Site-Specific Information in Support of Establishing Numeric Nutrient Criteria for Perdido Bay

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Executive Summary

This report was prepared by the Florida Department of Environmental Protection (FDEP), in cooperation with the U.S. Environmental Protection Agency (EPA) and local scientists, to support the development of numeric nutrient criteria for Perdido Bay.[1] The primary purpose of the proposed numeric nutrient criteria is to protect healthy, well-balanced natural populations of flora and fauna from the effects of anthropogenic nutrient enrichment.

Historically, Perdido Bay has sustained a general loss of benthic production due to salinity stratification and hypoxia, both of which directly resulted from dredging and subsequent saltwater intrusion from the Gulf of Mexico. Perdido Bay has also been impacted by anthropogenic sources of nutrient enrichment, with impacts documented in a long-term (19-year) study of the Perdido River and Bay system. The study evaluated the impact of anthropogenic sources of nutrients on the food web organization of the estuary, with an emphasis on the interaction of nutrient loading, plankton response, and induced changes of food webs due to algal bloom generation (Livingston 2010).

A relatively natural, well-balanced plankton community was observed in Perdido Bay from 1988 to 1991. However, a series of phytoplankton blooms began in 1993 and 1994, attributable to drought conditions and increased nutrient loading by a pulp mill into Elevenmile Creek (Livingston 2010). Blooms of the blue-green alga, *Merismopedia tenuissima,* and the raphidophyte, *Heterosigma akashiwo* (a toxin-producing diatom), were first noted from 1996 to 1997. *Merismopedia* blooms, mainly in Elevenmile Creek, were associated with high levels of nutrients during drought periods. The *Merismopedia* blooms were statistically associated with severely altered food webs and a significant loss of biological productivity in Elevenmile Creek. *Heterosigma* blooms in the upper bay occurred primarily during periods of increased rainfall and increased loading of ammonia and orthophosphate from the pulp mill. From 2002 to 2003, additional loading from a sewage treatment plant in the upper bay was associated with considerable *Heterosigma* blooms. Hurricane Ivan (September, 2004) had minimal effects on the plankton blooms. Repeated blooms of *Heterosigma* resulted in severe damage to formerly productive parts of the upper bay and the loss of biological components of the lower bay (Livingston 2010). FDEP interprets these algal blooms and significant changes in the bay's food web dynamics, which led to reductions in beneficial productivity, as nutrient-induced imbalances in flora and fauna, in non-compliance with Paragraph 62-302.530 (47)(b), Florida Administrative Code (F.A.C.).

After 2003, reductions in nutrient loadings to the bay were implemented, and biological recovery was observed, although there was evidence that the previous damage made biological communities less resilient to further anthropogenic nutrient enrichment. FDEP proposes that the nutrient loading that was characteristic of the bay prior to the harmful algal blooms (HABs) be adopted as protective numeric criteria. This specific nutrient loading, which was associated with healthy, well-balanced aquatic communities, would protect the designated use of Perdido Bay. This concept was upheld during 2010 court proceeding. In Big Lagoon, because the seagrass community has been stable over time and no HABs were observed, DEP proposes to base nutrient criteria on the maintain existing healthy conditions approach, using data from the past 12 years.

Table 1 summarizes the potential nutrient-related responses for Perdido Bay.

Nutrient targets are summarized in **Table 6** on page 41 of this report.

[1] Contributors to this report include Skip Livingston, Tom Gallagher (HydroQual), Alan Niedoroda (URS), Jim Hagy (EPA Gulf Breeze), Just Cerbian (USA), Ken Heck (USA), and Russel Frydenborg (FDEP).

Table 1. Checklist of nutrient enrichment symptoms in Perdido Bay.

- = Empty cell/no data

Response variable	Observed Historically?	Observed Currently?	Explanation
Low dissolved oxygen (DO) (hypoxia/anoxia)	Yes	Yes	Low DO concentrations have been observed historically, and current periodic low DOs are associated with natural salinity stratification and natural organic material delivered by river systems (Niedoroda 1992, Livingston, 1984a, 1989; Livingston *et al.* 2000).
Reduced clarity	No	No	Turbidity is a temporary phenomenon associated with storm events (Heck 1996).
Increased chlorophyll a concentrations	Yes	No	Annual mean chlorophyll *a* exceeded 11 micrograms per liter (μg/L) once during a period of HABs (FDEP 2006).
Phytoplankton blooms (nuisance or toxic)	Yes	Recovering	Problematic algae blooms were historically observed, but recovery is ongoing, associated with nutrient reductions from point sources (Livingston 2010).
Problematic epiphyte growth	No	No	Epiphyte growth was not found to be an issue.
Problematic macroalgal growth	No	No	Problematic macroalgal growth has not been observed.
Submerged aquatic vegetation (SAV) community changes or loss	Yes	No	SAV reductions occurred due to salinity changes associated with dredging a pass that changed the salinity regime, not from nutrient enrichment (Kirschenfeld *et al.* 2006). SAV has been stable in Big Lagoon (FWCC 2011).
Emergent or shoreline vegetation community changes or loss	No	No	None reported.
Coral/hardbottom community changes or loss	No	No	Not present.
Impacts to benthic community	Yes	No	HABs affected benthic communities in 1990s, but present communities improving (Livingston 2010).
Fish kills	Yes	No	None reported.

Geographic and Physical Description

Perdido Bay, classified as an Outstanding Florida Water (OFW), is located in western Florida and is contiguous with the Alabama border **(Figure 1)**. The Perdido River and Bay are interstate waters that form the boundary between Alabama and Florida (the state line bisects the middle of the river and bay). The Perdido River is the major freshwater tributary to the bay, with additional freshwater input from Elevenmile Creek, Bayou Marcus, Soldier Creek (Alabama), and Palmetto Creek (Alabama). The bay is separated from the Gulf of Mexico by Perdido Key, a sand-based barrier island. Perdido Bay is connected to Big Lagoon and Pensacola Bay via the dredged Gulf Intracoastal Waterway (GIWW), and to the Gulf of Mexico via a dredged pass near Orange Beach, Alabama. The bay was divided into four segments by EPA **(Figure 2)**. The upper bay extends from the mouth of the Perdido River and Elevenmile

Creek southwest to a constriction in the bay created by Grassy and Double Points. Bayou Marcus and Bridge Creek drain into the upper bay. The central bay is bounded at the lower end by a line from Red Bluff south to the north side of Inerarity Point. Tarkiln Bayou and Garcon Bayou drain to the central bay. The lower bay connects the central bay to the Gulf of Mexico through Perdido Pass and includes Bayou St. John. This segment extends east to join the Big Lagoon near the State Road 292 Bridge. Soldier Creek, Palmetto Creek, and Wolf Bay drain to the lower bay. The last segment is Big Lagoon. The Big Lagoon and GIWW connect Perdido Bay to Pensacola Bay.

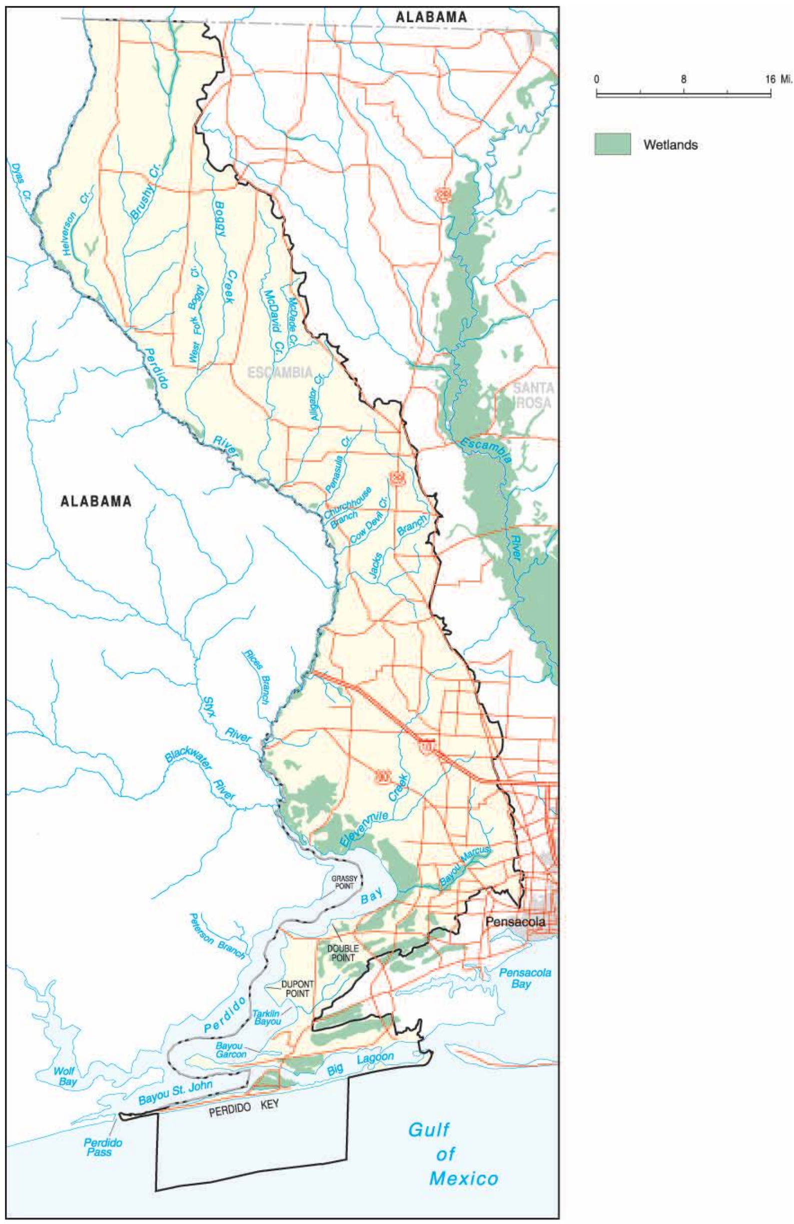


Figure 1. Perdido Bay watershed.

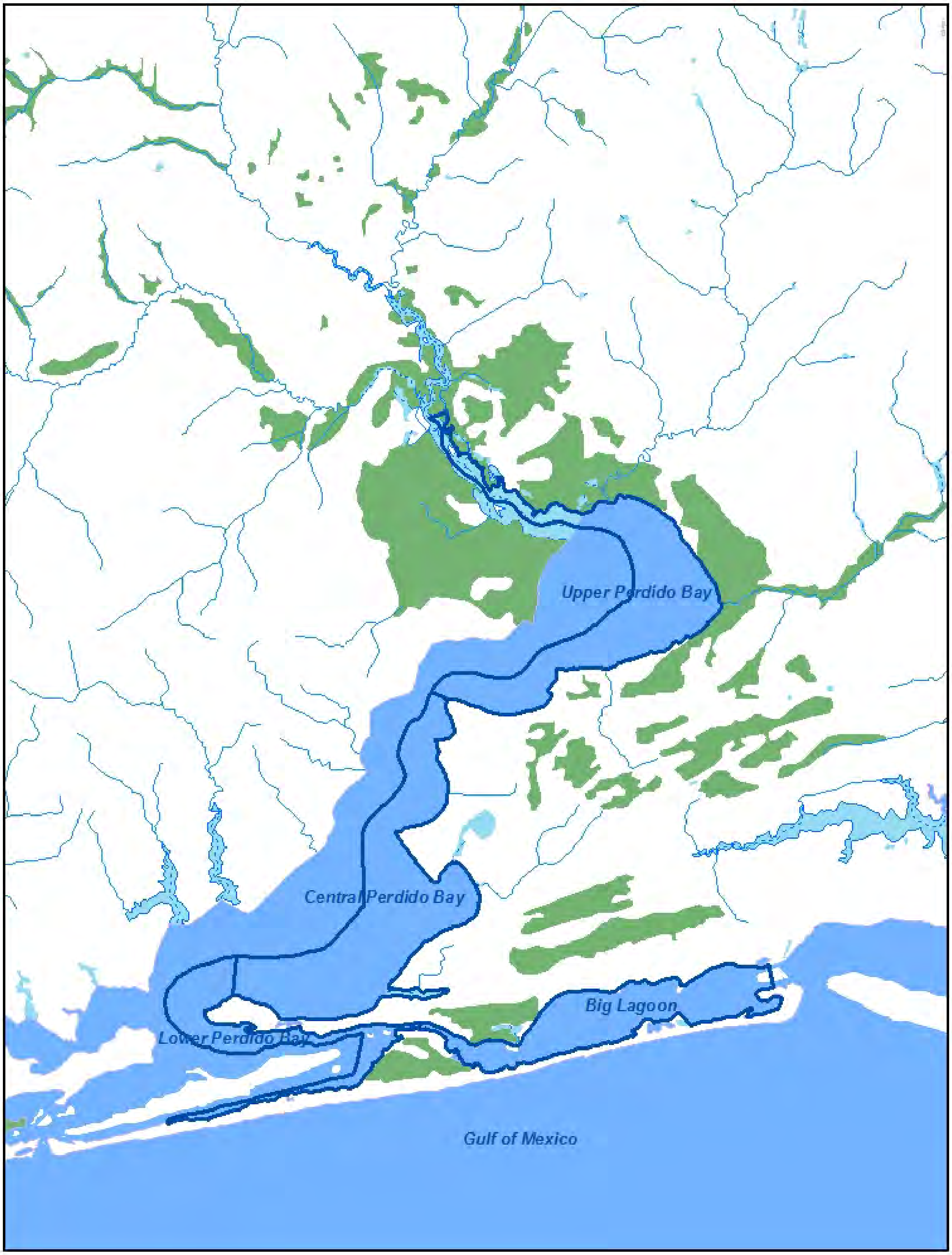


Figure 2. Map of Perdido Bay showing the four estuary segments.

The opening of Perdido Bay to high-salinity water from the Gulf in the early 20th century adversely affected the secondary productivity of the system (Livingston 2010). Prior to dredging of the marine passes, Perdido Bay was oligohaline, with freshwater biota inhabiting the upper bay. Due to the bay's current physiographic characteristics and a relatively large freshwater inflow compared with the volume of its tidal prism (Niedoroda 1992), Perdido Bay is a highly stratified estuary **(Table 2)**. The steep density gradient (pycnocline) effectively suppresses vertical mixing. The relatively short fetch relative to prevailing wind currents enhances stratification in deeper parts of the bay. Warm summer temperatures, which cause lower surface densities; the (northeast to southwest) orientation of the bay, which is parallel to the direction of frequent strong winds; and the small tidal range, which averages 0.15 meters [m]), contribute to the high stratification of the bay **(Figures 3 and 4; Table 3)**.

The downward diffusion of oxygen is arrested at the pycnocline, and bottom waters become relatively depleted at the deeper, more-salinity-stratified stations. DO profiles indicate reduced oxygen supply in the bottom layer of the lower bay. DO in each part of the bay (river-estuary, upper bay, and lower bay) is specifically related to its geographic position in the bay and corresponding water depth. Stepwise regression indicates that 44% of the variability in DO distribution in Perdido Bay is a function of temperature, depth, salinity concentration, and the level of stratification. With an increase in bottom salinity during warm periods of the year, there is an associated reduction of DO. The highly stable stratification conditions usually are directly related to these hypoxic conditions.

The hypoxia at depth is statistically associated with the reduction of several biological indices, including the Fish/Invertebrate/Infauna Index (Livingston 2010). This loss of production is similar to findings in other bay systems (Livingston 1984a, 1989; Livingston *et al.* 2000).

Table 2. Summary of physical properties, including depth, sediment type, stratification, and circulation regimes of Perdido Bay (after Niedoroda 2010).

Bay Regime	Physical Properties
Lower Perdido River	Deep (~7 m or ~ 23 feet [ft]) Silty mud bottom Strong stratification Circulation–surface fast but bottom stagnant
Upper Bay	Shallow (2 m or 6 ft) Sand-silt-clay Low to moderate stratification Tidal circulation–sluggish Advective flushing (1 to 2 days) River, creek, and bayou inputs
Middle Bay	Intermediate depth (~3 m or ~10 ft) Clayey silt Stratification–persistent Tidal circulation–moderate Advective flushing–(½ to 1 day)
Lower Bay	Significant depth (~4-5 m or ~13-16 ft) Clayey silt to sand Stratification–persistent Tidal circulation–good Advective flushing (1 to 3 days) Gulf water input

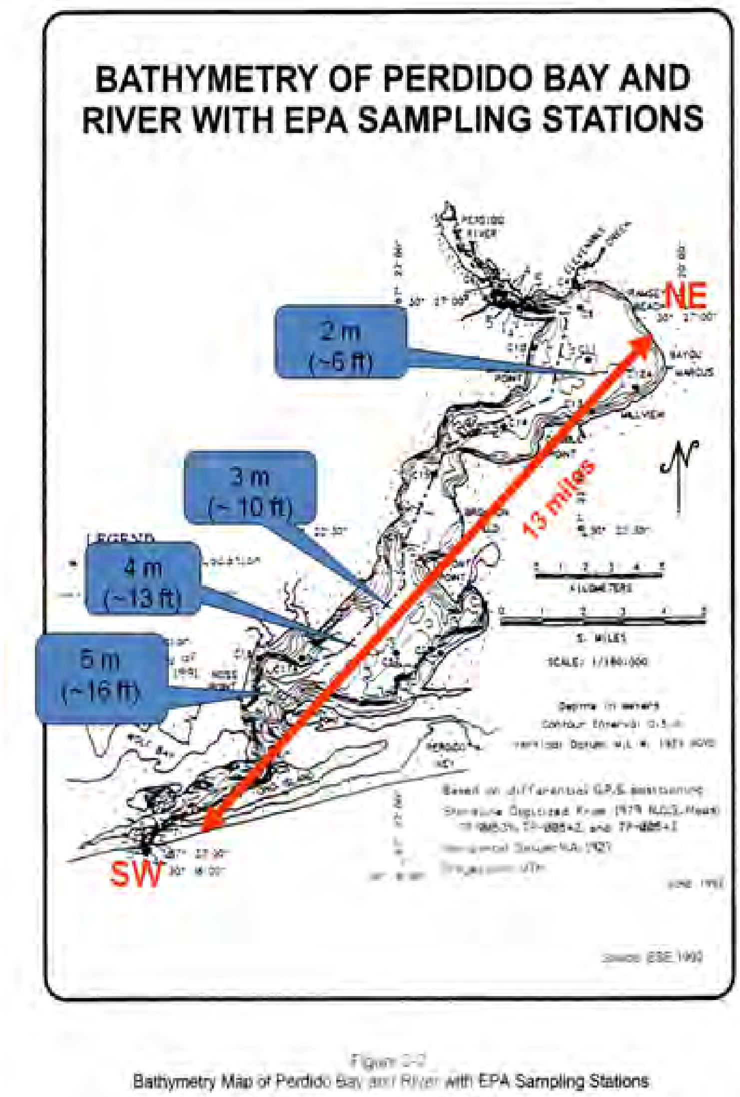
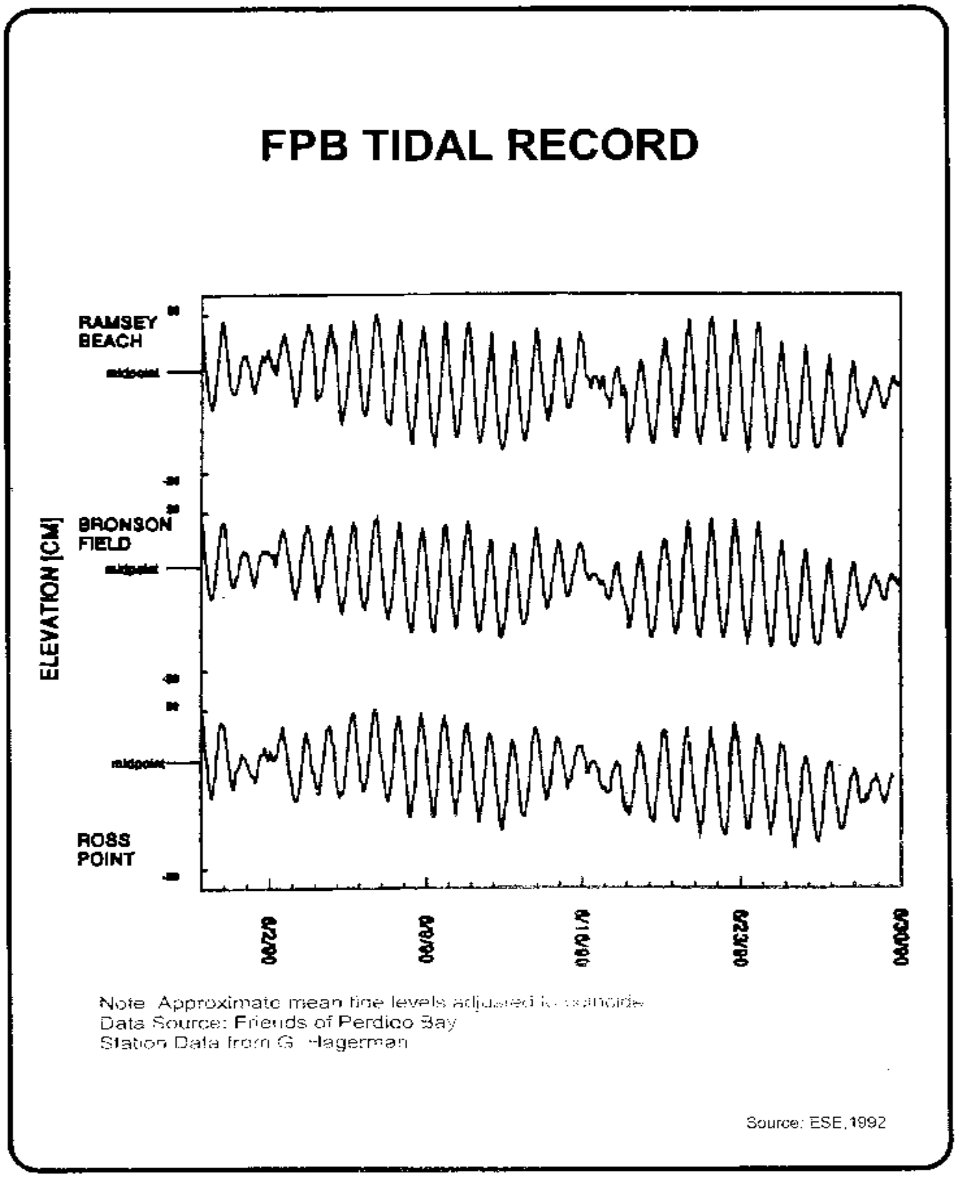


Figure 3. Bathymetry and orientation of Perdido Bay (after Niedoroda 2010).



A Tidal Curve for Friends of Perdido Bay Gage

Figure 4. Tidal regime of Perdido Bay.

Table 3. Summary of physical/chemical information for Perdido Bay.

Physical/Chemical Information	Value	Source
Estuarine surface area (square kilometers [km^2])	129	National Oceanic and Atmospheric Administration (NOAA)
Watershed area (km^2)	2,928	NOAA
Land use % in watershed	Forest 64.2% Agriculture 23.6% Wetland 3.6% Urban 8.6%	NOAA
Mean depth (m)	1.53	NOAA
Volume (cubic meters [m^3])	197,370,000	NOAA
Tidal range (m)	0.15	NOAA
Tidal freshwater inflow (1,000 cubic meters per day [m^3d^{-1}])	3,910,000	NOAA
Mean water residence time/tidal exchange (days)	29	NOAA
Average salinity (Practical Salinity Units [PSU])	13	NOAA
Annual loading of total nitrogen (TN) and total phosphorus (TP)	TN= 2,534,000 kilograms per year (kg/yr) or 19,643.4 kilograms per square kilometer per year ($kg/km^2/yr$) TP= 98,890 kg/yr or 766.59 $kg/km^2/yr$	NOAA

Waters on the 303(d) List

With one exception, annual mean chlorophyll *a* values have generally been below the 303(d) impairment threshold for estuaries (11 μg/L) in the IWR (Chapter 62-303, F.A.C.), with annual mean values of 12.83 μg/L (1994), 7.7 μg/L (1998), 7.310 μg/L (1999), 8.316 μg/L (2000), 7.449 μg/L (2001), 7.887 μg/L (2002), and 6.41 μg/L (2003). Livingston (2010) noted blooms of *H. akashiwo* (a toxin-producing diatom) occurred during the same period (2004) that chlorophyll *a* exceeded 11 μg/L. The system was N:P co-limited based on median TN/TP ratio of 16.35, using 35 values (FDEP 2008).

Bayou Marcus Creek was listed as impaired for dissolved oxygen with TN identified as the causative pollutant because it was elevated relative to comparable reference condition waters (exceeded 0.62 mg/L).

Elevenmile Creek was on the 1998 303(d) list for turbidity, however, the creek was assessed as not impaired for turbidity during cycles 1 and 2 of the basin rotation. The Perdido River and Bay are not impaired for turbidity.

Data Source Information and Data Interpretation

The datasets used for NNC development consisted of data from Run 44 of the IWR database for the years 1966-2011. Additional data from the State of Alabama Department of Environmental

Management (ADEM) for years 1987-2008 and Skip Livingston (EP&A) for years 1988-2004 was appended to the Run 44 data. After the complete dataset was assembled, data were screened for fatal qualifier codes. These fatal codes were H, J, K, N, O, Q, Y, and ? If a qualifier code of U or T was given, half of the reported MDL value was used (**Table 4** provides qualifier code descriptions from Rule 62-160.700, F.A.C.). Total nitrogen values were calculated by adding nitrate/nitrate and TKN values (using samples collected on the same day and at the same location).

Marine data obtained by Florida COASTWATCH was used where appropriate. The lab that analyzes the COASTWATCH samples does not have the accreditation required by the DEP Quality Assurance (QA) Rule (62-160, F.A.C.), and does not comply with some components of the QA Rule. FDEP notes the following considerations for using COASTWATCH results to inform water quality standards development:

1. Chlorophyll a is reported without correction for phaeophytin. FDEP has determined that phaeophyton-corrected chlorophyll a are more appropriate for water quality criteria, and therefore the uncorrected chlorophyll a data may be considered as estimated values. Additionally, samples for chlorophyll are prepared using a procedure different than those provided in the chlorophyll methods approved by DEP. See http://www.dep.state.fl.us/water/sas/qa/docs/application-chlorophyll-a-methods.pdf
2. The method for the determination of TN in water samples is not listed as an EPA-approved method at 40 CFR, Part 136.3. The preservation method for the TN and TP samples (freezing) is not an approved preservation method in the DEP SOPs. However, Bachmann and Canfield (1996) and Canfield *et al.* (2002) demonstrated that results from these methods are comparable to results from other labs using approved methods. Two recent comparison studies between the FDEP lab in Tallahassee and the COASTWATCH lab showed very comparable results between labs for TN and TP. These studies suggest that it is appropriate to use the long-term COASTWATCH dataset, in conjunction with other data sources where available, to inform numeric nutrient criteria proposals.
3. COASTWATCH lab results do not include appropriate data qualifiers, as required by the FDEP QA Rule, for cases in which lab quality control measures did not pass or unusual circumstances surround the sampling events. Therefore, users of the data should be cautious regarding use of outliers or unusual data points.

Table 4. Qualifier codes used for data screening (Rule 62-160.700, F.A.C.).

H	Value based on field kit determination; results may not be accurate. This code shall be used if a field screening test (i.e., field gas chromatograph data, immunoassay, vendor-supplied field kit, etc.) was used to generate the value and the field kit or method has not been recognized by the Department as equivalent to laboratory methods.
J	Estimated value. A "J" value shall be accompanied by a detailed explanation to justify the reason(s) for designating the value as estimated. Where possible, the organization shall report whether the actual value is estimated to be less than or greater than the reported value. A "J" value shall not be used as a substitute for K, L, M, T, V, or Y, however, if additional reasons exist for identifying the value as an estimate (e.g., matrix spiked failed to meet acceptance criteria), the "J" code may be added to a K, L, M, T, V, or Y. Examples of situations in which a "J" code must be reported include: instances where a quality control item associated with the reported value failed to meet the established quality control criteria (the specific failure must be identified); instances when the sample matrix interfered with the ability to make any accurate determination; instances when data are questionable because of improper laboratory or field protocols (e.g., composite sample was collected instead of a grab sample); instances when the analyte was detected at or above the

	method detection limit in a blank other than the method blank (such as calibration blank or field-generated blanks and the value of 10 times the blank value was equal to or greater than the associated sample value); or instances when the field or laboratory calibrations or calibration verifications did not meet calibration acceptance criteria.
K	Off-scale low. Actual value is known to be less than the value given. This code shall be used if:
	1. The value is less than the lowest calibration standard and the calibration curve is known to be non-linear; or
	2. The value is known to be less than the reported value based on sample size, dilution.
	This code shall not be used to report values that are less than the laboratory practical quantitation limit or laboratory method detection limit.
N	Presumptive evidence of presence of material. This qualifier shall be used if:
	1. The component has been tentatively identified based on mass spectral library search; or
	2. There is an indication that the analyte is present, but quality control requirements for confirmation were not met (i.e., presence of analyte was not confirmed by alternative procedures).
O	Sampled, but analysis lost or not performed.
Q	Sample held beyond the accepted holding time. This code shall be used if the value is derived from a sample that was prepared or analyzed after the approved holding time restrictions for sample preparation or analysis.
Y	The laboratory analysis was from an improperly preserved sample. The data may not be accurate.
?	Data are rejected and should not be used. Some or all of the quality control data for the analyte were outside criteria, and the presence or absence of the analyte cannot be determined from the data.
T	Value reported is less than the laboratory method detection limit. The value is reported for informational purposes only and shall not be used in statistical analysis.
U	Indicates that the compound was analyzed for but not detected. This symbol shall be used to indicate that the specified component was not detected. The value associated with the qualifier shall be the laboratory method detection limit. Unless requested by the client, less than the method detection limit values shall not be reported (see "T" above).

Sources and Fates of Nutrients

There are two facilities in Florida that are permitted to discharge to surface waters in the Perdido Bay Basin under the National Pollutant Discharge Elimination System (NPDES). The largest discharger to Perdido Bay is the International Paper Company Mill (ID#FL0002526), which is permitted to discharge up to 28 million gallons per day (MGD) of industrial wastewater to a wetlands that discharges to Elevenmile Creek and Upper Perdido Bay. The second discharger is the Bayou Marcus Wastewater Treatment Plant (ID#FL0031801), which is permitted to discharge up to 8.2 MGD of domestic wastewater to Bayou Marcus Creek and Upper Perdido Bay. Five other point sources are in Alabama and are shown in **Figure 33**.

As part of the ongoing Total Maximum Daily Load (TMDL) rotating basin assessment, FDEP (2006) summarized the existing nutrient data for Perdido Bay (**Table 5**). A water quality model was developed by Hydroqual for the International Paper Mill for the purpose of establishing Water Quality–Based Effluent Limits (WQBELs) for the pulp mill's discharge to Elevenmile Creek. The model included the mill discharge to Elevenmile Creek and to Perdido Bay through wetlands **(Figures 5-7)**. WQBELs were developed to address nutrient and DO issues. Major areas of the bay system addressed by the model include the Perdido River, Elevenmile Creek (impaired for low DO), and Perdido Bay. The model was calibrated for steady-state periods during the summers of 1989 and 1990. It includes a nutrient-algal model (Pritchard-WASP). The model includes a time-variable period (1990) coupled with hydrodynamic modeling (circulation and color).

Table 5. Perdido Bay Basin nitrogen (N) to phosphorus (P) ratios for TMDL assessment (from FDEP 2008).

Median and Ratio	Value
TN median	0.592 (milligrams per liter [mg/L])
TP median	0.042 (mg/L)
N to P ratio median	16.346
N to P ratio minimum	7.586
N to P ratio maximum	37.5

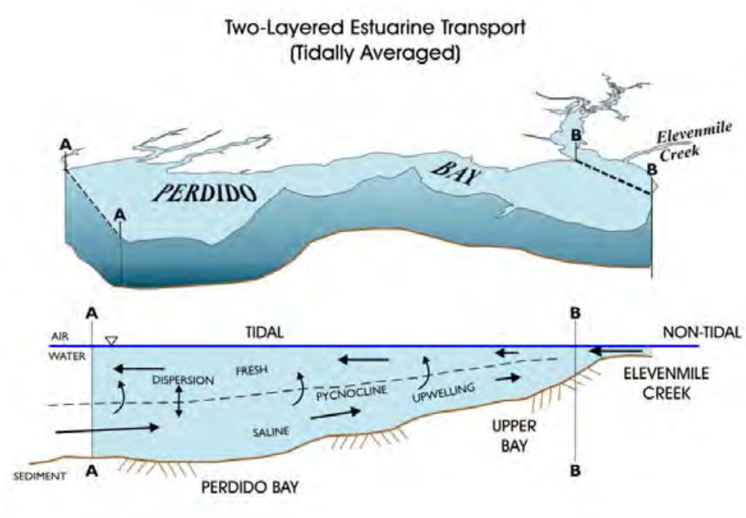


Figure 5. Cross sectional view of Perdido Bay showing freshwater output/saline input pattern.

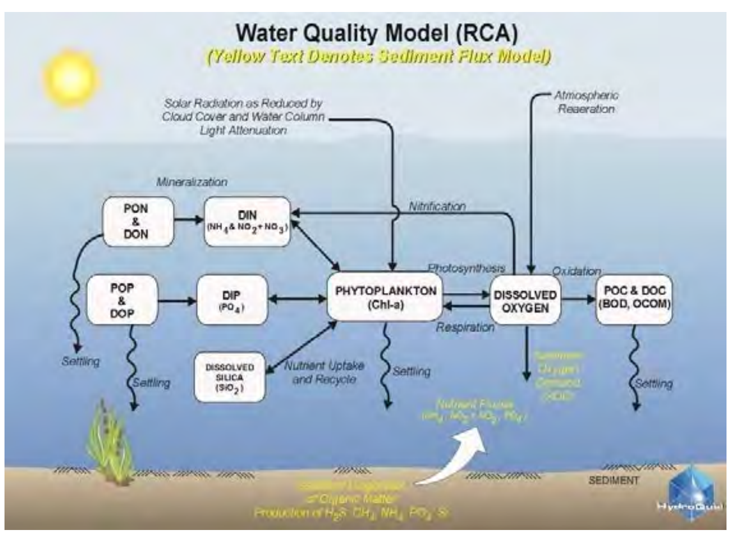


Figure 6. Conceptual aspects of Perdido model.

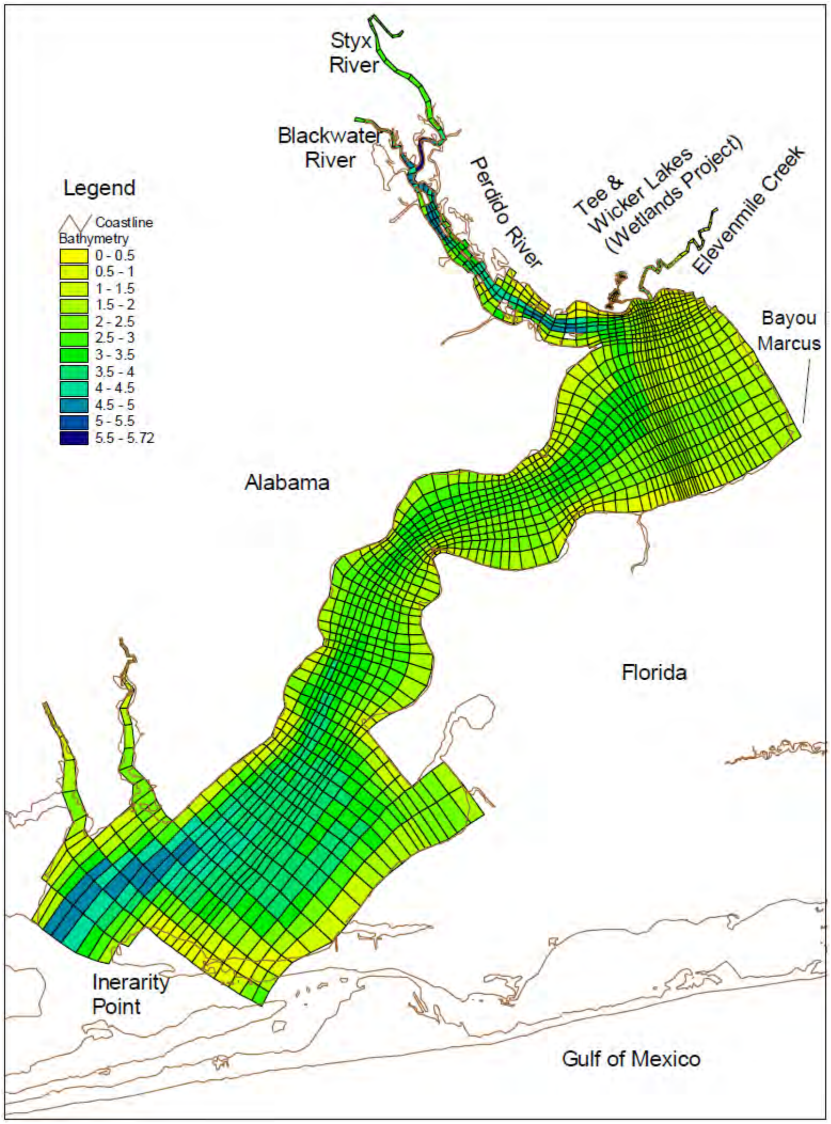


Figure 7. Grids and depths for three-dimensional (3-D) hydrodynamic model.

TN loading was estimated by the U.S. Geological Survey (USGS) using Florida water quality data for the Perdido River at the U.S. Highway 90 Bridge (Hagy 2010). The average for 1992 to 2004 was 561,000 kg N y^{-1}, from which the average yield was computed to be 443 kg N/km^2/y. TP loading at the same location averaged 22,000 kg y^{-1}, from which the average yield was computed to be 17 kg P/km^2/y. The TN:TP (atomic) loading ratio was 57. Hagy (2009) calculated the yield of TN delivered to Perdido Bay from subwatersheds of the Perdido Bay watershed **(Figure 8)**.

Table 6 shows a trend analysis for the Perdido River and Elevenmile Creek. Note that this analysis for the Perdido River only used data from the DEP trend site near Barrineau Park collected from 1999 to 2011. For the Perdido River, the median TN over this period was 0.5 mg/L, with a range from 0.218 to 0.79 mg/L, and no TN trend was observed over time. The median TP in the Perdido River was 0.018 mg/L, with a range from 0.006 to 0.072 mg/L. An extremely weak increasing trend for TP was observed in the Perdido River (Sen Slope estimate of 0.0003666222 mg/L per month). Elevenmile Creek TN and TP values were higher over this period (4.663 mg/L and 0.37 mg/L, respectively), but showed no trends for nutrients.

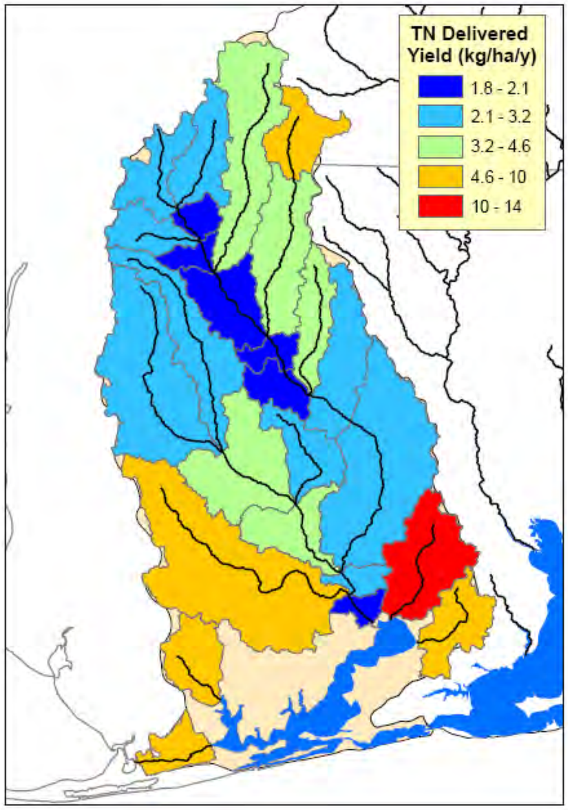


Figure 8. Yield of TN delivered to Perdido Bay from subwatersheds of the Perdido Bay watershed.

Table 6. Trend Analysis for Perdido River and Elevenmile Creek from 1999-2011.

Station	River	Nitrate-Nitrite	Total Kjeldahl Nitrogen	Total Nitrogen	Total Phosphorus	Total Organic Carbon	Chlorophyll *a*	Fecal Coliform	pH	Dissolved Oxygen
3542	Perdido	-	+	o	+	+	o	-	o	o
3565	Eleven Mile Creek	o	o	o	o	o	o	o	-	o

+ = increasing trend
- = decreasing trend
o = no trend

Flow data for the Perdido River is shown in **Figure 9**. Annual flows during the "healthy period" from 1988-1991 were very characteristic of the river, well within the range of flows observed since 1970. The long-term average flow for the river since 1970 is 812 cubic feet per second (cfs).

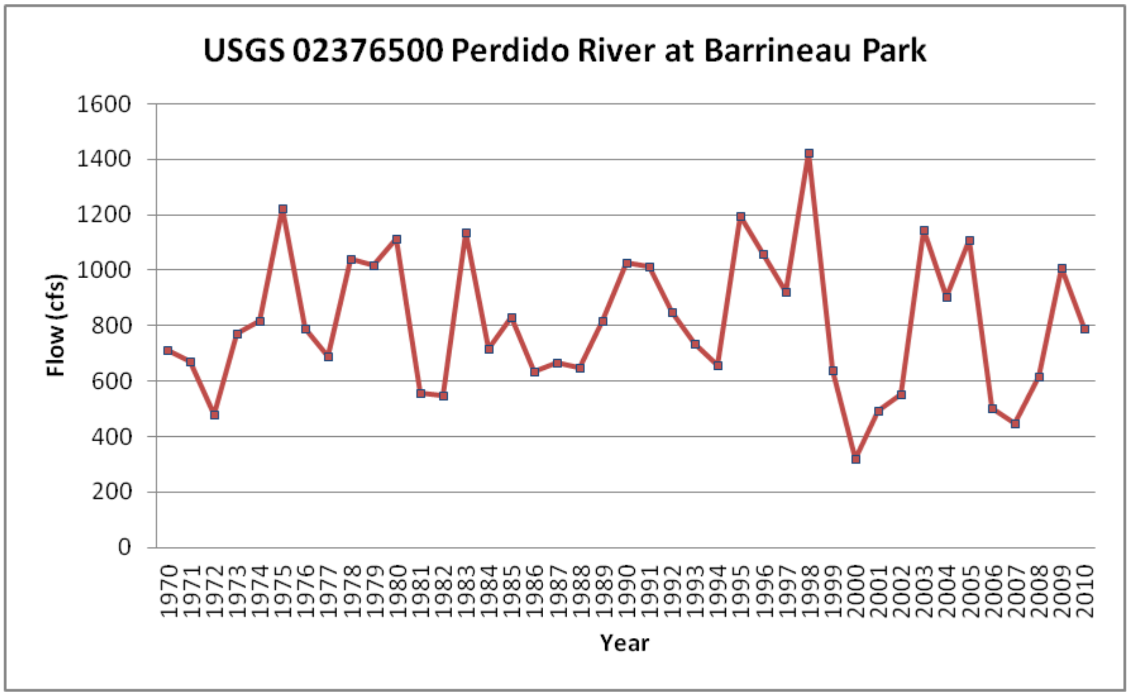


Figure 9. Annual Average Flows for the Perdido River from 1970-2010.

The nutrient and chlorophyll a data for each bay segment were analyzed to assess trends over time. Annual averages for TN, TP, and chlorophyll a were calculated for each bay segment **(Figures 10-21)**. The box plots show an increase in TN in the mid 1980s and late 2000s and an increase in TP and chlorophyll a for Big Lagoon in the 2000s.

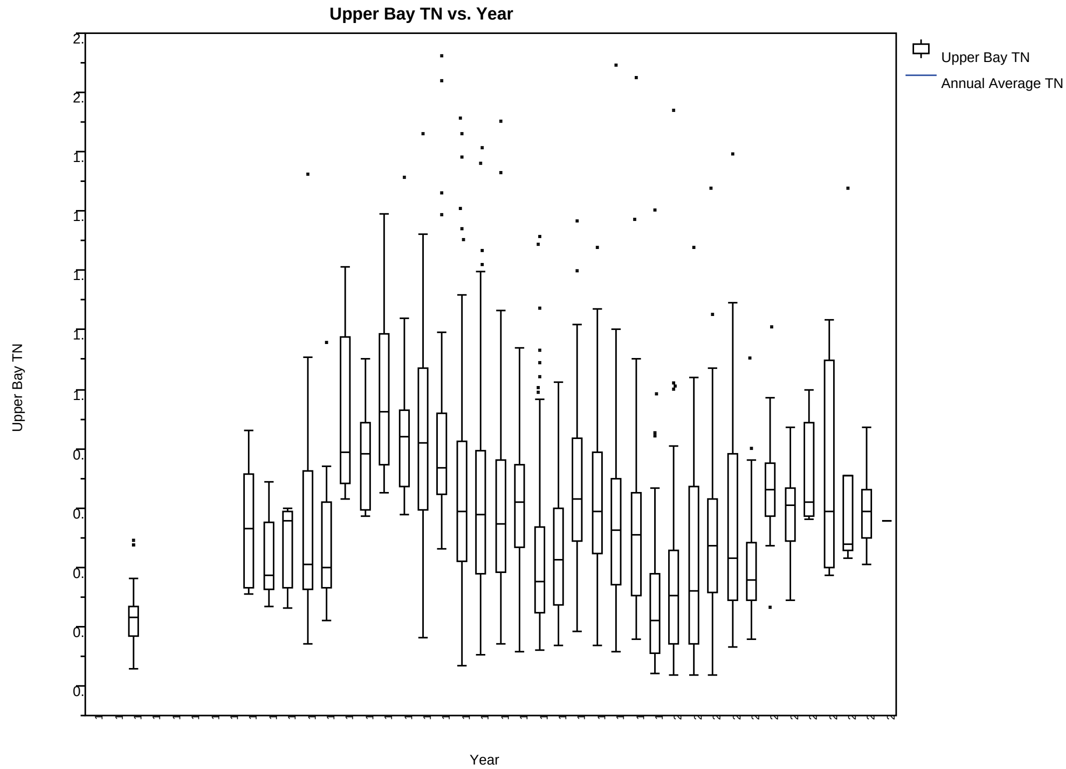


Figure 10. Box plot of TN (mg/l) for Upper Perdido Bay.

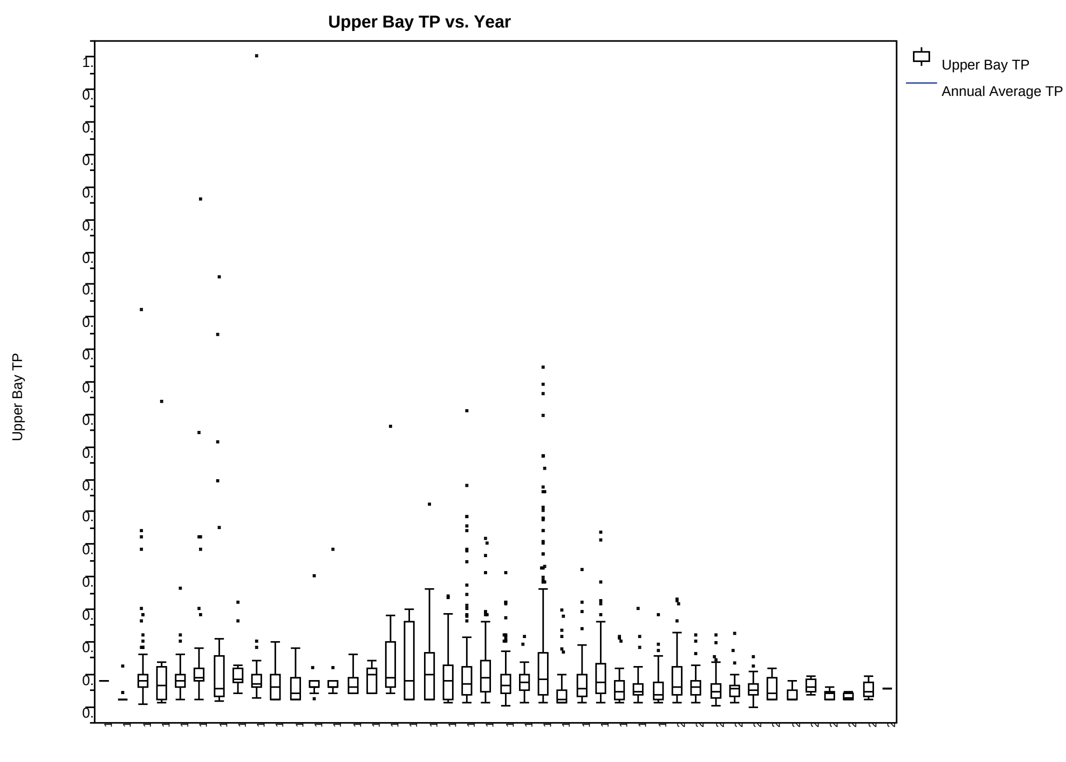


Figure 11. Box plot of TP (mg/l) for Upper Perdido Bay.

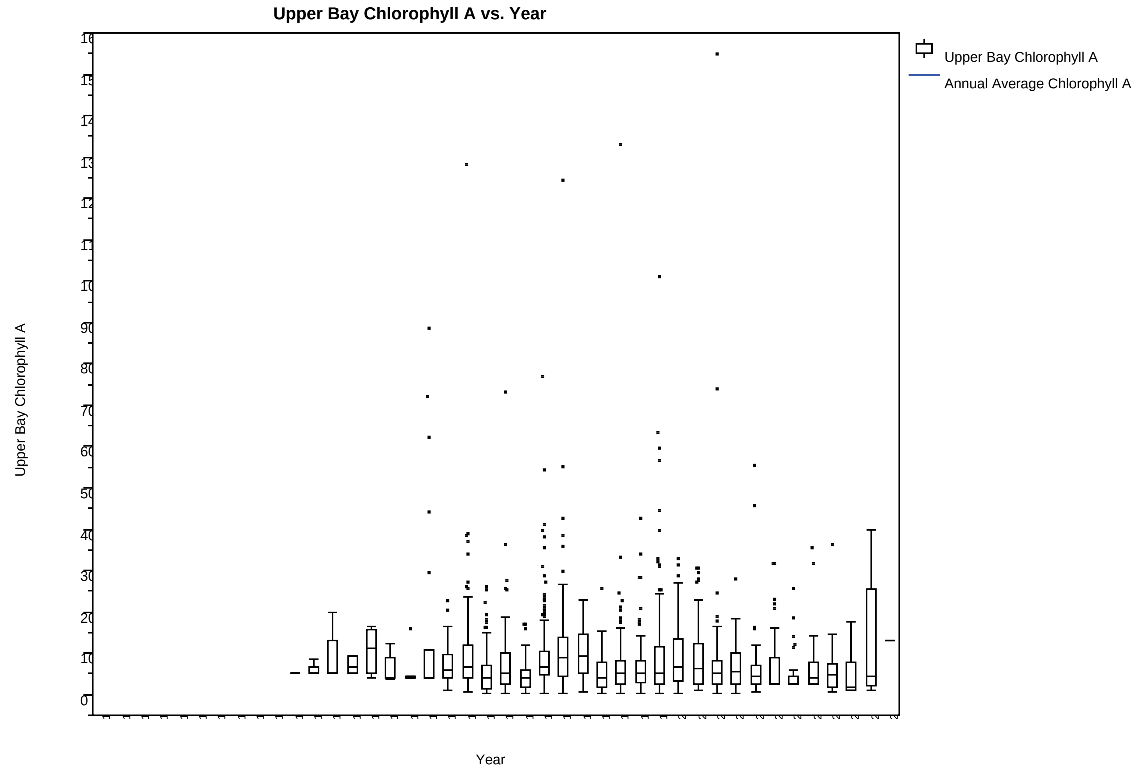


Figure 12. Box plot of chlorophyll a (ug/l) for Upper Perdido Bay.

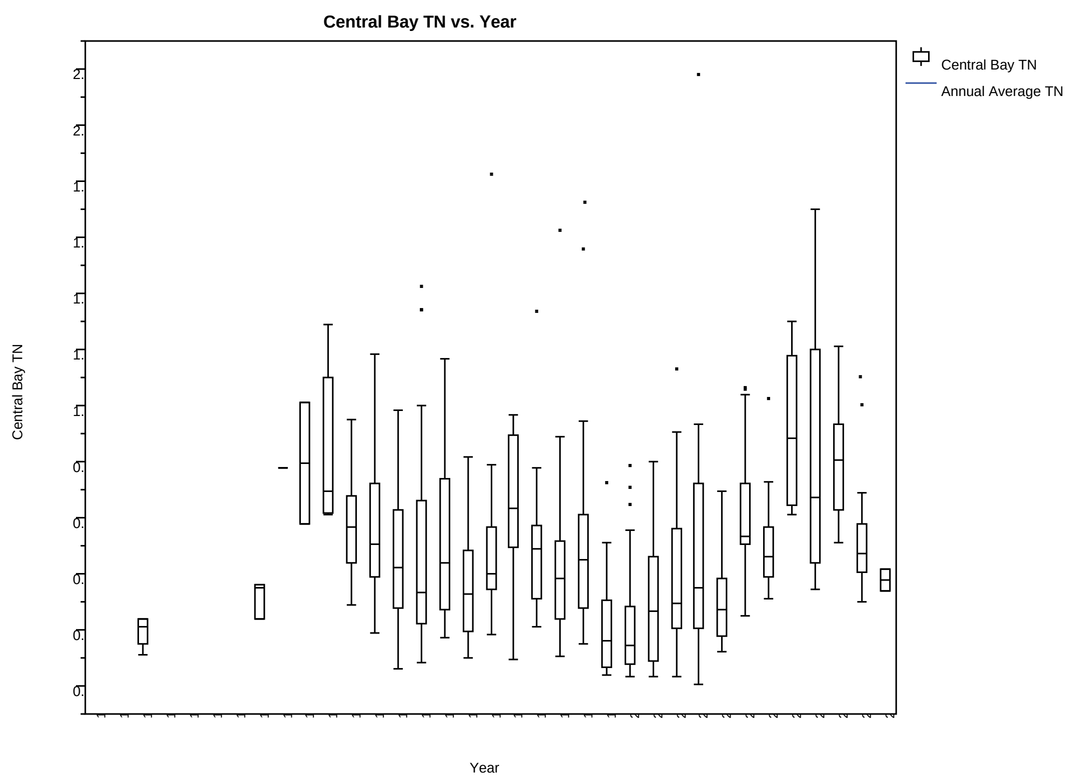


Figure 13. Box plot of TN (mg/l) for Central Perdido Bay.

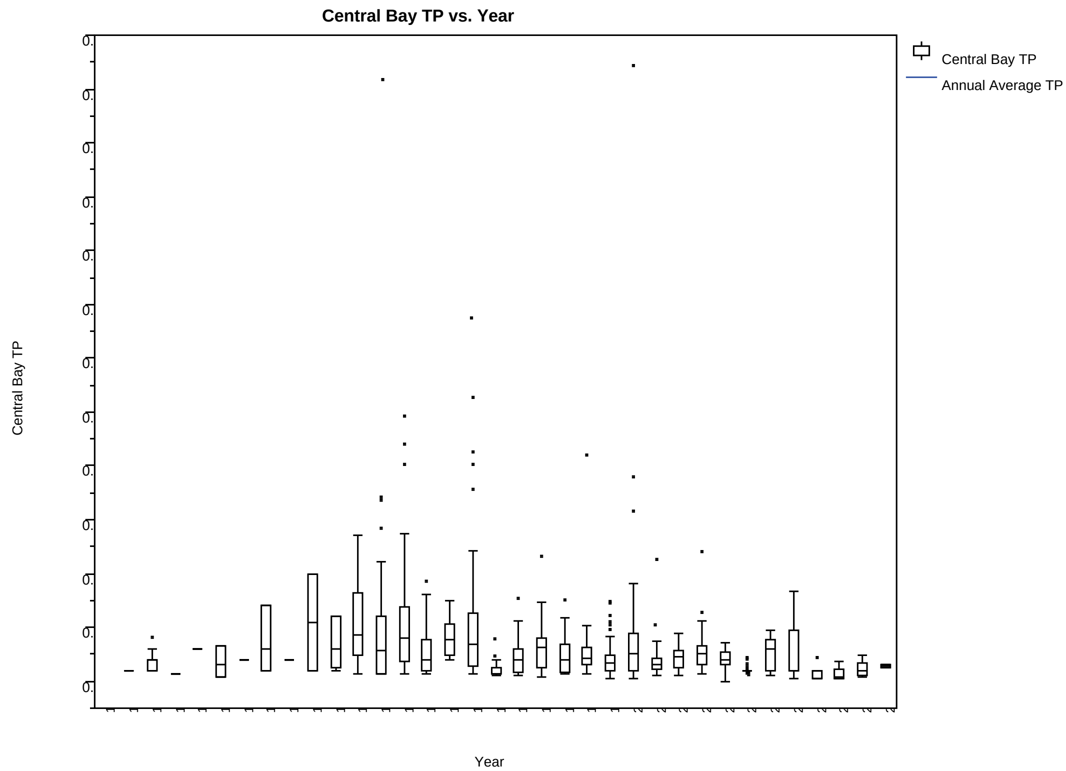


Figure 14. Box plot of TP (mg/l) for Central Perdido Bay.

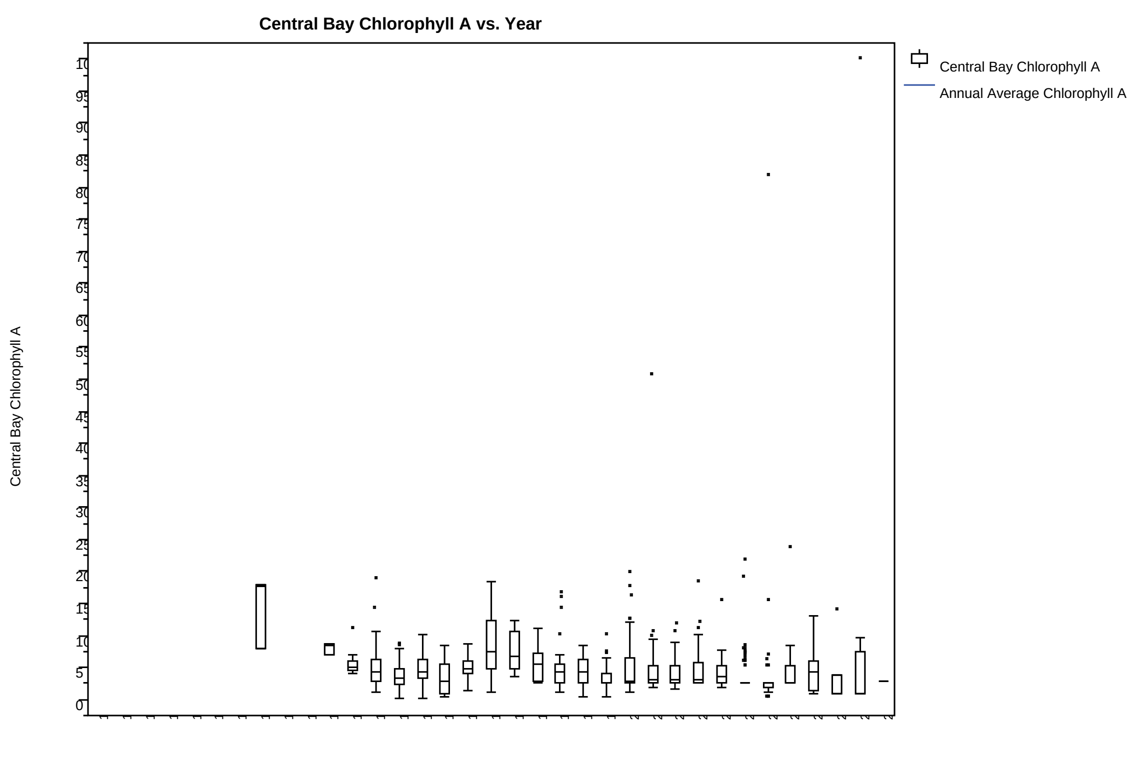


Figure 15. Box plot of chlorophyll a (ug/l) for Central Perdido Bay.

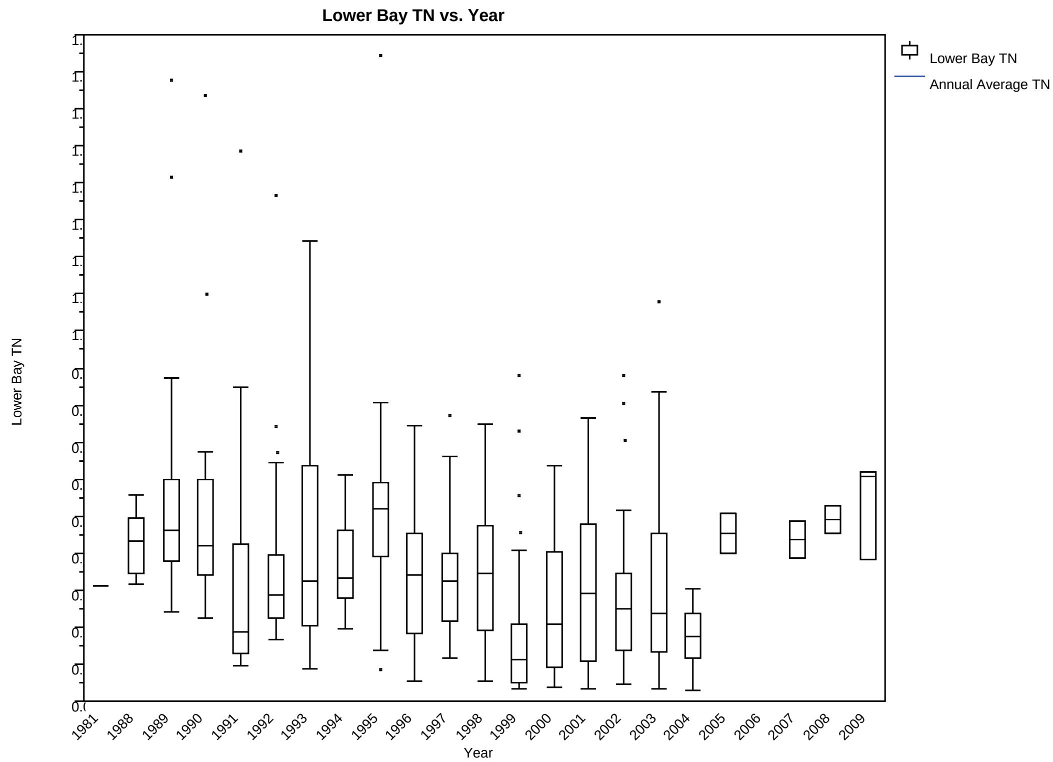


Figure 16. ***Box plot of TN (mg/l) for Lower Perdido Bay.***

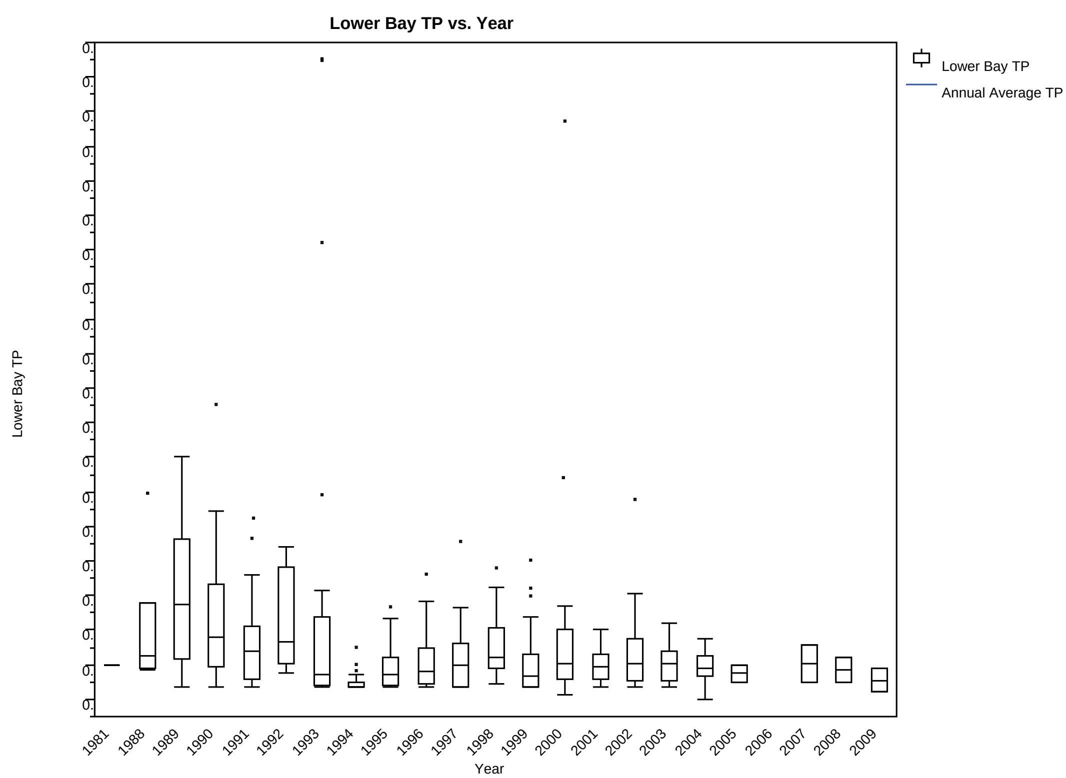


Figure 17. Box plot of TP (mg/l) for Lower Perdido Bay.

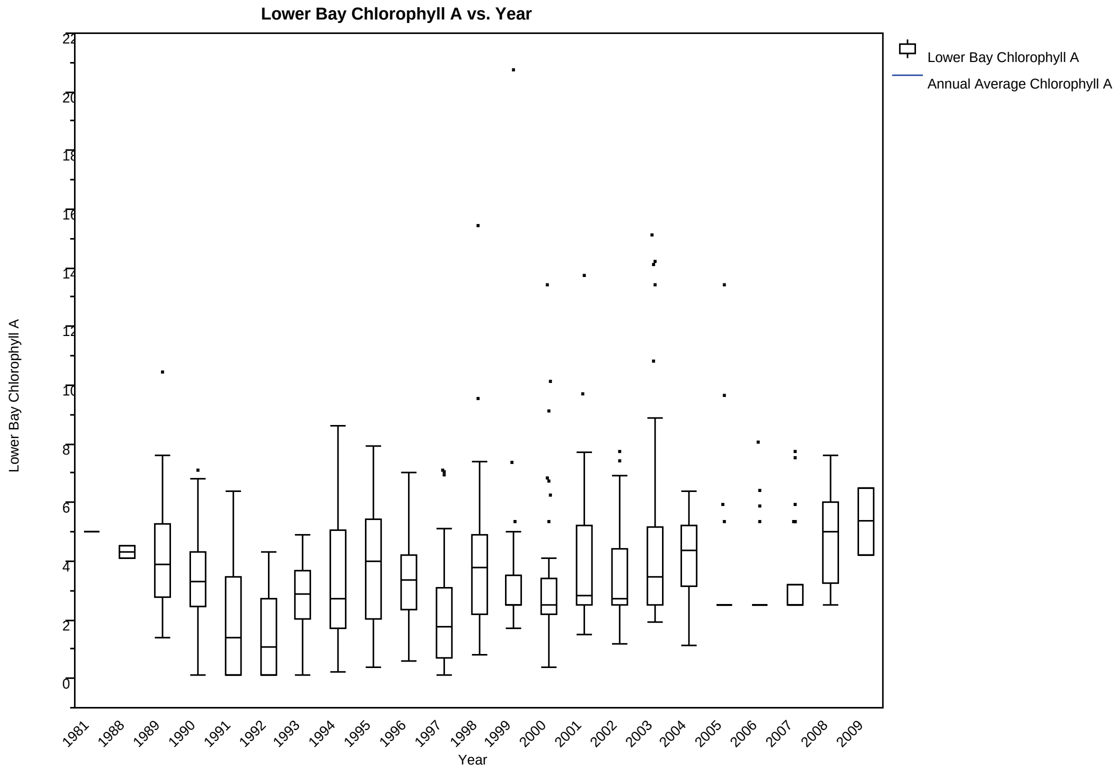


Figure 18. Box plot of chlorophyll a (ug/l) for Lower Perdido Bay.

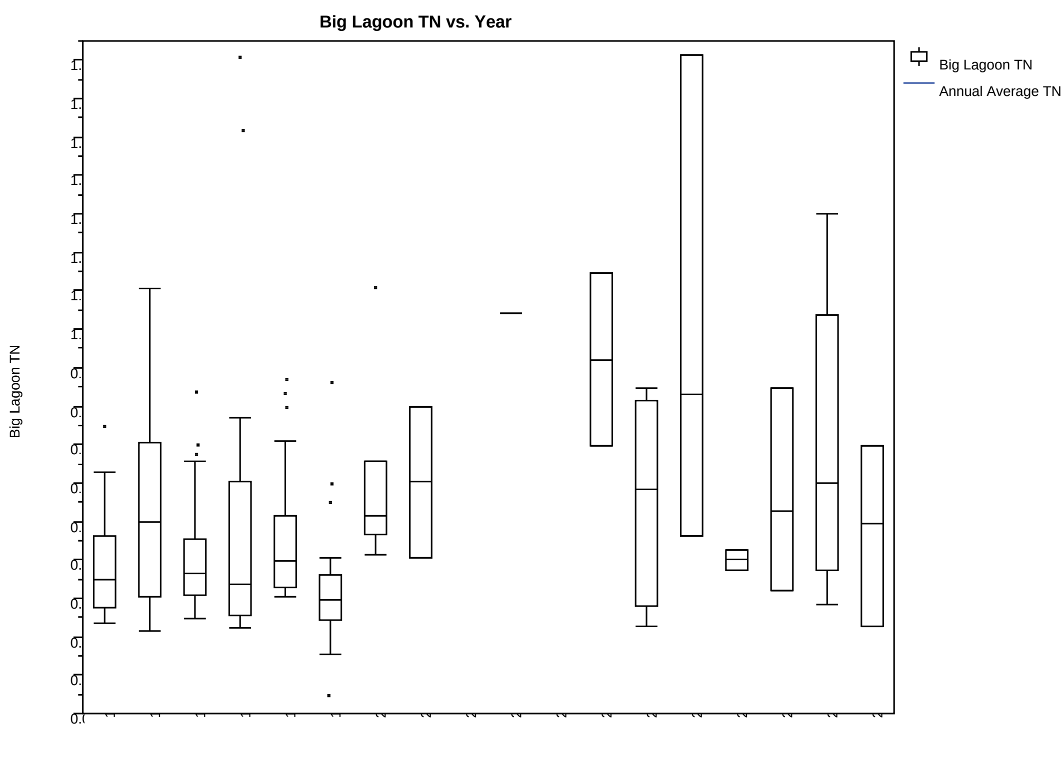


Figure 19. Box plot of TN (mg/l) for Big Lagoon.

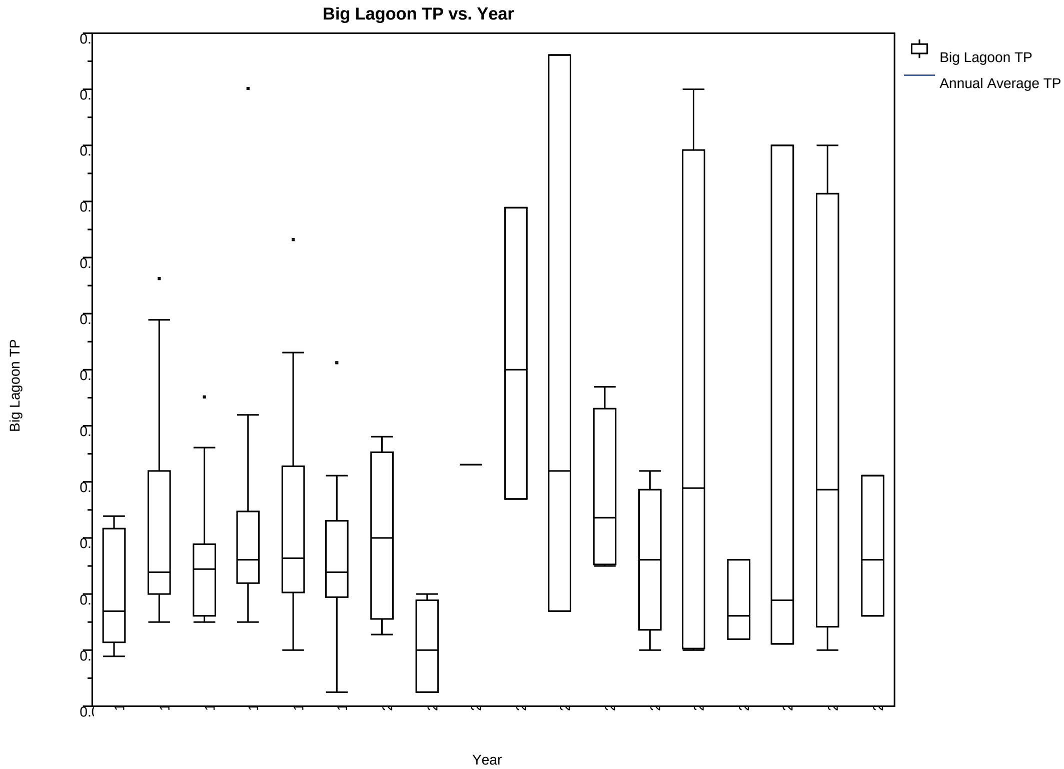


Figure 20. Box plot of TP (mg/l) for Big Lagoon.

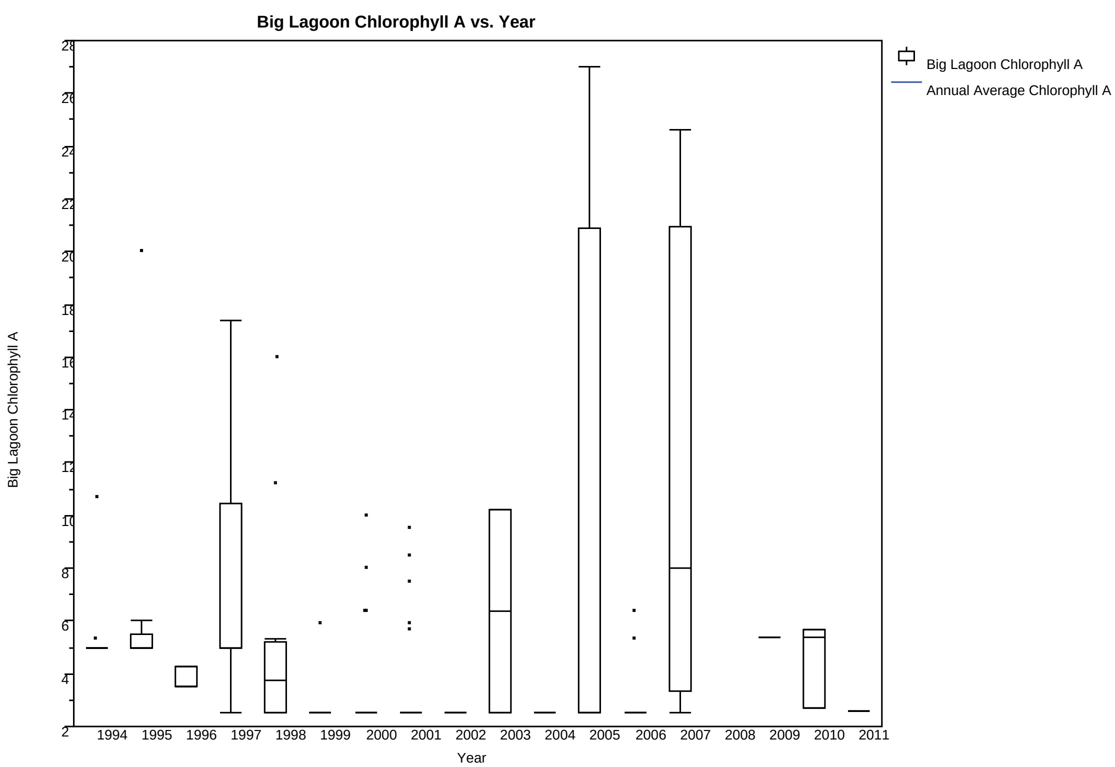


Figure 21. Box plot of chlorophyll a (ug/l) for Big Lagoon.

Low Salinity Areas in River Dominated Estuaries

In an estuary such as Perdido Bay that is dominated by a large, alluvial river, it is important to recognize that the oligohaline zone (the lower salinity portion of the estuary where river water first enters the estuary), has very different ecological characteristics than the higher salinity areas in the lower reaches of the estuary that are more influenced by Gulf of Mexico waters. Because of their distinct ecological characteristics, there should be different expectations for nutrients, turbidity, chlorophyll, and biological productivity in oligohaline areas.

Due to the seasonal variability of river flow in response to rainfall events, low salinity zones of an estuary vary and shift, and can undergo rapid change affecting physical, chemical and biological variables (SFWMD, 2009). As illustrated in **Figure 22**, material carried by freshwater inflow enters the oligohaline zone of the estuary, undergoes geochemical processes associated with a zone of maximum turbidity, and then biological processes associated with a zone of maximum productivity (Church 1986). Suspended sediments derived from terrestrial runoff (and carried by river flow) are trapped in high concentrations near the freshwater/saltwater interface (Jassby, 1995; Eyre, 1998, Lin *et al*., 2003; North *et al*., 2001, 2003, 2005; Fain *et al.,* 2001). Such zones of high turbidity characterize the upper reaches of partially mixed estuaries around the world (Schubel *et al*., 1986).

Adjacent to the zone of maximum turbidity, nutrients and other compounds bound to sediments are released, resulting in high aquatic productivity (SFWMD, 2009). Because the high turbidity suppresses primary production (due to light extinction), a zone of maximum productivity typically develops further downstream in clearer waters (Fisher *et al.,* 1988). The zone of maximum productivity may be composed of several sub-areas, including a zone of maximum primary production (chlorophyll *a*), followed by zones of high abundance of zooplankton, copepods, and fish larvae **(Figure 22)**. These high secondary production zones develop as the algae produced are used as a food source by epibenthic feeders such as polychaetes, mysids, and amphipods (Diaz *et al.,* 1990). In turn, these epibenthic feeders serve as food sources for larval and juvenile fishes. Freshwater inputs containing nutrients help maintain this beneficial production (Fisher *et al.,* 1988; Day *et al*., 1989; Montagna et al., 1992), with higher freshwater flows leading to higher yields of desirable species (Loneragan *et al.,* 1999).

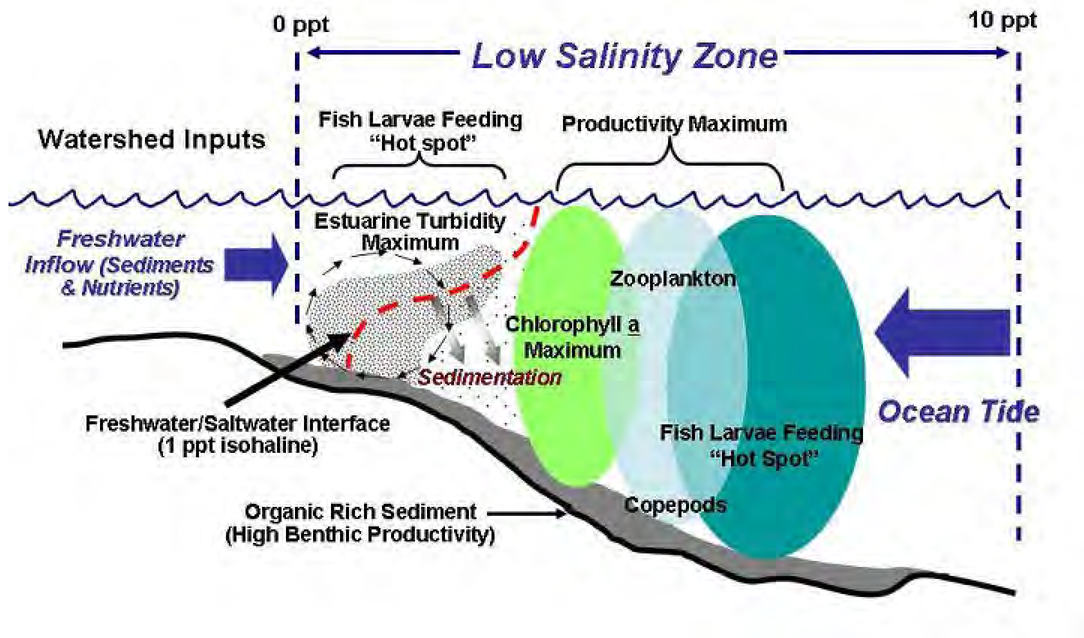


Figure 22. Conceptual representation of a low salinity zone and associated processes, transitioning to an open water estuary (from SFWMD 2009, adapted from Eyre 1998).

One of the most important ecological functions of estuaries consists of their function as nursery areas for the larval and juvenile stages of many species, including commercially important fish and shellfish (Gunter, 1961; Rozas *et al.,* 1983, 1984; Odum *et al.,* 1984; Jassby *et al.,* 1995; Fain *et al*., 2001; North *et al.,* 2001, 2003, 2005; Yozzo *et al.,* 1999). The oligohaline zone is considered critical to the life histories of many of these organisms (Holmes *et al*., 2000; Hughes *et al,*. 2000), and provides habitat for a wide variety of juvenile and adult freshwater, estuarine, and marine fishes (Rozas *et al.,* 1983; Odum *et al*. 1984, 1988; Peterson *et al.,* 1991). Low salinity tidal wetlands provide nursery grounds for many anadromous and catadromous fishes, such as shad, herring (alosids), striped bass (*Morone saxatilis*), and eels (*Anguilla rostrata*) (Massmann, 1954). These tidal low salinity areas are characterized by increased concentrations of organic matter, derived from freshwater inputs and *in situ* production (Odum *et al*., 1984). Low salinity tidal creeks provide exceptional habitat for small or larval fishes (Roman *et al.*, 2001; North *et al.,* 2001, 2003, 2005).

Oligohaline zones are known to provide an abundance of food sources and protection from predators, to a broad array of micro- and macroinvertebrates and fish (Diaz *et al.,* 1990; Yozzo *et al.,* 1999). Protection from marine predators is associated with both the low salinities and the low visibility associated with suspended solids, color, and abundant phytoplankton (Chesney, 1989; Kimmerer, 2002). This protection may help explain why the smallest fish are typically found in low salinity areas (Gunter, 1961).

In establishing marine numeric nutrient criteria, it is important to consider that low salinity areas may be expected to exhibit higher nutrient and chlorophyll a levels than higher salinity open water areas. For example, in a study of eight minimally disturbed tidal creeks in South Carolina, Dame *et al.* (2000) showed that summertime chlorophylls typically exceeded 10 ug/L, and were as high as 40 ug/L **(Figure**

23). In contrast, most Florida open water estuaries are characterized by annual chlorophyll a concentrations of less than 9 ug/L **(Figure 24)**.

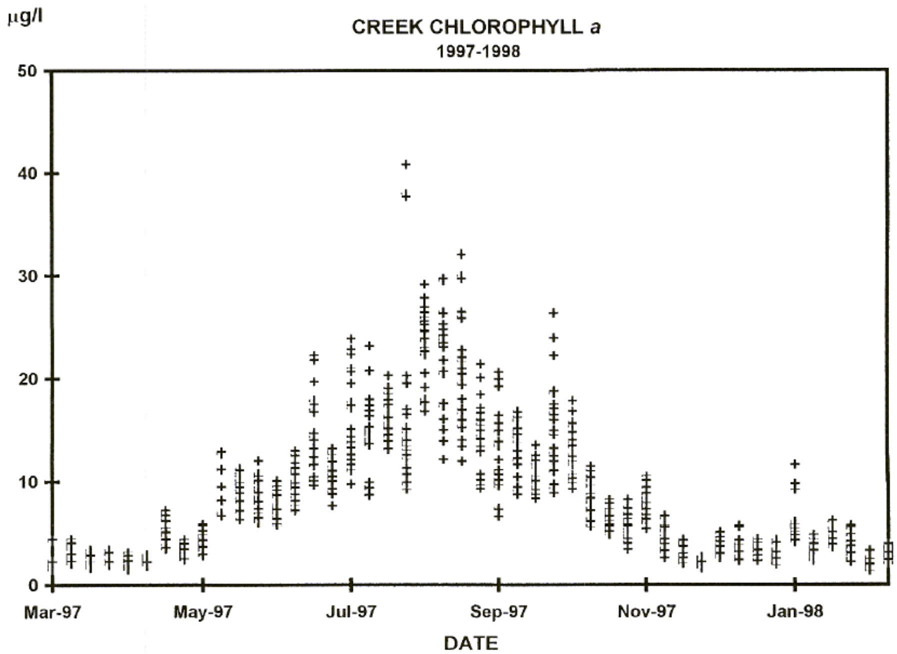


Figure 23. Background chlorophyll a concentrations (ug/L) from unnamed, minimally disturbed tidal creeks associated with North Inlet, South Carolina, from 1997 to 1998 (triplicates shown) (from Dame et al. 2000).

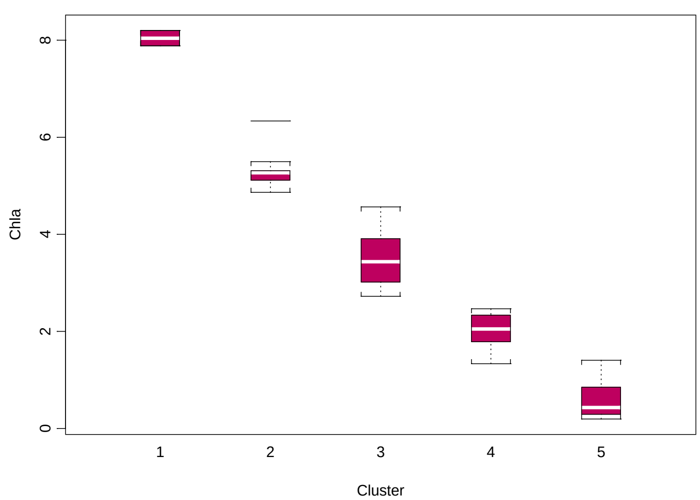


Figure 24. Box plot of long-term geometric mean chlorophyll a for 75 open water, biologically healthy estuarine segments, which were grouped into 5 clusters generated by an agglomerative cluster analysis (from FDEP 2010).

Biological Summary

Perdido Bay and its watershed contain a wide diversity of habitats and aquatic biological resources. **Table 7** lists the natural communities that characterize the watershed.

Table 7. Natural communities in the Perdido watershed, including surface area occupied (FDEP 2008).

Description	Acres	Mi^2	% area
Coastal strand	379.18	0.592	0.15
Sand/beach	1,146.22	1.791	0.45
Xeric oak	147.45	0.230	0.06
Sand pine scrub	281.77	0.440	0.11
Sandhill	93.85	0.147	0.04
Mixed hardwood pine forest	12,801	20.002	5.02
Hardwood hammock forest	5,911.9	9.237	2.32
Pineland	87,154.45	136.179	34.21
Freshwater marsh/wet prairie	1,105.08	1.727	0.43
Shrub swamp	133.88	0.209	0.05
Bay swamp	5,968.39	9.326	2.34
Cypress swamp	709.44	1.108	0.28
Mixed wetland forest	14,213.2	22.208	5.58
Hardwood swamp	14,046.85	21.948	5.51
Salt marsh	267.1	0.417	0.10

Biological Resources

The following description of biological resources is paraphrased from FDEP 2006. The basin's coastal beaches, scrub, and strand communities provide important habitat for many species listed as threatened or endangered. Scrub and strand communities west of Perdido Key State Recreation Area are important to migratory birds that use the coastal areas for feeding and resting during migration between the tropics and North America. From March to August, sandy beaches provide nesting habitat for the royal tern (*Sterna maxima*), state-listed snowy plover (*Charadrius alexandrinus*), black skimmer (*Rynchops niger*), least tern (*Sterna antillarum*), and federally-listed endangered piping plover (*Charadrius melodus*). The Perdido Key beach mouse (*Peromyscus polionotus trissyllepsis*) is a federally endangered species limited in range to sand dunes located on Perdido Key. Four species of marine sea turtles—loggerhead (*Caretta caretta*), leatherback (*Dermochelys coriacea*), Ridley (*Lepidochelys kempii*), and green sea (*Chelonia mydas*)—use coastal beaches for nesting from May to September, though the most common sea turtles are loggerheads and green sea turtles. Godfrey's golden aster (*Chrysopsis godfreyi*) can be found on patches of scrub and coastal strand. Based on information from the US Fish and Wildlife Service, no threatened or endangered mussels have been found to occur in the basin.

Perdido Bay has three species of seagrasses: turtle grass (*Thalassia testudinum*), shoal grass (*Halodule wrightii*), and widgeon grass (*Ruppia maritima*). Eel grass (*Vallisneria americana*) is also present in the freshwater and brackish portions of the bay. Seagrasses provide habitat for many commercially and recreationally important species, including shrimp (*Penaeus* sp.), crabs (*Callinectes* sp.), scallops (*Argopecten* sp.), speckled trout (*Cynoscion* sp.), redfish (*Sciaenops* sp.), and mullet (*Mugil* sp.).

A comparison of the SAV acreage between 1941 and 1992 revealed that the total bay acreage had decreased by 74% to 307 acres (Kirschenfeld *et al.* 2006). Based on an analysis of 1992 data, seagrasses were not detected in middle Perdido Bay, and the lower Perdido Bay contained approximately 303 acres of SAV (Kirschenfeld *et al*. 2006). Data from the Fish and Wildlife Conservation Commission (FWCC 2011) were consistent with the above findings although the estimates of SAV acreage are different from Kirschenfeld *et al.* (2006). FWCC (2011) found that seagrass in lower Perdido Bay (primarily shoal grass) declined by 80% between 1987-2002, decreasing from 642 acres to 125 acres. However, from 1992-2003, FWCC found that seagrass in Big Lagoon was stable, increasing from 537 acres to 543 acres. Most of the SAV acreage in Perdido Bay is located around or near Ono Island and in Big Lagoon **(Figures 25 and 26)**.

Note that the presence of seagrass is highly influenced by salinity regime, and that the salinity regime in mid and upper Perdido Bay is dynamic (due to river inflows) and has been altered by the saline influence of the dredged passes. The former, primarily freshwater (oligohaline) regime would not have been expected to support marine seagrasses, and instead, would have supported freshwater species such as *Vallisneria*. The fluctuating salinity in the mid and upper bay would tend to prevent colonization of either freshwater or marine SAV species.

Except for Big Lagoon, FDEP has concluded that these complications limit the utility of using seagrass as a nutrient response variable for the bay, although the low chlorophylls observed during the 1988-1991 period would allow sufficient light transmission for SAV growth throughout the system. In Big Lagoon, HABs were not observed and seagrass has been stable (Heck 1996; FWCC 2011), making a “maintain existing conditions” approach to nutrient criteria development the preferred method for Big Lagoon. The current distribution of seagrass in Big Lagoon is similar to that of historical levels, which indicates that water quality has not declined below the threshold required for seagrass growth and reproduction (**Figure 26**). Heck (1996) found a constant percentage of SAV coverage over time in Big Lagoon, but noted that non-nutrient related issues (occasional mineral turbidity and fluctuating salinities) were potential stressors. The average depth for seagrass growth in Big Lagoon is 1.4 m, with the most shallow beds at the far west end (around Big Lagoon State Park) and slowly increasing in depth eastward toward the pass (**Figure 26**).

The Perdido River and Bay Basin provides habitat for several rare and threatened fish species. Three rare fish species were historically noted from the Perdido River: one listed species of special concern, the saltmarsh topminnow (*Fundulus jenkinsi*), as well as the crystal darter (*Crystallaria asprella*) and goldstripe darter (*Etheostoma parvipinne*). The Florida Fish and Wildlife Conservation Commission (FWCC) confirmed the presence of the saltmarsh topminnow during field sampling in 2001 and 2002 in tributaries of the Perdido Bay watershed. Striped bass also use the Perdido River throughout its length. The Gulf race of the Atlantic sturgeon (*Acipenser oxyrinchus desotoi*) uses the Perdido River, as documented by the Alabama Geological Survey in 2004.

Based on the 19 years worth of data from Livingston (2010), it has been determined that the most direct link between anthropogenic nutrients and adverse biological response involves HABs and their subsequent adverse effects on food webs (described below).

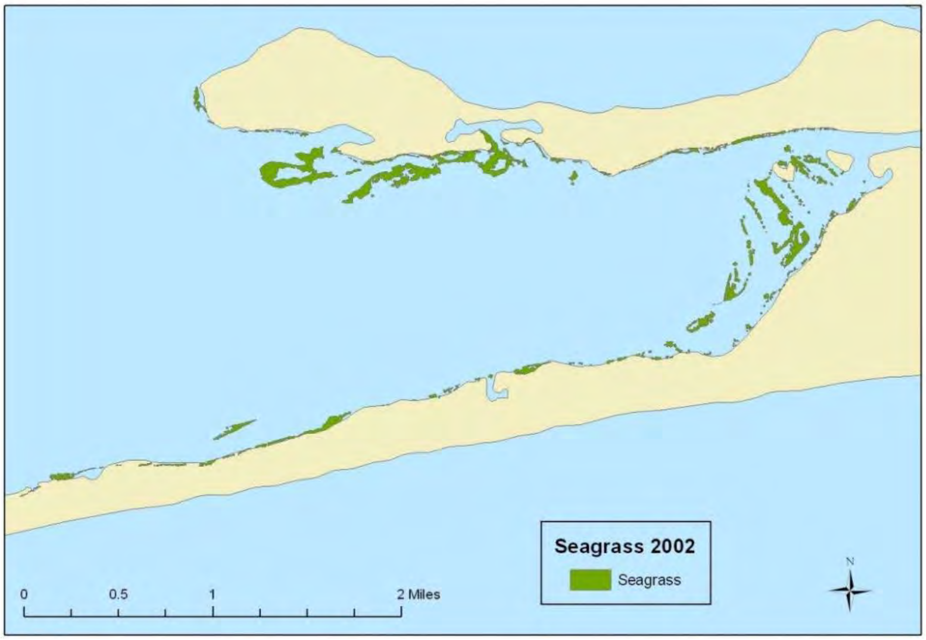


Figure 25. Seagrass cover in Perdido Bay, 2002.

Figure 26. Seagrass cover in Big Lagoon, 2003.

Biological Assessment Development in Florida Panhandle Estuaries to Support NNC

In 2012, DEP collected additional biological and water quality data from Panhandle estuaries to support the development of numeric nutrient criteria and to explore and refine the development of biological assessment methods in estuarine environments for eventual statewide use.

Apalachicola, Choctawhatchee, St. Andrew, St. Joseph, Pensacola, and Perdido Bays were each sampled twice between May, 2012 and July, 2012. Sampling stations were located in areas with minimal human impacts to establish baseline expectations. Site selection was based on a combination of aerial photographs, local knowledge, and a site reconnaissance. The biological communities targeted were epibenthic invertebrates and juvenile fish. These groups were selected for study because, in addition to providing important information on an estuary's key ecological functioning, the effort level needed to sample and identify these organisms is practical from a human resource perspective.

DEP used multiple gear types (fyke nets, beach seines, and beam trawls) in each estuary to determine which gear, or combination of gears, would yield the best information for the level of sampling effort. All nets were deployed in relatively shallow waters (< 1.5 m deep) with gradually sloping bottoms. Fyke nets are passive sampling devices, especially useful in areas where the substrate (e.g., mangrove roots, oyster beds) may interfere with an active sampling method or where sediments are too soft to allow active wading. Each fyke net was deployed perpendicular to shore for roughly 24 hours. Four nets per site were deployed, with each approximately 25 meters from the next net.

Seines are active sampling devices that are commonly used in nearshore, shallow-water habitats. In this study, a 14.5 meter beach seine was deployed parallel to shore at a depth no more than 1.5 meters. Each end of the seine was pulled toward the shore while maintaining contact with the bottom, until the two sides met at the shoreline. Care was taken to avoid loss of organisms when consolidating the catch in a single bucket. The seine was deployed four times per area, approximately 25 meters apart.
Beam trawls are an effective gear type for sampling small epibenthic invertebrates and provide useful information on the foundation of the food web in near shore estuarine environments. A 2 meter beam trawl was deployed parallel to shore at a depth no greater than 1.5 meters. Four trawls were deployed per area, approximately 25 meters apart.

Results of the most commonly captured taxa for all gear types combined are shown in **Table 8** followed by environmental information for each species. Taxa lists by gear type can be found in Appendix A.

Table 8. Perdido Bay Biological Sampling Results (Top 10 Species)

Species	Number	%
Anchoa mitchilli	6,776	55.70
Americamysis bahia	3,547	29.16
Menidia beryllina	613	5.04
Ariopsis felis	285	2.34
Lagodon rhomboides	115	0.95
Anchoa hepsetus	99	0.81
Palaemonetes spp.	81	0.67
Membras martinica	72	0.59
Leiostomus xanthurus	65	0.53
Mugil	54	0.44
Subtotal	**11,707**	**96.24**
Total	**12,165**	**100**

Anchoa mitchilli: Bay anchovies occur from the Gulf of Maine and Cape Cod, MA, south to Yucatan, Mexico, and throughout the Gulf of Mexico (Hoese *et al.* 1977; Fives *et al*. 1986; Robbins *et al*. 1986). *Anchoa mitchilli* primarily occurs in the water column, a habitat preference that is consistent with the zooplanktivorous dietary habits of the species. Individuals are encountered over seagrass beds and unvegetated benthic areas (Orth *et al*. 1980). Bay anchovies occur in protected waters and tide pools as well as in beach surf zones (Crabtree *et al.* 1982; DeLancey 1989). Bay anchovies are a major component in the diets of several species of piscivorous fish, including commercially important species such as weakfish (*Cynoscion regalis*) and striped bass (*Morone saxatilis*) (Baird *et al.* 1989). Bay anchovies are economically important as a species used for fish oil and fishmeal. They also represent a critical component of marine and estuarine food webs, both as a predator and a prey species.

Americamysis: *Americamysis* is a new genus of mysid shrimp that is native to the Atlantic and Gulf of Mexico regions of North America. The distribution of the species within *Americamysis* extends along the Atlantic coasts of the Americas from the northeastern United States to Colombia. The known species of this genus are endemic to estuarine and shallow shelf waters, and are considered to be permanent, endemic hyperbenthic fauna of estuarine and other coastal ecosystems. These shrimp are commonly found on sandy or muddy sediments in bays, but may also be associated with *Thalassia* seagrass beds or high salinity estuaries depending on species. *Americamysis* is considered to be omnivorous and has been shown to feed on benthic algae and detritus as well as copepods. These mysid shrimp, which contribute up to 40% of the standing stock of omnivores in some systems, are vital food sources for many commercially and recreationally important fish such as anchovies, catfish, seatrout and drum (Johnson *et al.* 2005). They often occur in high numbers and are ecologically important, particularly for role in food chains as a link between the benthic and pelagic systems. These shrimp are known to be sensitive to environmental stressors, and are particularly sensitive to chemical contaminants as illustrated by their relatively low 96-h LC_{50} values. Due to this sensitivity, EPA promotes the use of *Americamysis (Mysidopsis) bahia* for laboratory testing for acute and chronic toxicity assays.

Menidia beryllina: The Inland Silverside is widespread along the Atlantic coast from Maine to Florida, and along the Gulf of Mexico, and is often found well upstream (Hubbs *et al.* 1991). In the Mississippi River they can be found in backwaters and reservoirs as far north as Missouri (hundreds of miles inland). The habitat of the silverside is often shallow, hard bottoms, with frequent migrations to open water in search of food. This species feeds primarily on zooplankton, and is in turn fed on by larger fish and birds. Due to its sensitivity to environmental stressors, the Inland Silverside is approved by the EPA as a standard test organism for acute and chronic toxicity testing.

Ariopsis felis: The range of *Ariopsis felis*, the hardhead catfish, extends from North Carolina to Florida and throughout the Gulf of Mexico to the Yucatán peninsula. The hardhead catfish is a generalist, tolerating a wide range of salinities from open ocean to fresh water; however, its occurrence in fresh waters is less common. It may be found over muddy bottoms or in murky waters (Acero 2002). Hardhead catfish are opportunistic feeders that utilize mud and sand flats as feeding grounds. Algae, seagrasses, cnidarians, sea cucumbers, gastropods, polychaetes, shrimps, crabs, and smaller fishes comprise the bulk of the diet (Merriman 1940). Several authors have noted that blue crabs are a principal food source in the sea catfish diet (Gallaway *et al.* 1974). Reported predators of hardhead catfishes are the longnose gar, bull shark, and large finfishes. Hardhead catfishes are also commonly caught as bait for large gamefishes such as the cobia. Though edible, the hardhead catfish is not generally consumed as a food fish, with many commercial and sport fishers regarding it as a nuisance species due to its dorsal and pectoral spines, which are large, serrated, and capable of causing painful wounds. However, catfishes do have limited commercial importance and are harvested for industrial purposes in commercial bottom trawling operations and are taken recreationally for both bait and as food (Muncy *et al*. 1983).

Lagodon rhomboides: The pinfish inhabits coastal waters of the Gulf and Atlantic states, stretching from Massachusetts to the Yucatan peninsula. Adult pinfish prefer protected waters between 30 and 50 feet deep, while juveniles are common over seagrass beds or other structure such as rocky bottoms, jetties, pilings, and in mangrove areas where there is cover from predators. They prefer water that has a higher salinity. Pinfish can be found near structure that supports barnacles and mollusks. While this species spawns in deeper water, it is still considered to be estuarine-dependant and is commonly found around vegetated bottoms or reefs and mangroves. The primary diet of pinfish consists of shrimp, mysids and amphipods; nevertheless, they have been found to exhibit strict herbivory or carnivory depending on conditions or development stage (Muncy 1984). This species is tolerant of temperatures ranging from 10-35 C and salinities ranging from 1-75 ppt, indicating that they can adapt to these environmental variables. Pinfish are known to exhibit schooling behavior, and can consume the epifauna associated with seagrass communities to the point of altering the structure (Stoner 1982). *Lagodon rhomboides is* commonly consumed by larger fish, including game species such as spotted sea trout and flounder. While pinfish may be of little commercial value, they are commonly used as bait fish in recreational fisheries. In bioassays, pinfish were highly sensitive to the pesticide Antimycin A at 7 ppb (Finucane 1969), as well as PCB's (Hansen *et al.* 1971) and mirex (Tagatz 1976). Petrochemical wastes have been shown to depress respiratory rates of the pinfish and cause mortality (Wohlschlag *et al.* 1967).

Anchoa hepsetus: This species is abundant in the Atlantic from Massachusetts south to Fort Pierce, Florida (but not Florida Keys) and is also found in the northern Gulf of Mexico. This anchovy forms dense schools, often in shallow waters close to shore. It can adapt to a wide range of salinities, from hypersaline to almost fresh waters. *A. hepsetus* feeds on copepods when young, then on gastropods, foraminifers, ostracods and annelids. Breeding was recorded in April through to July at Beaufort, North Carolina in harbors, estuaries and sounds. This species is fished commercially for both bait and food (Binohlan 2012).

Paleomenetes spp.: The genus *Paleomenetes,* also known as ghost shrimp, consists of a number of small transparent shrimp that inhabit both coastal and inland waters throughout the Americas and Europe. Ghost shrimp are among the most widely distributed shallow water benthic macroinvertebrates in Gulf of Mexico and Atlantic estuaries (Anderson 1985). *Palaemonetes* matures at 1.5 to 2 months of age and 15-18 mm length (Anderson 1985). Although their value as bait or food for humans is minimal, they serve an unquestionable importance to the estuarine trophic system. Their diet as detrivores is varied, and includes organic matter and benthic microinvertebrates. These shrimp are in turn consumed by fish and other macroinvertebrates.

Membras martinica: The rough silveriside is primarily found in coastal waters from New York southward to Mexico, including the Gulf of Mexico (Hubbs *et al.* 1991). It occurs in the water column over a number of different habitat types. It typically occurs off exposed shoreline and beaches, over a firm substrate and is also known to inhabit coastal rivers. *Membras martinica* is considered to be zooplanktivorous, feeding mainly on planktonic crustaceans. On the Gulf coast, this species spawns between March and September in temperature range of 21.2-30.7 degrees C and salinity range of 9.4-31.1 ppt; spawning occurs in salinity range of 5-25 ppt (Martin *et al.,* 1978).

Leisostomus xanthurus: *Leisostomus xanthurus*, or Spot, is commonly found from Chesapeake Bay to the Florida Keys, and in the Gulf of Mexico to Campeche, inhabiting estuarine and coastal waters (Phillips *et al.* 1989). This species is seasonally dependant on estuaries, migrating between shallow water of estuaries and deeper water throughout their development. Spot can adapt to low dissolved oxygen and high CO_2 conditions, allowing it to inhabit the shallow tidal creeks that serve as this species' nursery (Cochran 1994). Because Spot are so abundant, they serve as key species in the transfer of biologic energy from nearshore areas to offshore. Therefore, they are considered as an important species indicating healthy estuarine systems. The diet for this species consists mainly of benthic invertebrates and zooplankton. Many larger game fish such as striped bass, seatrout and flounder are often predators of *Leisostomus xanthurus*. Historically, commercial fishing of this species has been economically important on the Atlantic coast of Florida. Following Florida's ban on gill nets in 1995, the Spot commercial fishery all but vanished (McRae *et al.* 1997). Spot migrate seasonally, staying in bays and estuaries in the spring, until late summer when they move offshore to spawn. Spot mature around the age of two or three, and grow seven to eight inches in length. They can live up to six years, although fish older than four are rare. Spawning takes place offshore from fall to early spring. The larvae have been known to hatch as far as 63 nautical miles offshore but they migrate towards the coast and inhabit estuaries and inlets while they develop into juveniles. As they mature, Spot migrate toward higher salinity areas.

Mugil cephalus: Striped mullet occurs worldwide from approximately 42° N to 42° S latitude (Bok 1979; Render *et al.* 1995), where it inhabits estuarine intertidal, freshwater and coastal marine habitats. In the western Atlantic Ocean, *M. cephalus* ranges from Cape Cod to Brazil, including the Gulf of Mexico, Caribbean, and West Indies (Amos *et al.* 1997). Juveniles occupy the high intertidal zone of estuaries where water temperatures and salinity fluctuate greatly. Older mullet inhabit deeper waters with more stable environmental conditions. Given their specialized gizzard-like stomach, they can feed on a wide variety of food substrates and are considered to be heterotrophs. Detritus and epiphytic material are the main food sources for this species (Service *et al.,* 1992). Mullet serve as a food source for valuable game fish such as mahi, snook, and snapper. The striped mullet is a high value fishery species within Florida. The statewide commercial catch of *Mugil cephalus* between the years 1987-2001 was 232.9 million pounds, with a dollar value of over $115.2 million. Mullet is commonly sold in markets as a fresh or smoked product, and is quite popular on the Gulf Coast from Florida to Louisiana.

2012 Biological Sampling Conclusions

A variety of trophic levels were represented in the Perdido Bay biological samples, including taxa that consume phytoplankton, zooplankton, organic detritus, and higher trophic levels such as fish and invertebrates, indicating an intact food web. Some taxa, such as *Mugil*, *Paleomenetes*, and *Americamysis*, occupied lower levels of the trophic structure, largely feeding on detritus or phytoplankton. Primary consumers such as *Menidia, Anchoa*, and *Membras* are zooplanktivorous, feeding mainly on planktonic crustaceans, which in turn require sufficient phytoplankton resources. Note that both *Menidia* and *Americamysis* have been demonstrated to be sensitive to environmental stressors, and have been selected by EPA as standard laboratory test organisms for use in acute and chronic toxicity assays. Other predator taxa included *Leisostomus, Ariopsis,* and *Lagodon*. Note that all these organisms also serve as prey for other taxa and represent critical energy pathways in the estuarine food web. The interconnectedness and complexity of the epibenthic invertebrate and fish community in Perdido Bay suggests the system is currently a healthy, well-balanced ecosystem.

Water Quality Studies

The primary response to anthropogenic nutrient enrichment observed in Perdido Bay was the proliferation of HABs during a period of elevated point source nutrient loading that resulted in secondary effects on the bay's trophic functioning **(Figure 27)** (Livingston, 2010). From 1988 to 1996, the plankton communities indicated healthy, well-balanced conditions in Perdido Bay, with a low occurrence of plankton blooms (occurrences of more than 1 million cells per liter [> 10^6 cells L^{-1}]). The numerically dominant species included the diatom *Cyclotella choctawhatcheeana,* with the highest numbers of phytoplankton noted in mid-bay areas. *Miraltia throndsenii*, *Prorocentrum cordatum*, *Gymnodinium splendens*, and *Skeletonema costatum* were present in the bay but were noted in relatively low numbers. Cryptophytes and nannoplankton were most numerous in mid-bay areas.

During 1997 and 1998, subsequent to two years of increased nutrient loading to the bay through Elevenmile Creek, there were major changes in the phytoplankton assemblages in the bay. Phytoplankton abundance was highest in the upper bay, where the raphidophyte *H. akashiwo* became dominant (and was also present in all parts of the bay. *H. akashiwo* is well known for ichthyo-toxic blooms (Honjo 1994). Concurrently, the formerly dominant diatom *C. choctawhatcheeana* was greatly reduced in the upper bay, although this taxon was still dominant in mid- and lower bay areas. Nannococcoids, pennate diatoms, and prymnesiophytes were no longer prevalent in the bay, and cryptophytes had increased in all three parts of the system. The blue-green alga *M. tenuissima* was first noted in Elevenmile Creek, although in relatively low numbers.noted in Elevenmile Creek, although in relatively low numbers.

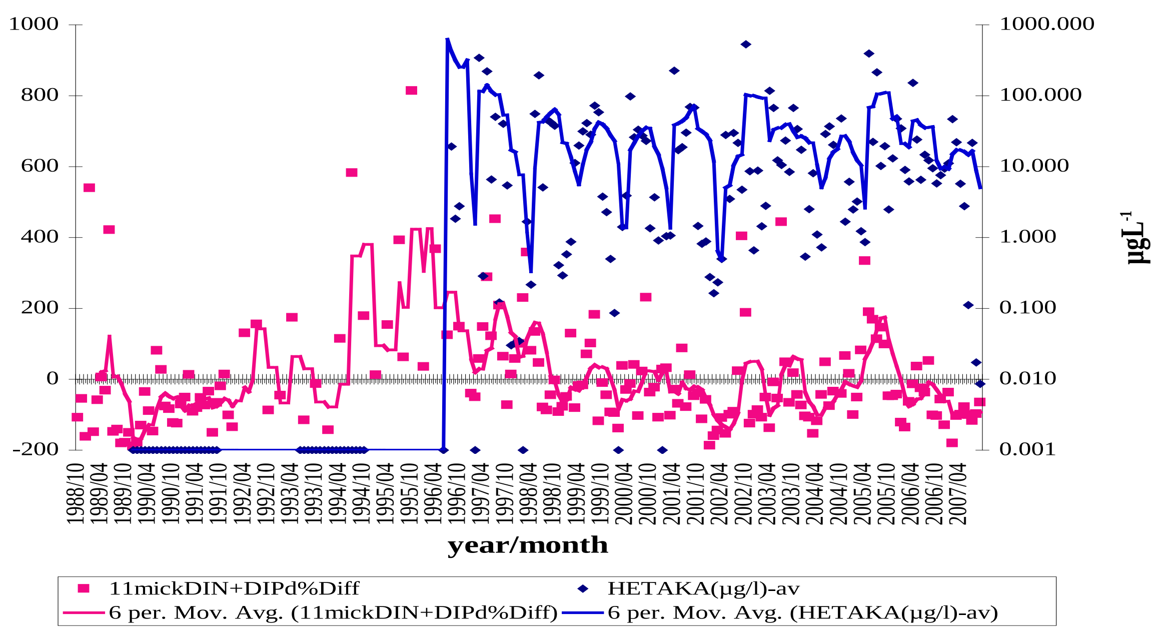


Figure 27. The percent differences in the sum of inorganic nitrogen (IN) and inorganic phosphorus (IP) loading from Elevenmile Creek to upper Perdido Bay (red line), compared with the mean H. akashiwo biomass averaged over all Perdido Bay stations (blue line), 1988–2007. Data are presented as six-month moving averages (from Livingston 2010).

Because of reduced nutrient discharges from the point source (pulp mill) to Elevenmile Creek starting in 1998, from 2001 to 2002 the phytoplankton community began to shift (Livingston 2010). *M. tenuissima* became the top dominant in the upper bay, and phytoplankton abundance there largely consisted of cryptophytes and nannoflagellates. In the mid- and lower bay areas, *C. choctawhatcheeana* was dominant, and although *H. akashiwo* was still present in all parts of the bay, its abundance was reduced.

In 2002 and 2003, nutrient inputs from a discharge to Bayou Marcus (upper bay) were correlated with the occurrence of *H. akashiwo* in high numbers in this part of the upper bay. At the same time, *M. tenuissima* became a dominant taxon in the Elevenmile Creek drainage and was also found in mid-bay areas. This coincided with reduced numbers of *H. akashiwo* in the Elevenmile drainage, a direct result of the reduced nutrient loading in this area. However, *H. akashiwo* was dominant in mid-bay areas, and appeared to respond to nutrient loading trends in the eastern part of the upper bay. Cryptophyte abundance in mid- and lower bay areas had increased, and the overall numbers of phytoplankton in the bay increased significantly due to the above-noted changes in species representation baywide (Livingston, 2010).

Both ammonia and orthophosphate loading from Elevenmile Creek were significantly ($P<0.05$) associated with *H. akashiwo* cell numbers (Livingston, 2010). The number of *Heterosigma* blooms in the upper bay was inversely related to the number of *C. choctawhatcheeana* blooms. In the upper bay, these species were inversely associated ($R^2 = -0.36$, $P< 0.05$). The annual average *Cyclotella* density peaked with the downward trend of *Heterosigma* during the period of high but diminishing nutrient loading from Elevenmile Creek (1994–1999). The blue green alga, *M. tenuissima*, was directly associated with bottom salinity ($R^2 = 0.38$, $P< 0.05$) and salinity stratification ($R^2 = 0.45$, $P<0.05$). There were general increases in salinity stratification during the drought periods from 1999 to 2002 and 2006 to 2007. The cryptophytes and nannoflagellates in the bay near Elevenmile Creek peaked during the drought of 1999 and 2002, with nannococcoids reaching peak values at the end of the drought. The combination of the history of nutrient loading and drought appeared to affect the long-term distribution of these phytoplankton groups.

There were seasonal trends in both the nutrient loading characteristics and the presence of dominant plankton species in the bay. Elevenmile Creek ammonia loading peaked during April, and orthophosphate loading peaked from May through September **(Figure 28)**. When standardized as percent loadings of these nutrients as a function of the overall mean, there were peaks from April through August. Peak numbers of *H. akashiwo* occurred from April through July, and *C. choctawhatcheeana* peaked during April and May. Bloom species occurrence was timed to both seasonal and interannnal cycles of nutrient loading in Elevenmile Creek (Livingston 2010).

During the July, 2012 DEP public workshop, an alternate hypothesis, involving the pulp mill's use of chlorine dioxide, was offered by a local resident to potentially explain the HABs that occurred in the bay during the time period described above. Historically, the pulp and paper industry utilized elemental chlorine in the pulp bleaching and lignification processes to break-down lignin and to whiten and improve the characteristics of the resulting paper. The use of elemental chlorine had the potential to result in significant levels of environmentally harmful chlorinated organic compounds, including dioxin, furan and other trihalomethanes (THMs) and haloacetic acids (HAAs). These chlorinated byproducts form when chlorine reacts with natural organic matter. In the early 1990's, the industry started to shift away from the use of elemental chlorine in the bleaching process due to greater regulation of these hazardous organochlorine compounds in wastewater (NCASI 2009).

Chlorine dioxide (ClO_2) is a widely used alternative to elemental chlorine because it is an oxidizing agent rather than a chlorinating agent, and therefore, will not form chlorinated byproducts such as HAAs and THMs under typical conditions. Chlorine dioxide, which has a "molecular free radical", also has an odd number of electrons and is highly reactive by oxidation, unlike chlorine which reacts by adding or substituting a chlorine atom. Because chlorine dioxide oxidizes rather than chlorinates organic matter, chlorinated organic byproducts are not produced.

Chlorine dioxide is a broad spectrum bactericide, fungicide, virucide and algaecide that is effective at low concentrations and short contact times (USEPA 1999). Chlorine dioxide attacks micro-organisms by oxidizing the cellular membrane components causing cell destruction. In the environment, chlorine dioxide rapidly photolyzes when exposed to UV light and because of its high reactivity, it will breakdown rapidly in natural waters containing moderate amounts of organic matter. The breakdown products are chloride ion and oxidized products of organic matter.

Due to its mode of action and short life in the environment, DEP found no literature to support the hypothesis that the use of chlorine dioxide by the pulp mill had a significant effect on the algae in the bay, or that the proliferation of HABs could in any way be linked to the use of chlorine dioxide. Additionally, due to its broad spectrum biocidal action, there is no evidence that chlorine dioxide preferentially reacts with desirable algal species while simultaneously stimulating harmful algal blooms. As described above, the evidence indicates that the HABs were correlated to nutrient loading, and that restoring the nutrient regime to that observed during the 1988-1991 time period would protect healthy, well balanced biology communities.

The series of HABs from 2002 to 2005 described above resulted in a significant adverse effect on the trophic functioning of Perdido Bay's fauna (Livingston 2010). The biomass of consumer trophic levels (including commercially valuable shrimp, crab, and fish species) in Perdido Bay decreased markedly after the occurrence of *H. akashiwo* blooms **(Figure 29)**. This is evidence that the level of nutrient loading responsible for the HABs interfered with the designated use of the bay, and that reducing nutrients to the level that occurred prior to the HAB proliferation would return the system to a healthy, well-balanced state.

Livingston developed a Fish/Infauna/Invertebrate Index (FII) to describe the health of estuaries based on trophic relationships. The index includes determining the biomass (g/m^2) of herbivores, omnivores, and three levels of carnivores (primary= C1, secondary= C2, and tertiary=C3). **Figure 29** depicts the pattern and distribution of the various Fish/Infauna/Invertebrate Index trophic levels in Perdido Bay over the 19-year study period. Herbivore biomass was present mainly in the limited seagrass beds of upper Perdido Bay, but herbivores were reduced during the period of increased nutrient loading. Herbivore biomass increased during periods of low nutrient loading and when *Heterosigma* concentrations were low (1998–1999; 2003–2004; 2006). Omnivore biomass increased during periods of high nutrient loading and when *Heterosigma* concentrations were high (1995–2000; 2003–2005).

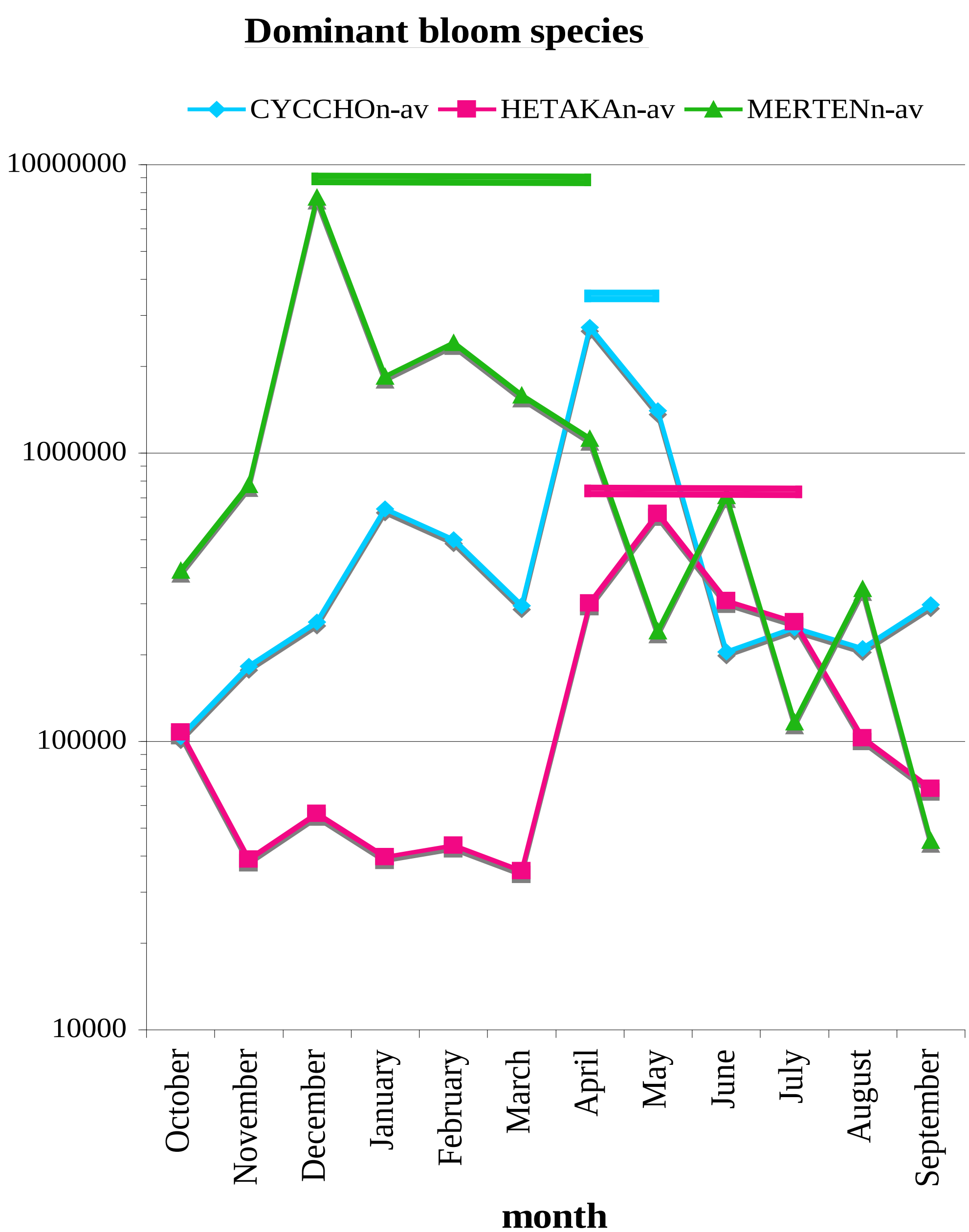


Figure 28. Seasonal abundance peaks of C. choctawhatcheeana (blue), H. akashiwo (red), and M. tenuissima (green) in Perdido Bay following a period of increased ammonia and orthophosphate loading from Elevenmile Creek.

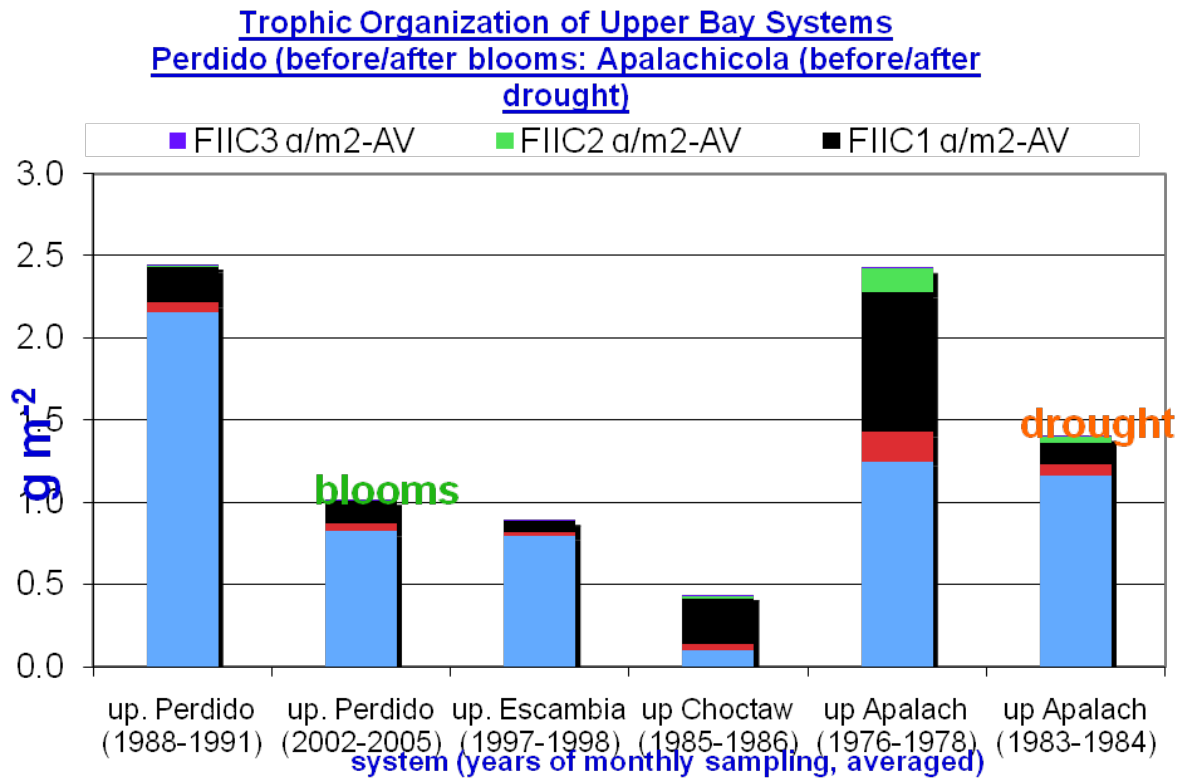
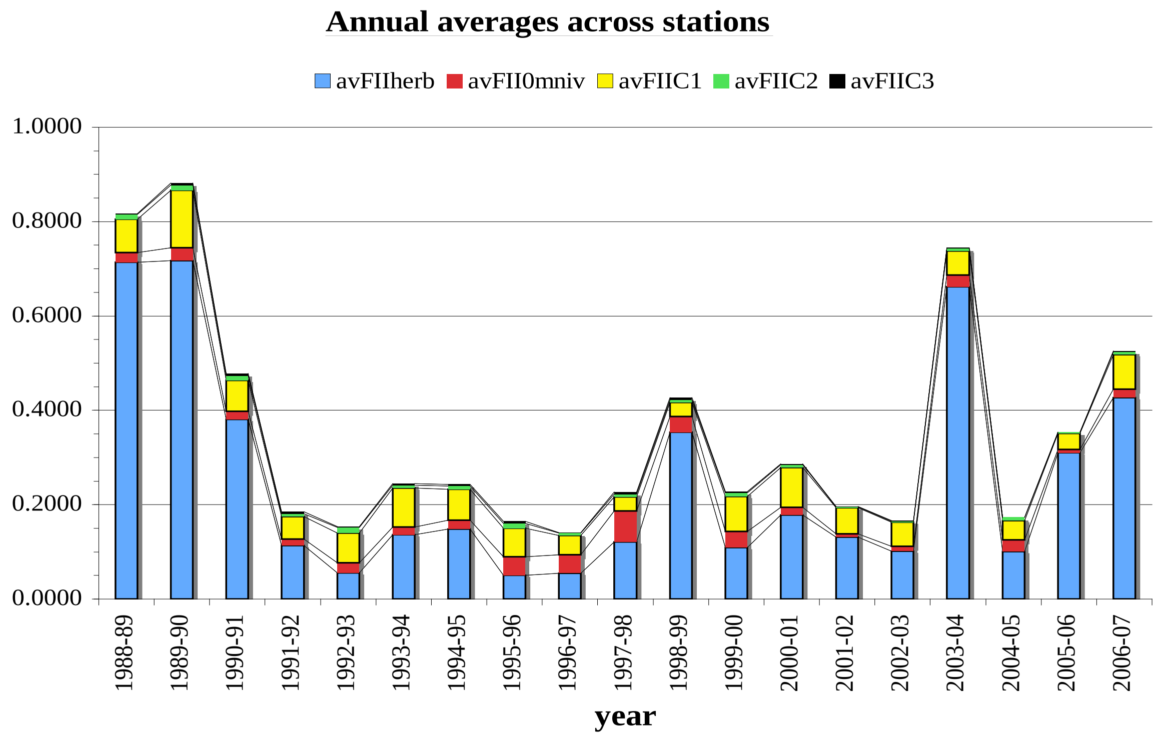


Figure 29. Biomass of three consumer trophic levels at selected north Florida bays, including data for Perdido Bay before and after the occurrence of HABs, and data for Apalachicola Bay, before and after a drought decreased available nutrients.

From 1988 to 1991, the biomass of primary, Level 1 carnivores (C1 carnivores) was highest in upper Perdido Bay compared with the remainder of the bay **(Figure 30)**. With increased nutrient loading from Elevenmile Creek, C1 biomass decreased in the upper bay, and from 2004 to 2006, C1 carnivores were primarily restricted to a station near Grassy Point. However, the recovery of C1 carnivores was noted at the end of the study period. Secondary, Level 2 carnivores (C2 carnivores) were distributed over a number of stations during the early years, with subsequent decreased coverage following bloom periods. The biomass of C2 carnivores was lowest during the blooms of 2002 to 2003 and 2005 to 2006. There was a general decrease of C2 carnivore biomass with time. Tertiary, Level 3 carnivores (C3 carnivores) increased in the upper bay from 1998 to 2000, but decreased throughout the bay (except in Elevenmile Creek), with no significant subsequent recovery, potentially due to a delayed response associated with the earlier HAB events. Because ecosystem recovery is ongoing, a reasonable decision would be to establish nutrient criteria based upon the conditions that occurred from 1988 to 1991, when the bay was demonstrated to be healthy.



Blue=herbivores, Red=omnivores, Yellow= Level 1 consumers, Green = Level 2 consumers, black = Level 3 consumers

Figure 30. Annual averages of the Fish/Infauna/Invertebrate Index trophic organization across stations from 1988–89 through 2006–07.

Escambia County conducted a study in 2007-2008 to determine the concentrations of nutrients and heavy metals in nearshore sediments and surface water (Escambia County 2009). Water quality samples were collected at 37 stations for TP and TN **(Figure 31)**. Metals and nutrients were highest at stations 8, 13, and 14, potentially attributable to urban stormwater runoff and/or municipal wastewater discharge from the Bayou Marcus wastewater treatment plant. Surface water sampling showed that the highest concentrations of nutrients occurred near a cluster of stations in the vicinity of Elevenmile Creek. Nutrient levels are listed in Appendix B.

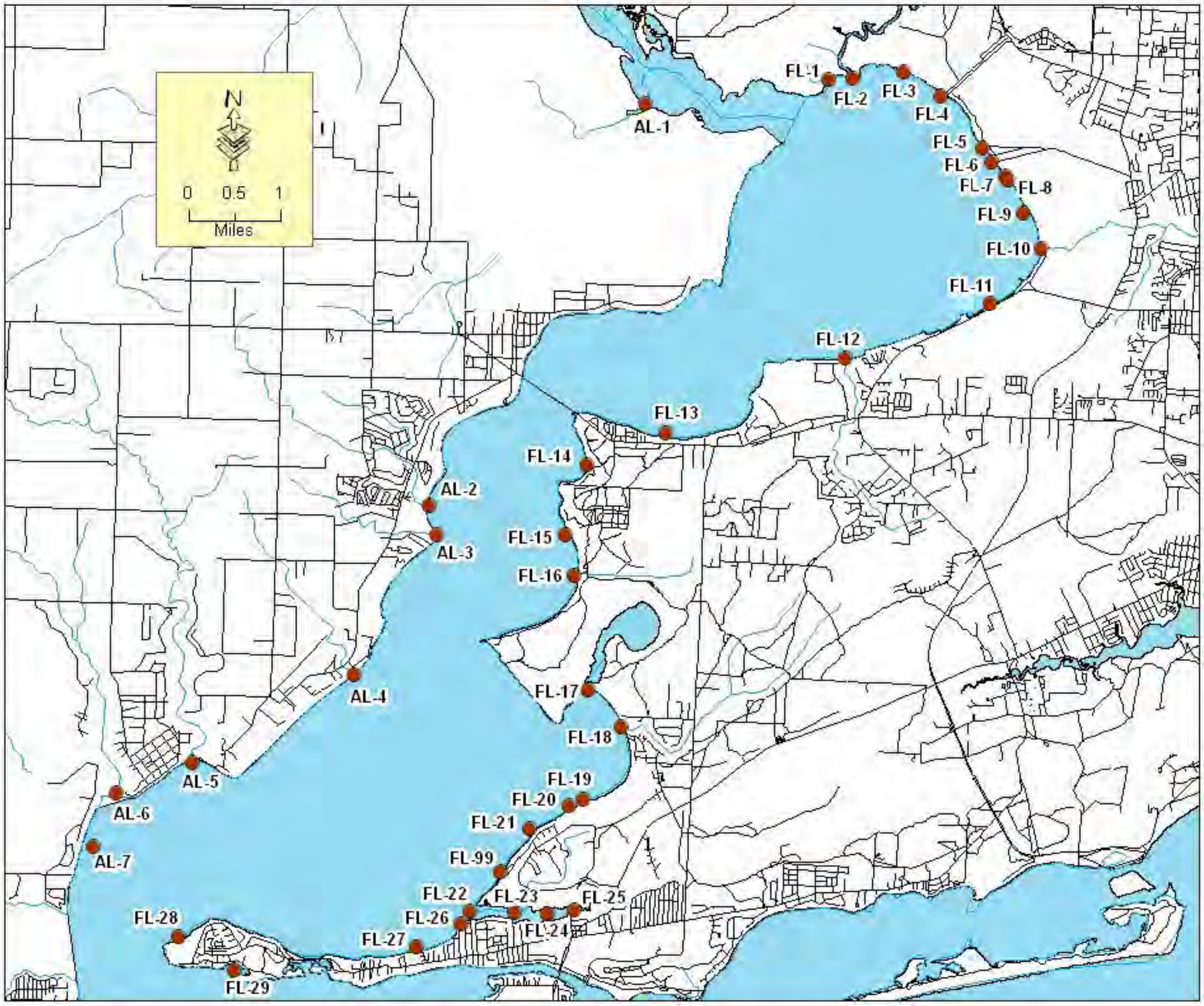


Figure 31. Locations of sediment and surface water sampling stations in Perdido Bay (Escambia County 2009).

Application of Water Quality Models to Support Numeric Nutrient Criteria

Background

As outlined in the EPA's document "Methods and Approaches for Deriving Numeric Criteria for Nitrogen/Phosphorus Pollution in Florida's Estuaries, Coastal Waters, and Southern Inland Flowing Waters", the application of water quality simulation models was one of the approaches used by EPA to develop NNC. Tetra Tech Inc. was contracted to setup and calibrate a series of linked watershed and estuarine models for Florida estuaries. These models link causal variables such as TN and TP to ecological indicators such as chlorophyll *a* and water clarity, and establish protective nutrient levels based on specific biological assessment endpoints.

The FDEP is evaluating the use of these models in panhandle estuaries as another line of evidence in the development of NNC that would be protective of designated uses as described in the state's water quality regulations. FDEP included information about the models in this document to inform stakeholders about the models and their possible application, but it should be noted that the models were not used to develop the draft nutrient criteria proposed for the Perdido Bay estuarine system.

Watershed Model

A dynamic watershed model, Loading Simulation Program in C++ (LSPC), was used to estimate the quantity of water and pollutants associated with runoff from rain events associated with the contributing watershed of the estuary. The LSPC model includes streamlined Hydrologic Simulation Program Fortran (HSPF) algorithms that simulate surface and subsurface flow from pervious land areas and surface flow from impervious land areas, and determines nutrient loading by using buildup-washoff algorithms. The model also has the ability to simulate direct point sources to the stream reaches. Water quality and hydrology over the 1997 -2009 period was simulated based on the most current land cover information available. LSPC provides tributary flows and temperature to the hydrodynamic model used and tributary water quality concentrations to the water quality model used. In addition to a simulation under existing conditions, "background" scenarios could be simulated in which point sources were removed and land uses were converted to natural (combination of forest and wetland).

Estuary Hydrodynamic and Water Quality Models

The Environmental Fluids Dynamic Code (EFDC) is a multifunctional, surface-water modeling system, which includes hydrodynamic, sediment contaminant, and eutrophication components. The model uses a curvilinear-orthogonal horizontal grid and a sigma or terrain-following vertical grid. The EFDC hydrodynamic model was run independently and a hydrodynamic linkage file was linked with the Water Quality Analysis Simulation Program (WASP7) to simulate the hydrodynamics and water quality conditions in each estuary. The hydrodynamic file generated by EFDC transfers segment volumes, velocities, temperature and salinity, as well as flows between segments.

WASP7 is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. The time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in the basic program. Water quality processes are represented in special kinetic subroutines that are either chosen from a library or written by the user. **Figure 32** illustrates linkages between the models and the associated outputs.

LSPC to EFDC to WASP

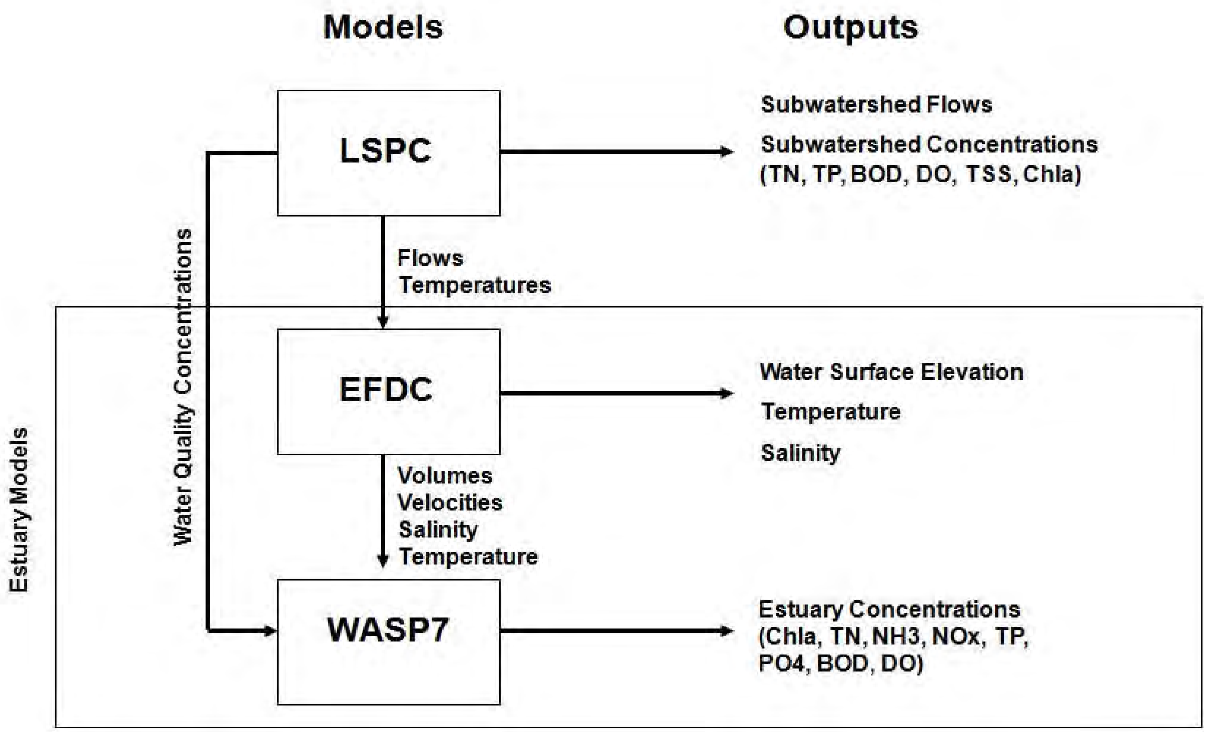


Figure 32. Linkages between Watershed and Estuary Models

Watershed Model Components

The watershed and subwatersheds for the Perdido basin were based on the United States Geological Survey (USGS) Hydrologic Unit Code (HUC) level 12 delineations and the National Hydrography Dataset (NHD) 100,000:1 catchments and flowlines **(Figure 33)**. Information on land uses **(Figure 34)**, soil characteristics **(Figure 35)**, weather stations **(Figure 36)**, and point sources **(Figure 37)** are all essential input elements to the watershed model. Sites with long-term flow and water quality records are used in the model calibration and validation process.

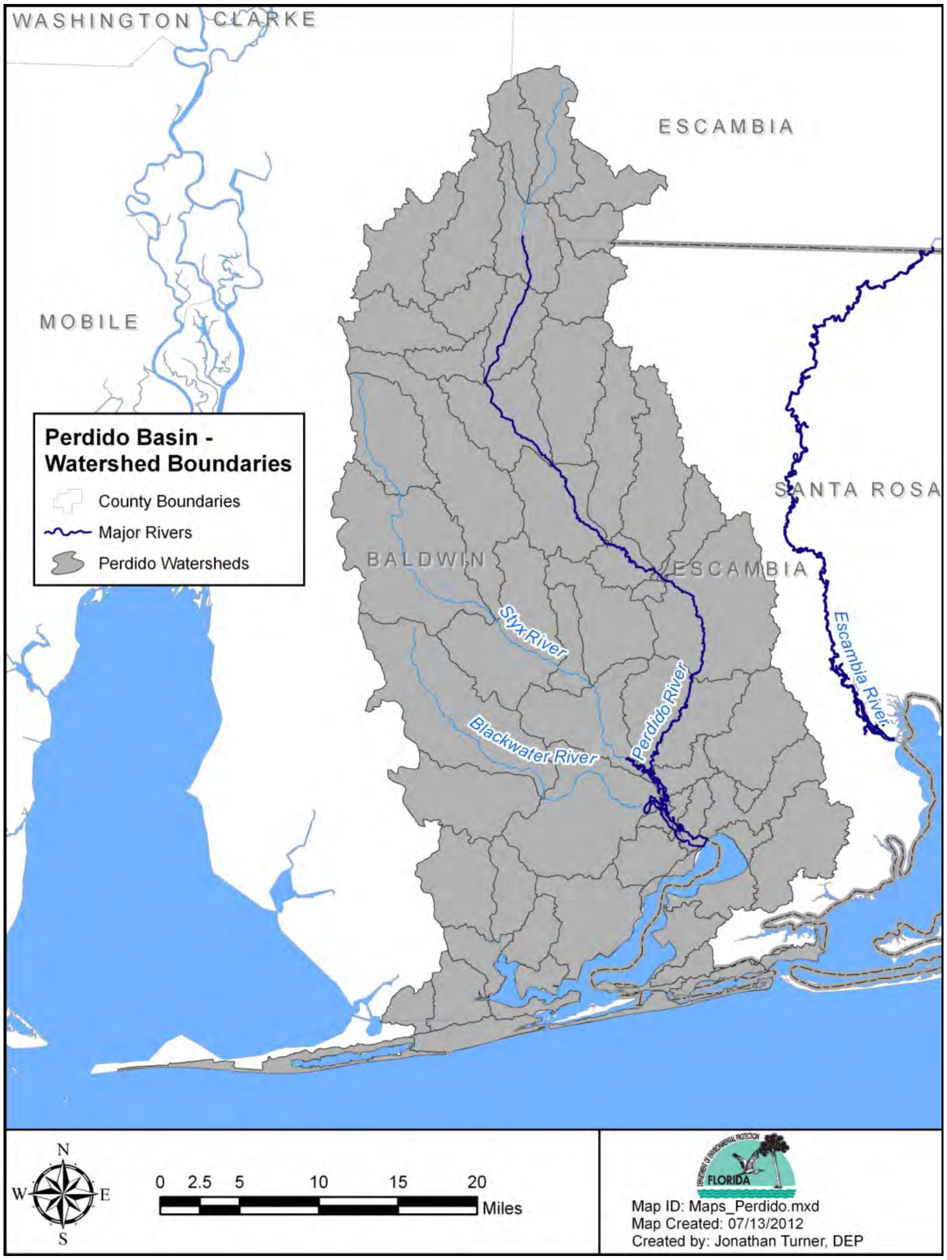


Figure 33. Perdido Basin Delineation.

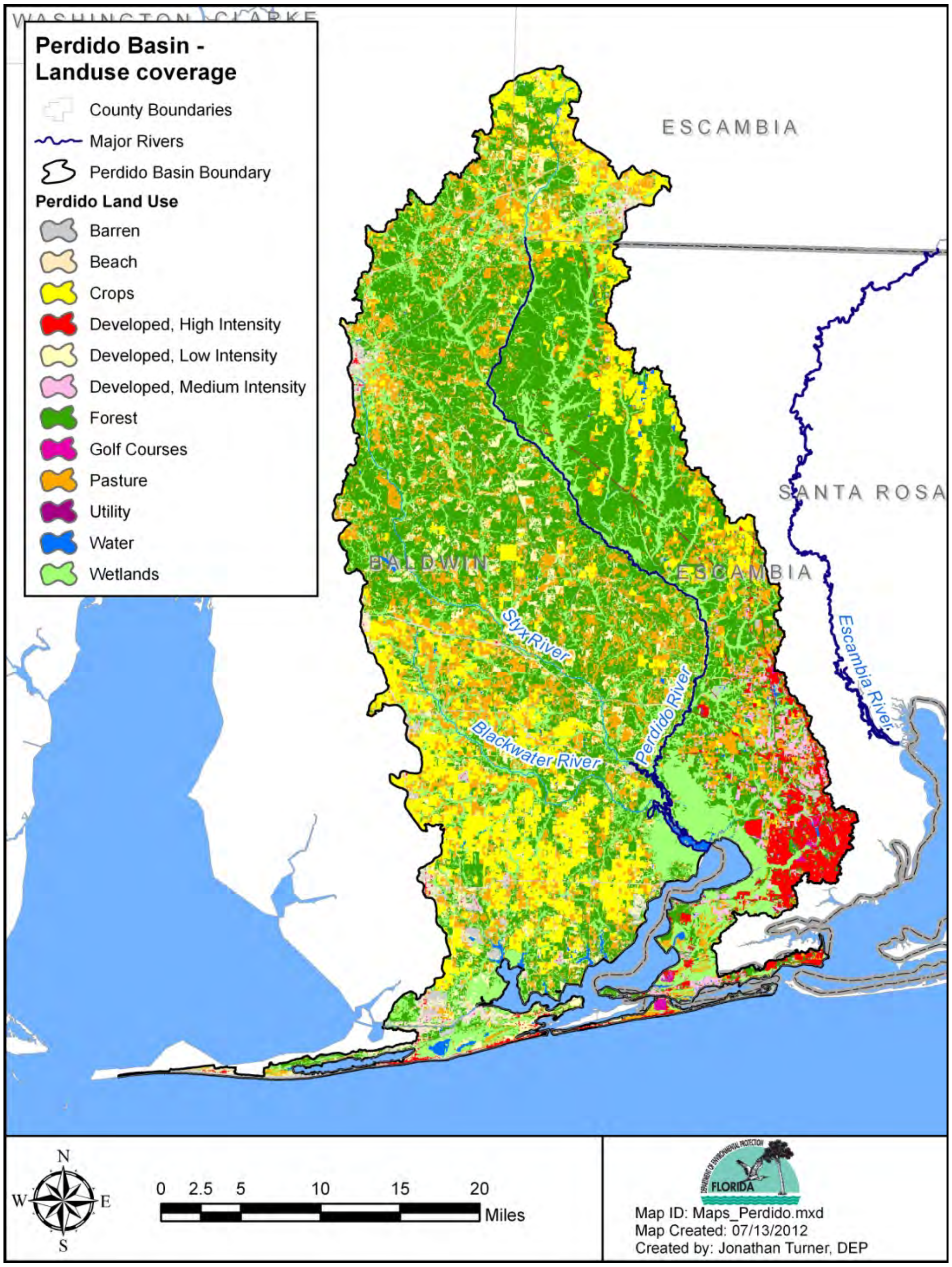


Figure 34. Perdido Basin Landuse Delineations.

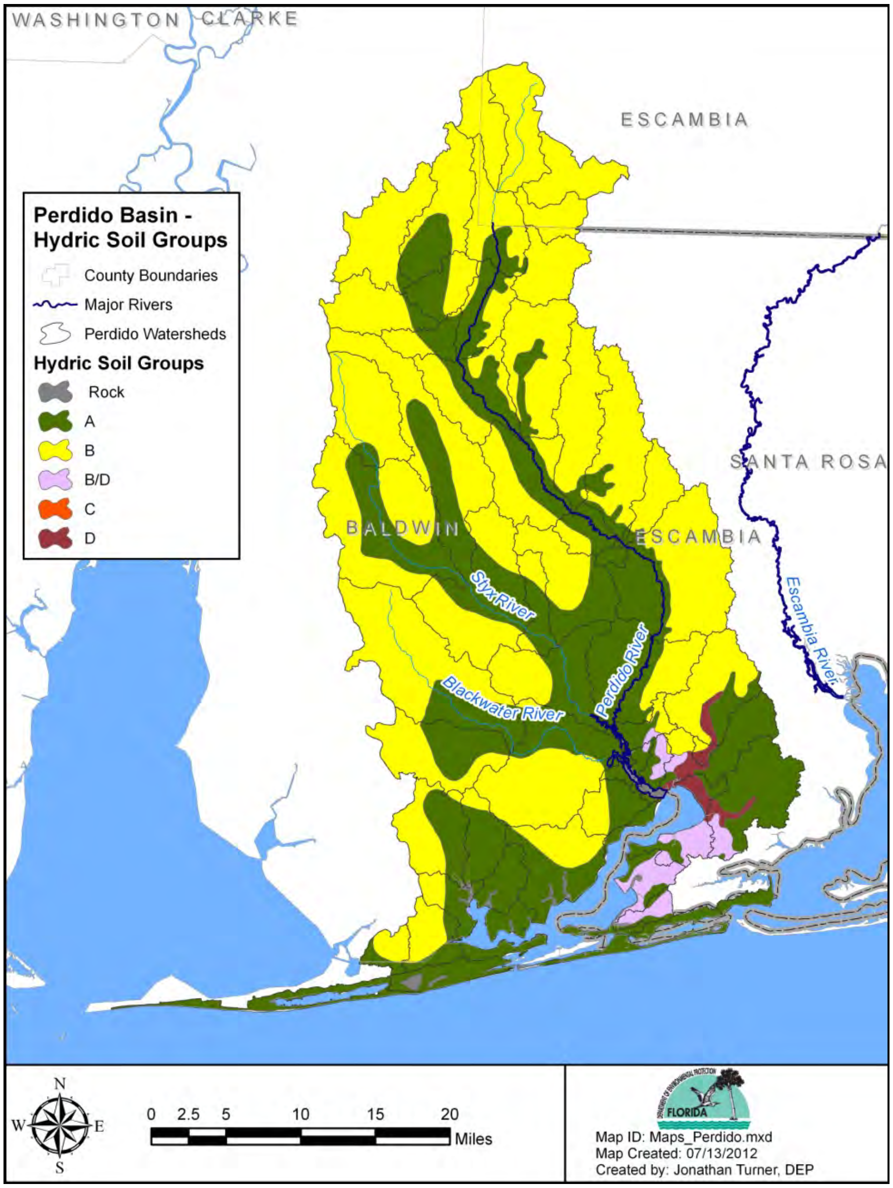


Figure 35. Perdido Basin Hydric Soil Groups.

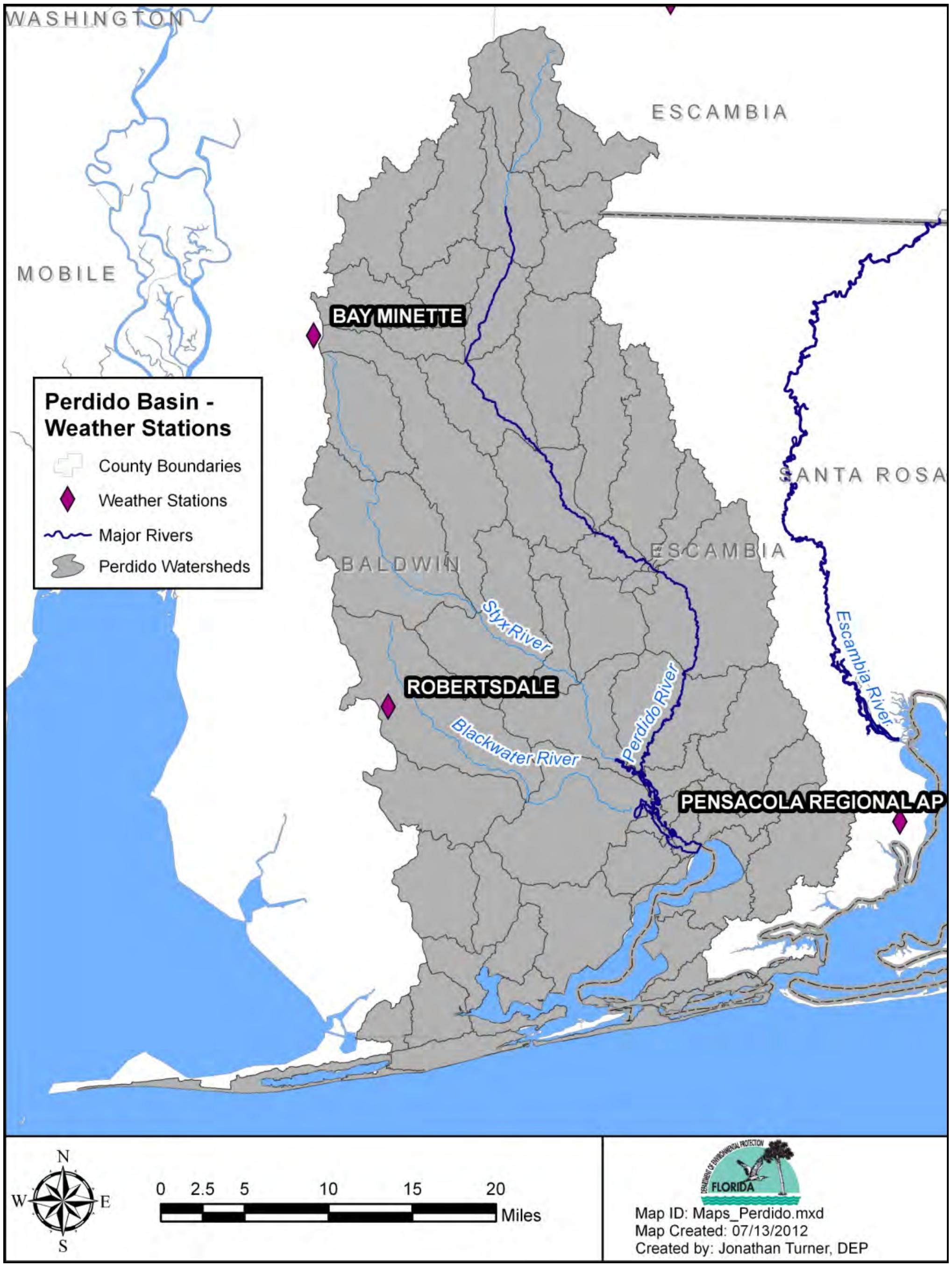


Figure 36. Perdido Basin Weather Stations.

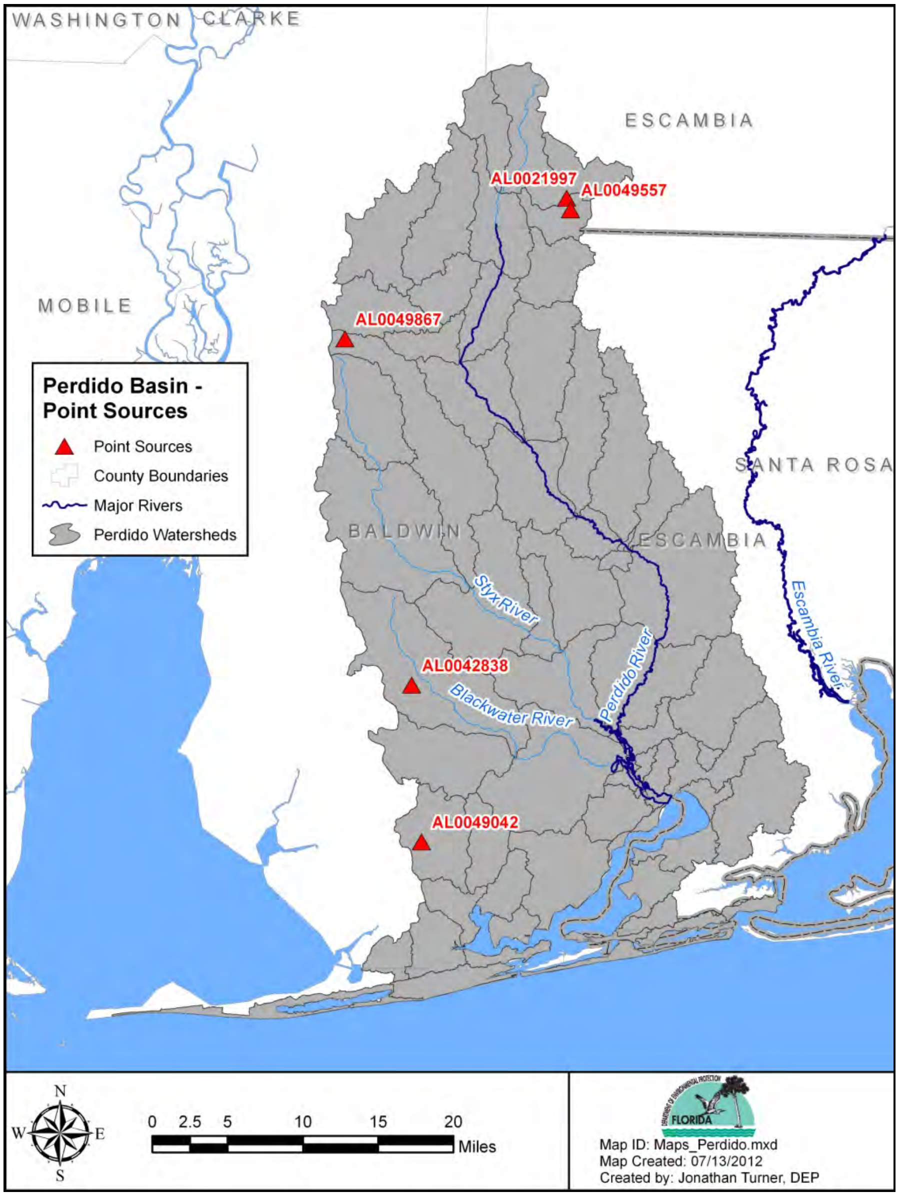


Figure 37. Perdido Basin Point Sources.

The Perdido Estuary Model consisted of 453 horizontal cells and 5 layers **(Figure 38)**. There were nineteen locations where watershed outputs from LSPC entered the EFDC and WASP model grids **(Figure 39)**.

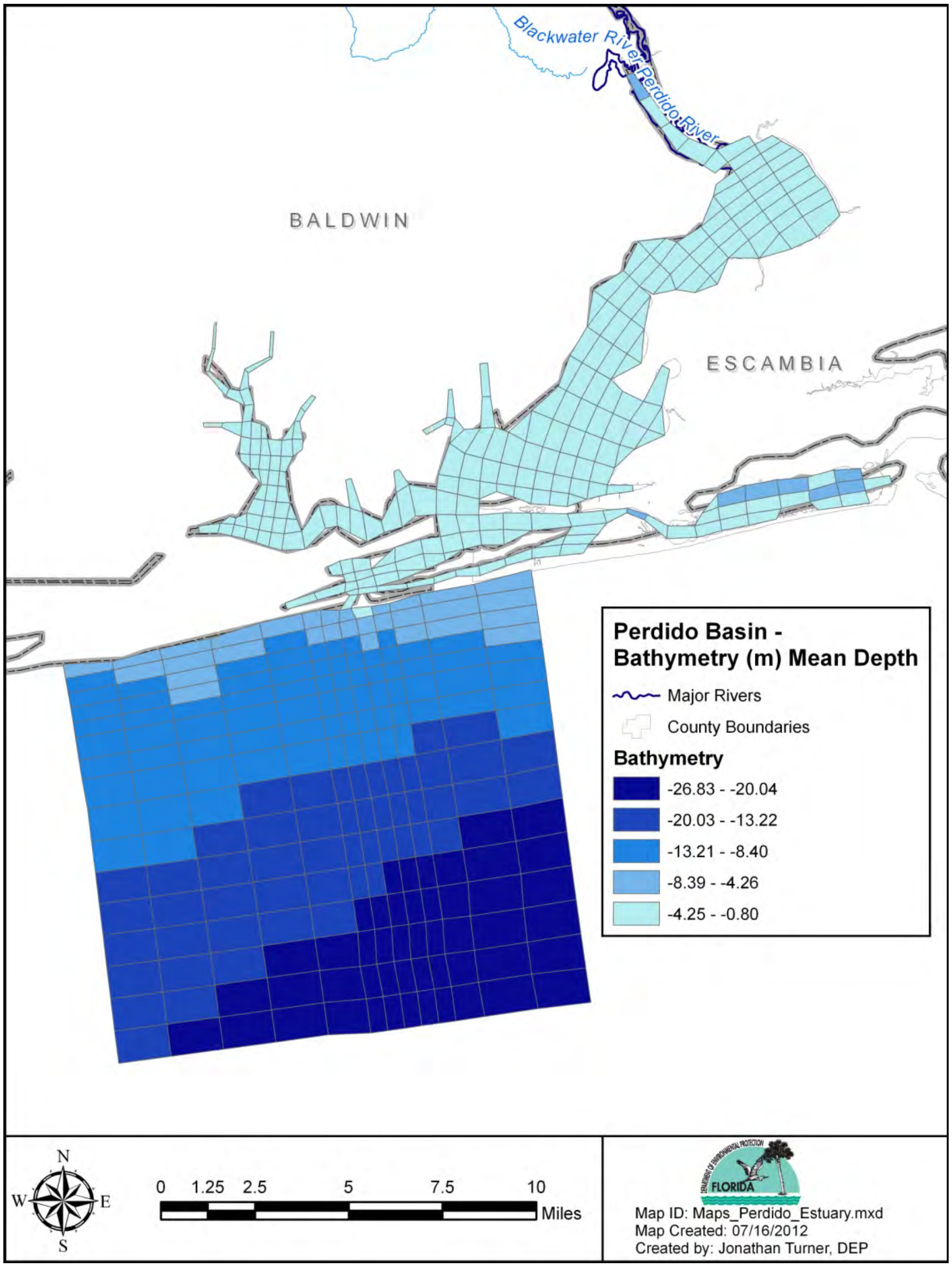


Figure 38. EFDC and WASP Model Domain.

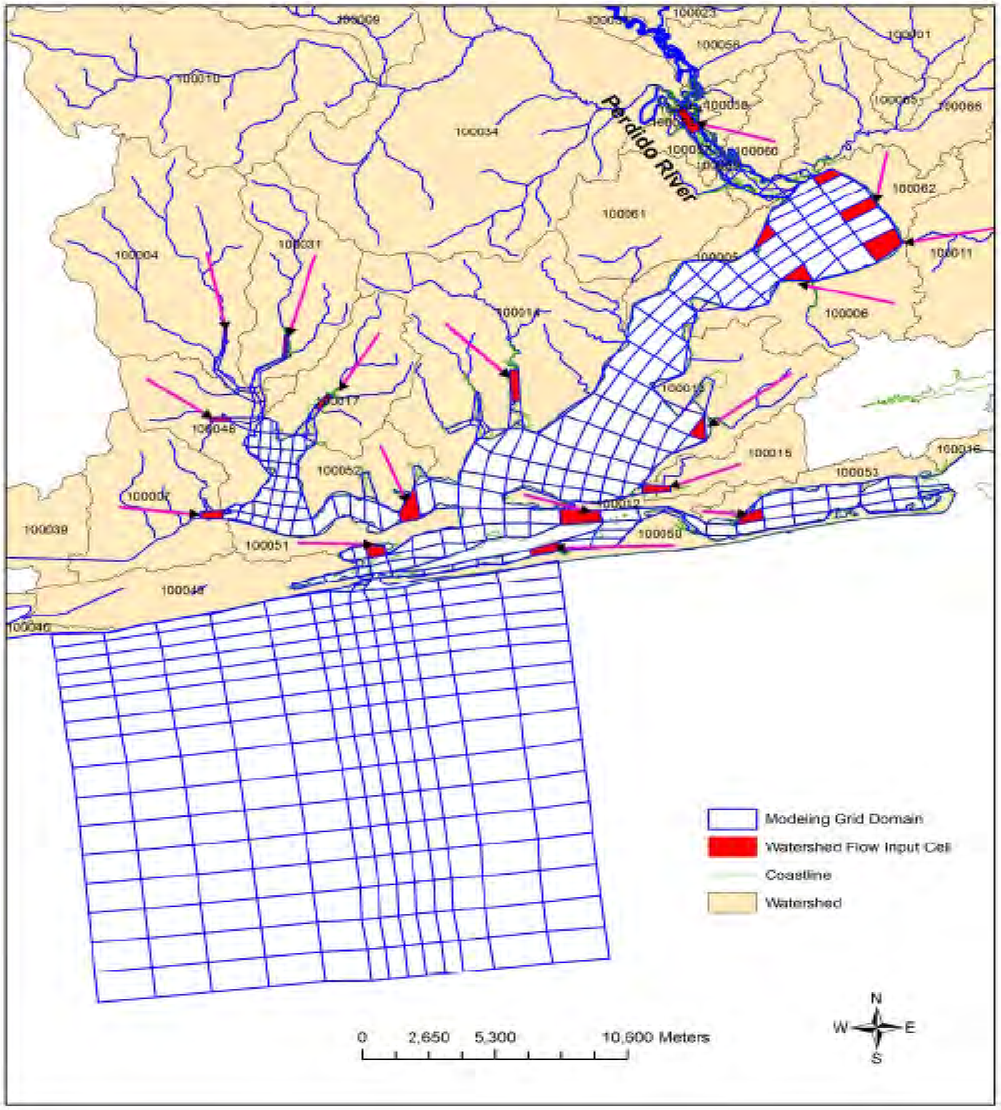


Figure 39. Watershed inputs to the EFDC and WASP Models.

The estuary was divided into six zones based on salinity contours (**Figure 40**). Model outputs from simulations over the 2002-2009 period can be aggregated over time within each zone to evaluate nutrient concentrations based on specific ecological endpoints.

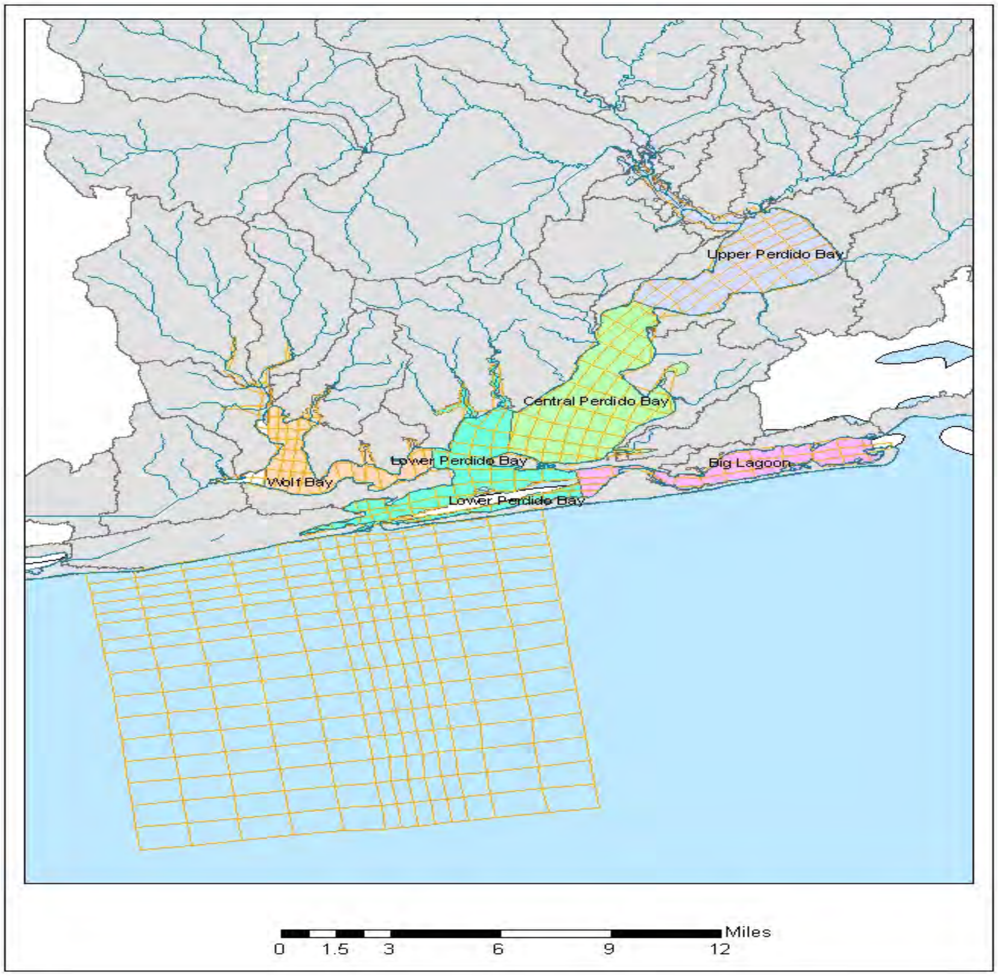


Figure 40. Perdido Estuary Zones.

Model Targets

The Environmental Protection Agency (EPA) is in the process of developing nutrient criteria for Florida's estuaries. While EPA's draft criteria will not be available until Nov. 30, 2012, Department staff met with a representative of EPA Region 4 and EPA Headquarters' modeling consultants (Tetra Tech) in Atlanta, Georgia to review their modeling results and evaluation criteria and to obtain copies of the LSPC, EFDC, and WASP models EPA used to asses both the current condition (EPA calibrated model) and a background condition (natural condition) as described above. Based on the information provided during these meetings and teleconferences, it is the Department's understanding that EPA is using a multiple line of evidence approach to determine if Perdido Bay meets Florida's narrative criteria for nutrients. Central to the methodology was the establishment of a series of 4 zones (segments) based on salinity gradients within the Perdido Bay system. These zones are depicted in **Figure 40**.

Both the FDEP and EPA approaches to the development of numeric nutrient criteria ensure water quality standards are met and designated uses are protected. While FDEP primarily used a weight of evidence approach involving empirical data, both FDEP and EPA considered the following endpoints:

- Balanced faunal communities;
- Healthy seagrass communities; and
- Balanced phytoplankton biomass and production.

The multiple lines of evidence that EPA considered are described below.

A. Balanced Faunal Communities: Dissolved Oxygen (DO) Requirements

To ensure that faunal communities were protected, each Zone was required to achieve:

1. A daily average DO of 5.0 mg/L (as a water column average) 90% of the time over the 2002 to 2009 simulation period (note that FDEP proposed marine DO criteria requires a DO saturation of 42%);

2. A minimum DO of 4.0 mg/L (as a water column average) 90% of the time over the 2002 to 2009 simulation period; and

3. A three-hour average DO no lower than 1.5 mg/L (as an average of the bottom two layers in WASP and the bottom 4 layers of RCA) over the 2002 to 2009 simulation period.

B. Healthy Seagrass Communities

To ensure that nutrients do not interfere with the establishment, maintenance or restoration of healthy seagrass communities, EPA established depth targets for seagrass colonization for each Zone and then evaluated the depth to which seagrass could successfully colonize and propagate by:

1. Determining the locations where the growing season average bottom light equals or exceeds 20% of the surface light, for both the current and natural conditions;
2. Comparing the areas where historic seagrass coverage achieved the 20% (or greater) bottom light target (for both current and natural conditions); and
3. Comparing areas where the growing season average 20% bottom light target was achieved against the Zone depth targets developed by EPA.

C. Balanced Phytoplankton Biomass and Production

To ensure that harmful algal blooms did not occur, chlorophyll *a* levels were required to not exceed 20 µg/L more than 10% of the time in any Zone during the 2002-2009 simulation period.

Downstream Protection

The empirical data demonstrated that the nutrient and chlorophyll a levels observed during the 1988-1991 time period were fully protective of balanced faunal communities, healthy seagrass communities, and balanced phytoplankton biomass and production. Furthermore, because the downstream segments were also healthy at the 1988-1991 nutrient loads, the proposed criteria are inherently protective of downstream waters.

Court Decision Regarding Proposed Approach

The nutrient effluent limits specified in the pulp mill's National Pollutant Discharge Elimination System (NPDES) permit for its discharge to Perdido Bay was the subject of litigation (Division of Administrative Hearings [DOAH] 2010). During the proceedings, FDEP argued that the conditions in Perdido Bay that occurred prior to the onset of HABs represented the historically healthy, well-balanced biological expectation for the bay. FDEP also argued that the nutrient loadings that occurred during this period would fully protect the designated use of the bay.

The court decision clearly demonstrates that the numeric criteria proposed here, using an analogous approach, are legally and scientifically defensible. After extensive testimony, Judge Bram Canter wrote the following decision:

> *In 1989, the Department and Champion signed a Consent Order to address water quality violations in Elevenmile Creek. Pursuant to the Consent Order, Champion commissioned a comprehensive study of the Perdido Bay system that was undertaken by a team of scientists led by Dr. Robert Livingston, an aquatic ecologist and professor at Florida State University. The initial three-year study by Dr. Livingston's team of scientists was followed by a series of related scientific studies.*
>
> *The Livingston studies represent perhaps the most complete scientific evaluation ever made of a coastal ecosystem. Dr. Livingston developed an extensive biological and chemical history of Perdido Bay and then evaluated the nutrient loadings from Elevenmile Creek over a 12-year period to correlate mill loadings with the biological health of the Bay. The Livingston studies confirmed that when nutrient loadings from the mill were high, they caused toxic algae blooms and reduced biological productivity in Perdido Bay. Some of the adverse effects attributable to the mill effluent were most acute in the area of the Bay near the Lanes' home on the northeastern shore of the Bay because the flow from the Perdido River tends to push the flow from Elevenmile Creek toward the northeastern shore.*
>
> *Because Dr. Livingston determined that the nutrient loadings from the mill that occurred in 1988 and 1989 did not adversely impact the food web of Perdido Bay, he recommended effluent limits for ammonia nitrogen, orthophosphate, and total phosphorus that were correlated with mill loadings of these nutrients in those years. The Department used Dr. Livingston's data, and did its own analyses, to establish WQBELs for orthophosphate for drought conditions and for nitrate-nitrite. WQBELs were ultimately developed for total ammonia, orthophosphate, nitrate-nitrite, total phosphorus, BOD [biochemical oxygen demand], color, and soluble inorganic nitrogen.*

The WQBELs in the proposed permit were developed to assure compliance with water quality standards under conditions of pollutant loadings at the daily limit (based on a monthly average) during low flow in the receiving waters. Petitioners failed to prove that any new data in the December 2007 report of the Livingston team demonstrate that the proposed WQBELS are inadequate to prevent water quality violations in Perdido Bay.

Numeric Nutrient Criteria Recommendations

Proposed Numeric Nutrient Criteria

To be applied consistently and to provide an appropriate level of protection, water quality criteria need to include magnitude, frequency, and duration components. The magnitude is a measure of how much of a pollutant may be present in the water without an unacceptable adverse effect. Duration is a measure of the time period over which the magnitude will be applied. It is preferable to derive the magnitude component of a criterion through a cause-effect relationship (such as that measured through toxicity testing). The magnitude would then be set at a level that would protect a majority of the sensitive aquatic organisms inhabiting the system. The magnitude may be set at a level designed to maintain the documented historic healthy data distribution, accounting for natural temporal variability, since the historic conditions are protective of the designated uses of the waterbody.

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

Magnitude

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

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

Frequency and Duration

To provide a consistent and appropriate level of protection, the duration and frequency components of the criteria must be consistent with the derivation of the magnitude component. The magnitude component of the criteria was derived based on a historic geometric mean concentration, and, a statistical test can be developed to allow the application of the criteria on an annual basis.

For example, since the relationship between nutrient and chlorophyll *a* response in Florida lakes was extremely weak, with a much more robust relationship found when data were evaluated based on annually averaged log-transformed data, FDEP and EPA used an averaging period of a year to assess the enrichment in Florida lakes with the criteria being expressed as an annual geometric mean. Likewise, the nutrient criteria for estuaries will be assessed annually. Since the duration and frequency components of the criteria must be consistent with the derivation of the magnitude component to provide a consistent and appropriate level of protection, the historic geometric mean target cannot simply be applied as an annual mean. Doing so would result in unacceptably high Type I failure rate (identifying a healthy system as being impaired), since approximately 50% of the individual years can be expected to be above the historic mean. Therefore, the historic target must be adjusted to allow for the application to a shorter duration with an acceptable Type I error rate of no more than 10%. This assessment of the Type I error rate is related only to addressing the null hypothesis that future monitoring data are equivalent to the baseline distribution. The Type I error rate, for the current application, may be defined as the rate of incorrectly concluding that the mean of (future) monitoring data is greater than the historic mean condition. Type I statistical errors result in the management decision error to incorrectly list a healthy waterbody as impaired.

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

Summary of the Proposed Criteria

For a "healthy historic conditions" dataset, the Department considered several potential ways to express the NNC. The Department's proposed approach is to set the magnitude as an annual geometric mean limit established at the upper 80 percent prediction limit of the spatially averaged annual geometric means, with a frequency and duration of no more than 1 annual geometric mean exceeding the limit in a 3-year period.

DEP's preferred expression of healthy historic conditions nutrient criteria is an annual geometric mean not to be exceeded more than once in a three-year. Calculation of this limit ideally requires a minimum dataset of nine to ten years (*i.e*., at least three independent three-year periods) to confidently estimate the upper end of the long-term distribution of annual geometric means. The Big Lagoon segment criteria for TN and TP is expressed as annual geometric means. For Big Lagoon chlorophyll a and all other segments, however, the period of record is insufficient to derive such an annual limit. For these segments, the Department is proposing an alternative approach expressed as a single sample maximum value not to be exceeded in more than ten percent of the samples. The single sample maximum value was calculated as the upper 90% prediction limit of individual samples, assuming a lognormal distribution (Helsel and Hiersh 2002), for segments with a minimum of 30 samples. For segments with less than 30 samples, the nonparametric 90th percentile was set as the single sample maximum value. The Department is seeking any additional data sources.

A summary of the available data and proposed criteria for the protection of a healthy, well-balanced aquatic community for four segments in Perdido Bay are provided in **Table 9**. The final criteria will be rounded to 2 significant digits.

Table 9. Proposed numeric nutrient criteria for all segments of Perdido Bay including TP, TN, and chlorophyll a. Notes are provided at the bottom of the table to detail which approach is most appropriate based on data limitations.

TP (mg/L)									
Annual Geometric Mean Limit Approach						Single Sample Value Approach			
Segment	Historic Geometric Mean	Number of Calculated Annual Geometric Means	Standard Deviation (Ln TP)	Maximum Annual Geometric Mean (1 of 3-year exceedance rate)		Geometric Mean	Standard Deviation (Ln TP)	Number of total samples	Single Sample Limit not to be exceeded in >10% of samples
Upper Perdido Bay	0.0340	3	0.1073	0.0387		0.0349	0.8248	105	0.102
Central Perdido Bay	0.0267	2	0.3193	0.0457		0.0312	0.9089	36	0.104
Lower Perdido Bay	0.0319	2	0.2602	0.0494		0.0356	0.8598	29	0.110
Big Lagoon	0.0237	12	0.3945	0.0358		0.0252	0.804	74	0.0719
TN (mg/L)									
Annual Geometric Mean Limit Approach						Single Sample Value Approach			

Segment	Historic Geometric Mean	Number of Calculated Annual Geometric Means	Standard Deviation (Ln TN)	Maximum Annual Geometric Mean (1 of 3-year exceedance rate)		Geometric Mean	Standard Deviation (Ln TN)	Number of total samples	Single Sample Limit not to be exceeded in >10% of samples
Upper Perdido Bay	0.606	4	0.1796	1.010		0.677	0.4832	65	1.27
Central Perdido Bay	0.430	3	0.1586	0.522		0.463	0.5579	36	0.970
Lower Perdido Bay	0.377	3	0.3774	0.808		0.474	0.4474	29	0.779
Big Lagoon	0.434	9	0.2358	0.608		0.496	0.4608	61	0.91
Chlorophyll a (ug/L)									
Annual Geometric Mean Limit Approach						**Single Sample Value Approach**			
Segment	**Historic Geometric Mean**	**Number of Calculated Annual Geometric Means**	**Standard Deviation (Ln TN)**	**Maximum Annual Geometric Mean (1 of 3-year exceedance rate)**		**Geometric Mean**	**Standard Deviation (Ln TN)**	**Number of total samples**	**Single Sample Limit not to be exceeded in >10% of samples**
Upper Perdido Bay	4.89	4	0.3255	6.98		5.004041	0.6367	56	11.51
Central Perdido Bay	3.57	3	0.2067	4.59		3.976889	0.6197	29	7.47
Lower Perdido Bay	1.94	3	0.8430	5.46		3.377736	0.8168	26	6.88
Big Lagoon	4.02	8	0.4154	6.42		3.278377	0.5163	127	6.39
Notes:									

1- All TN and TP standard deviations are based on natural log transformations.

2- The Big Lagoon segment has sufficient data to develop nutrient criteria by means of the annual geometric mean limit approach for TN and TP. The criteria are expressed as a maximum annual geometric mean not to be exceeded in more than one out of three years.

3- The Upper, Central, and Lower Bay segments have criteria developed using the single sample value approach for TN, TP, and chlorophyll a. The criteria is set as a single sample limit not to be exceeded in >10% of samples.

4- The Big Lagoon chlorophyll a is based on the single sample value approach and will be expressed as a single sample limit not to be exceeded in >10% of samples.

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Appendix A: FDEP Biological Sampling Results by Method

Fyke Net Species	Number
Menidia beryllina	597
Ariopsis felis	276
Palaemonetes	76
Lagodon rhomboides	66
Mugil	53
Litopenaeus setiferus	35
Farfantepenaeus	33
Callinectes sapidus	30
Sphoeroides parvus	27
Bairdiella chrysoura	24
Paguroidea	21
Menidia	16
Caranx	7
Cynoscion nebulosus	5
Orthopristis chrysoptera	5
Callinectes	4
Leiostomus xanthurus	4
Nassarius vibex	4
Paralichthys	4
Anchoa mitchilli	3
Oligoplites saurus	3
Portunidae	3
Anchoa hepsiis	2
Eucinostomus harengulus	2
Farfantepenaeus aztecus	2
Isopoda	2
Jenkinsia lamprotaenia	2
Nassarius	2
Sciaenops ocellatus	2
Amphipoda	1
Chaetodipterus faber	1
Chrysaora	1
Fundulus similis	1
Membras martinica	1
Micropogonias undulatus	1
Myrophis punctatus	1
Xanthidae	1

Seine	
Species	**Number**
Anchoa mitchilli	6698
Anchoa hepsetus	99
Membras martinica	71
Leiostomus xanthurus	61
Lagodon rhomboides	48
Americamysis bahia	47
Eucinostomus	22
Jenkinsia lamprotaenia	19
Menidia beryllina	16
Farfantepenaeus	15
Sphoeroides parvus	14
Menidia	11
Ariopsis felis	9
Oligoplites saurus	9
Micropogonias undulatus	7
Mulina	7
Paralichthys	7
Synodus foetens	7
Callinectes sapidus	5
Harengula clupeola	5
Pylodidis olivaris	5
Farfantepenaeus aztecus	3
Harengula jaguana	3
Bivalvia	2
Chrysaora	2
Dasyatis sabina	2
Gastropoda	2
Myliobatiformes	2
Orthopristis chrysoptera	2
Paguroidea	2
Palaemonetes spp.	2
Callinectes	1
Litopenaeus setiferus	1
Lutjanus griseus	1
Mugil	1
Palaemonetes	1
Prionotus tribulus	1
Syngnathidae sp.	1
Xanthidae	1

Beam Trawl

Species	Number
Americamysis bahia	3500
Anchoa mitchilli	75
larval fish	16
Xanthidae	15
Portunidae	7
Cumacea	4
Litopenaeus setiferus	4
Bittium varium	3
Amphipoda	2
Edotea triloba	2
Palaemonetes	2
Cirolina	1
Lagodon rhomboides	1
Pagurudae	1
Panaeidae	1
Syngnathinae	1

Appendix B: Results of Sediment and Surface Water Analysis of Nutrients in Perdido Bay

Sediment

	Total Phosphorus (mg/kg)		
Station ID	0-5 cm	5-10 cm	10-20 cm
FL-01	306.4	110.1	*N.D.*
FL-02	*N.D.*	*N.D.*	52.3
FL-03	*N.D.*	*N.D.*	*N.D.*
FL-04	*N.D.*	*N.D.*	*N.D.*
FL-05	377.1	207.1	*N.D.*
FL-06	*N.D.*	*N.D.*	*N.D.*
FL-07	524.8	362.9	58.2
FL-08	693.0	717.0	578.0
FL-09	394.1	312.0	91.1
FL-10	367.9	272.5	327.6
FL-11	*N.D.*	*N.D.*	*N.D.*
FL-12	*N.D.*	*N.D.*	*N.D.*
FL-13	684.0	767.0	720.0
FL-14	705.0	647.0	554.0
FL-15	*N.D.*	*N.D.*	*N.D.*
FL-16	*N.D.*	*N.D.*	*N.D.*
FL-17	49.7	*N.D.*	*N.D.*
FL-18	*N.D.*	*N.D.*	*N.D.*
FL-19	*N.D.*	*N.D.*	*N.D.*
FL-20	*N.D.*	*N.D.*	*N.D.*
FL-21	*N.D.*	*N.D.*	*N.D.*
FL-22	406.3	406.3	186.0
FL-23	*N.D.*	*N.D.*	*N.D.*
FL-24	206.5	*N.D.*	*N.D.*
FL-25	310.1	310.1	18.3
FL-26	*N.D.*	*N.D.*	*N.D.*
FL-27	*N.D.*	*N.D.*	*N.D.*
FL-28	*N.D.*	*N.D.*	*N.D.*
FL-29	220.4	*N.D.*	**N.S.**
FL-99	*N.D.*	*N.D.*	*N.D.*
AL-01	104.1	*N.D.*	53.2
AL-02	*N.D.*	*N.D.*	*N.D.*
AL-03	*N.D.*	*N.D.*	*N.D.*
AL-04	*N.D.*	*N.D.*	*N.D.*
AL-05	*N.D.*	*N.D.*	*N.D.*
AL-06	*N.D.*	*N.D.*	*N.D.*
AL-07	*N.D.*	*N.D.*	*N.D.*

	Total Nitrogen (g/kg)		
Station ID	0-5 cm	5-10 cm	10-20 cm
FL-01	0.9	0.1	0.3
FL-02	*N.D.*	*N.D.*	*N.D.*
FL-03	0.1	0.0	*N.D.*
FL-04	*N.D.*	*N.D.*	*N.D.*
FL-05	0.6	0.3	0.3
FL-06	*N.D.*	*N.D.*	*N.D.*
FL-07	1.7	0.6	0.1
FL-08	4.2	4.1	3.1
FL-09	1.0	1.0	0.6
FL-10	1.5	1.1	1.0
FL-11	*N.D.*	*N.D.*	*N.D.*
FL-12	*N.D.*	*N.D.*	*N.D.*
FL-13	4.0	4.2	3.4
FL-14	3.5	3.6	2.2
FL-15	*N.D.*	*N.D.*	*N.D.*
FL-16	*N.D.*	*N.D.*	*N.D.*
FL-17	3.3	0.6	0.6
FL-18	*N.D.*	*N.D.*	*N.D.*
FL-19	*N.D.*	*N.D.*	*N.D.*
FL-20	*N.D.*	1.3	*N.D.*
FL-21	*N.D.*	*N.D.*	*N.D.*
FL-22	2.8	2.8	0.9
FL-23	0.9	*N.D.*	*N.D.*
FL-24	1.4	0.8	0.8
FL-25	2.6	2.6	1.3
FL-26	*N.D.*	*N.D.*	*N.D.*
FL-27	*N.D.*	*N.D.*	*N.D.*
FL-28	*N.D.*	*N.D.*	*N.D.*
FL-29	0.9	0.7	**N.S.**
FL-99	*N.D.*	*N.D.*	*N.D.*
AL-01	2.6	3.0	3.6
AL-02	*N.D.*	*N.D.*	*N.D.*
AL-03	*N.D.*	*N.D.*	*N.D.*
AL-04	*N.D.*	*N.D.*	*N.D.*
AL-05	*N.D.*	*N.D.*	*N.D.*
AL-06	*N.D.*	*N.D.*	*N.D.*
AL-07	0.9	1.0	1.2

Surface Water

Station ID	Sample date	Total N mg/L	Total P mg/L
FL-01	3/28/2007	1.408	0.083
FL-02	3/28/2007	0.596	0.046
FL-03	3/28/2007	0.590	0.039
FL-04	5/3/2007	0.710	0.043
FL-05	5/3/2007	0.691	0.040
	3/25/2008	0.258	0.017
FL-06	5/3/2007	0.653	0.043
	3/25/2008	0.318	0.014
FL-07	5/3/2007	0.696	0.042
	3/25/2008	0.392	0.018
FL-08	5/3/2007	0.695	0.040
	3/25/2008	0.384	0.018
FL-09	6/13/2007	0.678	0.036
	3/25/2008	0.643	0.018
FL-10	6/13/2007	0.678	0.038
	3/25/2008	0.575	0.013
FL-11	6/13/2007	0.576	0.037
	3/25/2008	0.000	0.012
FL-12	6/13/2007	0.483	0.030
	3/25/2008	0.520	0.014
FL-13	6/13/2007	0.615	0.036
	3/25/2008	0.556	0.023
FL-14	6/13/2007	0.524	0.039
	3/26/2008	0.419	0.021
FL-15	6/13/2007	0.488	0.037
	3/26/2008	0.342	0.032
FL-16	7/10/2007	0.522	0.039
	3/26/2008	0.320	0.017
FL-17	7/10/2007	0.606	0.043
	3/26/2008	0.256	0.041

Station ID	Sample date	Total N mg/L	Total P mg/L
FL-18	7/10/2007	0.567	0.042
	3/26/2008	0.283	0.009
FL-19	7/10/2007	0.522	0.041
	3/26/2008	0.258	0.013
FL-20	7/10/2007	0.463	0.033
	3/26/2008	0.176	0.015
FL-21	7/10/2007	0.524	0.039
	3/26/2008	0.187	0.009
FL-22	9/10/2007	0.453	0.029
	4/23/2008	0.337	0.023
FL-23	7/10/2007	0.472	0.033
	4/23/2008	0.512	0.024
FL-24	9/10/2007	0.483	0.018
	4/23/2008	0.492	0.016
FL-25	9/10/2007	0.535	0.035
	4/23/2008	0.420	0.029
FL-26	9/10/2007	0.455	0.024
	4/23/2008	0.328	0.018
FL-27	9/10/2007	0.436	0.031
FL-28	9/10/2007	0.361	0.027
FL-29	9/10/2007	0.420	0.029
FL-99	7/10/2007	0.568	0.045
AL-01	3/28/2007	0.451	0.010
AL-02	12/6/2007	0.393	0.025
AL-03	12/6/2007	0.741	0.030
AL-05	11/7/2007	0.520	0.026
AL-06	11/7/2007	0.530	0.032
AL-07	11/7/2007	0.588	0.028