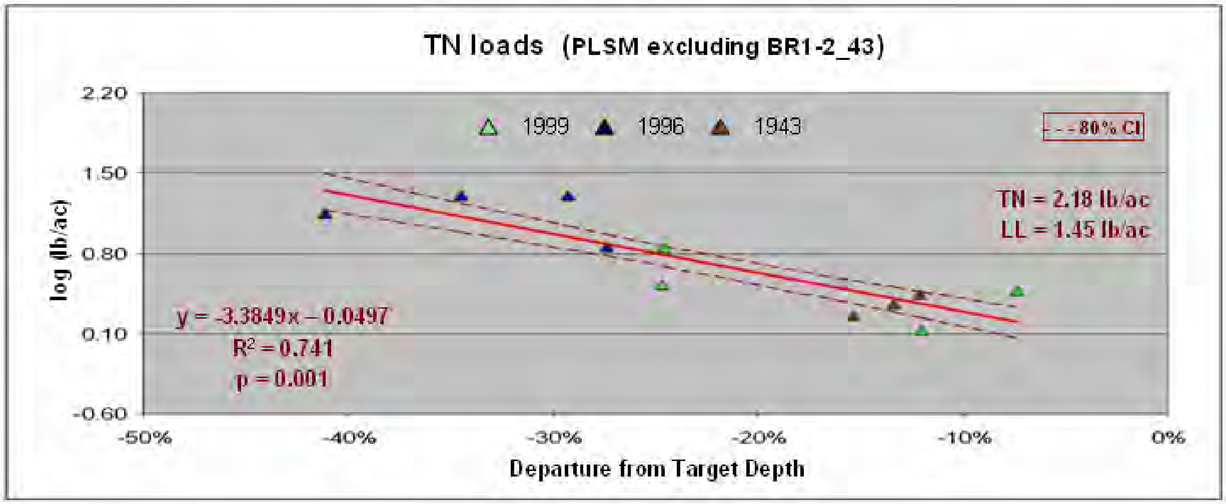
APPENDIX C. Central IRL annual runoff & point-source loads vs. % departure from seagrass depth-limit targets: 1996, 1999 & 2001

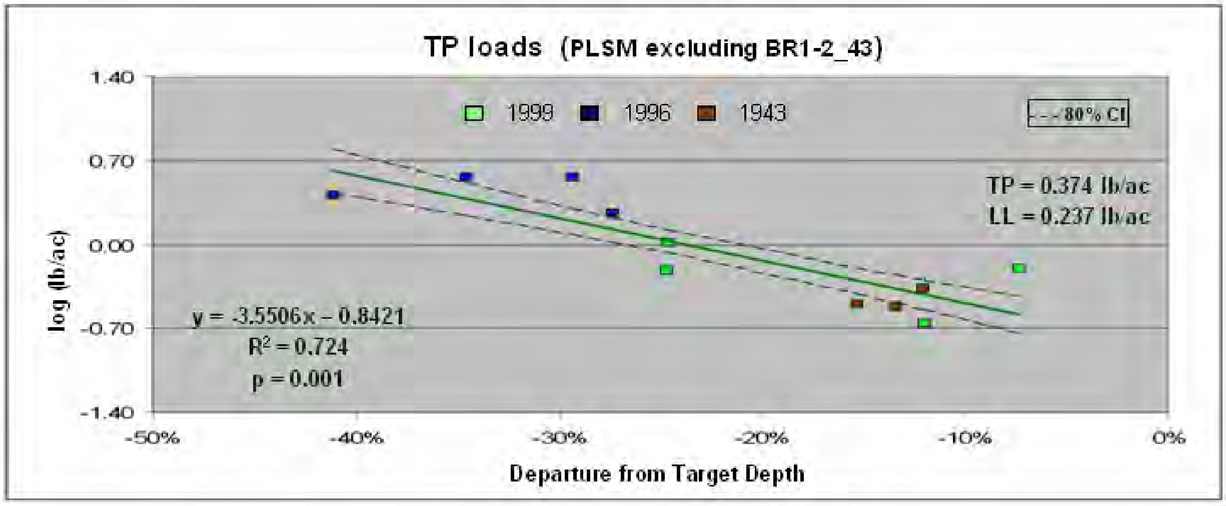


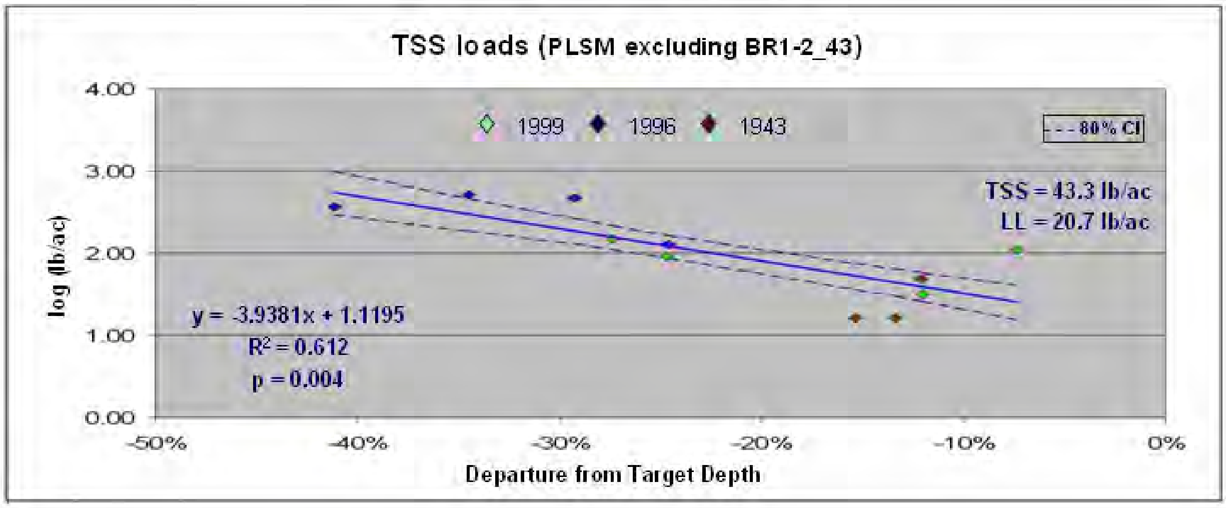




APPENDIX D. Banana River annual runoff & point-source loads vs. % departure from seagrass depth-limit targets: 1943, 1996 & 1999







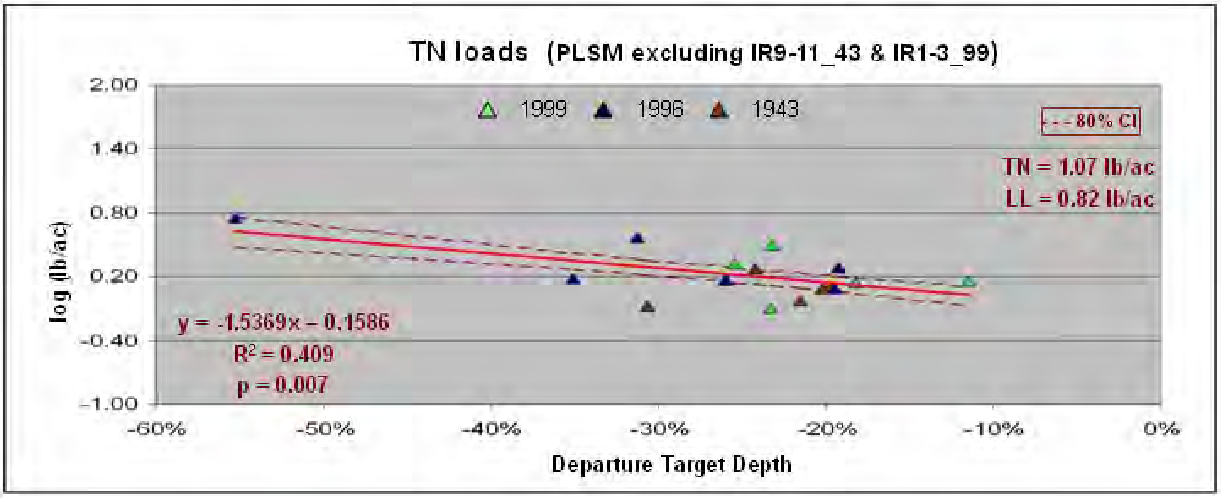
APPENDIX E.

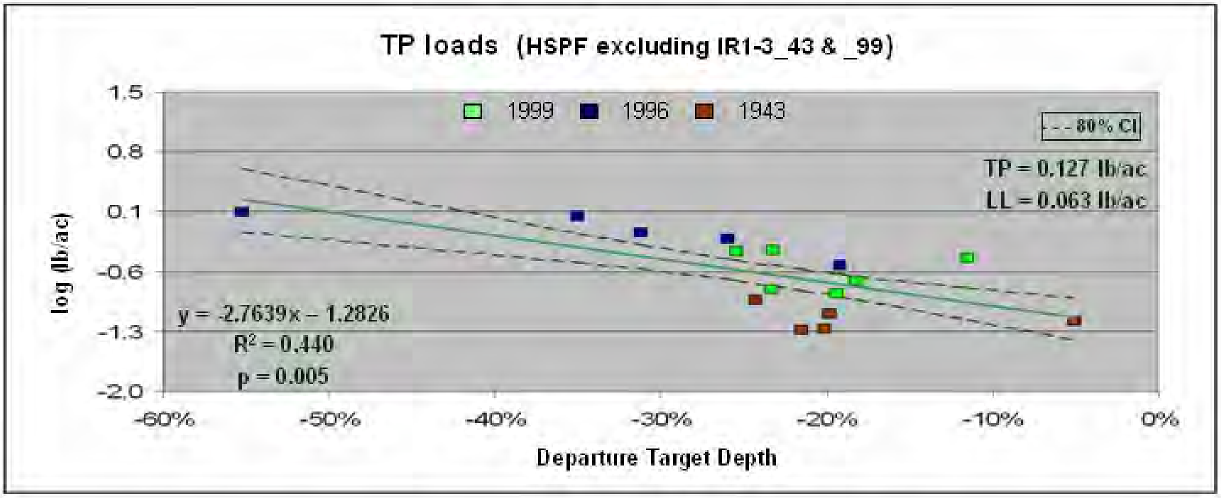
Indian River and Banana River Lagoons
NONPOINT loads estimated for 1943, c. 2000, and build-out conditions

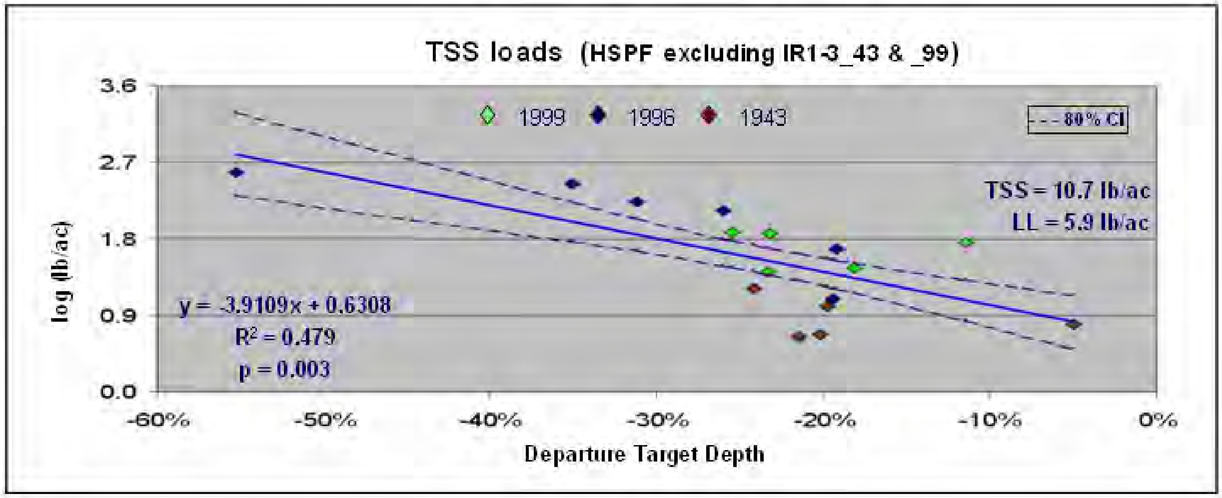
Sub-lagoons & segments	1943 loads, lb/yr*			Current (*c.* 2000) loads, lb/yr**			Build-out loads, lb/yr*		
	TN	TP	TSS	TN	TP	TSS	TN	TP	TSS
North IRL	342,371	55,856	3,537,548	576,413	93,507	12,683,132	838,458	177,411	24,393,713
IR1-3	107,506	19,147	1,078,020	134,970	13,902	1,453,331	222,693	51,844	3,805,165
IR4	9,251	2,094	151,082	20,742	4,435	548,083	28,720	6,263	1,063,334
IR5	84,717	10,181	778,114	125,855	20,377	2,649,289	187,031	39,442	6,109,752
IR6-7	67,716	12,509	732,120	115,901	18,618	2,344,802	167,737	32,492	4,721,363
IR8	12,722	2,894	248,920	24,288	4,418	596,461	31,367	6,441	1,236,171
IR9-11	60,459	9,031	549,292	154,657	31,758	5,091,166	200,910	40,929	7,457,928
Central IRL	1,513,459	183,296	12,355,694	1,796,062	309,008	29,556,073	2,112,772	367,370	42,146,741
IR12	430,700	44,546	2,917,191	508,473	81,662	9,631,919	632,441	105,450	15,028,415
IR13	62,650	7,863	446,699	62,789	7,743	574,355	85,756	11,267	1,087,877
IR14-15	712,510	80,785	5,166,125	728,452	121,192	8,989,415	771,744	130,340	10,450,464
IR16-20	302,605	48,985	3,749,176	484,024	96,052	10,009,392	605,170	117,078	15,100,117
IR21	4,994	1,117	76,503	12,323	2,359	350,992	17,661	3,235	479,868
Banana River	118,156	15,610	957,403	289,117	54,980	9,026,550	408,564	85,414	14,051,798
BR1-2	79,244	9,562	478,199	127,783	20,660	3,057,460	214,049	43,069	6,331,671
BR3-5	18,605	2,907	309,408	73,704	17,043	3,122,572	86,324	19,902	3,828,564
BR6	10,413	1,821	97,146	46,213	9,723	1,709,726	59,212	12,265	2,126,686
BR7	9,894	1,320	72,650	41,417	7,554	1,136,792	48,979	10,178	1,764,877

*** PLSM-estimated loads. 1943 land use was used with mean annual rainfall based on a 20-year rainfall (1930 - 1950) and, in the case of build-out loads, a projected build-out land use was used with a mean annual rainfall based on a 30-year rainfall record (1965 – 1995).**
**** 2000 land use, mean annual rainfall calculated from 30-year period of record; all PLSM-estimated loads except for North IRL TP, which is HSPF-estimated**

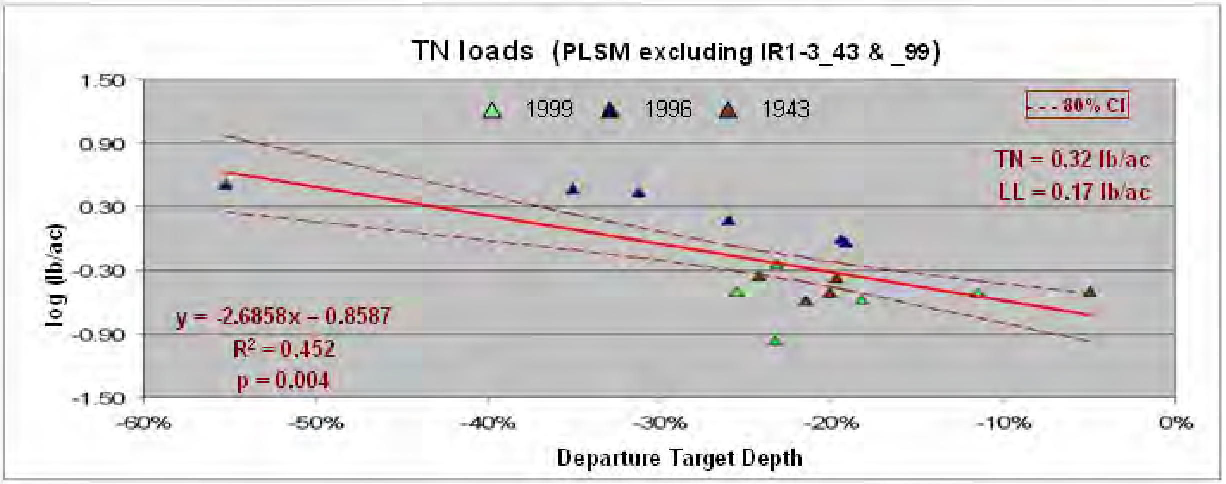
APPENDIX F.1. North IRL wet season (Aug-Oct) runoff & point-source loads vs. % departure from seagrass depth-limit targets: 1943, 1996 & 1999

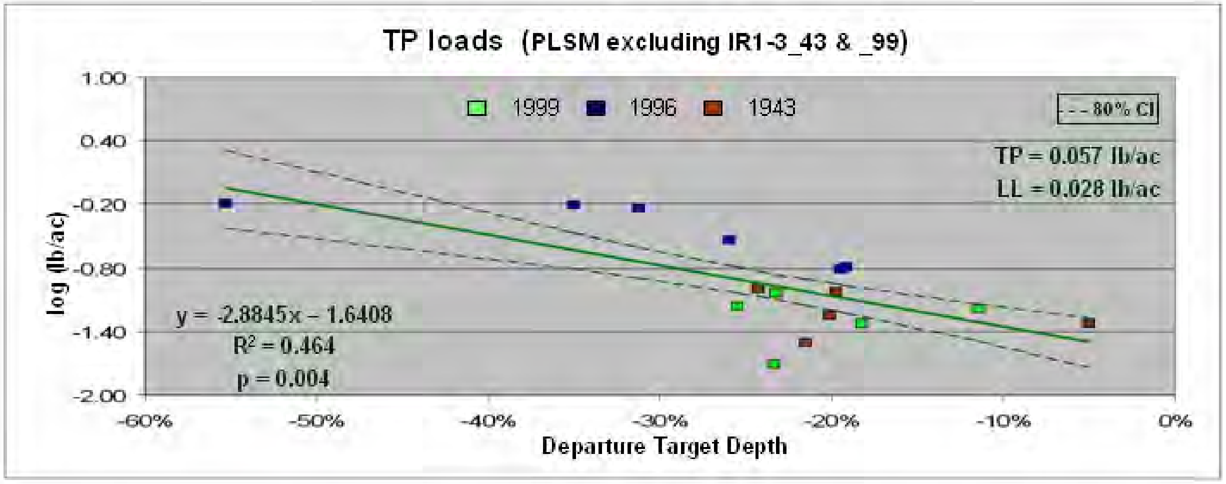


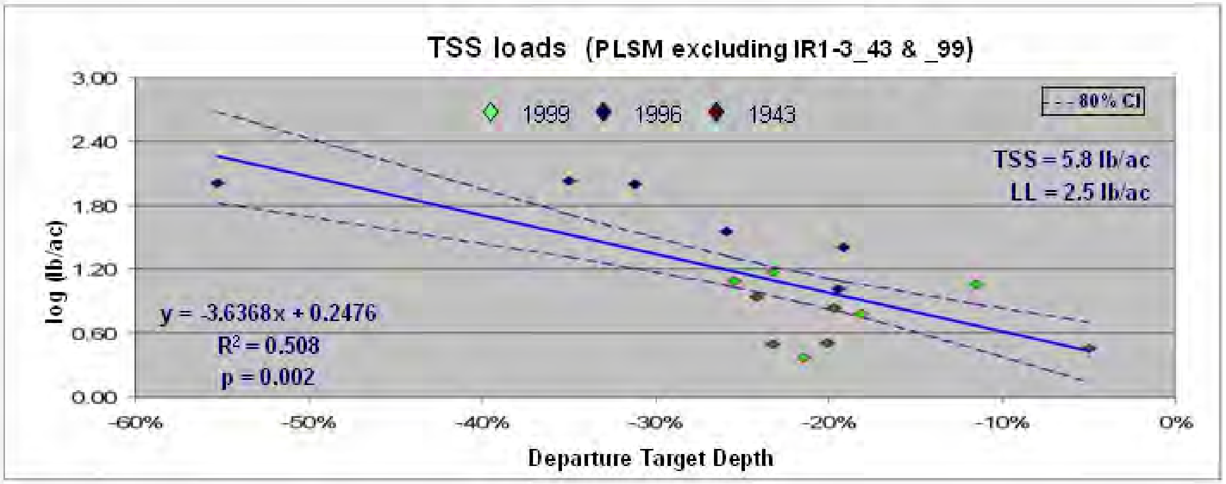




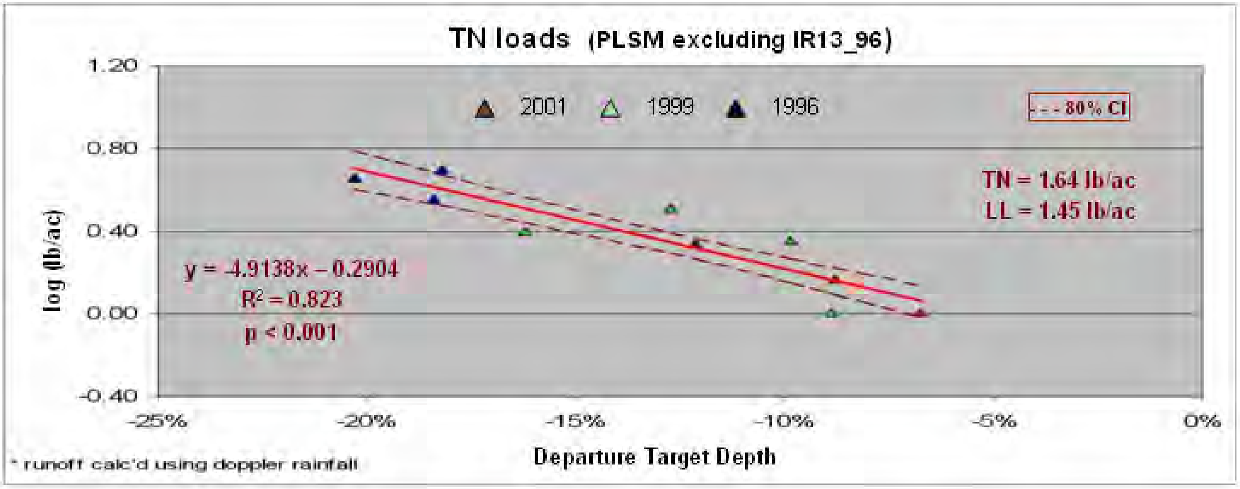
APPENDIX F.2. North IRL dry season (Feb-Apr) runoff & point-source loads vs. % departure from seagrass depth-limit targets: 1943, 1996 & 1999

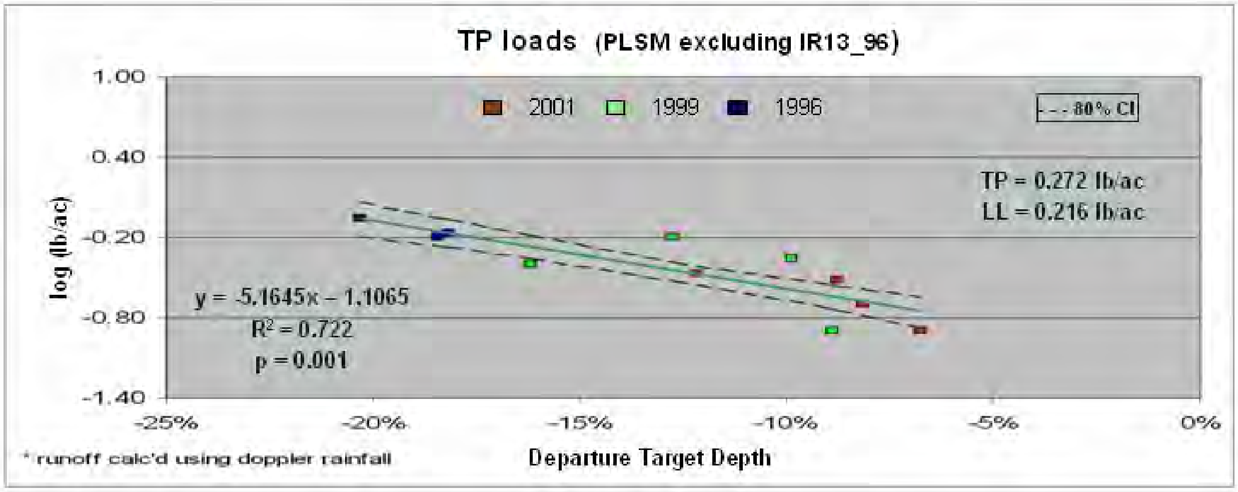


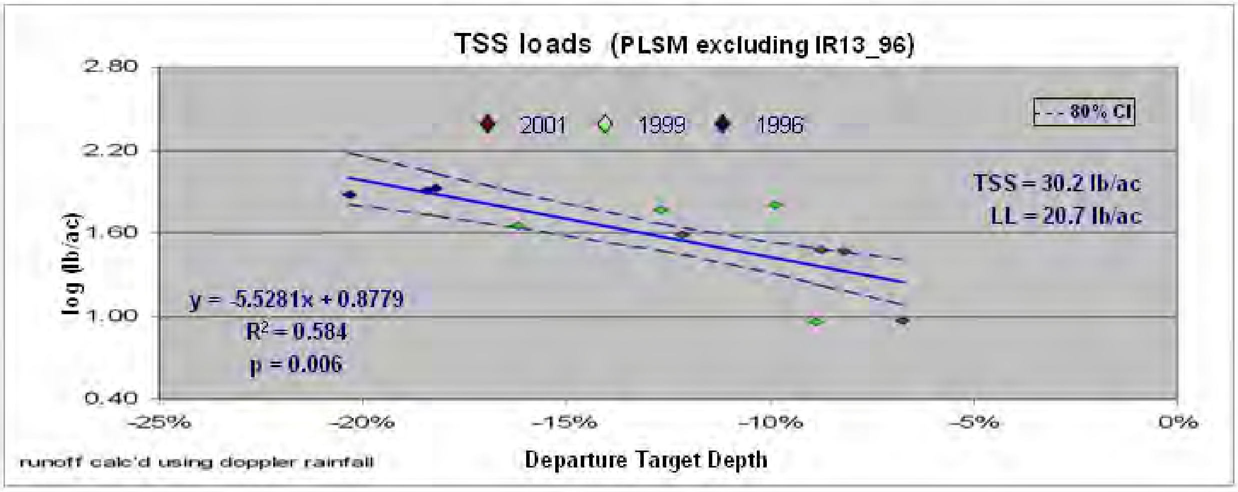




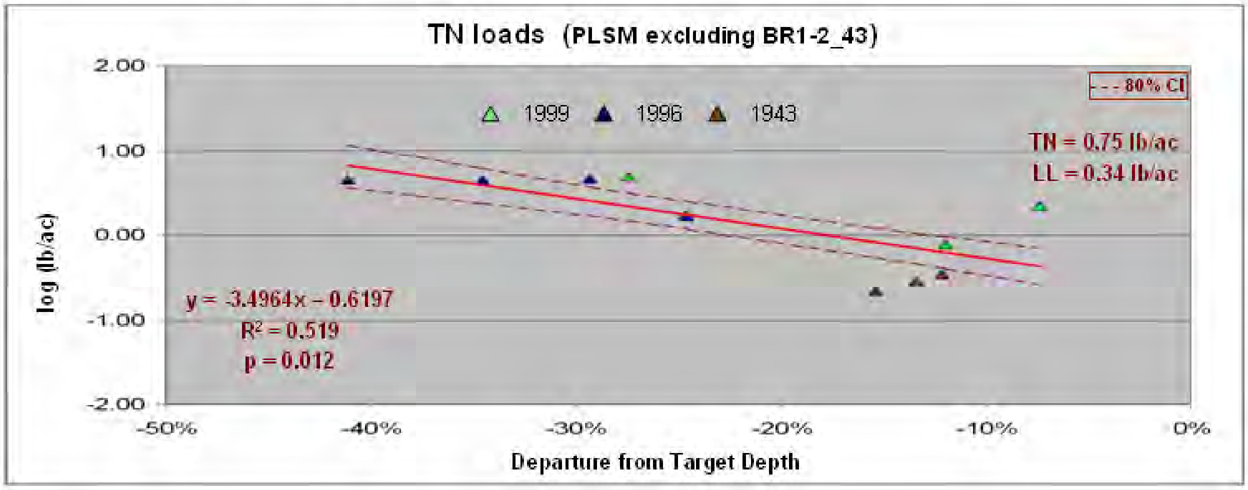
APPENDIX F.3. Central IRL wet season (Aug-Oct) runoff & point-source loads vs. % departure from seagrass depth-limit targets: 1996, 1999 & 2001

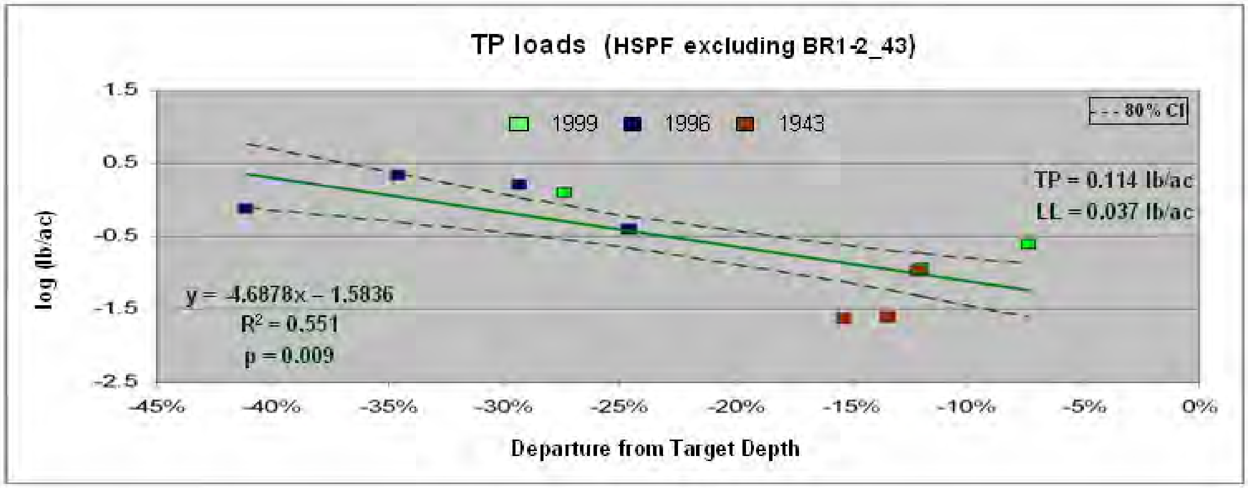


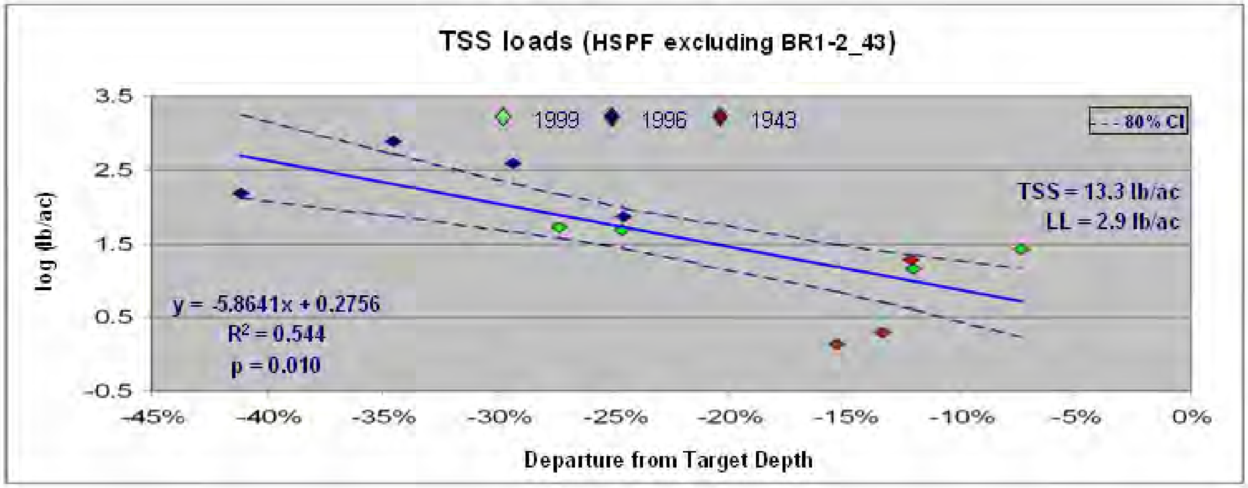




APPENDIX F.4. Banana River wet season (Aug-Oct) runoff + point source loads vs. % departure from seagrass depth-limit targets: 1943, 1996, 1999







APPENDIX F.5. Banana River dry season (Feb-Apr) runoff + point source loads vs. % departure from seagrass depth-limit targets: 1943, 1996, 1999