Chapter 12: Management and Restoration of Coastal Ecosystems

Edited by Peter Doering and Richard Alleman

SUMMARY

The South Florida Water Management District (SFWMD or District) has selected the Caloosahatchee River and St. Lucie River estuaries to highlight for Water Year 2009 (WY2009) (May 1, 2008–April 30, 2009) in this chapter of the *2010 South Florida Environmental Report – Volume I*. The primary role of the Coastal Watersheds Program is to provide the information needed to design effective restoration and protection measures for the District's priority coastal ecosystems. The District began a systematic planning process that culminated in the submission of watershed protection plans for the St. Lucie River and Caloosahatchee River estuaries to the Florida legislature in January 2009. The plans included an assessment of existing monitoring systems and needs, delineated science strategies for water quality improvement and ecosystems restoration, and provided recommendations for additional numeric modeling tools.

During the wet season of WY2009, coastal ecosystems experienced partial relief from the drought conditions that prevailed during WY2008. One major event, Tropical Storm Fay, which made landfall near Naples on August 19, 2008, dominated freshwater inflow to many bays and estuaries in South Florida. After runoff from this storm subsided, relatively dry conditions returned. Tropical Storm Fay played a major role in the annual hydrology of coastal systems, as reflected in this chapter.

- **St. Lucie River Estuary.** In WY2009, work began on a Water Reservation for the Indian River Lagoon – South Project under the Comprehensive Everglades Restoration Plan (CERP). A suite of well-calibrated models was employed to help develop the reservation. A watershed model provided input to the St. Lucie River Reservoir Operation and Optimization Model to simulate freshwater flows to the project from the watershed. Output from the optimization model was used to drive an estuarine hydrodynamic/salinity model. Results were evaluated using a set of salinity and hydrologic performance measures to determine if flows were beneficial to larval and juvenile fish in the North Fork of the St. Lucie Estuary. To support the Restoration Plan for the Northwest Fork of the Loxahatchee River, the District completed a study of the effects of flow and stage on fish communities.
- **Caloosahatchee River Estuary.** In 2007, as part of the Caloosahatchee River Watershed Protection Plan, land was purchased along the Caloosahatchee River (C-43) for the construction of a water quality treatment and testing facility. The purpose of this project is to remove nitrogen and improve the quality of water in the Caloosahatchee River and Estuary. Planning was initiated for the design of a pilot test treatment facility that should provide information to optimize a future full-scale water quality treatment facility. Several preliminary studies on the character and biological reactivity of nitrogen in the river and estuary were conducted during WY2009. To help understand the distribution of submerged

aquatic vegetation, studies were initiated to determine the mixing behavior of colored dissolved organic matter and its contribution to light attenuation. A study of fish larvae in the low salinity zone continued.

ACTIVITIES IN OTHER ESTUARIES

- In cooperation with several state and local partners, the District began work on an updated science plan for the Loxahatchee River and Estuary. Studies of the fish communities in relation to freshwater inflow and salinity were completed, in addition to several other cooperative monitoring and restoration projects. A map of seagrasses in the Lake Worth Lagoon for the year 2007 was produced using the same techniques as in 2001, creating the first true, large-scale trend comparison of this system. Results indicate that little net change (2.5 percent) has occurred since 2001 in the areas covered by seagrasses in the lagoon.
- Monitoring continued in Biscayne Bay and, overall, conditions remained stable; however, annual hypersaline events in the southwestern area continued to occur. Nutrient loading from canals was estimated. Development of criteria for minimum flows and reservations of freshwater inflow to Biscayne Bay also continued.
- In Florida Bay, the eastern algal bloom that persisted for several years since fall 2005 completely subsided during WY2009. Chlorophyll *a* returned to background levels, and concentrations of nutrients were at or below long-term averages. Low rainfall in the watershed led to continued elevated salinities in the bay. The removal of a causeway that had restricted circulation in Lake Surprise for a century resulted in declines in chlorophyll, organic carbon, and nutrient levels in the lake. A study of trends in waterfowl abundance suggested that declines in bird populations in recent decades might not be linked to global pressures but to habitat degradation at wintering sites within the Everglades. Process-level studies of seagrass population dynamics and phytoplankton dynamics yielded insight into thresholds determining bottom vegetation type and the triggers of water column algal blooms. A suite of ecological models developed to study pink shrimp (*Farfantepenaeus duorarum*), lobster (*Panulirus argus*), the seagrass community, and the mangrove community has the capability to predict system responses to restoration and is being used in Restoration Coordination and Verification (RECOVER) and Minimum Flows and Levels planning.
- Monitoring of salinity at three stations in Naples Bay continued this year. In addition, monitoring of freshwater inflow from the Golden Gate Canal resumed in April 2008. In support of the Naples Bay Surface Water Improvement and Management Plan, data from both these sources will be used to calibrate a hydrodynamic/salinity model of the bay.
- In Estero Bay, studies were initiated to measure oyster spat settlement in three estuarine tributaries. Data will be used to quantify the freshwater inflow requirements of the bay. The District sponsored a workshop with stakeholders to identify science needs to understand the Estero Bay system.

INTRODUCTION

This chapter provides an overview of key science and technical activities associated with priority coastal ecosystems within the South Florida Water Management District (SFWMD or District) as these activities relate to freshwater inflows and science strategies. A primary role of the Coastal Watershed Program is to provide the required information to design effective restoration and protection measures for the estuaries, and inform decision makers. The District concentrates this effort within several major coastal ecosystems in South Florida (**Figure 12-1**, **Table 12-1**). These coastal systems share common problems; however, the magnitude of any one issue may be quite different among areas. The District conducts or participates in scientific research and monitoring for the majority of these ecosystems, and works closely with other local, state, and federal organizations in those areas where the District is not so heavily involved.

Inherent in the District mission is the responsibility to provide water quality, water supply, flood control, and the protection of natural systems for people living in the region. To protect estuaries, a primary goal is to ensure that these systems are supplied with the appropriate volumes of fresh water at the appropriate times. To attain this objective, the District uses an approach based primarily on the salinity requirements of Valued Ecosystems Components (VECs) (USEPA, 1987). At the District, the VEC approach focuses on critical estuarine habitat. In many instances, that habitat is biological and typified by one or more prominent species, such as seagrass meadows and oyster reefs (Doering et al., 2002; Chamberlain and Doering, 1998a; SFWMD, 2006a). In other cases, the habitat may be physical, such as an open-water low salinity zone (SFWMD, 2002). Enhancing and maintaining these biological and physical habitats should lead to a generally healthy and diverse ecosystem. Once salinity requirements are known, a series of linked watershed and estuarine hydrodynamic models are used to estimate the amount of fresh water needed to meet the requirements of the VEC (Wan et al., 2002, 2006; Chang et al., 2008). Ecological models simulate the response of the VEC and predict the outcome of new management alternatives (Chang et al., 2008). **Table 12-2** summarizes these modeling tools.

The freshwater quantity required by the VEC may form the basis for setting Minimum Flows and Levels, establishing Water Reservations, and determining preferred flow or salinity envelopes that provide guidance for day-to-day management of freshwater discharges. While each of the coastal systems may have its own specific set of VECs, common to almost all District estuaries are submerged aquatic vegetation (SAV) and oysters. These VECs are routinely monitored in many systems by Restoration Coordination and Verification (RECOVER), an interagency Comprehensive Everglades Restoration Plan (CERP) program. Detailed methods for SAV and oyster monitoring programs are provided in the *Southern Indian River Lagoon and St. Lucie Estuary* section of this chapter.

In keeping with the goal of maintaining brevity, this year's chapter provides brief summaries of the status of key VECs in each of several priority estuaries, while giving more detailed descriptions of additional issues and results in the St. Lucie River and Caloosahatchee River (C-43 canal) estuaries. Each year, the District selects one or two of the estuaries to highlight. It should be noted that the St. Lucie River Estuary [St. Lucie Estuary (SLE)] and the Caloosahatchee River Estuary [(CRE) or Caloosahatchee Estuary] are included in the Northern Everglades and Estuaries Protection Program (NEEPP). Since a strong emphasis continued this past water year on these systems, they are highlighted again in this year's report.

The Caloosahatchee River and St. Lucie River Watershed Protection Plans (CRWPP and SLRWPP, respectively) have been developed in response to the state legislation, which authorized NEEPP [Section 373.4595, Florida Statutes (F.S.)]. The NEEPP requires the District, in collaboration with the Florida Department of Environmental Protection (FDEP) and the Florida Department of Agriculture and Consumer Services (FDACS), and in cooperation with local governments, to develop (1) the Lake Okeechobee Watershed Construction Project Phase II Technical Plan (P2TP), (2) the St. Lucie River Watershed Protection Plan, and (3) the Caloosahatchee River Watershed Protection Plan. The SLRWPP and CRWPP were submitted to the Florida legislature in January 2009.

Coordination efforts are ongoing for implementation of all three plans between the teams of the Caloosahatchee River and St. Lucie River Watershed Protection Plans and the team of the Lake Okeechobee Watershed Construction Project P2TP. Refinements to the Coastal Ecosystem Science Plan during Water Year 2009 (May 1, 2008–April 30, 2009) have concentrated on the Caloosahatchee River and Estuary and St. Lucie Estuary to support NEEPP. A science plan is also under development for the Loxahatchee River Estuary (LRE).

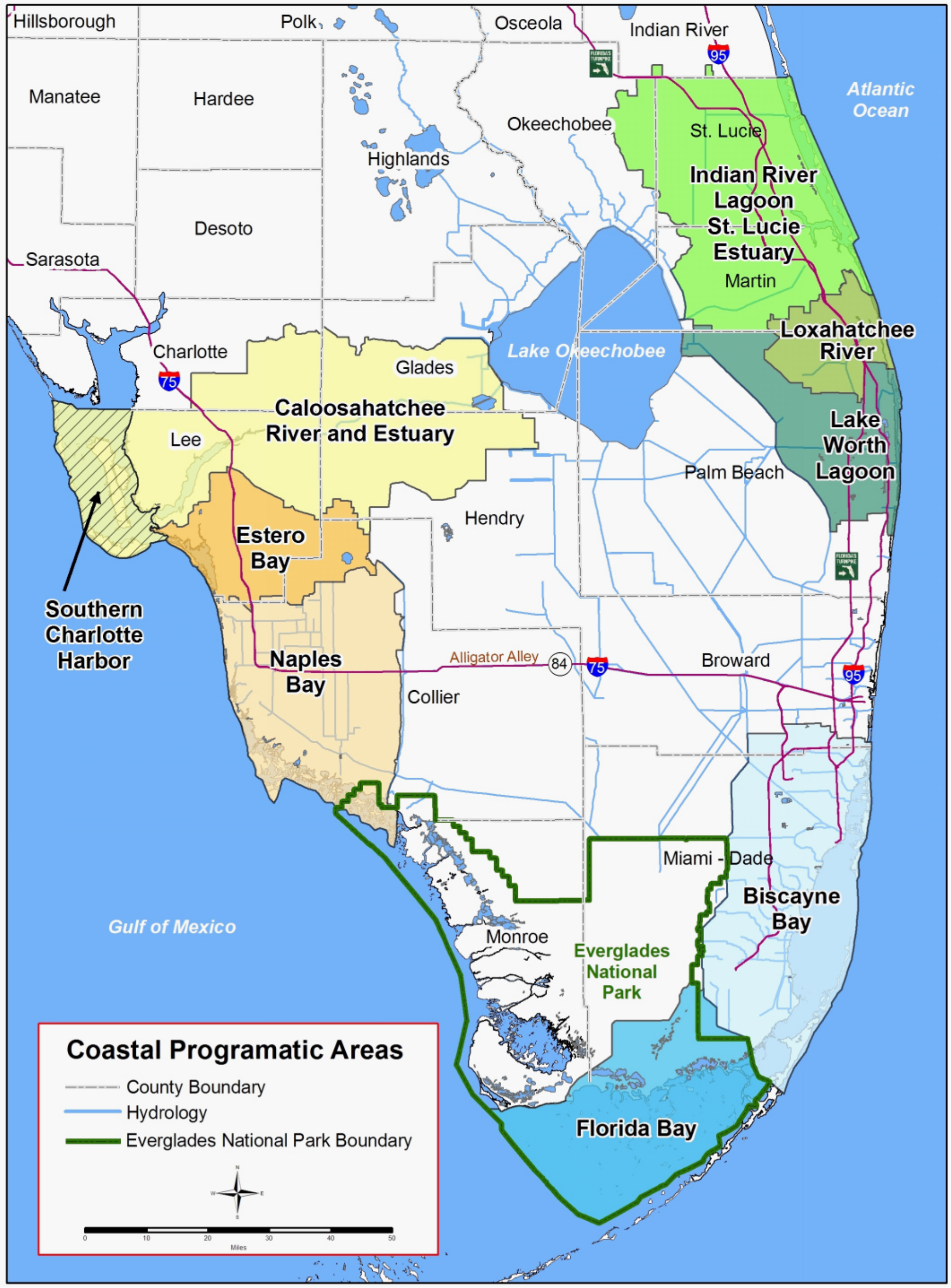

Figure 12-1. Priority coastal wetlands within the South Florida Water Management District (SFWMD or District).

Table 12-1. Estuaries of the SFWMD with general physical characteristics.

ESTUARY	AREA		VOLUME		DESCRIPTION
	km^2	mi^2	Mm^3	ac-ft (k)	
Southern Indian River Lagoon	126	49	242	196	Designated for special study, protection, and restoration as part of the regional National Estuary Program; characterized by the great species diversity; supports fishing, clamming, ecotourism, agriculture, and recreation.
St. Lucie River Estuary	34	13	81	66	Part of the Indian River Lagoon estuary system with drainage from several creeks and canals that flow into the North or South Fork of the St. Lucie River before entering the lagoon near the St. Lucie Inlet; receives discharges from Lake Okeechobee; provides habitat for thousands of plant and animal species, and supports commercial, recreational, and educational activities.
Loxahatchee River Estuary	6	2	12	10	First federally designated National Wild and Scenic River; watershed contains large tracts of undisturbed land, protected parcels, and agricultural land; diverse habitat includes coastal sand pine scrub, pinelands, xeric oak scrub, hardwood hammocks, freshwater marshes, wet prairies, cypress swamps, mangrove swamps, seagrass beds, tidal flats, oyster beds, and coastal dunes.
Lake Worth Lagoon	29	11	92	75	Watershed is mostly urbanized; lagoon was historically a freshwater lake with occasional brackish conditions; converted to a marine environment in the early 1900s with the opening of inlets; most runoff is conveyed into the lagoon through canals.
Biscayne Bay	718	277	1422	1153	Subtropical estuary with diverse habitats including hardground; designated as an aquatic preserve and Outstanding Florida or Outstanding National Resource Water; the southern portion is contained within Biscayne National Park or the Florida Keys National Marine Sanctuary; the northern watershed is urbanized, but the northern bay was historically brackish until the opening of inlets; most runoff is conveyed into the bay through canals; wetlands border the southwestern shoreline.
Florida Bay	2200	849	NA	NA	About 80 percent of the bay is within Everglades National Park; a broad, shallow expanse of brackish-to-salty water that contains numerous small islands, extensive mud banks, and grass flats; mangroves and seagrasses provide valuable habitat for many species; the Florida Keys Watershed consists of a limestone island archipelago of about 800 islands extending southwest for over 320 kilometers (200 miles) contained with the Florida Keys National Marine Sanctuary.
Naples Bay	2	4	4	3	Urbanized watershed with a physically altered shoreline and bottom; seagrass and oyster habitats have been greatly reduced since the 1920s; most runoff enters from the Golden Gate Canal.

Table 12-1. Continued.

ESTUARY	AREA		VOLUME		DESCRIPTION
	km^2	mi^2	Mm^3	ac-ft (k)	
Estero Bay	38	15	44	36	A shallow water body; several barrier islands separate the bay from the Gulf of Mexico; the bay has five rookery and roosting islands utilized by thousands of native birds; most runoff enters the bay from three primary rivers.
Caloosahatchee River Estuary	77	30	193	156	Caloosahatchee River flow mixes with the Gulf of Mexico; lower reaches of the estuary are characterized by a shallow bay, extensive seagrass beds and sand flats; extensive mangrove forests dominate undeveloped shoreline area; most runoff enters via the Caloosahatchee River, which can include excess water from Lake Okeechobee.
Southern Charlotte Harbor	150	58	330	268	Charlotte Harbor is Florida's second-largest open water estuary and one of the state's major environmental features; designated for special study, protection, and restoration as part of the regional National Estuary Program; area contains three national wildlife refuges and four aquatic preserves. The SFWMD's boundary includes the southern portion.

km^2 – square kilometer
mi^2 – square mile
Mm^3 – million cubic meters
ac-ft (k) – acre-feet per thousand

Table 12-2. Status of coastal modeling products for each estuary.

NUMERIC WATERSHED MODELS		
Watershed	**Present Conditions**	**Historical Conditions**
St. Lucie River and Southern Indian River Lagoon	Calibrated WASH Model for hydrology. Field data for inflows and water quality being collected for verification WASH water quality component under development (FDEP) Northern Everglades Regional Simulation Model HSP Model hydrology simulations completed	HSP Model hydrology simulations completed
Loxahatchee River	Calibrated WASH Model for hydrology Groundwater model under development RSM under development	RSM under development. will be converted to hindcast conditions
Lake Worth Lagoon	North Palm Beach County – Part I Project flow modeling ongoing using LECsR Modflow Model	NA
Biscayne Bay	SFWMM used, but not appropriate for all applications RSM developed WMM Model in development to estimate watershed loading A groundwater/surface water model under development (USGS)	NA
Florida Bay	SFWMM, USGS TIME Model calibrated	Natural System Model output used to estimate water levels
Naples Bay	NA	NA
Estero Bay	NA	NA
Caloosahatchee River and Estuary	HSPF (hydrology and water quality) and EFDC (hydrodynamic and water quality) under development (FDEP) (Calibrated MIKE SHE Regional Model for stage and flow (hydrology) Northern Everglades Regional Simulation Model AFSIRS/WATBAL Model	Natural system information for input to MIKE SHE Model is compiled
Southern Charlotte Harbor	NA	NA

Table 12-2. Continued.

NUMERIC ESTUARINE MODELS				
Estuary	**Hydrodynamics**	**Salinity**	**Water Quality**	**Sediment**
St. Lucie River Estuary and Southern Indian River Lagoon	CH3D calibrated; additional data being collected for verification	CH3D calibrated; additional data being collected for verification	CH3D calibrated; additional data being collected for verification	CH3D calibrated; additional data being collected for verification
Loxahatchee River Estuary	RMA calibrated; integrated surface/groundwater model under development	RMA calibrated; integrated surface/groundwater model under development	NA	NA
Lake Worth Lagoon	North Palm Beach EFDC Model will be used to establish flow targets to meet desired salinity ranges	North Palm Beach EFDC Model will be used to establish flow targets to meet desired salinity ranges	NA	North Palm Beach County – Part 1 flow modeling; ongoing using LECsR ModFlow Model
Biscayne Bay	Calibrated TABS-MDS Model	Calibrated TABS-MDS Model	NA	NA
Florida Bay	Calibrated EFDC Model	Calibrated EFDC Model and FATHOM mass balance completed	EFDC Model water quality developed, but not calibrated	NA
Naples Bay	CH3D Model under development	CH3D Model under development	NA	NA
Estero Bay	CH3D Model under development	CH3D Model under development	NA	NA
Caloosahatchee River Estuary	CH3D Model calibrated EFDC Model developed (FDEP)	CH3D Model calibrated and regression models used to estimate salinity EFDC Model developed	EFDC water quality component developed (FDEP) WASP Model developed (FDEP)	NA
Southern Charlotte Harbor	EFDC Model developed (FDEP)	EFDC Model developed (FDEP)	EFDC and WASP models developed (FDEP)	NA

Table 12-2. Continued.

	ECOLOGICAL MODELS				
Estuary	**SAV**	**Oyster**	**Fish**	**Floodplain or Wetlands**	**Other**
St. Lucie River Estuary and Southern Indian River Lagoon	NA	Spreadsheet model, daily time step of oyster stress/salinity	Under development; spawning and survival success of estuarine-dependent fishes	NA	
Loxahatchee River Estuary	NA	NA	NA	Under development; a Digital Elevation Model and plant species composition	
Lake Worth Lagoon	NA	NA	NA	NA	
Biscayne Bay	Salinity effects on turtle and shoal grass (*Thalassia/Halodule)* competition	NA	Salinity HSI models for shoreline fish	NA	Wading bird abundance based on water levels
Florida Bay	SEACOM Model (multispecies; complete for *Thalassia* and *Halodule*)	NA	General additive statistical models (populations and forage base) completed	NA	Pink shrimp (*Farfantepenaeus duorarum*) population model; lobster (*Panulirus argus*) population model; roseate spoonbill *(Ajaja ajaja*) statistical model; documentation underway
Naples Bay	NA	NA	NA	NA	
Estero Bay	NA	NA	NA	NA	
Caloosahatchee River Estuary	(1) HSI Model depends on predicted salinity and inflow; (2) tape grass (*Vallisneria*) numerical model with daily time step of density/salinity, light, and temperature	HSI Model (depends on predicted salinity and flow from models)	HSI Model (depends on predicted salinity and inflow from other models) — blue crabs (*Callinectes sapidus*), fish, and zooplankton	NA	Target Flow Index (spreadsheet model) that compares project flows to S-79 target flow distribution
Southern Charlotte Harbor	NA	NA	NA	NA	NA

Table 12-2. Continued.

MODEL INTEGRATION AND APPLICATION	
Estuary	**Description**
St. Lucie River Estuary and Southern Indian River Lagoon	Indian River Lagoon - South Feasibility Study Initial Water Reservation NEEPP St. Lucie River Watershed Protection Plan Ten Mile Creek Adaptive Management
Loxahatchee River Estuary	Restoration Plan for the Northwest Fork of the Loxahatchee River Scenarios for the North Palm Beach County – Part 1 Project
Lake Worth Lagoon	Scenarios for the North Palm Beach County – Part 1 Project
Biscayne Bay	Scenarios for Biscayne Bay Coastal Wetlands Project
Florida Bay	Scenarios for the Florida Bay and Florida Keys Feasibility Study Scenarios for the Minimum Flow and Level Rule development Scenarios for the C-111 Spreader Project
Naples Bay	Support the implementation of SWIM Plan and Southwest Florida Feasibility Study
Estero Bay	NA
Caloosahatchee River Estuary	C-43 Basin (CERP) Phase I and II Southwest Florida Feasibility Study NEEPP Caloosahatchee River Watershed Protection Plan Salinity Position Analysis associated with Lake Okeechobee operation
Southern Charlotte Harbor	NA

AFSIRS – Agricultural Field Scale Irrigation Requirements
CERP – Comprehensive Everglades Restoration Plan
CH3D – Curvilinear-grid hydrodynamics 3D hydrodynamic/salinity model
EFDC – Environmental Fluid Dynamics Code
FATHOM – Flux Accounting and Tidal Hydrology at the Ocean Margin
HSI – Habitat Suitability Index
HSP – Hydrological Simulation Program
HSPF – Hydrological Simulation Program - Fortran
LECsR – Lower East Coast Sub-regional
ModFlow – Modular finite-difference flow
MIKE SHE – MIKE System Hydrologique European
NA – No Model Available
NEEPP – Northern Everglades and Estuaries Protection Program
RMA – Resource Management Associates hydrodynamic model
RSM – Regional Simulation Model
SEACOM – Seagrass Ecosystem Assessment and Community Organization Model
SFWMM – South Florida Water Management Model
SWIM – Surface Water Improvement and Management Plan
TABS-MDS – Multidimensional hydrodynamic numerical model
TIME – Tides and Inflows in the Mangrove Ecotone
USGS – U.S. Geological Survey
WASH – WAterSHed system model
WASP – Water Quality Analysis Simulation Program
WATBAL – Water Balance Model
WMM – Watershed Management Model

ST. LUCIE RIVER AND CALOOSAHATCHEE RIVER WATERSHED PROTECTION PLANS

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The Northern Everglades and Estuaries Protection Program (Section 373.4595, F.S., 2007) legislation required the development of watershed protection plans for the three Northern Everglades watersheds: the Lake Okeechobee Watershed, the Caloosahatchee River Watershed, and the St. Lucie River Watershed (**Figure 12-2** and **Figure 12-3**). Accordingly, the CRWPP and the SLRWPP were developed by the SFWMD in coordination with the FDEP and the FDACS, and in cooperation with Lee, Martin, and St. Lucie counties. The plans were submitted to the Florida legislature on January 1, 2009. The three main components of the watershed protection plans are (1) a Watershed Construction Project that identifies water quality and storage projects to improve hydrology, water quality, and aquatic habitats within the watershed; (2) a Watershed Pollutant Control Program with a multifaceted approach to reducing pollutant loads by improving management of pollutant sources within the watershed; and (3) a Watershed Research and Water Quality Monitoring Program to monitor progress of the programs and the health of the estuaries (**Figure 12-2**). The CRWPP and SLRWPP will be implemented using a phased approach. Phase I will include projects initiated or constructed between 2009 and 2012 followed by subsequent phases. The watershed protection plans build upon existing and planned programs and projects, and successfully consolidate previous restoration efforts into a broader approach focused on restoring the entire Northern Everglades system.

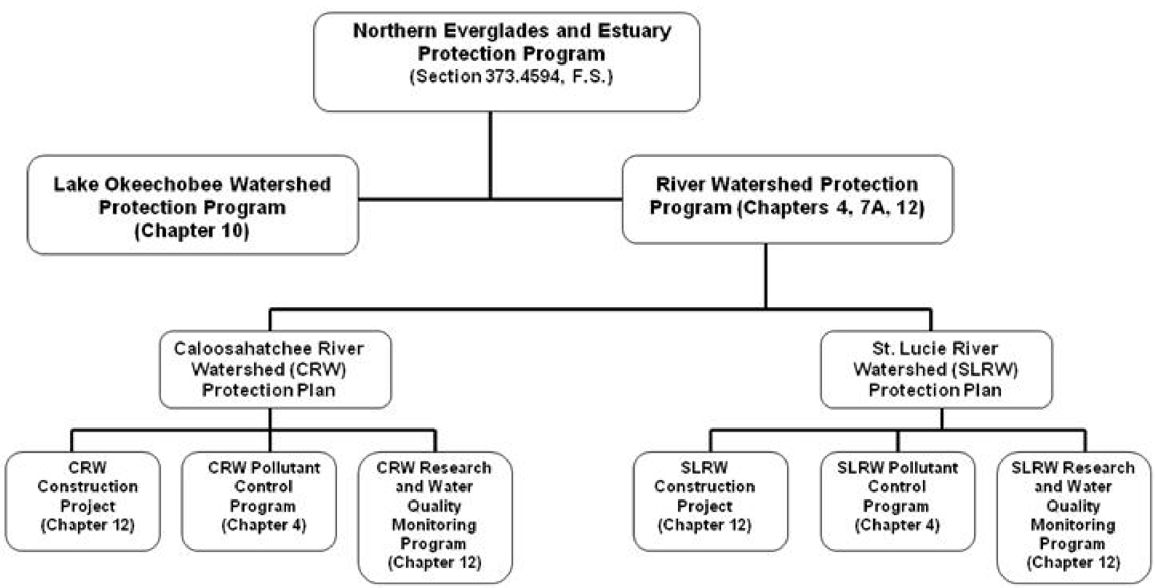


Figure 12-2. The Northern Everglades and Estuaries Protection Program (NEEPP) structure, outlining the River Watershed Protection Program elements and the chapters in the *2010 South Florida Environmental Report* (SFER) – *Volume I* where additional information is provided.

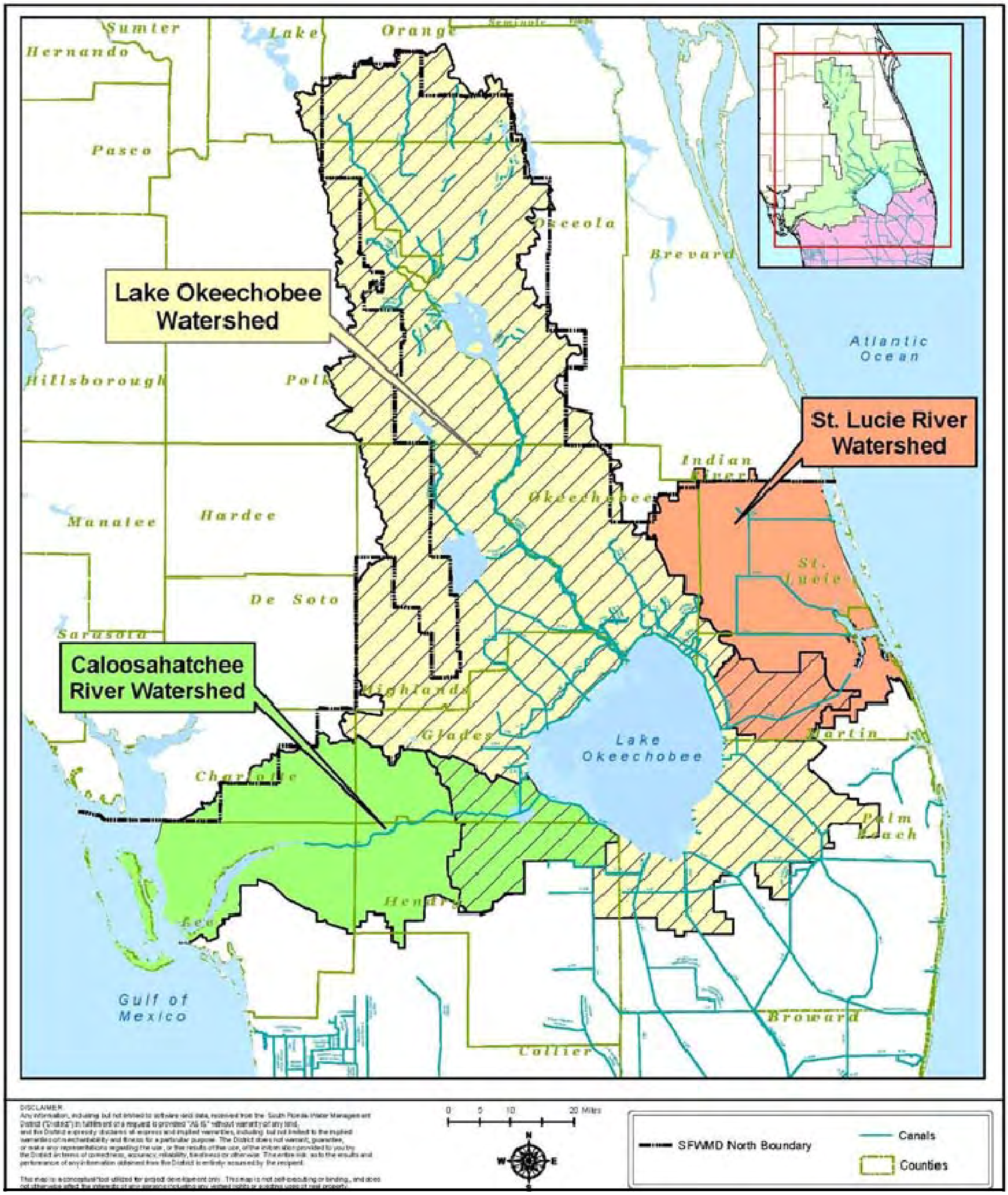


Figure 12-3. The NEEPP area as defined by the Florida legislature.

Major benefits of the CRWPP will include:

- Implementation of best management practices (BMPs) on more than 430,000 acres (ac) of agricultural lands and 145,000 ac of urban lands
- Completion of proposed rule revisions
- Construction of approximately 36,000 ac of reservoirs and 15,000 ac of Stormwater Treatment Areas (STAs), and restoration of more than 2,000 ac of wetlands
- Provision of approximately 400,000 acre-feet (ac-ft) of water storage within the Caloosahatchee River Watershed
- Potential reduction of total phosphorus (TP) loads to the Caloosahatchee Estuary by 166 metric tons per year (mt/yr) (39 percent) and total nitrogen (TN) loads by 1,840 mt/yr (38 percent)

Major benefits of the SLRWPP will include:

- Implementation of BMPs on more than 297,000 ac of agricultural lands and nearly 84,000 ac of urban lands
- Completion of proposed rule revisions
- Construction of approximately 11,800 ac of reservoirs and more than 8,500 ac of STAs and restoration of 95,000 ac of wetlands and natural areas in the St. Lucie River Watershed
- Provision of approximately 200,000 ac-ft of water storage within the St. Lucie River Watershed
- Potential reduction of TP loads to the St. Lucie Estuary by 209 mt/yr (55 percent) and TN loads by 1,210 mt/yr (56 percent)
- Removal of more than 8 million cubic yards (yd^3) of silty muck sediment from the St. Lucie Estuary

These river watershed protection plans (RWPPs) are based on the best available information to date, incorporating agricultural and urban BMPs to reduce pollutant loads at the source and green technologies to help remove excess nutrients and improve water quality. As additional data and understanding of the dynamics of the watersheds are developed and analyzed, features of these plans may be modified. Plan revisions will be included in the three-year plan updates, and annual progress reports will be submitted as required by NEEPP legislation. This approach allows for maximum flexibility in implementing proposed and additional management measures to achieve any adopted nutrient Total Maximum Daily Loads (TMDLs), desirable salinity ranges, flow regimes, and related restoration goals for the Caloosahatchee and St. Lucie River watersheds and receiving estuaries. The CRWPP and SLRWPP and their appendices are available at www.sfwmd.gov/northerneverglades.

The FDEP adopted nutrient TMDLs (TP and TN) for the St. Lucie Basin in March 2009 and for the Tidal Caloosahatchee (TN only) in June 2009. However, the TMDLs were under development at the time of the river watershed protection plan development process; hence, the plans use an interim goal of maximizing load reductions. The potential load reductions are based on the analyses conducted for the Caloosahatchee and St. Lucie River watersheds under the CRWPP and SLRWPP, which identified water quality projects to achieve the TMDLs, including source control, regional treatment projects, local water quality projects, etc.

This section constitutes the required annual progress report and provides updates on the status of projects and activities being implemented under each watershed protection plan by the District. Summaries of the conditions of hydrology, water quality, and aquatic habitat in the Caloosahatchee River and St. Lucie River watersheds are also provided in the *Southern Indian*

River Lagoon and St. Lucie Estuary and *Caloosahatchee River Estuary and Southern Charlotte Harbor* sections of this chapter. The Annual Work Plan for NEEPP is presented in Appendix 7A-5.

CALOOSAHATCHEE RIVER WATERSHED CONSTRUCTION PROJECT

The Caloosahatchee River Watershed Construction Project includes both regional and local components and identifies watershed storage and water quality projects needed to help improve the quality, timing, and distribution of water in the natural ecosystem. Several projects identified under Phase I of the CRWPP are currently under way, including the C-43 Water Quality Treatment and Testing Facility, the Spanish Creek/Four Corners Environmental Restoration Phase I Project, and the Powell Creek Algal Turf Scrubber.

C-43 Water Quality Treatment and Testing Facility

In September 2007, the District entered into an agreement with Lee County to develop a water quality treatment and testing facility near the Caloosahatchee River in the Caloosahatchee Basin. Pursuant to the agreement, the District purchased the Boma property (approximately 1,770 acres) to build the project. The purpose of the project is to provide TN treatment, with a focus on the conversion of bioavailable organic nitrogen (N) to a non-bioavailable form as well as other incidental nutrient treatment of Caloosahatchee Basin water upstream of the S-79 structure located within the Caloosahatchee River. It is anticipated that the project will include a water quality treatment area consisting of natural system treatment cells and flow-ways, pump station(s), hydraulic control and spillway structures, and other ancillary structures. Several major tasks have been completed, including cultural resources fieldwork and Phase I and II Environmental Site Assessments. Environmental remediation, topographic surveys, and water quality evaluation are currently under way. In addition, a work order is currently being drafted for the design of a testing facility to conduct pilot-scale studies and full-size testing prior to the design and construction of the full water quality treatment area. More information about this project is provided in Chapter 7A of this volume.

Spanish Creek/Four Corners Environmental Restoration Phase I

Four Corners is an area in southwestern Florida where the four counties of Charlotte, Glades, Lee, and Hendry meet. The natural surface flow patterns in the region have undergone drastic change due to the evolution of mostly agricultural and some residential development. Phase I of the project consists of several tasks currently underway, including (1) installation of monitoring wells and staff gauges to obtain initial data relative to existing surface water and groundwater levels within the project area; (2) surveys to obtain cross-sections of County Line ditch and associated infrastructure for use in modeling the existing flows; (3) permit coordination related to gopher tortoise (*Gopherus polyphemus*) relocation; and (4) work with Hendry County to coordinate County Line ditch clearance to improve flow conditions. Subsequent stages will include design recommendations for the restoration effort as well as design and construction of features based on available funding.

Powell Creek Algal Turf Scrubber

In August 2007, the District and Lee County entered into an agreement for the county to conduct a water quality project on the Powell Creek By-Pass canal, a tributary to the Caloosahatchee River. The project involves a pilot project using Algal Turf Scrubber™ technology to remove phosphorus (P) and N from the water. This technology, developed by Hydromentia, Inc., involves the cultivation of a mixed community of periphytic algae cultured on an engineered geomembrane through which nutrient-rich waters are discharged. Algae growing on the geomembrane are periodically scraped and collected with an automatic rake at a harvesting station. The purpose of this project is to evaluate the effectiveness of the Algal Turf Scrubber™ in treating both freshwater and estuarine waters given the location of the pilot unit. In the rainy season, the source water for the pilot unit will be upland storm water from the Powell Creek watershed; during the dry season, brackish water from the Caloosahatchee River will be treated.

Pilot project construction was completed, and influent and effluent data collection began in December 2008. The pilot unit is growing algae and generally working as expected by removing P and N. The Quarterly Operational Report for Quarter One, December 11, 2008, through March 12, 2009, indicated consistent water quality improvement averaging 38 percent TP removal and 12 percent TN removal. These removal rates are within the ranges projected within the Basis of Design Report submitted in October 2008. The second quarter of testing was completed in June 2009, and the Quarterly Operational Report for Quarter One and Two (December 11, 2008–June 11, 2009) has been submitted. For the combined first and second quarters, the report conveyed that the average percent TP removal was 24 percent and the average percent TN removal was 3 percent, indicating a decline in P and N removal in the second quarter. Contributing factors may have included vandalism, high variability in salinity levels, N fixation, and other surrounding environmental factors such as herbicide spraying of the canal. The third quarter of testing was completed September 10, 2009; however, the third Quarterly Operational Report is pending. Testing will be completed by the end of 2009, and the final report is slated for January 2010. Due to the above-mentioned factors and limited monitoring data submitted to date, it is not yet possible to make a definitive statement regarding its effectiveness.

CALOOSAHATCHEE RIVER WATERSHED POLLUTANT CONTROL PROGRAM

The Caloosahatchee River Watershed Pollutant Control Program is designed to be a multifaceted approach in reducing pollutant loads by improving the management of pollutant sources within the Caloosahatchee River Watershed. Such improvements will be made through (1) the implementation of regulations; (2) the development and implementation of BMPs; (3) the improvement and restoration of hydrologic function of natural and managed systems; and (4) the utilization of alternative technologies for pollutant reduction, such as cost-effective biologically based, hybrid wetland/chemical, and other innovative nutrient-control technologies.

Source control programs in the Caloosahatchee River Watershed are evolving and expanding through cooperative and complementary efforts by the FDEP, the FDACS, and the District. The NEEPP legislation further defined the responsibilities of coordinating agencies, including the FDACS' role in implementation of nutrient BMPs on agricultural lands and the FDEP's role in implementing source control programs, primarily targeting urban and non-agricultural issues within NEEPP watershed areas. The coordinating agencies will facilitate the utilization of federal, state, and local programs that offer opportunities for water quality treatment, including preservation, restoration, or creation of wetlands on agricultural lands.

As part of the overall source control program effort, the District developed a nutrient source control program project plan for the Caloosahatchee River Watershed in Fiscal Year 2009 (FY2009) October 1, 2008–September 30, 2009). The project plan provides a roadmap to implement a regulatory framework that will require on-site source controls to be implemented on all agricultural and non-agricultural lands within the watershed, including the establishment of water quality performance levels to assess if the collective implementation of on-site source controls is achieving the intended effect. The project plan comprises five sequenced activity phases. The first three activity phases (water quality monitoring, agricultural and urban pollutant source assessments, and performance measure development) will in turn be translated into implementation guidelines for the SFWMD through a rulemaking phase (fourth phase), which is expected to be completed by 2012. The fifth phase includes rule implementation, which will be initiated after 2012. In accordance with NEEPP legislation, the District's rulemaking phase will involve revising Chapter 40E-61, Florida Administrative Code (F.A.C.), to implement the District's nutrient source control program for the Caloosahatchee River Watershed. The coordinating agencies will be working out the details of resources, responsibilities, and efforts to implement each agency's respective statutory assignment at the same time. Chapter 4 of this volume contains more details on source control efforts for the Caloosahatchee River Watershed being implemented by the FDEP, the FDACS, and the District.

CALOOSAHATCHEE RIVER WATERSHED RESEARCH AND WATER QUALITY MONITORING PROGRAM

Research Program

The Caloosahatchee River Watershed Research and Water Quality Monitoring Plan (available at www.sfwmd.gov/northerneverglades) identified four research areas that supported the project goals of achieving pollutant load reductions, salinity envelopes, and freshwater inflow targets: (1) Estuarine Nutrient Budget, (2) Dissolved Oxygen Dynamics, (3) Low Salinity Nursery Zone, and (4) Light Attenuation in San Carlos Bay.

Updates on these projects are provided in the *Caloosahatchee River Estuary and Southern Charlotte Harbor* section of this chapter.

Water Quality Monitoring

The Caloosahatchee River Watershed Research and Water Quality Monitoring Plan assessed existing monitoring to identify gaps in the watershed. The recommended plan builds upon the existing monitoring efforts and made recommendations/modifications to these efforts to better achieve and assess the goals and targets of the CRWPP. A description of the existing monitoring program and site locations can be found at www.sfwmd.gov/northerneverglades under Appendix E of the CRWPP.

The most significant improvement to existing water quality monitoring in the Caloosahatchee Estuary west of S-79 was enhanced spatial coverage. Existing monitoring was confined to four stations in the upper and mid-estuary (see the *Caloosahatchee River Estuary and Southern Charlotte Harbor* section of this chapter. The plan recommended adding four stations in the lower estuary. Through the District's reengineering program, these stations have been added.

Assessment of existing monitoring also found that both flow and water quality monitoring in the watershed east of S-79 was inadequate. The monitoring plan recommended a reach-level monitoring program in the C-43 canal, but the information was insufficient to implement the plan effectively. Therefore, a pilot project to measure flows and loads to the C-43 canal from its major tributaries was implemented during the wet season of WY2009. The pilot project includes collection of biweekly flow and water quality data during the wet season at 16 tributary stations. This short-term project also aims to develop a dataset that can be used to establish the framework needed for regulatory source control rule development as described in Chapter 4 of this volume.

Based on the results of the monitoring program, the status of hydrology, water quality, and aquatic habitat is described in the *Caloosahatchee River Estuary and Southern Charlotte Harbor* section of this chapter.

ST. LUCIE RIVER WATERSHED CONSTRUCTION PROJECT

The St. Lucie River Watershed Construction Project includes the CERP Indian River Lagoon – South (IRL-S) Final Integrated Project Implementation Report projects and an array of local projects. Chapter 7A of this volume contains a status update on the IRL-S projects.

Some local projects are being implemented through a cost-sharing approach using state, District, and Martin County funds. The following provides a status update of these four projects, which aim to improve water quality in the St. Lucie River:

- **Old Palm City Phase 3 Stormwater Quality Improvement Project.** The objective is to improve water quality by developing a neighborhood stormwater quality management system. Land acquisition was completed in April 2009 with the closing on the final three lots. Acquisition of an additional two lots to increase the storage capacity of the project is currently under way.
- **North River Shores Vacuum Sewer System.** This project provides sanitary sewer service to approximately 450 single-family and multifamily parcels of land in the North River Shores area. The project, which includes the construction of an underground collection system and a vacuum sewage collection and pumping facility, will enhance water quality in the North Fork of the St. Lucie River by eliminating nutrient loading from septic systems. In addition, the project will route wastewater to the North Wastewater Treatment Plant, where it will be converted to irrigation-quality water for reuse. Construction plans are completed and the required permits have been received. Construction is expected to start by the end of calendar year 2009 (CY2009).
- **Manatee Creek Basin Water Quality Retrofit.** This project provides stormwater quality treatment for 135 of the 833 acres of residential, commercial, and industrial development that discharges into Manatee Pocket. Survey and redesign are complete. Phase II land acquisition is complete. Phase III project layout has been reconfigured and all essential parcels have been acquired, but additional parcels are still being identified.
- **Manatee Pocket Dredging.** The work covered under this project includes (1) dredging a navigation channel through the pocket measuring up to 10 feet (ft) deep and 100 ft wide, (2) removing accumulated muck in areas and at depths where seagrasses might recruit, and (3) adding signage and buoys. Public participation is ongoing. Permits from the FDEP and U.S. Army Corps of Engineers (USACE) have been obtained; however, modifications were requested to allow for additional dredging flexibility. A contractor has been selected, and mobilization of equipment is under way. Construction is expected to start by the end of 2009.

ST. LUCIE RIVER WATERSHED POLLUTANT CONTROL PROGRAM

The St. Lucie River Watershed Pollutant Control Program is designed to be a multifaceted approach in reducing pollutant loads by improving the management of pollutant sources within the St. Lucie River Watershed. Approaches to reduce pollutant loads include: (1) the implementation of regulations; (2) the development and implementation of BMPs; (3) the improvement and restoration of hydrologic function of natural and managed systems; and (4) the utilization of alternative technologies for pollutant reduction, such as cost-effective biologically based, hybrid wetland/chemical, and other innovative nutrient control technologies.

Pollutant control is integral to the success of any water resource protection or restoration program. Source control programs in the St. Lucie River Watershed are evolving and expanding through cooperative and complementary efforts by the FDEP, the FDACS, and the District. The NEEPP legislation further defined the responsibilities of coordinating agencies, including the

FDACS' role in implementation of nutrient BMPs on agricultural lands and the FDEP's role in implementing source control programs, primarily targeting urban and non-agricultural issues within NEEPP watershed areas. The coordinating agencies will facilitate the utilization of federal, state, and local programs that offer opportunities for water quality treatment, including preservation, restoration, or creation of wetlands on agricultural lands.

As part of the overall source control program effort, the District developed a nutrient source control program project plan for the St. Lucie River Watershed in FY2009. The project plan provides a roadmap to implement a regulatory framework that will require on-site source controls to be implemented on all agricultural and non-agricultural lands within the watershed, including the establishment of water quality performance levels to assess if the collective implementation of on-site source controls is achieving the intended effect. The project plan comprises five sequenced activity phases. The first three activity phases (water quality monitoring, agricultural and urban pollutant source assessments, and performance measure development) will in turn be translated into implementation guidelines for the SFWMD through a rulemaking phase (fourth phase) which is expected to be completed by 2012. The fifth phase includes rule implementation, which will be initiated after 2012. In accordance with NEEPP legislation, the District's rulemaking phase will involve revising Chapter 40E-61, F.A.C., to implement the District's nutrient source control program for the St. Lucie River Watershed. The coordinating agencies will be working out the details of resources, responsibilities, and efforts to implement each agency's respective statutory assignment at the same time. Chapter 4 of this volume contains more details on source control efforts for the St. Lucie River Watershed being implemented by the FDEP, the FDACS, and the District.

ST. LUCIE RIVER WATERSHED RESEARCH AND WATER QUALITY MONITORING PROGRAM

Research Program

The St. Lucie River Watershed Research and Water Quality Monitoring Plan (www.sfwmd.gov/northerneverglades) identified three research areas that supported the project goals of achieving pollutant load reductions, salinity envelopes, and freshwater inflow targets: (1) Estuarine Nutrient Budget, (2) Dissolved Oxygen Dynamics, and (3) Low Salinity Nursery Zone. Updates on these projects are provided in the *Southern Indian River Lagoon and St. Lucie Estuary* section of this chapter.

Water Quality Monitoring

Assessment of existing monitoring showed that the current monitoring efforts in the St. Lucie River Watershed are adequate. Therefore, the St. Lucie River Watershed Research and Water Quality Monitoring Plan recommended continuing existing monitoring efforts and optimizing the existing watershed network. A description of the existing monitoring program and site locations can be found at www.sfwmd.gov/northerneverglades under Appendix E of the SLRWPP. Based on the results of monitoring program, the status of hydrology, water quality, and aquatic habitats is described under the *Southern Indian River Lagoon and St. Lucie Estuary* section of this chapter.

SOUTHERN INDIAN RIVER LAGOON AND ST. LUCIE RIVER ESTUARY

Zhiqiang Chen, Marion Hedgepeth, Rebecca Robbins,
Detong Sun, Daniel Haunert, Chris Buzzelli and Rod Braun

DESCRIPTION OF STUDY AREA AND MAJOR ISSUES

The St. Lucie Estuary is a relatively large brackish water body on the east-central coast of Florida in Martin and St. Lucie counties, and is a primary tributary to the Southern Indian River Lagoon (SIRL) (**Figure 12-4**). Most of the watershed drains into the North and South Forks [6.4 square miles (sq mi) or 16.6 square kilometers (km^2)] that converge and flow to the middle estuary (4.7 sq mi; 12.2 km^2), which extends east for about 5 miles [8 kilometers (km)] to the Indian River Lagoon (IRL) and the Atlantic Ocean at the St. Lucie Inlet.

Historically, the SLE was a freshwater system that was exposed to ocean waters only when large storms opened ephemeral passes in the protective barrier islands. In 1892, however, the St. Lucie Inlet was dredged and maintained to provide a connection with ocean waters, allowing for a partially mixed tidal estuary. The typical tidal range and tidal current are about 0.20 meters (m) and approximately (~) 0.2 meters per second (m/s), respectively. The dominant tidal constituent is M2 (= 12.42 h) with a typical tidal prism of about 8.9 x 106 cubic meters (m^3) and a tidal excursion of about 2–4 km (Ji et al., 2007). Depending on the freshwater discharge, the residence time of the SLE was estimated to range from days to months (Ji et al., 2007).

To accommodate human development, the SLE watershed has also been highly altered from natural sloughs and wetlands to a complex drainage system of canals (**Figure 12-4**). As part of a South Florida flood control project, the South Fork of the estuary was connected to Lake Okeechobee to control water levels in 1924 via Canal 44. Periodic high-volume flood control discharges from the lake can turn the entire estuary to fresh water, from days to months at a time, causing considerable negative impacts to the system. Between 1935 and 1960, an extensive drainage system was constructed in the watershed, which included dredging and channelizing the North Fork Narrows and C-23 and C-24 canals.

These projects changed the geomorphology of the SLE system, altered the watershed, and exerted significant stresses on riverine and estuarine resources. As a result, dramatic changes have occurred in the quantity, quality, timing, and distribution of inflows to the estuary, causing degradation in estuarine resources, such as losses in SAV, oyster communities, and fisheries (URS Greiner Woodward Clyde, 1999).

To restore and protect the estuarine resources, a Minimum Flows and Levels (MFLs) rule for the North Fork of the St. Lucie Estuary was established in 2002 (SFWMD, 2002). The rule states that monthly average inflows at the Gordy Road structure should not fall below 28 cubic feet per second (cfs) (0.8 m^3/s) for two consecutive months. The intent of this MFL Rule is to protect the low salinity nursery zone in the North Fork of the St. Lucie River. To protect historic oyster beds in the middle estuary, a flow envelope was developed as part of the CERP Indian River Lagoon – South Project. Based on developed relationships between inflows and estuary salinity, preferred monthly average inflows from the watershed, groundwater, and/or from Lake Okeechobee should range from 350–2000 cfs (~10–56 m^3/s). These flows will maintain salinity in the range of 8–25 practical salinity units (psu) at the Roosevelt Bridge.

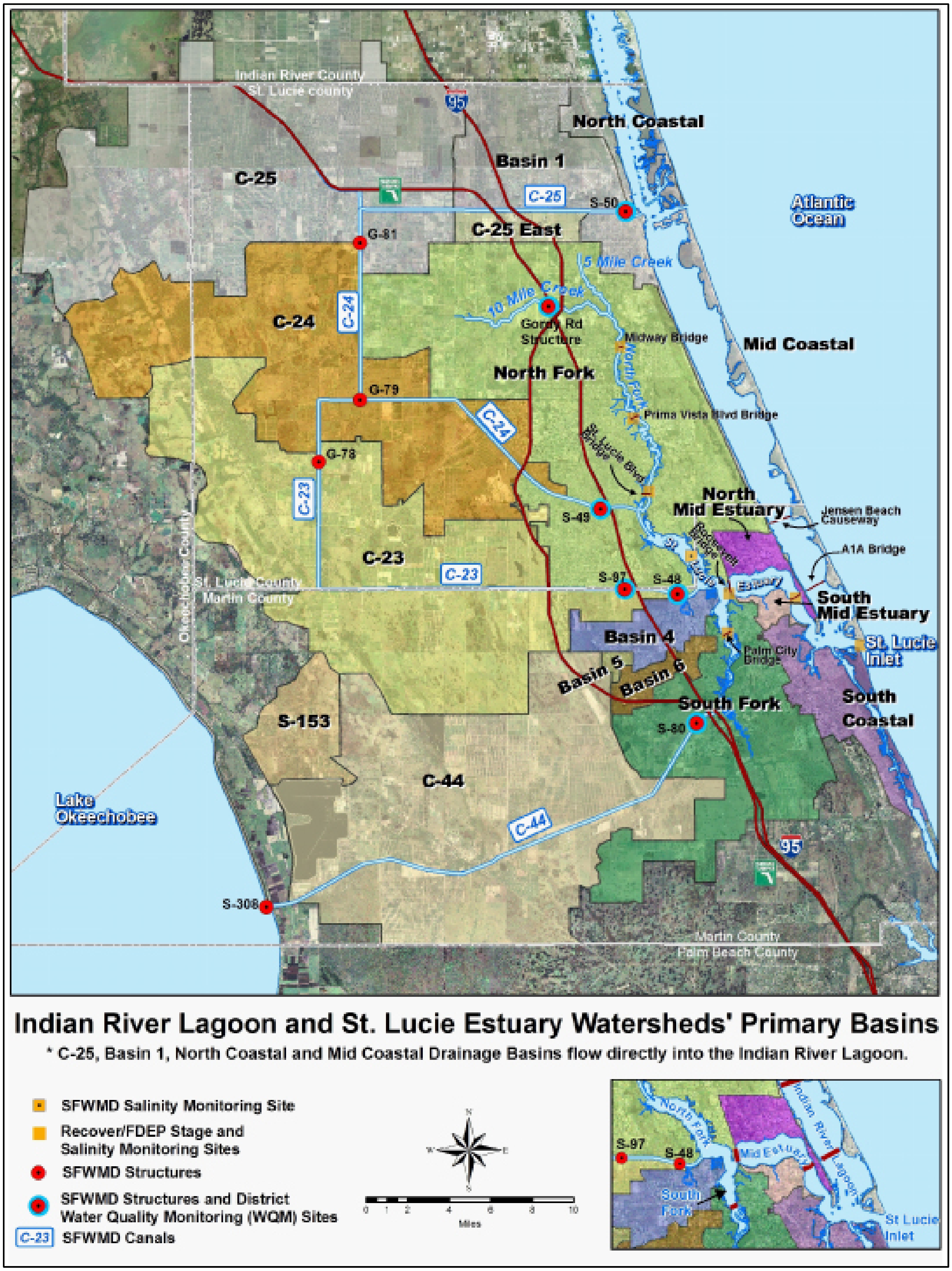


Figure 12-4. The primary basins in the Indian River Lagoon and St. Lucie watersheds.

STATUS OF THE ST. LUCIE ESTUARY

This section provides a summary of freshwater inflows to the SLE, salinity and water quality in the estuary, and the status of three VECs (SAV, oysters, and floodplain vegetation).

Freshwater Inflows and Salinity in the St. Lucie Estuary

Freshwater inflows to the SLE in WY2009 were about twice those in WY2008 (**Table 12-3**). The increases are primarily due to significantly higher flow rates in August and September 2008 [daily flow greater than (>) 10,000 cfs], which resulted from Tropical Storm Fay (**Figure 12-5**). Discharges attributable to Tropical Storm Fay came from both the local watershed and flood control releases from Lake Okeechobee (**Figure 12-5** and **Table 12-3**). During these months, the flow rates exceeded the recommended maximum flow rate of 2,000 cfs. Because of the drought conditions that extended into WY2009, annual freshwater inflow was still lower than the long-term mean (**Table 12-3**), and the contribution of water from Lake Okeechobee to the total inflow (~24 percent) was relatively smaller than the long-term mean (41 percent, **Table 12-3**).

Salinity responded to flow rates in a predictable way; that is, high flow rates decrease salinity in the SLE. The lowest salinity levels were observed in October of WY2008 and August of WY2009 in the main estuary (**Figure 12-5)**, which coincided with the highest flow rates in those two months. However, responses of the lower estuary to flow rates are different between WY2008 and WY2009. No apparent low salinity water was observed in WY2008 in the lower estuary, whereas pronounced lower salinity waters were observed in WY2009. This is apparently due to the different freshwater inflows in these two years.

Flow at the Gordy Road structure never fell below 28 cfs (0.8 m^3/s) (**Figure 12-6**) during WY2009. The MFL criteria for the North Fork of the St. Lucie Estuary were not exceeded in WY2009.

Table 12-3. Annual summary of freshwater flows and nutrient loads to the St. Lucie Estuary (SLE) from gauged structures S-80, S-49, S-48, and Lake Okeechobee for Water Years (WY) 1992–2007, WY2008 (May 1, 2007–April 30, 2008), and WY2009 (May 1, 2008–April 30, 2009).

Water Year	Total freshwater flow (m^3x106)	Total freshwater from Lake Okeechobee (m^3x106)	TP (mt)	TP from Lake Okeechobee (mt)	TN (mt)
Average WY1992–2007	928	387	243	63	1,555
WY2008	258	0	110	0	430
WY2009	517	126	234	23	891

m^3 – cubic meter
mt – metric ton
TP – total phosphorus
TN – total nitrogen

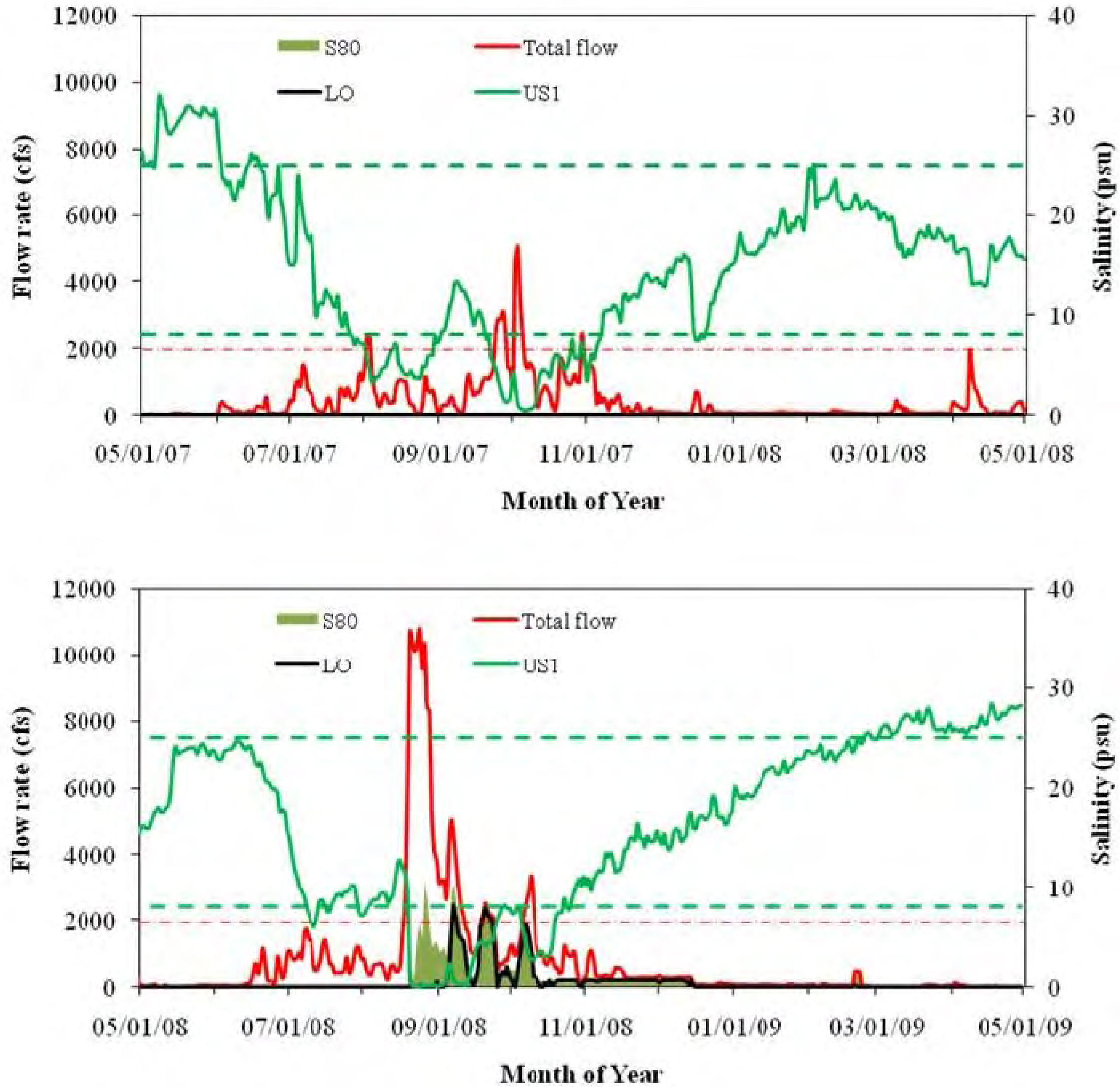


Figure 12-5. Daily flows (cubic feet per second, or cfs) from S-80 (light green), S-308 (Lake Okeechobee, LO, black line) and total flow (red lines) from S-80, S-48, S-49, Gordy Road, and surface salinity [~1.0 meter (m), practical salinity units (psu)] at the U.S. Highway 1 station (US1, green line) in WY2008 (top panel) and WY2009 (bottom panel), respectively. The two dashed green lines represent the salinity envelope (8–25 psu) at US1, whereas the red dashed lines represent the maximum freshwater inflow of 2,000 cfs to ensure the proper salinity envelope in the SLE.

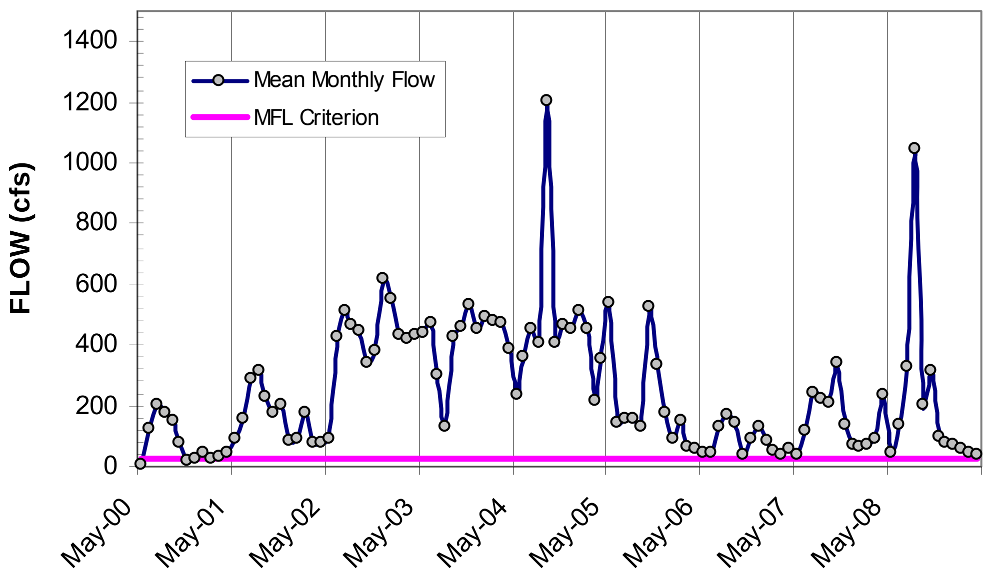


Figure 12-6. Average monthly freshwater flow to the North Fork (Gordy Road structure) compared with the minimum flow criterion (cfs) [0.8 cubic meters per second (m^3/s)]. A violation occurs when freshwater flow falls below 28 cfs for two consecutive months and two consecutive years.

Nutrient Loading from Watershed and Trends

Loadings of TN and TP to the SLE from canal inflows were estimated using inflow and nutrient concentration data collected by the District from WY1992–WY2009 (**Table 12-3**). The average annual loading from canals totaled 1,555 metric tons per year (mt/yr) for TN and 243 mt/yr for TP during WY1992–WY2007. Interannual variation in freshwater discharge accounts for up to 80 percent of the variation in TN and TP loads (Wan et al., 2003). Thus, like flow rates, loads of both TN and TP in WY2009 nearly doubled compared with those in WY2008 (**Table 12-3**). The contributions of TN and TP from Lake Okeechobee also significantly increased in WY2009 due to increasing freshwater discharges to the estuary. The nutrient loadings for TN and TP in WY2008 and WY2009 were still below the long-term means.

The above nutrient loads were calculated using data only from gauged structures S-80, S-49, S-48, and Lake Okeechobee. The nutrients are also delivered into the SLE from ungauged tributary basins where flow rates and water quality data are not available. Previous modeling results showed that canal inputs are dominant sources for both freshwater flows and nutrient loads, accounting for about 85 percent of total flows and TN and TP from all inputs (Wan et al., 2003).

The Seasonal Kendall test was used to detect temporal trends in freshwater flows, TN, and TP from canal inputs during WY1992–WY2009. No statistically significant trends were detected ($p > 0.05$, $n = 216$).

Water Quality in the Estuary

Monitoring water quality and understanding water quality variations are critical to develop sound and science-based management decisions and to evaluate the effectiveness of those management activities on the estuarine system. The District has maintained an extensive water quality monitoring program in the SLE since 1990 (**Figure 12-7)**. The monitoring frequency is primarily monthly for a suite of water quality parameters, including nutrients, trace metals, dissolved oxygen (DO), and chlorophyll *a* (Chl*a*). Previous South Florida Environmental Reports (SFERs) (SFWMD, 2008; 2009a) and the CERP RECOVER system status reports (RECOVER, 2007b) have reported general spatial and temporal distributions of water quality parameters in the SLE.

The major findings are as follows:

- Distinctive spatial gradient of most water quality parameters from North and South Forks to the mouth of the SLE as a result of nutrient-laden freshwater inflows to the upper estuary
- Distinctive seasonal variability of most water quality parameters can be attributed to seasonal variation of freshwater inputs; thus, temporal changes in water quality are focused on the relationship with watershed discharge

The results of some water quality parameters that characterize water quality conditions are given, and the results for the last two water years are compared with long-term statistics. These selected parameters are:

- Salinity
- Secchi disk depth
- Nutrients [TP, TN, dissolved inorganic nitrogen (DIN), and orthophosphate (OPO_4)]
- Chl*a*

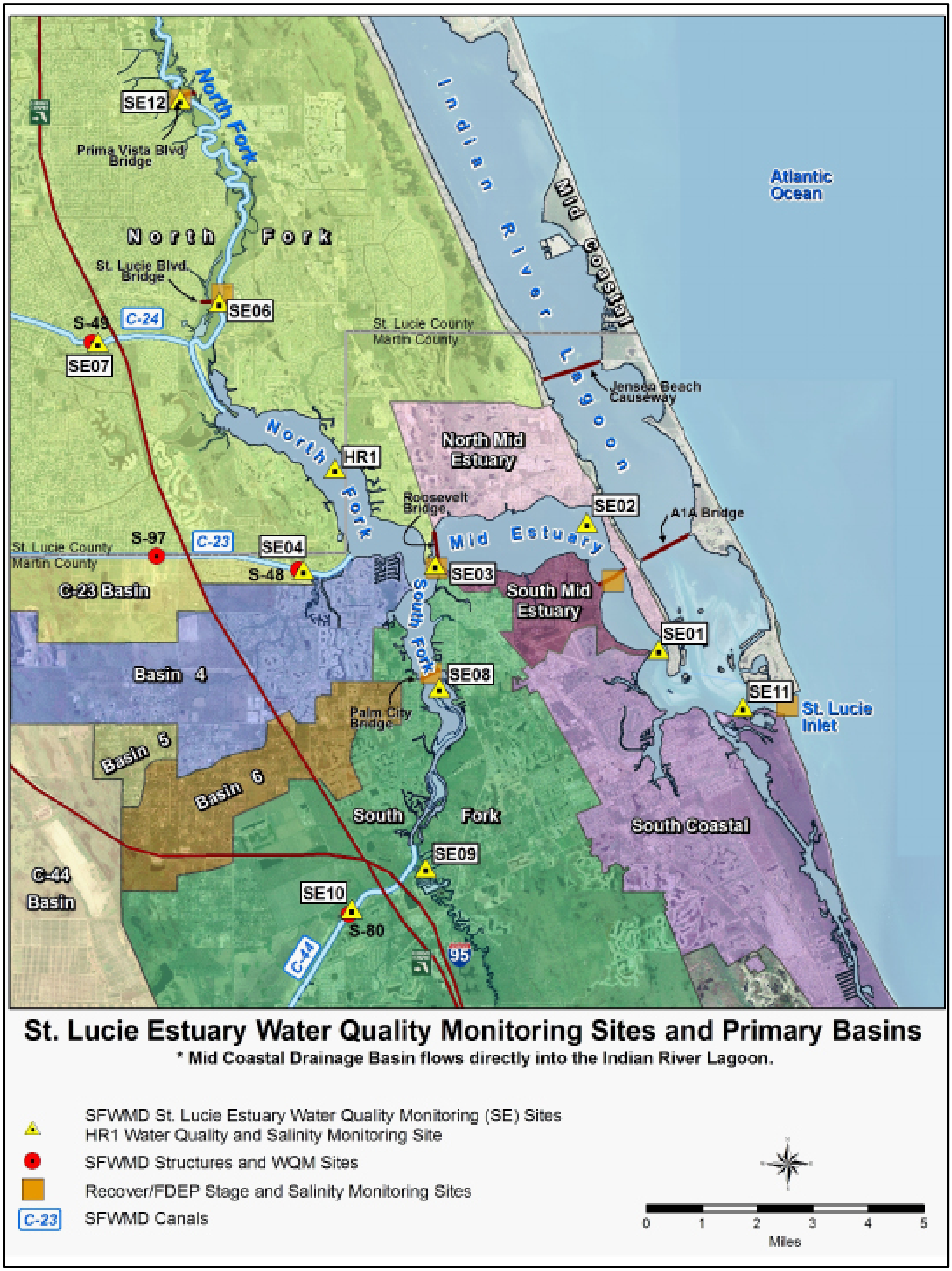


Figure 12-7. Location of water quality monitoring stations in the SLE.

In addition, the estuary was divided into four segments (**Figure 12-7**) (1) the inlet (SE11); (2) main estuary (SE01, SE02, and SE03); (3) North Fork (SE04, HR1, SE06, and SE07); and (4) South Fork (SE08, SE09, SE10). In each section, one station was selected to represent conditions in WY2008 and WY2009 and mean conditions during the period of record (POR) from WY1992–2007. **Table 12-4** shows the statistical summaries of those selected parameters in four segments for these time frames.

To further illustrate the changes of these parameters relative to long-term means, monthly values of several parameters in the upper estuary (HR1) and at the mouth of the estuary (SE11) for WY2008 and WY2009 were plotted in **Figure 12-8.**

Nutrient concentrations were typically near annual maxima during August and September, which coincides with the greatest freshwater inflows (**Figure 12-8**). By contrast, water clarity declined. Phytoplankton responded to freshwater inflows differently in the upper estuary and at the mouth of estuary. Over the long term, annual chlorophyll *a* concentration maxima tend to coincide with nutrient maxima. The lower chlorophyll *a* concentration in the upper estuary is primarily due to the wash-out effects of high freshwater flows on phytoplankton concentrations (Chamberlain and Hayward, 1996; Doering, 2006). The increased chlorophyll *a* concentration at the mouth of estuary may be due to a combination of higher light levels and enhanced nutrient supply.

Analysis of long-term monthly data (WY1992–WY2009) using the Seasonal Kendall Tau statistic did not reveal any significant trends in water quality ($p > 0.05$, $n = 216$).

Table 12-4. Statistical summary of selected water quality parameters in WY2008 and WY2009 and mean conditions from WY19991–WY2007.

Water Years	WY1992–2007				WY2008				WY2009			
Parameter	mean	25th	50th	75th	mean	25th	50th	75th	mean	25th	50th	75th
South Fork (SE 08B)												
Salinity (psu)	3.85	0.18	0.82	5.45	12.31	8.75	9.64	15.70	9.69	0.24	8.39	18.20
Secchi disk depth (m)	0.31	0.11	0.21	0.49	0.55	0.50	0.55	0.65	0.55	0.30	0.55	0.80
Total nitrogen (mg/L)	1.48	1.06	1.38	1.82	1.11	0.86	0.99	1.31	1.01	0.69	1.13	1.34
Dissolved inorganic nitrogen (mg/L)	0.37	0.24	0.37	0.53	0.18	0.11	0.17	0.23	0.16	0.04	0.19	0.29
Total phosphorus (mg/L)	0.222	0.160	0.220	0.280	0.218	0.160	0.220	0.270	0.165	0.130	0.150	0.220
Ortho phosphorus (mg/L)	0.102	0.060	0.080	0.130	0.149	0.110	0.130	0.190	0.097	0.070	0.090	0.120
Chlorophyll *a* (mg/L)	9.34	4.00	7.00	15.00	18.33	8.00	9.00	15.00	8.29	6.00	8.00	9.00
North Fork (HR1)												
Total nitrogen (mg/L)	1.10	0.86	1.09	1.31	0.96	0.66	1.09	1.19	0.89	0.55	0.71	1.05
Salinity (psu)	8.81	1.90	6.91	14.90	12.07	5.00	13.40	17.70	12.03	3.29	14.80	19.50
Secchi disk depth (m)	1.06	0.75	1.00	1.31	0.63	0.50	0.65	0.85	0.85	0.67	0.96	1.10
Dissolved inorganic nitrogen (mg/L)	0.12	0.01	0.04	0.21	0.10	0.02	0.04	0.26	0.07	0.01	0.02	0.13
Total phosphorus (mg/L)	0.205	0.140	0.190	0.240	0.236	0.110	0.260	0.340	0.179	0.130	0.150	0.240
Ortho phosphorus (mg/L)	0.159	0.090	0.150	0.200	0.174	0.070	0.190	0.220	0.126	0.100	0.100	0.170
Chlorophyll *a* (mg/L)	12.04	5.70	9.50	14.20	10.33	6.00	9.00	15.00	8.00	4.00	8.00	11.00
Main Estuary (SE 03)												
Salinity (psu)	12.31	4.90	12.10	18.90	16.83	13.90	16.80	21.50	14.88	4.17	17.50	23.70
Secchi disk depth (m)	0.95	0.62	0.97	1.22	0.58	0.45	0.65	0.80	0.76	0.50	0.80	0.85
Total nitrogen (mg/L)	1.07	0.76	1.00	1.33	0.91	0.64	0.85	1.17	0.79	0.59	0.67	1.05
Dissolved inorganic nitrogen (mg/L)	0.16	0.03	0.11	0.26	0.11	0.03	0.09	0.22	0.08	0.02	0.05	0.14
Total phosphorus (mg/L)	0.184	0.120	0.160	0.210	0.198	0.110	0.190	0.280	0.152	0.110	0.120	0.210
Ortho phosphorus (mg/L)	0.134	0.080	0.120	0.180	0.136	0.070	0.130	0.200	0.096	0.060	0.080	0.150
Chlorophyll *a* (mg/L)	9.60	4.80	7.20	12.00	10.75	5.00	6.00	9.00	6.86	5.00	6.00	8.00
Inlet (SE 11)												
Salinity (psu)	27.51	23.90	29.31	33.00	33.64	32.10	35.00	35.70	30.20	33.10	34.40	35.70
Secchi disk depth (m)	1.23	0.95	1.25	1.50	1.00	0.65	0.90	1.20	1.74	1.10	1.80	2.40
Total nitrogen (mg/L)	0.68	0.28	0.63	0.87	0.28	0.20	0.28	0.37	0.35	0.12	0.16	0.49
Dissolved inorganic nitrogen (mg/L)	0.09	0.02	0.04	0.14	0.02	0.01	0.01	0.03	0.06	0.00	0.01	0.06
Total phosphorus (mg/L)	0.08	0.03	0.05	0.10	0.03	0.02	0.03	0.04	0.05	0.01	0.01	0.07
Ortho phosphorus (mg/L)	0.046	0.010	0.030	0.060	0.011	0.004	0.010	0.010	0.026	0.002	0.006	0.040
Chlorophyll *a* (mg/L)	4.06	2.00	3.00	4.80	2.71	1.00	2.00	4.00	2.25	0.50	2.00	4.00

Note: All parameters were sampled at mid-depth of water column except Secchi disk depth
m – meter
mg/L – milligrams per liter
psu – practical salinity units

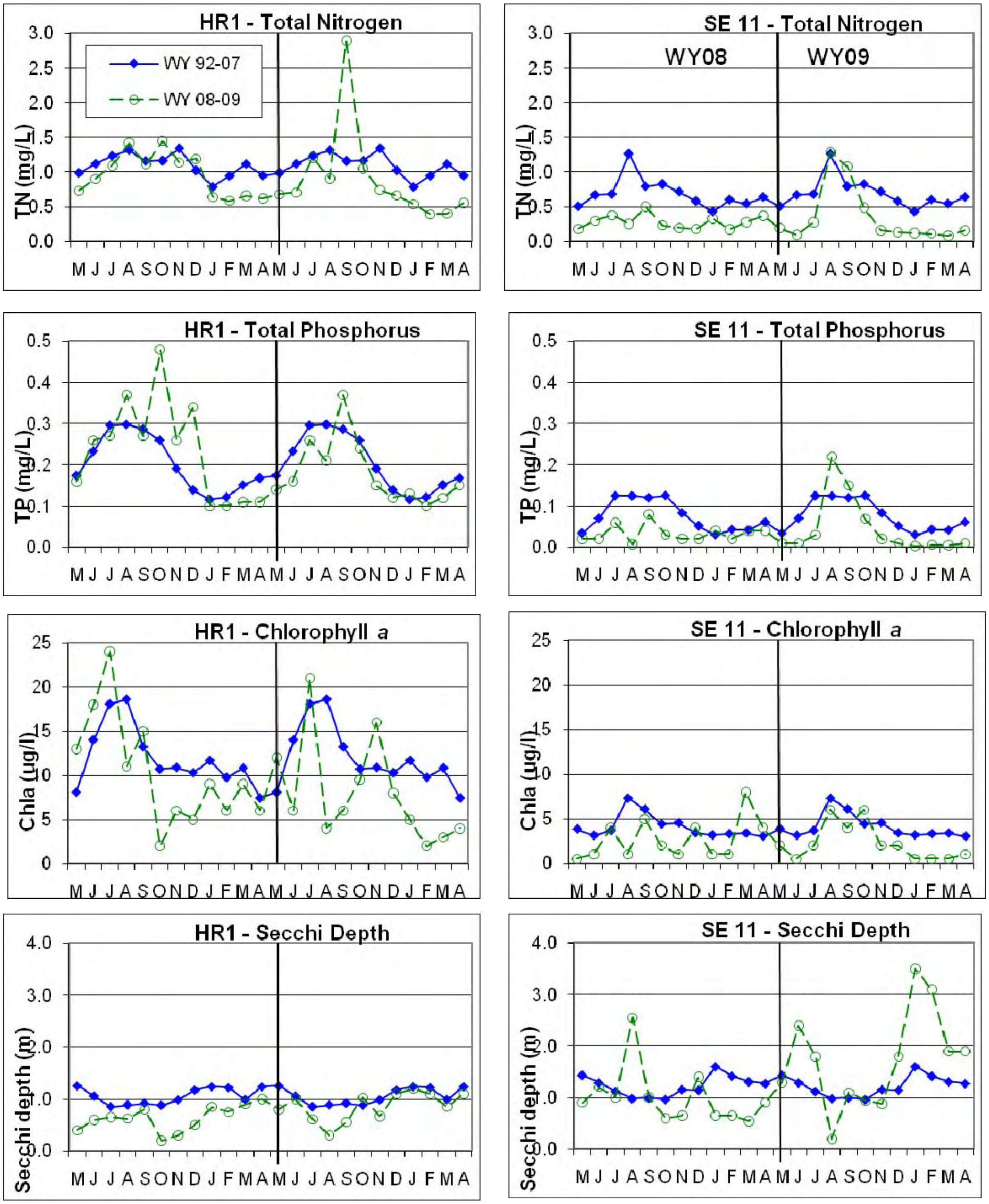


Figure 12-8. Monthly total nitrogen (TN) [milligrams per liter (mg/L)], total phosphorus (TP) (mg/L), chlorophyll *a* (Chl*a*) [micrograms per liter (µg/L)], and Secchi disk depth (m) in the North Fork (at HR1) and inlet (at SE11) during WY2008 and WY2009 (open green circles) compared with monthly mean (filled diamonds) from WY1992–WY2007.

Submerged Aquatic Vegetation

Seagrasses, often referred to as SAV, are considered indicators of ecosystem health. SAV mapping and monitoring data provide valuable information for assessing the health of an estuary, and for making water management decisions regarding the impacts of freshwater releases on marine resources (Doering et al., 2002; Thayer et al., 1984; Tomasko et al., 1996). SAV monitoring in the SLE/SIRL system is conducted at two spatial scales: (1) landscape scale (mapping from aerial photographs), and (2) patch scale (in situ monitoring using transects and/or quadrats). The map data provide an estuary-wide picture of SAV distribution and allow for evaluation of large-scale distribution changes (trends and natural variation) over time. Patch scale monitoring provides the ability to detect small-scale changes over time. More importantly, this in situ monitoring provides species-specific data — a level of detail that cannot be obtained from maps created by using aerial photographs.

Of the six species of true seagrasses that occur in the SIRL and SLE, Johnson's seagrass (*Halophila johnsonii*) is the only species listed as "threatened" by the federal government. This listing is due to its limited geographic distribution; Johnson's seagrass has only been found from just north of Sebastian Inlet to northern Biscayne Bay. One of 10 sites identified as critical habitat is located in the SIRL near the mouth of the SLE. The designation as "critical habitat" means the federal government has determined that the designated area is vital to the conservation of the listed species.

Seagrass restoration/preservation targets for the SIRL and SLE are based on depth targets for the deep edge of the bed. A 1994 study determined that a depth target of about 1 m was recommended for SAV restoration in the SLE (Steward et al., 1994). Depth targets will vary throughout the lagoon based on how deep light can penetrate through the water column to support seagrass growth. Other depth targets currently being considered for the SIRL are 1.3 m (based on Crean et al., 2007, which compared water quality data and seagrass deep edge depth in the SIRL) and 1 m for areas in and near the St. Lucie River (Steward et al., 1994).

Submerged Aquatic Vegetation Mapping

Indian River Lagoon. Lagoon-wide SAV mapping from aerial photography is normally done in partnership with the St. Johns River Water Management District every two to three years to document trends over time. The most recent map was created in 2007 and presented in the 2009 SFER – Volume I, Chapter 12 (SFWMD, 2009a)**.** The 2009 mapping effort was completed. Aerial images were acquired in June and July 2009. The SFWMD is currently ground-truthing the data to support this effort. Map preparation is contracted out and dependent on funding availability.

Changes in SIRL SAV acreage and distribution from 1986–1999 are documented in Robbins and Conrad (2001). Acreage changes from 1999–2007 are summarized by lagoon segment (**Figure 12-9** and **Figure 12-10**). Potential depth targets are also shown for each segment. One outstanding feature is that from 2003–2006, total acreage or the dense SAV category declined over all segments except segment 23. The acreage declines are likely a result of hurricane impacts in 2004 and 2005. All segments showed an increase in acreage after 2006 with total SIRL SAV acreage increasing from 8,030 acres (2006) to 8,847 acres (2007). These acreage increases are assumed to be a post-hurricane recovery of SAV resources.

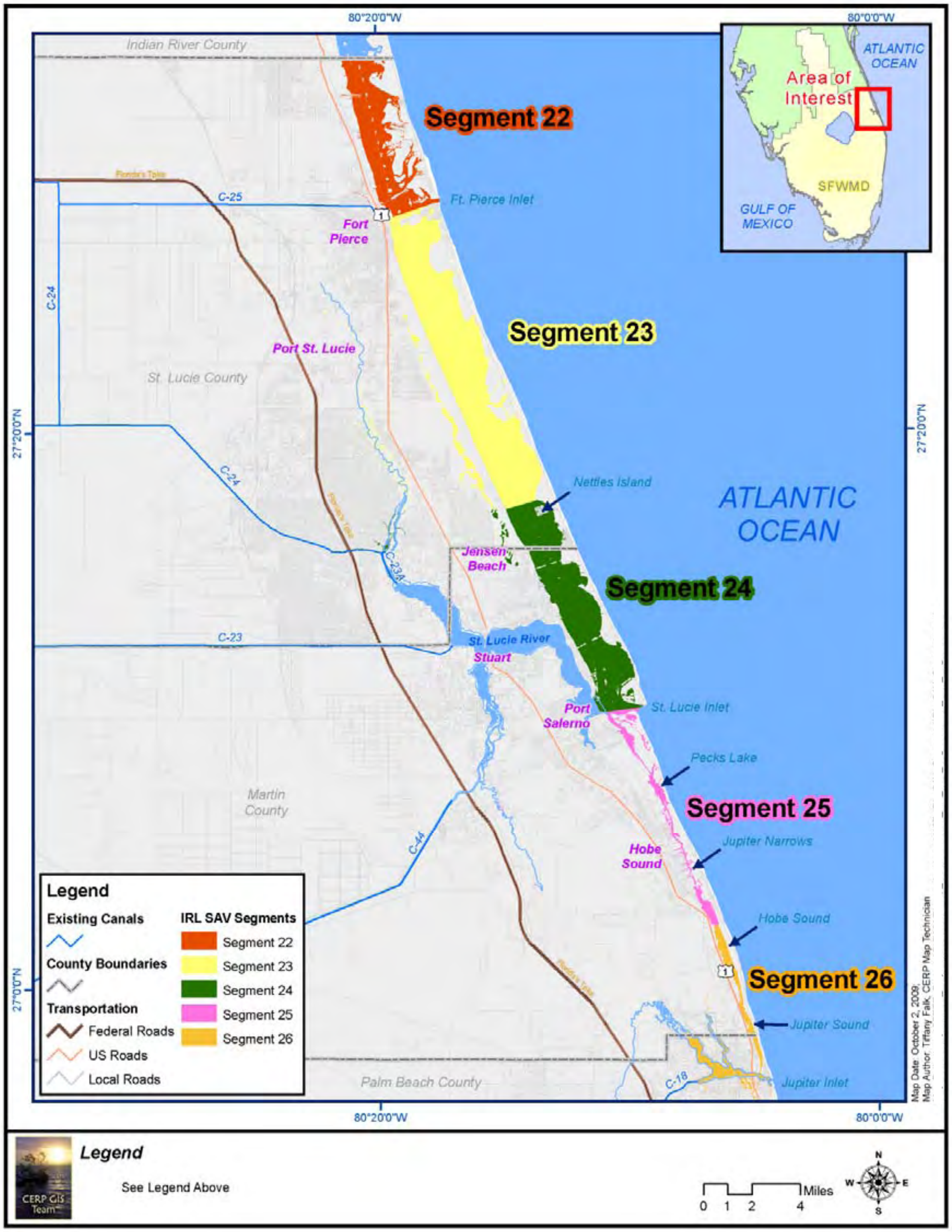


Figure 12-9. Indian River Lagoon (IRL) seagrass management segments (areas with relatively homogeneous water quality).

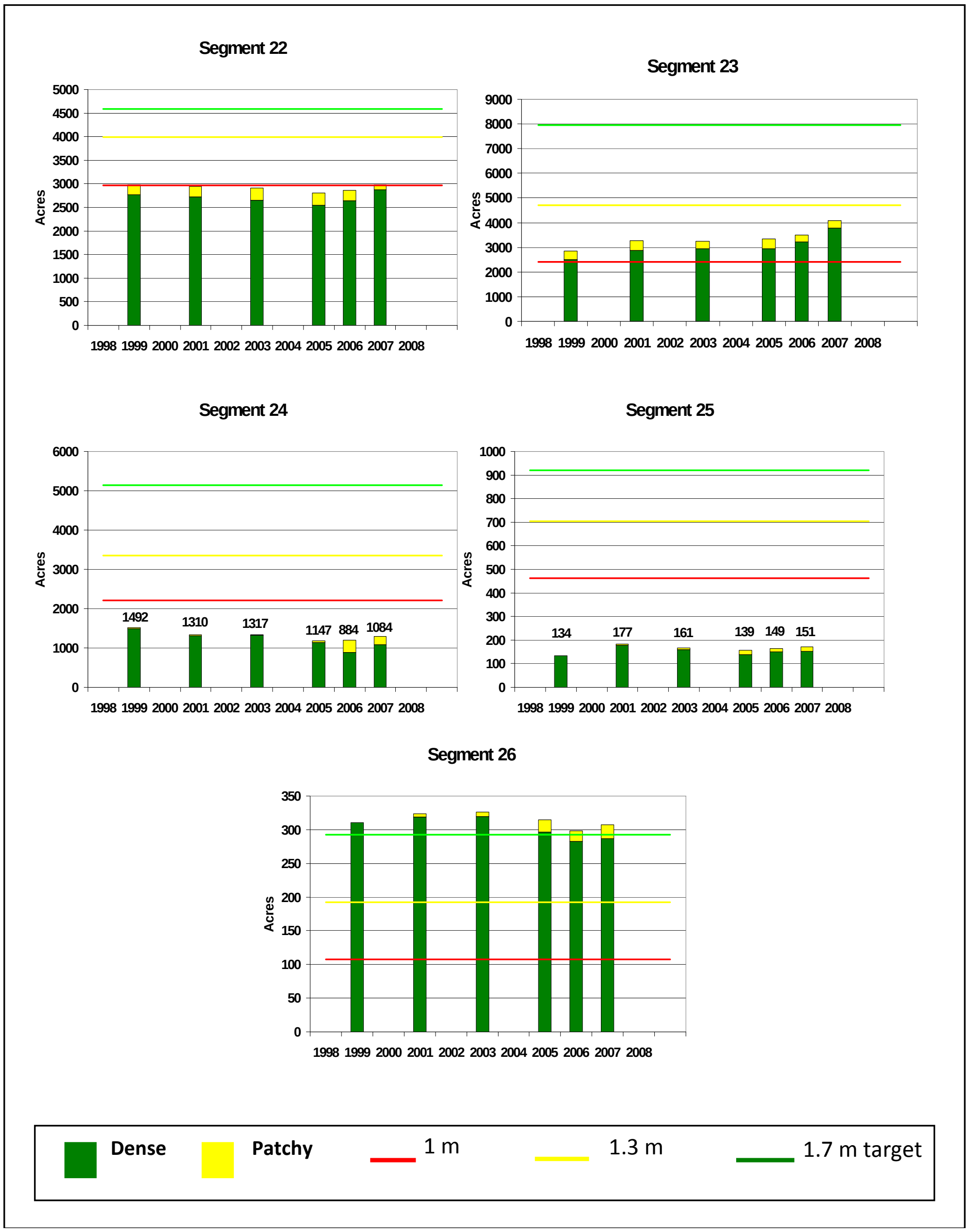


Figure 12-10. Southern Indian River Lagoon (SIRL) seagrass acreage from 1999–2007 compared with lagoon bottom acreage associated with seagrass depth targets. Depth targets are based on the depth that light can penetrate through the water column to support seagrass growth. The 1.7 m target is an IRL Surface Water Improvement and Management (SWIM) Plan lagoon-wide target that will be revised, as necessary, by lagoon segment. The 1.3 m target is based on a detailed comparison of SIRL water quality and seagrass data (Crean et al., 2007). The 1 m target was proposed for the SLE in the IRL SWIM Plan (Steward et al., 1994).

Lagoon-wide SAV maps, based on aerial photographs, provide an overall understanding of the SAV coverage and distribution in the IRL. However, these maps do not provide information about SAV species distribution. Understanding SAV species distribution is important for water management considerations because the SAV species found in SIRL have species-specific salinity thresholds (Irlandi, 2006). Once restoration projects are completed, species shifts may occur that would not be detected from maps created from aerial photographs. The portion of the SIRL most affected by water management practices is the area that receives discharges from the St. Lucie River. Accordingly, the area of the IRL adjacent to the mouth of the St. Lucie River was the focus of a 2007–2008 species-specific mapping test project using extensive fieldwork and sub-meter accuracy Global Positioning System (GPS) technology. Results of this project are shown in **Figure 12-11**.

Of the area mapped, almost 50 percent was occupied by shoal grass (*Halodule wrightii*), which can grow on shoals and other shallow areas exposed at low tide. Dominance by this species is likely due to two factors: bathymetry and salinity tolerance. Other canopy-forming species present in the SIRL, such as manatee grass (*Syringodium filiforme*) and turtle grass (*Thalassia testudinum*), are less successful in these very shallow areas. Additionally, of the canopy-forming species, shoal grass has the greatest salinity tolerance (both salinity range and variability (Irlandi, 2006), and can better adapt to the fluctuating salinities experienced near the mouth of the SLE. As distance from the mouth of the SLE increased, the percentage of shoal grass declined and turtle grass and paddle grass (*Halophila decipiens*) increased. The lack of shoals and a more stable salinity regime may account for these differences. Since the species-specific mapping fieldwork was done following the 2004 and 2005 hurricane seasons, it is expected that over time, some areas mapped as *Halophila* sp. and *Halodule wrightii* will shift to *Syringodium filiforme*-dominant beds as observed at a nearby monitoring site (SFWMD data for Site 2 of the Indian River Lagoon monthly monitoring program 2002–2007; see **Figure 12-12**).

St. Lucie Estuary. The results of some studies suggested that seagrass beds historically extended all the way up from the mouth of estuary to the North Fork along the shoreline (URS Greiner Woodward Clyde, 1999). Due to the dark water in the SLE, it is not possible to map SAV from aerial photographs. Instead, intensive fieldwork coupled with sub-meter accuracy GPS technology was used to map SLE SAV during summer 2007 (Ibis Environmental, Inc., 2007) (**Figure 12-13**). The 2007 field data show that most areas examined did not support SAV. Very sparse [less than (<) 10 percent cover in most areas] SAV was present in the lower and mid-estuaries, but not in either of the Forks. Three seagrass species occurred within the survey boundary: (1) shoal grass, (2) Johnson's seagrass, and (3) paddle grass with Johnson's seagrass as the dominant SAV species. Johnson's seagrass extended farther upstream than any other SAV species. However, the majority of the SAV occurred in small isolated patches; no distinct beds were mapped. Compared to a previous study, most changes were observed in the middle estuary. The 2007 study documented the presence of small amounts of both shoal grass and Johnson's seagrass in the middle estuary where no SAV was observed in 1997. It is likely that the drought conditions experienced in WY2007 helped provide suitable conditions for this upstream expansion.

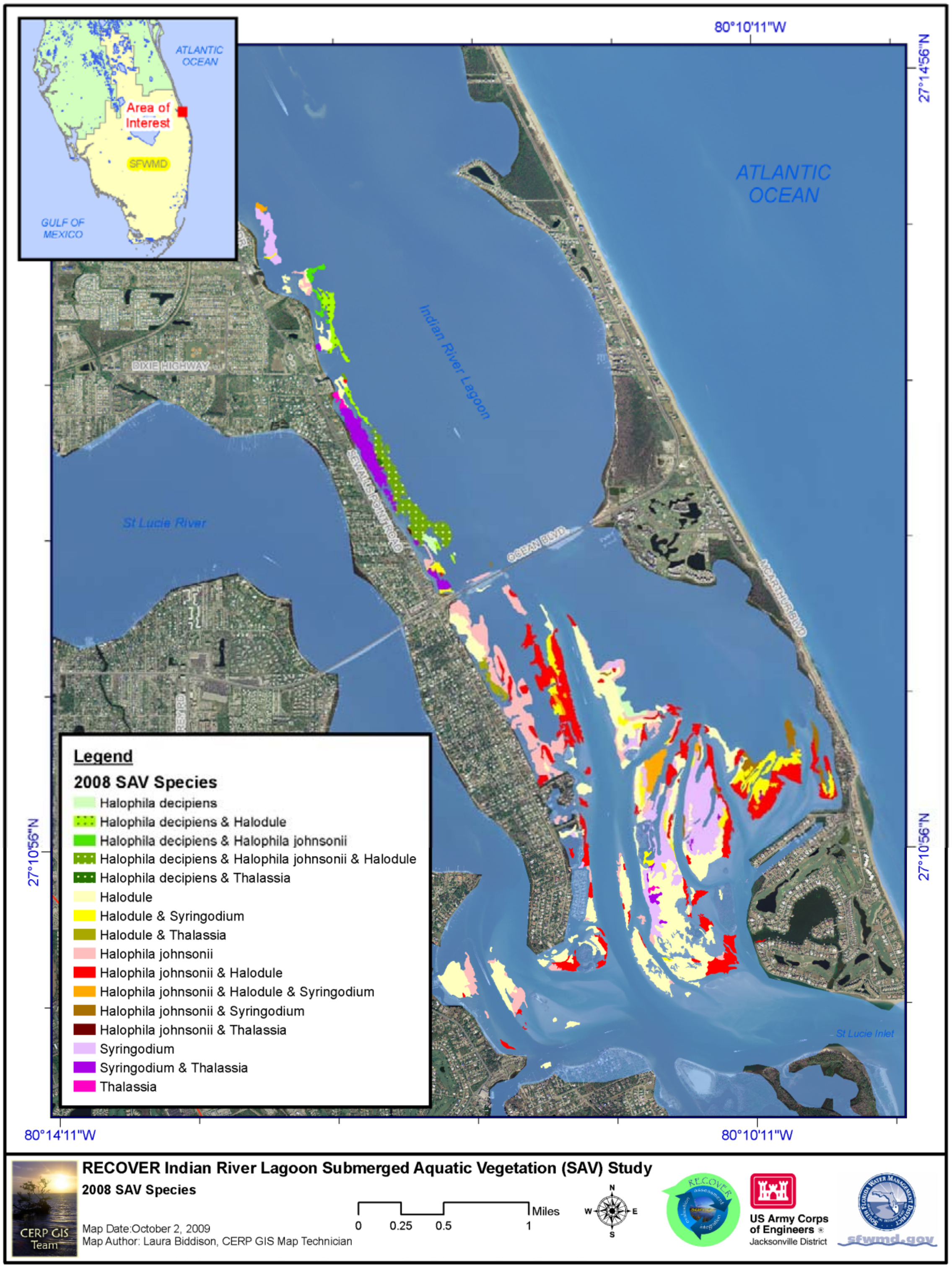


Figure 12-11. Species-specific submerged aquatic vegetation (SAV) map of a test area near the mouth of the St. Lucie River.

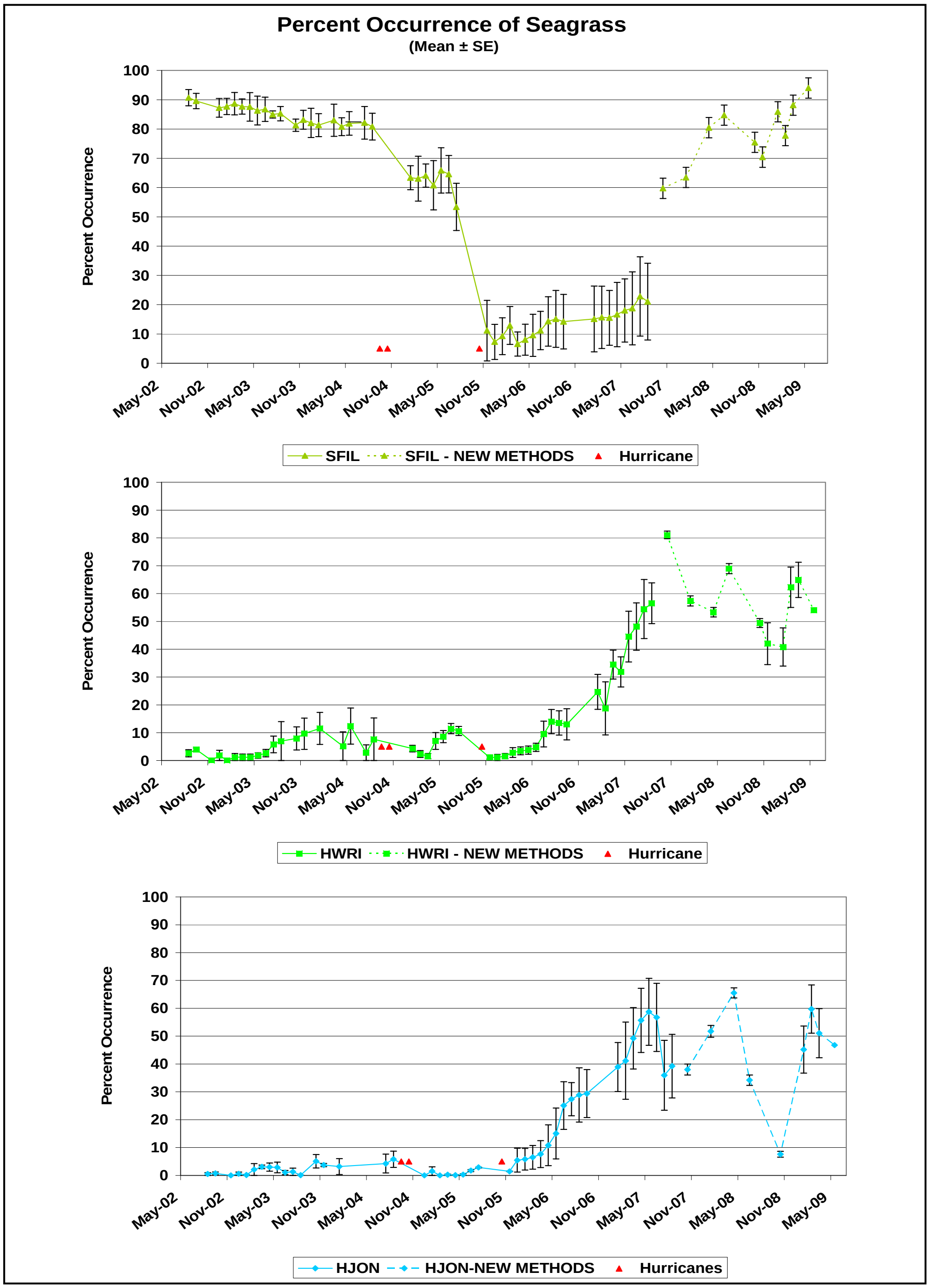


Figure 12-12. Percent occurrence of three seagrass species at a site in the IRL north of the St. Lucie Inlet (BSI site shown in **Figure 12-13**). SFIL = *Syringodium filiforme* (manatee grass), HWRI= *Halodule wrightii* (shoal grass), and HJON = *Halophila johnsonii* (Johnson's seagrass).

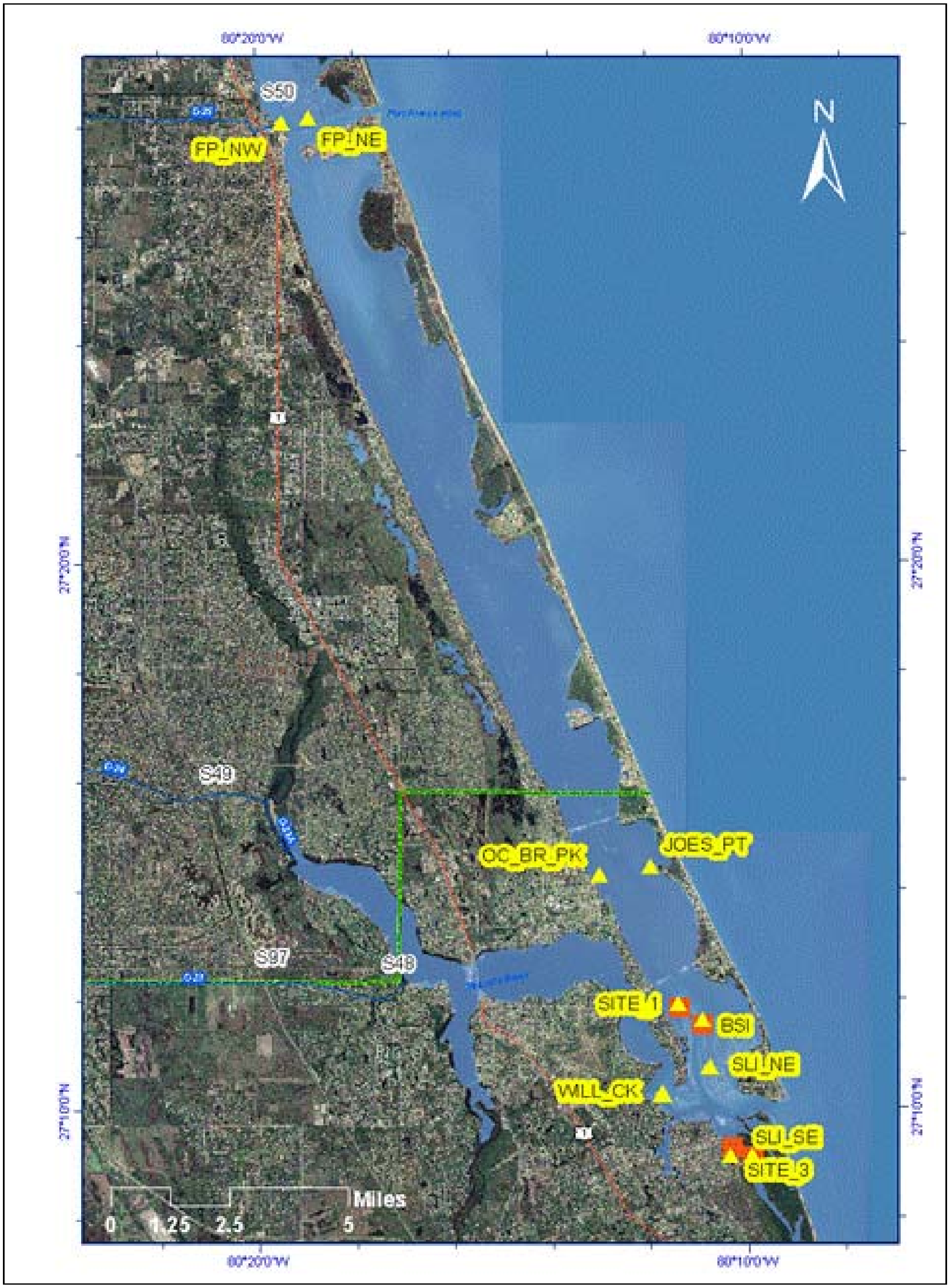


Figure 12-13. SIRL SAV monitoring locations established by the Restoration Coordination and Verification (RECOVER) Program [red squares indicate locations of previous monitoring conducted monthly (August 2002–August 2007); yellow triangles show 10 IRL sites currently being monitored].

Manual Submerged Aquatic Vegetation Monitoring

In addition to aerial mapping in SIRL and fieldwork inside the SLE, a monthly manual SAV monitoring project was conducted near the mouth of the SLE since 2002. In 2008, the monthly monitoring program was replaced with a new SAV monitoring initiative using a methodology developed by an interagency RECOVER SAV sub-team to standardize SAV monitoring methods in all CERP Northern Estuaries (St. Lucie, Loxahatchee, Lake Worth Lagoon, and Caloosahatchee). The new method calls for deploying quadrats in a haphazard manner within a pre-defined boundary, while the older method used fixed transects. However, both methods identify species composition, occurrence percentage, and document species shifts over time, as well as canopy height. The new monitoring is conducted every two months (at a minimum) at sites shown on **Figure 12-13**. Three of the four sites formerly included in the monthly monitoring are included in the new monitoring program. The fourth site was discontinued because it was heavily impacted by boat wakes.

Seagrass monitoring sites near the St. Lucie Inlet showed significant signs of damage from hurricane impacts in 2004 and 2005, especially the pronounced decline of the dominant canopy species, manatee grass, and the recovery process after 2006 (**Figure 12-12**). The recovery began with colonization of bare substrate by the smallest seagrass species (Johnson's seagrass) and the pioneer species, shoal grass, followed by slower recovery of manatee grass. During late summer/early fall 2008, freshwater discharges into the SLE greatly reduced salinities in the estuary (**Figure 12-5**). The low salinities may have affected the percent occurrence of seagrasses (especially Johnson's seagrass) in the Indian River Lagoon (**Figure 12-5**).

Eastern Oyster Abundance and Distribution

Reefs and beds of the Eastern oyster (*Crassostrea virginica*) can provide a variety of essential ecosystem functions, including production of meat, stabilization of benthic environments, water filtration, bio-deposition, and habitat for a variety of estuarine fauna. Oyster populations in South Florida estuaries have declined due to the effects of altered discharge and salinity. The distribution, density, and condition of oysters provide an excellent performance measure for watershed management improvements related to CERP. Oysters are monitored by RECOVER in the St. Lucie Estuary, Loxahatchee Estuary, Lake Worth Lagoon, and Caloosahatchee Estuary.

Five aspects of oyster ecology are monitored at monthly or seasonal frequencies including (1) spatial and size distribution patterns of adult oysters, (2) reproduction and recruitment, (3) juvenile oyster growth and survival, (4) physiological condition [as measured by condition index (CI)], and (5) the distribution and frequency patterns of the oyster disease dermo (RECOVER, 2007b). As a measure of the status of estuarine oyster beds, the District reports on the density of live and dead adult oysters sampled on a seasonal (wet, dry) basis. Wet and dry season oyster monitoring was implemented at three stations in the North, Central, and South Forks of the St. Lucie Estuary in 2005. Stations and segments were aggregated to total numbers for the whole SLE for this analysis.

The SLE had wide ranges in oyster densities and salinity from 2005–2009. Live oyster density results indicate a strong positive relationship to salinity. Oyster density was lower in 2005, then increased in 2006, and peaked in 2007 before another dramatic decline in 2008. Similarly, there were very few live oysters in 2005, followed by a dramatic increase from 2007–2008 as salinity rose to > 10 psu. Both salinity and live oyster density dropped precipitously in the SLE during the wet season of 2008. Live oyster numbers began to rebound into the dry season of 2009 (**Figure 12-14**).

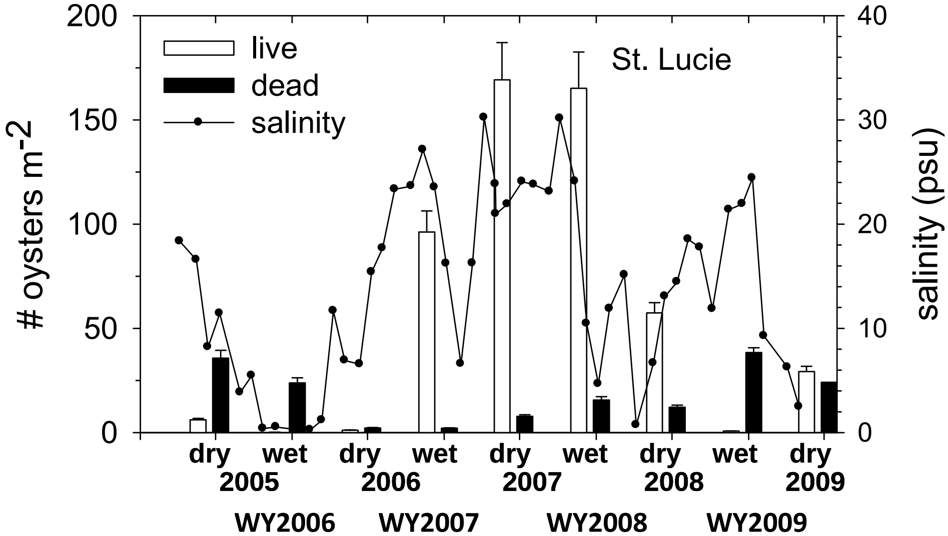


Figure 12-14. Live and dead oyster densities (left axis) and salinity (right axis) from spring 2005 to spring 2009 in the SLE. To compare oyster data with other parameters, the water years are provided below the calendar years.

Floodplain Vegetation

The floodplains of the St. Lucie River consist of tropical and temperate zone riparian forest and marshes. The riparian-forested wetland vegetative communities are adapted and respond to variable water levels. The major forest types are hammock and swamp with some components of bottomland hardwood species. The dominant hammock species on the North Fork of the St. Lucie River are cabbage palm (*Sabal palmetto*), laurel oak (*Quercus laurifolia*), and live oak (*Quercus virginica*). In freshwater reaches of the St. Lucie River, the dominant bottomland hardwood species include red maple (*Acer rubrum*), water hickory (*Carya aquatica*), and a variety of bay (*Persea* spp.). Swamps on the floodplains of the St Lucie River consist primarily of red and white mangroves (*Rhizophora mangle* and *Laguncularia racemosa*, respectively), pond apple (*Annona glabra*), and pop ash (*Fraxinus caroliniana*). The number of bald cypress (*Taxodium distichum*) is lower than expected, probably because of past logging in the area.

During the 1920s to 1940s, the entire lengths of two North Fork tributaries (Ten Mile and Five Mile creeks) were dredged to provide deeper channels (Post, Buckley, Schuh & Jernigan, Inc., 2003). Spoil material from the dredging was placed in the floodplain to form berms (2–25 ft high and 10–15 ft wide) that still exist today. Since their placement, the berms have isolated floodplain forests, oxbows, and marshes from the main river channel. This has resulted in altered salinity gradients, stagnant stream reaches, and sedimentation within the isolated oxbows (Post, Buckley, Schuh & Jernigan, Inc., 2003). The FDEP Aquatic Preserve has completed several oxbow and wetland reconnection projects along the river and is currently examining the possibility of future projects to restore hydrology to the isolated wetland systems.

The North Fork of the St. Lucie River Floodplain Study, initiated in February 2009, will identify floodplain vegetation communities, examine the current health of these communities, and make recommendations on the impact of enhancing current freshwater flow and salinity patterns to these wetland systems and the river. Benchmarks were established at the upland end of four belt transects along segments of the North Fork of the St. Lucie River and Ten Mile Creek (**Figure 12-15**). Light Detection and Ranging (LIDAR) technology was flown over the North Fork of the St. Lucie River in St. Lucie County in February 2007, and vegetative field sampling of the transects was conducted in April, May, and June 2009. Vegetation and soil data for all four transects are being processed at this time. In addition, the SFWMD contracted with Habitat Specialist, Inc. to provide initial taxonomic support on the identification of floodplain vegetation communities, prepare an inventory list of plants to be encountered along the four transects, and, to prepare a dried collection of voucher specimens using standard herbarium practices for species verification and a St. Lucie River reference collection.

Transect locations were chosen to represent lower tidal, upper tidal, and riverine reach communities on the North Fork of the St. Lucie River. Benchmark 1 (Crowberry Drive, **Figure 12-16**) represents a lower tidal vegetative community, Benchmark 2 (Beach Avenue) and Benchmark 3 (Rivers Edge Elementary School) represent upper tidal vegetative communities, and Benchmark 4 (Miller Oxbow) on 10 Mile Creek represents a riverine vegetative community. Also, transect locations were chosen to examine the effects of both bermed and unbermed hydrological conditions. Benchmarks 1 and 4 are mostly bermed, while Benchmarks 2 and 3 are partially bermed and tidally influenced. The Miller Oxbow site (**Figure 12-17**) was chosen as a transect because an oxbow reconnection project is planned for the site in 2010. Therefore, baseline data should show how dry the area had become since the berms were constructed and later monitoring should reveal how the vegetation reacts to the increase in hydroperiod. At this time, swamp species are only present in the low areas (blue) of the old oxbow channel.

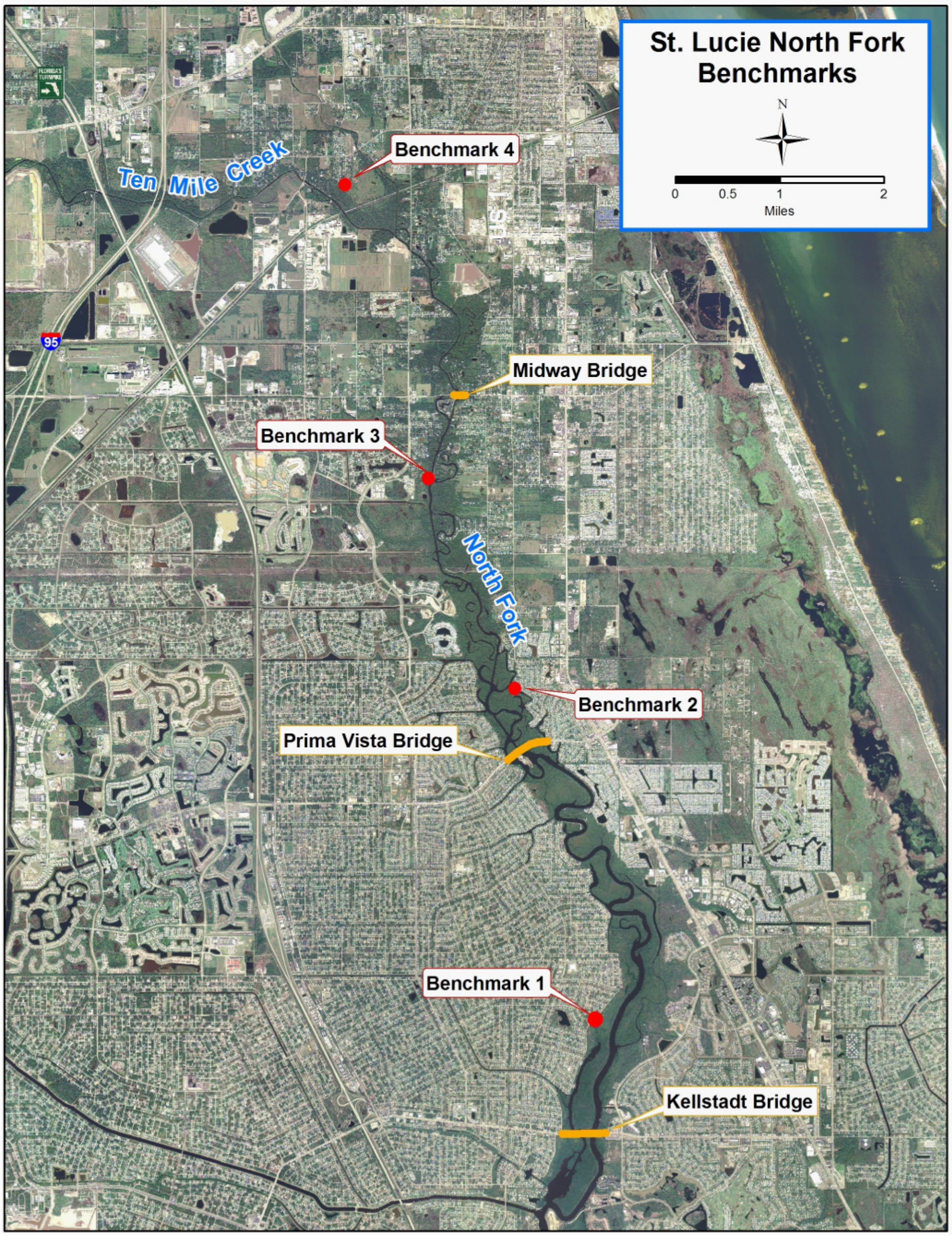


Figure 12-15. The four St. Lucie floodplain benchmarks (yellow) established at each of the vegetative belt transects.

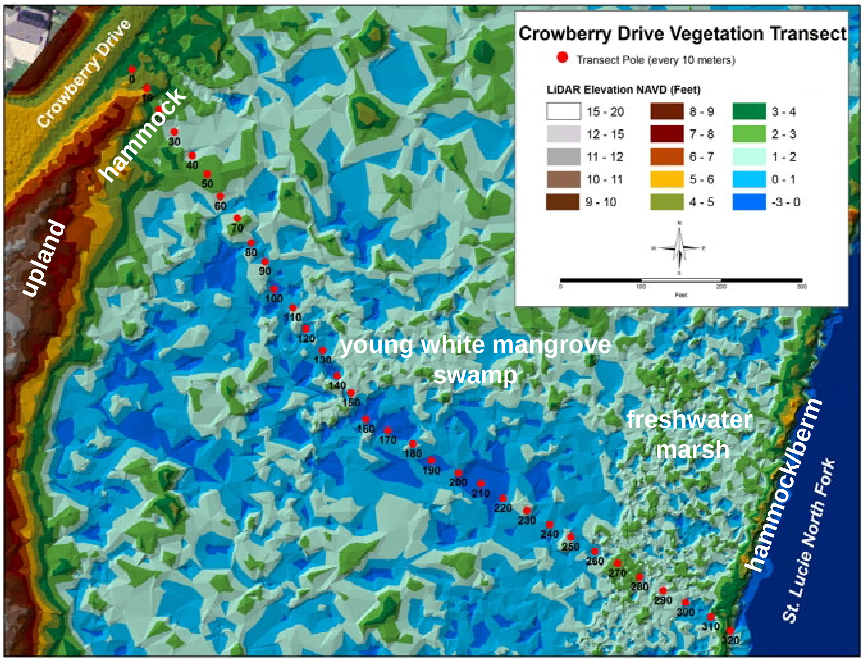


Figure 12-16. Light Detection and Ranging (LIDAR) interpretation of ground elevations and major vegetative communities at the Crowberry Drive transect.

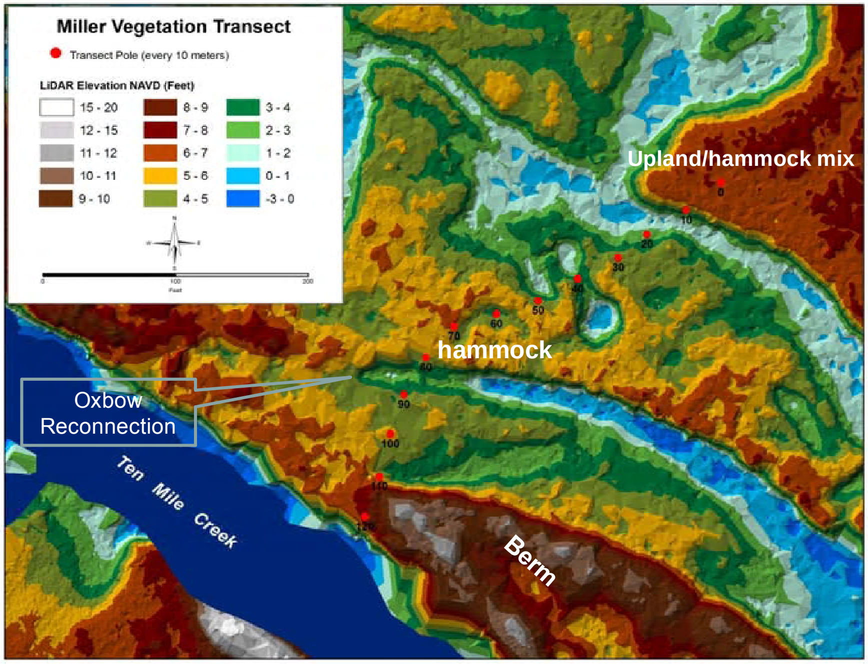


Figure 12-17. LIDAR interpretation of ground elevations, major vegetative communities, and the oxbow reconnection at the Miller Oxbow Transect on Ten Mile Creek.

STRATEGIES AND RESEARCH ACTIVITIES FOR THE ST. LUCIE ESTUARY

As part of the SLWPP, a Research and Water Quality Monitoring Plan was adopted. The objective of research in the SLE is to reduce key uncertainties in TMDLs, improve flow and salinity relationship envelopes, and optimize the operation of infrastructure to meet multiple objectives. Four research projects were formulated and previously described in detail in the 2009 SFER – Volume I, Chapter 12. Briefly these four projects are:

1. **Estuarine Nutrient Budget**. A well-constrained nutrient budget is critical to understanding the origin, magnitude, and management of problematic nutrient loads and guide prioritization for load reductions. This project will construct nutrient budgets of N and P for the SLE.
2. **Dissolved Oxygen Dynamics.** Low oxygen concentrations are often associated with excess nutrient loading (Gray, 1992) and have been a recognized problem in the SLE (Chamberlain and Hayward, 1996). This project will identify the factors causing the DO impairment in the SLE. Once causes are known, appropriate management solutions can be implemented. The results of this study will provide critical information that will guide the selection of these management solutions.
3. **Low Salinity Zone.** This project examines the effects of freshwater discharges on the production of fish larvae and utilization of the low salinity zones in the North and South Forks of the St. Lucie Estuary as a nursery area. Results of this study will be used to refine the salinity envelope and to provide environmental guidelines for delivery of fresh water to the North and South Forks of the SLE.
4. **Integrated Modeling Framework**. The integrated modeling system consists of watershed models, including surface water and groundwater components, and estuarine models, including hydrodynamic, sediment transport, water quality, and ecological models. The watershed model estimates the quantity, timing, and quality of freshwater inflow to the estuary. The estuarine hydrodynamic, sediment transport, and water quality models simulate the estuarine conditions in terms of salinity, water quality, and sediment transport. The ecological models simulate the responses of estuarine resources and processes to the estuarine conditions. Integrated modeling can provide the needed technical support for adaptive management, and implementation of management measures because modeling not only aids in calculating loads that presently exist, but also in estimating future load reductions that may be required and evaluate various scenarios of the management measures to arrive at a preferred plan.

This report provides a brief update on the activities and progress toward achieving the research goal in WY2009.

Dissolved Oxygen Dynamics Project

The objective of this project is to identify the factors causing dissolved oxygen impairment in the St. Lucie Estuary with the ultimate management goal of improving DO concentrations in the SLE by selection of appropriate management solutions.

For this purpose, in WY2009 the spatial and temporal variability of bottom DO was examined using existing long-term monthly water quality monitoring measurements from 1991–2007, weekly sampled data in 2000, and high-frequency (once per 30 minutes) continuous monitoring data in 2005. The major findings from this study are:

- Bottom DO shows a strong longitudinal gradient from the upper to lower estuary with a higher incidence of hypoxia (< 2 mg/L) in the upper estuary (e.g., up to 30 percent frequency at stations located near water control structures)

- Bottom DO exhibits a distinct seasonal pattern, with hypoxia more frequently observed in the wet season than the dry season
- Lower DO is strongly influenced by stratification (**Figure 12-18**)
- Phytoplankton blooms may cause lower DO (**Figure 12-19**)

The management implications of this project are:

- Physical processes are an important factor controlling hypoxia along with biological processes; thus, the evaluation of high nutrient loading as a possible cause of hypoxia should also account for physical effects on hypoxia
- DO is highly variable; therefore, a continuous, high-frequency sampling is required to fully understand the variability and causative factors

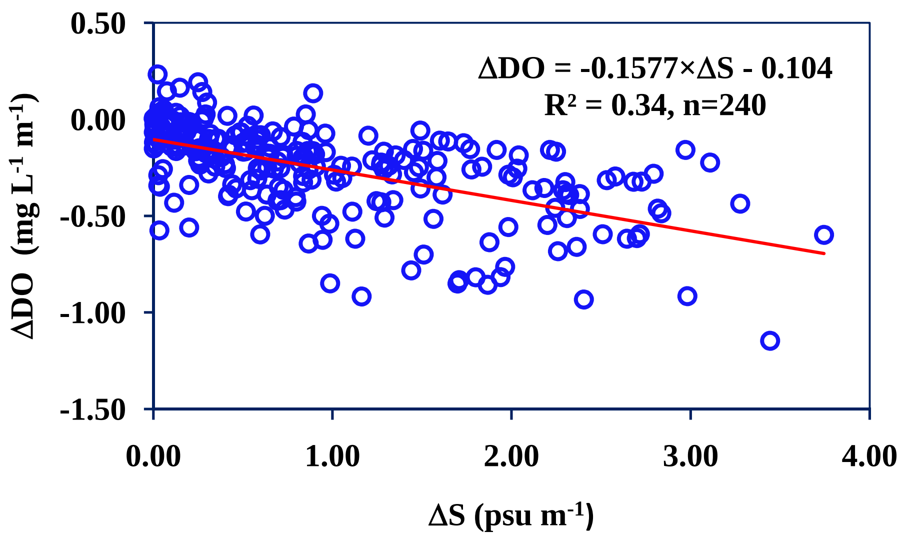


Figure 12-18. The relationship between surface and bottom oxygen difference (ΔDO, mg L^{-1} m^{-1}) and salinity difference (ΔS, psu m^{-1}, an indicator of stratification) normalized to depth at Station 03 from the data 1991–2007. Figure shows that increasing water column stratification will decrease bottom dissolved oxygen (DO) concentration.

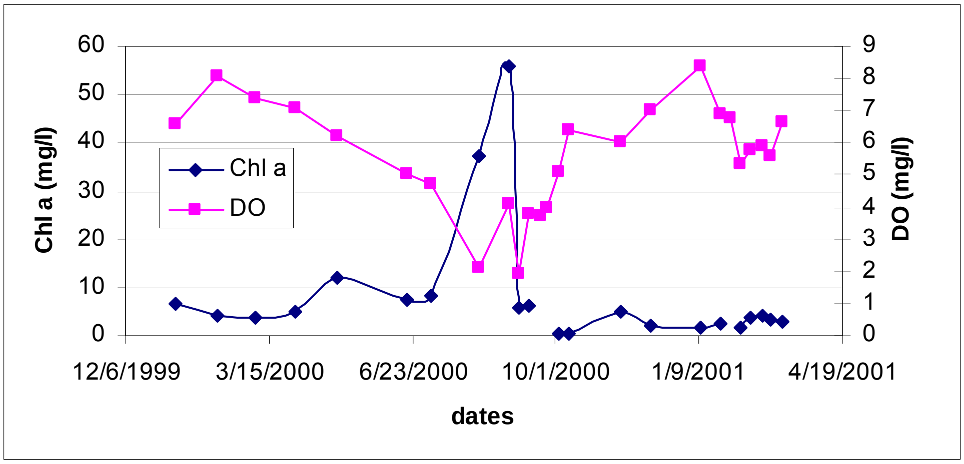


Figure 12-19. The weekly or biweekly time-series of DO and Chl*a* concentration at Station 03 from 1991–2007 data, showing the relationship between DO consumption and phytoplankton bloom in the SLE.

Integrated Modeling Framework

In WY2009, two efforts were addressed within the Integrated Modeling Framework: (1) model applications for the St Lucie River Water Reservation Project, and (2) further improvement of model performances by fine-tuning codes and advancing understanding of simulated physical and water quality processes.

A suite of calibrated models was applied to the St. Lucie River Water Reservation Project (SFWMD, 2009b). The SLE Watershed Model (WASH) was used to simulate the freshwater inflows and irrigation demand for the future (2050) base without project condition. These data were used as the input data for the St. Lucie River Reservoir Operation and Optimization Model (OPTI-6) to simulate the freshwater flows delivered from the watershed with project features proposed in the CERP Indian River Lagoon – South Project. A 130 cfs monthly flow over Gordy Road structure was the hydrologic targets used in OPTI-6 simulations. A 41-year POR (1965–2005), consisting of daily freshwater flows into the estuary, was simulated to ensure that a wide range of climatic conditions was included. The simulated daily flows under future (2050) base with and without project conditions were used as input data for the SLE hydrodynamic/salinity (CH3D) model, which predicted salinity within the North Fork of the SLE and the downstream estuary. Results from these models were evaluated using a set of hydrologic and salinity performance measures and targets to evaluate how these flows affect larval and juvenile fishes within the North Fork and oyster communities within the mid-estuary.

The modeling results show that the target flow distributions were met or exceeded within the North Fork. Under the future (2050) base with project condition, mean monthly flows released from the Gordy Road structure to the North Fork are maintained above 130 cfs for more than 90 percent of the time over the 41-year simulation period. As a result, the low salinity zone habitat will be greatly enhanced and expanded with a significant increase in the frequency of 1 psu isohaline that can be dynamically maintained between the Kelsdadt Bridge and the Prima Vista Bridge. Additional analyses indicate that reserving water for the low salinity zone in the North Fork will also enhance the oyster habitat for both low salinity and high salinity regimes in the mid-estuary.

Substantial efforts have been made to improve the performance of the SLE water quality model, which is one of the District's comprehensive modeling efforts toward developing an integrated, sophisticated modeling system including hydrodynamic/salinity, sediment transport, and water quality modules. Activities included:

- Performing data analysis to understand water quality processes under different spatial and time scales
- Identifying dominant water quality processes in the estuary and therefore better representing the processes in the water quality model
- Utilizing primary production data to improve modeling of algal growth
- Improving model algorithm for better accuracy

The new model shows better accuracy compared with field data and the results of old models (**Figure 12-20**).

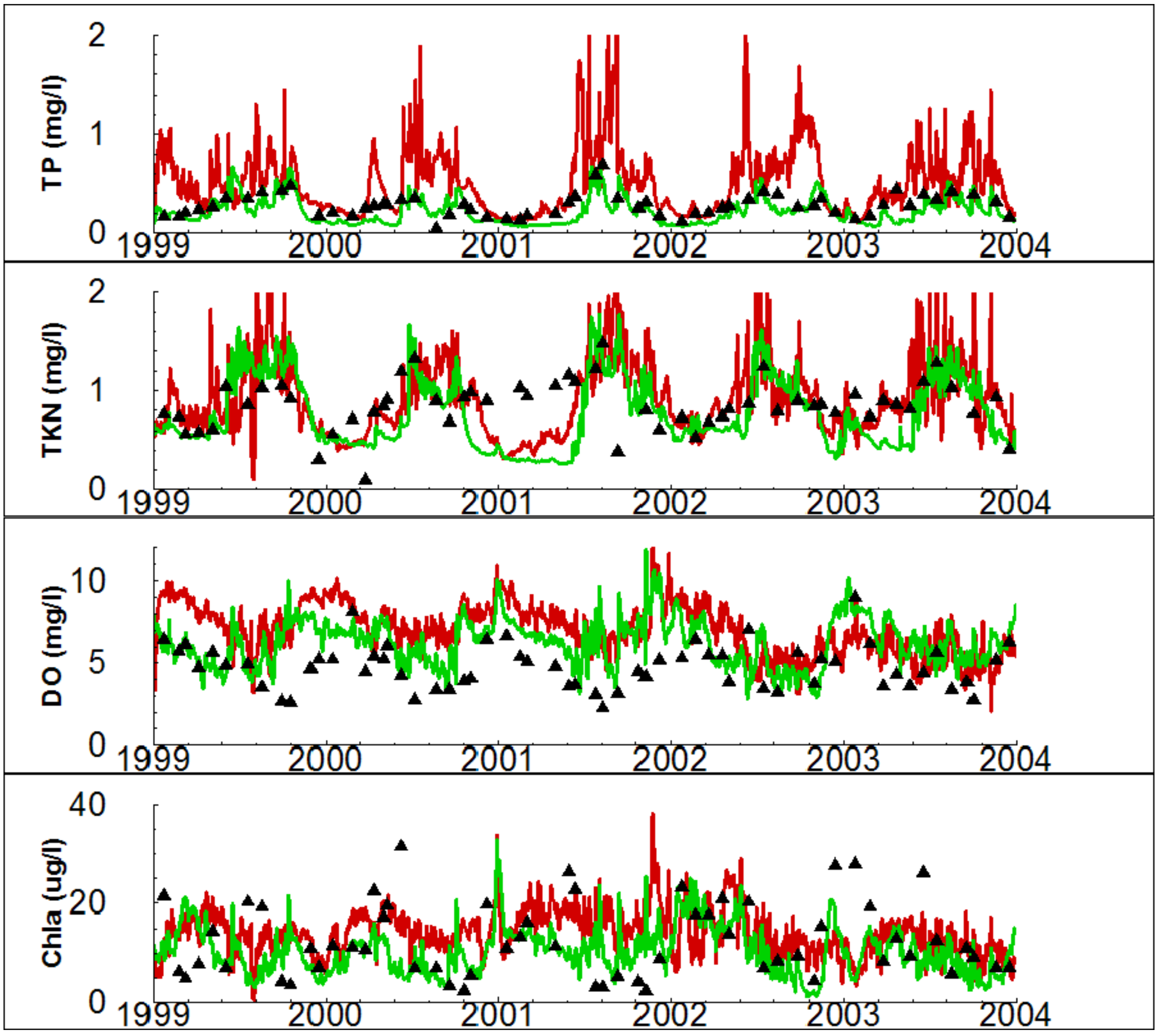


Figure 12-20. Modeling results for TP, total Kjeldahl nitrogen (TKN), DO, and Chl*a* at station HR1 during 1999–2004 using old (red line) and newly improved (green line) water quality models in comparison to field measurements (filled triangles).

CALOOSAHATCHEE RIVER ESTUARY AND SOUTHERN CHARLOTTE HARBOR

Peter Doering, Kathleen Haunert, Chenxia Qiu
and Teresa Coley

INTRODUCTION

Charlotte Harbor, located on Florida's southwest coast, is Florida's second-largest open-water estuary, and one of the state's major environmental features with three national wildlife refuges and four aquatic preserves. It has a broad barrier island chain, extensive SAV meadows and a largely intact mangrove shoreline. Only the southern portion of the Charlotte Harbor system lies within the District's boundaries, which includes the Caloosahatchee River Estuary, (also known as CRE or Caloosahatchee Estuary), San Carlos Bay, and almost all of Pine Island Sound and Matlacha Pass.

The major source of fresh water to the Caloosahatchee Estuary is the Caloosahatchee River (C-43), which runs 70 km [43 miles (mi)] from Lake Okeechobee at Moore Haven (S-77) to the Franklin Lock and Dam (S-79) at Olga. Separating fresh and brackish water, the Franklin Lock demarcates the head of the Caloosahatchee Estuary, which extends 42 km (26 mi) downstream to Shell Point, where it empties into San Carlos Bay in the southern portion of the greater Charlotte Harbor system (**Figure 12-21**).

The Caloosahatchee River and Estuary comprise a system that has been highly altered from its natural state by human intervention and engineering. The Caloosahatchee River was once a sinuous river originating near Lake Flirt, approximately 3.2 km (2 mi) east of LaBelle at Fort Thompson (**Figure 12-21**). Since the 1880s, the river has been connected to Lake Okeechobee, straightened and deepened, and three water control structures have been added (Antonini et al., 2002). No longer free-flowing, the river is operated as two pools; one at an elevation of about 0.3 m (11 ft) between S-77 and S-78, and the other at an elevation of about 0.9 m (3 ft) between S-78 and S-79. The river provides irrigation water, drainage, and potable water as well as conveyance of regulatory releases of water from Lake Okeechobee to tide. Modifications to the Caloosahatchee River allowed development in the watershed. A network of secondary and tertiary canals now overlays the Caloosahatchee River Watershed. This network provides conveyance for both drainage and irrigation to accommodate citrus groves, sugarcane, cattle grazing, and urban development.

The estuarine portion of the Caloosahatchee River west of S-79 has also been significantly altered (Chamberlain and Doering, 1998a). Early descriptions of the Caloosahatchee Estuary characterize it as barely navigable, owing to extensive shoals and oyster bars (Sackett, 1888). A navigation channel was dredged and a causeway was built across the mouth of San Carlos Bay in the 1960s.

As a result of these changes, freshwater inflow to the estuary has a high seasonal variance. During the wet season, high flows can drive the system entirely fresh, causing mortality of marine organisms in the lower estuary and San Carlo Bay. The lack of flow during the dry season allows salt to intrude up to the head of the estuary at S-79, with salinity sometimes reaching 20 psu, causing mortality of brackish-water organisms that normally inhabit this area. Aside from altered freshwater inflows, additional concerns for the estuary are nutrient enrichment and habitat loss that can extend into Southern Charlotte Harbor (SFWMD, 2005; SFWMD, 2006b).

To better manage inflows to the estuary, the SFWMD has established preferred flow ranges for discharges at S-79 using SAV as a primary VEC (Doering et al. 2002; Chamberlain and Doering, 1998a, b). A considerable amount of work has demonstrated that these flows are not harmful to other components of the ecosystem, including fish and shellfish, zooplankton, and ichthyoplankton (Volety et al., 2003; SFWMD, 2003; Chamberlain and Doering, 1998b). An MFL was established for the Caloosahatchee River and Estuary in 2001 (SFWMD, 2000) and reviewed in 2003 (SFWMD, 2003). A detailed discussion of the MFL and preferred freshwater inflows at S-79 was presented in the 2009 SFER — Volume I, Chapter 12.

To better address nutrient enrichment problems, the FDEP recently completed work on and proposed a TMDL for the Caloosahatchee Estuary (Bailey et al., 2009). As directed by the Florida legislature, the SFWMD completed the CRWPP (SFWMD et al., 2009). The major goals of the plan are reducing nutrient loads to the estuary to meet any adopted TMDL and to reduce the frequency and duration of undesirable salinity ranges (SFWMD et al., 2009).

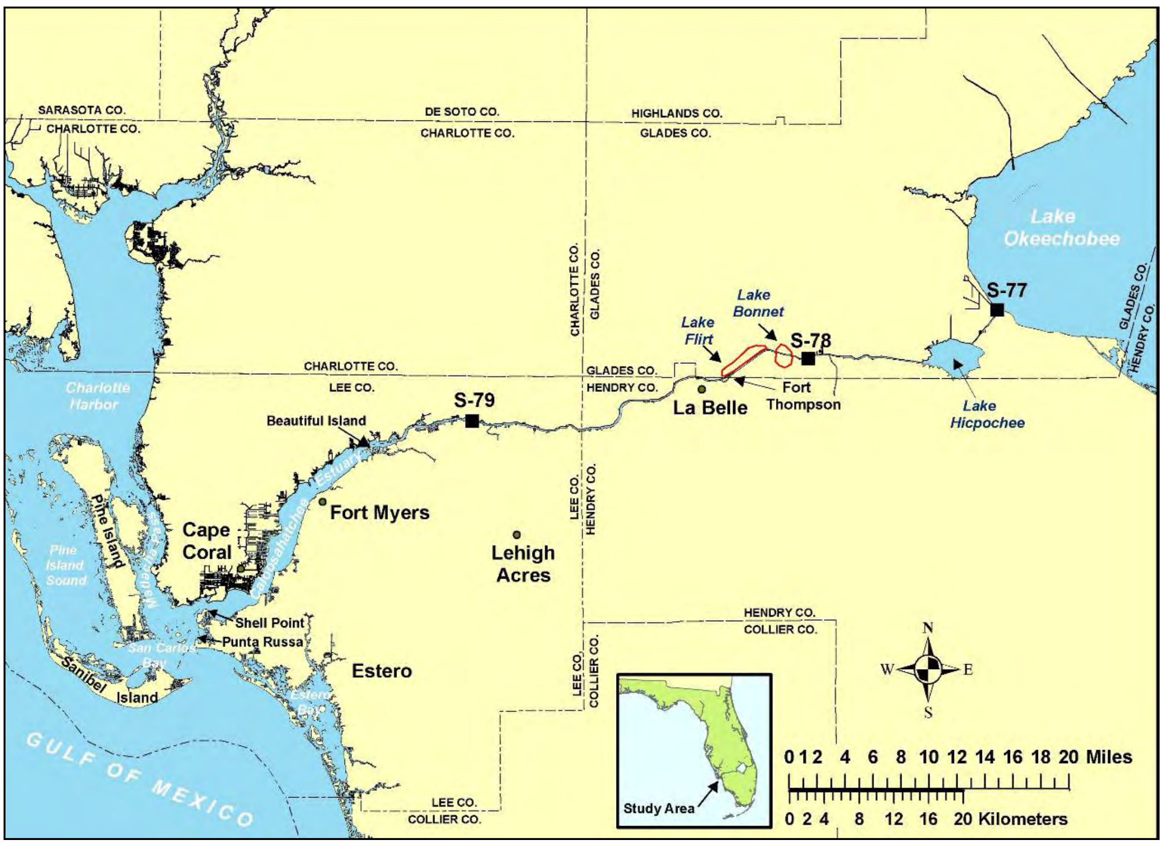


Figure 12-21. Location of Charlotte Harbor and the Caloosahatchee River and Estuary. S-79 is the Franklin Lock and Dam.

STATUS OF THE CALOOSAHATCHEE RIVER ESTUARY AND SOUTHERN CHARLOTTE HARBOR

Freshwater Inflows at S-79 and Salinity in the Caloosahatchee River Estuary

Freshwater inflow to the CRE at S-79 during WY2009 was two orders of magnitude greater than the drought year of WY2008, but still below the long-term average (**Table 12-5**). Much of difference between the last two water years was due to the landfall of Tropical Storm Fay near Naples on August 19, 2008. The storm generated considerable basin runoff and precipitated regulatory releases from Lake Okeechobee that began on September 4 and ended on October 11, 2008 (**Figure 12-22**). Despite the increase in WY2009 compared with WY2008, releases of water from Lake Okeechobee comprised about 25 percent of the total discharge measured at S-79. The long-term average is about 43 percent (**Table 12-5**).

Six continuous salinity sensors are located in the CRE (**Figure 12-23**). The salinity from the Fort Myers and Shell Point recorders is depicted in **Figure 12-22**. Salinity at both locations was much different during WY2009 compared to WY2008. Reflecting the dry conditions during WY2008, salinity at Shell Point never fell below 20 psu. By contrast, in WY2009 a combination of runoff and releases of water from Lake Okeechobee from Tropical Storm Fay drove wet season salinities to 5 psu or below. This same pattern was evident at Fort Myers, where daily salinity fell to zero in WY2009. In WY2008, daily average salinity fell below 10 psu for only 11 days during the entire wet season.

In WY2009, both MFL criteria were exceeded at Fort Myers. The 30-day average surface salinity exceeded 10 psu, and the daily average exceeded 20 psu (**Figure 12-22**). A series of base flow releases (450 cfs, October 31–December 15, 2008; 650 cfs, December 16, 2008–January 18, 2009) and pulse releases (January 19–May 8, 2009) from Lake Okeechobee (**Figure 12-22**) did not prevent exceedances of MFL criteria at Fort Myers. However, these releases did allow a sparse population of freshwater tape grass (*Vallisneria americana*) to survive the dry season in the upper estuary near the Interstate 75 bridge (see the *Submerged Aquatic Vegetation* section of this chapter).

Table 12-5. Total annual discharge of fresh water [in thousands of acre-feet per year (ac-ft/yr) to the Caloosahatchee River Estuary (CRE) at S-79 from both the C-43 Basin and Lake Okeechobee.

	Discharge from C-43 Basin	Discharge from Lake Okeechobee	Total Discharge at S-79
Average WY1991–2007	886.5	668.9	1,555
WY2008	84.1	0.412	84.5
WY2009	752.2	262.4	1,041

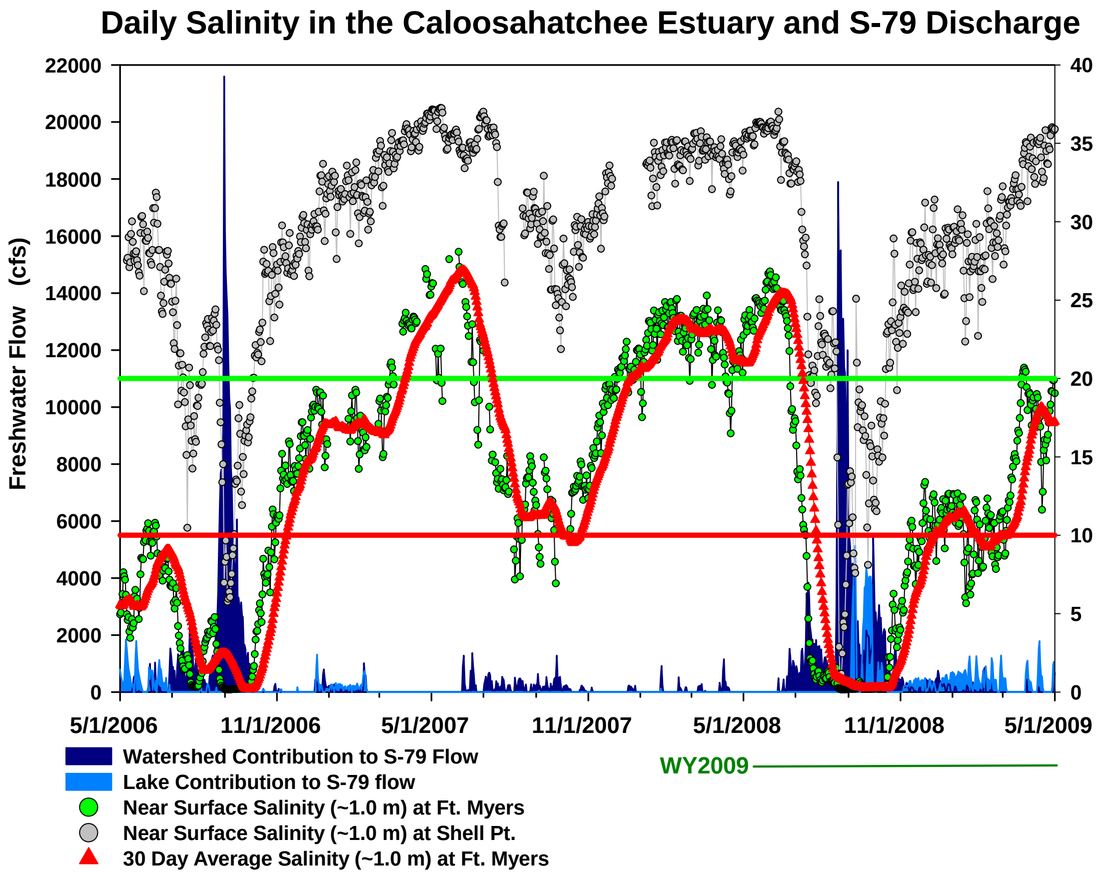


Figure 12-22. Daily discharge at S-79 with contribution from Lake Okeechobee and corresponding salinity at Fort Myers and Shell Point. Also shown are the minimum flow and level (MFL) salinity criteria measured at Fort Myers [salinity not to exceed a 30-day average of 10 parts per thousand (ppt), or a daily average of 20 ppt].

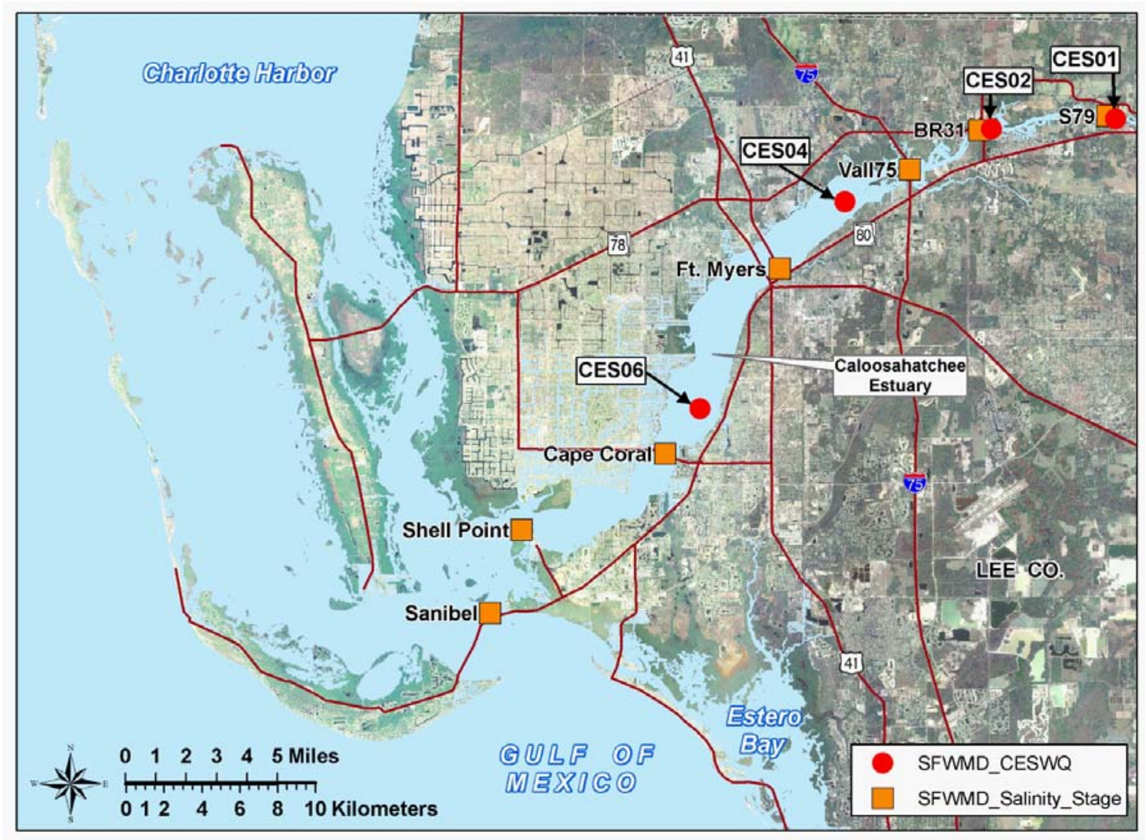


Figure 12-23. Location of salinity sensors and water quality sampling stations in the CRE.

Nitrogen and Phosphorus Loads to the Caloosahatchee Estuary at S-79

Annual loads of TN and TP to the CRE at S-79 were an order of magnitude higher this water year than last water year (**Figure 12-24**). A total of 2,031 mt of N and 287 mt of P was delivered to the downstream estuary. The nitrogen load was below the long-term average, while the phosphorus load was slightly above it (**Table 12-6**). On average, about half the N load comes from the C-43 Basin and half from Lake Okeechobee. For phosphorus, long-term proportions are 70 percent from the basin and 30 percent from the lake. In WY2009, the basin proportion was relatively higher for N (66 percent) and P (75 percent). No trends in annual loads for N and P, or discharge were detected during the period WY1991–WY2009 (Kendall Tau, $p > 0.05$, $n = 19$).

Table 12-6. Annual TN and TP loads [in metric tons per year (mt/yr)] at the Franklin Lock and Dam (S-79) from both the C-43 basin and Lake Okeechobee.

	Total Nitrogen			Total Phosphorus		
	S-79	C-43 Basin	Lake Okeechobee	S-79	C-43 Basin	Lake Okeechobee
Average WY1991–2007	2,848	1,440	1,404	251	173	78
WY 2008	143	109	34	23	21	2
WY 2009	2,031	1,325	706	287	215	72

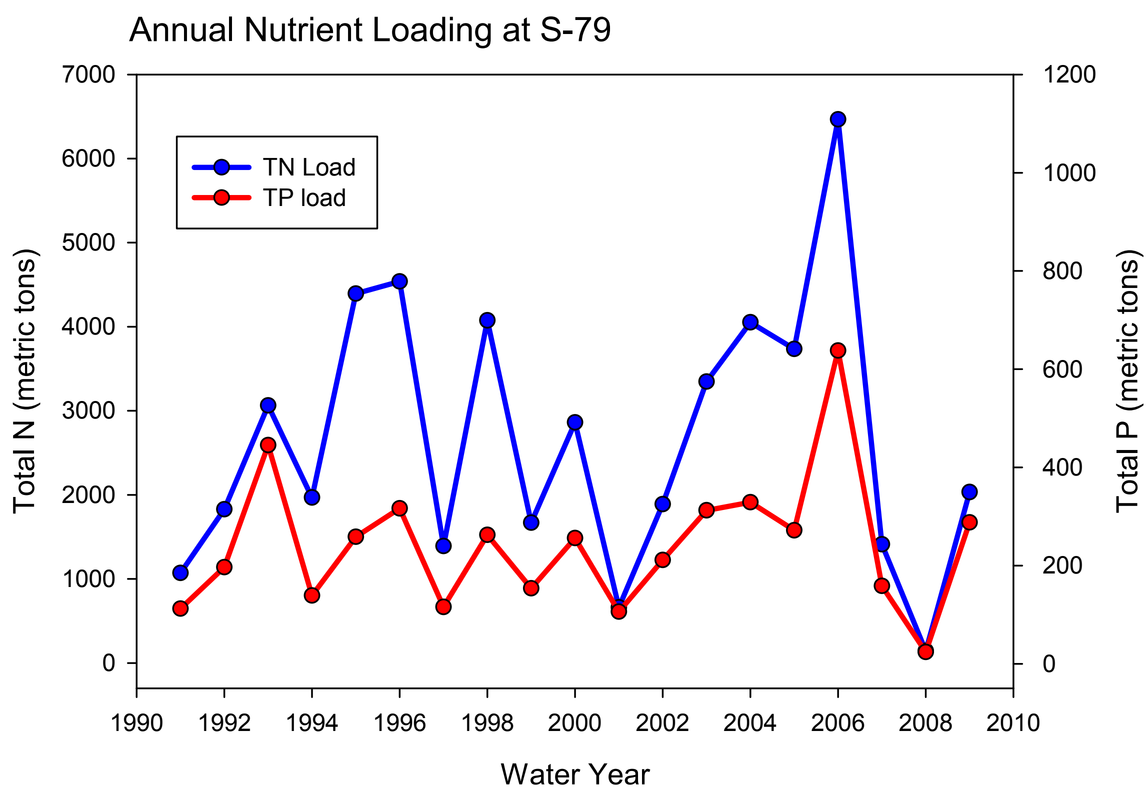


Figure 12-24. Annual loads of TN and TP delivered to the CRE at the Franklin Lock and Dam (S-79).

Water Quality Status and Trends

The SFWMD monitors four fixed stations in the CRE (**Figure 12-23**). CES01 is located upstream of the Franklin Lock and Dam (S-79), while CES03, 04, and 06 are in the downstream estuary. At all stations, annual median concentrations of TN and DIN for WY2008 and WY2009 fell within or very slightly above the range encompassed by the 25th and 75th percentiles (**Table 12-7**). Monthly concentrations of TN during the past two years fluctuated around long-term average values (**Figure 12-25**). By contrast, concentrations of both TP and OPO_4 were at or above the range encompassed by the long-term 25th and 75th percentiles at CES01, and this pattern was reflected at CES03 and CES04 in the downstream estuary (**Table 12-7**, **Figure 12-26**). Increased P in the downstream estuary during the past two water years is undoubtedly due to an increase in the freshwater concentration at S-79 (**Figure 12-26**), particularly during the wet season. It is unknown why long-term concentrations were exceeded upstream of S-79. WY2008 was far drier than WY2009, but this difference in hydrology does not easily account for differences in concentration.

Median concentrations of chlorophyll *a* (a measure of phytoplankton biomass) were higher than the long-term average at CES01, 03, and 04 in WY2008 but not in WY2009. In WY2009, the average concentration of Chlorophyll *a* at stations CES03 and CES04 exceeded the Florida Impaired Waters Rule criterion of 11 micrograms per liter (μg/L) (**Table 12-7**). A sizable bloom (> 50 μg/L) occurred during the wet season of WY2009 at the most downstream station (CES06). The following dry season, a peak of nearly 50 μg/L occurred farther upstream at CES04 (**Figure 12-27**). The position of the maximum concentration of chlorophyll *a* is a function of freshwater inflow, with peaks occurring farther upstream at lower flows like those occurring during the dry season (Doering et al., 2006).

Time-series of water quality values at three estuarine stations were analyzed for trends using the appropriate Kendall or Seasonal Kendall Tau statistic (Hill and Iricanin, 2008). For the period from 1999–2005, no trends in TP were detected at any of the stations. Apparent increases in TN, dissolved inorganic nitrogen, and dissolved inorganic phosphorus were detected (**Table 12-8**). Decreases in chlorophyll *a* also were detected. To confirm these trends, the analysis should be repeated using the longer period of record that now exists.

Table 12-7. Summary of nutrient concentrations at four permanent monitoring stations in the Caloosahatchee River and Estuary. Mean, median, 25th, and 75th percentiles are given. All units are mg/L except Chl*a*, which is micromoles per liter (μm/L).

	TN			DIN			TP			OPO_4			CHL*a*		
CES01	**1999-2007**	**2008**	**2009**	**1999-2007**	**2008**	**2009**	**1999-2007**	**2008**	**2009**	**1999-2007**	**2008**	**2009**	**1999-2007**	**2008**	**2009**
mean	1.33	1.33	1.46	0.34	0.30	0.26	0.125	0.181	0.170	0.072	0.132	0.127	9.95	14.17	8.69
median	1.36	1.41	1.50	0.32	0.27	0.25	0.118	0.180	0.161	0.070	0.126	0.119	4.69	11.50	7.00
25th p	1.17	1.20	1.32	0.22	0.05	0.16	0.082	0.146	0.108	0.044	0.115	0.067	2.83	4.00	2.38
75th p	1.49	1.44	1.54	0.46	0.53	0.38	0.150	0.221	0.226	0.093	0.153	0.182	10.20	25.50	12.88
CES03															
mean	1.23	1.12	1.39	0.24	0.13	0.20	0.121	0.188	0.185	0.072	0.134	0.127	9.73	17.00	16.58
median	1.24	1.11	1.40	0.23	0.07	0.22	0.110	0.172	0.159	0.067	0.135	0.114	5.67	15.00	12.50
25th p	1.07	1.08	1.25	0.11	0.06	0.06	0.074	0.153	0.128	0.047	0.096	0.083	3.80	5.50	4.00
75th p	1.41	1.17	1.54	0.36	0.18	0.26	0.160	0.205	0.255	0.092	0.174	0.155	13.08	25.75	17.00
CES04															
mean	1.16	1.05	1.28	0.22	0.10	0.15	0.120	0.206	0.166	0.068	0.113	0.107	8.52	10.83	13.75
median	1.15	1.04	1.25	0.21	0.07	0.10	0.104	0.157	0.153	0.066	0.098	0.088	5.33	11.00	8.50
25th p	0.92	0.96	1.09	0.07	0.03	0.03	0.080	0.138	0.118	0.040	0.060	0.065	3.20	8.25	5.00
75th p	1.40	1.14	1.42	0.33	0.14	0.23	0.140	0.211	0.204	0.088	0.146	0.122	9.81	13.50	17.75
CES06															
mean	0.95	0.81	0.91	0.15	0.07	0.09	0.104	0.110	0.118	0.052	0.065	0.073	10.94	6.17	9.00
median	0.90	0.77	0.87	0.08	0.06	0.02	0.093	0.109	0.075	0.041	0.061	0.040	6.95	6.00	3.00
25th p	0.67	0.66	0.69	0.03	0.02	0.01	0.061	0.081	0.069	0.022	0.050	0.035	3.58	4.75	2.00
75th p	1.23	0.90	1.03	0.23	0.12	0.15	0.133	0.142	0.166	0.075	0.082	0.092	11.71	6.50	5.25

Chl*a* – chlorophyll *a* corrected for phaeophytin
OPO_4 – dissolved inorganic phosphorus
TN – total nitrogen
TP – total phosphorus

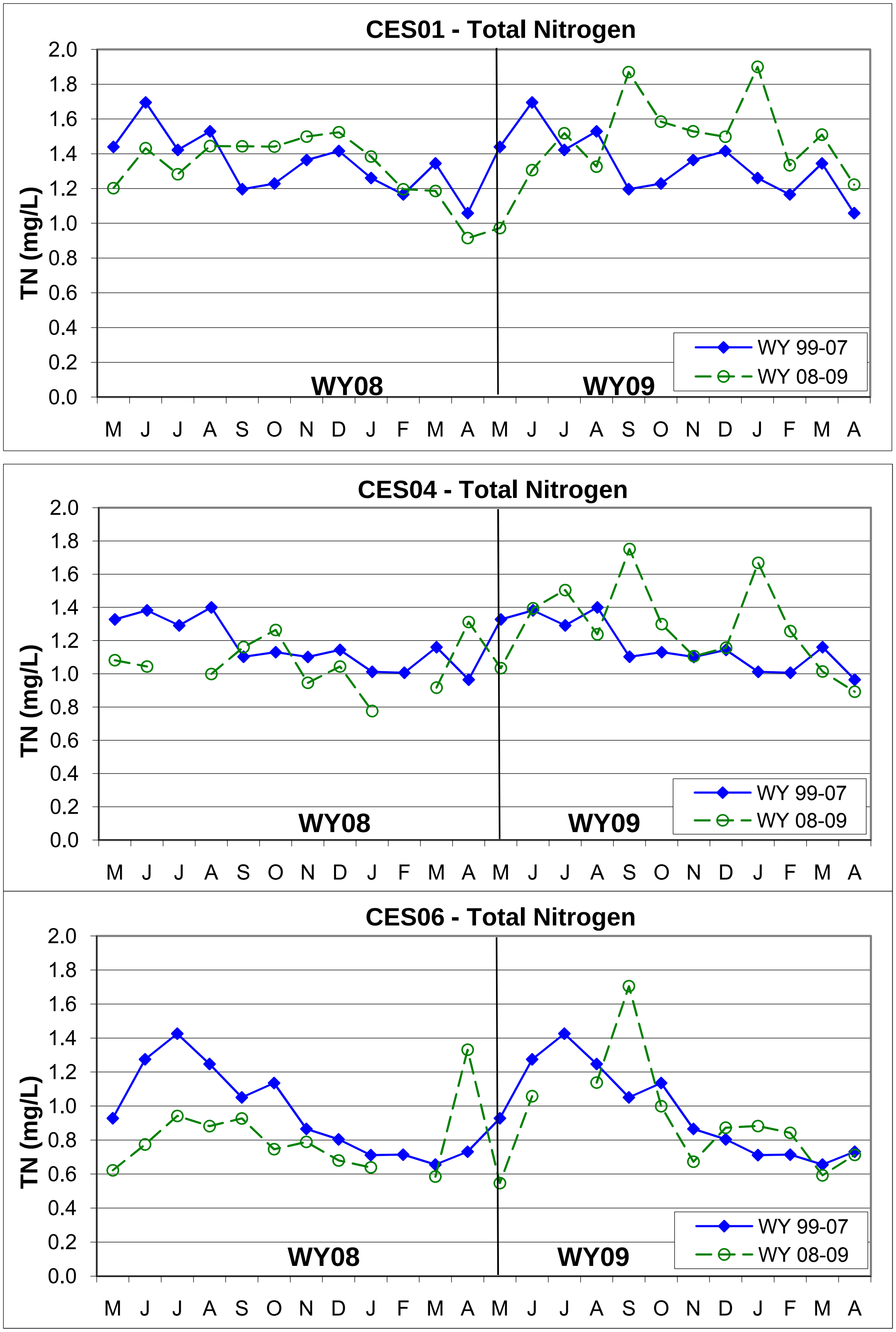


Figure 12-25. TN at three stations in the Caloosahatchee River and Estuary (see **Figure 12-23** for locations).

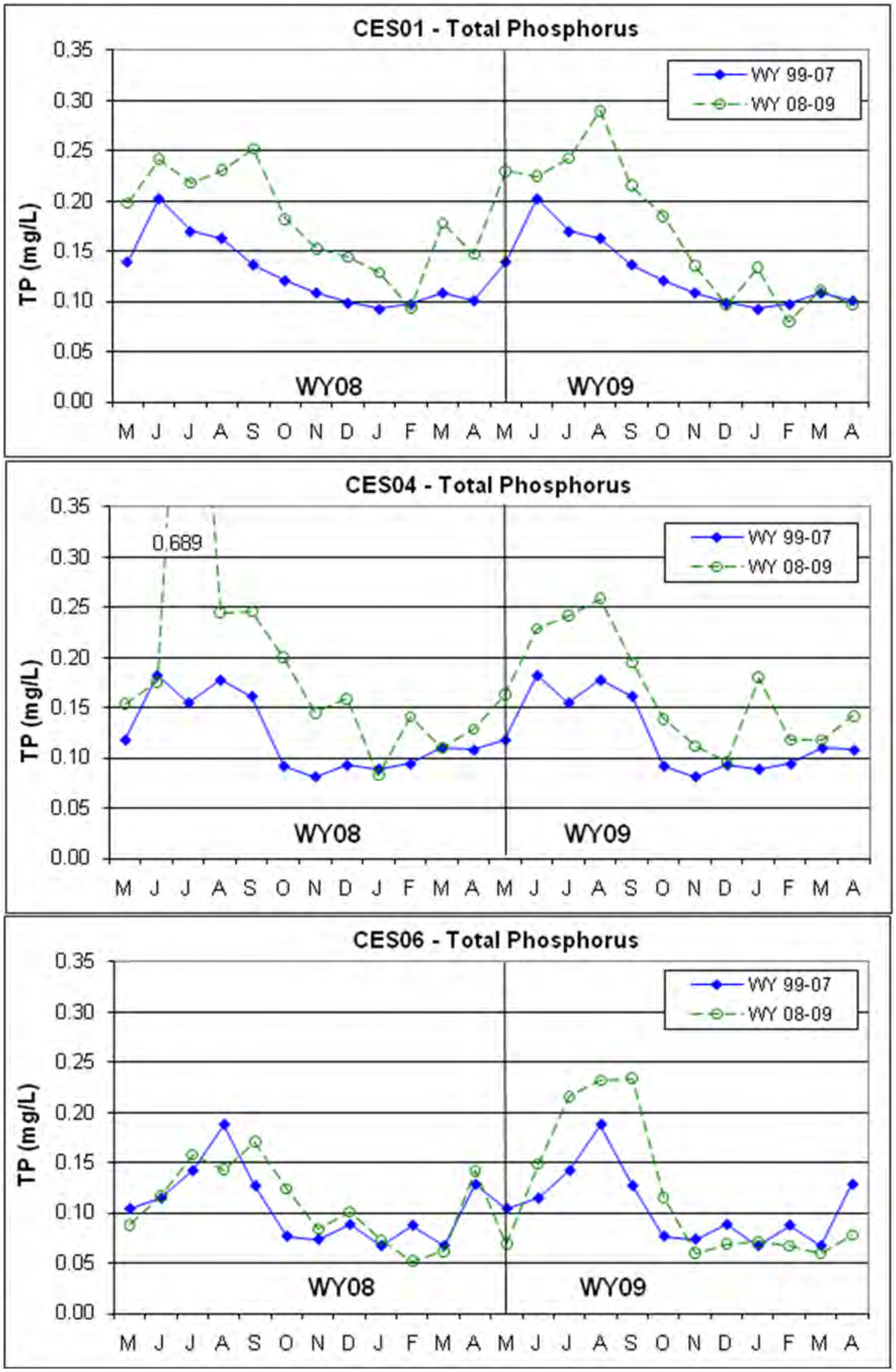


Figure 12-26. TP at three stations in the Caloosahatchee River and Estuary (see **Figure 12-23** for locations).

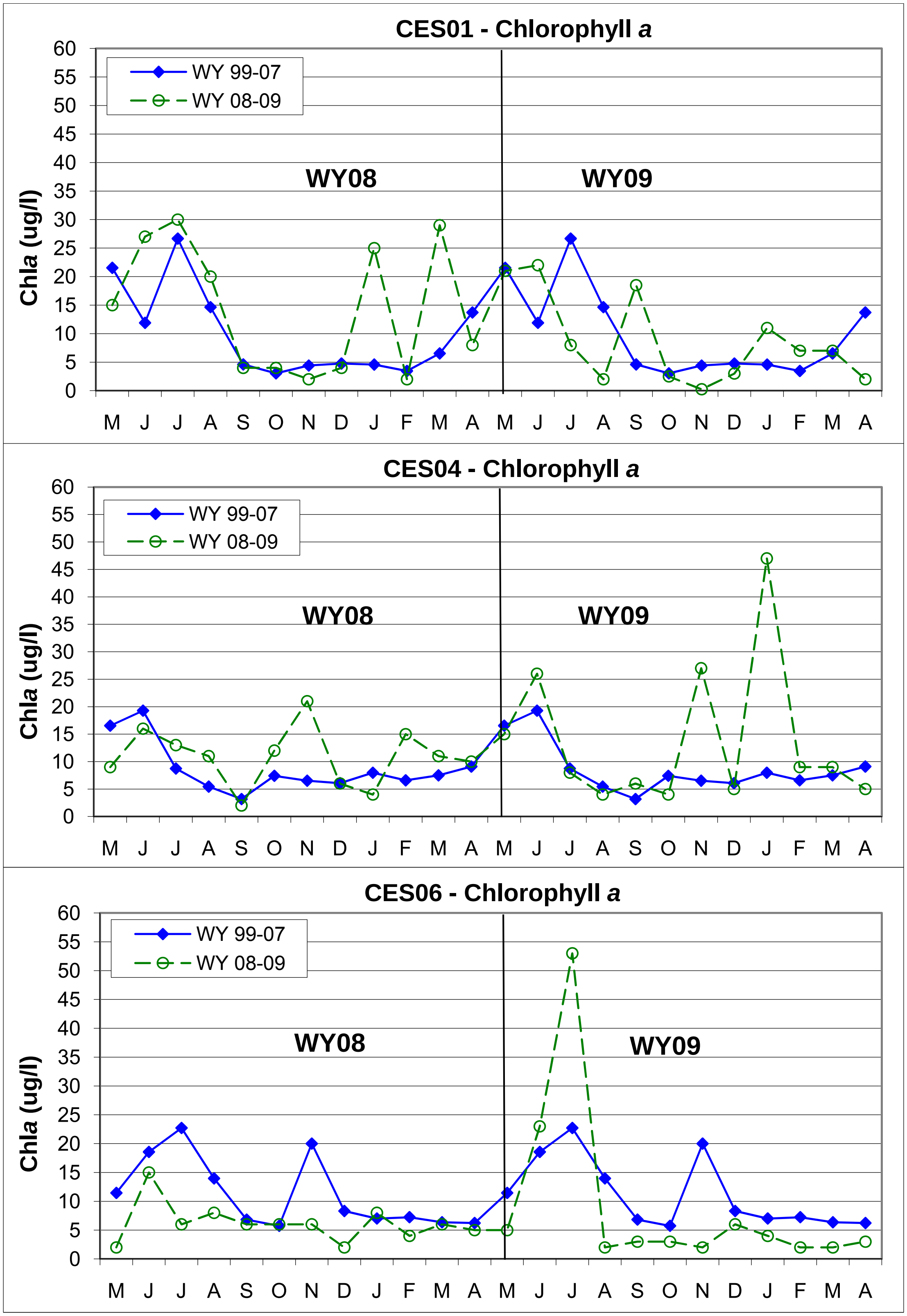


Figure 12-27. Chla at three stations in the Caloosahatchee River and Estuary (see **Figure 12-23** for locations).

Table 12-8. Results of water quality trend analysis at stations in the CRE. Data were taken monthly for 84 months from 1999–2005. Statistical analysis indicated that there were no trends in TP at any station (results not shown).

Station	Parameter	N	Tau	Slope	Units	P-value
CES03	TN	79	0.194	0.048	mg/L/yr	0.048
CES04	TN	79	0.235	0.006	mg/L/yr	0.002
CES06	TN	79	0.374	0.079	mg/L/yr	0.000
CES03	DIN	79	0.195	0.002	mg/L/yr	0.011
CES04	DIN	79	0.287	0.003	mg/L/yr	0.000
CES06	DIN	79	0.282	0.002	mg/L/yr	0.000
CES03	OPO_4	76	0.088	0.207	μg/L/yr	0.264
CES04	OPO_4	76	0.207	0.455	μg/L/yr	0.008
CES06	OPO_4	77	0.211	0.425	μg/L/yr	0.007
CES03	CHL*a*	77	-0.246	-0.508	μg/L/yr	0.013
CES04	CHL*a*	78	-0.267	-0.089	μg/L/yr	0.001
CES06	CHL*a*	78	-0.122	-0.044	μg/L/yr	0.115

Submerged Aquatic Vegetation

The SFWMD uses the environmental requirements of VECs to establish acceptable freshwater inflow ranges and as an indicator of ecosystem condition. SAV are monitored at three spatial scales. Aerial photographs were photo-interpreted, ground-truthed, and used to develop spatially explicit maps depicting SAV within the estuary. The goal of the project is to gain a better understanding of the dynamics at an estuarine scale by identifying areas of change (loss or gain), and stability. Image acquisition began in 1999 and is being conducted every two to five years contingent on funding.

Maps based on aerial photographs do not capture seasonal fluctuations in SAV coverage and cannot detect SAV in water heavily colored by tannins and other dissolved organic material typical of many estuaries in South Florida. The SFWMD also monitors SAV using a hydroacoustic approach (Chamberlain et al., 2009). This technique is used to monitor SAV at the square kilometer scale. A digital echo sounder linked with GPS equipment records both position and acoustic reflections from aquatic vegetation. A mathematic algorithm converts information contained in the acoustic reflections to percent cover and canopy height (Sabol et al., 2002). This effort originally began under contract with the USACE in 1996 and continued through 2004. These data continue to be collected tri-annually by the SFWMD.

Through RECOVER, the SFWMD also monitors SAV on the patch or transect scale [square meters (m^2)]. The locations of the transect monitoring stations extend from the upper Caloosahatchee Estuary to San Carlos Bay (**Figure 12-28**).

The species composition of SAV in the Caloosahatchee Estuary changes along the main axis of the system, primarily as a function of the prevailing salinity gradient (**Table 12-9**). Tape grass, also known as American wild celery, has been the dominant species in the upper Caloosahatchee Estuary, colonizing littoral zones in water of less than 1 m (Chamberlain and Doering, 1998a). Tape grass is a freshwater species that tolerates salinities less than 10 psu (Doering et al., 1999; French and Moore, 2003). Widgeon grass (*Ruppia maritima*) is also found in the upper Caloosahatchee Estuary, but at considerably lower densities than tape grass. Widgeon grass is also considered to be a freshwater species with a pronounced salinity tolerance and can be found in hypersaline waters (Kantrud, 1991).

Shoal grass, found in the lower estuary in Iona Cove, is a true seagrass considered to be tolerant of low salinity (McMillan and Moseley, 1967). Widgeon grass can also occur here, but not frequently.

The seagrass community in San Carlos Bay is composed of both shoal grass and turtle grass. Other species that occasionally occur are star grass (*Halophila engelmannii*), manatee grass, and widgeon grass.

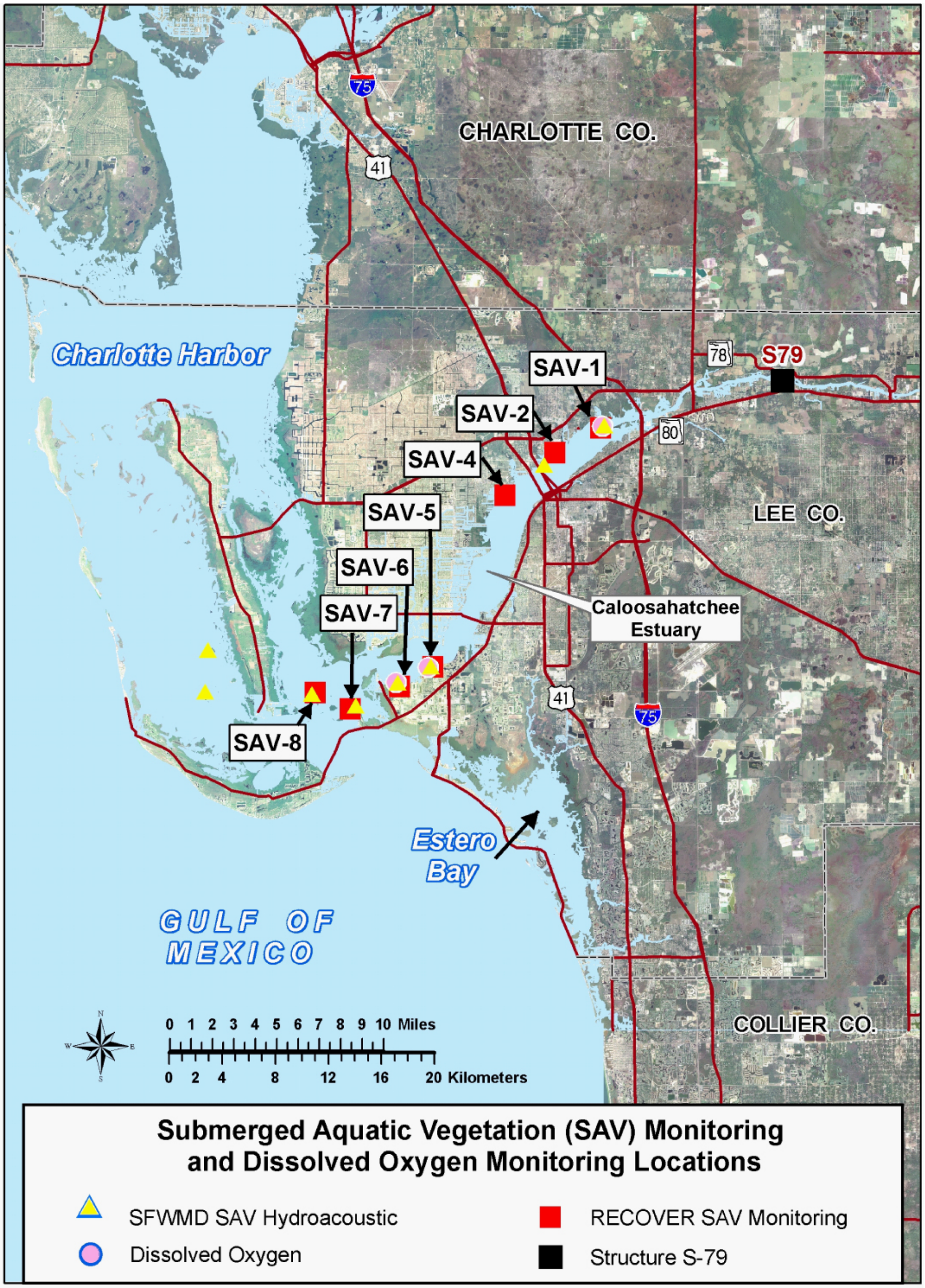


Figure 12-28. Location of SAV monitoring sites in the CRE and Southern Charlotte Harbor.

Table 12-9. Dominant SAV species at sampling sites in the CRE.

Segment	Site Number	SAV Species
Upper Caloosahatchee River Estuary	1 2	*Vallisneria americana* *Ruppia maritima*
	4	*Ruppia maritima* *Vallisneria americana*
Lower Caloosahatchee River Estuary	5 6	*Halodule wrightii* *Ruppia maritima*
San Carlos Bay	7 8	*Halodule wrightii* *Thalassia testudinum* *Ruppia maritima*

RECOVER Transect Monitoring

Upper Estuary Sites 1 and 2. No tape grass has been recorded on transects at Sites 1 and 2 in the upper Caloosahatchee Estuary since January 2007 (**Figure 12-29**). During the drought conditions experienced that year, salinity rose to intolerable levels (> 10 psu) for this plant. Although not detected by sampling, it is worth noting that since the wet season of WY2009, isolated *Vallisneria* rosettes have been found adjacent to the sampling transects at Site 1. Releases of water from Lake Okeechobee during the ensuing dry season did not prevent salinity from exceeding 10 psu at Fort Myers (**Figure 12-29**). However, plants did survive farther upstream at Site 1.

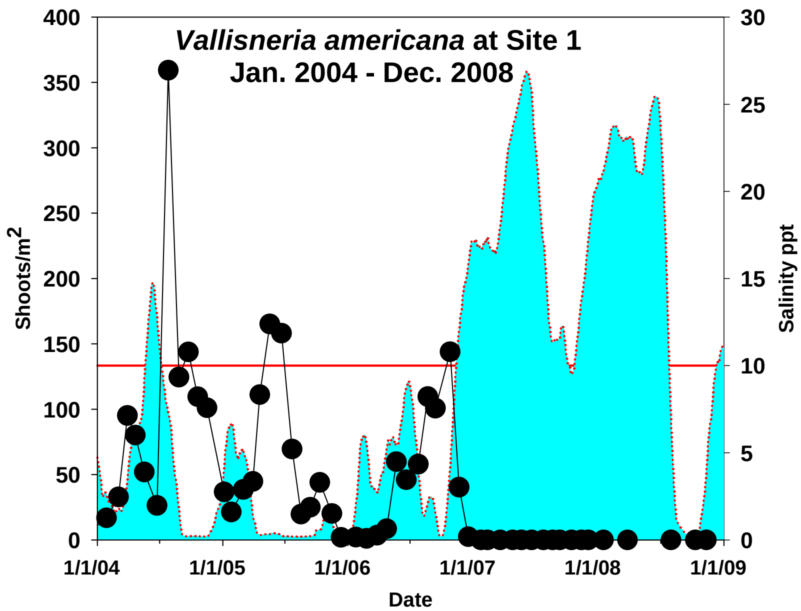
Widgeon grass has been virtually absent from the transects since 2004 and historically has been an occasional and sparsely distributed member of the SAV community. Like *Vallisneria*, a few plants were noted at Site 1 at the beginning of the WY2009 wet season.

Mid-Estuary Site 4. Over the past several years, SAV has been occasionally present at Site 4, with widgeon grass being found most frequently. Since September 2007, no SAV has been recorded at this site (**Figure 12-30**). Although the hypothesis requires testing, it may be that environmental conditions are too variable for SAV to exist for very long.

Lower Estuary Sites 5 and 6. Shoal grass is the dominant SAV in the lower Caloosahatchee. Since 2004, shoot densities generally have been higher at the upstream Site 5 than at Site 6 farther downstream (**Figure 12-31**). At both sites, shoot density increased during the drought year of 2007 and exhibited a typical decline during the winter dry season of 2007–2008. Tropical Storm Fay turned the entire estuary fresh from S-79 to Shell Point. Despite this reduction in salinity, shoot densities did not decline to levels recorded after Hurricane Wilma in 2005, which also turned the estuary fresh.

San Carlos Bay Sites 7 and 8. The density of seagrasses in San Carlos Bay was greatly reduced by the runoff and regulatory releases from Lake Okeechobee resulting from Hurricane Wilma in October 2005 (**Figure 12-31**). Shoal grass recovered quickly, and by the summer 2006, achieved pre-hurricane densities at both sites in San Carlos Bay. By contrast, turtle grass achieved pre-hurricane densities at only one site in the second summer (2007); at the second site, turtle grass has yet to fully recover. In terms of percent cover, these changes in density have resulted in a change in species dominance at the two sites (**Figure 12-32**).

During the winter months, the density of both species typically declines. The apparent decline in WY2009 for both species reached levels commensurate with those observed after Hurricane Wilma. The normal winter decline may have been exacerbated by discharges from Tropical Storm Fay that drove salinity nearly to zero at Shell Point in a short period of time (**Figure 12-22**). The response of shoal grass located in San Carlos Bay was relatively greater than that of shoal grass at the more upstream Sites 5 and 6.



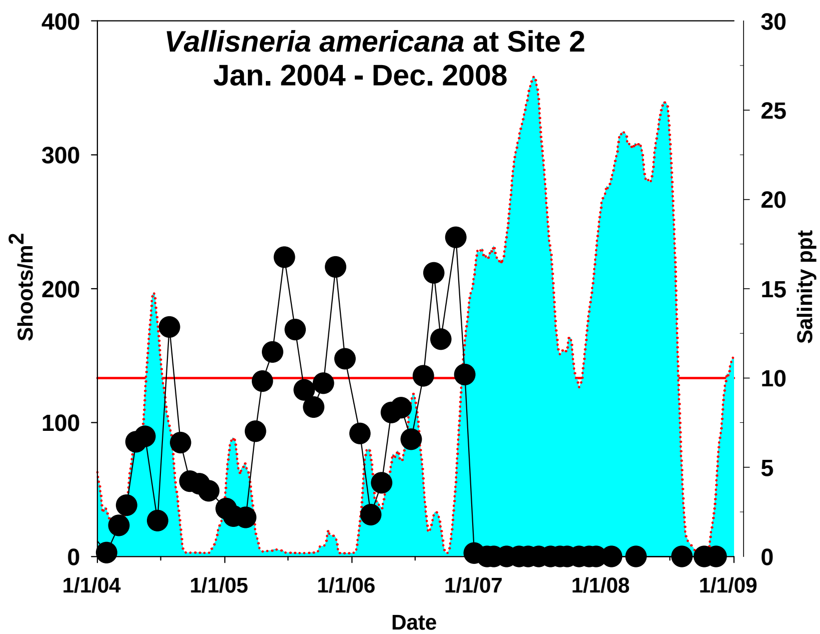


Figure 12-29. Density of *Vallisneria americana* at Upper Estuary Sites 1 and 2 in the CRE (black circles). The 30-day average salinity at Fort Myers (shaded area) and the 10 ppt MFL salinity criterion (red reference line) are shown.

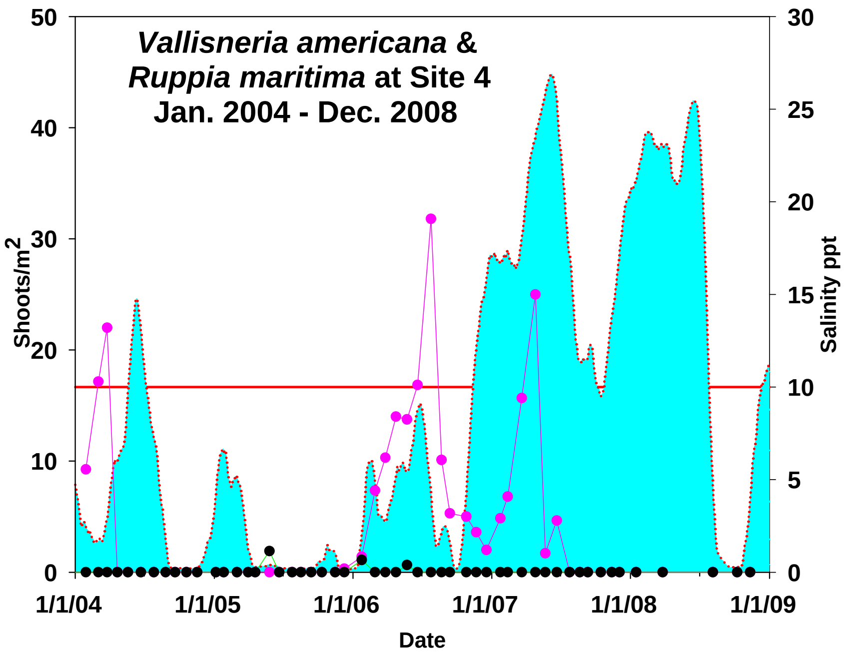


Figure 12-30. Density of *Vallisneria americana* (pink circles) and *Ruppia maritima* (black circles) at Mid-Estuary Site 4 in the CRE. The 30-day average salinity (shaded area) at Fort Myers and the 10 ppt MFL salinity criterion (red reference line) are shown.

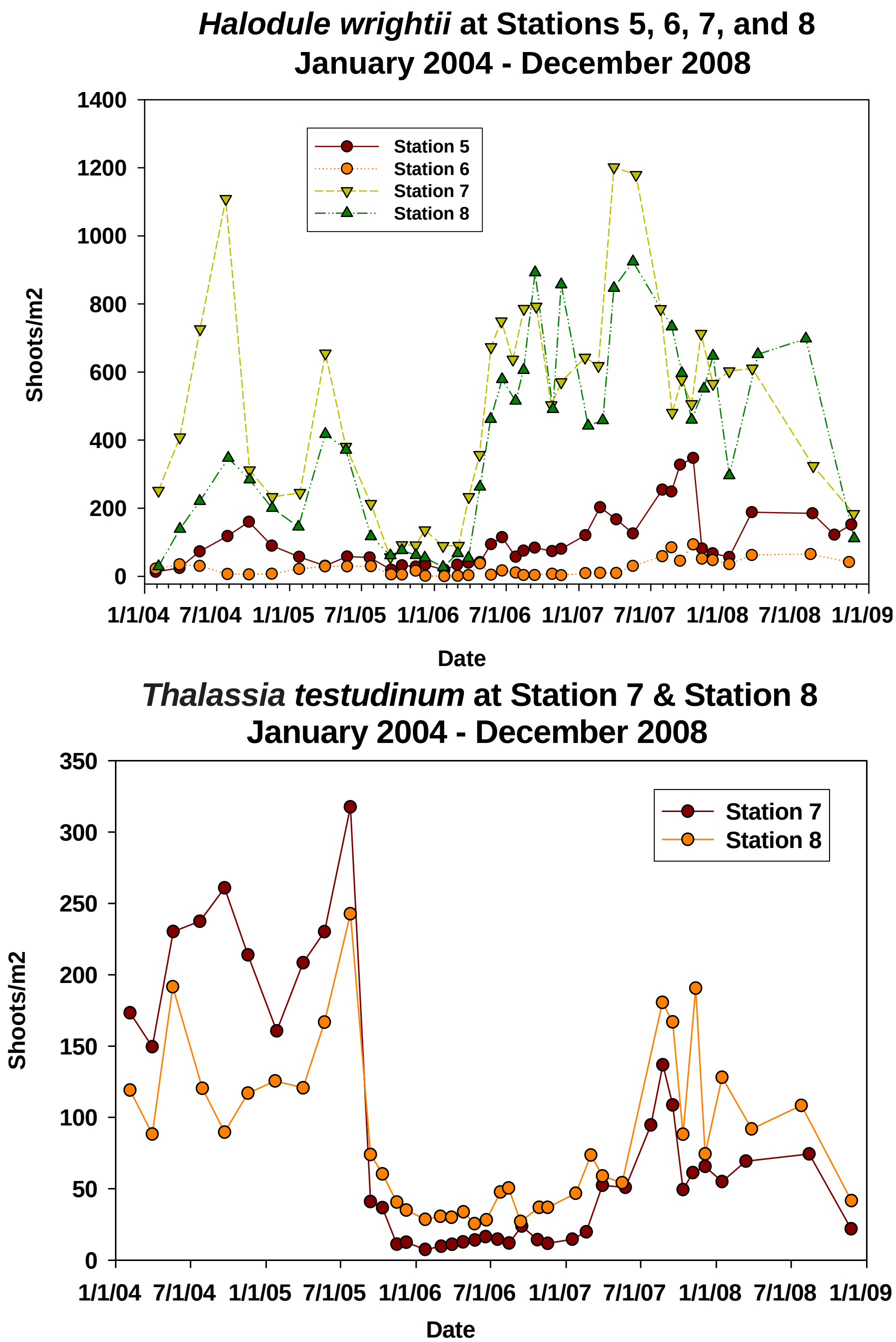


Figure 12-31. Densities of the seagrasses *Halodule wrightii* and *Thalassia testudinum* in the Lower Caloosahatchee Estuary Sites 5 and 6 and San Carlos Bay Sites 7 and 8.

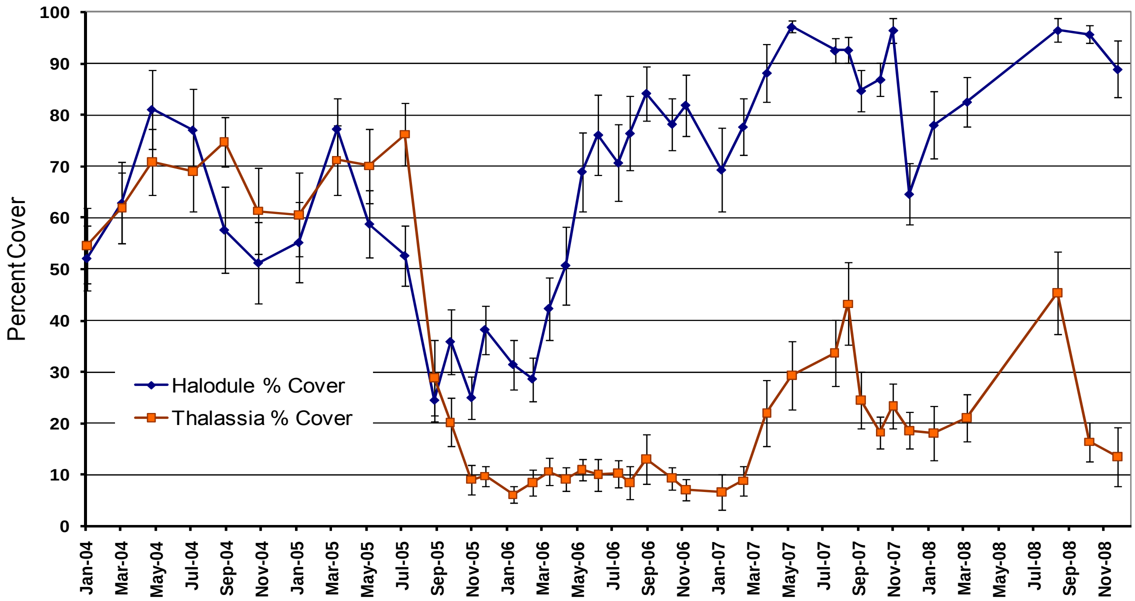


Figure 12-32. Coverage of the seagrasses *Thalassia* and *Halodule* at Site 7 in San Carlos Bay. Coverage expressed as a percentage of the bottom.

Estuarine Scale Aerial Maps

The SFWMD has been conducting aerial surveys of seagrasses in Lower Charlotte Harbor since 1999. Janicki et al. (2009) summarized these data by segments (**Figure 12-33)** in a draft report for the Charlotte Harbor National Estuary Program as part of an ongoing effort to establish water quality targets. Recent acreages (1999–2006) were compared with 1950s acreages determined through photo-interpretation of aerial photos of the study area from circa 1950 obtained from the National Archives in Washington, DC. (**Table 12-10**). The 1950s acreages were further adjusted for non-restorable areas (e.g., dredged channels).

During the 1999–2006 period, seagrass coverages in San Carlos Bay and Pine Island Sound have been equal to or greater than estimates from 1950s aerial photographs. There appear to have been losses in the Tidal Caloosahatchee and Matlacha Pass. Although seagrass coverage in Matlacha Pass has increased with each survey since 1999, an 18 percent loss was observed between the 2006 and 1950s surveys. Data from the Tidal Caloosahatchee segment are difficult to interpret because the water is usually a strong tea color, which inhibits detection of seagrass from aerial photographs. Comparison of 1950s maps with more recent ones indicate that the 1950s map probably includes tape grass beds in the upper estuary that are not present on more recent maps. Maps that are more recent include beds of shoal grass in the lower estuary that are not present on the 1950s map.

Table 12-10. Acreages of seagrasses mapped in segments of Lower Charlotte Harbor. The 1950s coverage has also been adjusted for areas that are not restorable.

Segment	Year					
	1950s	1950s adj	1999	2003	2004	2006
Tidal Caloosahatchee	211	93	2	103	61	56
San Carlos Bay	3,243	3,118	3,709	4,338	5,192	5,376
Matlacha Pass	9,577	9,315	6,055	7,182	7,479	7,619
Pine Island Sound	24,113	23,757	25,941	26,892	28,034	29,204
Total	37,144	36,283	35,707	38,515	40,766	42,255

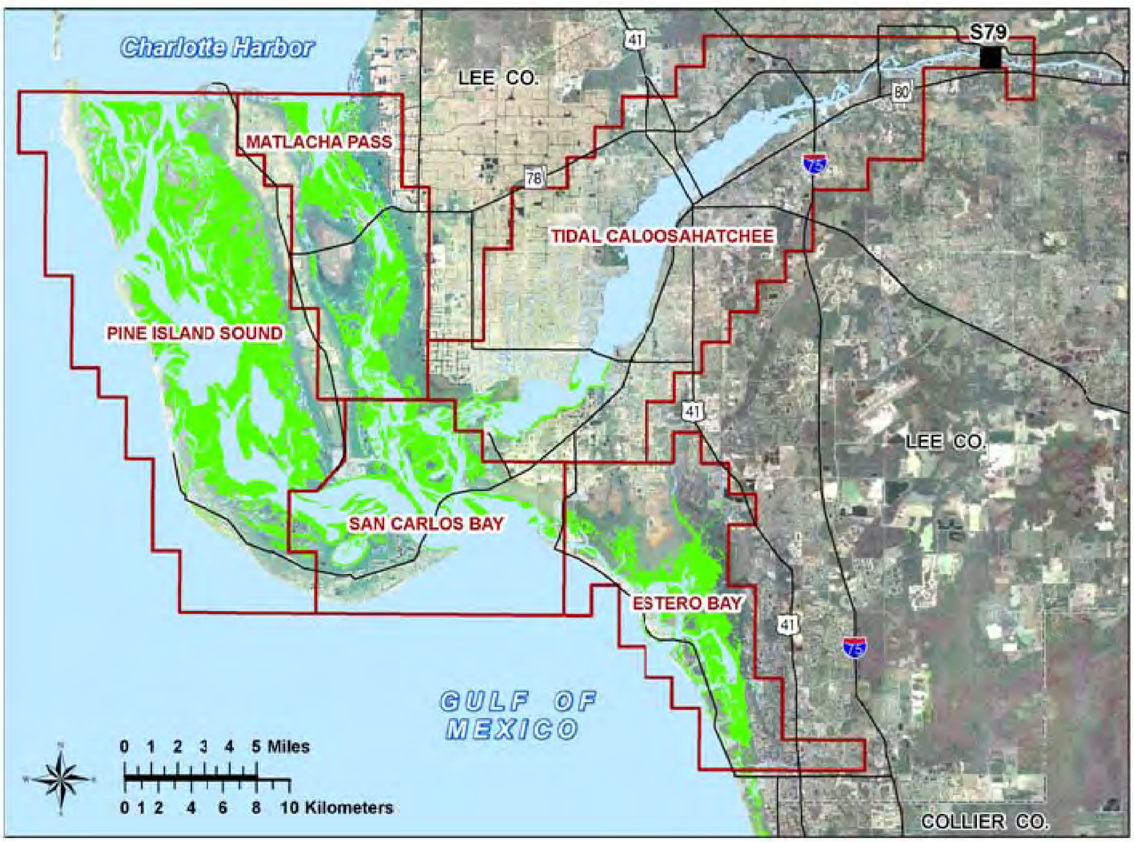


Figure 12-33. Segmentation scheme used to report seagrass coverage from aerial photographs.

Hydroacoustic Monitoring

The locations of hydroacoustic monitoring stations maintained by the District extend from the upper Caloosahatchee Estuary through San Carlos Bay into Pine Island Sound (**Figure 12-28**). Samplings were conducted in March, June, and September 2008. A comparison found that hydroacoustic and manual quadrat sampling methods revealed very similar seasonal and spatial patterns (Chamberlain et al., 2009).

Conclusions

SAV have been absent from the upper Caloosahatchee Estuary since 2007. Tape grass began to reappear during the wet season of WY2009. Releases of lake water during the WY2009 dry season allowed plants to survive into the following wet season.

In recent years, seagrass coverages in San Carlos Bay and Pine Island Sound have been equal to or greater than estimates from the 1950s. A reduction in coverage of about 20 percent has occurred in Matlacha Pass. Patch or transect level monitoring suggests that seagrass coverage in San Carlos Bay has recovered from the declines associated with Hurricane Wilma in October 2005. This recovery in coverage is supported by the aerial surveys, which recorded an increase in the number of acres of seagrass in San Carlos Bay between 2004 and 2006. Transect monitoring indicates a shift in species dominance from turtle grass prior to the hurricane to shoal grass upon recovery. Shoal grass is generally considered a rapid colonizer (Dunton, 1990), and its dominance at this time is expected. If conditions remain favorable, the expectation is for turtle grass to reestablish its dominance.

EASTERN OYSTER ABUNDANCE AND DISTRIBUTION

Oyster Monitoring

Oysters are monitored in the CRE as part of RECOVER. The target for the CRE, predicted with the full implementation of CERP projects, is "to provide about 400 acres of suitable oyster habitat with at least 100 acres of living oyster reefs" (RECOVER, 2007a).

Monitoring is currently in progress at six stations in the CRE: (1) Pepper Tree Point (PTP), (2) Iona Cove (IC), (3) Cattle Dock (CD), (4) Bird Island (BI), (5) Kitchel Key (KK), and (6) Tarpon Bay (TB) (**Figure 12-34)**. As a measure of the status of estuarine oyster beds, the District reports on the density of live and dead adult oysters sampled on a seasonal (wet, dry) basis. Wet and dry season monitoring of oyster adult condition and spat fall was implemented in 2000. Monitoring of live oyster densities (number of oysters/m^2) at each of the sites started in 2006. Mean live oyster densities for the five stations in the lower Caloosahatchee Estuary are presented in **Figure 12-35.**

Live oyster density results indicate a strong positive relationship to salinity. Total number of oysters was greatest starting in CY2006 at approximately 1,300/m^2. Oyster density fell in CY2007 along with salinity before a modest rebound in fall 2007. The number of live oysters was low during the dry season of 2008 despite high salinity values. This may have been due to greater predation during a prolonged period of high salinity (**Figure 12-35**). While oyster density was reduced in summer 2008, live oyster numbers peaked once again early in 2009.

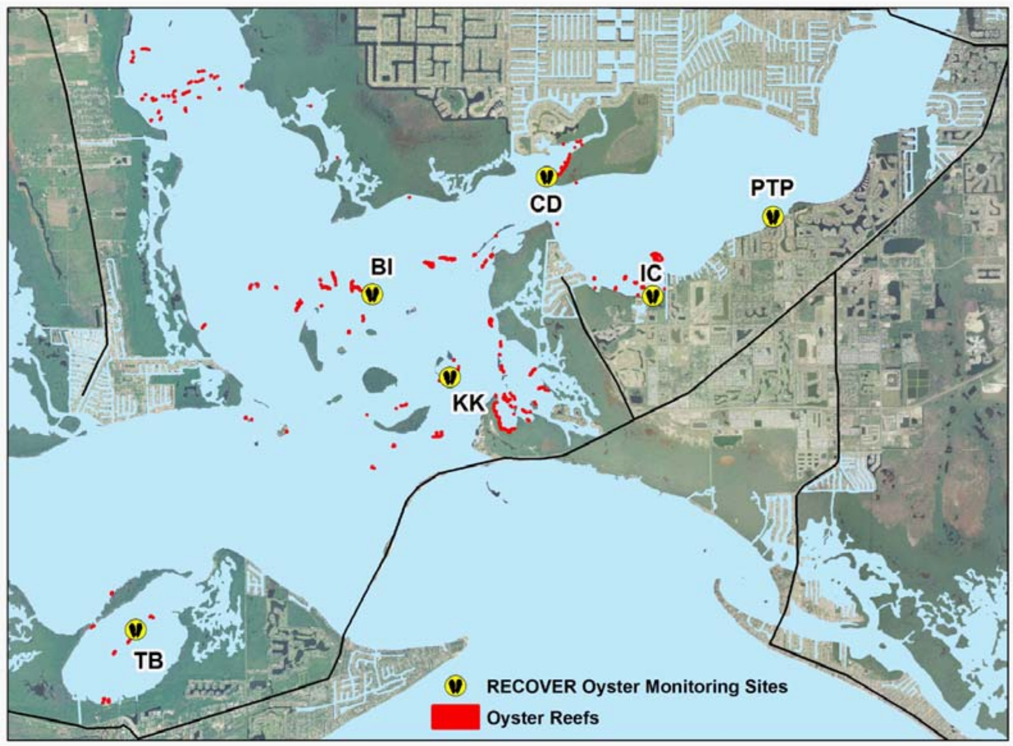


Figure 12-34. Oyster sampling stations.

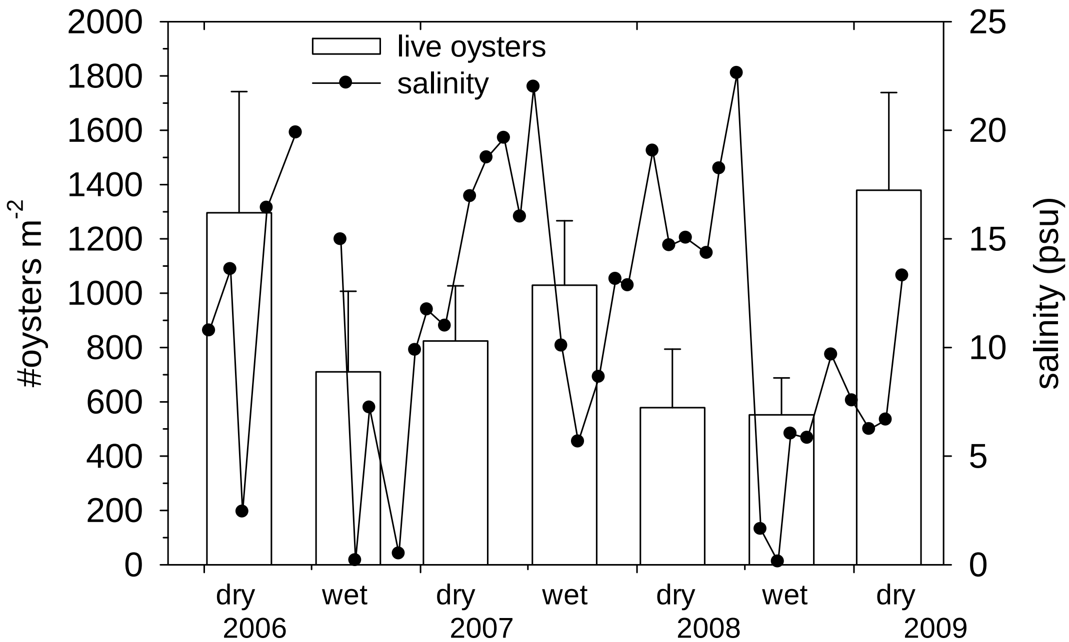


Figure 12-35. Live oyster densities (left axis) and salinity (right axis) from spring 2006 to spring 2009 in the CRE. Oyster values are average and standard errors from five stations in the lower CRE. Only live oysters were counted.

STRATEGIES FOR THE CALOOSAHATCHEE RIVER ESTUARY

Research Plan

A Research and Water Quality Monitoring Plan was developed as part of the CRWPP. Research projects are intended to reduce or eliminate key uncertainties related to TMDLs and flow and salinity envelopes, and optimize operational protocols. Four research projects were identified, and a detailed presentation of these projects can be found in the 2009 SFER – Volume I, Chapter 12 and in Appendix E of the Caloosahatchee River Watershed Protection Plan (SFWMD et al., 2009).

1. **Estuarine Nutrient Budget.** This project will construct nutrient budgets of N and P for the Caloosahatchee Estuary and increase the capability to predict the effects of nutrient management efforts.
2. **Dissolved Oxygen Dynamics.** This project will identify the factors causing DO impairment in the CRE. Understanding dissolved oxygen dynamics will also help to identify impacts from pollutant loads to estuarine ecosystems.
3. **Low Salinity Zone.** This project examines the effects of freshwater discharges on the production of fish larvae in the estuary and utilization of the low salinity zones as a nursery area. Results can be applied to establishing water reservations, to refining flow and salinity envelopes, and to providing guidelines for delivery of freshwater to the CRE.
4. **Light Attenuation in San Carlos Bay.** This study will examine how relative contributions of chlorophyll *a*, colored dissolved organic matter (CDOM), and turbidity to light attenuation vary with season and freshwater inflow in San Carlos Bay. Results can be used to determine when, and under what conditions, resource light attenuation goals may be met.

Estuarine Nutrient Budget Project

Overview and Background

Over-enrichment of estuaries with nutrients from urban and agricultural sources is both a local problem for the CRE and a problem for most estuaries worldwide. In the 1980s, the Florida Department of Natural Resources (FDNR) determined that the Caloosahatchee system had reached its nutrient loading limits based on high chlorophyll *a* and low DO concentrations (DeGrove, 1981). More recently, blue-green algal blooms (cyanobacterial), red tides, and massive accumulation of drift algae (Lapointe and Bedford, 2006) have been taken as an indication that nutrient loads to the Caloosahatchee Estuary are too high and the system suffers from eutrophication. A well-constrained nutrient budget is critical to understanding the origin, magnitude, and management of problematic nutrient loads, and guide prioritization for load reductions. The project will construct nutrient budgets for N and P for the Caloosahatchee Estuary. Terms in the nutrient budget will be determined by a variety of methods. Some of the terms in the budget can be derived from existing information (i.e., nutrient load at S-79). Others, such as stormwater runoff from the Tidal Caloosahatchee Basin, may require a modeling effort. Still others, such as the flux of nutrients out of the bottom sediments, may require direct measurement.

Management Objective

The Estuarine Nutrient Budget Project supports nutrient loading goals for the Caloosahatchee Estuary by quantifying the magnitude of nutrient loads from various sources so that appropriate methods and approaches to load reductions can be identified.

Progress in Water Year 2009

Work completed in WY2009 focused on two aspects of the nutrient problem in the Caloosahatchee Estuary. The first was nutrient limitation of phytoplankton growth. Although results of monitoring studies suggest that nitrogen concentration is linked to macroalgal productivity in the estuary, no recent studies have experimentally determined whether N or P limits algal production in this system. The second was the bioavailability of dissolved organic nitrogen (DON). Measurements from monitoring programs indicate that much of the nitrogen load to the CRE is organic (about 80 percent), but the extent to which this organic fraction can support algal production or is susceptible to remineralization by bacteria is not known.

Nutrient Limitation of Phytoplankton Growth. This project began in 2006 and was conducted under contract with Florida Gulf Coast University (FGCU). Four sites (**Figure 12-36**) in the Caloosahatchee Estuary were sampled every three months from May 2006–February 2008 (Loh, 2008a). Traditional bioassays, adding nitrogen alone, phosphorus alone, and N and P in combination were conducted. Results indicated that nitrogen most often limited growth of phytoplankton. Limitation was strongest during the wet season when blooms normally occur.

Degradation of Dissolved Organic Nitrogen. At the same time nutrient addition bioassays were conducted, assays measuring the susceptibility of DON to remineralization by bacteria were conducted using water from the four sites (Loh, 2008a). As measured by the production of DIN in filtered samples, DON present in the Caloosahatchee Estuary was susceptible to remineralization by bacteria (**Figure 12-37**). The majority of remineralization occurred within 14 to 28 days (**Figure 12-37**), and although results varied, 20 to 60 percent of the DON appeared available (**Figure 12-37**). Another important result was that the DIN produced during the first 14 to 28 days was subsequently taken up, suggesting the presence of an active microbial loop that may compete with autotrophs for inorganic nitrogen.

Dissolved organic nitrogen present in the downstream estuary may come from various sources, including tidal tributaries, wastewater treatment facilities, and phytoplankton. Therefore, the District also contracted with FGCU to examine the bioavailability of DON entering the Caloosahatchee Estuary at the Franklin Lock and Dam (S-79). Experiments were conducted in January, February, and March 2008 (during the dry season of a drought year) when fresh DON input was expected to be minimal. Although some photolysis was detected in laboratory experiments, it did not appear that bacteria converted DON into inorganic nitrogen, and it did not form particulate aggregates upon mixing with seawater (Loh, 2008b). However, results from the incubations indicated a rather rapid cycling between DIN and DON that was mediated by bacteria. Again, these data suggest the presence of an active microbial loop in the CRE.

These two projects have demonstrated there is an active microbial loop in the CRE that can mediate cycling between DIN and DON. DON found in the estuary was remineralized to DIN by bacteria. DON from the freshwater Caloosahatchee River was not. Further studies are necessary to examine DON from the freshwater Caloosahatchee River during non-drought conditions, when fresh, more labile DON is expected.

Phytoplankton Productivity. The ultimate goal of many nutrient reduction programs is to improve water quality (e.g., water clarity, DO) by reducing the magnitude and frequency of phytoplankton blooms. An understanding of the factors that control phytoplankton growth and quantification of the growth rate itself is central to predicting the results of nutrient reduction.

In WY2009, a project was initiated to measure primary productivity and to establish an empirical model that relates phytoplankton productivity to chlorophyll *a* biomass and light intensity, if possible. The work quantifies productivity through a simulated in situ incubation technique that measures changes in DO at several light levels. In addition, it provides guidance to the calibration of a water quality model for the Caloosahatchee River and Estuary system. The calibrated water quality model can be employed to assess the benefit of the Caloosahatchee Basin Management Action Plan (BMAP) in the watershed to the estuary ecosystem. The BMAP describes the actions that will be taken to achieve the TMDL. As required by the legislation, the RWPPs also provide the basis for the BMAP, which will be developed by the FDEP and incorporated into future RWPP updates.

The major objectives of this project are to (1) determine spatial and temporal patterns of primary production at four sites, one each in the upper estuary, middle estuary, lower estuary, and San Carlos Bay; (2) characterize key water quality parameters that directly or indirectly affect primary production, and are essential to efforts to model vertically integrated production, including macronutrient levels (TN and P, DIN and phosphorus, and silica), temperature, salinity, and vertical attenuation of photosynthetically active radiation (PAR light); and (3) define the structure and abundance of the phytoplankton community.

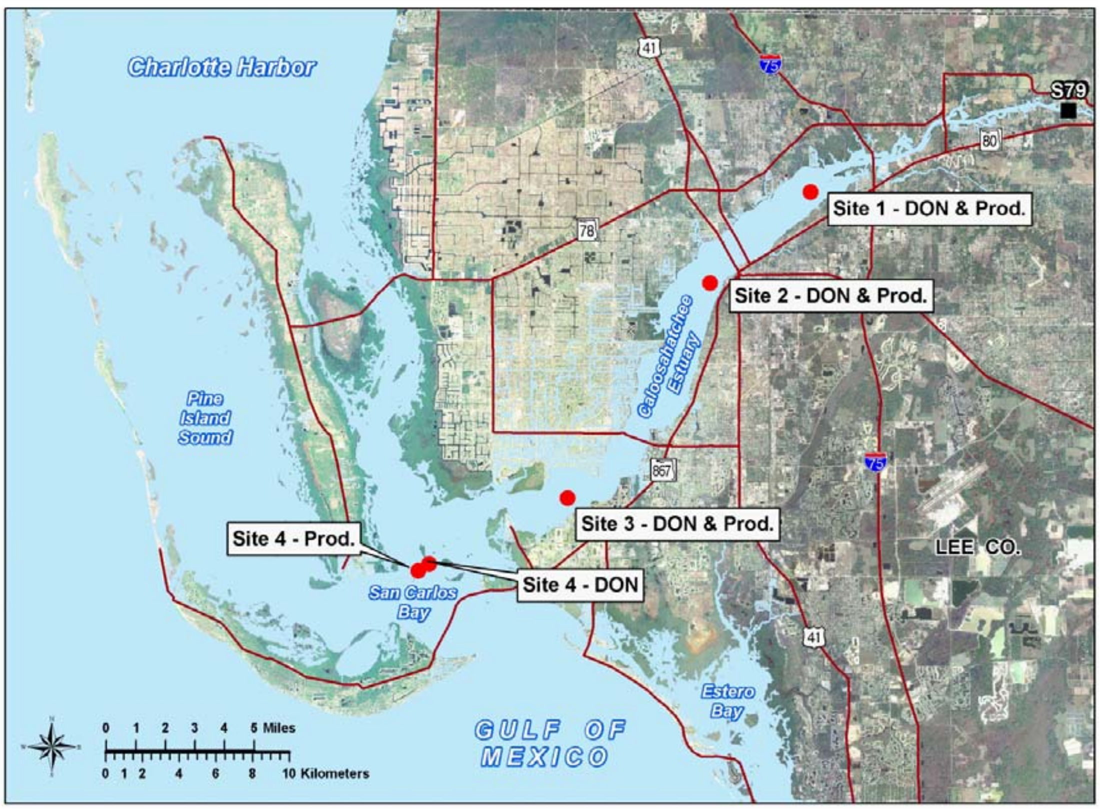


Figure 12-36. Sampling sites for dissolved organic nitrogen (DON) in the CRE and San Carlos Bay.

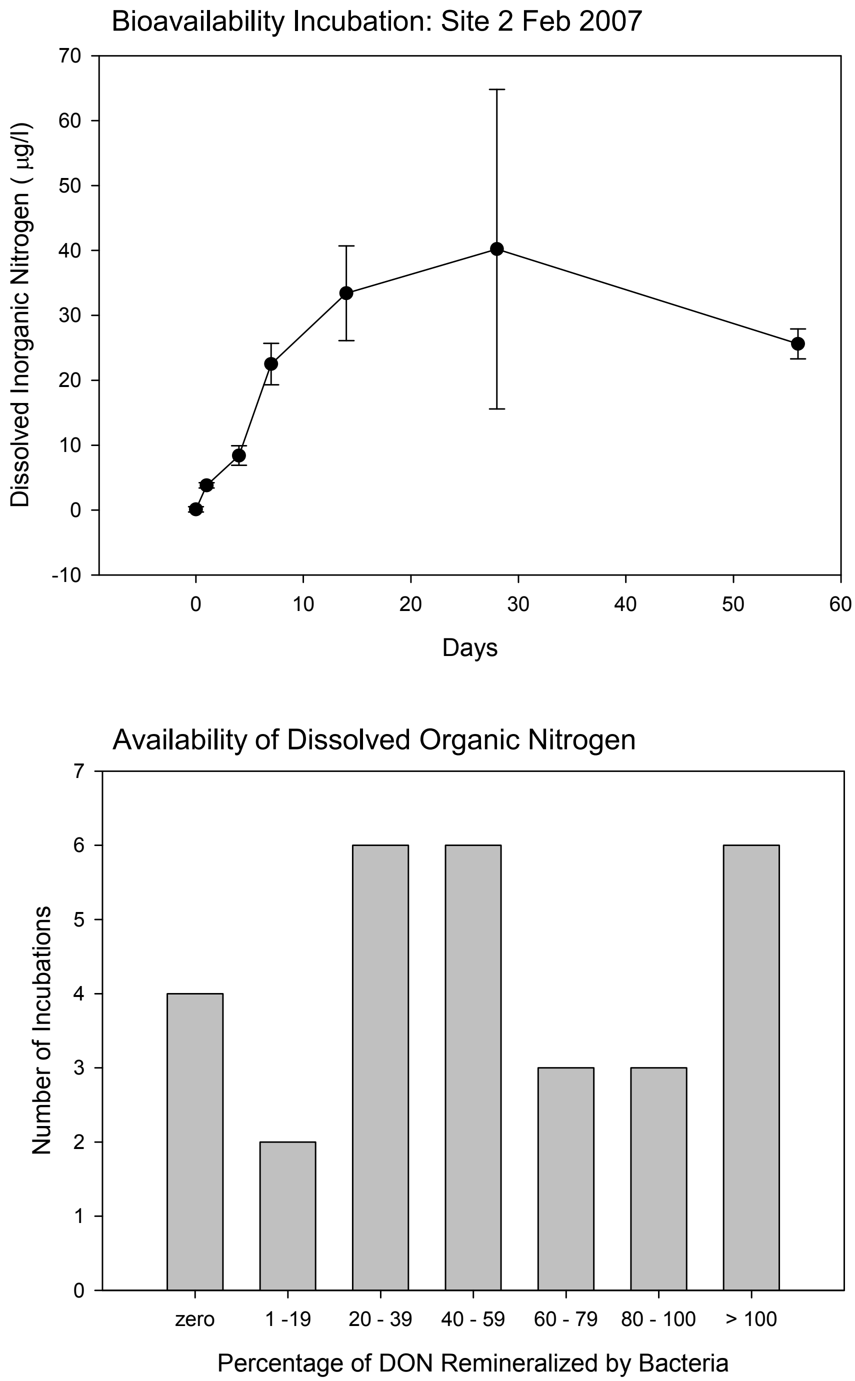


Figure 12-37. Top Panel: Example of a bioavailability incubation measuring the production of dissolved inorganic nitrogen (DIN) resulting from the remineralization of DON in the CRE. Bottom Panel: Results of incubations from all four sampling sites are summarized. Vertical bars are the number of incubations in which a particular percentage of DON was remineralized. Raw data from Loh, 2008b.

Dissolved Oxygen Dynamics Project

Overview and Background

Low oxygen concentrations are often associated with excess nutrient loading (Gray, 1992), and have been a recognized problem in the Caloosahatchee system since the 1980s (DeGrove, 1981). Oxygen concentrations falling below the state standard of 4.0 mg/L (for Class III Salt Water Region) occur most often in the upper estuary during the warmer months of the year. The CRE is listed as impaired for DO and nutrients by the FDEP. The DO Dynamics Research Project will identify the factors responsible for the DO impairment in the Caloosahatchee Estuary. The results of this study will provide critical information that will guide the selection of management solutions.

Management Objective

This project supports the management goal of improving DO concentrations in the CRE.

Dissolved Oxygen Time-Series

Continuous measurements of DO were taken at three sites in the Caloosahatchee from February through September 2008 (**Figure 12-28**). One site was in the upper estuary, an area normally occupied by tape grass, and two sites were located in shoal grass beds in the more marine-oriented lower estuary. Data have not yet been analyzed.

Low Salinity Zone Project

Overview and Background

One of the management goals for the CRE is to minimize the occurrence of undesirable salinity patterns in certain areas. In general, low flow and high salinity are a concern for the plants and animals living in the upper portions of an estuary. High flow and low salinity are troubling for the saltier, more marine regions. The low flow requirements of the CRE have been primarily based on salinity-tolerant tape grass living in the low salinity zone located near the head of the system.

Typically, these low salinity zones (0–10 psu, Holmes et al., 2000) are highly productive, serving as a nursery area for early life stages of economically important fish and shellfish (Day et al., 1989). It is not clear that the low freshwater flow targets established to satisfy the requirements of tape grass will also maintain these other nursery functions.

Management Objective

This project examines elements of the estuarine food web, including planktonic and benthic algae as well as zooplankton and fish larvae within the estuarine turbidity maximum of the CRE. The ultimate goal of this program is to understand the role of freshwater discharge and production of fish larvae in the CRE. This project supports the District's mission to improve natural systems by establishing water quantities that protect fish and other wildlife. Results of this study will be used to refine the salinity envelope and to provide environmental guidelines for delivery of fresh water to the CRE.

Methodological Approach

The study area consists of the lower Caloosahatchee River and Estuary (**Figure 12-38**). Seven zones were sampled from San Carlos Bay to just below the Franklin Lock and Dam. Each zone was sampled twice (seven zones x two samples x two sample dates = 28 samples for demonstration project).

The following samples and data were collected within each zone of the study area:

- Zooplankton (500 µm plankton net)
- Phytoplankton (10 µm plankton net)
- Benthic microalgae (diving pulse amplitude modulation fluorometry greased plates)
- Water-column chlorophyll *a* (in situ fluorometry)
- Estuarine turbidity maximum (location and strength)
- CDOM fluorometry
- Standard water quality measurements (i.e., salinity, conductivity, temperature, DO)
- Nanoplankton (whole water samples)

Progress in Water Year 2009

A demonstration project initiated in CY2008 was conducted by staff from FGCU and the University of South Florida. Because this was a demonstration project, sampling was limited to two events, one during a seasonally dry month (May) and one during a seasonally wet month (September) in 2008 (Tolley et al., 2009). Collection of a longer-term dataset continued in WY2009.

The following provides a brief summary of the results for zooplankton. Freshwater discharge at S-79 was 0 cfs during the May sampling and almost 4,600 cfs during September. Zooplankton samples were dominated by decapod crustaceans, representing 73.4 percent of the total catch. Other major groups in order of abundance were fish (9.7 percent), amphipods (5.1 percent), copepods (4.8 percent), arrow worms (2.3 percent), cumaceans (0.9 percent), mysids (0.8 percent), and gelatinous predators (0.7 percent).

In general, the number of taxa increased from the river mouth upstream to S-79 in both seasons, but total density of zooplankton was substantially higher during May (low flow) than September (high flow). In September, during high-flow periods, freshwater zooplankton and insect larvae were present in Zones 4-7. Large differences in spatial distribution were also observed, with many organisms washed downstream in September relative to May (**Figure 12-39**). Of particular note is the distribution of the gelatinous predator *Clytia* sp., which was found in highest densities immediately downstream of the Franklin Lock and Dam. MacDonald et al. (2006) found a strong inverse relationship between freshwater inflow and the abundance of *Clytia* sp. in the Hillsborough River, and suggested that because hydromedusae prey on and compete with larval fish for food, increased inflow served to displace this species "downstream and away from tidal river nursery habitats." In addition to the presence of *Clytia* sp. upstream in the Caloosahatchee, the predatory ctenophore *Mnemiopsis* sp. was found only at the upper two stations, just downstream of the lock and dam.

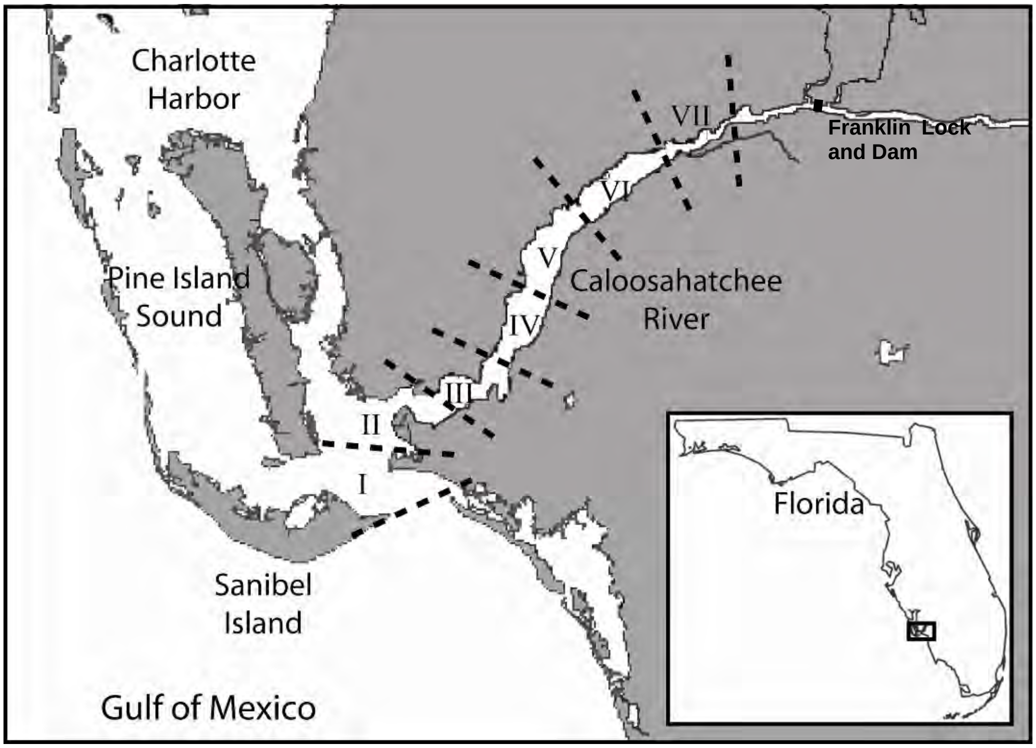


Figure 12-38. Low Salinity Zone Project study area indicating zones selected for biological and water quality sampling.

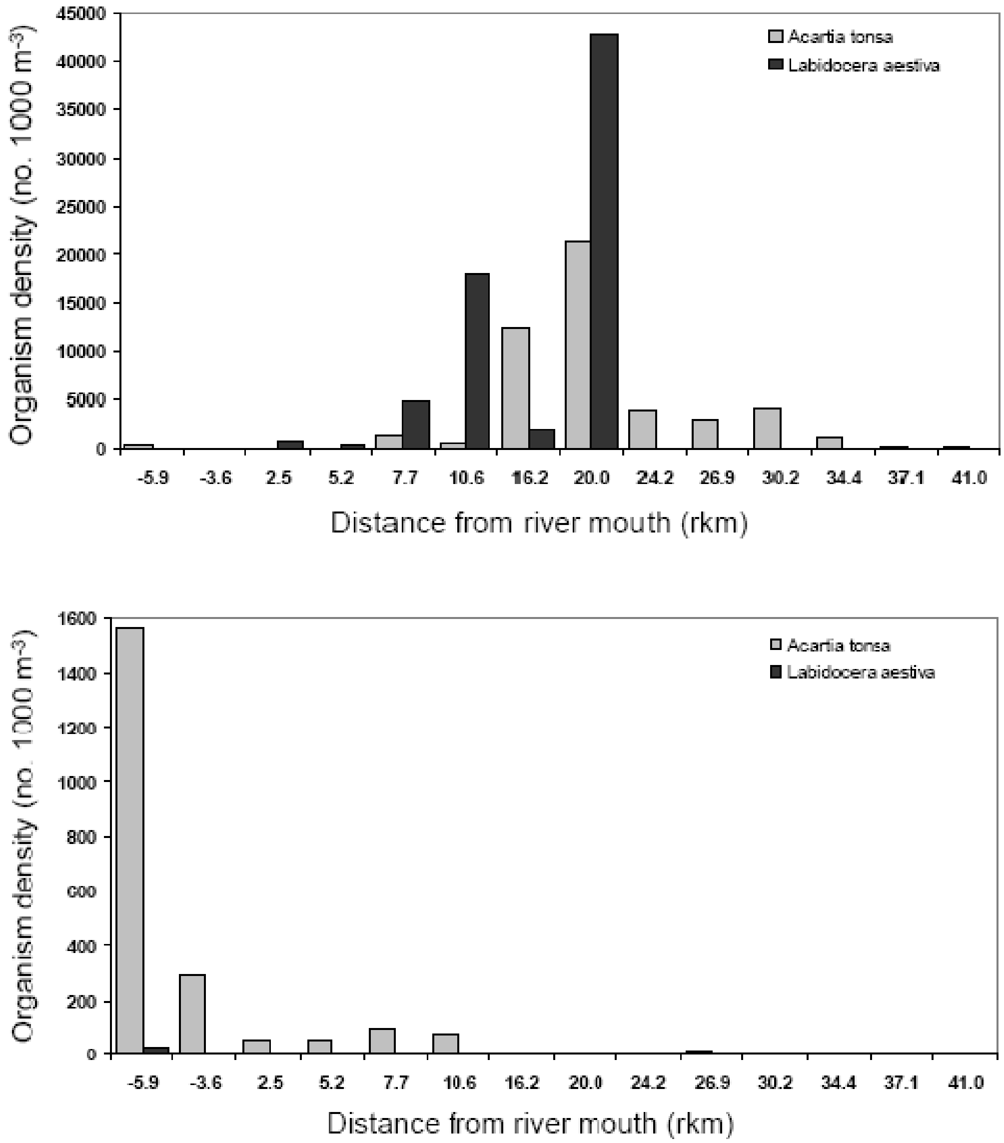


Figure 12-39. Density of two species of copepods as a function of distance from the mouth of the CRE in May and September.

Light Attenuation Project in San Carlos Bay

Overview and Background

A resource-based method (Corbett and Hale, 2006) is being used to establish nutrient TMDLs in the Caloosahatchee Estuary. Nutrient load reductions are based on achieving water clarity in San Carlos Bay that allows enough light for seagrasses to grow to a depth of 2.2 m. Three major water quality constituents have been identified that attenuate light in the Southern Charlotte Harbor: turbidity, CDOM, and chlorophyll *a* (McPherson and Miller, 1994). In San Carlos Bay, existing evidence suggests that in some years CDOM may account for most of the light attenuation, while chlorophyll may dominate in others (Dixon and Kirkpatrick, 1999; Doering et al., 2006). This light attenuation research study will determine how relative contributions to total light attenuation of chlorophyll *a*, CDOM, and turbidity vary with season and freshwater inflow in San Carlos Bay. Information from this study will better define controls on light attenuation in San Carlos Bay and the relationship between the TMDL and its resource goal. Results can be used to determine when, and in what conditions, resource light attenuation goals may be met.

Progress in Water Year 2009

District staff initiated a project to examine the mixing behavior of CDOM from the Franklin Lock and Dam, through San Carlos Bay into the Gulf of Mexico. Apparent mixing behavior is examined by measuring salinity and CDOM at 11 stations along the transect. These apparent mixing curves are compared to curves developed in the laboratory by mixing fresh water from the Caloosahatchee River and salt water from the Gulf.

Two examples are provided in **Figure 12-40.** In the top panel, both apparent mixing behavior measured on field sampling and laboratory mixing curves indicate conservative mixing of CDOM from the Caloosahatchee River. In the bottom panel, apparent mixing behavior indicates a substantial loss of CDOM in the estuary, while the laboratory curve indicates conservative behavior. These results suggest that the apparent loss of CDOM in the estuary does not result from physiochemical flocculation, but may arise from photo-bleaching or changing concentrations of CDOM in the fresh water end member.

An in situ sonde unit has been purchased that measures CDOM, turbidity, and chlorophyll *a*. Studies to determine the relative contribution of these parameters to light attenuation began in September 2009.

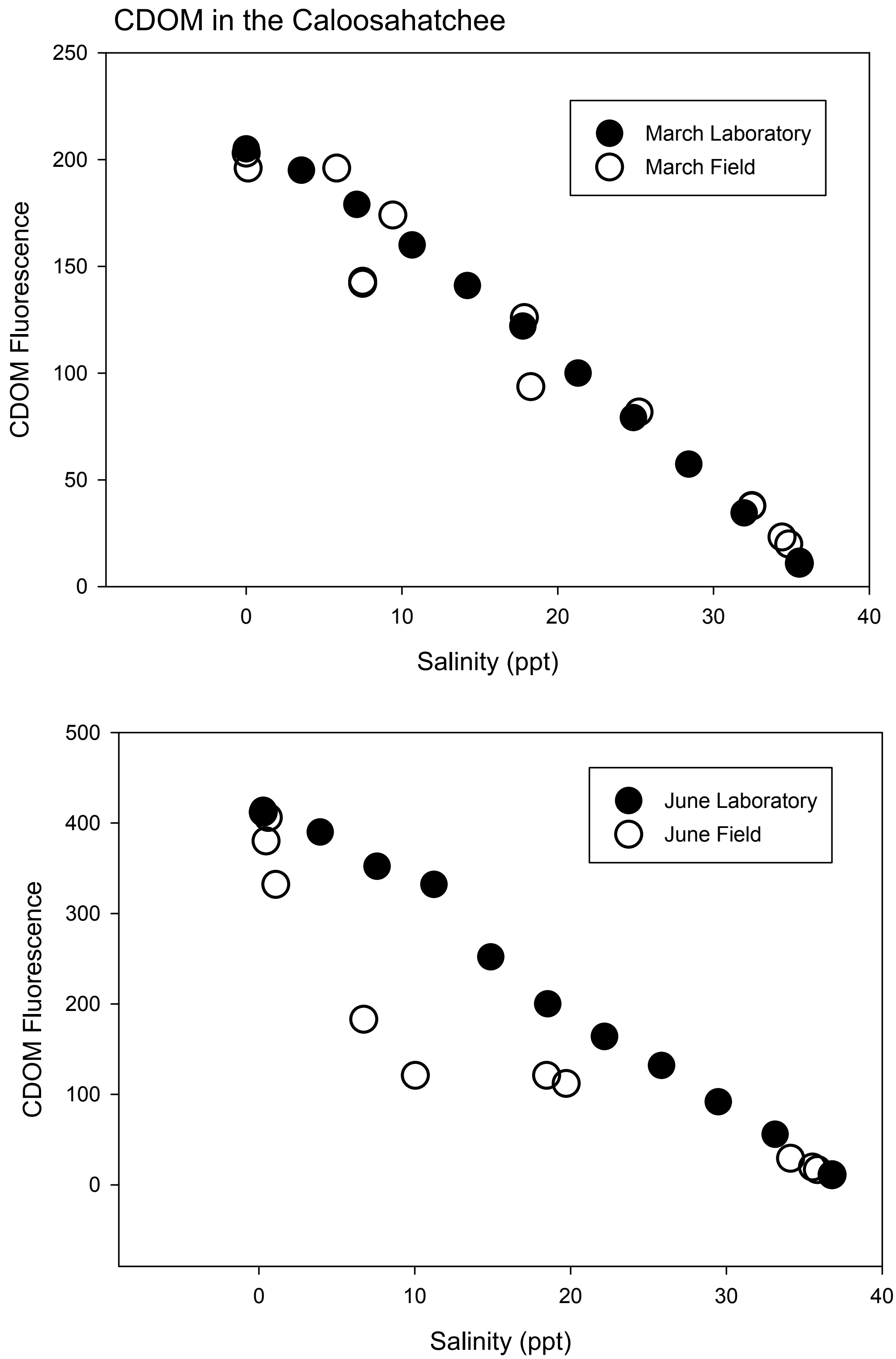


Figure 12-40. Apparent mixing behavior of colored dissolved organic matter (CDOM) in the field (March and June 2009) and in the laboratory.

Integrated Modeling Framework

An integrated modeling framework, combining the resource-based VEC approach and linked watershed and estuarine models, has been proposed to meet some of the water management objectives for coastal ecosystems protection and restoration. A detailed discussion of this approach is presented in the 2008 SFER – Volume I, Appendix 12-1. Integrated or linked models simulate the effects of changes in population, land use or management practices in the watershed on estuarine physics, chemistry, and ecology (Chesapeake Bay Program and IAN, 2005; Wan et al., 2002, 2006).

- The watershed model estimates the quantity, timing, and quality of freshwater inflow to the estuary
- The estuarine hydrodynamic, sediment transport, and water quality models in turn simulate the estuarine conditions in terms of salinity, water quality, and sediment transport
- The ecological models simulate the responses of estuarine resources and processes to the estuarine conditions

The District has been using this approach for several years for addressing MFLs and in restoration projects.

These modeling tools make a critical contribution toward achieving the management goals of the CRE by providing insight about how the systems respond under present conditions and possible future scenarios. For example, one of the primary goals is to meet pollutant load targets through nutrient load reductions. Modeling not only aids in calculating loads that presently exist, but also in estimating future load reductions that may be required. In practice, load targets will be achieved through a combination of management measures, ranging from BMPs to large filter marshes (e.g., STAs) and reservoirs. Models can help formulate and evaluate various combinations of these measures to arrive at a preferred plan. Other modeling tools will be used to optimize operation of water management systems. In the adaptive management process, models can be used to synthesize information and generate testable hypotheses that will refine targets or performance measures, and the plan to achieve them.

Modeling Needs and Strategies for the Caloosahatchee River Estuary

A full assessment of modeling needs for the CRE was presented in the 2009 SFER – Volume I, Chapter 12. This section provides a brief review, followed by a summary of progress made this year.

Watershed Hydrology and Water Quality Modeling

Effective management that aims to protect water quality requires a big-picture view of water resources at the watershed scale. Watershed models provide the necessary links for this purpose, particularly when it comes to understanding how nonpoint sources of pollution interact with point sources, and how these jointly affect the downstream water quality.

With regard to watershed hydrology and water quality simulation, modeling tools are needed that are capable of (1) simulating the hydrologic interaction of the Caloosahatchee River Watershed with other components of the Northern Everglades (Lake Okeechobee and St Lucie River watersheds), (2) watershed loading simulation, and (3) optimizing operations and sizing of features. Existing tools include the Northern Everglades Regional Simulation Model (NERSM), MIKE System Hydrologique European (MIKE SHE) Model, Agricultural Field Scale Irrigation Requirements/Water Balance (AFSIRS/WATBAL) Model, water quality, and Hydrological Simulation Program – Fortran (HSPF) Model (**Table 12-2**).

Prior to the development of the Southwest Florida Feasibility Study (SWFFS), the SFWMD and the USACE had developed four sub-regional MIKE SHE models to evaluate the hydrologic and hydraulic aspects of the Big Cypress Basin, the C-43 basin, the Estero Basin, and the Tidal Caloosahatchee River Basin. These updated sub-regional models were calibrated and then integrated into a single MIKE SHE Regional Model for the SWFFS.

Three modeled scenarios were developed for comparisons: (1) existing condition (year 2000 base condition), (2) a future year (2050) "without project" condition, and (3) the assumed pre-development condition using the Natural Systems Model.

The existing MIKE SHE models in the C-43 basin and the Tidal Caloosahatchee Basin will serve as a basic tool to assess hydraulic and watershed alteration in this area.

Estuary Hydrodynamic Water Quality Modeling

With regard to estuary hydrodynamic and water quality simulation, modeling tools are needed that are capable of (1) simulating the impacts induced by the watershed loading, (2) estuary hydrodynamics, and (3) estuary water quality processes. Existing tools include the District's Caloosahatchee Estuary curvilinear-grid hydrodynamics 3D hydrodynamic/salinity (CH3D) Model (hydrodynamic component) and the FDEP's Environmental Fluid Dynamics Code (EFDC) Model (hydrodynamic and water quality components), and the FDEP's Water Quality Analysis Simulation Program (WASP) Model (**Table 12-2**). The hydrodynamic component of the CH3D Model has been fully calibrated against five-year field data from 2000–2004, including both dry and wet years. It has been successfully applied in several critical initiatives, such as the CERP Caloosahatchee River (C-43) West Basin Storage Reservoir Project Implementation Report (PIR) and the SWFFS. However, to apply the CH3D Model in this area would require additional refinements with groundwater seepage data and sediment transport scheme, and integration with a water quality component.

The District utilized the calibrated CH3D hydrodynamic and salinity model for various applications, including salinity simulation results for ecological model inputs. The weekly operation of Lake Okeechobee relies on the salinity model to predict the distribution of salinity under various flow conditions. **Figure 12-41** and **Figure 12-42** show examples of the products generated from the CH3D model results.

The District initiated the development of a water quality model in the Caloosahatchee River and Estuary in 2008. Two simplified versions of the EFDC Model were developed: one with 12-variables and the other with nine variables, in contrast to the full version of the EFDC Model with 22 state variables. The full version EFDC model contains 22 state variables including (1) three algae, (2) refractory particulate organic carbon (refractory POC), (3) labile particulate organic carbon (labile POC), (4) dissolved organic carbon (SOC), (5) refractory particulate organic phosphorus (refractory POP), (6) labile particulate organic phosphorus (labile POP), (7) dissolved organic phosphorus (DOP), (8) TP, (9) refractory particulate organic nitrogen (refractory PON), (10) labile particulate organic nitrogen (labile PON), (11) DON, (12) ammonia nitrogen (NH_4), (13) nitrate nitrogen (NO_{23}), (14) particulate biogenic silica, (15) dissolved available silica, (16) Chemical Oxygen Demand (COD), (17) DO, (18) total active metal, (19) fecal coliform bacteria, and (20) macroalgae. The simplified version II contains nine state variables including phytoplankton chlorophyll *a*, total organic carbon (TOC), total organic nitrogen (TON), NH_4, $NO_{2,3}$, total organic phosphorus (TOP), PO_4, DO, and COD. The simplified versions are coded with options to aggregate water quality state variables similar to the ones of the WASP Model or other commonly used water quality models. Model diagnostic options were also added in the EFDC Model to let users turn off certain biochemical processes. Two simplified versions were tested and compared with an existing EFDC Model in the St. Lucie Estuary. The simplified version I with 12 state variables and the full version have very similar results. The simplified version II with nine state variables needs further tuning of kinetic parameters in order to achieve similar results as the full version.

Estuarine Ecologic Response Modeling

Future efforts regarding estuarine ecologic response modeling should simulate the habitats for seagrasses, oysters, and fish larvae to represent the entire spectrum of the VECs in the estuary.

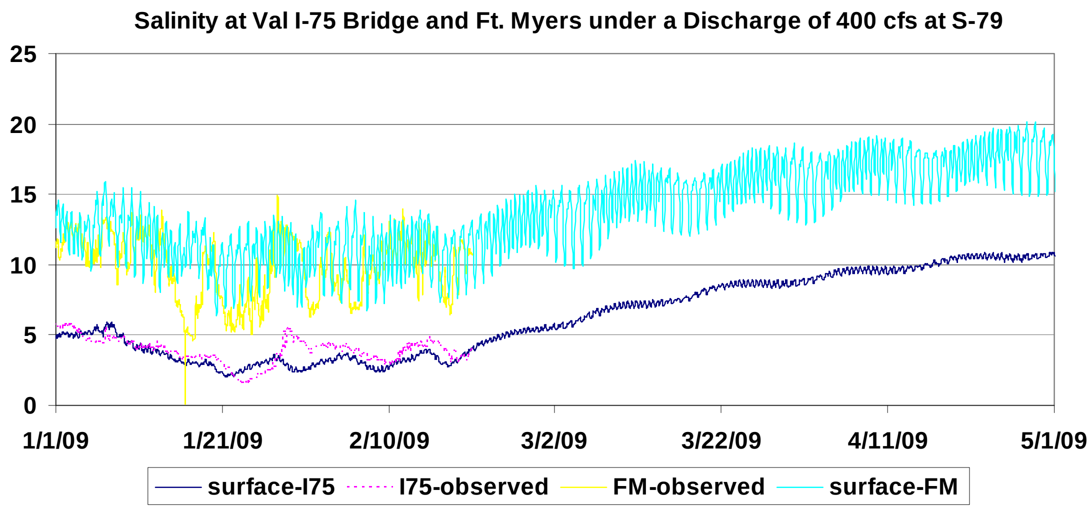


Figure 12-41. An example of CH3D Model applications used for Lake Okeechobee operation; salinity prediction at two stations (see **Figure 12-42**) in the estuary under constant release of 400 cfs.

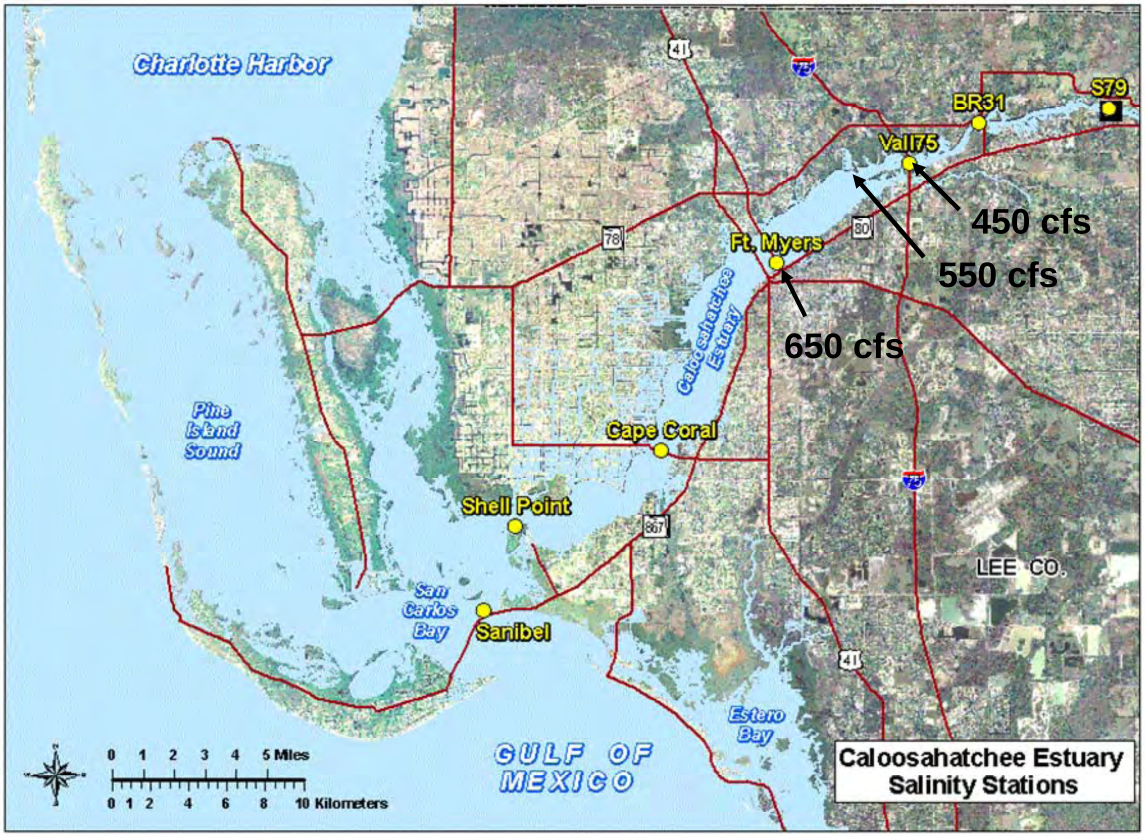


Figure 12-42. An example of CH3D Model applications used for Lake Okeechobee operation; approximate location of 10 ppt salinity contour as a function of discharge at S-79.

KEY SFWMD PROJECTS

Stormwater Improvement Projects

Billy Creek Filter Marsh

The Billy Creek Filter Marsh Project is a collaborative effort between Lee County, the SFWMD, and the City of Fort Myers. The purpose of the Billy Creek Filter Marsh is to implement surface water system projects, including a filter marsh facility and a water control structure, that will improve the water quality of storm water conveyed through Billy Creek and discharged to the Caloosahatchee River. The project is expected to provide additional surface water storage that would mitigate flooding in the affected drainage basins. The water control structure diverts flows into the filter marsh facility, providing additional attenuation of stormwater flows within the channel itself. The filter marsh facility will consist of an 8-acre open-water lake, a 13-acre wetland marsh, and an existing, newly restored 12-acre cypress hammock. The improvements will also provide educational and recreational opportunities, and aesthetic benefits to the affected neighborhoods. Phase 1 (exotic vegetation removal) was completed in 2008. Phase 2 is in process.

Caloosahatchee Creeks Preserve Restoration

The SFWMD partnered with Lee County Conservation 20/20 to remove exotic vegetation and restore natural hydroperiod functions in the Caloosahatchee Creeks Preserve. Perimeter and interior ditches were plugged and backfilled in areas, and the site was leveled to allow a more natural sheetflow of water across the landscape. The restoration design allows water from the Caloosahatchee River to flow into the preserve to alleviate high water and provide water quality improvements.

Harns Marsh Phase I Project

East County Water Control District (ECWCD) held a groundbreaking ceremony at Harns Marsh, a 578-acre preserve that serves as a major stormwater retention/detention area in Lehigh Acres on June 10, 2009. It is expected to be completed in December 2009. The Harns Marsh Phase I Project replaces three existing water control structures to regulate the flow of water and incorporates computer-controlled gates providing remote control of water flows. The Harns Marsh Phase I Project will also reduce flooding to downstream neighbors on the Orange River, improve water quality, and recharge local groundwater aquifers. In addition, this retention/detention area serves as a lush wildlife habitat.

Yucca Pens Hydrologic Restoration Reconnaissance Study

The District kicked-off this project in April 2009, and has contracted with consulting firm BPC Group to conduct a reconnaissance study of the water characteristics of the Yucca Pens Unit. The firm will also complete a comprehensive evaluation of the findings and issues relating to water supply, flood protection, water quality, and natural systems. Results from this study will be used to develop a multifunctional water management plan for implementing hydrologic restoration in the Yucca Pens Unit and restoration of historic sheet flow. The project will investigate the potential for restoring the historic outfall to the following systems: (1) Yucca Pen Creek, (2) Durden Creek, (3) Greenwell Branch, (4) Longview Run, and (5) Gator Slough. Runoff to these systems originates in the Webb Water Management Area and must pass through Charlotte County to reach the outfall in Lee County. Restoration of the historic flow will reduce the amount of water that has been redirected to Gator Slough and lessen the impact of damaging point discharges through the Gator Slough Canal.

LOXAHATCHEE RIVER ESTUARY

Marion Hedgepeth, Becky Robbins, Fawen Zheng,
Bahram Charkhian and Rod Braun

INTRODUCTION

As Florida's first National Wild and Scenic River, the Loxahatchee River is South Florida's last free-flowing river system. The river's floodplain features a subtropical cypress swamp and mixed hardwood forest. The swamp, one of the last remaining of its kind in South Florida, contains bald cypress trees that are 300 or more years old. Additionally, the Loxahatchee River's tidal floodplains and estuary are valuable ecological resources within the Loxahatchee River Watershed, which has been designated an Aquatic Preserve and an Outstanding Florida Waters, and flows through Jonathan Dickinson State Park.

The Loxahatchee River and Estuary lie between southern Martin County and northern Palm Beach County on the east coast of Florida. A system of inland wetlands, known locally as Grassy Waters Preserve and the Loxahatchee and Hungryland sloughs, forms the headwaters of the watershed and drain to the Northwest Fork of the Loxahatchee River. Floodplain plant communities, soils, and salinity regimes can be used to identify and characterize three distinct reaches: (1) riverine, (2) upper tidal, and (3) lower tidal along the river system (**Figure 12-43**). The Northwest Fork of the Loxahatchee River contains approximately 320 hectares (ha; 791 ac) of riverine, and 24 ha (59.3 ac) of upper tidal floodplain, and 45 ha (111.2 ac) of lower tidal floodplain (SFWMD, 2009). The riverine reach is generally unaffected by salinity, and bald cypress dominates the vegetative communities with pop ash, red maple, pond apple, and water hickory. The upper tidal reach experiences some saltwater intrusion during the dry season, and is dominated by pond apple, red and white mangroves, cabbage palms, and some bald cypress communities. The lower tidal reach, dominated primarily by salt-tolerant species of red and white mangroves, is highly influenced by tides and salinity in the water and soils.

Despite these enduring natural resources, the Loxahatchee Watershed has been permanently altered by the influence of Jupiter Inlet, which heightens the effects of tidal amplitude and saltwater intrusion. Drainage canal systems have also altered the natural pattern of freshwater inflow and inundation of the floodplain. Saltwater intrusion and reduced freshwater inflows to the riverine and upper tidal reaches of the Northwest Fork have particularly been issues. As a result, in 2003 the District adopted an MFL rule (Chapter 40E-8, F.A.C.) for the Northwest Fork of the Loxahatchee River. An MFL exceedance occurs when flows over the Lainhart Dam (**Figure 12-43**) decline below 35 cfs (0.99 m^3/s) for more than 20 days or the average salinity at River Mile 9.2 (RM 9.2), expressed as a 20-day rolling average, exceeds 2 psu.

The Restoration Plan for the Northwest Fork of the Loxahatchee River (SFWMD, 2006a) provides ecological target species, performance measures, and monitoring requirements needed to track the success of restoration goals and provide guidance for future adaptive management and operational practices. The plan identified five VECs for the Northwest Fork of the Loxahatchee River: (1) cypress swamp and hydric hammock in the freshwater riverine floodplain, (2) cypress swamp in the tidal floodplain, (3) fish larvae in the low salinity zone, (4) oysters in the mesohaline zone, and (5) seagrasses in the polyhaline zone downstream. Monitoring of these communities continues along the river.

A Preferred Restoration Flow Scenario was selected that incorporated both dry and wet season hydrologic flow patterns, while providing the greatest ecological benefit to the freshwater riverine and tidal floodplains and with minimal impacts to the estuary. The Preferred Restoration Flow Scenario was established as "variable dry season flow between 50 cfs and 110 cfs, with a mean monthly flow of 69 cfs over Lainhart Dam, while providing an additional 30 cfs of flow from the downstream tributaries." Several plans and projects are under way to achieve the goals of the Preferred Restoration Flow Scenario (see *Key SFWMD Projects in the Loxahatchee River Estuary* section of this chapter). These include the North Palm Beach County – Part 1 Project (USACE and SFWMD, 2005), Loxahatchee River Preservation Initiative, and additional projects of the FDEP Florida Park Service in conjunction with Jonathan Dickinson State Park, Loxahatchee River District, and Palm Beach and Martin counties. Final draft of a Loxahatchee River Science Plan is scheduled for completion in FY2010.

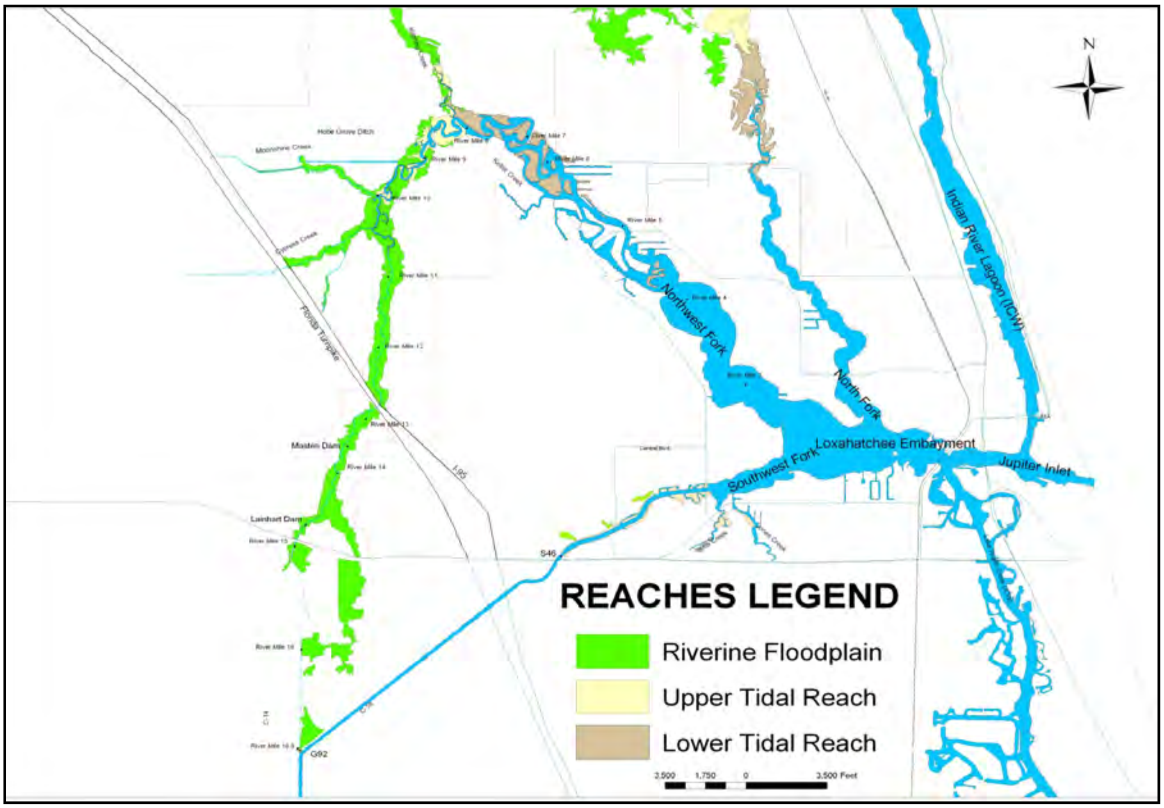


Figure 12-43. Reaches of the Loxahatchee River.

STATUS AND TRENDS IN THE LOXAHATCHEE RIVER

Salinity and Freshwater Inflows

Five tide and salinity stations have been deployed in the Loxahatchee River since 2002, and were maintained in WY2009 to monitor salinity for compliance with the MFL rule and assess the benefits of supplemental dry season flows in terms of salinity in the Northwest Fork and lower estuary. During the past water year, the flow over Lainhart Dam was mostly maintained above the MFL criterion of 35 cfs, except in May 2008 (22 days from May 1 to May 22) (**Table 12-11** and **Figure 12-44**). As a result of the low freshwater inflow, the 20-day rolling average salinity at RM 9.1 exceeded the 2 psu threshold from May 19–24, 2008. Therefore, salinity and freshwater conditions have continued to improve since the 1960s and 1970s when the river would run dry in portions, and salt water would creep up into the riverine reach of the Northwest Fork.

Table 12-11. Monthly mean flow at Lainhart Dam and salinity at River Mile 9.1 of the Northwest Fork of the Loxahatchee River.

MONTH-YEAR	SALINITY AT RIVER MILE 9.1 (psu)	FLOW AT LAINHART DAM (cfs)
May-08	1.51	28.5
Jun-08	0.32	58.7
Jul-08	0.25	107.1
Aug-08	0.20	124.2
Sep-08	0.19	135.2
Oct-08	0.20	135.5
Nov-08	0.35	99.5
Dec-08	0.33	68.6
Jan-09	0.69	55.4
Feb-09	1.13	40.1
Mar-00	0.89	44.2
Apr-00	1.38	31.7

psu – practical salinity units
cfs – cubic feet per second

Nutrients

The Loxahatchee River District (LRD) has established a comprehensive water quality monitoring network at 32 sites in the freshwater and tidal segments of the Loxahatchee River for about 30 parameters, including salinity, nutrients, chlorophyll, and bacteria. In response to the 2008 SFER peer-review panel comments, water quality is now gathered at select sites on a monthly basis, which should result in improved trend detection and predictive capability. From May 2007–April 2008, the average concentration of TN in the estuary and the tributaries was 0.77 mg/L. The average concentration of TP at the same sites was 0.06 mg/L. Long-term (1992–2007) monthly averages for TN, TP, salinity, and chlorophyll at RM 1 (Station 40, A1A Bridge/Railroad Track) were computed and compared with WY2008 and WY2009 monthly data (**Figure 12-45**). These concentrations are in line with the interim water quality targets for the Loxahatchee River and Northwest Fork water quality monitoring sites.

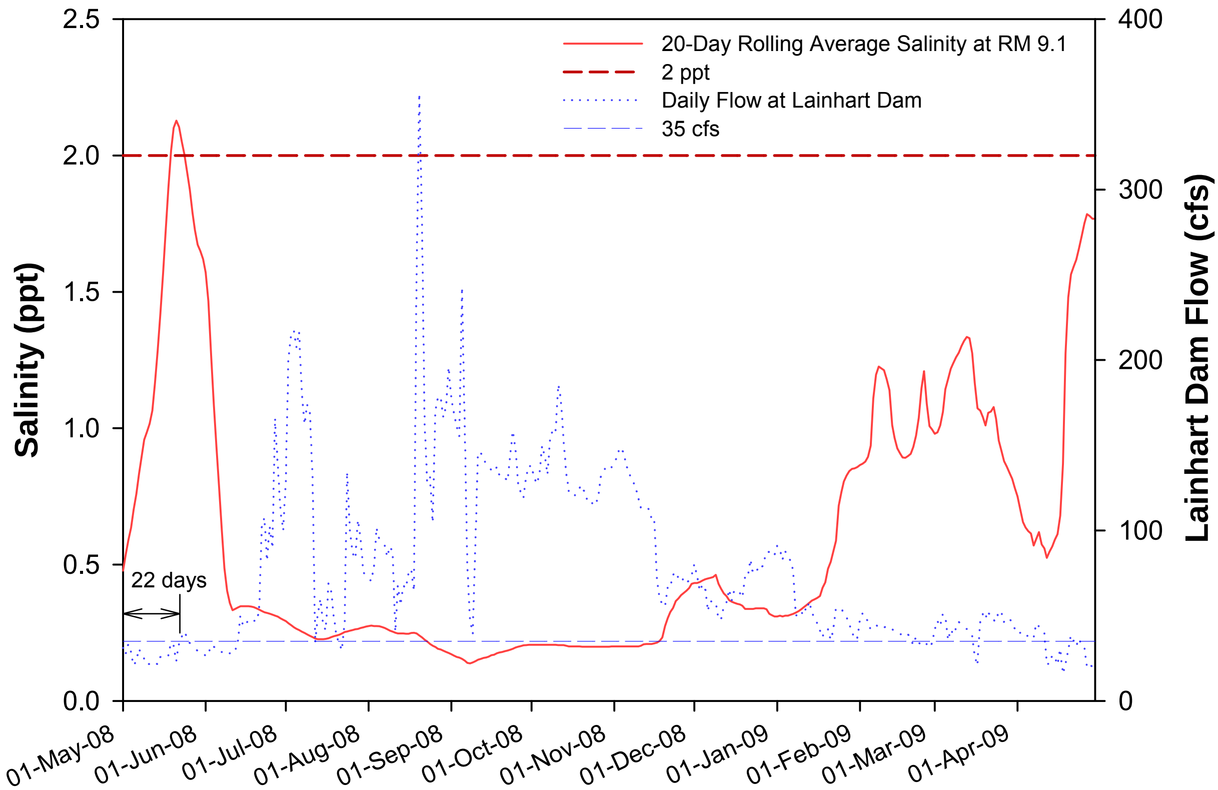


Figure 12-44. Flow at Lainhart Dam compared to the Total Maximum Daily Load (TMDL) criterion for WY2009.

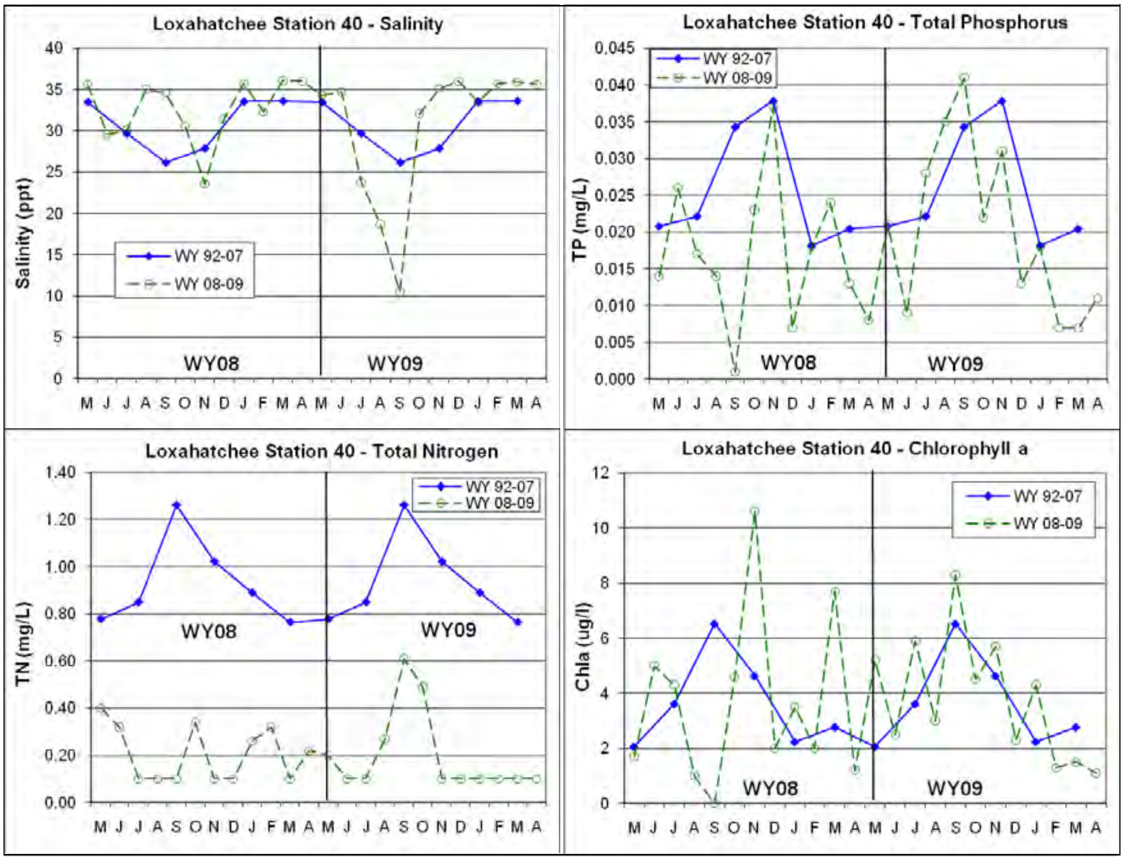


Figure 12-45. Comparison of monthly water quality over the past two water years with the long-term monthly average pattern at Station 40.

Submerged Aquatic Vegetation

The most recent Loxahatchee Estuary seagrass map was completed by the Loxahatchee River District in 2007 (and included in the 2009 SFER – Volume I, Chapter 12). The LRD plans to map Loxahatchee Estuary seagrasses again in the summer of 2010 using the 2007 methods (extensive fieldwork using 9 m^2 quadrats, and GPS technology). Loxahatchee River Estuary seagrass communities were heavily impacted during the 2004 and 2005 hurricane seasons (Ridler et al., 2006). Ongoing monitoring by the LRD documents the recovery process. The LRD monitors five sites (**Figure 12-46**) every other month.

Data from a previous monthly study and the bimonthly monitoring are shown in **Figure 12-47**. Two species of seagrass, *Halodule wrightii* and *Halophila johnsonii*, dominate the upstream sites. Higher species richness and percent cover occur farther downstream. The data show hurricane impacts at the two downstream monitoring sites, Sand Bar and North Bay, where *Syringodium filiforme* was severely impacted and has yet to recover to pre-storm abundance.

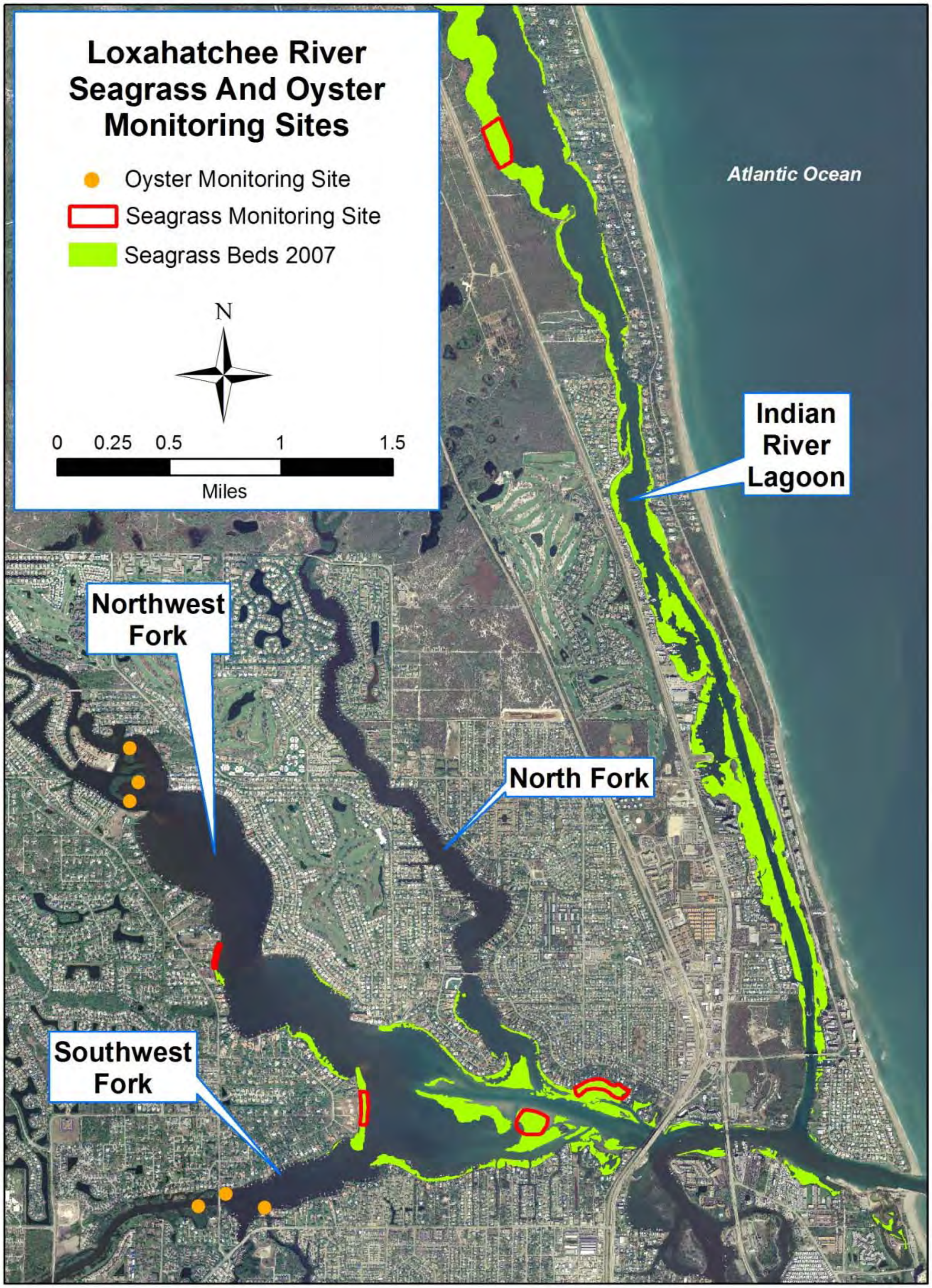


Figure 12-46. Seagrass monitoring locations [four Loxahatchee River Estuary (LRE) sites and one reference location in the Southern Indian River Lagoon]**.**

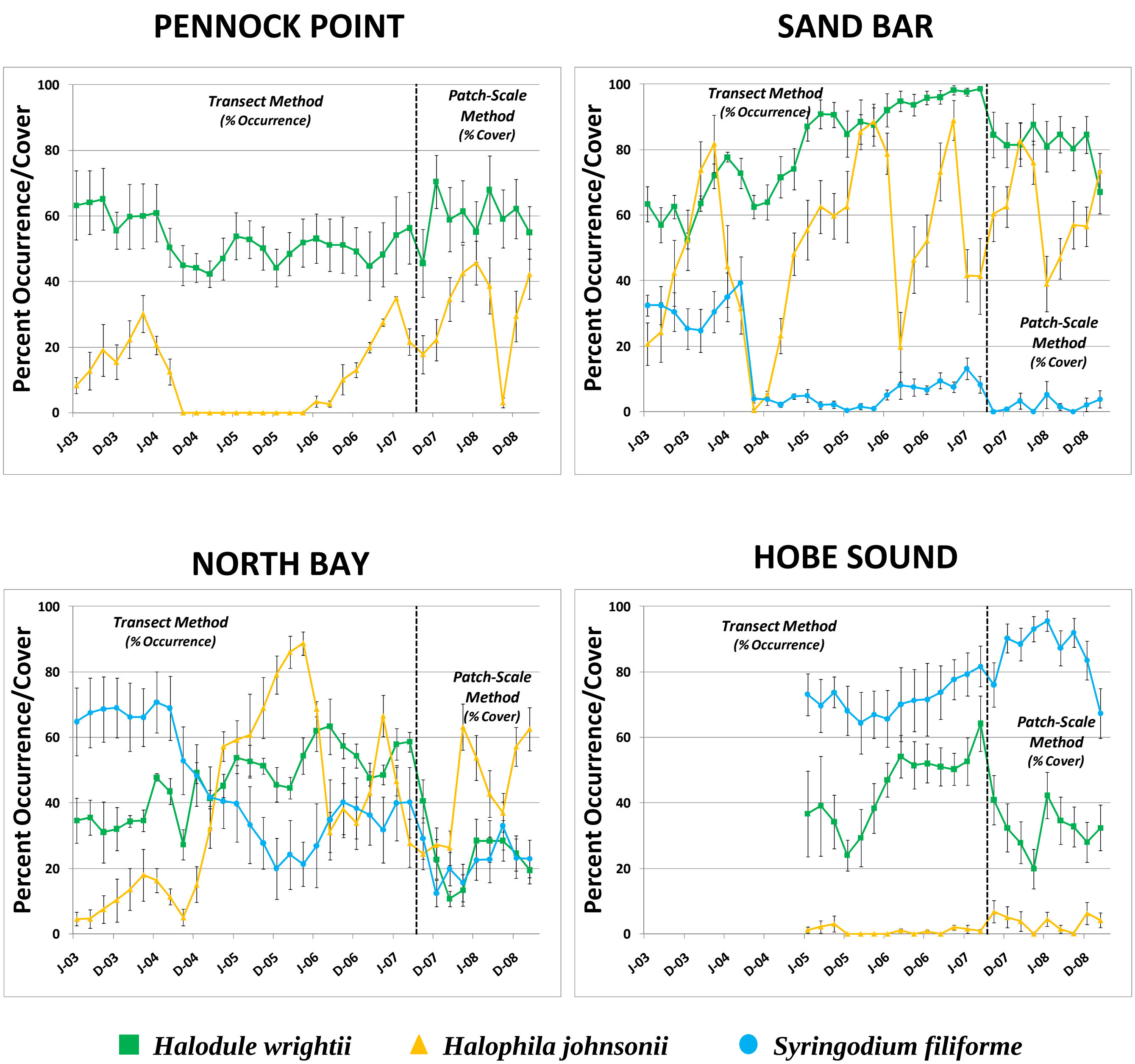


Figure 12-47. Summary of percent occurrence/percent cover at four sampling sites, 2003 through 2008. Error bars represent ± 1 standard error (S.E.).

Eastern Oyster Abundance and Distribution

As a measure of the status of estuarine oyster beds, the District reports on the density of live and dead adult oysters sampled on a seasonal (wet, dry) basis by RECOVER. Eastern oyster health and abundance have been monitored semiannually at three locations in both the Northwest and Southwest Forks since 2005. Stations and segments were aggregated for this analysis.

Live oyster density in the LRE has ranged from about 50 per m^2 to 240 per m^2 since 2005. Live density results indicate a strong positive relationship to salinity (**Figure 12-48**), and support the notion that oyster survival is optimized when salinity is greater than 10 psu. The total number of live oysters at the monitoring sites varied from year to year and seasonally. During the period 2006 and 2007 when salinity was the highest, live oyster density was the greatest.

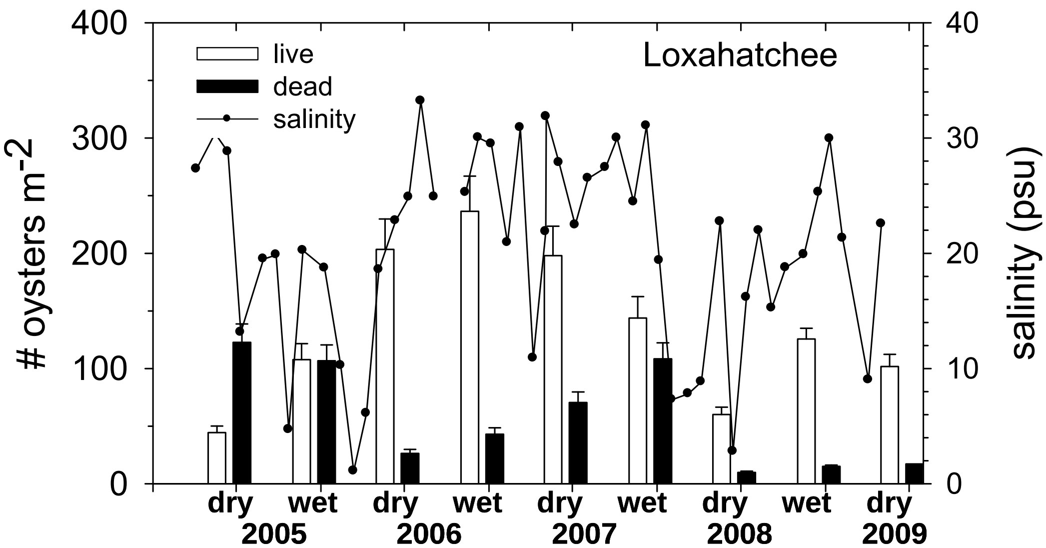


Figure 12-48. Live and dead oyster densities (left axis) and salinity (right axis) from spring 2005 to spring 2009 in the LRE.

Fish Communities

To observe the effects of lowered freshwater flow and increases in salinity within the Loxahatchee River and Estuary, several fish studies have been conducted. These studies have provided additional background information on fish abundance and distribution relative to salinity and freshwater flow within this system. In 2007, Continental Shelf Associates International, Inc. (CSA International, 2009) first compiled a background literature review for the District on the effects of freshwater flow and salinity on South Florida fishes, and then conducted a search for Loxahatchee fish specimens at the Florida Museum of Natural History (FMNH), University of Florida. The investigation showed that the Loxahatchee River Watershed supported an ichthyofauna comprising 34 native freshwater species, 41 marine species, and seven exotic species. Distinctive species, collected only in the 1960s, were iron color shiner (*Notropis chalybaeus*) and redface killifish (*Fundulus rubrifrons*). The presence and abundance of species, such as smallscale snook (*Centropomus parallelus*), burro grunt (*Pomadasys croco*), river goby (*Awaous banana*), bigmouth sleeper (*Gobiomorus dormitor*), and mountain mullet (*Agonostomus monticola*), confirm that tropical peripheral species are an integral component of the freshwater fish assemblage in the upper Loxahatchee River. The composition of fish fauna determined from this analysis indicated that river channel, wet prairie, and tributary creeks supported common native freshwater species.

In 2008, CSA International conducted a study for the District to examine the effects of dry season flow and stage on fish assemblages within the riverine reach of the Northwest Fork. Also in summer 2008, Florida International University (FIU) conducted extensive fieldwork on the Loxahatchee River for the District in an attempt to document the movement patterns of common snook (*Centropomus undecimalis*). The specific objectives of the CSA study were to (1) obtain data on fish abundance, biomass, size, body depth, and species composition in response to flow and stage changes in the river channel during the dry season; (2) examine habitat characteristics and environmental factors (temperature, conductivity, dissolved oxygen) associated with flow variation that may influence fish distribution in the river channel; and (3) summarize the current status of endangered, threatened, or species of special concern and exotic fish species on the river and the effects of changes in flow and stage levels on these species.

Fish were sampled by electrofishing along four reaches of the upper Northwest Fork between RM 10 and RM 16 within the Wild and Scenic portion of the Loxahatchee River. The design was to place the reaches at regular intervals (i.e., systematically) or at least far enough apart to avoid autocorrelation. **Figure 12-49** indicates the flows over Lainhart Dam and eight dates when fish sampling occurred. **Figure 12-50** shows the location of the sampling reaches, designated Reach 1 through Reach 4, along the Northwest Fork of the Loxahatchee River.

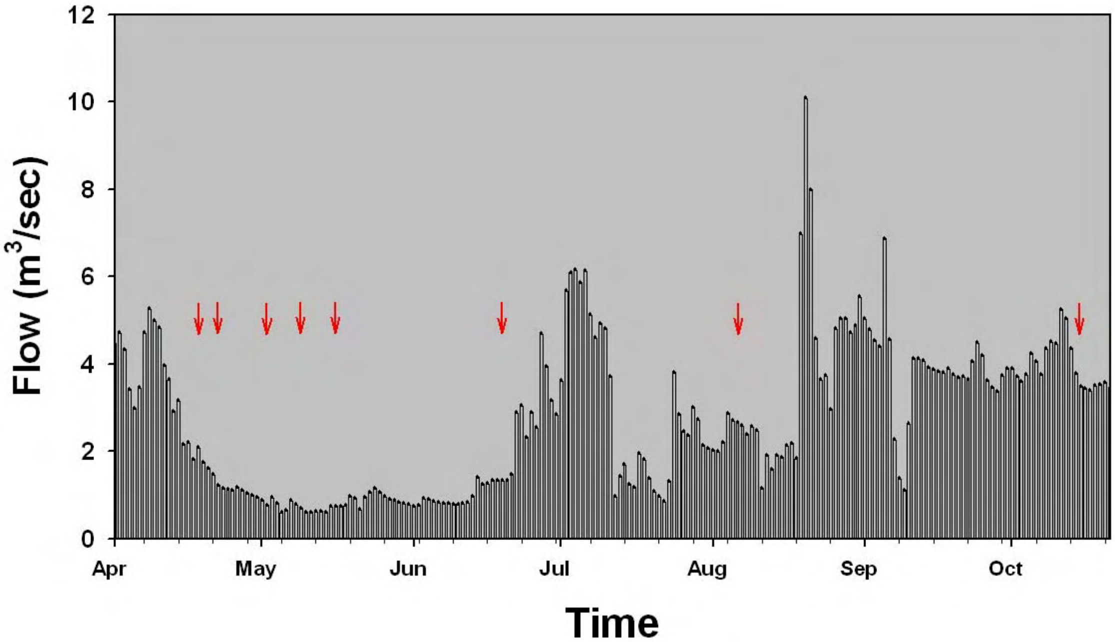


Figure 12-49. Daily flows over Lainhart Dam for the April–October 2008 study period. Red arrows indicate fish sampling dates.

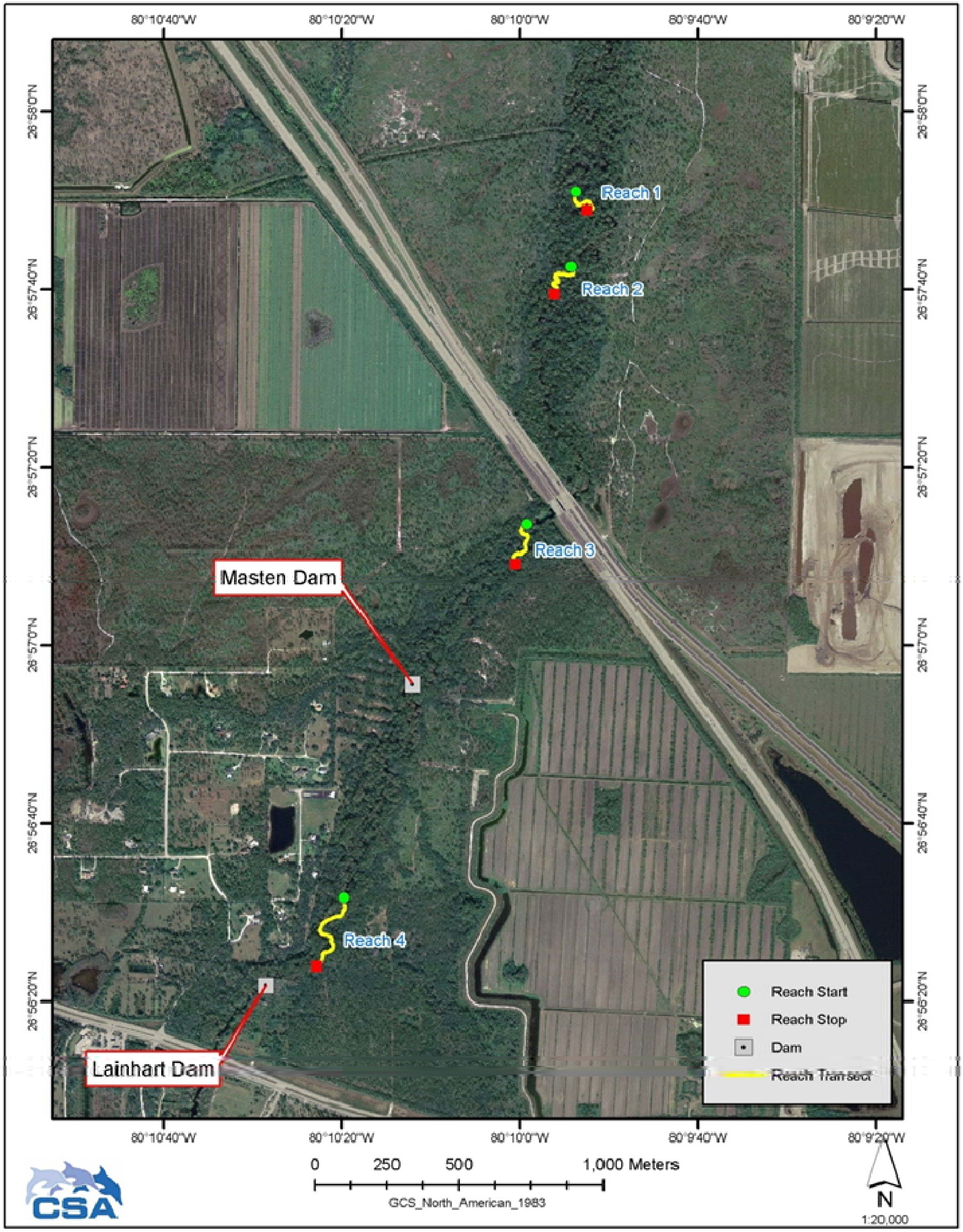


Figure 12-50. Fish sampling reaches in the upper Northwest Fork of the Loxahatchee River (Reach 1=136 m, Reach 2=171 m, Reach 3=194 m, and Reach 4=328 m in length).

This survey represented the first systematic fish sampling program undertaken in the upper Northwest Fork of the Loxahatchee River. The fish assemblage present in this segment of the river was composed of freshwater, marine, catadromous, and exotic species (**Table 12-12**). The presence of euryhaline marine fish in freshwater reaches of coastal rivers is a common phenomenon in Florida (Gilbert, 1987; Gilmore, 1995). The freshwater fish assemblage component was composed mostly of sunfish, Florida gar (*Lepisosteus platyrhincus*), and bowfin (*Amia calva*). The marine component includes euryhaline species such as tarpon (*Megalops atlanticus*), common snook, striped mojarra (*Eugerres plumieri*), striped mullet (*Mugil cephalus*), gray snapper (*Lutjanus griseus*), and sheepshead (*Archosargus probatocephalus*). The American eel (*Anguilla rostrata*) was included as the only truly catadromous species in the collections. The presence and abundance of species, such as smallscale fat snook, burro grunt, river goby, bigmouth sleeper, and mountain mullet, confirm that tropical peripheral species are an integral component of the freshwater fish assemblage in the upper Loxahatchee River. Four exotic species were collected during the surveys: walking catfish (*Clarias batrachus*), Orinoco sailfin catfish (*Pterygoplichthys multiradiatus*), spotted tilapia (*Tilapia mariae*), and Mayan cichlid (*Cichlasoma urophthalmus*). Orinoco sailfin catfish and spotted tilapia were among the highest contributors to total numbers collected and occurred frequently in the samples. Walking catfish and Mayan cichlid were both represented by six individuals collected on four occasions. No species listed by the U.S. Fish and Wildlife Service (USFWS) or the Florida Fish and Wildlife Conservation Commission (FWC) as endangered, threatened, or special concern were collected during the survey. However, smallscale fat snook, bigmouth sleeper, and driver goby are listed by the American Fisheries Society as species at risk for extinction (Musick et al., 2000).

Catch data indicated that during low- and medium-flow sampling, more fish were collected, which included a greater portion of smaller individuals, whereas during high flows, fewer numbers of fish were taken but larger (heavier) individuals continued to be collected. Clearly, water flows and levels can influence sampling efficiency. During low-flow conditions, fish are obviously more concentrated and therefore more susceptible to capture. Alternatively, during high-flow conditions, fish tend to be more widely dispersed and less vulnerable to capture. Sample frequency was small; therefore, additional observations are needed to get a clearer picture of response to changes in freshwater flow.

Also in 2008, common snook movements were compared to freshwater discharge through flood control structures at the river’s headwaters. Ultrasonic transmitters, in conjunction with arrays of automated, submerged acoustic receivers, permit remote monitoring of fish in the natural environment and alleviate the need to track each tagged individual continuously. Twenty-four transmitters (automated underwater hydrophones by Vemco: VR2 and VR2W) were surgically implanted into the body cavity of fishes. Acoustic gates were installed at the mouth of Jupiter Inlet, the intersection of the Indian River Lagoon and the Loxahatchee River, the mouth of the Intracoastal Waterway where it heads south from the Loxahatchee River, the mouths of the North and Southwest Forks of the Loxahatchee River, and the central portion of the Loxahatchee River’s main embayment (**Figure 12-51**). By the end of the summer, fish movements in the Loxahatchee River were continuously monitored by an array of 43 receivers. Preliminary results suggest a positive relationship between freshwater discharge and extreme upstream movements in snook. Snook numbers increased in upstream sections of the river several days after the start of discharge events.

Table 12-12. Phylogenetic listing of fishes collected by electrofishing in the Northwest Fork of the Loxahatchee River.

Family	Common Name	Scientific Name	Freshwater	Marine	Exotic	Catadromous	Standard Length (mm)	Occurrence	Percent
Lepisosteidae	Florida gar	*Lepisosteus platyrhincus*	●				140-550	17	73.9
Amiidae	Bowfin	*Amia calva*	●				450-680	4	17.4
Megalopidae	Tarpon	*Megalops atlanticus*		●			470-520	1	4.3
Anguillidae	American eel	*Anguilla rostrata*				●	130-560	12	52.2
Ictaluridae	Brown bullhead	*Ameiurus nebulosus*	●				280-280	1	4.3
Clariidae	Walking catfish	*Clarias batrachus*			●		105-360	6	26.1
Loricariidae	Vermiculated sailfin catfish	*Pterygoplichthys disjunctivus*			●		93-354	17	73.9
Poeciliidae	Eastern mosquitofish	*Gambusia holbrooki*	●				20-36	4	17.4
	Sailfin molly	*Poecilia latipinna*	●				40-40	1	4.3
Centropomidae	Smallscale fat snook	*Centropomus parallelus*		●			40-480	8	34.8
	Tarpon snook	*Centropomus pectinatus*		●			415-465	1	4.3
	Common snook	*Centropomus undecimalis*		●			40-780	12	52.2
Centrarchidae	Warmouth	*Lepomis gulosus*	●				95-130	3	13.0
	Bluegill	*Lepomis macrochirus*	●				52-190	15	65.2
	Dollar sunfish	*Lepomis marginatus*	●				50-50	1	4.3
	Redear sunfish	*Lepomis microlophus*	●				75-202	8	34.8
	Spotted sunfish	*Lepomis punctatus*	●				45-168	15	65.2
	Largemouth bass	*Micropterus salmoides*	●				160-581	15	65.2
Lutjanidae	Gray snapper	*Lutjanus griseus*		●			135-230	12	52.2
Gerreidae	Tidewater mojarra	*Eucinostomus harengulus*		●			45-103	13	56.5
	Striped mojarra	*Eugerres plumieri*		●			92-280	12	52.2
Haemulidae	Burro grunt	*Pomadasys crocro*		●			60-390	7	30.4
Sparidae	Sheepshead	*Archosargus probatocephalus*		●			280-290	3	13.0
Cichlidae	Mayan cichlid	*Cichlasoma urophthalmus*			●		80-176	4	17.4
	Spotted tilapia	*Tilapia mariae*			●		25-192	19	82.6
Mugilidae	Mountain mullet	*Agonostomus monticola*		●			55-142	13	56.5
	Striped mullet	*Mugil cephalus*		●			180-440	16	69.6
Eleotridae	Fat sleeper	*Dormitator maculatus*		●			25-78	8	34.8
	Largescale spinycheek sleeper	*Eleotris amblyopsis*		●			54-111	7	30.4
	Bigmouth sleeper	*Gobiomorus dormitor*		●			95-350	20	87.0
Gobiidae	River goby	*Awaous banana*		●			75-110	4	17.4
Achiridae	Hogchoker	*Trinectes maculatus*		●			28-94	12	52.2
Total		**32**	**11**	**16**	**4**	**1**			

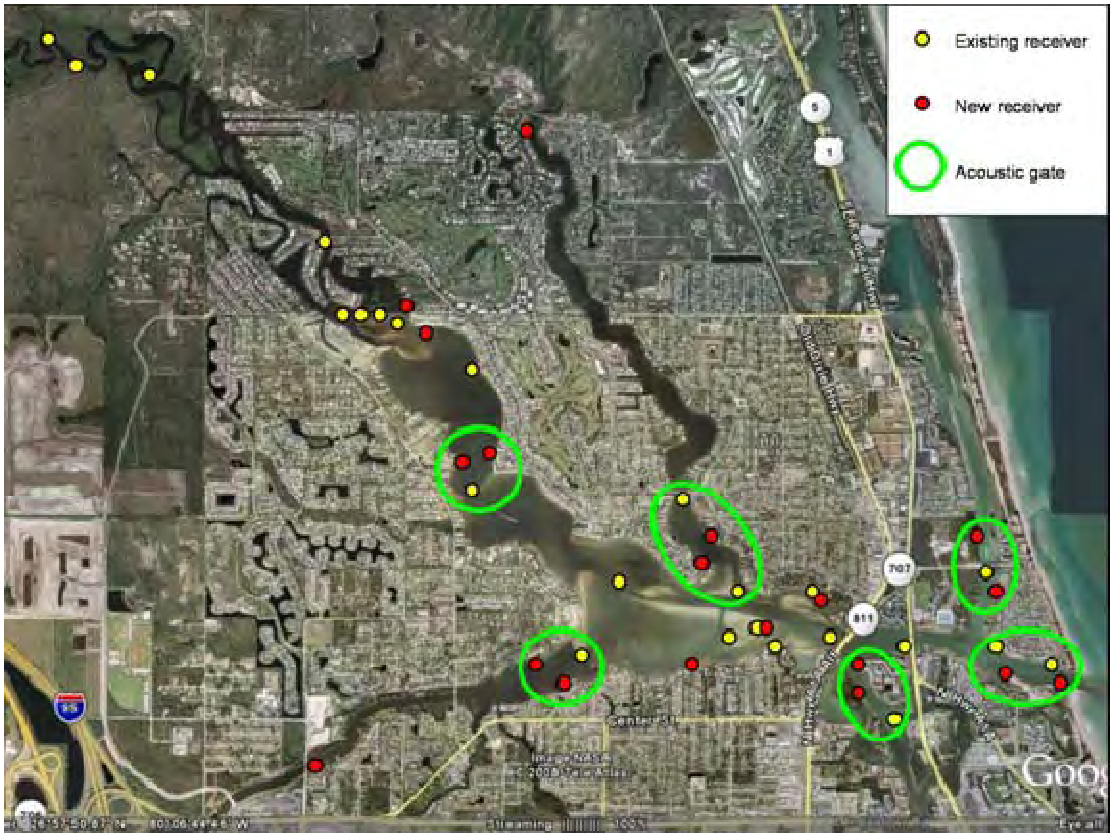


Figure 12-51. The Loxahatchee River system, showing the locations of the 43 automated acoustic receivers for tracking common snook (*Centropomus undecimalis*) movement. Receivers added to the telemetry array during the summer of 2008 are indicated by red circles; existing receivers are marked in yellow. Green ellipses show the locations of acoustic gates within the river.

Floodplain Vegetation

The SFWMD and the FDEP published results of vegetation monitoring from 10 transects on the Loxahatchee River in a two-volume report (SFWMD and FDEP, 2009). Additional vegetation monitoring results from a single transect dating back to 1967 provides a long-term history of changes caused by saltwater intrusion (Roberts et al., 2008). Freshwater vegetative species increased in upper tidal floodplain areas over time; however, this was not attributed to increases in freshwater flow, but to increases in availability of light as a result of canopy damage from the three hurricanes in 2004 and 2005. In the lower tidal reaches, tidal amplitude combined with low ground elevations, and increasing salinity prohibited the recruitment of most freshwater vegetative species, with the exception of pond apple In the riverine reach, recruitment of native canopy swamp species was low, presumably due to inadequate hydroperiods, and low levels of light reaching the floor of the floodplain prior to the hurricanes. It also appears that the loss of canopy trees may have contributed to the expansion of exotic vegetation. Additional work is proceeding on comparing the 2003 and 2007 shrub and groundcover data, while conducting field sampling for a 2009 canopy survey. The information obtained on the Loxahatchee River floodplain will be used to develop a Floodplain Salinity Index for the Loxahatchee River similar to one that the U.S. Geological Survey (USGS) created for the Apalachicola River in northern Florida.

In 2008, the University of Florida, Institute of Food and Agricultural Sciences (UF/IFAS), Tropical Research and Education Center conducted an additional bald cypress seedling project for the District (Liu and Li, 2009). The overall goal of this project was to continue assessing changes in soil water and salinity within the floodplain of the Loxahatchee River in order to understand the relationship between surface water, groundwater, and soil interactions, and to determine the duration of inundation, moisture, and salinity events relative to river dynamics. Therefore, the specific objects were: (1) to determine the range of flooding and salinity tolerance on the survival and growth of bald cypress seedlings in a controlled mesocosm experiment; (2) examine the effects of oxygen fertilizers and no oxygen fertilizers on survival and growth of bald cypress seedlings in a controlled mesocosm experiment; and (3) examine the effects of oxygen fertilizers and no oxygen fertilizers on survival and growth of bald cypress seedlings in field trials in plots established at the Ornamental Garden Site in Jonathan Dickinson State Park. During mesocosm experiments, bald cypress seedlings were top submerged or left moist and placed in salinities of 0, 2-3, 9, and 15 psu.

In field studies at the Ornamental Garden Site, bald cypress seedlings grew better in inundated conditions with oxygen fertilization than without oxygen fertilization. Where soils were drained, oxygen fertilization had no significant effect on growth. In a mesocosm experiment, 67 percent of unfertilized bald cypress seedlings died when inundated with water containing 9 psu salinity (Liu et al., 2009). Those that received various treatments of oxygen fertilizer survived both flooding and salinity stresses. In summary, oxygen fertilizer kept flooded soils in an oxidized condition. This may explain how solid oxygen fertilizer improved the growth of flooded seedlings under field and mesocosm conditions.

Valued Ecosytem Components Results Summary

Valued Ecosystem Components for the Loxahatchee River are floodplain vegetation, seagrass, oyster, and larval fishes and benthic invertebrates. Larval fish studies have not been conducted since 2004 while benthic invertebrate results are inconclusive. Trends in the floodplain vegetation analysis indicate that the existing shortness of hydroperiod on the riverine floodplain is an issue with regard to loss of canopy trees, and the intrusion of transitional, upland, and exotic species, and poor recruitment of new bald cypress seedlings/saplings and other swamp species. In the upper tidal reach, freshwater plant communities are on the increase with good seedling/sapling recruitment of swamp species due to better levels of soil moisture throughout the year and rare occasions of harmful salinities. In the lower tidal reach, species diversity remains low in plant communities due to higher levels of salinity and higher tidal amplitude.

Overall, there was a strong relationship between high salinity and increased live oyster density. Oyster density peaked from 2006 through 2007 before another dramatic decline during 2007–2008. Live oyster numbers began to rebound into the 2009 dry season. Salinity was generally favorable for oysters (> 15 psu) throughout the sampling period except in the wet seasons of 2005 and 2008. There were many live oysters in the Loxahatchee Estuary throughout 2006–2007 until the 2007 wet season. Oyster densities have stabilized since the 2008 dry season. The monitoring data support the notion that oyster survival is optimized when salinity is 10.0–25.0 psu. While individuals are stressed and die when salinity is < 7.5 psu, marine predators and parasites can limit population growth when salinity is > 25 psu. Disease prevalence and predator abundance are limited by both low temperature and low salinity. Thus salinity is the primary factor influencing oyster survival in South Florida as biological loss processes are minimized in the summer (low salinity) and winter (low temperature) seasons.

KEY SFWMD PROJECTS IN THE LOXAHATCHEE RIVER ESTUARY

Loxahatchee River Science Plan

The Restoration Plan for the Northwest Fork of the Loxahatchee River (SFWMD, 2006a) recommended the development of a science plan for the Loxahatchee to (1) monitor effects of restoration efforts to support adaptive management of the system, and (2) to fill knowledge gaps critical to successful restoration. The Loxahatchee River Interagency Science Plan Team (LIST) team was formed in 2008 to provide details and focus to the Loxahatchee River Science Plan (LRSP). The LIST is composed of representatives from the SFWMD, the FDEP Florida Park Service (FPS) – District 5, the FDEP Southeast District, the LRD, Martin County, Palm Beach County Environmental Resources Management (PBCERM), and FIU. The LRSP is designed to establish and support monitoring programs that gather information on a structured, focused basis that provide information on water quantity, water quality, timing, and distribution of increased dry season flows and improved wet season flows. The information will be used for modeling, predictive analysis, and evaluation purposes, which will form the basis for adaptive management decision making (SFWMD, 2006a). Progress to date includes the development of a draft decision analysis framework that details an overall management goal, management objectives, as well as relevant research objectives.

Loxahatchee River Preservation Initiative Projects

Loxahatchee River Preservation Initiative (LRPI) projects are deployed throughout the watershed extending into both Palm Beach and Martin counties A list of LRPI projects during WY2008–WY2009 is provided in **Table 12-13**. The LRPI was formed in 2000 to seek funding assistance for projects that improve and protect the natural resources within the watershed. Funding for many of the projects is provided by specific, annual legislative appropriations and administered by the SFWMD. Various activities center on habitat restoration, stormwater treatment, sanitary sewer infrastructure, and monitoring. Partners include but are not limited to Palm Beach County, Martin County, the FWC, the FDEP Division of Recreation and Parks, the LRD, the Town of Jupiter, and the Jupiter Inlet District. Partners are responsible for carrying out the projects. The overall objective of these projects is to preserve the Loxahatchee River by improving water quality, restoring historic hydrology, removing exotics, promoting pollution reduction, and monitoring resources.

Table 12-13. Loxahatchee River Preservation Initiative projects within the LRE during WY2008–WY2009.

Project Number	Description of Project	Sponsor	Status
39	Limestone Creek Restoration – Phase II	LRPI/SFWMD/PBCERM	Completed
40	Urban Stormwater Management System Rehabilitation – Phase II	LRPI/SFWMD/Town of Jupiter	Completed
43	Jones Creek Parcel Hydrological Restoration	LRPI/SFWMD/Town of Jupiter	Completed
44	Surface Water Recharge System Improvements	LRPI/SFWMD/Town of Jupiter	Completed
45	Loxahatchee River Water & Biological Monitoring – Phase I	LRPI/SFWMD/LRD	Completed
48	Loxahatchee River Public Outreach – Projects II & III	LRPI/SFWMD/LRD	Completed
50	Kitching Creek Restoration – Phase V	LRPI/SFWMD/Martin County	Completed
53	Sandhill Crane E. Loxahatchee Slough Restoration Project – Phase I	LRPI/SFWMD/Martin County	Completed
57	Loxahatchee River Water & Biological Monitoring – Phase I	LRPI/SFWMD/LRD	Completed
59	Wildlife Utilization of the Loxahatchee River Flood Plain – Phase II	LRPI/SFWMD/FDEP	Completed
12	Kitching Creek Restoration – Phase II	LRPI/SFWMD/Martin County	Completed
16	Kitching Creek Restoration – Phase III	LRPI/SFWMD/Martin County	Completed
17	Cypress Creek Restoration (Martin County) – Phase I	LRPI/SFWMD/Martin County	Completed
33	Wild and Scenic River Corridor Exotic/Pest Plant Control – Phase I	LRPI/SFWMD/FDEP	Completed
38	Delaware Scrub Natural Area Restoration	LRPI/SFWMD/PBCERM	Completed
35	Cypress Creek Restoration – Phase II	LRPI/SFWMD/Martin County	Ongoing
36	Cypress Creek/Loxahatchee River Project	LRPI/SFWMD/Martin County	Ongoing
37	Kitching Creek Restoration – Phase IV	LRPI/SFWMD/Martin County	Ongoing
51	Limestone Creek Restoration N. – Phase III	LRPI/SFWMD/PBCERM	Ongoing
52	Cypress Creek Restoration – Phase III	LRPI/SFWMD/Martin County	Ongoing

Table 12-13. Continued.

Project Number	Description of Project	Sponsor	Status
55	Urban Stormwater Management System Rehabilitation – Phase IV; Jupiter River Estates	LRPI/SFWMD/Town of Jupiter	Ongoing
56	Loxahatchee River Oyster Reef Enhancement	LRPI/SFWMD/LRD	Ongoing
58	Wildlife Utilization of the Loxahatchee River Floodplain, Continuation 2008/2009 – Phase II	LRPI/SFWMD/FDEP	Ongoing
60	Cypress Creek/Loxahatchee River Project – Phase IV	LRPI/SFWMD/Martin County	Ongoing
61	Sandhill Crane E. Loxahatchee Slough Restoration Project – Phase II	LRPI/SFWMD/PBCERM	Ongoing
62	Delaware Scrub Natural Area Restoration Project – Phase II	LRPI/SFWMD/PBCERM	Ongoing
63	Wild and Scenic River Corridor Exotic/Pest Plant Control – Phase III 2008/2009	LRPI/SFWMD/FDEP	Ongoing
64	Loxahatchee River Water Quality & Biological Monitoring	LRPI/SFWMD/LRD	Ongoing

FDEP – Florida Department of Environmental Protection
LRD – Loxahatchee River District
LRPI – Loxahatchee River Preservation Initiative
PBCERM – Palm Beach County Environmental Resources Management
SFWMD – South Florida Water Management District

Implementation of the Northwest Fork Loxahatchee River Restoration Plan with its Preferred Restoration Flow Scenario is being achieved through plans and projects currently underway within the Loxahatchee River Watershed. These projects and the agencies involved are:

- Regional Water Availability Rule (SFWMD)
- Implementation of North Palm Beach County Project – Part 1 elements (SFWMD, USACE)
- Construction of additional water management/control structures (SFWMD)
- Development and implementation of operational protocols (SFWMD)
- Jonathan Dickinson State Park Unit Management Plan (FDEP FPS)
- Loxahatchee River Science Plan 2010
- Loxahatchee River Preservation Initiative
- Loxahatchee River National Wild and Scenic River Management Plan Update 2009
- Continued community participation through the Loxahatchee River District and the Loxahatchee River Coordinating Council

KEY NON-SFWMD PROJECTS IN THE LOXAHATCHEE RIVER ESTUARY

The LRD continues to maintain a comprehensive water quality monitoring network at 40 sites in the freshwater and tidal segments of the Loxahatchee River for salinity, nutrients, chlorophyll, and bacteria. Monitoring frequency is monthly at some of the key sites, which is expected to result in improved trends analysis and predictive analyses. The LRD has implemented a storm event monitoring program in the watershed and is seeking to strengthen the program. The LRD also complements the District’s oyster monitoring program by monitoring three additional sites in the estuary and performs extensive seagrass monitoring. The District is a funding partner for this water quality and biological monitoring.

LAKE WORTH LAGOON

Rod Braun and Richard Alleman

DESCRIPTION OF LAKE WORTH LAGOON AND MAJOR ISSUES

Lake Worth Lagoon (LWL), an estuary located in eastern Palm Beach County (**Figure 12-52**) bounded by barrier islands, is about 35.4 km (22 mi) long and typically 1.8−3 m (6–10 ft) in depth. The Atlantic Intracoastal Waterway channel runs through the entire length from north to south. Tidal exchange with the Atlantic Ocean occurs at North Lake Worth (Palm Beach) and South Lake Worth (Boynton) inlets. The LWL Watershed is about 1,165 km^2 (450 sq mi) with most of the land urbanized.

Lake Worth Lagoon is divided into three geographical segments (north, central, and south) based on hydrodynamic factors including water quality, circulation, and physical characteristics. The north segment includes waters north of Flagler Memorial Bridge to PGA Boulevard. The central segment includes waters from the Flagler Memorial Bridge to Lake Worth Bridge, and the south segment includes waters from Lake Worth Bridge to the Boynton Beach Bridge at Ocean Avenue (**Figure 12-53**). Sources of freshwater runoff include primary and secondary canal systems. The major sources of fresh water are the C-17 canal (Earman River), C-51 canal (West Palm Beach Canal), and the C-16 canal (Boynton Canal). The C-51 canal contributes about 50 percent of the freshwater runoff into the lagoon. Studies indicate that about 75 percent of the C-51 canal discharge turns northward in the lagoon and about 25 percent southward (Chui et al., 1970).

Like many of South Florida's heavily urbanized coastal areas, anthropogenic changes have negatively affected LWL. Sedimentation and turbidity are problematic. To date, no MFL or Water Reservation has been developed for LWL. The primary concern is that excessive fresh water is sometimes discharged into the lagoon. Differences observed in the macroinvertebrate community structure have been attributed to physical effects caused by the velocity of fresh water from the C-51 canal. The average daily flow is 419 cfs (11.9 m^3/s), but ranges up to more than 7,000 cfs (198 m^3/s). Salinity can be below thresholds considered optimum for key species such as the Eastern oyster and Johnson's seagrass. An evaluation target was established by an interagency team in 2007 to protect seagrasses and oysters near the outfall of the C-51 canal (SFWMD, 2007). Therefore, current performance measures are targeted at limiting the discharges from the C-51 canal so that salinity does not stay below 15 psu for more than 26 days or less than 5 psu more than seven days from April–July each year.

Figure 12-52. Location of Lake Worth Lagoon (LWL).

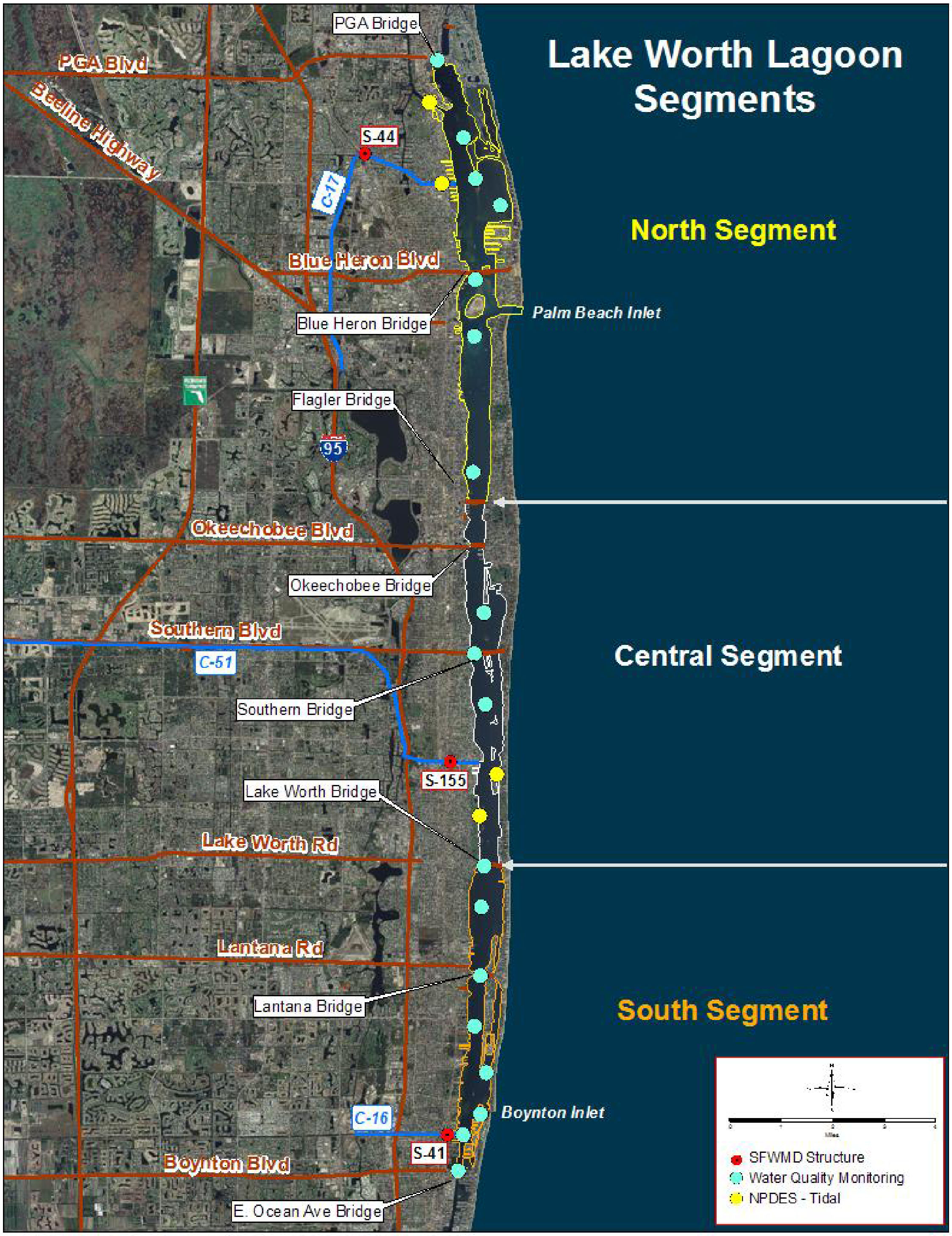


Figure 12-53. LWL segments and water quality stations established in 2007.

STATUS AND TRENDS IN LAKE WORTH LAGOON

Salinity and Freshwater Inflows

WY2009 conditions in the estuary were affected by an ongoing regional drought. Freshwater inflows and water quality are summarized by each major region. Plots indicate the long-term monthly means for the canal inflows. Inflows were particularly low during the end of WY2009, and salinity rose to around 35 psu in each region during the dry season. Freshwater inflows were sufficient in August 2008 to lower the average salinity in the central region to 13.6 psu (below the target 15 psu). Average inflows from C-51 appear to be level over the long term, although frequent large peaks occur within this average (**Figure 12-54**).

Water Quality

The LWL water quality monitoring network has changed over time. New stations were established in July 2007 (**Figure 12-53**). **Figure 12-55**, **Figure 12-56**, and **Figure 12-57** summarize the mean macronutrient concentrations by region for the last two years. Phosphate phosphorus is an estimate of inorganic phosphorus, and nitrate/nitrate nitrogen plus ammonia/ammonium nitrogen estimates total inorganic nitrogen (TIN).

Phosphorus and nitrogen were lowest within the northern region of the lagoon, and concentrations generally increased everywhere during months of greatest inflows from the canals.

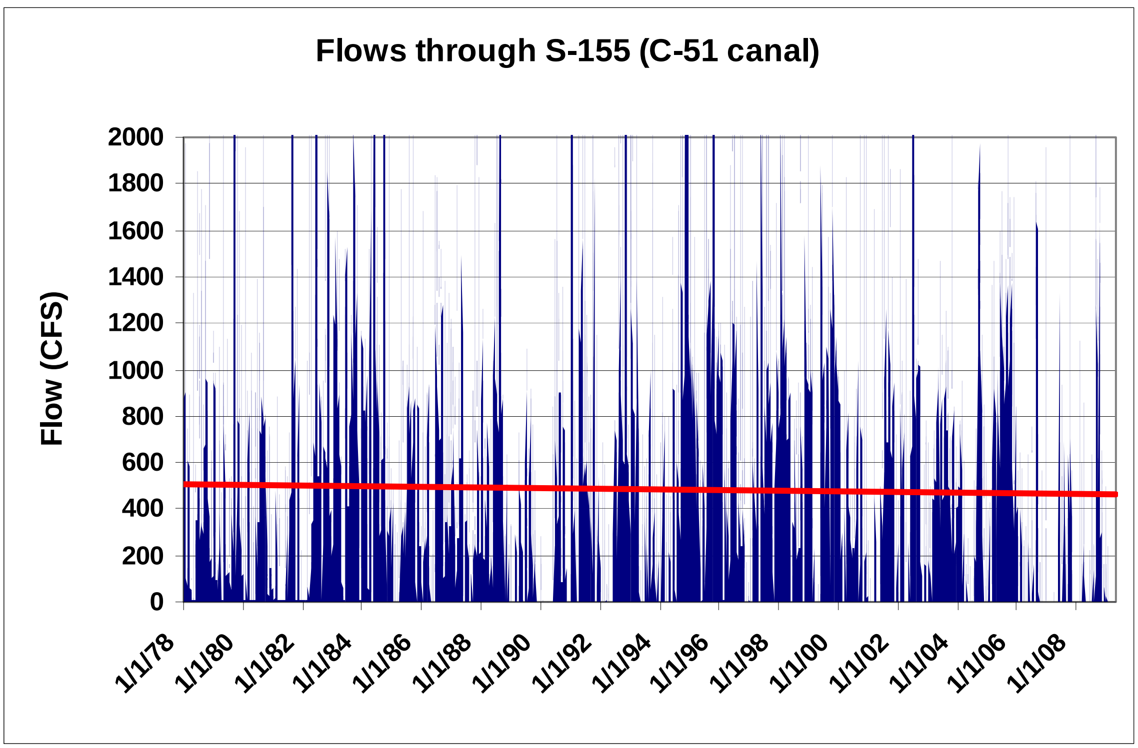


Figure 12-54. Long-term daily flow from the C-51 canal into central LWL. The red line is a time-series regression. Y-scale is truncated to show detail. There were 11 excursions of flow greater than 2,000 cfs.

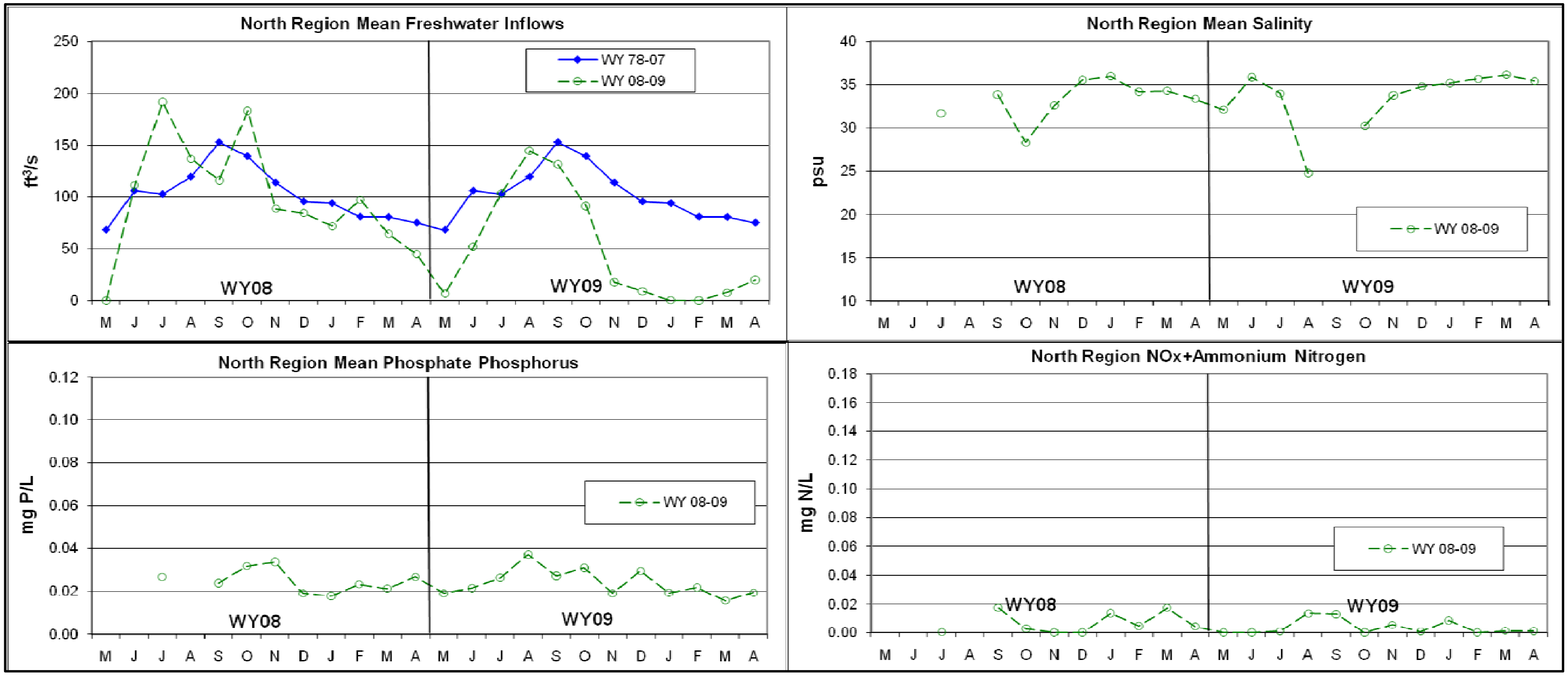


Figure 12-55. Monthly mean regional freshwater canal inflows and water quality in the north region.

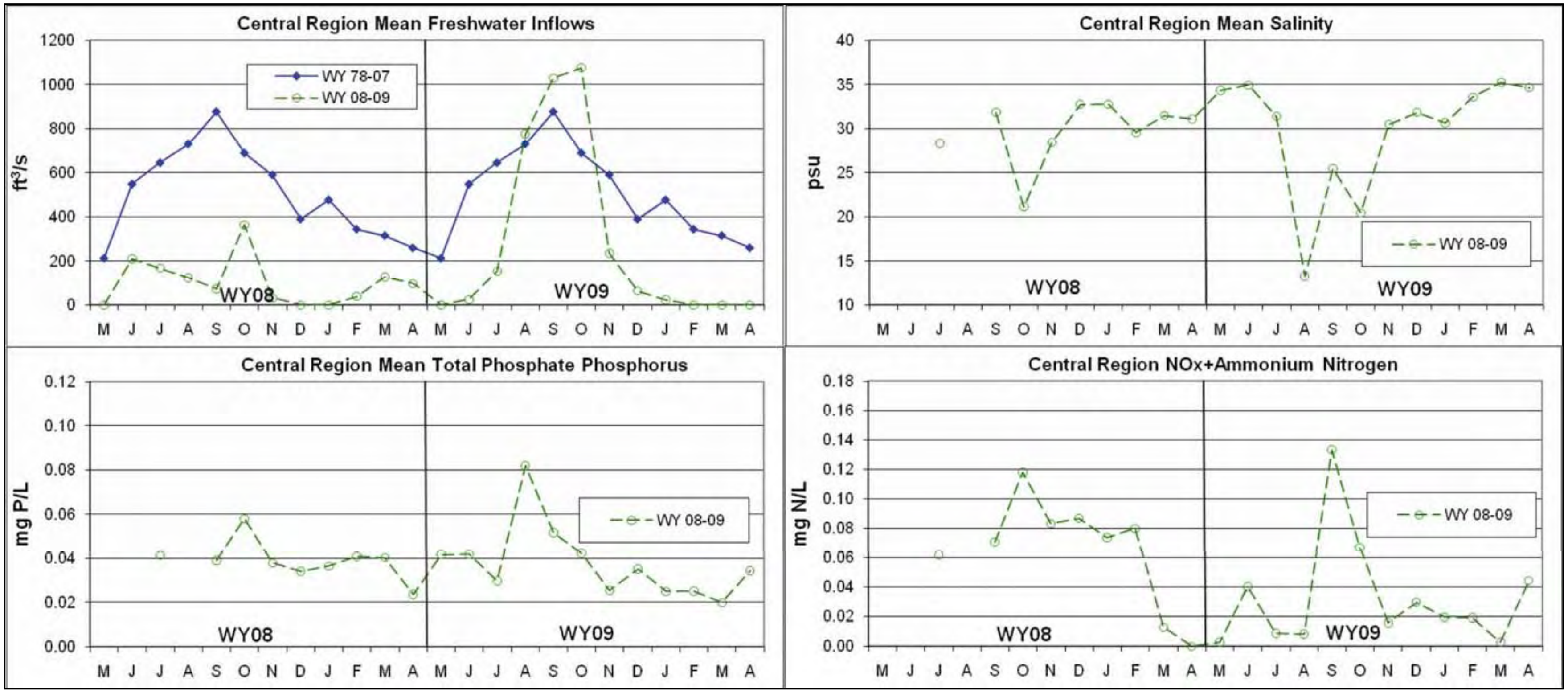


Figure 12-56. Monthly mean regional freshwater canal inflows and water quality in the central region.

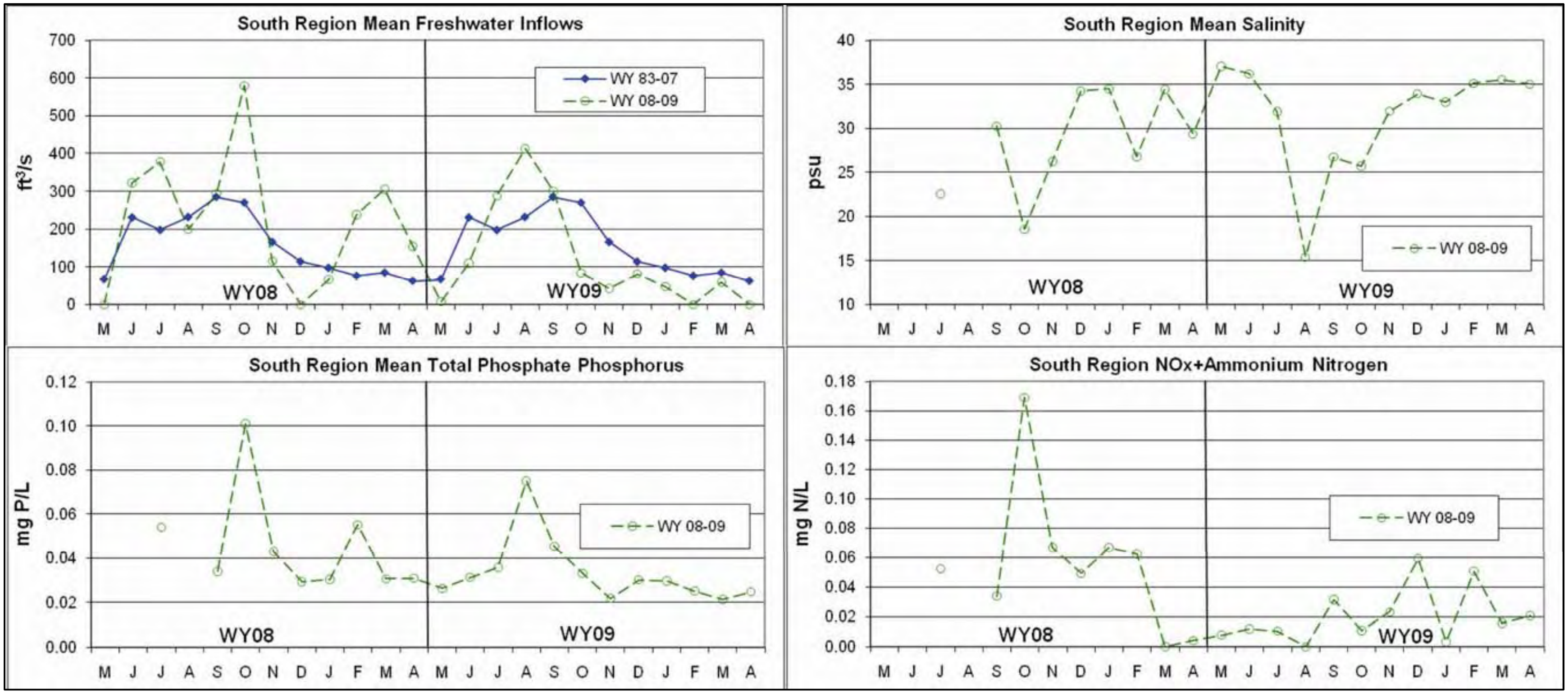


Figure 12-57. Monthly mean regional freshwater canal inflows and water quality in the south region.

Submerged Aquatic Vegetation

A 1990 Palm Beach County survey estimated a total of 813 ha (2,010 ac) of seagrass within the lagoon. Results of a 2001 mapping project indicated that seagrass beds covered at least 660 ha (1,631 ac) or 22 percent of the lagoon bottom. It is not clear if there was an overall loss of coverage of SAV between 1990 and 2001, because different methods were used. Seagrass coverage (percentage of bottom) varies throughout the lagoon, with coverage being higher in the north than in the south. Aerial images were collected in 2007 as part of the 2007 Habitat Classification and Mapping Project conducted by PBCERM. The project includes mapping of seagrasses, mangroves, oysters, and cord grasses *(Spartina* spp.) within the estuarine boundaries of Palm Beach County. This mapping effort employed the same methodologies utilized to map and classify the 2001 seagrass beds, allowing for the first true large-scale trend comparison between any two years. Results of the 2007 mapping showed that seagrass beds covered at least 683 ha (1,688 ac), or 21.7 percent, of the LWL. This was a 2.5 percent 17 ha (42 ac) increase over the 2001 calculation of 666 ha (1,646 ac), and was probably not a significant increase given the resolution of the aerials (PBCERM, 2008). Nevertheless, the majority of the increase can be attributed to an increase of patchy seagrass beds throughout the LWL. More seagrass was identified in the northern end than in the central or southern ends of the lagoon (**Table 12-14**; RECOVER, in prep., 2009).

Table 12-14. Seagrass acreage and percent change in 2001 versus 2007 in LWL.

	Acreage			
Segment	2001 Seagrass	2007 Seagrass	Change	Percent Change
Northern	1,149	1,090	(59)	(5%)
Central	195	205	10	5%
Southern	302	390	88	29%
Totals	**1,646**	**1,688**	**42**	**2.5%**

Seagrass Monitoring: Fixed Transects

In 2000, PBCERM initiated a long-term seagrass monitoring project that included an annual SAV assessment of nine fixed transects throughout LWL (**Figure 12-57**). As water quality improves, seagrasses are expected to expand to greater depths and/or increase in density and diversity. The first five years of surveys showed fluctuation in seagrass cover with no obvious pattern of increase or decrease until the 2004 hurricanes. The surveys conducted in June 2005 and June 2006 showed a major decrease in seagrass cover in most areas of the lagoon. This loss is most likely due to increased turbidity caused by runoff from the hurricanes, discharges from Lake Okeechobee, and burial and scour from wave action. Areas suffering the least impact were shallow sites and sites closer to inlets where water quality was least impacted (Applied Technology and Management, Inc., 2008). The 2007 survey reported record highs in terms of total number of cells in which seagrass was observed and percent coverage within the monitoring stations. It also documented the expansion of beds into deeper waters than observed in 2005 and 2006.

The results of the 2008 survey did not exceed the record highs of the 2007 survey; however, the 2008 survey was still the third-highest year on record for total number of cells containing seagrass and percent coverage. Results of the 2008 survey indicate that five of the nine deep-water stations recorded highs for number of cells with seagrass present; and at six of the nine transects, seagrass expanded into deeper waters than in previous years. Seagrass was documented at two of the deep-water stations that had never recorded seagrass during the nine years of the previous monitoring (Applied Technology Management, Inc., 2009).

The cumulative total number of cells with seagrass at all stations of the transects for each monitoring year were compiled and graphed in a smoothed-line format together with the cumulative yearly flow from the C-17, C-51 and C-16 canals (**Figure 12-58**). The graph provides a lagoon-wide perspective that shows the general inverse relationship between canal discharge and seagrass presence. This relationship is the most evident in the years from 2003 through 2008, which includes the lagoon-wide decreases after the 2004 hurricanes (Applied Technology Management, Inc., 2009).

Seagrass coverage varies throughout the lagoon, with more seagrass found in the northern segment than in the central or southern segments. Based on the fixed transect data, paddle grass is usually present at most of the stations. In 2008, paddle grass was observed in 67 percent of the stations. Johnson's seagrass is usually present in the second-highest number of stations, and in 2008, it was observed at 56 percent of the stations. Shoal grass is usually only present at a few of the stations, and in 2008, it was observed in 4 percent of the stations. While turtle grass and manatee grass are found in the lagoon, they were not observed in any of the stations associated with the fixed transects (RECOVER, in prep., 2009).

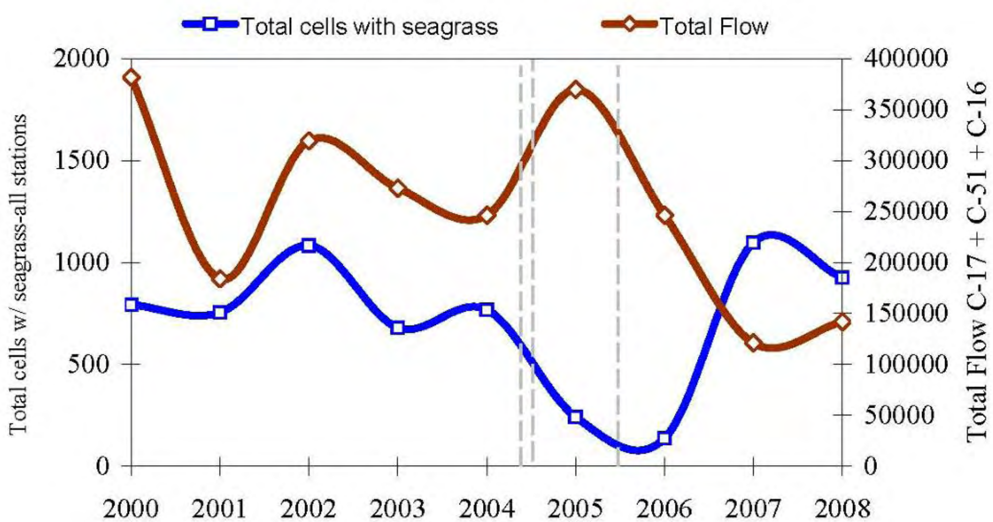


Figure 12-58. Combined seagrass abundance at all LWL transects from 2003–2008 compared with total canal flow data.

Eastern Oyster Abundance and Distribution

On a contract basis with the FWC, oysters in the LWL have been monitored as part of RECOVER since 2005. Within the LWL, three oyster reefs are sampled twice annually in March and September. Data include the density of live and dead adult oysters, including measurements of live oyster shells. Results from the three years of monitoring are presented in **Figure 12-59**.

Live oyster density results indicate a strong positive relationship to salinity. Early in 2005, the total number of oysters decreased, and then from 2006 through 2007, oyster density peaked before another dramatic decline in 2007 and 2008. Live oyster numbers began to rebound into the dry season of 2009.

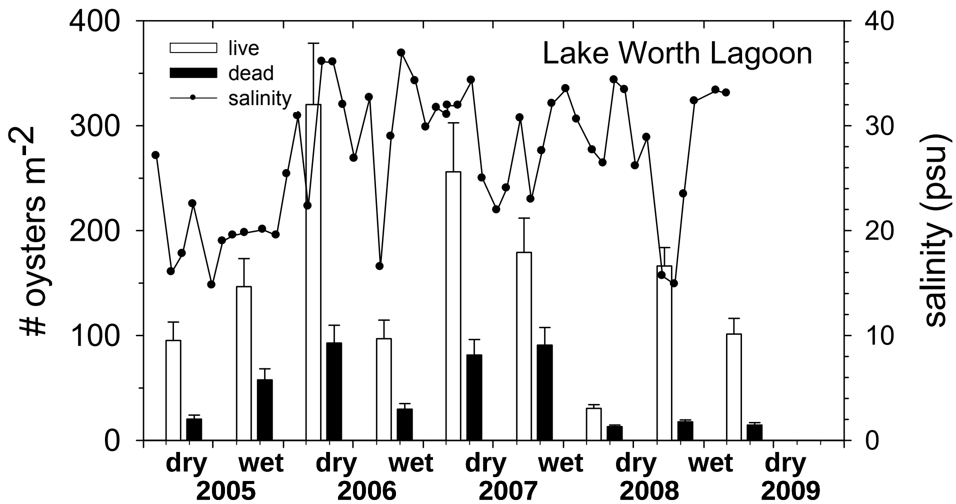


Figure 12-59. Live and dead oyster densities (left axis) and salinity (right axis) from spring 2005 to spring 2009 in LWL.

Sediments

Over the years, a large area of the lagoon has been covered with a layer of anaerobic muck. Muck sediments are thought to inhibit seagrass colonization and are associated with decreased diversity of benthic invertebrates. A portion of these sediments is very fine-grained and remain in suspension, or is easily resuspended by wave and wind action, attenuating light penetration of the water column and further inhibiting seagrass growth — even in areas with suitable substrate. The construction and operation of water storage and treatment facilities in the C-51 basin, combined with an active program of sediment inflow reduction using sediment traps, should reduce sediment inflow.

PPCERM, in a partnership with the District, initiated a study in 2008 to determine the sources of sediments entering LWL from the C-51 canal. Extensive bottom sediment sampling was performed in watershed canals and LWL, predominantly in the C-51 basin. Additionally, suspended solids analyses will be performed during storm events in CY2009 and linked to sources of total suspended solids (TSS) and muck sediments. Results are expected at the end of CY2009.

RESEARCH STRATEGIES FOR LAKE WORTH LAGOON

SAV mapping will provide a baseline to evaluate the future health of the ecosystem, and to evaluate the effectiveness of restoration projects over time.

The LWL Watershed and Stormwater Loading Analysis Project was initiated in early 2009 and completed in September 2009. The project assessed pollutant loading, especially nutrients, to the lagoon from various land uses within the LWL Watershed. Preliminary loadings were estimated, although event mean concentrations (EMCs) could not be calculated due to the lack of appropriate data. An EMC monitoring plan is to be developed.

The redirection of flows and additional retention of stormwater runoff from the C-51 basin, and sediment removal and control technologies within the C-51 canal are to be evaluated within the North Palm Beach County – Part 1 Project. Additional evaluations are focused on removal or trapping of existing sediment deposits in the lagoon downstream of the S-155 structure. The draft Project Implementation Report to be completed in CY2009 is expected to provide more details.

KEY SFWMD PROJECTS IN LAKE WORTH LAGOON

The District and PBCERM are collaborating on an expanded water quality monitoring network in LWL. The new program was initiated in October 2007.

The North Palm Beach County – Part 1 Project includes six separable elements including (1) Pal-Mar and J.W. Corbett Wildlife Management Area hydropattern restoration, (2) L-8 basin modifications, (3) C-51 and L-8 reservoir, (4) LWL restoration, (5) C-17 backpumping and treatment, and (6) C-51 backpumping and treatment. These separable elements have been combined into a single project to address the interdependencies and trade-offs between the different elements and provide a more efficient and effective design of the overall project.

The LWL element of this project includes sediment removal in the C-51 canal and sediment removal or capping within a distance of 2.5 mi downstream of the confluence of the C-51 canal and LWL. A prototype project was constructed to determine the feasibility of removing and disposing of sediments in the lagoon. Approximately 100,000 $y^3$of muck sediments were dredged and used beneficially. This project includes the evaluation of sediment traps to reduce future accumulation of sediment. The purpose of this project is to improve water quality and allow for the reestablishment of seagrass and benthic communities. The PBCERM began construction of the Ibis Isle Restoration Project in summer 2009 as part of the sediment management component of this project. Muck sediments will be capped and cord grass and mangroves will be established in the project area.

The District, PBCERM, and the FDEP began the Lake Worth Lagoon Initiative (LWLI) in January 2009. The LWLI is a multiagency and stakeholder-based advisory group organized primarily to (1) coordinate local, state, and federal agencies' activities that affect LWL and its associated watershed; (2) increase awareness of the LWL, its resources, and issues; (3) carry out the mission, action plans, and projects outlined in the Lake Worth Lagoon Management Plan; and (4) coordinate LWL technical conferences. Four major programs were identified and lead agencies were assigned by the executive committee as follows:

- Water (SFWMD)
- Habitat (PBCERM)
- Pollution Prevention (FDEP)
- Public Outreach (PBCERM)

KEY NON-SFWMD PROJECTS IN LAKE WORTH LAGOON

PBCERM and the FDEP are the acknowledged lead agencies for LWL. The Palm Beach Board of County Commissioners and the District's Governing Board approved the updated Lake Worth Lagoon Management Plan in April 2008. PBCERM will continue to implement projects through the Lake Worth Lagoon Partnership Grant Program.

It is anticipated that many existing information gaps relative to resource assessment and future enhancements of the LWL will be addressed through investigations by PBCERM. This agency is currently monitoring seagrasses in Lake Worth Lagoon.

The Eastern oyster is monitored by PBCERM and the District. Initiated in March 2008, PBCERM monitoring is currently in the second year of monitoring. One more year of monitoring is planned depending upon funding. Monitoring of oysters in LWL began in 2005.

BISCAYNE BAY

Richard Alleman and Bahram Charkhian

DESCRIPTION OF BISCAYNE BAY AND MAJOR ISSUES

Biscayne Bay is a shallow, subtropical estuary located along Florida's southeastern coast (**Figure 12-60**). The bay covers about 711 km^2 (275 sq mi), and the watershed is about 2,201 km^2 (850 sq mi). Most of the northern and central areas of the watershed are urban, with Miami being the largest city. Everglades National Park (ENP or Park) shares some of the watershed along the southwestern boundary. Biscayne National Park (BNP) encompasses a large area of the central region of Biscayne Bay. Card and Barnes sounds (southern region) are contained within the Florida Keys National Marine Sanctuary. Biscayne Bay is also designated an Outstanding Florida Waters that provides some enhanced protection by law.

Development of the watershed has altered the delivery of freshwater inflows into the bay. The northern and central regions of Biscayne Bay have been strongly affected by urbanization and growth of the surrounding metropolitan area. Southern Biscayne Bay is influenced by drainage systems extending from the ENP and managed stormwater runoff from the southern watershed for urban and agricultural land uses. The SFWMD manages and maintains a primary drainage network consisting of 16 outfalls into the bay that regulate water levels within the watershed for flood control and water supply. Drainage of the watershed has primarily changed the location and timing of freshwater inputs to the bay. Timing affects runoff velocity on both a seasonal scale and during rainfall events occurring over several days. The concentration of runoff into canals that historically flowed into the bay through small rivers, streams, and groundwater flux has altered distribution. In addition, the opening of artificial inlets and construction of artificial islands and channels, particularly in the northern area, have contributed to the bay's transition from a freshwater estuary to more of a marine lagoon.

From the 1900s to today, salinity has been increasing in the southern area of the bay, especially along the western nearshore areas (Wingard et al., 2004). The cause of increased salinity in southern Biscayne Bay is not clear, but may be a combination of reduced average rainfall, sea level rise, and diversion or altered timing of freshwater inputs. About half of the total freshwater input to the bay consists of discharges from the primary canals, and total about 1.73 billion m^3 (1.4 million ac-ft) per year on average. Additional significant sources of fresh water include rainfall that averages about 60 inches per year (1.68 billion m^3; 1.37 million ac-ft/year), and groundwater influx, which is estimated to be roughly 5 percent of surface water inputs (Langevin, 2001).

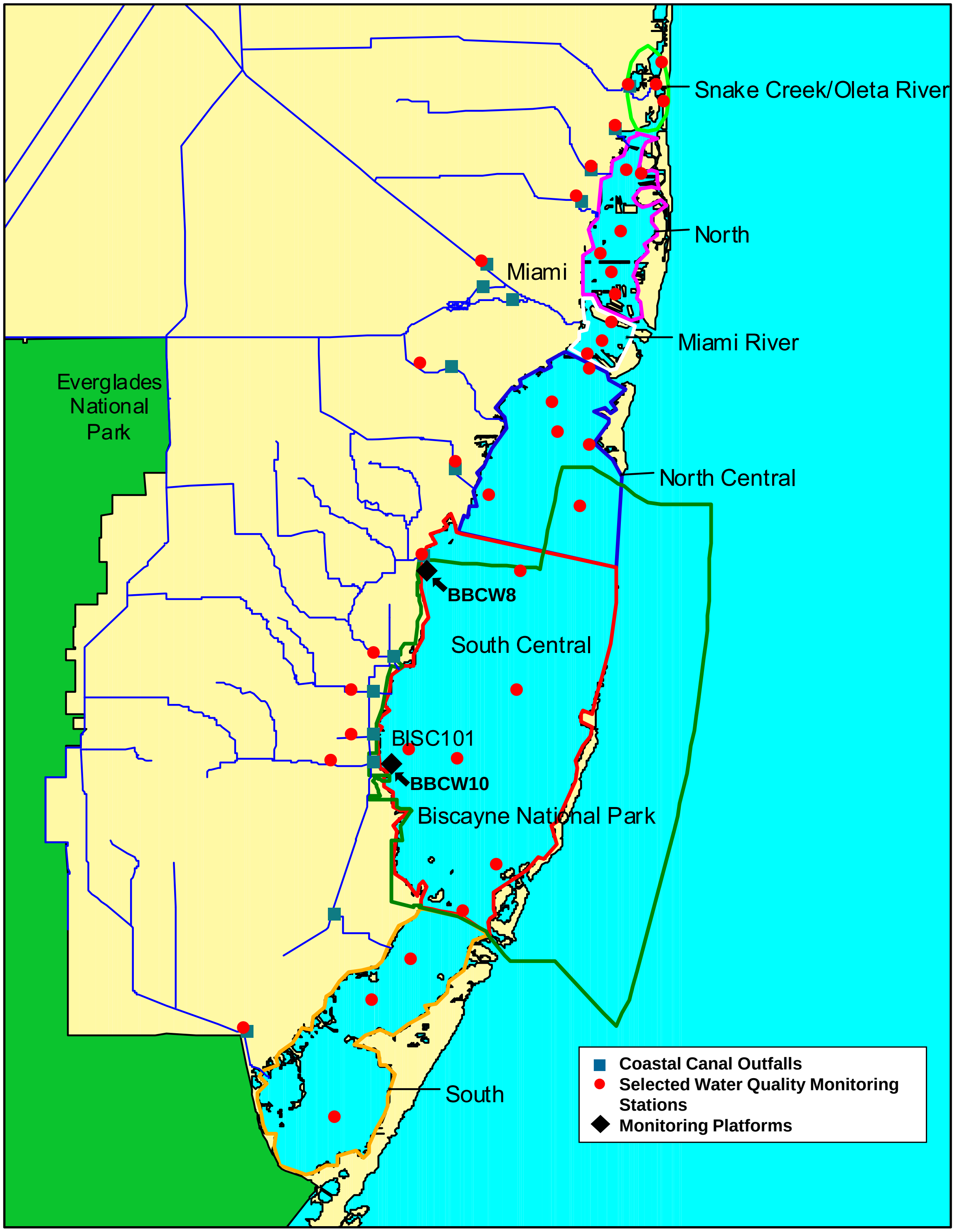


Figure 12-60. Biscayne Bay regions and selected water quality monitoring stations.

Water quality in Biscayne Bay has been impacted by raw sewage discharges, a practice that ceased in the 1950s, and increasing stormwater runoff from developed lands. More recently, water quality has been improving, and despite some dramatic physical and chemical changes, the bay supports extensive SAV and hardground communities. On the other hand, some fisheries that were once abundant, such as redfish or red drum (*Sciaenops ocellatus*), mullet (*Mugil* sp.) and spotted seatrout (*Cynoscion nebulosus*), have declined substantially. The bay still supports a large recreational fishery and viable commercial pink shrimp (*Farfantepenaeus duorarum*) fishery. Eastern oysters were abundant prior to the changes to Biscayne Bay, but now exist in a few isolated pockets. Large areas of coastal wetlands have been filled, and most of the remaining coastal wetlands are in the central and southern areas of Biscayne Bay. These wetlands have been largely starved of fresh water because of diversion of the freshwater flows. The CERP Biscayne Bay Coastal Wetlands Project will restore some overland freshwater flow to coastal wetlands in southern Biscayne Bay (see Chapter 7A of this volume).

STATUS AND TRENDS IN BISCAYNE BAY

Salinity and Freshwater Inflows

Neither MFL criteria have been formally adopted for Biscayne Bay to date nor specific quantities of water reserved. The SFWMD is proceeding, however, to develop a reservation of water for the Biscayne Bay Coastal Wetlands – Phase 1 Project (see Chapter 7A of this volume) in accordance with the Water Resources Development Act of 2000 and programmatic regulations for CERP. This proposed reservation would apply to a portion of the southern watershed and the quantity of water made available by the project. In addition, the information and tools to facilitate the process of producing freshwater inflow criteria are continuing to be developed. For example, a recently completed report by a panel of experts discussed the adequacy of the technical information to date to support minimum freshwater inflow needs for Biscayne Bay (Montagna et al., 2008). The panel called for some urgency to protect Biscayne Bay, especially from hypersalinity (see the SFER – Volume II, Chapter 3). The CERP (USACE and SFWMD, 1999) committed to no decrease of freshwater inflows to Biscayne Bay, and used the period from 1965–1995 as the baseline. A presumption in CERP is that most of the freshwater influx to Biscayne Bay is via the regional canal network, and preserving the overall water delivered to the bay not only protects existing resources, but also preserves some future opportunity to manage the water more effectively.

The best records of freshwater inputs to Biscayne Bay are estimates of flow rates at 16 coastal outfalls. These results represent the majority of flows discharged by the canal network. Simulation results from the South Florida Water Management Model (SFWMM) indicate that the magnitude of canal flow is sensitive to changes in the regional water management system, and even to changes in local wellfield withdrawal rates. The primary driver of canal flows from year to year is climate; therefore, when simulations are conducted, climatic conditions are kept the same among scenarios. It is more difficult to conduct comparisons using the empirical data because rainfall patterns have not only changed each year, but have changed over the long term. The period of reliable and systematic canal flow records vary for each canal outfall, but generally date back to the late 1970s to mid-1980s. **Figure 12-61** displays the total mean flow from the canal outfalls by calendar year from 1986 through 2008. Magnitude of flow corresponds with annual rainfall quantities. For example, the lowest flow occurred in 1989, the driest year on record, and the highest flow occurred in 1995, the wettest year on record. It does not appear that freshwater inflows via canals have diminished over the period of record, but the District does not have an effective way to eliminate "noise" in the data caused by variability of rainfall.

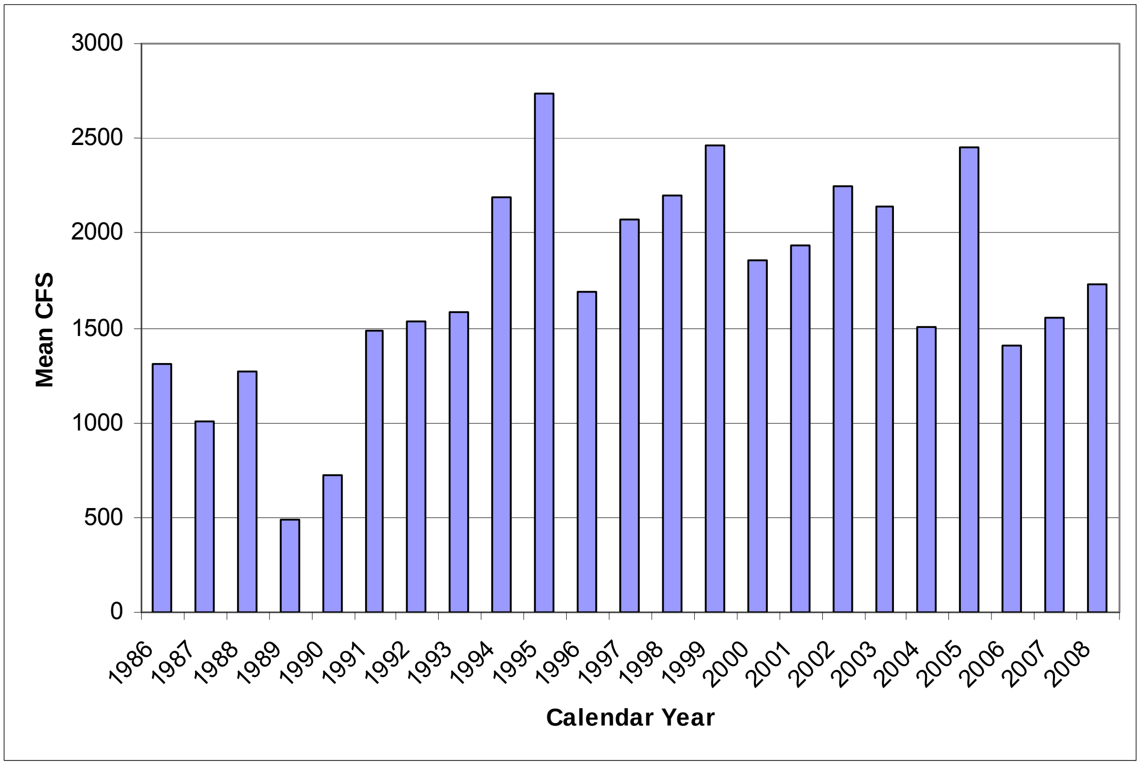


Figure 12-61. Mean annual freshwater inflows from the 16 primary coastal canal outfalls into Biscayne Bay.

Systematic and spatially comprehensive monthly salinity monitoring in Biscayne Bay began in 1979 by the Miami-Dade Department of Environmental Resources Management (DERM), and has continued to date. **Figure 12-62** shows long-term freshwater inflows and mean salinity in the Miami River region compared with results from the last two water years. Monthly mean canal inflows and water quality results are shown in **Table 12-15**. In general, freshwater inflows were average or above average during the wet season, but were below average during the dry season, especially in WY2009.

One area of particular interest is along the mainland nearshore area within Biscayne National Park. At station BISC101 (monitored by FIU), bottom salinity exceeded 35 psu most years, usually at the end of the dry season, even though the average salinity was 29.9 psu (**Figure 12-63**). Station BISC101 is located 2 km east of the shoreline. Salinity values tend to be highest close to the shoreline, but these results suggest that salinity has been increasing in this location since 1993. In addition, seasonal salinity maxima appear to be getting higher and more frequent. The large seasonal swings in salinity, ranging from about 15 psu to 45 psu, are a concern. It may be that this shallow southwestern, nearshore environment behaves differently than other areas of Biscayne Bay due to higher water temperatures, small current velocities, and influx of hypersaline water from tidal flushing of the adjacent wetlands. In April 2009, the District began obtaining real time data from two permanent platforms installed in this nearshore environment. These data (**Figure 12-64**) indicate that salinity continued to increase throughout April 2009 peaking in May, and then moderating as rainfall broke the dry season. Freshwater inputs from the canals in the area typically cease to flow at the end of the dry season each year, and groundwater influx is at the lowest because of low water stages in the watershed.

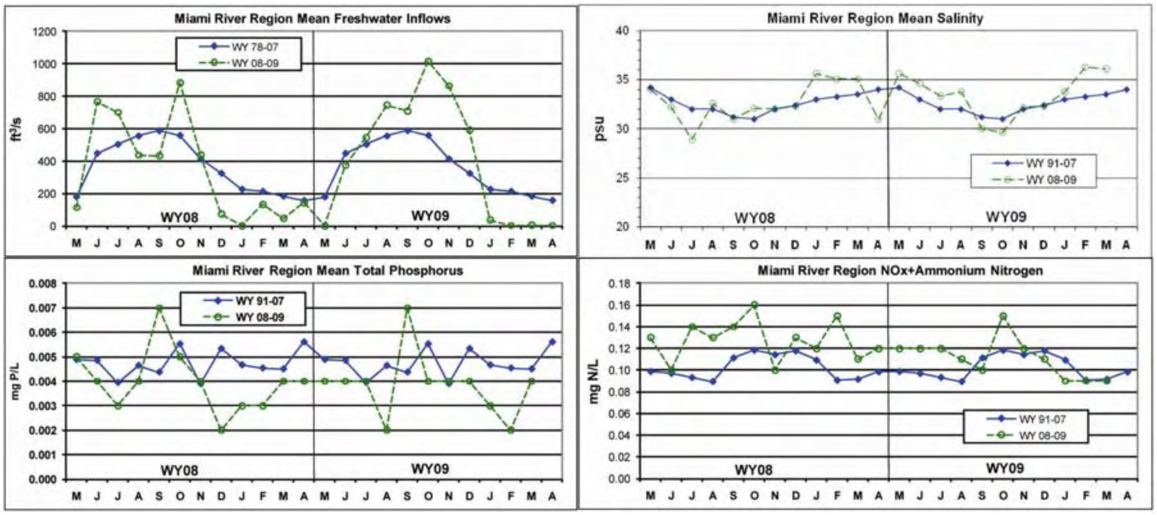


Figure 12-62. Freshwater canal inflows and water quality concentrations in the Miami River region of Biscayne Bay.

Table 12-15. Monthly mean freshwater inflows and water quality.

Region	Canal Freshwater Inflow (cfs)		Salinity (psu)		Total Phosphate Phosphorus (mg/L)		DIN[1] (mg/L)	
	WY78-08	WY09	WY91-08	WY09	WY91-08	WY09	WY91-08	WY09
Snake Creek/ Oleta River	298	161	28.6	31.8	0.009	0.006	0.07	0.08
North	262	203	30.8	32.3	0.007	0.007	0.08	0.09
Miami River	359	407	32.5	33.4	0.006	0.004	0.09	0.11
North-Central	142	161	32.5	33.2	0.004	0.003	0.09	0.09
South-Central	514	121	34.9	34.5	0.003	0.003	0.09	0.11
South	68	37	31.6	34.4	0.004	0.002	0.09	0.13

[1]DIN – dissolved inorganic nitrogen; values are represented by ammonia + nitrate + nitrite
cfs – cubic feet per second
psu – practical salinity units

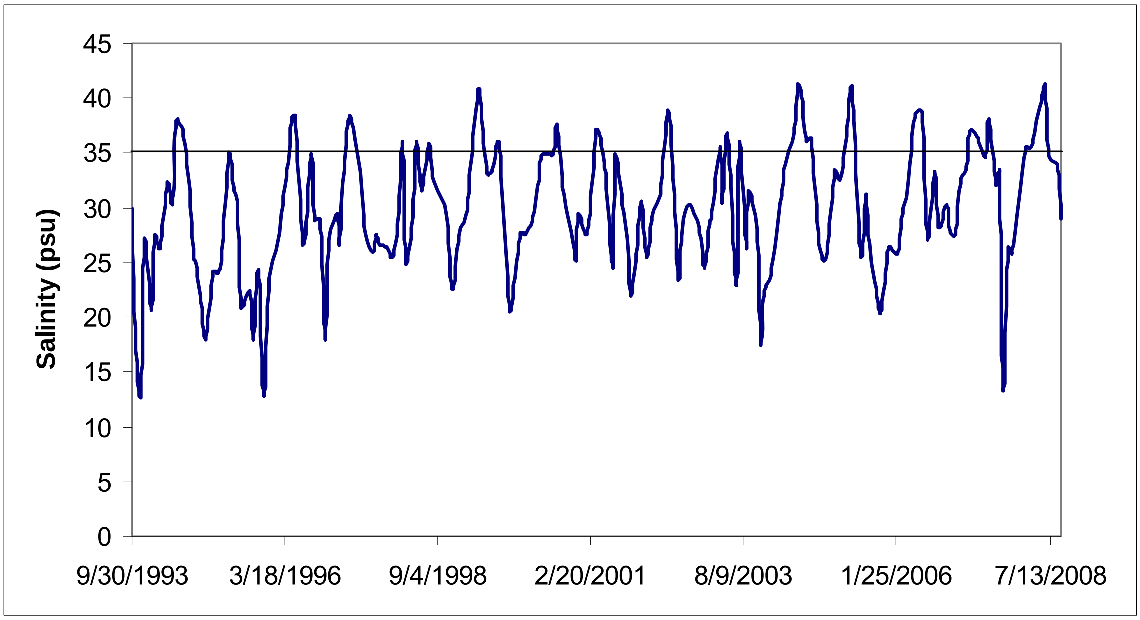


Figure 12-63. Long-term salinity results at station FIU101.

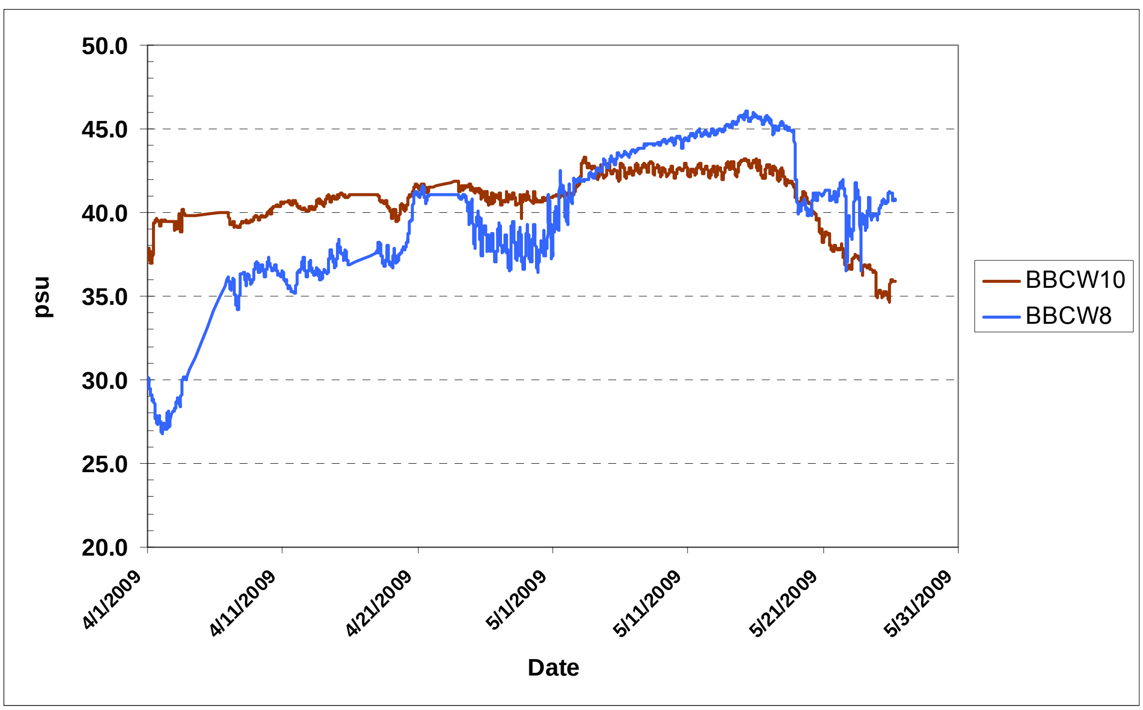


Figure 12-64. Provisional salinity data from permanent monitoring platforms.

Nutrients

Mean phosphorus and nitrogen concentrations do not vary greatly on a seasonal basis, and results from WY2007–2009 were similar to the long-term average monthly results by region (**Figure 12-61**, **Table 12-15**). Overall, mean DIN concentrations at the DERM monitoring stations ranged from about 0.07 mg/L to 0.10 mg/L. Phosphorus is considered to be a limiting nutrient in Biscayne Bay (Brand, 1988). Mean TP concentrations at the DERM stations ranged from about 0.004 mg/L to 0.007 mg/L. Phosphorus and chlorophyll *a* concentrations are consistently higher in the Snake, North, and Miami river regions than in the central and southern regions of the bay. Phosphorus concentrations in Biscayne Bay have decreased over the long term (Miami-Dade County, 2005), but some evidence suggests that trends may have reversed more recently with increasing phosphorus and chlorophyll concentrations (UF/IFAS, 2008).

Nutrient loading into Biscayne Bay has been estimated by different approaches. Caccia and Boyer (2007) reported that most of the inorganic nitrogen load into the bay (88 percent or 1,687 mt/year), and 66 percent (28 mt/year) of the inorganic phosphorus load came from canal inflows. Caccia and Boyer estimated that the balance of loads came from atmospheric deposition and groundwater influx, but did not estimate loads from organic sources, benthic fluxes, or offshore inputs. UF/IFAS (2008) estimated that the canals contributed an average of 1,160 mt of inorganic nitrogen and 19 mt of phosphorus to the bay each year. The lower estimates in this second study may be attributed to the fact that water quality data used in the calculations came from some monitoring stations located downstream of the canal outfalls in the bay where concentrations were diluted. Another issue regarding both estimates is their calculation based on data from monthly grab samples, causing concern about whether the data sufficiently captured significant loads occurring during storm events.

Epibenthic Habitats

The bottom community in Biscayne Bay is dominated by seagrasses, but a large area of hardground exists in the south-central region. While the predominant seagrass is turtle grass, shoal grass and manatee grass are commonly found, and paddle grass and widgeon grass are also present. Shoal grass occurs mostly in the northern region and along the southwestern shoreline within roughly 1 km of the shore. Shoal grass out competes turtle grass in these areas due to the variable salinity (Lirman and Cropper, 2003). More than 200 species of macroalgae are present in Biscayne Bay (Biber, 2002), and macroalgae comprise a significant portion of the bottom vegetative community. Macroalgae dominated by *Laurencia* are prolific nearshore of the south-central area of Biscayne Bay, and exhibit a seasonal growth pattern. Biber tied growth rates to excessive nitrogen loads in this area, but algae do not seem to exclude seagrasses in most areas. It is not clear whether macroalgal cover has changed overall in Biscayne Bay since detailed information about coverage and density does not exist. Seagrass cover in Biscayne Bay has been stable overall, and has likely expanded in extent in the last 20 to 30 years (Alleman et al., 1995), particularly in northern Biscayne Bay and the north-central area. The expansion of seagrass beds may have resulted from decreased nutrient loads and improved water clarity over time as suggested by water quality results. Bay-wide mapping of SAV species has not been conducted since the early 1980s.

Monitoring results suggest that changes in freshwater inflow patterns could improve the diversity of seagrasses in areas such as the western nearshore area of the south-central region (Lirman et al., 2008). For example, a more distributed inflow pattern causes changes in salinity that could promote the growth of shoal grass in areas now dominated by turtle grass.

Eastern Oyster Abundance and Distribution

Historically, Eastern oysters were so common in Biscayne Bay that their abundance was described as "luxuriant" (Smith, 1896). It is known that Eastern oyster reefs were present in the past near the outlets of the natural rivers and streams (Meeder et al., 1999). Increased salinity, particularly in northern Biscayne Bay, caused by the opening of inlets in combination with modified freshwater inflow hydrographs, are believed to have severely affected the population. Ironically, Smith (1896) recommended opening an inlet to northern Biscayne Bay to improve the oyster fishery. Small numbers of Eastern oyster are still present throughout Biscayne Bay close to the western shorelines. The current total population is unknown. A recent survey along the western shoreline within BNP documented the presence of a few small oyster bars adjacent the mouths of small creeks, and small numbers of live oysters were common in the mangroves. However, very little documented information is available about the current abundance and distribution of Eastern oysters in most areas within Biscayne Bay.

Fish Communities

The fish community in Biscayne Bay is diverse and supports large recreational and some commercial fisheries. Pink shrimp, in particular, are harvested commercially in the central region of the bay. The abundance of some species such as red drum, spotted seatrout, and striped mullet has declined over time. Spotted seatrout are more common in the northern region. Most of the central and southern regions of Biscayne Bay favor marine fishes, but salinity gradients that set up in the wet season along the western shoreline influence fish communities. The lower salinity along the western nearshore increases the probability that species, such as spotted seatrout, will occur. By contrast, when salinity exceeds 36 psu, fish communities tend to be less diverse with reduced assemblage structure (Serafy et al., 2008). It is assumed that lower average and less variable salinity in Biscayne Bay favors the estuarine fish community.

Coastal Wetlands

Some relatively large areas of coastal or salt-intruded wetlands remain in the central and southern regions of Biscayne Bay. Prior to artificial drainage and subsequent saltwater intrusion, the saltwater wetlands were smaller and hugged the shoreline. Overland runoff formed a series of creeks and small rivers that passed through the wetlands to the bay, similar to the morphology still present in Florida Bay (see *Florida Bay* section of this chapter). This ecotone consisted of meso- and oligohaline habitats. The District and the USACE are restoring some of these areas, which are included in the Biscayne Bay Coastal Wetlands Project. As a result, a monitoring plan has been formulated that aligns with several key performance indicators, such as hydrology, wetland vegetation, salinity, SAV, oysters, and fish. The monitoring plan is part of a draft Project Implementation Report scheduled to be published in the Federal Register for comments in CY2010. The SFWMD and Miami-Dade County have led an effort to acquire most of the remaining coastal wetlands within the project area.

RESEARCH STRATEGIES FOR BISCAYNE BAY

A 2002 strategic science plan identified several general gaps in information about Biscayne Bay (Alleman et al., 2002). Knowledge that could assist resource managers to answer questions in the short term includes:

- Improving estimates of historical freshwater inflows and salinity patterns
- Characterizing seasonal and daily salinity variability
- Improving estimates of nutrient loads from all sources
- Understanding the relative effect of salinity patterns on the abundance and distribution of SAV species
- Understanding the relationship of macroalgae abundance and distribution to nutrient concentrations
- Characterizing the current abundance and distribution of Eastern oysters
- Characterizing salinity and water quality in the coastal wetlands
- Improving estimates of fish abundance and distribution by species

KEY SFWMD PROJECTS IN BISCAYNE BAY

Biscayne Bay Coastal Wetlands Project

The Biscayne Bay Coastal Wetlands Project is a cooperative restoration project between the SFWMD and the USACE. The project includes three sequential steps: (1) expedited features in three geographic areas, (2) Phase 1, which includes the expedited elements plus additional features, and (3) Phase II, which is the entire project described as Alternative O. During FY2008, the Tentatively Selected Plan was identified for Biscayne Bay Coastal Wetlands – Phase I Project, and preparation of the draft PIR is in progress. As of April 2009, permits were issued by the FDEP (No. 0271729-002) and the USACE (No. SAJ-1994-1327) for the expedited construction of two components of the expedited project (L-31E culverts and Deering flow-way). Construction has not yet commenced on any part of the project. Once construction begins, results are expected to be provided in future SFERs. More information about the Biscayne Bay Coastal Wetlands Phase 1 Project is available at www.evergladesplan.org/pm/projects/proj_28_biscayne_bay.aspx.

Minimum Flow and Reservation Criteria Development

Work on defining minimum flow criteria continued in WY2009. Last year, a mass-balance analysis of freshwater inflows and salinity in Biscayne Bay was completed describing how general salinity patterns relate to inflows in different areas of Biscayne Bay (Marshall et al., 2008). A panel of experts reviewed relevant information for the development of criteria in 2008, and made recommendations for going forward (Montagna et al., 2008). A proposed reservation of water was developed for the Biscayne Bay Coastal Wetlands – Phase I Project, and included in the draft Project Implementation Report. To help understand short-term variability and obtain real time data, the District established two permanent platforms in the southwestern nearshore area of the bay to monitor surface water salinity. Additional information about SFWMD's planning process is provided in the SFER – Volume II, Chapter 3.

Water Quality Monitoring

The District maintained a cooperative agreement with DERM to continue water quality and SAV monitoring in Biscayne Bay. Currently, the water quality monitoring network consists of 85 stations located in Biscayne Bay and canals within the watershed. The SAV monitoring includes 11 fixed sites that have been monitored since 1984 and 102 random sites throughout Biscayne Bay.

KEY NON-SFWMD PROJECTS IN BISCAYNE BAY

The USACE continued funding a cooperative project with BNP to maintain about 40 continuous salinity recorders in the nearshore area of central and southern Biscayne Bay. The park instituted monitoring in 2004 to fill the geographic gaps in salinity results in this variable and dynamic environment near the canal discharges.

Federal funding also assisted the continuation of an annual seagrass monitoring program conducted by researchers at the University of Miami. SAV is documented photographically within a 500-m zone along the shoreline in south-central Biscayne Bay using digital imagery and a geopositioning system. This program now has results dating back to 2003.

FLORIDA BAY

Christopher Madden, Robin Bennett, Stephen Kelly,
Amanda McDonald, David Rudnick and Kevin Cunniff[1]

DESCRIPTION OF FLORIDA BAY AND MAJOR ISSUES

Covering a triangular area of 2,200 km^2 (850 sq mi) at the southern tip of the state, Florida Bay lies between the Everglades and the Florida Keys (**Figure 12-64**). About 80 percent of the estuary lies within the ENP, which is part of the Everglades Protection Area. The shallow bay has an average depth of about 1 m (3.3 ft), and most of the bottom is covered by SAV, particularly seagrass, which is beneficial habitat for many invertebrate and fish species. Since 1987, when widespread seagrass die-off began, a cascade of ecosystem changes has occurred, including subsequent seagrass die-off events, algal blooms, and high turbidity, widespread mortality of sponges, and decreases in some other invertebrates and fish species (Fourqurean and Robblee, 1999). A major premise of the Everglades restoration strategy is that historical decreases in freshwater inflow from the Everglades and resultant increases in salinity have contributed to these ecological changes (Rudnick et al., 2005).

The CERP C-111 Spreader Canal Western Project (C-111 Project), which aims to reduce water losses from Taylor Slough to the eastern boundary of the Everglades, is scheduled to begin implementation in 2010. This project features construction activities that will create a hydrologic ridge along the eastern border of Taylor Slough, thus increasing the flow of water to Florida Bay via the slough. As a result of the project, important changes in the hydrology and ecology of the Southern Everglades wetland, the mangrove ecotone, and Florida Bay are expected to occur. The District has monitored and researched this region for the past decade, and with the implementation of the project monitoring plan written in WY2009 (USACE and SFWMD, 2009) is well positioned to document and understand the project's effects.

A recent algal bloom that began in fall 2005 in eastern Florida Bay and southern Biscayne Bay subsided in WY2009. Hurricane disturbance, water management, and construction along the Florida Keys' Overseas Highway (U.S. Highway 1) are hypothesized to have contributed to the bloom. Efficient nutrient recycling and relatively low flushing rates are thought to have sustained the bloom for three years. Research and modeling activities are under way to gain a better understanding of phytoplankton dynamics in the bay.

The District has sustained a program of monitoring, research, and modeling in Florida Bay to (1) better understand the importance of water management as a driver of these and other ecological changes, (2) improve the ability to forecast the impacts of changing water management, and (3) improve management structures and operations for the protection and restoration of the Florida Bay ecosystem. In this section, results from major monitoring projects are highlighted, emphasizing hydrologic and salinity conditions, water quality, seagrass habitat, and upper trophic levels including waterfowl, shrimp, and lobster. An update on research and modeling activities and research planning is also provided, summarizing key results related to water management operations, Florida Bay Minimum Flows and Levels, and CERP (C-111 Project and RECOVER).

[1] CDM, West Palm Beach, FL

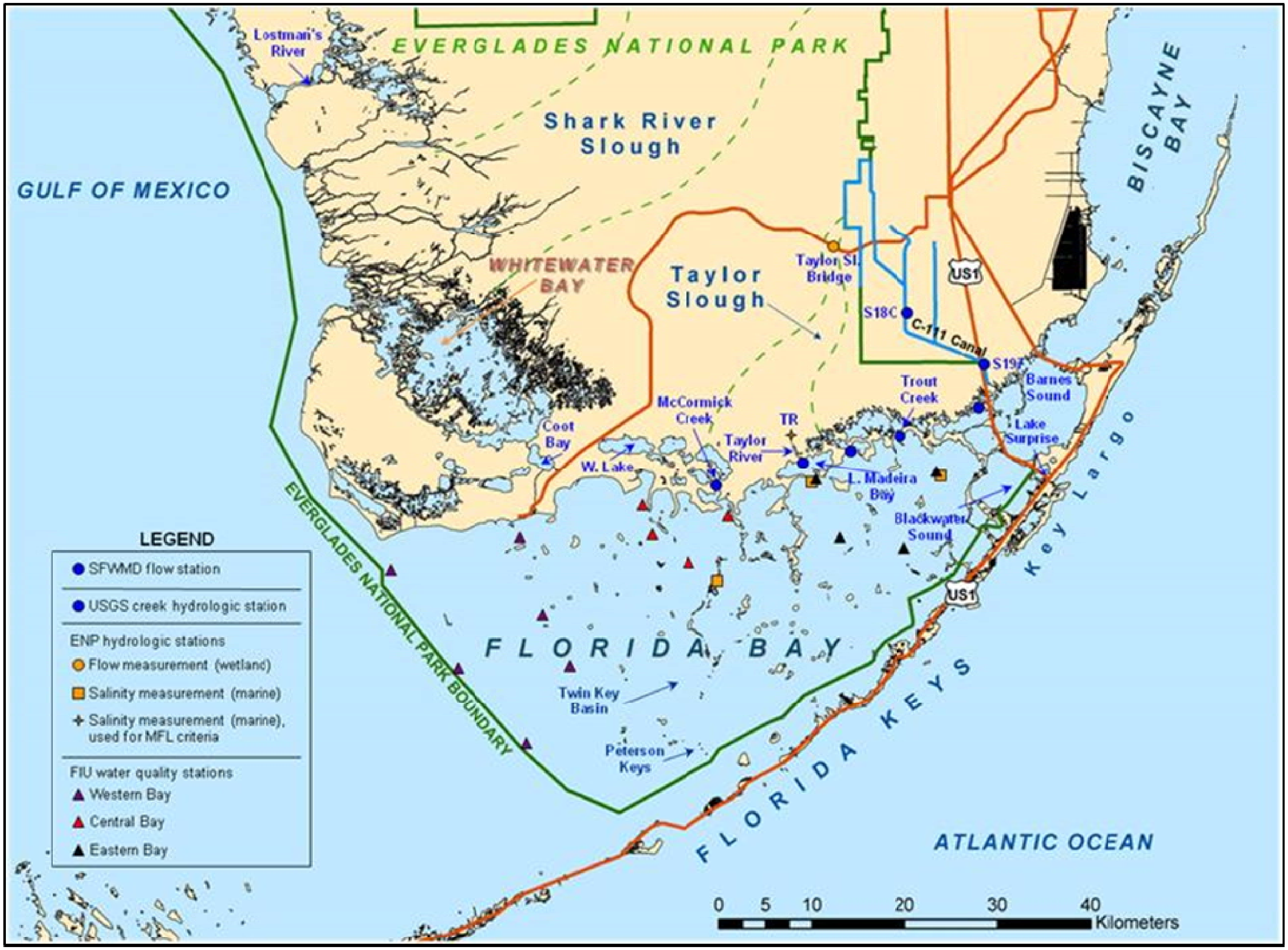


Figure 12-65. Florida Bay and major features.

STATUS AND TRENDS IN FLORIDA BAY

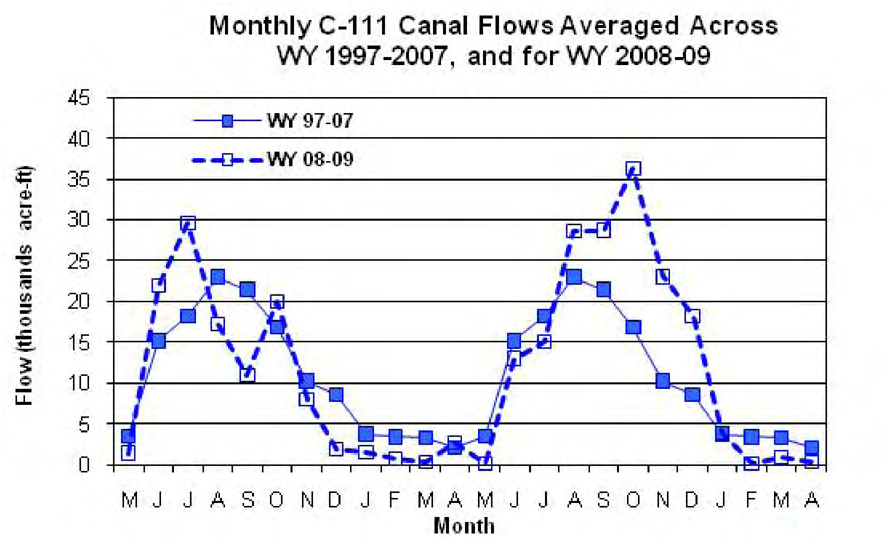
Freshwater Inflows

Florida Bay rainfall was calculated on a daily basis as the mean precipitation measured at several eastern bay (mean of Little Madeira, Duck Key, Long Sound, and Highway Creek) and central bay (mean of Whipray Basin and Terrapin Bay) ENP platforms. With WY2009 precipitation totals of 32.4 in. and 36.8 in. (82.3 cm and 93.47 cm), respectively, both eastern and central Florida Bay received below-average rainfall (WY1997–WY2007: 45 in.; 114 cm). The Everglades wetlands, where rainfall totals are slightly higher than that of Florida Bay proper, also received below-average annual precipitation (43 in.; 109 cm); for additional details, see Chapter 2 of this volume. While wet season precipitation was slightly below average in the bay, particularly in the eastern areas, (which includes a modest contribution during Tropical Storm Fay in August 2008), historically low dry season precipitation caused the system to experience a significant drought, with rainfall totals of only 3–4 in. (8–10 cm), which is 6–7 in. (15.2–17.8 cm) below the long-term average.

Flows measured through two major paths of water for eastern and central Florida Bay, the C-111 canal, and at Taylor Slough Bridge (TSB) are presented in **Figure 12-66**. Deliveries toward Florida Bay through both areas increased dramatically during the latter part of the WY2009 wet season. Based on low rainfall during this time, these discharges may be attributed to water management efforts to move excess water into the Southern Everglades. Moreover, these additional deliveries allowed WY2009 discharge totals for both the C-111 canal [168,100 ac-ft; 207 millions of cubic meters (Mm^3)] and TSB (63,700 ac-ft; 79 Mm^3) to remain above their long-term averages (C-111, WY1997–2007 average = 129,200 ac-ft; TSB, WY1997–2007 average = 44,800 ac-ft). With minimal tropical activity in WY2009, the only C-111 water diverted away from Florida Bay through S-197 (into Manatee Bay) occurred during a short period of releases in mid-August 2008 (after Tropical Storm Fay), totaling 5,000 ac-ft (6 Mm^3).

Discharges from three major creeks that flow into the bay are shown in **Figure 12-67**. Based on USGS measurements of nine mangrove creeks flowing into northern Florida Bay, these creeks were estimated to account for about 60 percent of all creek flow (Hittle et al., 2001). Serving as the major contributor of flow into the bay, Trout Creek had an annual discharge of 110,420 ac-ft (136 Mm^3) in WY2009, approximately 25 percent lower than its long-term average annual discharge (WY1997–2007) of 150,000 ac-ft (184 Mm^3). To the west, Taylor River annual discharge (21,520 ac-ft; 26.5 Mm^3) was also 25 percent below average (WY1997–2007 average = 30,000 ac-ft). Flow into the central bay through McCormick Creek remained near the long-term average annual discharge [WY2009 = 17,500 ac-ft (21.6 Mm^3); WY1997–2007 average = 17,300 ac-ft (21.3 Mm^3)].

Total annual discharge from five major creeks (three described above, plus Mud Creek and West Highway Creek), was nearly 25 percent lower in WY2009 than the long-term mean of 257,100 ac-ft (317 Mm^3). This total is monitored as one of the Florida Bay MFL criteria. Flow was particularly low during the early part of the wet season (May–July) across all creeks, producing a net negative cumulative discharge with Florida Bay water moving upstream into the creeks through August 2008, when rainfall associated with Tropical Storm Fay increased positive flow to the bay. Days prior to the landfall of Tropical Storm Fay, the 365-day cumulative discharge from the five creeks dropped to just above the 105,000 ac-ft threshold specified in the Florida Bay MFL Rule, the second-lowest total since creek monitoring began in the mid-1990s. Creek flows rebounded by the latter part of the wet season and early dry season. By February 2009, however, the drought had again attenuated flows through the creeks into the bay.



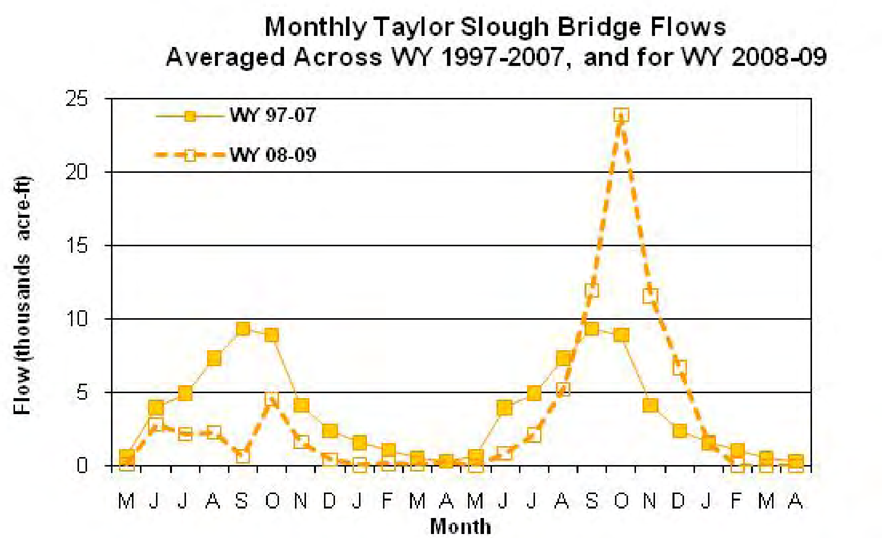


Figure 12-66. Monthly cumulative discharge from Taylor Slough Bridge and the C-111 canal (measured as the difference of flow between structures S-18C and S-197) into the Southern Everglades in WY2008 and WY2009, compared with mean monthly discharge from WY1997–WY2007. Data for Taylor Slough Bridge are provisional and provided courtesy of Everglades National Park (ENP or Park).

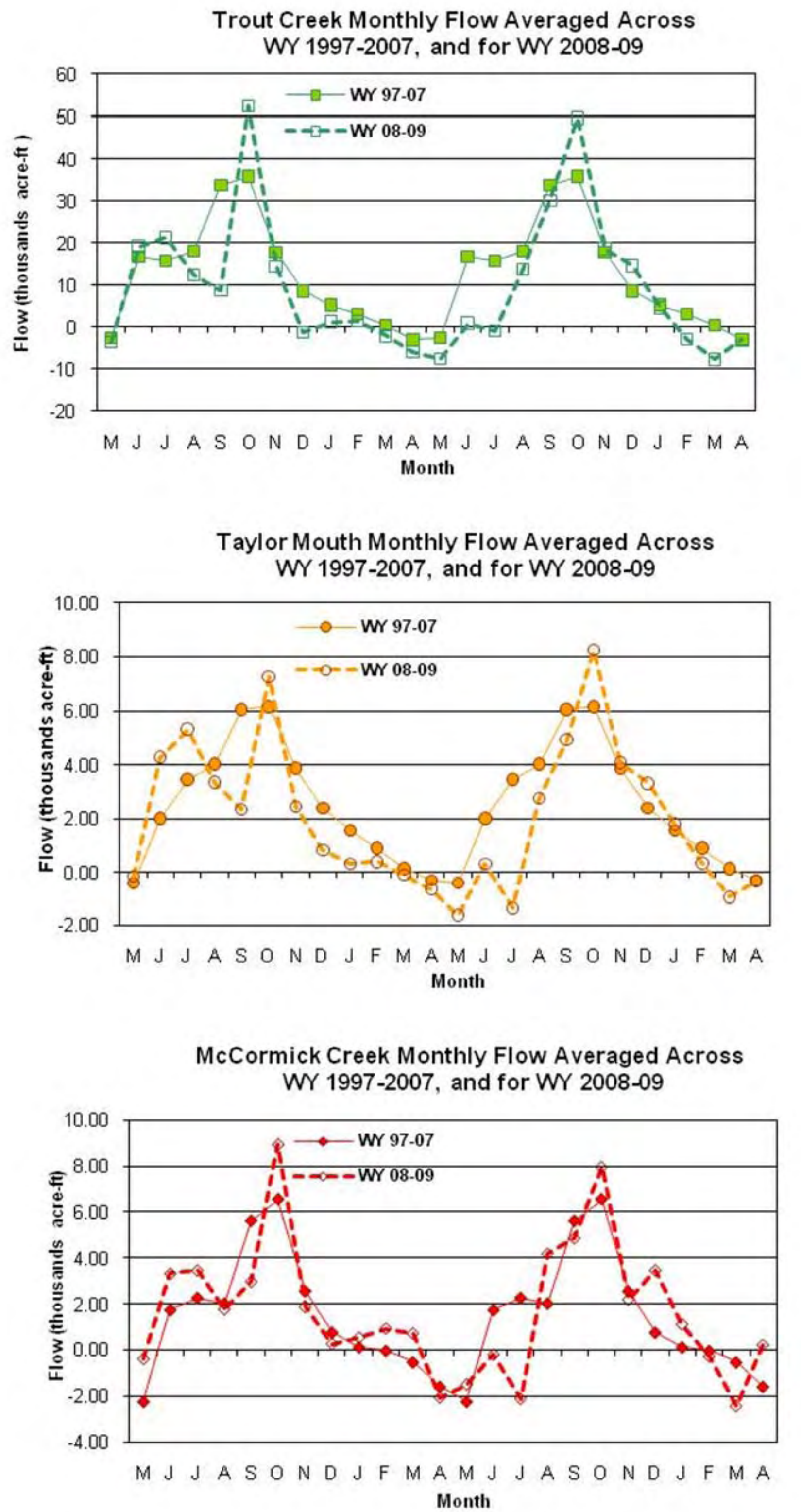


Figure 12-67. Monthly cumulative discharge to Florida Bay through three creeks in WY2008 and WY2009 compared with the mean monthly discharge from WY1997–WY2007. Data for WY2008 and WY2009 are provisional, supplied courtesy of the U.S. Geological Survey.

The spatial pattern of creek flows continued to indicate a westward shift in water distribution relative to the long-term decadal average, a trend first described in the 2008 SFER –Volume I, Chapter 12 (SFWMD, 2008). The proportion of discharge from three central creeks (Mud Creek, Taylor River, and McCormick Creek) relative to discharge from the eastern creeks (Trout Creek and West Highway Creek) has increased over time (**Figure 12-68**). This spatial pattern was still evident in WY2009, though the discharge total for the five creeks was below the long-term mean for the past three water years, particularly because flow through Trout Creek was well below average. Understanding the upstream causes and downstream effects of this trend will be a focus of continued SFWMD research. A westward shift of discharge may be, to some extent, the consequence of the C-111 Project and operations under the Interim Operational Plan for Protection of the Cape Sable Seaside Sparrow, which is designed to decrease eastward seepage of water from the ENP.

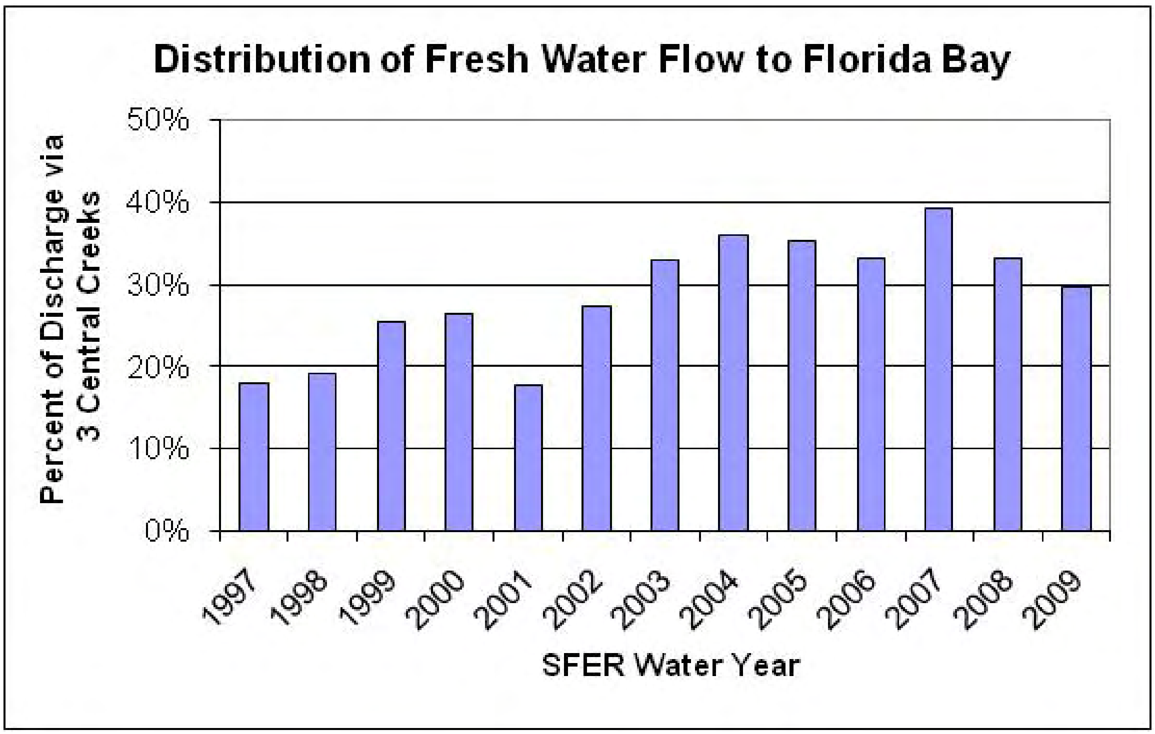


Figure 12-68. The proportion of annual creek discharge (measured in five creeks) via the three most western creeks (McCormick Creek plus Taylor River plus Mud Creek).

Salinity in Florida Bay

Salinity dynamics in Florida Bay are determined by multiple factors: freshwater flow from the Everglades, precipitation, evaporation, groundwater input, exchanges with marine waters from the Gulf of Mexico and Atlantic Ocean, and internal circulation. Because Florida Bay is shallow and its circulation is restricted by mud banks, it is susceptible to rapid and abrupt changes in salinity and to hypersalinity events that affect the biology and chemistry of the bay. Salinity data are collected continuously at stations in the ENP's Marine Monitoring Network (MMN), continuously at creek mouth stations monitored by the USGS, and monthly as part of the SFWMD's Coastal Water Quality Marine Monitoring Network (CWQMMN), providing information on spatial and temporal trends in salinity throughout the bay. Monthly average salinity for representative MMN and USGS sites (Trout Creek, Duck Key, and Little Madeira Bay for the eastern bay, and Whipray Basin for the central bay) were averaged with monthly grab salinity data collected in the corresponding months and regions.

Salinity across both eastern and central Florida Bay remained above the long-term average for much of WY2009 (**Figure 12-69**). This is not surprising given the below-average inputs of precipitation and creek flows. Concentrations were hypersaline (above 40 psu) across the central bay and at or above marine (35 psu) concentrations in the eastern bay for five months of WY2009. The rate of salinity increase after January 2009 in the eastern bay was particularly striking, nearly double (4 psu/month) that of an average year (2 psu/month). An above-average rate of salinity increase was also a factor in the mangrove ponds north of Florida Bay in WY2009; the 30-day running average salinity from the Taylor River (TR) station in the transition zone crossed the 30 psu threshold specified in the Florida Bay MFL Rule multiple times during the water year (**Figure 12-70**). Exceeding this threshold within a given calendar year counts as an exceedance for the year. Because the water year spans two calendar years, these concentrations represented exceedance events over two consecutive years, an occurrence allowed only one time every 10 years before constituting a violation of the Florida Bay MFL Rule.

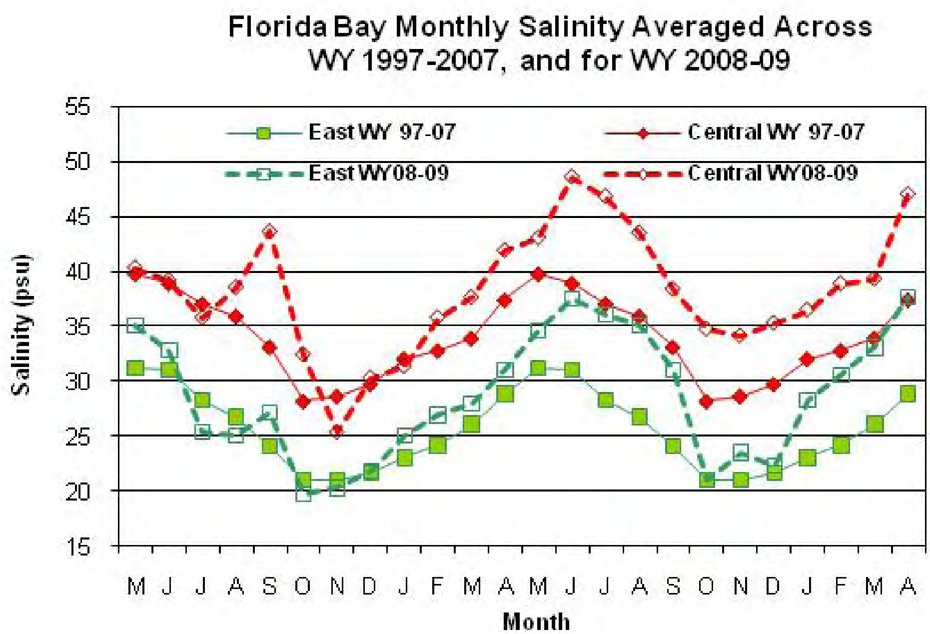


Figure 12-69. Mean monthly salinity values in eastern and central regions of Florida Bay in WY2008 and WY2009 compared with monthly means from WY1997–WY2007.

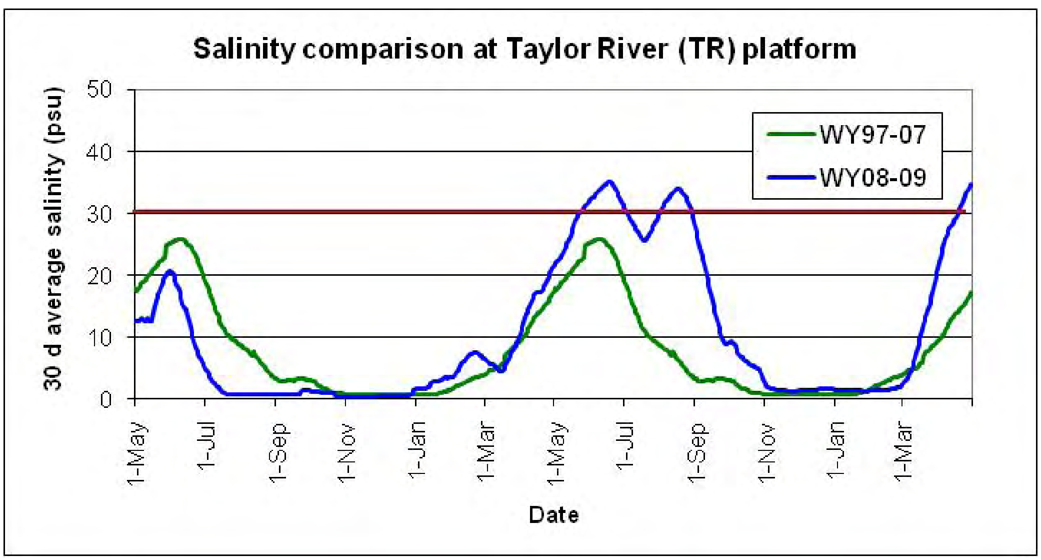


Figure 12-70. Salinity (30-day running average) at the Argyle-Hendry pond (Station TR) in upper Taylor River for WY2008 and WY2009 compared with daily mean values calculated from WY1997–WY2007. The Florida Bay MFL threshold for an exceedance is the occurrence of this running average exceeding 30 psu within a calendar year. Exceedances occurred in both 2008 and 2009.

Nutrients and Algal Blooms

Assessment of water quality in Florida Bay is necessary in order to ensure that District operations and projects protect and restore the ecosystem to the extent possible. The CERP performance measures [in RECOVER and the Florida Bay and Florida Keys Feasibility Study (FBFKFS)] focus on chlorophyll *a* concentrations (as an indicator of algal blooms) and call for no increase in the magnitude, duration, or spatial extent of blooms compared to conditions since monitoring began in 1991. Therefore, water quality is considered a constraint on restoration efforts, with the objective of doing no harm.

During WY2009, the District changed contractors for the collection and analysis of samples for the CWQMMN. This resulted in a three-month gap in data collection (October through December 2008), and all data analyses reported in this section are for the remaining nine months for which the District has data. In addition to this data gap, any analytical differences due to changing laboratories from the Southeast Environmental Research Center (SERC) at FIU to the District's Environmental Services Lab have not been evaluated and are assumed to be negligible for the purposes of this report. The only exception is that chlorophyll *a* results from January through April 2009 were generated by District research staff using a fluorometric method, as part of an inter-calibration exercise with District monitoring analytical staff using a spectrophotometric method. FIU samples through September 2008 were also analyzed fluorometrically.

Concentrations of water quality constituents in Florida Bay were near or below long-term (WY1992–WY2006) averages. Monthly chlorophyll *a* and TP concentrations in all three regions of the bay were lower than average overall (**Figure 12-71**). The one marked exception to this was a high chlorophyll *a* concentration measured in the central bay in January 2009. While the concentration was not unprecedented, the timing was unusual (annual chlorophyll *a* maxima typically occur in early fall). Unfortunately, data for the period prior to that (October through December 2008) is lacking, making an assessment impossible. Total organic carbon and turbidity also remain at or below long-term averages in all three regions. The eastern region of the bay had a notable peak [to 22 micromoles per liter (µm/L) = 307 µg/L] in DIN in September 2008. Most of the DIN (85 percent) was in the form of ammonium and may have been related to the high creek flows during this time and the C-111 releases in mid-August 2008 (**Figure 12-66**).

In the southern bay, the algal bloom observed near the Florida Keys beginning in late summer 2005 and reported in the 2009 SFER – Volume I, Chapter 12 has been greatly reduced during WY2009. The two stations in the water quality monitoring network near areas with this bloom (Twin Key Basin and Peterson Key, **Figure 12-65**) showed a dramatic decline in both chlorophyll *a* concentration (reduced by 73 percent to 0.5 µg/L) and turbidity [reduced by 53 percent to 1.7 nephelometric turbidity unit (NTUs)] from WY2008–WY2009. Both parameters are now below their long-term, non-bloom mean concentrations.

In the eastern boundary waters of Florida Bay and southern Biscayne Bay, algal blooms (indicated by chlorophyll *a* concentrations) and associated water quality attributes (TP, TOC, and turbidity) continued to decrease in WY2009. Changes between WY2008 and WY2009 in two basins that have been at the center of this bloom, Blackwater Sound and Barnes Sound (**Figure 12-65** and **Figure 12-72**), are presented in **Table 12-16**.

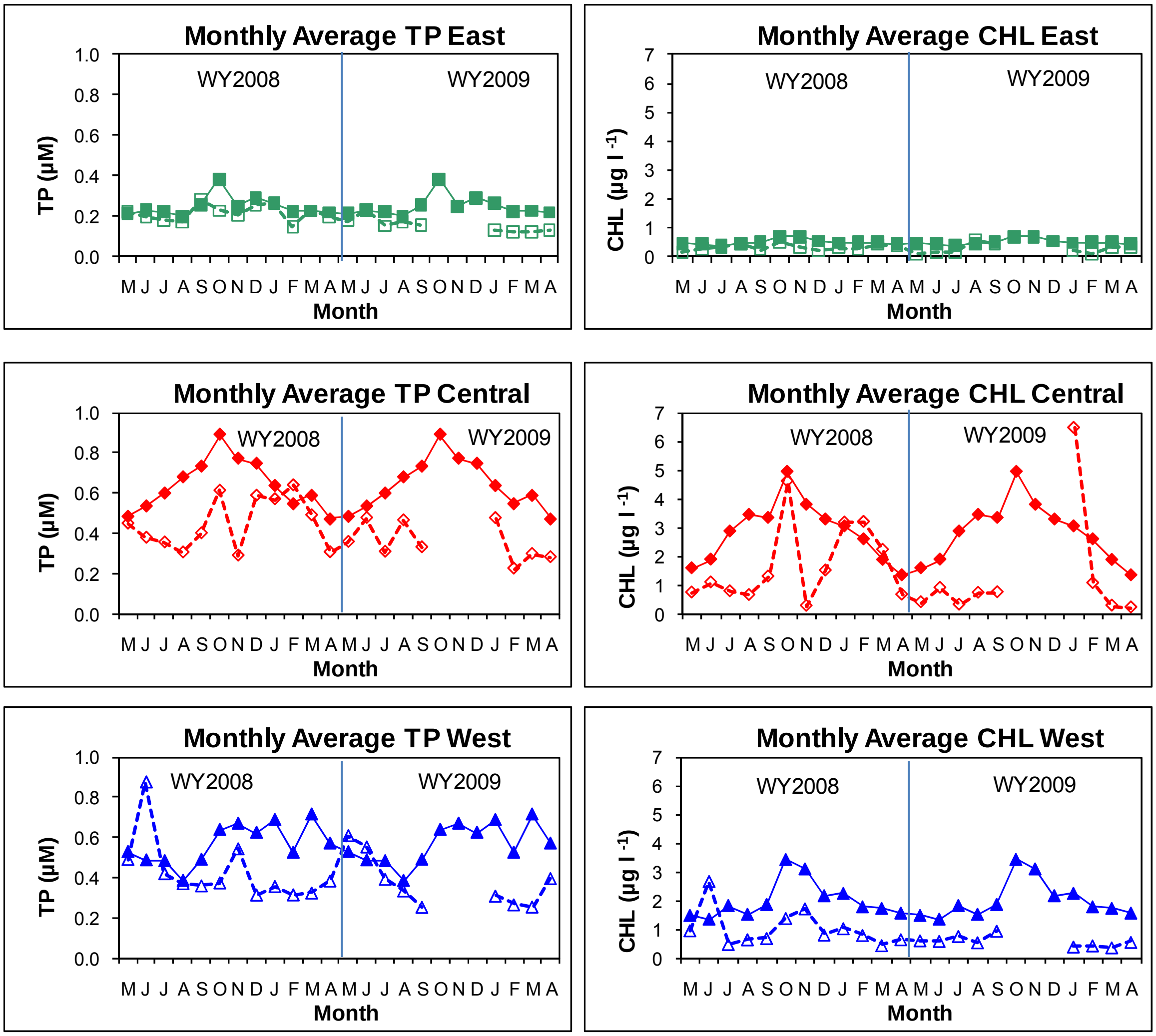


Figure 12-71. Monthly TP (TP, 1 µM = 31 µg/L) and Chl*a* concentrations in the three regions of Florida Bay during WY2008 and WY2009 (dashed line with open symbols) compared with monthly means from WY1992–WY2007 (solid line with closed symbols). Samples were not collected from October through December 2008.

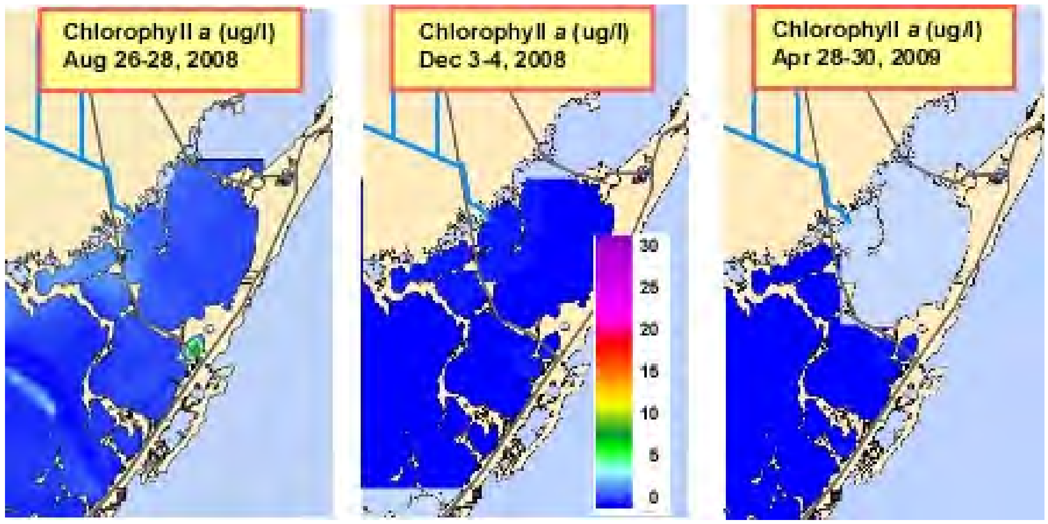


Figure 12-72. Status of phytoplankton bloom in eastern Florida Bay and southern Biscayne Bay in August and December 2008 and April 2009. Chl*a* concentration maps estimated from spatial mapping of the region using the Dataflow Continuous Flow and Multiprobe System (Madden and Day, 1992). High-resolution surveys measure in vivo chlorophyll *a* fluorescence. Each survey through the area shown includes tracks with several thousand data points. By December 2008, the bloom is not evident in this region.

Table 12-16. Water quality parameters in two eastern basins of Florida Bay where a prolonged phytoplankton bloom occurred from WY2006–WY2009. Samples in WY2009 were not collected from October through December 2008.

	Chlorophyll *a* (µg/L)		TP (µm/L) (µg/L)		TOC (µm/L) (mg/L)		Turbidity (NTU)	
Means	**Blackwater**	**Barnes**	**Blackwater**	**Barnes**	**Blackwater**	**Barnes**	**Blackwater**	**Barnes**
Pre-bloom	0.5	0.5	0.23 7.1	0.22 6.8	612 7.4	572 6.9	1.1	1.1
WY2008	1.6	1.5	0.36 11.1	0.36 11.1	539 6.5	520 6.2	2.9	2.3
WY2009	0.5	0.6	0.18 5.6	0.16 5.0	469 5.6	427 5.1	2.5	2.0
Decrease (from WY2008–WY2009)	70%	54%	50%	56%	13%	18%	14%	13%

µg/L – micrograms per liter
µm/L – micromoles per liter
NTU – nephelometric turbidity unit

There was a decrease of 50 percent or more in chlorophyll *a* and TP between WY2008 and WY2009. The WY2009 mean chlorophyll *a* concentrations in both basins are now at or near the long-term, pre-bloom (WY1992–WY2005) mean concentration, while TP is now below the long-term mean concentration. TOC concentrations, which increased to very high levels during the bloom in WY2005–WY2006, are now below the long-term, pre-bloom mean concentration in both basins affected by the bloom. While turbidity decreased from WY2008–WY2009 by over 10 percent, mean values are still above the long-term, pre-bloom mean concentrations.

Algal taxonomic identification and enumeration since February 2006 confirm that the cyanobacteria, *Synechoccocus elongatus*, dominated the blooms in Barnes Sound, Blackwater Sound, and Lake Surprise (**Figure 12-73**). Heterotrophic flagellates (microbial grazers of *Synechoccocus* dominated by dinoflagellates) and other autotrophic phytoplankton species (including diatoms and green algae) are also quantified in **Figure 12-73**. Peak cyanobacteria concentrations were measured in July 2006 in Barnes Sound and Lake Surprise, and in October 2006 in Blackwater Sound. Overall, the micrograzers made up a higher proportion of the non-cyanobacteria species in Barnes Sound (mean of 49 percent) versus Lake Surprise (mean of 38 percent) and Blackwater Sound (mean of 23 percent). In addition, Lake Surprise, the geographic center of the bloom, had the highest number of cyanobacteria as well as other phytoplankton for the period of record, which may be due to the isolated, shallow, and poorly flushed nature of the lake. This is expected to change, however, as a result of the removal in WY2009 of a causeway that bisected the lake, reuniting the two isolated halves for the first time in a century.

This restoration effort reestablished natural hydrologic connections, improved conditions for the endangered American crocodile (*Crocodylus acutus*) and other fauna, and increased access for public recreation adjacent to the Crocodile Lake National Wildlife Refuge in eastern Lake Surprise. District researchers focused on documenting diel DO conditions in Lake Surprise during fall 2008 when causeway removal was scheduled to begin. The primary concern was that excavation could increase turbidity and decrease light and photosynthesis, while increasing oxygen demand during this particularly vulnerable time for hypoxia and anoxia. The District documented multiple low DO events during this time leading to a recommendation to the Florida Department of Transportation (FDOT) regarding the timing of causeway removal. Causeway removal began in early November 2008. **Figure 12-74** shows a time-series of chlorophyll *a*, TOC, and TKN before and after the start of the removal. Data collected by District researchers are presented from both halves of the lake (west and east), as well as the two surrounding basins (Barnes Sound and Blackwater Sound) collected as part of the CWQMMN.

The water quality indicators chlorophyll *a*, TKN, and TOC show differences between the eastern and western halves of the lake before causeway removal, as well as differences between the lake and the surrounding basins (**Figure 12-74**). After causeway removal, there was an immediate and sustained similarity of these indicators in all of the basins, suggesting this restoration project was successful. While this convergence may be due to other variables (time of year, wind speed and direction, etc), removal of the causeway likely resulted in increased flushing of the lake as well.

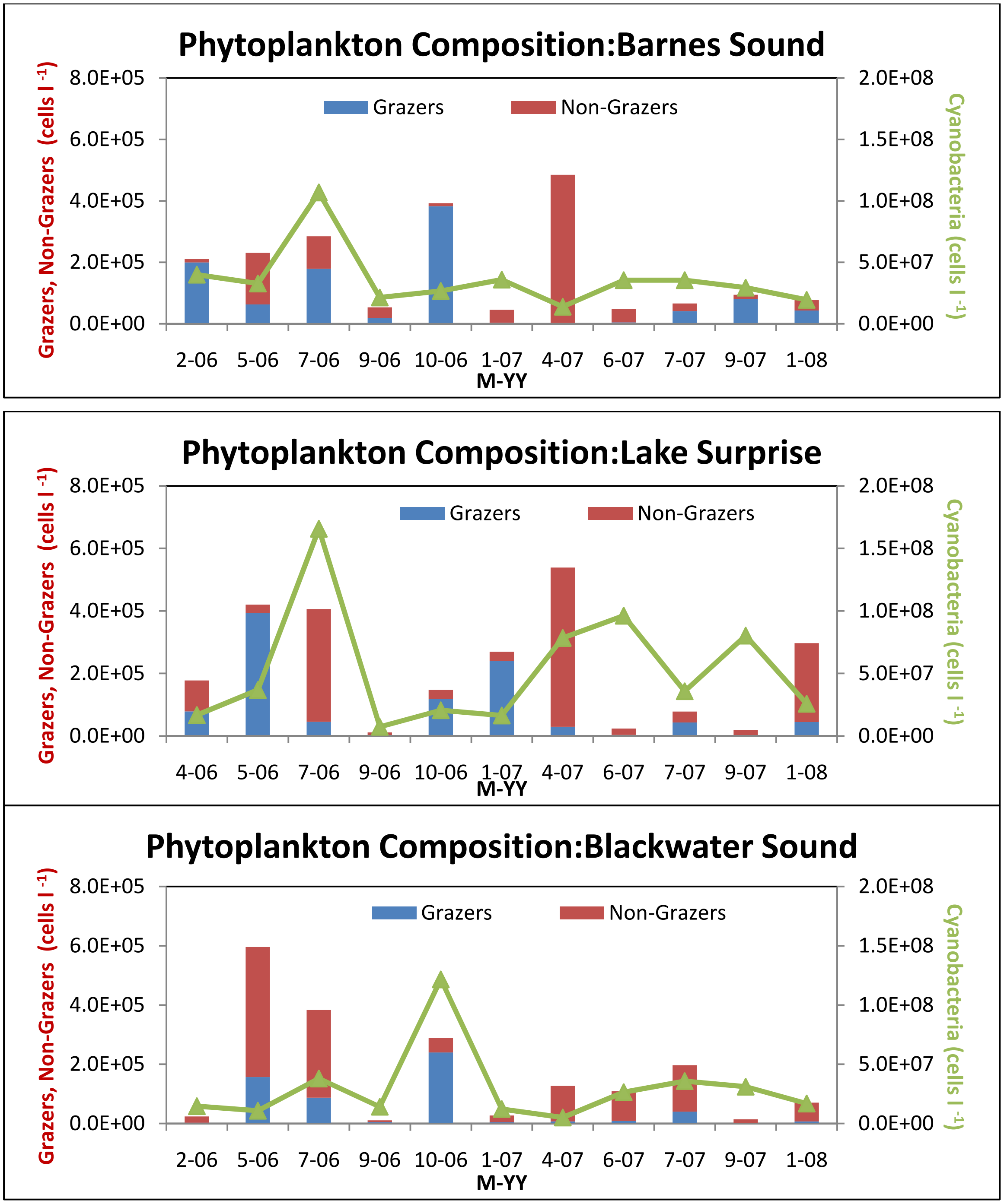


Figure 12-73. Phytoplankton species composition [cells per liter (cells/L)] in Barnes Sound, Lake Surprise, and Blackwater Sound. Phytoplankton are grouped as cyanobacteria or all other taxa (grouped as heterotrophic micrograzers or autotrophic non-grazers). Note the difference in scale between cyanobacteria (right axis) and grazers and non-grazers (left axis).

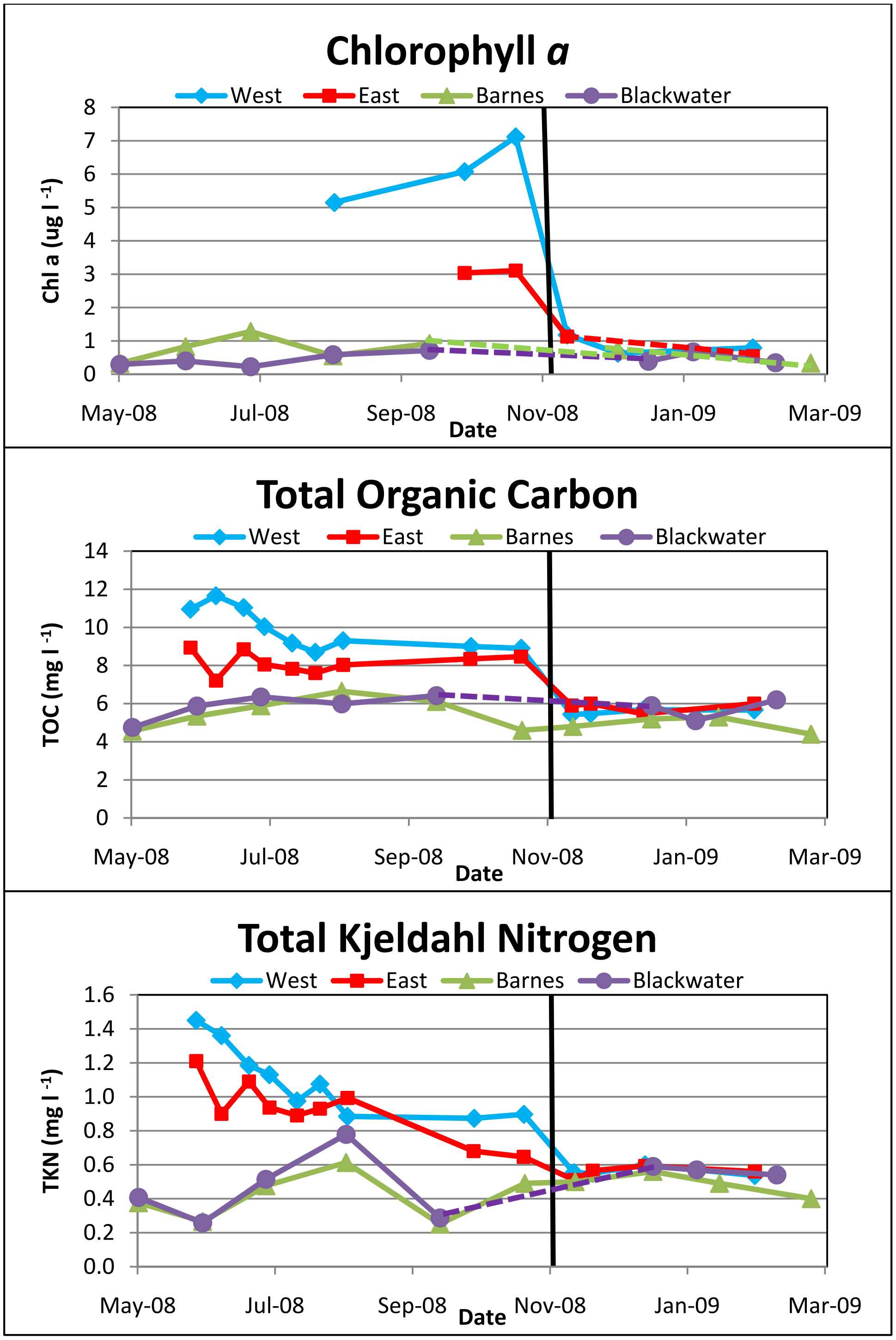


Figure 12-74. Time-series of Chla, TOC, and TKN in the eastern and western halves of Lake Surprise, and two adjacent basins (Barnes Sound and Blackwater Sound). The black line indicates the start of causeway removal.

Benthic Habitat

SAV habitat is the central performance measure for Florida Bay assessment and restoration (Rudnick et al., 2005). A restoration target for the bay is the sustainability of mixed-species seagrass beds with moderate-to-dense cover through most subregions. Performance measures involving SAV species composition are documented for both RECOVER and the FBFKFS. Assessment of ecological changes and prediction of potential restoration effects on SAV require the use of long-term datasets from spatially comprehensive benthic habitat surveys. In this report, data from the benthic habitat surveys conducted by two organizations are used to assess the status of Florida Bay SAV. The DERM and the FWC currently receive funding from the District to conduct these surveys.

The DERM conducts benthic habitat surveys in eastern Florida Bay and southern Biscayne Bay. These surveys are done quarterly within each of the 12 monitoring basins using a modified Braun-Blanquet Cover Abundance Index (BBCA) (Fourqurean et al., 2002), where benthic cover is visually estimated by bottom occlusion. Four or 12 randomly selected sites are sampled in each basin area using four haphazardly thrown 0.25 m^2 quadrats per site. These data are aggregated to the basin level for analysis and can be used to determine intra- and interannual trends in benthic habitat cover.

The FWC Fisheries Habitat Assessment Program (FHAP) has been sampling in 10 basins of Florida Bay since 1995. In 2004, RECOVER began funding the program and expanded the region covered by FHAP. Currently, FHAP samples 17 basins within an area that stretches from Lostman's River to Barnes Sound on the east side of U.S. Highway 1. Sampling is conducted annually in May using the same methodology and BBCA scale as DERM at 30 sites within each sampling basin (with eight haphazardly thrown 0.25 m^2 quadrats per site). The increased resolution within the basins allows for the analysis of spatial distributions within the individual basins, but the coarse temporal resolution precludes the assessment of intra-annual trends.

In May 2008, an inter-calibration workshop and field exercise was conducted to ensure comparability between the two independently collected datasets. During the workshop, a new and expanded set of metrics, including total seagrass cover and total macroalgal cover, was agreed upon by both agencies to bring more consistency to the data reporting and to provide more information for relating changes between functional groups of benthic vegetation (i.e., seagrass versus macroalgae). Results of the field exercise demonstrated consistent scoring between divers of both agencies, and new quality assurance methods were agreed upon to prevent divergence in reporting among staff performing the measurements.

In the 2009 SFER – Volume I, Chapter 12, attention was focused on two areas of Florida Bay that had experienced algal blooms: eastern Florida Bay and Twin Key Basin. In May 2007, it was reported that Twin Key Basin showed an increase in both the frequency of occurrence and the density of shoal grass in an area normally dominated by turtle grass. May 2008 data showed a further slight increase in only the frequency of occurrence of shoal grass, up 4 percent from 16 percent measured in May 2007. However, density of shoal grass decreased; of the 50 quadrats showing the presence of shoal grass, only one had more than 5 percent cover. Turtle grass showed no change in the frequency of occurrence from May 2007–May 2008, but density of this species decreased in that the frequency of observations with > 50 percent cover declined. The results are consistent with an area that had been impacted by an algal bloom, because shoal grass is more tolerant of low light than turtle grass (Dunton and Tomasko, 1994).

In the eastern bay, an algal bloom that had begun in fall 2005 and persisted for three years dissipated during WY2009. Turtle grass coverage has not returned to pre-bloom levels, though shoal grass has increased slightly (**Figure 12-75**). This can be expected since shoal grass has a faster rate of growth than turtle grass. The frequency of observations with SAV present did not persistently decline throughout the bloom period, but the frequency of observations with significant cover (> 5 percent) declined. In WY2009, as the bloom subsided, the frequency of observations with significant cover appeared to increase in Blackwater Sound, but showed no clear recovery in other basins. Intra-annual variability of this SAV cover category remained high since the onset of algal blooms in 2005, with a range of 0.25 in WY2009, which is an order of magnitude higher than the WY2001–WY2005 average of 0.05.

Another noteworthy area is the northern transition zone where exceedances of the MFL salinity criterion for Florida Bay occurred during WY2009. In Little Madeira Bay, turtle grass experienced a slight increase in frequency of occurrence and shoal grass density declined sharply (**Figure 12-76**). Although the frequency of shoal grass presence did not decline, the frequency of shoal grass with > 5 percent cover showed a significant decline (WY2009 mean compared to WY2008 mean, $p < 0.05$). Quadrat observations with > 5 percent shoal grass cover averaged 40 percent from WY2001–WY2008. In WY2009, the average dropped to 13 percent, and a survey in March 2009 reported only 2 percent of observations with > 5 percent cover. This thinning in shoal grass is consistent with an hypothesis derived from Florida Bay MFL seagrass modeling that posits that turtle grass dominates over shoal grass in areas with persistent high salinity and low nutrients.

Farther west along the northern transition zone, Madeira Bay showed the opposite trend. Shoal grass increased in frequency and density, while turtle grass decreased for the third consecutive year (**Figure 12-77**). Between May 2007 and May 2008, the presence of shoal grass increased from 26 to 49 percent of observations, the highest recorded since measurements began in 1995. The average frequency of occurrence of shoal grass from 1995–2007 was 16 percent. Shoal grass observations with > 5 percent cover averaged 8 percent over the same period. In May 2008, the percentage of > 5 percent cover increased to 43 percent, more than five times the average. The cause of this increase seems not to be the result of freshwater inflow, as Madeira Bay receives no direct creek discharges of fresh water. Although only suggestive, contemporaneously measured salinity has decreased by nearly 8 psu, and temperature has increased by 5 ºC from 2006–2008 in May when the BBCA data were taken.

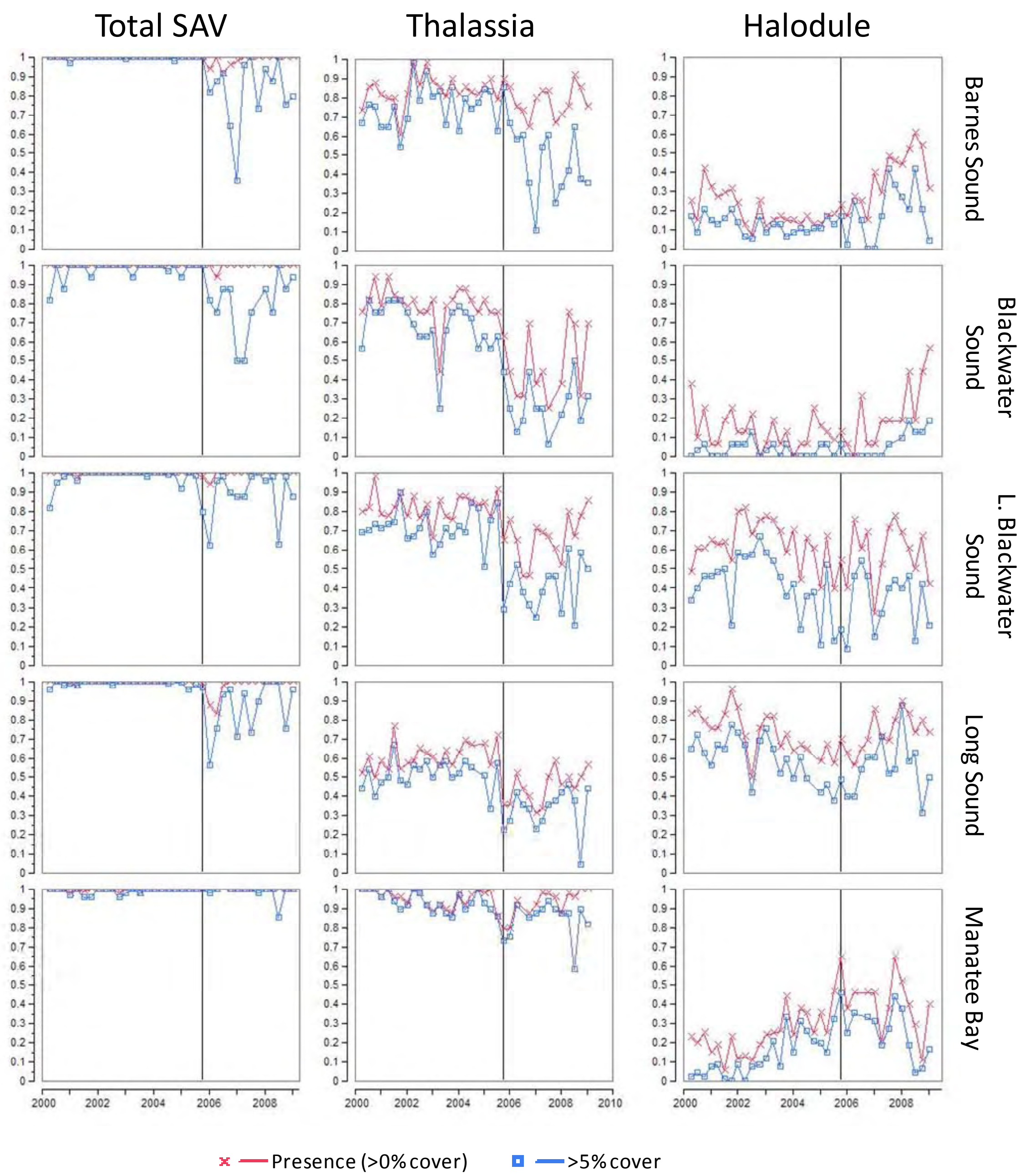


Figure 12-75. Eastern Florida Bay seagrass cover data collected by Miami-Dade Department of Environmental Resources Management (DERM). Lines with x denote frequency of presence, while lines with □ denote frequency of observations with greater than 5 percent bottom occlusion. The reference line indicates when the algal bloom began in this area. SAV communities have not returned to pre-bloom state. *Thalassia* = Turtle Grass, *Halodule* = Shoal Grass, TOT = Total SAV.

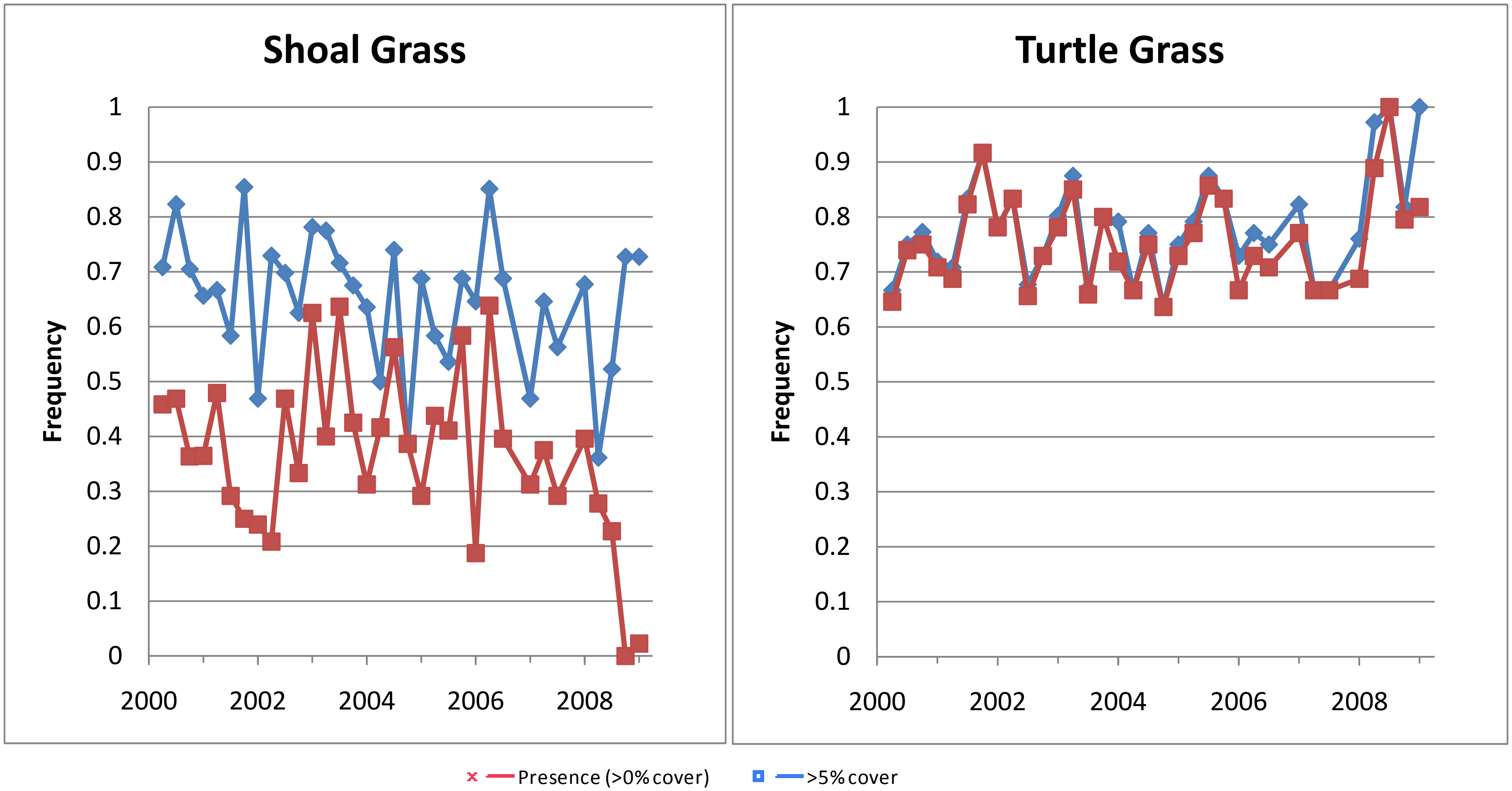


Figure 12-76. Seagrass cover data from Little Madeira Bay showing frequency of observations where each species is present (> 0 percent cover) and frequency where the species is present with more than 5 percent bottom occlusion. Lines with x denote frequency of presence, while lines with □ denote frequency of observations with greater than 5 percent bottom occlusion. Turtle grass showed a slight increase in frequency of occurrence during WY2009, while shoal grass showed a large decrease in density with nearly all shoal grass observations having less than 5 percent bottom occlusion by the end of the water year. Data are collected by DERM.

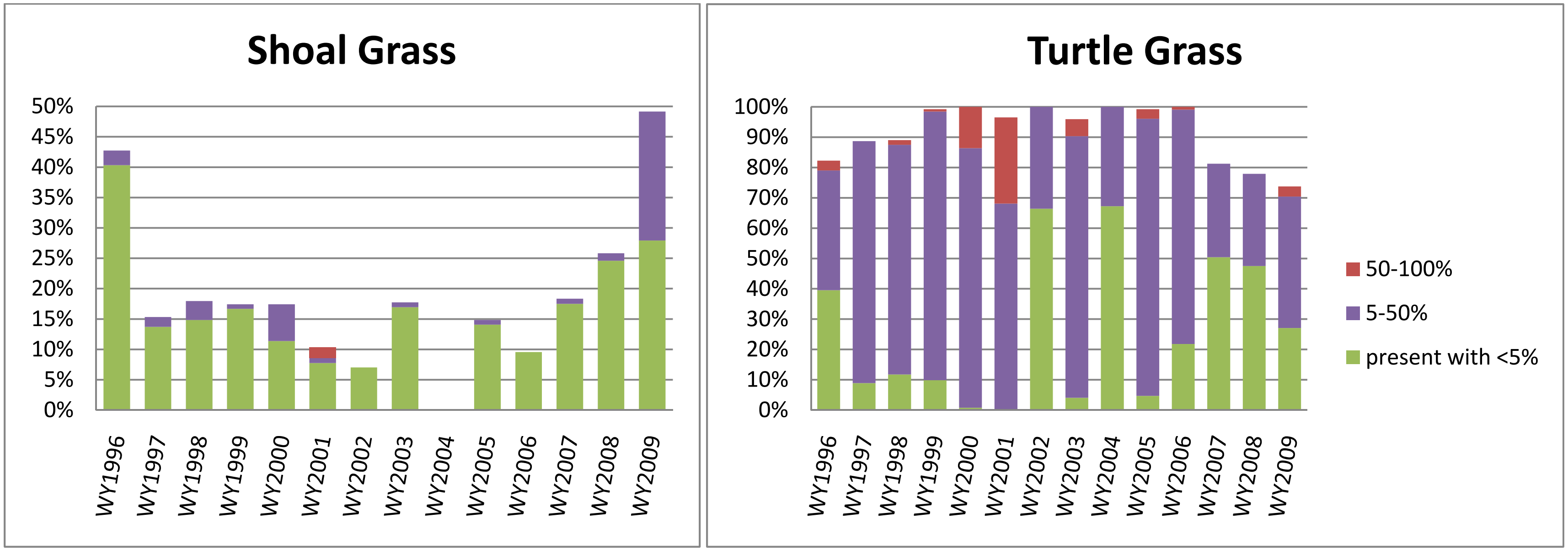


Figure 12-77. Seagrass cover data from Madeira Bay showing the changing frequency distribution of bottom cover categories for each species of seagrass. Bottom cover is a proxy for density. Shoal Grass showed a large increase in frequency and density in WY2009, while turtle grass showed a decline in frequency for the third straight year. Data are collected by the Florida Fish and Wildlife Conservation Commission Fisheries Habitat Assessment Program in May of each year.

Higher Trophic Levels

Pink Shrimp Model

Pink shrimp is a major fishery species in Florida, with fishing grounds near the Dry Tortugas that are supported by recruitment from nurseries in Florida Bay and other South Florida estuaries (Browder et al., 2002). Young pink shrimp settle into areas with SAV, where they spend several months growing to maturity. Over the past year, a model simulating pink shrimp was used as part of evaluations for the FBFKFS. This unit-area model simulates growth, survival, and production capacity from a cohort of shrimp entering Florida Bay. Response surfaces used in the model were developed from results of laboratory experiments that examined effects on pink shrimp held at various water temperature and salinity combinations (Browder et al., 2002; Browder and Johnson, 2008). Prior to its use for the FBFKFS, the Pink Shrimp Model has been employed for other South Florida water management projects that include (1) the Picayune Strand Hydrologic Restoration Project, (2) CERP 2005 Interim Goals and Targets, (3) Biscayne Bay Coastal Wetland Restoration, and (4) Florida Bay Minimum Flows and Levels.

Daily mean water temperature and salinity output from the Environmental Fluid Dynamics Code (EFDC) Florida Bay hydrodynamic model was used for 10 locations (grid cells) in the western and central bay. For each grid cell, shrimp response was modeled for three 18-month periods chosen to represent high, low, and average salinity conditions, respectively, over the EFDC Model scenario simulation period (1990–1999). Results from four seasonal shrimp cohorts (January, April, July, and October) were evaluated using output metrics of daily growth [millimeters per day (mm/day)], survival (proportion of individuals surviving to 121 days, after which time shrimp may emigrate), and a composite metric of cumulative potential harvest (kg). Survival rates were consistently high across all simulations (> 98 percent surviving), with variable results in response to salinity. In general, survival rate was lowest for the central bay areas (cells 4, 5, 7, 8, and 9), which have more variable salinity and temperature regimes compared with areas in the western bay. For all areas, juvenile shrimp growth was lowest in high salinity simulations and reduced in low and average salinity scenarios (**Figure 12-78**). Cumulative potential harvests reflected both of these trends; harvests were predicted to be lower in most central bay locations, but were consistently higher across all areas for average and low salinity simulations when compared to the high salinity scenarios.

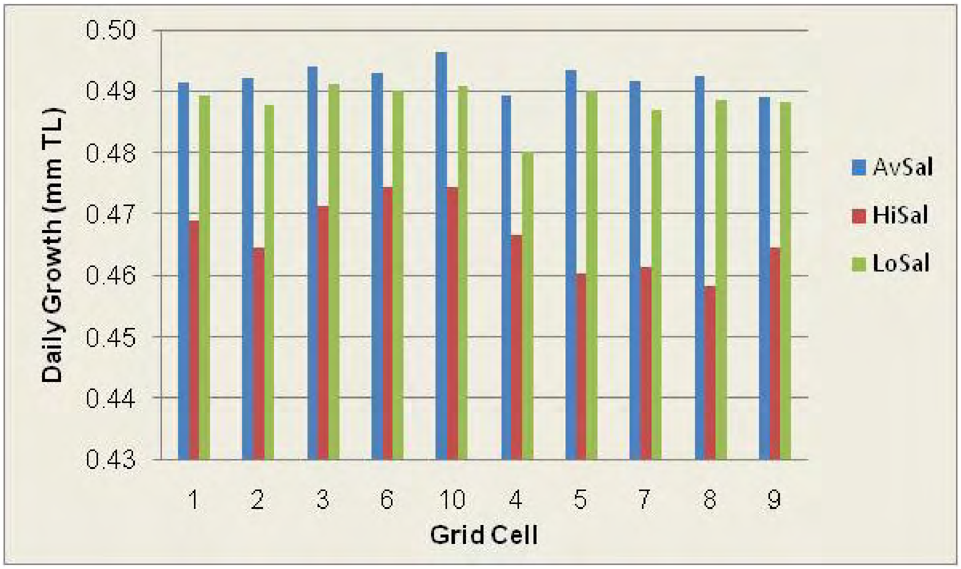


Figure 12-78. Mean simulated response of four pink shrimp cohorts' daily growth for representative average, high, and low salinity scenarios at 10 sites in Florida Bay. The vertical line separates cells in the Gulf-influenced western and southern parts of the bay (cells 1, 2, 3, 6, and 10), from cells that have more variable temperature and salinity in the northern and central parts of the bay (cells 4, 5, 7, 8, and 9).

Lobster Model

As part of the FBFKFS, the potential effects of restoration on the Caribbean spiny lobster (*Panulirus argus*) were examined using a model of spiny lobster survival (Butler and Dolan, 2009). The Caribbean spiny lobster was chosen as an ecological performance measure because of its great commercial and ecological importance in the region. It utilizes hard-bottom habitat in southern Florida Bay and the Florida Keys as a nursery area, and is dependent on the large sponges and octocorals of the hard-bottom community for shelter. Both the lobsters and the fauna that provide their shelter are sensitive to changes in salinity and temperature, and the sponges are also sensitive to changes in water quality. The spatially explicit, individual-based model used in this evaluation simulates juvenile lobster abundance relative to salinity, temperature, and shelter availability as determined by sponge and octocoral abundance, which are also simulated relative to salinity, temperature, and water quality.

Ten separate scenarios were run of varying salinities and water quality conditions for a 10-year simulation period. Focus was placed on decreasing salinity within this area to address concerns that increasing freshwater inputs to Florida Bay for restoration would negatively affect the hard-bottom community. The scenario that produced the largest lobster decline included decreasing salinity together with an annually occurring algal bloom within the lobster nursery habitat. This produced a 24 percent reduction in juvenile lobster abundance, of which a third could be attributed to salinity alone. The algal bloom scenarios were more detrimental to lobster abundance, because the blooms harmed the large sponges on which lobsters are dependent for survival. Approximately 60 percent of sponges were lost in the scenarios with annually occurring algal blooms. Sponge recruitment was not included in the model so recovery of lost habitat was not possible, but this is not unrealistic for a 10-year simulation because newly recruited sponges would not be able to grow to sufficient size for lobster shelter within the 10-year period.

Waterfowl

Florida is considered one of the most important wintering grounds for waterfowl migrating through the Atlantic and the Mississippi Flyways (Chamberlain, 1960,; Rodgers 1974; and Bellrose, 1980). An examination of waterfowl trends in the Southern Everglades was conducted as part of an update for the Florida Bay MFL criteria. Historical evidence shows that the ponds and lakes north of Florida Bay were major wintering areas for several waterfowl species as recently as the 1970s (Simmons and Ogden, 1998; Kushlan et al., 1982). Anecdotal accounts suggest waterfowl numbers across the Southern Everglades have dropped dramatically in recent decades (O. Bass, Jr., and J. Ogden, pers. comm.).

The goal of this investigation was to examine the validity of such accounts, to explore potential mechanisms for this decline, and to tie this information back to salinity and habitat criteria used for previous and future iterations of the Florida Bay MFL Rule. Several sources of information were available for the initial phase of this research, including background literature, interviews with current and former ENP biologists and at other National Wildlife Refuges in Florida (for comparison with the ENP), and historical datasets from the National Audubon Society.

Many of the brackish lakes in the Florida Bay transition zone were once (Craighead, 1971), and on occasion still are, blanketed with large areas of SAV, particularly widgeon grass and varieties of *Chara* spp. (macroalgae commonly called musk grass). Both species are recognized as important food sources for American coots (*Fulica americana*) (Brisbin et al., 2002) and many of the common waterfowl species that occur in the Southern Everglades estuaries (Chamberlain, 1960; Bellrose, 1980; Kushlan et al., 1982; Swiderek et al., 1988; Smith et al., 1989; Dubowy, 1996; Thompson et al., 1992; Mowbray, 1999; Rohwer et al., 2002). In estuarine areas of the Yucatan Peninsula, shallow open-water areas surrounded by mangroves and filled with these SAV species are preferred by wintering waterfowl that use them for both feeding (open water with SAV) and resting/preening (mangrove shoreline) activities (Thompson and Baldassarre, 1991). The Merritt Island National Wildlife Refuge (MINWR, located in Brevard County, near Cape Canaveral), which is recognized as an important area for wintering waterfowl (Bellrose, 1980), actively manages its impoundments to produce lower salinity and higher water level conditions in the fall to promote growth of both widgeon grass and musk grass (S. Howarter pers. comm.). It is reasonable, therefore, to assume that similar conditions in the Southern Everglades could also benefit wintering waterfowl populations.

As the longest continuous record of survey information for bird populations in the ENP, data from Audubon Society's Christmas Bird Count (CBC) were used to examine long-term trends for waterfowl in the Southern Everglades. National Audubon Society provided survey data to District staff for the Coot Bay count circle (FLCE, POR 1951–2008) and, because of the similarities mentioned above, for the Titusville-Merritt Island count circles (FL19, POR 1952–1965, and FLMI, POR 1971–2008, both covering MINWR). Both count areas (each 15 mi diameter; 177 mi^2) encompass mixed habitats with open water, emergent marsh, and forested hammocks. In the ENP, the count area included West Lake and much of Whitewater Bay. Trends over time (examined as counts for given species per counter-hour) were compared in both areas for the American coot and 22 species of ducks and geese (Family: Anatidae) that occur in Everglades estuaries (Rodgers, 1974; Kushlan et al., 1982).

For the Coot Bay region (**Figure 12-79**), there were two obvious trends from analyses of several of the most common species: (1) species whose numbers dropped off since the 1980s [American widgeon (**Figure 12-79a**), northern shoveler (*Anas clypeata*), blue-winged teal (*Anas discors*), northern pintail (*Anas acuta*), ring-necked duck (*Aythya collaris*), and red-breasted merganser (*Mergus serrator*)], and (2) species whose numbers markedly declined after the 1970s [e.g., lesser scaup (*Aythya affinis*) (**Figure 12-79b**), and ruddy duck (*Oxyura jamaicensis*)]. Other species examined generally had insufficient numbers in the Coot Bay count circle (particularly once the data were standardized by counter effort) or displayed no trend over time, but were still used to calculate total standardized number of waterfowl for each survey year (**Figure 12-79c**). For this composite figure, the trend resembles that of the many species whose numbers declined since the late 1980s. Many of the higher standardized counts in Figure 12-79 represent total waterfowl counts the tens of thousands from both count circles (only pre-1980 for Coot Bay). Coot Bay total waterfowl counts (non-standardized) have only been in the hundreds since the late-1980s.There was a historic drought and high salinity event from 1989–1990 that likely led to the demise of most SAV in Coot Bay and surrounding lakes. During this period, salinities ranged from 20–47 psu during the waterfowl wintering period (November–March) in adjacent transition zone areas (Taylor River platform, described previously). These concentrations were well above the preferred range for nearly all waterfowl species (Bellrose, 1980). However, this does not explain the lack of recovery in numbers of wintering waterfowl relative to the range of hydrologic conditions the Southern Everglades has experienced over the past 20 years.

Given the large variability inherent in CBC survey data as well as insufficient long-term salinity or SAV monitoring data, it cannot be determined if these declining trends are related to local habitat factors or to broader trends affecting wintering waterfowl. Broader trends may include such factors as lower productivity in northern breeding areas, climate changes causing birds to "short-stop" north of once-preferred wintering grounds, changes in diet to exotic aquatic vegetation [e.g., hydrilla (*Hydrilla verticillata*)], which is found more abundantly in areas outside of the Southern Everglades, and other reasons. [Factors discussed in interviews with O. Bass, Jr., P. Gray, S. Howarter, and J. Kleen, pers. comm.] The District's CWQMMN discontinued sampling in Coot Bay (Station 50) in 2007, leaving a large gap in a salinity dataset dating back to 1992. As part of the RECOVER Monitoring and Assessment Plan, however, the FWC has conducted SAV monitoring since 2005 in Coot Bay proper as part of the FHAP survey program. Moreover, since 2006, the ENP has provided funding to FIU to monitor SAV and salinity in the adjacent transition zone, brackish water bodies north of Florida Bay (West Lake, Seven Palm Lake, Monroe Lake, etc.). These recent efforts will provide some indication of current foraging conditions available for wintering waterfowl in the Southern Everglades and allow for comparisons with future CBC data from Coot Bay.

The broad spatial and temporal causes for declining wintering waterfowl trends are not reflected in both Coot Bay and MINWR datasets, as few species displayed similar trends between these two regions. While there is some apparent decline in the total number of wintering waterfowl at MINWR over the past decade (a trend also described by S. Howarter) (**Figure 12-79**), a similar drop and subsequent rebound in numbers occurred from 1970 to the 1990s, complicating the interpretation of trends for this region. The longer-term absence or scarcity at Coot Bay for so many species, however, does suggest that the trend may be localized to the Southern Everglades, and thus may be remedied through improved habitat and foraging conditions (e.g., through CERP or other restoration efforts).

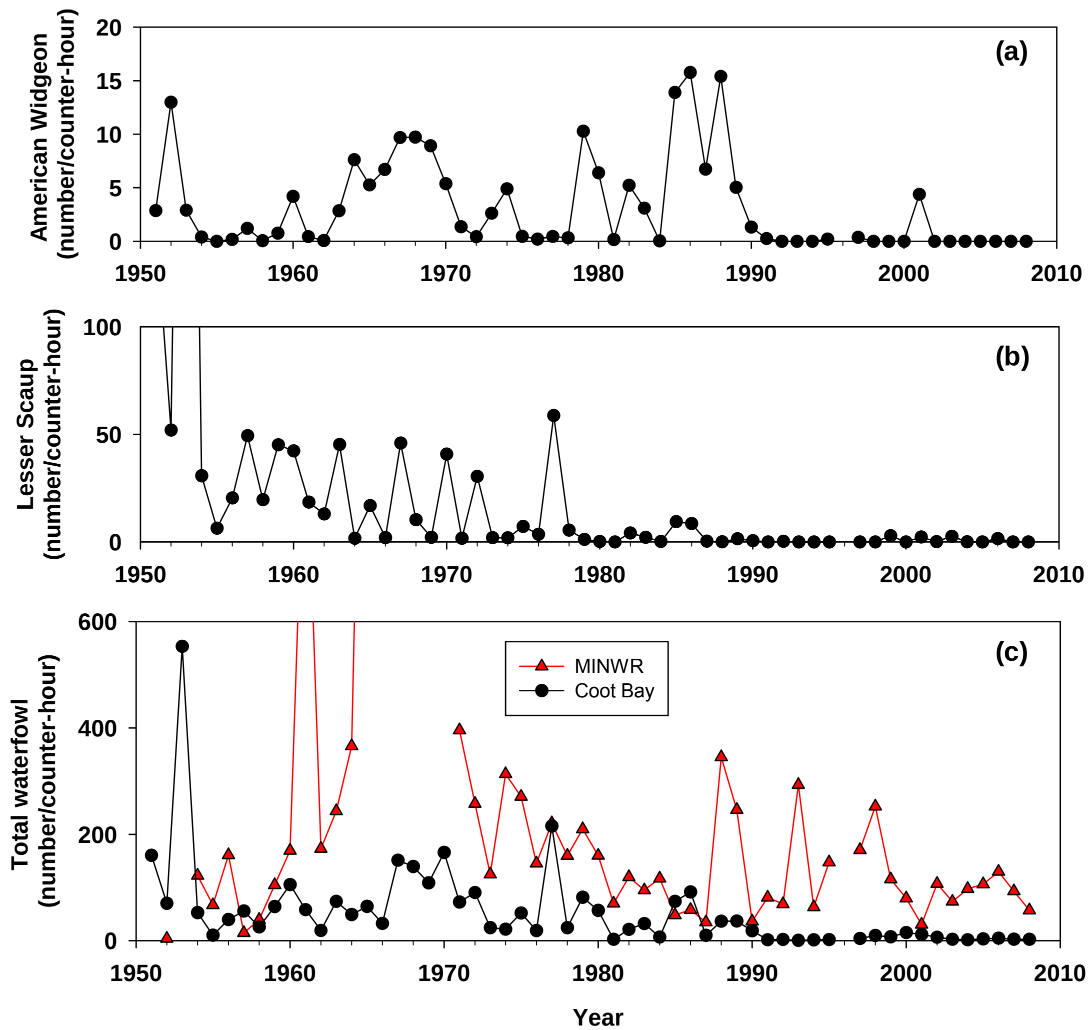


Figure 12-79. Standardized counts (number of waterfowl per counter-hour) from the Audubon Society's Christmas Bird Count in Coot Bay (the ENP) for (a) American widgeon (*Anas americana*), (b) lesser scaup (*Aythya affinis*), and (c) for total waterfowl (22 species), in both Coot Bay and Merritt Island National Wildlife Refuge (MINWR). Peak numbers in MINWR (off scale from this plot) were 1,035/counter-hour and 1,687/counter-hour in 1961 and 1965, respectively.

RESEARCH ACTIVITIES AND STRATEGIES

Research activities in WY2009 focused on meeting the information needs for an update of the Florida Bay MFL, weekly operations, and understanding the dynamics of the eastern Florida Bay algal bloom. Key strategies also included providing recommendations to the FDOT regarding causeway removal in Lake Surprise and establishing an ecological baseline for Phase I of the C-111 Project and RECOVER. A research strategy included in the 2008 SFER – Volume I, Chapter 12 focused on increased integration of Florida Bay research with Everglades wetland research (especially in the mangrove transition zone). Below are brief updates on WY2009 activities.

Algal Bloom Studies

A National Oceanic and Atmospheric Administration (NOAA)-District collaborative study of the locus and dynamics of the eastern bay phytoplankton bloom was conducted through WY2009 focused on parameterizing a new phytoplankton module within an existing SAV-phytoplankton community model. During the bloom, monitored through WY2009, the highest chlorophyll *a* concentrations, (above 20 µg/L), were common in Blackwater Sound, Barnes Sound, and Lake Surprise, and the bloom appeared to be spatially centered around U.S. Highway 1. Throughout its duration, the bloom was dominated by the picocyanobacterium, *Synechococcus*. Based on a genetic comparison of bloom organisms with the benthic microbial community, the bloom's *Synechococcus* appeared to be strictly pelagic (Boyer, unpub. data). During WY2009, when the bloom was in its third year, the species composition of the algal bloom changed from being almost exclusively composed of the picocyanobacterium *Synechococcus* to a mixed community with proportionately more flagellates, some of which were heterotrophic.

Measurements of phytoplankton response to a variety of N and P nutrient additions in bioassays performed prior to the bloom showed strong response to P additions, supporting the importance of P inputs in promoting new algal production and suggesting that the eastern bay bloom was initially P-limited. A series of bioassays during the bloom indicated a shift to N limitation, and highest growth responses occurred when both organic N and P were added, suggesting that the populations had become poised between N and P limitation (Glibert et al., 2007). The high-growth response of phytoplankton in bioassays when humics (concentrations of organic compounds) from water overlying Everglades wetlands were added indicated that humic compounds may be competing with phosphate for binding sites on carbonate particles, thereby mobilizing and increasing P availability to phytoplankton. At the end of the bloom, bioassays indicated that the community had again shifted to P limitation.

During its active period, the bloom appeared to be sustained by a number of interactive mechanisms common to prior blooms in Florida Bay, including nutrient release from SAV mortality, decreased grazing by benthic fauna (sponges), microbial and geochemical cycling of organic and inorganic nutrients in the water column and between the water column and sediments (both suspended particles and benthos), and very localized hypoxia and anoxia. Extensive mortality of turtle grass and benthic macroalgae, particularly in deep portions of Blackwater Sound and Barnes Sound, occurred following the cyanobacterial bloom initiation (Rudnick et al., 2007). These die-backs and associated nutrient releases likely provided additional sources to sustain the blooms, further attenuating light for SAV and causing mortality. As the bloom aged, and as additional microbial species became established, micrograzing became an apparent controlling factor and the bloom began to die off, either reduced to a lower stable level or disappearing completely in some sub-basins.

Submerged Aquatic Vegetation Studies

Widgeon grass is an important seagrass species found within the ecotone transition zone and low salinity areas of Florida Bay. Due to its value as a habitat resource, and its position at the fresh-salt interface, widgeon grass is also being used as a performance measure for assessing Everglades restoration and as a benchmark for Florida Bay MFLs. An analysis of long-term (WY2001–WY2009) water quality and SAV data at the mangrove-Florida Bay transition zone in northeastern Florida Bay focused on the environmental conditions in situ that determine SAV species composition and distribution in the transition zone (Koch et al., 2009). The work is a collaborative effort between the District, Florida Atlantic University (FAU), and the National Audubon Society, which provided long-term datasets (Lorenz and Frezza, unpub. data). Determination of how abiotic factors control species community dynamics at the freshwater-marine transition zone in Florida Bay is critical to understanding water management effects on the habitat resource. It is also invaluable to parameterization of the District's seagrass model being used to test scenarios of various water management practices and longer term climate change impacts on the plant communities and nutrient cycling processes in the bay.

Correlative studies of in situ conditions versus species distribution showed that salinity dynamics contribute, at least in part, to community structure in the ecotone. The frequency and duration of the high salinity events appear to be critical in determining the establishment of macroalgae and widgeon grass. In areas where salinity fluctuated slowly and the minimum salinity included sustained periods of freshwater, widgeon grass thrived, interspersed with short periods of macroalgae presence. Within the area of the transition zone where salinity fluctuations were extreme, no SAV cover was found. In the freshest areas of the ecotone, freshwater macroalgal species increased in cover during several weeks of continuous freshwater conditions and declined during saline events.

In mesocosm studies of the germination of widgeon grass seeds that were incubated at various salinity levels, most of the germinations (77 percent) occurred at salinity below 5 psu and very few seeds germinated above 15 psu (**Figure 12-79**). Thus, hypersaline conditions inhibited widgeon grass germination. Exposure to hypersalinity did not reduce the number of viable germinations when salinities were lowered to optimal oligohaline conditions for germination. In fact, germination of seeds seems to have been enhanced by pre-conditioning with high salinity exposure at 45 psu. Given the linkage of salinity regime to the hydrology of the system, salinity is likely a major factor determining the timing of onset of seed germination, not only whether but also when germination occurs. It is likely that widgeon grass was historically dominant at many of sites in the Florida Bay ecotone because its seeds can remain viable in the sediment seed bank for long periods. Prior to the alteration of Everglades hydrology, the length of time that freshwater conditions prevailed on an annual basis was likely sufficient to allow widgeon grass to develop.

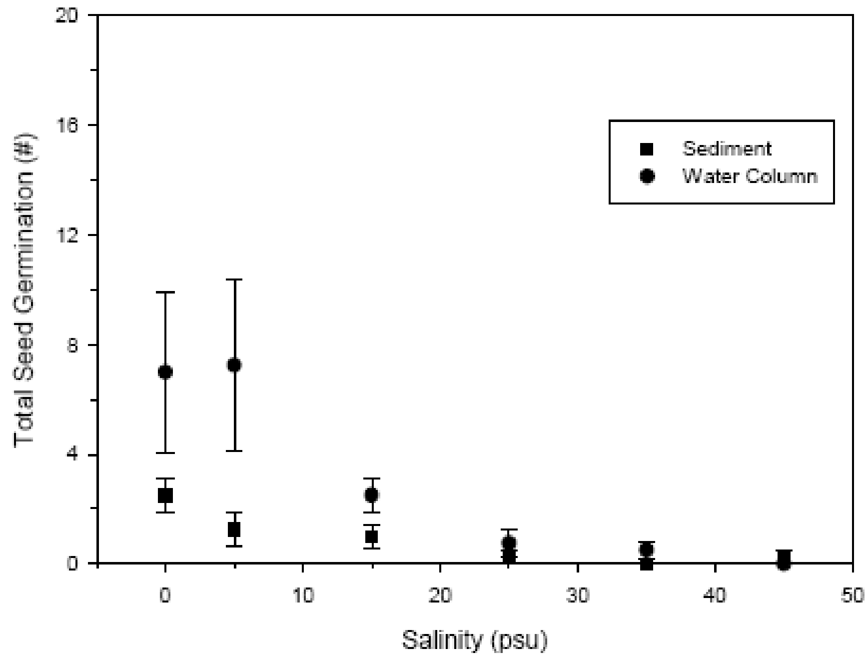


Figure 12-80. Widgeon grass seed germination frequency in mesocosms under different salinity conditions both hydroponically and in sediment. In both substrates, germination occurred almost exclusively in salinity of 15 psu or lower.

Florida Bay Seagrass Model Development

A mechanistic simulation model of seagrass-water column interactions developed for the Florida Bay ecosystem describes the biomass, production, composition, and distribution of SAV such as turtle grass, shoal grass, and widgeon grass as well as phytoplankton. Model development is aimed toward understanding the effect of hydrologic and salinity restoration via managed adjustments of the timing and amount of freshwater discharge on the SAV and phytoplankton communities. The Seagrass Ecosystem Assessment and Community Organization Model (SEACOM) is calibrated for nine basins in the bay and describes biological and nutrient dynamics with a time step of three hours.

The model is parameterized from experimental data in the field, mesocosms, bioassays, and monitoring. The SAV portion of the model has been updated to include the growth dynamics and recruitment of widgeon grass, a low-salinity species expected to expand with additional freshwater inputs to northern Florida Bay. It has been calibrated for several bay regions with seagrass, phytoplankton, and nutrient cycling data, light and residence time, and other physical parameters specific to each sector. The preliminary model is fully functional and has been used to depict the eastern bay phytoplankton bloom, and is useful in research planning and restoration strategy assessment. The model has demonstrated that a single injection of phosphorus, similar to that observed in 2005, can be sufficient to sustain phytoplankton blooms for months to years from internal recycling. The model is currently being updated with the most recent data on nutrient uptake kinetics by bay sector.

The model is being prepared for use in refining Florida Bay MFL calculations of freshwater inputs from the Everglades watershed required to maintain SAV community and ecosystem health. The model will also be used to evaluate the response of phytoplankton and SAV to pulsed nutrient inputs such as from tropical storm runoff. Model runs of SEACOM to test the effects of changing nutrient cycling rates and basin residence time (**Figure 12-81**) reveal thresholds or "tipping points" of ecosystem change where the system switches from SAV-dominant to algal bloom-dominant. Longer water residence times, efficient nutrient retention, and pulsed nutrient inputs can push the ecosystem toward algal dominance.

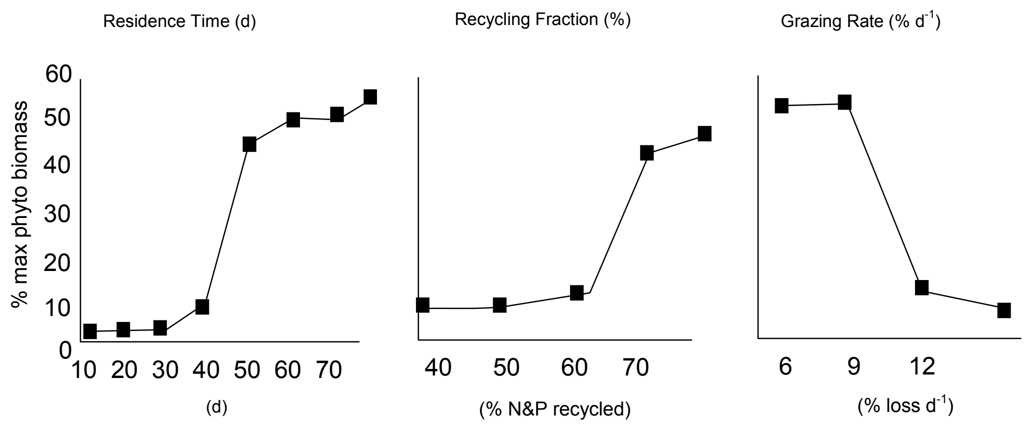


Figure 12-81. Model analysis of factors affecting phytoplankton biomass. Results of multiple scenario runs of SEACOM showing parameter thresholds for state change in phytoplankton biomass from nominal background levels of about 1–2 µg/L to bloom levels of 20–30 µg/L with changing residence time, P recycling fraction, and grazing pressure.

Mangrove Model Development

A major need for operational and restoration planning is to determine how passage of Everglades water through the mangrove ecotone influences salinity and nutrient loading to Florida Bay. The vegetation in the ecotone between the Everglades marshes and Florida Bay is dominated by scrub mangrove encompassing more than 6,000 ha (23 sq mi). The ecotone has a dynamic role as a sink, source, and transformer of nutrients, and discharge from the ecotone is a large source of N and carbon for Florida Bay (Sutula et al., 2001; Davis et al.; 2001; Childers et al., 2006). About 80 percent of the discharge to northeastern Florida Bay from the ecotone occurs during the wet season from May to October (Kelble et al., 2006). A hydrologic/water quality model (MIKE 21) is being developed by the District and Louisiana State University for analysis of ecotone system dynamics along lower Taylor River. The model will be utilized as a tool to evaluate how potential changes in water flow will affect the salinity, biogeochemistry, and water balance within the ecotone and influence water and materials loading to Florida Bay at Taylor mouth. The model's spatial domain has been established based on pond bathymetry, creek channel cross -sections, and wetland elevations, and includes wetland surface, groundwater, and creek flows. Boundary conditions are established at Argyle Hendry upstream and Taylor River mouth downstream and driven by USGS gauge data and the TIME Model (Swain et al., 2004) as inputs. The model is in the process of being calibrated and has demonstrated the capability to predict observed salinity throughout the domain during both the wet and dry seasons. A salinity calibration example (Pond 3, an area midway between the two boundary sites) is provided in **Figure 12-82**.

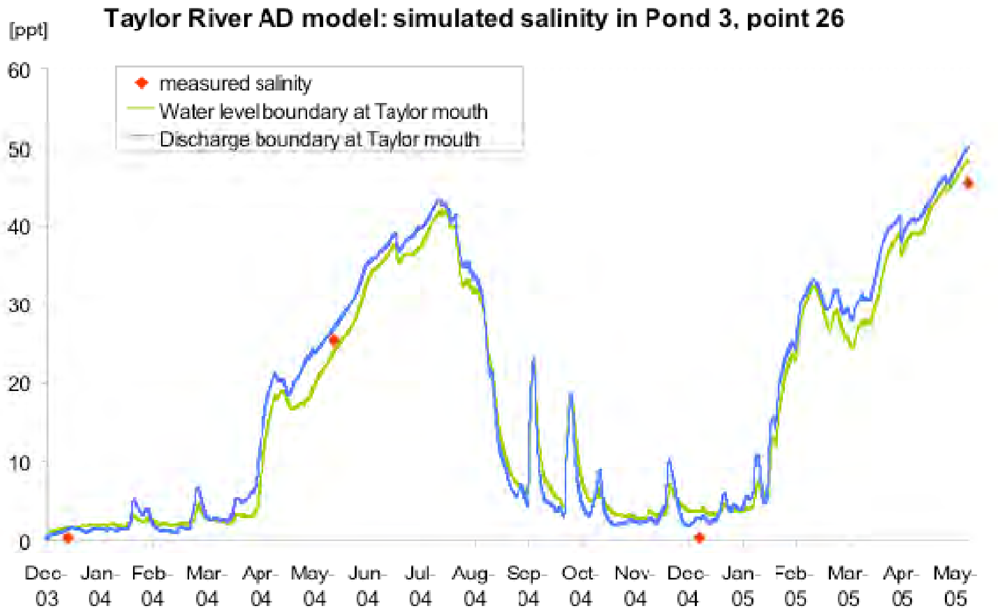


Figure 12-82. Calibration run of salinity simulation for Taylor River Pond 3 from December 2003–May 2005. Red points are data; blue and green lines show model salinity calculation using two types of boundary constraint at Taylor Mouth.

Florida Bay Ecosystem Assessment Indicators

As ecosystem restoration proceeds in South Florida, additional fresh water will be discharged to Florida Bay as a means to restore the bay's hydrology and salinity regime. Primary mechanisms for restoring ecological function of the seagrass community are based on the premise that hydrologic restoration will increase environmental variability and reduce hypersalinity. A suite of seagrass indicator metrics was developed to evaluate four essential measures of seagrass community status for Florida Bay (Madden et al., 2009). The measures are based on several years of District-sponsored monitoring data using the BBCA scale to derive information about seagrass spatial extent, abundance, species diversity, and presence of target species. Indicator metrics are assigned values at the basin spatial scale and are aggregated to five larger zones. Three index metrics are derived by combining indicator values. These indices are then aggregated to derive a single bay-wide system status score standardized on the system-wide indicator protocol. The indicators will provide a way to assess progress toward restoration goals or reveal areas of ecological concern. Each indicator, index, and overall system status score is summarized in a stoplight format, providing information in a readily accessible form for mangers, policy makers, and stakeholders in planning and implementing an adaptive management strategy.

Aggregated index scores for Florida Bay SAV show good status in the northeastern and western zones; fair status in the transition, central, and southern zones; and no poor status areas. Underlying the aggregated scores, SAV abundance indices (tracking areal coverage and abundance of SAV) in three of the zones were good in WY2009, showing improvement against the 10-year trend, whereas the central and southern zones show fair status. The target species index (tracking species diversity and presence of target species) in the transition zone was poor, reflecting the absence of widgeon grass, while other zones showed good status due to increased diversity against the 10-year trend and the presence of appropriate target species. The carrying capacity index (tracking the combined abundance and species indices) reflect fair status in the transition, central, and southern zones, and good in the northeastern and western zones.

Planning for the C-111 Spreader Canal Western Project

This project is focused on improvements to Taylor Slough and Florida Bay. The SFWMD is planning to continue studies that are currently measuring wetland hydrology, nutrients, soils, and plants in the Southern Everglades marshes of the C-111 basin, Taylor Slough (including the mangrove transition zone), and Florida Bay. This work is mostly being accomplished through collaborations and contracts with other agencies and institutions, particularly the USGS, the ENP, FIU, and FAU. Increased collaboration and contracting with Audubon of Florida are also providing improved understanding of the relationship of hydrologic conditions, SAV, prey base fish, and roseate spoonbill (*Ajaja ajaja*) status. The District also plans a new initiative to understand the character and dynamics of the western boundary of Taylor Slough — the lakes region between Seven Palm Lake and West Lake — a little-studied area. Preliminary data from the ENP, FIU, and District surveys show that this region (especially the chain of lakes, ponds, and streams from West Lake to Garfield Bight) has very high nutrient and chlorophyll *a* concentrations compared with Everglades wetlands (upstream of the lake region) or Florida Bay (downstream of the lakes region). Therefore, the District's plans for the C-111 Project include studies to document the ecological benefits of the project with regard to restoring more natural flows through Taylor Slough to Florida Bay, and investigations of short-term and long-term water quality consequences.

Planning for an Update of the Florida Bay MFL

An update of the MFL rule, which is due to the SFWMD and the FDEP in 2011, seeks to improve a scientific basis for the current rule (and potential revision). An MFL peer review in 2006 provided a basis for an MFL update research plan (described in the 2008 SFER – Volume I, Chapter 12), which is focusing on improved information about SAV habitat responses to freshwater flow and associated higher trophic-level responses. Research and model development regarding SAV has proceeded in WY2009. Collaboration with Audubon of Florida includes statistical analysis of long-term data on hydrologic variables, SAV density (percent cover), and prey fish density and biomass. The District is also planning experiments on the relationship of habitat quality (SAV density and species, mangrove prop root) and prey fish density and productivity.

NAPLES BAY

Chenxia Qiu

DESCRIPTION OF NAPLES BAY AND MAJOR ISSUES

Naples Bay and its watershed, located in western Collier County, were formed by the confluence of the Gordon River and other small tributaries that empty into the Gulf of Mexico through Gordon Pass. Dollar Bay, the portion of the Naples Bay system south of Gordon Pass, connects to Rookery Bay through a shallow waterway with a dredged channel (**Figure 12-82**). The width of this relatively narrow and shallow estuarine system ranges from 30−457 m (100–1,500 ft), and the depth varies from 0.3−4 m (1–13 ft). Naples Bay is typical of estuarine systems along the coast of Florida in that it has been heavily altered by drainage and land development. The construction of waterfront homes converted 70 percent of the fringing mangrove shoreline to residential developments. The perimeter of the shoreline doubled from 1927–1965 and was further expanded from 1965–1978.

Fresh water flows into Naples Bay from the Golden Gate Canal, Gordon River, Rock Creek to the north, Haldeman Creek to the east, and runoff from the urban areas that surround the bay. In the 1960s, the construction of the Golden Gate Canal system increased the Naples Bay watershed from 26 km^2–337 km^2 (10 sq mi–130 sq mi), magnifying freshwater inflow by 20 to 40 times. This major physical alteration of the watershed changed the volume, quality, timing, and mixing characteristics of freshwater flows reaching the bay. The increased volume of inflow from the canal and stormwater systems changed mixing and circulation patterns in Naples Bay, and negatively affected the survival and health of estuarine-dependent species. Salinity can vary widely within short periods. As a consequence of the combined effects of dredging and inflow alterations, seagrass and oyster habitats within Naples Bay have been reduced 80 to 90 percent (Yokel, 1979).

Figure 12-83. Naples Bay, Dollar Bay, and Rookery Bay on the southwest coast of Florida.

STATUS AND TRENDS IN NAPLES BAY

Salinity and Freshwater Inflows

Neither minimum flow criteria nor a reservation of water has been established for Naples Bay. The inflow from Golden Gate Canal, a key inflow point, was recorded from 1994−2002, and this monitoring resumed in April 2008. Discharge from the Golden Gate Canal monitoring station is shown in **Figure 12-84**. Generally, the discharge was low before June 20, 2008. Flow data were missing between June 27, 2008, and August 15, 2008. Between August 19, 2008, and September 3, 2008, the discharge increased and peaked at 1,300 cfs. After September 3, 2008, flow declined gradually and stopped at the end of December 2008. Discharge from the Golden Gate Canal in WY2009 is compared with the long-term historical record for this site (28 years; 1964–1984 and 1994–2002) in **Figure 12-85**. Discharge from the Golden Gate Canal during WY2009 had a peak flow in the range of 1,000 to 1,340 cfs in August 2008, which falls between the average and maximum historical flows in August. Discharges in the remaining months of WY2009 fell below the 28-year average.

High-frequency (30-minute intervals) salinity data were collected at three stations during WY2009. Sensors at Gordon Pass Inlet and Naples Pier (**Figure 12-86**), an offshore station, experienced fouling problems. Fouling was not a problem at the U.S. Route 41 Bridge station, located in fresher water. Generally, salinity in the upper estuary at the U.S. Route 41 Bridge had a wide daily range in August, September, and October when water discharged from the Golden Gate Canal, the major contributor of fresh water. Salinity went from 0 to 30 psu in one tidal cycle. After October, salinity increased and daily ranges decreased as flow gradually declined. In the dry season between January and May, salinity fluctuated from 30 to 35 psu within a narrow daily range of 2–5 psu (**Figure 12-87**).

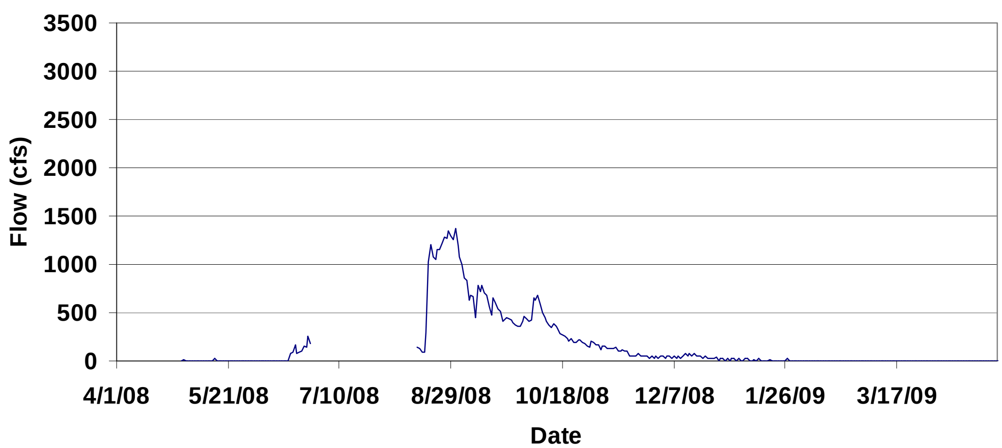


Figure 12-84. Flow data from Golden Gate Canal.

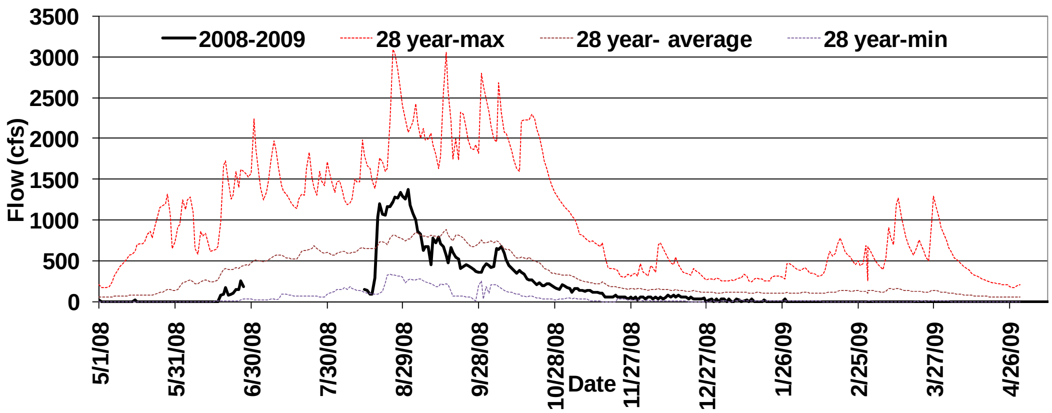


Figure 12-85. Flow from 2008–2009 compared with the historical 28-year flow.

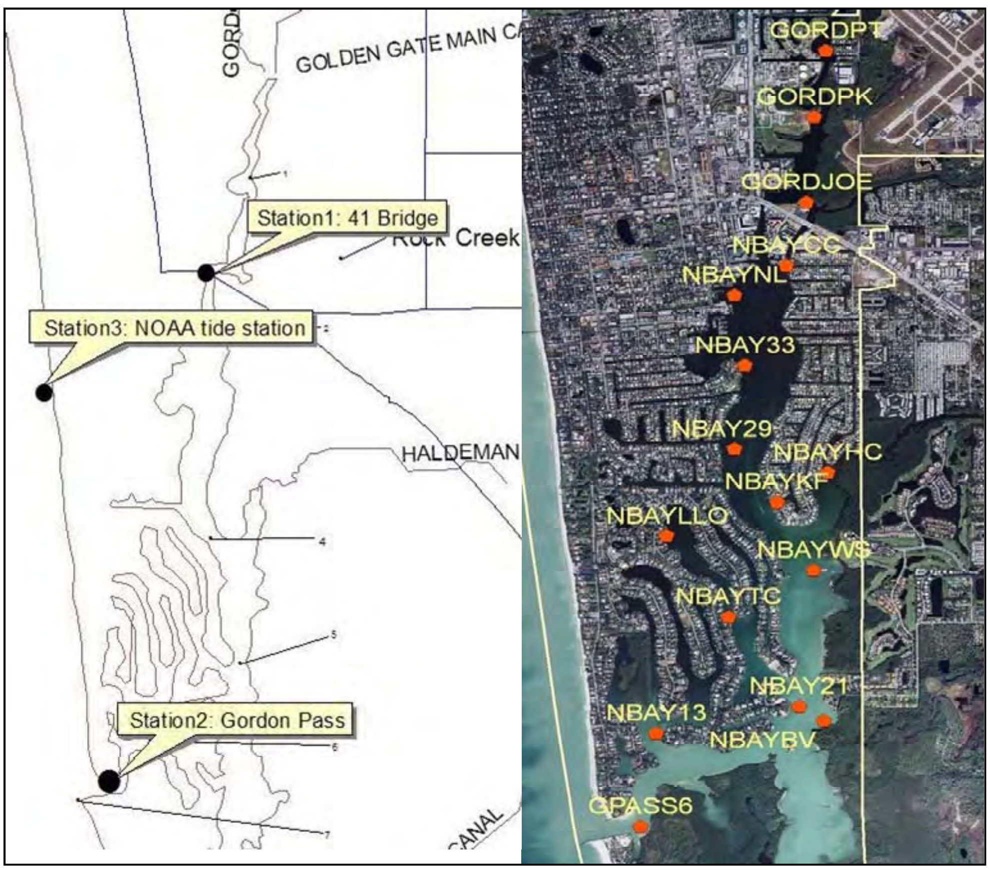


Figure 12-86. Naples Bay monitoring stations and canals. Left: Salinity and tide monitoring stations maintained by the District. Right: water quality stations maintained by the City of Naples since 2006; eight sites are monitored one month and eight different sites are monitored the next month.

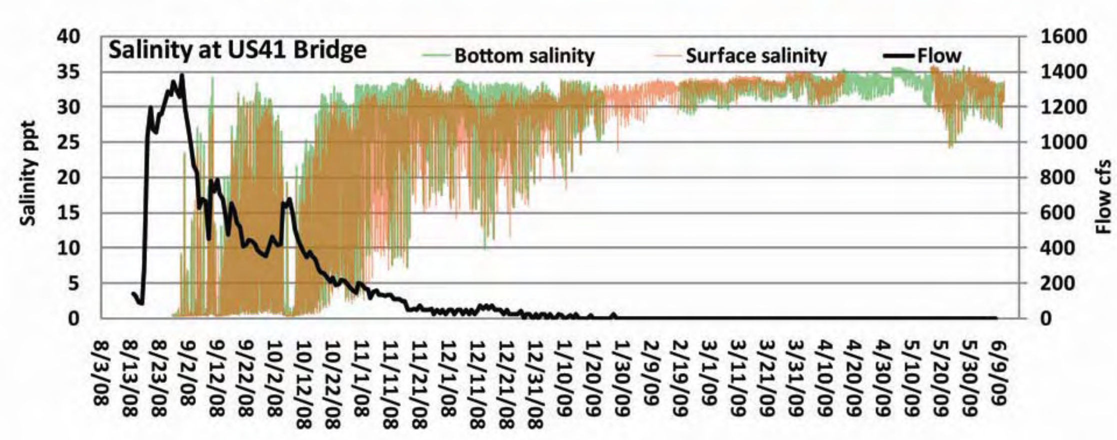


Figure 12-87. Observed salinity at the US41 Bridge and water flow at Golden Gate Canal.

Nutrients and Water Quality

The City of Naples has been monitoring water quality in the bay at 16 different locations; alternating between eight sites one month and the other eight sites the next month (**Figure 12-86**). The city continued its monitoring program in 2008 and measured DO, pH, salinity, water temperature, Biochemical Oxygen Demand (BOD), TOC, chlorophyll *a*, phaeophytin, TKN, nitrate + nitrite, ammonia, TP, OPO_4, sulfate, Secchi disk depth, color, turbidity, copper, lead, calcium, and zinc.

According to data collected by the City of Naples (unpublished), N, P, and chlorophyll *a* concentrations exhibited strong seasonal patterns in 2008, following the similar seasonality observed in 2006 and 2007, with highs in the wet season and lows in the dry season (**Figure 12-88**). Total phosphorus clearly shows a yearly declining trend over the three years of sampling. However, TN concentration shows a slightly elevated peak in 2008. It is difficult to explain the declining trend of phosphorus with only three years of data. A longer-term dataset and more research work are needed to confirm the trend and its cause. The elevated values of nitrogen concentration in summer 2008 are likely associated with the increased rainfall and runoff observed in the summer. Chlorophyll *a* concentration is higher in the summer than at other times.

In 2008, after analyzing three years of data and using Geographic Information Systems (GIS) mapping, the City of Naples identified copper as a major pollutant in Naples Bay. These results were validated by the release of a report this year from the NOAA that found oysters in Naples Bay to have one of the highest sampled levels of copper in the nation (O'Connor and Gunnar, 2005; Kimbrough et al., 2008). The copper concentration within the bay was in the range of 0.5–9 µg/L with a distinct seasonal pattern. Higher values were observed at the upper bay stations in the summer, and lower values were found at lower bay stations in the winter.

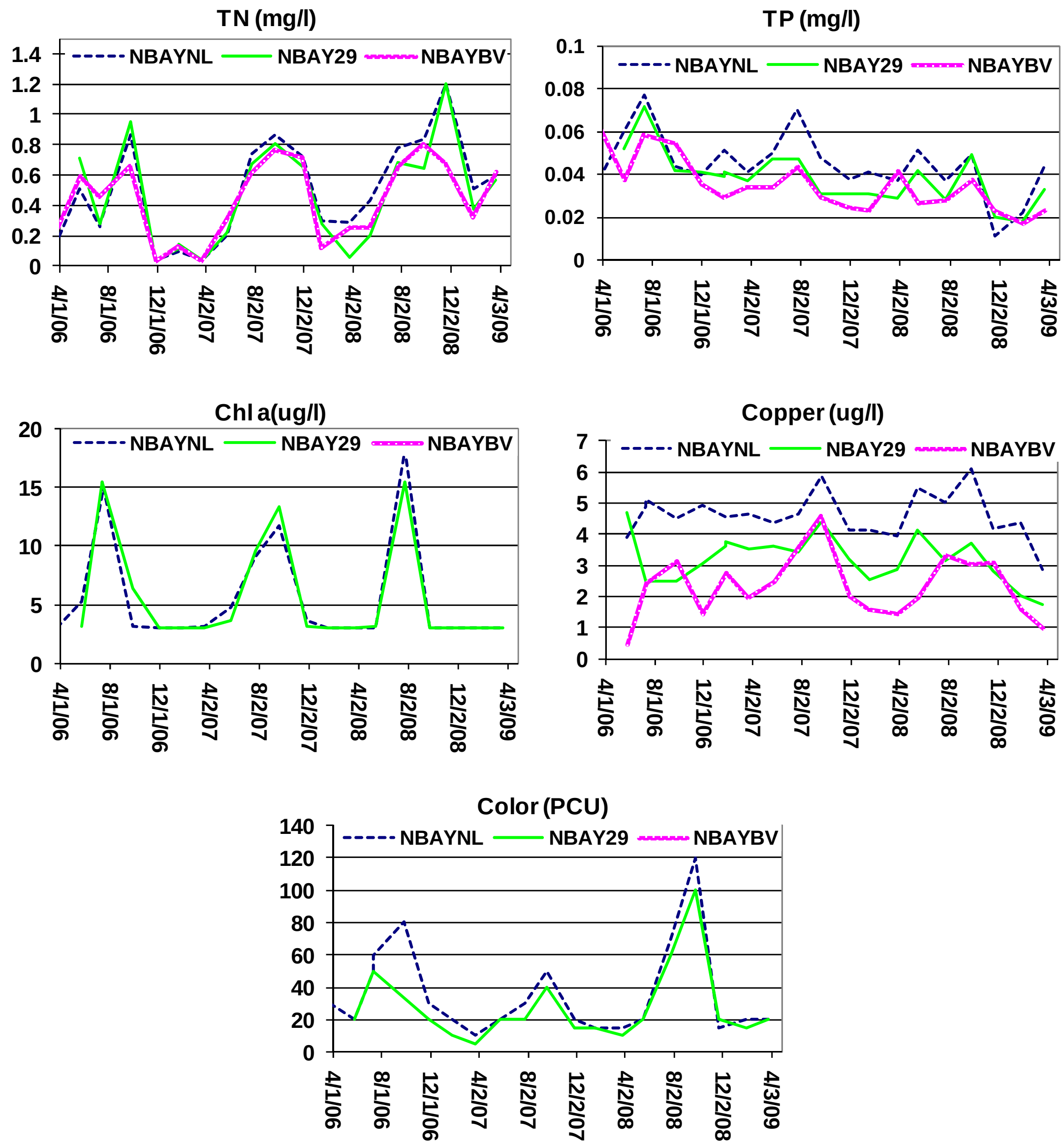


Figure 12-88. Water quality results from January 2006–March 2009 collected bimonthly by the City of Naples at NBAYNL, NBAY29, and NBAYBV.

Submerged Aquatic Vegetation Habitats

A 2006 chronological study documented changes to the shoreline and bottom of Naples Bay since before the 1950s using aerial photos and interviews (Schmid et al., 2006). Prior to development around Naples Bay in the 1950s, habitats included about 24 ha of seagrasses. In 2005, an inventory revealed that about 1.7 ha of sparse seagrass remained.

The City of Naples established seagrass monitoring at five transects south of Bayview Park (**Figure 12-89**). The transects run across the bay in straight lines. The lengths of the transects are approximately 28 m, 30 m, 35 m, 32 m, and 44 m at NChannel, BV1West, BV2Mid, BV3East and SPortRoyal, respectively. The 2008 data indicated that the seagrasses were relatively dense with long blades in May 2008 and September 2007. However, October 2008 data show fewer shoots and shorter blades (**Figure 12-90** and **Figure 91**. It is tempting to conclude that low density in October 2008 was due to low salinity and lower light availability caused by rain events in July and Tropical Storm Fay in August. Unfortunately, the time-series in Naples Bay is not long enough to support any conclusions.

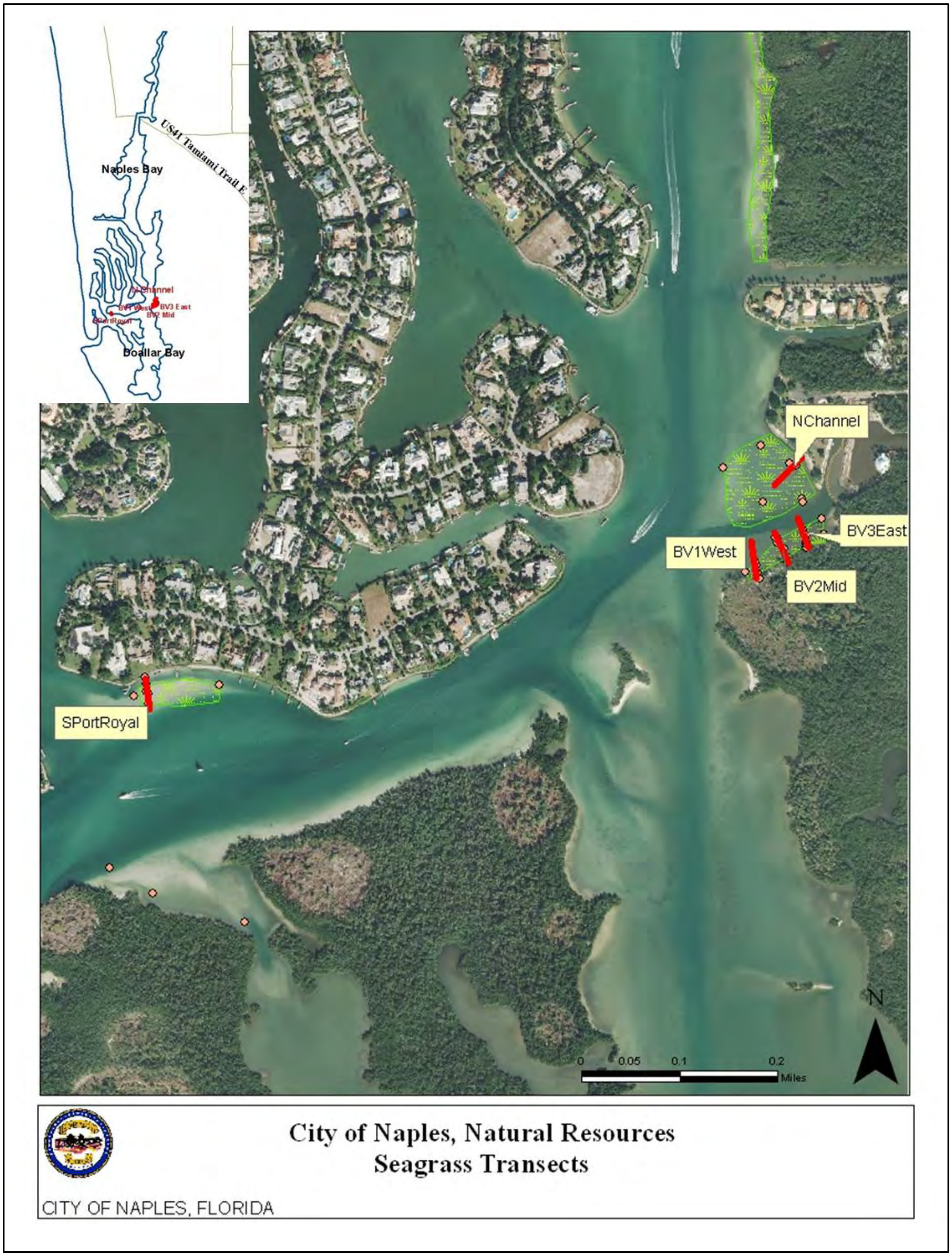


Figure 12-89. Location of the seagrass transects monitored by the City of Naples.

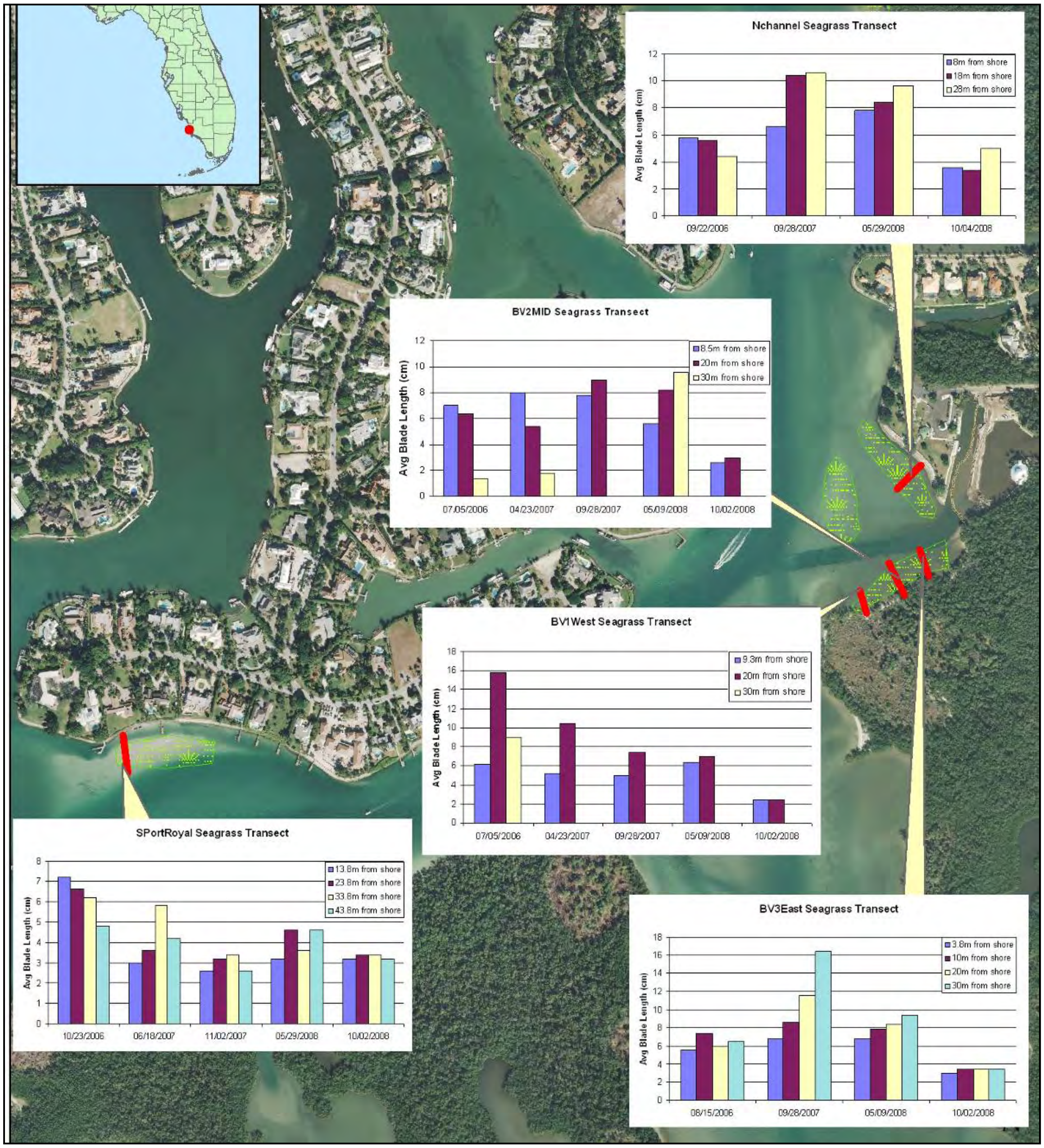


Figure 12-90. Seagrass transect data; average blade lengths.

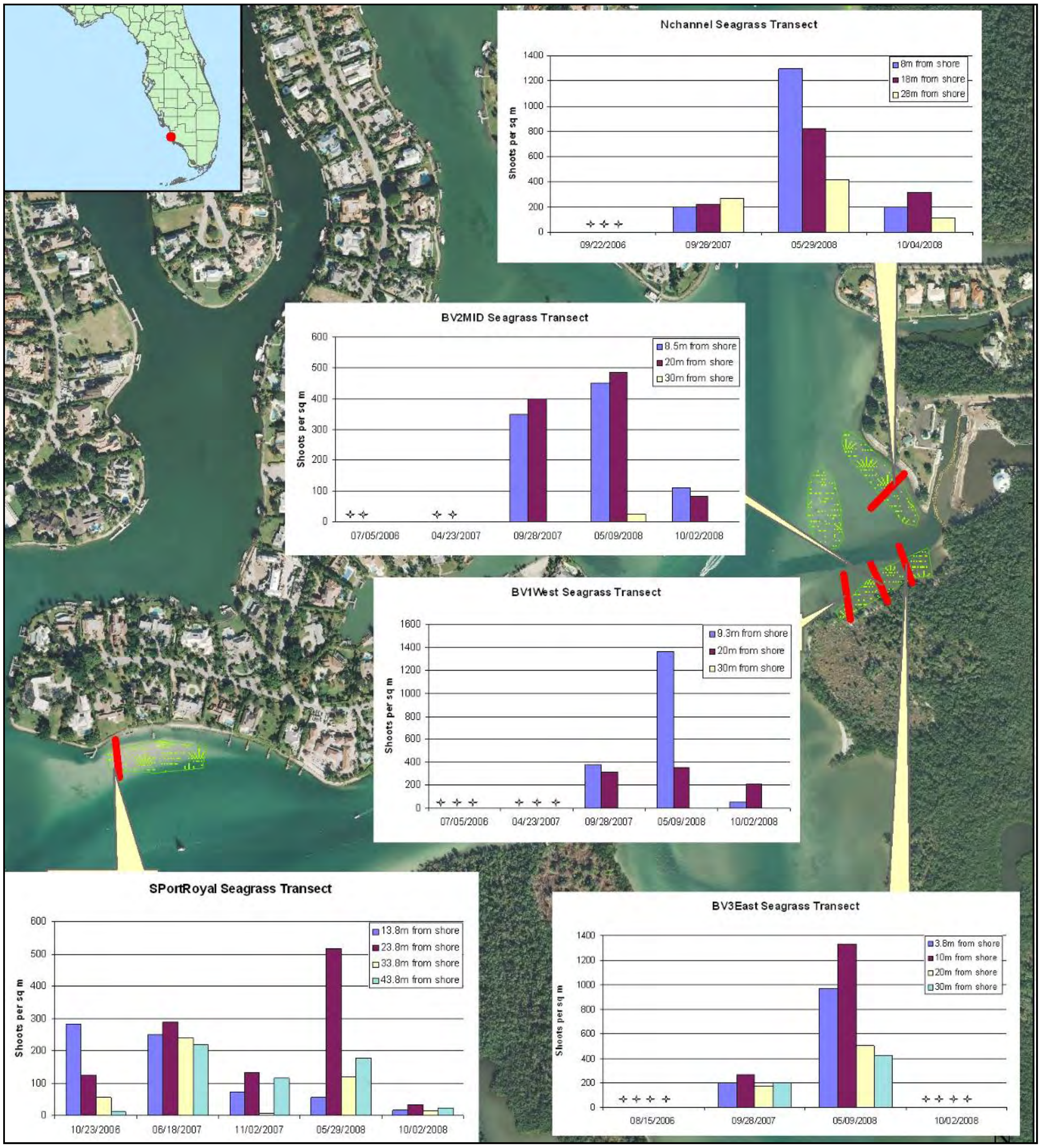


Figure 12-91. Seagrass transect data; average shoot counts per square mile.

Eastern Oyster Abundance and Distribution

A study by Schmid et al. (2006) estimated that about 21 ha of historical Eastern oyster habitat has shrunk to 5 ha currently. An oyster reef restoration demonstration project was completed in September 2005 to test the suitability of water quality for oyster reef development (Savarese et al., 2007). Approximately 400 shell bags were deployed at two sites (**Figure 12-92**) in Naples Bay by FGCU and the City of Naples and funded through the District's Big Cypress Basin. Many live adult oysters have been observed on the bags, and in 2008, were photographically documented by the City of Naples. The southern site, south of Haldeman Creek, has experienced significant recruitment onto the shell bags over the past two years. The northern site closer to the freshwater influence of the Golden Gate Canal has experienced less recruitment and slower oyster growth than the southern site. The northern site is also a bit deeper than the southern site, perhaps making it more susceptible to low DO levels in the summer when stratification is at its highest in Naples Bay.

Restoration efforts will continue at the southern site, and more shell bags will be deployed to add greater vertical relief to the newly created reef since a single layer of bags is quickly buried due to high wakes from boats.

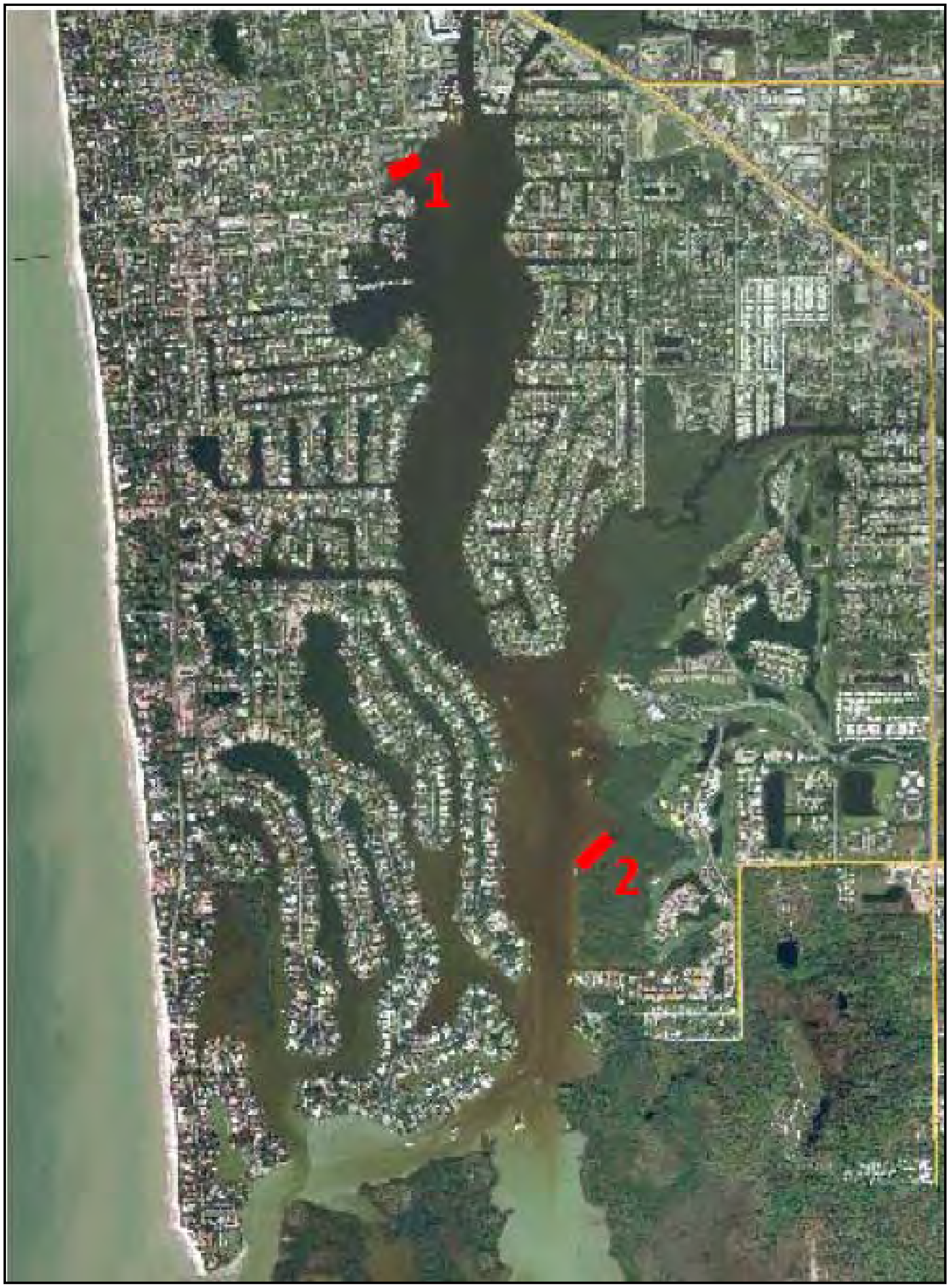


Figure 12-92. Location of the two oyster reef restoration sites: (1) upstream location at Naples Landing, and (2) the downstream site south of the confluence with Haldeman Creek and south of the Winstar development.

RESEARCH STRATEGIES FOR NAPLES BAY

To understand salinity patterns and the influence of variable freshwater inflow rates, a numeric hydrodynamic model is needed to simulate current and potential changes to major inflows such as the Golden Gate Canal. To calibrate and verify a model, and to characterize variability, a high-frequency time-series of salinity is required.

A long-term water quality dataset is needed to identify the status of the system and trends taking place. The existing water quality monitoring program is critical to interpret the trend found in the short-term data. Nutrient loading data are also needed to better understand water quality in the bay, and long-term SAV abundance and response are required to determine the status and trends of SAV coverage.

Continued monitoring of the artificial oyster reefs can provide information that may indicate better conditions for oyster reef development if water quality improves.

KEY SFWMD PROJECTS IN NAPLES BAY

The SFWMD continues monitoring flow discharged from Golden Gate Canal. The salinity monitoring project continued through 2008 at three sites within Naples Bay to obtain salinity values at a high frequency (**Figure 12-86**). The data will be used to characterize salinity throughout the bay, and to calibrate and verify a hydrodynamic/salinity model.

Freedom Park (Gordon River Water Quality Park)

An approximately 50-acre natural water quality treatment facility will provide flooding relief and tertiary treatment of stormwater runoff from the Gordon River Extension Basin. Based on the application of an interconnected system of multidepth ponds, polishing marshes, and wetlands, the man-made park will function as a natural filtration system similar to the Everglades.

Conservancy Filter Marsh Project

The Conservancy Filter Marsh Project will create a filter marsh to clean stormwater runoff currently discharging directly into the Gordon River from the City of Naples' northernmost stormwater pump. The filter marsh, a natural filtration system in a constructed wetland, will cleanse pollutants of stormwater runoff from parking lots and roadways in surrounding neighborhoods before it flows into the Gordon River and Naples Bay. The City of Naples received a grant from the SFWMD and the FDEP for the construction of this project. It is currently in the design and engineering phase.

Horsepen Strand Conservation Area – Phase I

The purpose of the Horsepen Strand Conservation Area (HSCA) – Phase I analysis was to determine the feasibility of reconnecting the HSCA to provide stormwater treatment, flood protection, water quality treatment, and habitat restoration for the Northern Golden Gate Estates area. Reconnecting the historic flow-way will redirect stormwater drainage away from North Golden Gate Estates canals, which eventually make their way to Naples Bay. Instead, stormwater drainage will move south toward North Belle Meade and naturally low county areas while allowing ground absorption along the way. Collier Soil and Water Conservation District managed and oversaw the project. Funding was provided by the SFWMD via a state appropriation and the FDEP, which oversees the Gulf American Corporation settlement agreement. This phase has been completed.

KEY NON-SFWMD PROJECTS IN NAPLES BAY

MONITORING WITHIN THE BAY

Prior to January 2006, limited water quality monitoring in Naples Bay had been carried out by the FDEP and Collier County. Since January 2006, the City of Naples began monitoring water quality in the bay at 16 different locations; eight sites one month and eight different sites the next month (**Figure 12-86**). The city continues its monitoring program in 2008 and measures DO, pH, salinity, water temperature, BOD, TOC, chlorophyll *a*, phaeophytin, TKN, nitrate + nitrite, ammonia, TP, OPO_4, sulfate, Secchi disk depth, color, turbidity, copper, lead, calcium, and zinc.

The City of Naples continued seagrass monitoring at five transects. The transects have been established with species type, sediment type, water depth, epiphyte coverage, blade lengths, and shoot counts being recorded at 10 m intervals along each transect. Transect monitoring occurs at a minimum of twice annually. As new areas are discovered, additional transects will be established. The city continued the monitoring of Eastern oysters on cultch placed in the bay in 2005 by an oyster reef restoration project, and the results of this effort were photographically documented.

ESTERO BAY

Beth Orlando and Marion Hedgepeth

DESCRIPTION OF ESTERO BAY AND MAJOR ISSUES

Located on the southwest coast of Florida, Estero Bay is a small, long and narrow, shallow bar-built estuary (**Figure 12-93**) with barrier islands separating it from the Gulf of Mexico. The bay's watershed includes central and southern Lee County and parts of northern Collier and western Hendry counties. In December 1966, the northern half of Estero Bay was designated as the state's first Aquatic Preserve, the Estero Bay Preserve State Park. During the 1983 Florida legislative session, the southern half of the bay was added to the preserve.

Surficial freshwater inflow comes from five major tributaries distributed along the eastern shore of the bay. From north to south, these are (1) Hendry Creek, (2) Mullock Creek, (3) Estero River, (4) Spring Creek, and (5) Imperial River. While four of the five tributaries empty into the main body of the estuary, the influence of the Imperial River may be limited to the most southern reaches of the bay.

Estero Bay is one of Florida's most significant natural watershed resources. The tributaries to Estero Bay received an Outstanding Florida Waters designation in 1990 by the FDEP. The designation is significant in that it provided statutory protection in the form of a "no-degradation standard" for water quality and biotic resources (FDEP, 1990). Because the tributaries can also be estuarine, salinity gradients in the bay and within the tributaries can form a complex temporal and spatial mosaic. The flora and fauna of the bay and its watershed are varied and abundant. Approximately 40 percent of the state's endangered and threatened species are found within this area. The estuary also indirectly supports a variety of commercial and sport fisheries by providing nursery area, which substantially adds to the local economy. The estuary is also an important home for bird-nesting colonies and a valuable stopover area for migrating birds. Both oysters and seagrasses are considered valuable ecosystem components.

Figure 12-93. Estero Bay and the locations of the four water quality sampling stations in green (BCP, EBN, EBS, and OCP).

STATUS AND TRENDS IN ESTERO BAY

Salinity and Freshwater Inflows

No MFL rule has been established for Estero Bay to date. As part of the SWFFS (http://www.evergladesplan.org), flow ranges have been developed to evaluate flows of three tributaries: Ten Mile Canal, the Estero River (South Branch), and the Imperial River. These flow ranges, which are based on the salinity tolerances of the Eastern oyster, are used to define flow envelopes that maintain appropriate salinity at river mouths where oysters are located. The preferred freshwater inflow ranges correlate with salinity levels from 15–25 psu that are optimal for adult oysters, and performance measures recommend that the number of days within this range be maximized. Inflows that cause salinity below 5 psu are assumed to be lethal to juvenile oysters (**Table 12-17**).

Freshwater inflows at the three major tributaries were compared to the recommended flows that should maintain appropriate salinity for adult Eastern oysters (**Table 12-18**). For the Imperial River, the number of days with flows producing favorable salinities for oysters and the number of days with flows producing lethal salinity for juveniles were both within historical ranges. By contrast, the South Branch had fewer favorable flow days and more lethal flow days than the historic ranges. For the Ten Mile Canal, the number of days with favorable flows was within the historical range, while the number of lethal flow days was greater.

Table 12-17. Recommended flows for the Eastern oyster in Estero Bay.

TRIBUTARY CONTROL STATION	MONITORING STATION	FLOW RANGES FOR SALINITY 15–25 psu	FLOWS RESULTING IN SALINITY < 5 psu
Imperial River	Imperial River mouth	8–26 cfs	> 94 cfs
South Branch Estero River	Estero River mouth	3–9 cfs	> 31 cfs
Ten Mile Canal	Mullock Creek downstream	4–50 cfs	> 215 cfs

psu – practical salinity units
cfs – cubic feet per second

Table 12-18. Comparison of historical and WY2008 tributary inflow in Estero Bay.*

TRIBUTARY CONTROL STATION	HISTORICAL MEAN (DAYS) 1988–2008	DAYS IN WY2009
Imperial River		
8–26 cfs	137 ± 68.7	164
> 94 cfs	99.2 ± 62.4	93
South Estero		
3–9 cfs	64.6 ± 37.7	24
> 31 cfs	41.5 ± 29.2	74
Ten Mile Canal		
4–50 cfs	142.7 ± 52.8	173
> 215 cfs	30.9 ± 29.9	65

*Note: The number of days in WY2009 when flow was within the minimum flow range is compared to the historical mean ± 95% confidence Interval (C.I.). The number of days in WY2009 when flow exceeded the recommended maximum is compared to the historical mean ± 95 percent C.I.
cfs – cubic feet per second

Nutrients

The Southeastern Environmental Research Center at FIU operates a network of 331 fixed sampling sites distributed throughout the estuarine and coastal ecosystems of South Florida. Beginning in January 1999, four stations in Estero Bay [Estero Bay North (EBN), Estero Bay South (EBS), Big Carlos Pass (BCP), and Outer Clam Pass (OCP), (**Figure 12-93**)] were sampled on a monthly basis for salinity, chlorophyll *a*, TP, and TN (**Figure 12-94** through **Figure 12-97**). The SFWMD Water Quality Monitoring Program in Estero Bay was discontinued; therefore, data are not available after September 2008.

Long-term monthly averages reveal a seasonal water quality signal driven by rainfall and runoff, with higher TN, TP, and chlorophyll concentrations and lower salinity in the wet season than in the dry season. This pattern appears more pronounced for TP and chlorophyll than for TN. There is considerable interannual variability as demonstrated by the comparison of WY2008 and WY2009. Generally, WY2009 had lower wet season salinity and higher concentrations of TP and chlorophyll. By contrast, TN was higher during the wet season of WY2008 than in WY2009. A more pronounced influence of internal sources during drier times may account for this difference.

Since 1999, through a collaborative effort between Lee County Environmental Lab and Estero Bay Aquatic Preserve, water quality has been sampled monthly within the tributaries of Estero Bay. These entities also coordinate with the Charlotte Harbor Estuaries Volunteer Water Quality Monitoring Network, which samples monthly at five fixed sites. Parameters sampled in both programs include chlorophyll *a*, nitrate, ammonia, TP, TN, turbidity, and fecal coliform bacteria. Continuous water quality monitoring efforts include three data sondes located throughout the bay. Information from these three programs provides baseline data that assists in determining the health of Estero Bay and assessing the impacts of development on the bay. Data have shown distinct water circulation patterns within the bay, including null zones characterized by reduced flushing and lower DO levels. Water quality data have also shown higher turbidity levels in Estero Bay than in Charlotte Harbor.

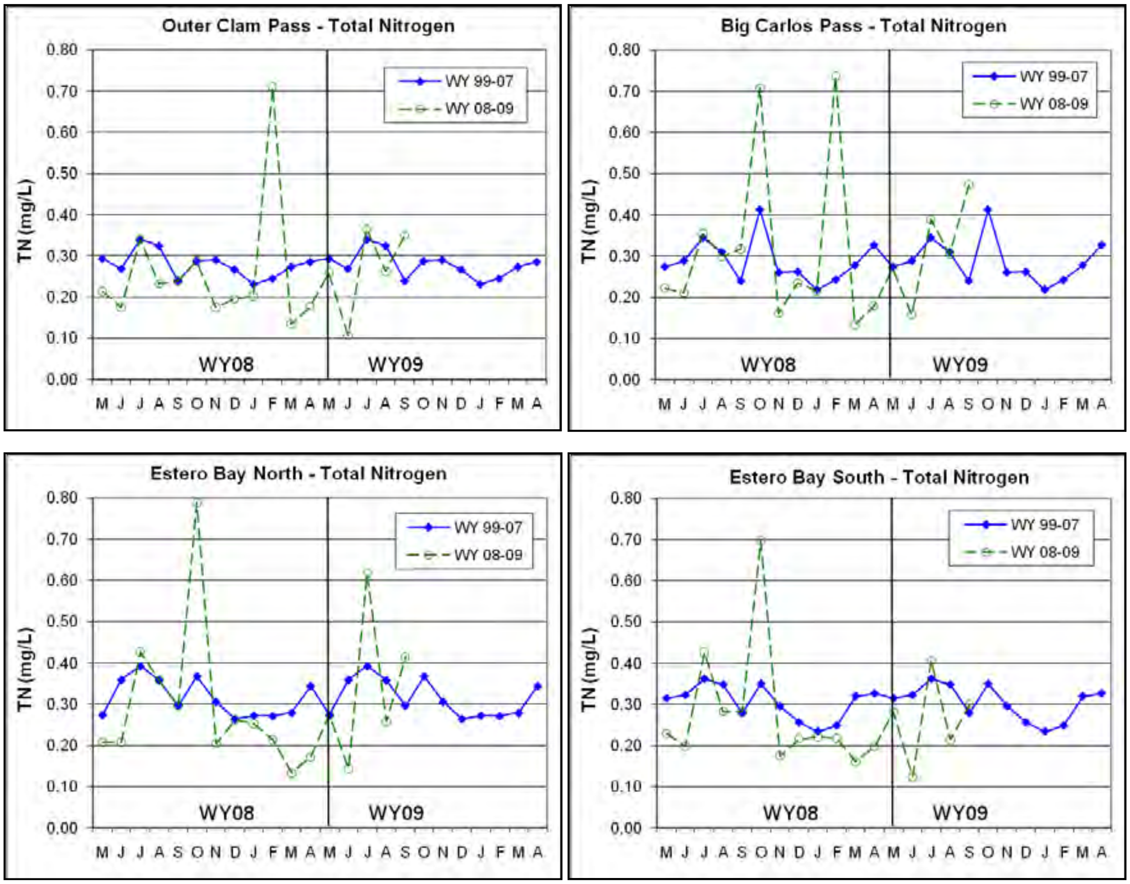


Figure 12-94. TN concentrations from WY2008–WY2009 compared with the long-term average at four stations in Estero Bay.

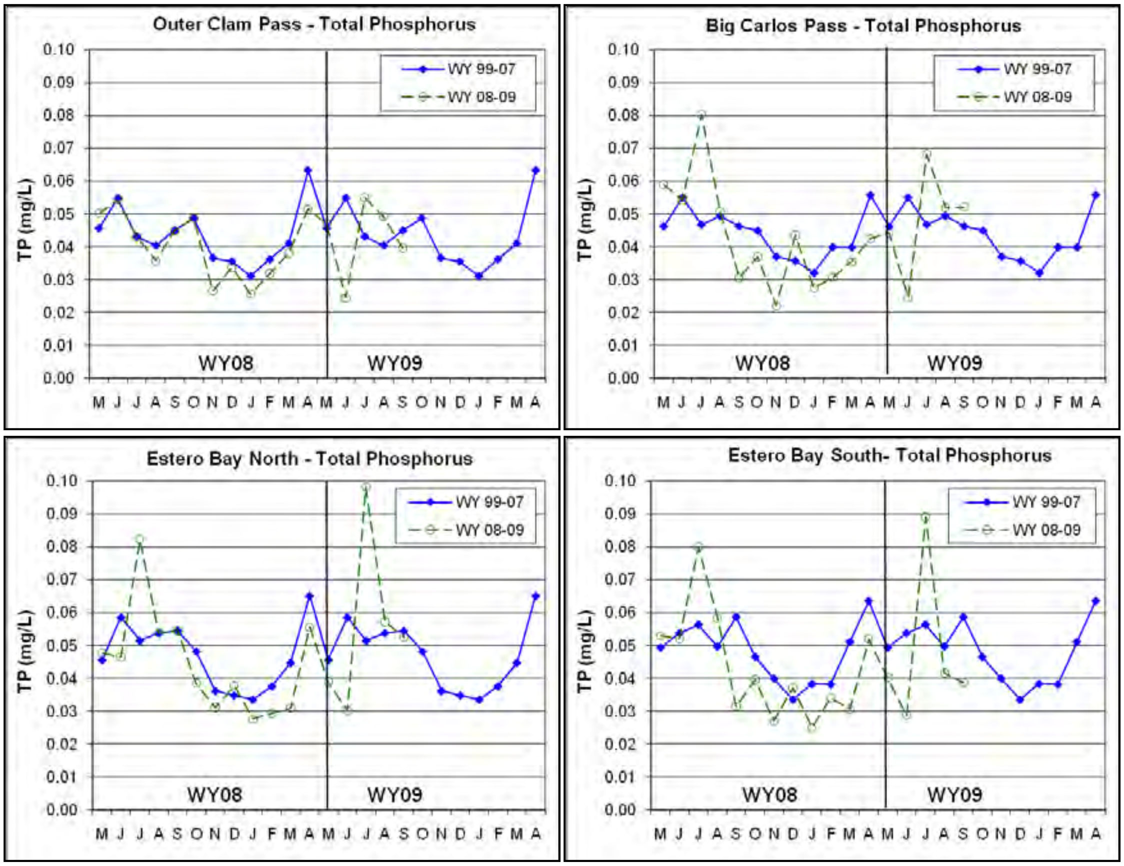


Figure 12-95. TP concentrations from WY2008–WY2009 compared with the long-term average at four stations in Estero Bay.

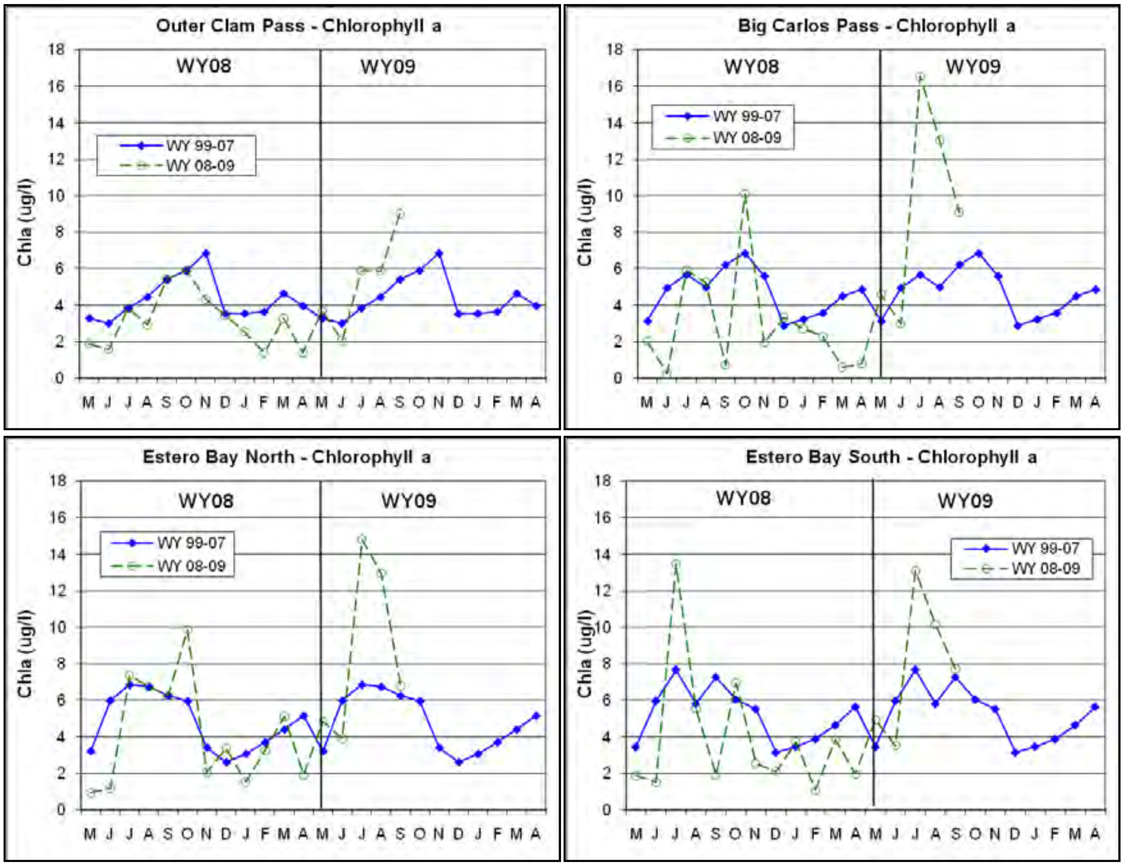


Figure 12-96. Chl*a* concentrations from WY2008–WY2009 compared with the long-term average at four stations in Estero Bay.

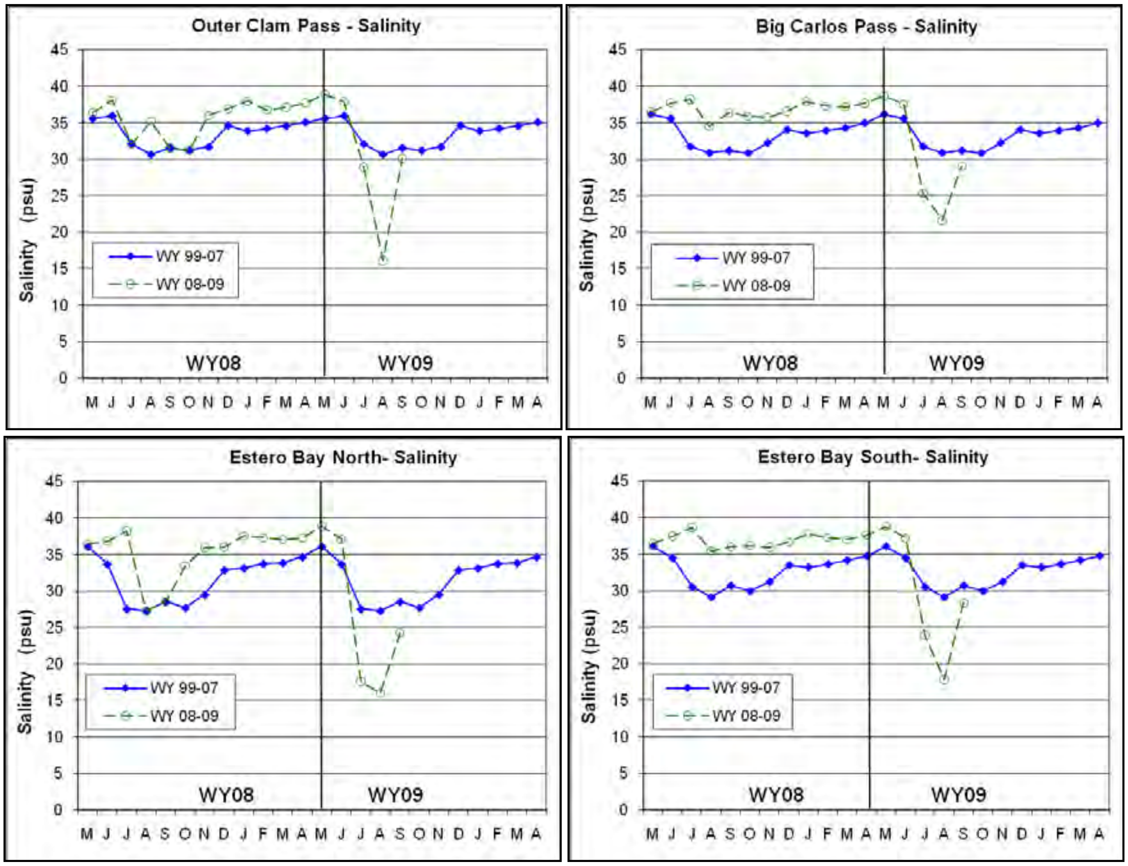


Figure 12-97. Salinity at monitoring stations in Estero Bay from WY2008–WY2009 compared with the long-term monthly averages.

Submerged Aquatic Vegetation Habitats

The District used aerial photography to quantify distribution and response of seagrasses to freshwater inflows in 1999, 2003, 2004, 2006, and 2008. According to WY2008 bottom vegetation maps, 18,290 ha (45,194 ac) of SAV cover (including macroalgae) was identified at the time of the survey. Cover increased by 2,831 ha (6,995 acres) from 1999–2008. The majority of this increase (2,041 ha; 5,043 acres) occurred before the 2004–2005 hurricane seasons. The comparatively lower increase in vegetative coverage between 2004 and 2006 (528 ha; 1,304 ac) may have been a result of increased freshwater flows following each of the two very active hurricane years.

The Estero Bay Aquatic Preserve semiannually monitors five transects in the bay in the winter and late summer. Parameters measured include species, abundance, epiphyte load, and macroalgae.

Eastern Oyster Abundance and Distribution

Although the District does not maintain oyster monitoring stations in Estero Bay, it contributed to a mapping effort in 2004. Based on WY2004 data, there were about 24 ha (60 ac) of live oyster habitat in Estero Bay, and another 3,346 ha (8,269 acres) of potentially suitable habitat where annual mean salinity was greater than 10 psu, but oysters were not present. This translates to 0.72 percent coverage of total surface area available in the estuarine portion. No new oyster maps were created in WY2009.

RESEARCH STRATEGIES FOR ESTERO BAY

Estero Bay Science Symposium

Florida Gulf Coast University hosted an Estero Bay Science Symposium from November 5–6, 2008. The symposium brought together researchers and managers to compile and discuss the current state of knowledge regarding the health and ecology of Estero Bay and its watershed. The aim of the symposium was to identify gaps that need to be addressed in future research endeavors to provide the data to best manage and protect Estero Bay in the future. Flow data are lacking for some tributaries (Hendry Creek), and many questions need answers regarding the overall dynamics of the system.

Drawing from the materials presented by symposium members, six categories emerged for further discussion: hydrology, water quality, geology, oyster reefs, seagrass beds, and plankton. Data gaps for each category were identified in the discussions and management questions were posed. From a management perspective, the following data gaps were determined to be the most relevant in addressing the freshwater requirements of Estero Bay:

- How has Ten Mile Canal altered the flows of Hendry and Mullock creeks?
- Has recent development increased the flashiness of the system?
- How is flow related to nutrient inputs, turbidity, and sediment transport?
- How much influence does the Imperial River have on southern regions of the bay?
- How is the hydrology of Hell Peckney Bay and Cow Slough/Creek affected by external drivers?
- Biotic productivity/distribution is inevitably linked to hydrology. Additionally, there are differences in organism distributions that may (or may not) be linked to hydrology.
- Is the dominance of oysters in the northern section of the bay, coupled with the dominance of seagrasses in the southern portion of the bay, the result of different hydrologic regimes in the two regions?
- Can the ideal hydrologic conditions be determined for seagrass and oyster productivity, and are the two conditions compatible given the above observation?
- Chl*a* concentrations can be exceedingly high in the bay and its tributaries, according to previous reports. What is unclear, however, is how these high levels of phytoplankton biomass are related to flow and nutrient loading. Are any nutrients limiting? Is light limitation a factor? Can grazing pressures control phytoplankton biomass?
- While much data have been gathered and reported concerning salinity influences on zooplankton distributions, oyster health and physiology, and oyster reef-associated biota, there remains a dearth of knowledge regarding salinity influences on reproduction and larval dispersion mechanisms.

- There is much concern about the exact nature of the impacts caused by land use and development in the Estero Bay Watershed. There is a lack of data to truly assess the impacts, much less offer solutions.
- Have freshwater inputs to Estero Bay been altered due to changing land use and development patterns in recent years?
- Are nutrient inputs increasing into Estero Bay?
- The cause-effect relationships of these questions need to be addressed before effective remedial measures can be taken.
- Watershed land use and development.

KEY SFWMD PROJECTS IN ESTERO BAY

Restoration of Oyster Reefs

The enhanced filtration rate of restored and enhanced oyster reefs can indirectly restore the water quality of Estero Bay. In an effort to establish healthy living oyster reefs, FGCU, in conjunction with the SFWMD, has created, maintained, restored, and enhanced oyster-shell reefs for the past three years. Data obtained from the 2007 and 2008 shell reefs have shown survival of oyster spat recruited to these areas.

Similar success is anticipated for a March 2009 oyster recruitment study the SFWMD initiated with FGCU. The purpose of this study is to quantify the effects of tributary inflows on oyster reefs, which are located at the mouths of the tributaries. Oyster spat recruitment will be used as an indicator of oyster reef success and will be examined at 13 locations near the mouth, above the mouth, and below the mouth of three tributaries to Estero Bay. Spat recruitment is being monitored monthly. Oyster spawning and spat recruitment occurs from May–October in Southwest Florida estuaries. To date, spat recruitment at all sites ranged between 0–6.7 spat/shell/month.

Oysters and Green Mussels (Student Intern Project)

Salinity has significant influence not only on the growth, survival, and reproduction of adult oysters, but also on the early life stages of oysters. In addition, salinity and substrate availability have the potential to facilitate the entry and establishment of nonnative bivalve species, such as green mussels (*Perna viridis*), which are more commonly seen in the estuaries and coastal areas of Southwest Florida. In 2009, a three-year study was initiated to examine the effects of fresh water (salinity) on various early life stages of oysters, and the effects of salinity and food on two species of shellfish, oysters, and green mussels. Study results can be used to better inform resource managers regarding (1) the regulation of freshwater inflows into the estuaries to maintain and facilitate oyster larval recruitment and to continue development of oyster reefs; (2) the benefits of oysters in maintaining and enhancing water quality and clarity; and (3) the interactions between native (oysters) and nonnative species (green mussels) and if there is an ecological need to minimize or eliminate nonnative species from local estuaries.

Preliminary results show a rapid mortality rate for green mussels exposed to salinities ≤ 10 psu, whereas green mussels exposed to salinities > 20 psu experienced little or no mortality. These results suggest that mitigation of green mussels can be accomplished through water releases and/or watershed runoff depressing salinities below 10 psu. This may explain greater prevalence of green mussels at or near the mouths of the bay where salinities tend to be near seawater strength, with little to none in the estuarine portions where salinities tend to change drastically.

Hendry Creek Stream Gauging Station

Two existing stream gauging stations on Hendry Creek were re-instrumented to complement ongoing studies in Estero Bay. These gauges are expected to reduce the uncertainty in the amount of fresh water flowing into the system and to improve the relationship between salinity and freshwater inflow.

Salinity Monitoring in Estero Bay Tributaries

The purpose of this study is to measure salinity in the tributaries of Estero Bay to develop a salinity flow relationship that will be used to establish an MFL or a Water Reservation for Estero Bay at a later date.

Floodplain Vegetation

Riparian zones have been typically identified as the interface between terrestrial and aquatic ecosystems. These zones provide storage and filtration of surface water, diverse habitats for plants and animals, corridors for the movement of animals and dissemination of plants, and provide a supply of nutrients to estuarine environments. Riparian vegetation serves as a non-motile integrator of salinity conditions over time, and proves useful for detecting shifting salinity gradients associated with altered freshwater flow. Within riparian vegetation communities, canopy species are generally used to characterize long-term health and sustainability, while shrub and groundcover species are used to assess short-term changes in the system.

In 2006, the SFWMD initiated a riparian vegetation analysis study with FGCU's Coastal Watershed Institute. The purpose of the study was to establish long-term vegetation transects that could provide reference data for detecting the impact of shifting salinity gradients, while providing an additional ecosystem indicator to evaluate MFL rulemaking needs. The study was completed in May 2007.

Corkscrew Regional Ecosystem Watershed

Corkscrew Regional Ecosystem Watershed (CREW) is a 60,000-acre watershed spanning Lee and Collier counties. CREW's 5,000-acre marsh is the headwater for the entire watershed. District scientists are trying to restore the marsh and sheetflow in the bottom seven sections of land, but are encountering flooding problems. One solution is to divert the water to the Imperial flow-way, which would eventually work its way to Estero Bay. The District intends to restore the marsh and the sheetflow in the bottom seven sections, but management of the water in the marsh must be balanced against downstream flood control and environmental objectives.

Wild Turkey Strand Preserve Restoration

For this restoration project, the SFWMD partnered with Lee County Conservation 20/20 to restore a portion of the 2,600 acres of preserve lands that extend between SR82 and Alico Road. Invasive exotics were removed and firebreak lines were re-leveled to allow more natural sheetflow. The former firebreaks were also replanted to reduce possible sediment loss and restore more native vegetation. The net result is better habitat for many important species and increased water quality in the region.

Deep Lagoon Preserve Restoration

The SFWMD partnered with Lee County Conservation 20/20 to restore a portion of the Deep Lagoon Preserve located in southwest Fort Myers. Invasive exotic plants were removed from the site to encourage regrowth of native vegetation and improve the hydroperiod to allow for water quality improvements and longer retention on-site.

Imperial Marsh

The SFWMD partnered with Lee County 20/20 to restore the hydrologic functions of this section of the preserve. The restoration will improve sheetflow and increase the health of on-site and nearby wetlands. This area of Lee County provides important habitat resources.

San Carlos Estates Water Control District

The SFWMD teamed up with the San Carlos Estates Water Control District (SCEWCD) in an effort to improve the quality of water discharged to the headwaters of Spring Creek while still providing flood protection. Previously, the SFWMD and SCEWCD partnered to implement the installation of a wetland. This past year, the partnership effort has included the addition of more plantings to the wetland area and work on the perimeter canal. The additional plantings will improve the water quality of the storm water by locking nutrients in their biomass. Restoring the cross-sections of the canal will prevent bank collapses and provide additional storage capacity, resulting in flood attenuation, a reduction of sediment and nutrient loading to the estuary, and aquifer recharge.

Halfway Creek Restoration

For this restoration project, the SFWMD partnered with Lee County Natural Resource Division to improve the conveyance system and water quality treatment capability of the Halfway Creek channel at the existing Florida Power & Light (FPL) easement, while minimizing impacts to an existing wastewater force main owned and operated by a private utility and existing FPL facilities. The channel improvement aims to reduce the channel velocity and head loss from increased flows within the upstream areas of the Halfway Creek Watershed, reduce the potential for erosion, and improve water quality by creating a littoral shelf along the banks of the improved creek cross-section.

KEY NON-SFWMD PROJECTS IN ESTERO BAY

Lee County

In a collaborative effort between Lee County and Estero Bay Aquatic Preserve, monthly water quality monitoring occurs at 14 locations within Estero Bay and its tributaries (http://www3.leegov.com/NaturalResources/Environmental/Autopage_T33_R20.htm).

Estero Bay Aquatic Preserve

The FDEP's Office of Coastal and Aquatic Managed Areas conducts several activities in Estero Bay, including coordinating land acquisition and water quality monitoring.

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