Chapter 12: Management and Restoration of Coastal Ecosystems

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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 2008 (WY2008) (May 1, 2007–April 30, 2008) in this chapter of the *2009 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 to develop watershed protection plans for the St. Lucie River and Caloosahatchee River estuaries, including assessment of existing monitoring systems and needs, and delineating science strategies for water quality improvement and ecosystems restoration. Some numeric models were further refined for these estuaries.

WY2008 monitoring results indicate that seagrasses near the St. Lucie Inlet damaged by hurricanes in 2004 and 2005 have recovered. Salinity conditions in the St. Lucie River Estuary in calendar years 2006 and 2007 were favorable for Eastern oyster (*Crassostrea virginica*) recruitment. Monitoring of submerged aquatic vegetation in the Caloosahatchee River Estuary indicates that tape grass (*Vallisneria americana*) density declined as a result of increased salinity caused by the continuing drought. Turtle grass (*Thalassia testudinum*) densities remained the same or increased, while shoal grass (*Halodule wrightii*) declined in some areas. Eastern oyster density in the Caloosahatchee River Estuary remained stable, but larval recruitment was lower than normal last year, perhaps due to increased predation facilitated by higher salinity.

Reports of scientific and modeling activities in the coastal ecosystems address a variety of ongoing studies, the initiation of baseline studies, and in some instances, the conclusions of data acquisition or analysis during WY2008. Minimum freshwater flow in the Loxahatchee River estimated at Lainhart Dam was maintained throughout the water year except during May and part of June in 2007. In cooperation with key partners, the District continued studies of bald cypress (*Taxodium distichum*) seedlings, and oyster abundance and water quality monitoring activities in the Loxahatchee River study area. Coverage of submerged aquatic vegetation in Lake Worth Lagoon has expanded since 2001, particularly in the southern region. The District collaborated with local partners to expand a water quality monitoring program within Lake Worth Lagoon. Overall, conditions in Biscayne Bay were stable, but annual hypersaline events in the southwestern area still occur frequently. Work is continuing to develop criteria for minimum flows and reservations of freshwater inflow to Biscayne Bay. Seagrass cover at monitoring stations in Naples Bay remained stable. Water quality monitoring at the discharge of Golden Gate Canal resumed. Independent fish monitoring in Estero Bay has confirmed a link between diversity and salinity. Inflows from the Imperial River and Ten Mile Canal exceeded the long-term average, but inflows from the Estero River (South Branch) were below average. The Florida

Bay section includes results from major monitoring projects (regarding hydrologic and salinity conditions, water quality, seagrass habitat, and roseate spoonbill *(Ajaja ajaja*) nesting), as well as brief updates regarding research and modeling activities and research planning. Most notably, algal blooms (with cyanobacteria, often called blue-green algae) that were sustained in eastern Florida Bay and southern Biscayne Bay from fall 2005 through WY2007 decreased markedly in WY2008, with improved overall water quality conditions. However, in 2005 a mass mortality of sponges in this region was reported. A similar sponge mortality event occurred in southern Florida Bay in summer 2007 and appeared to be caused by a separate cyanobacteria bloom in this region.

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 it relates to freshwater inflows and science strategies. A primary role of the Coastal Watershed Program is to provide the required information necessary 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**). 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 the lead agency.

In keeping with the goal of maintaining brevity, this year's chapter provides brief summaries of the status of key Valued Ecosystem Components (VECs) in each of several priority estuaries, while giving a more detailed description of additional issues and results in the St. Lucie River and Caloosahatchee River estuaries. Each year, the District selects one or two of the estuaries to highlight. It should also be noted that the St. Lucie Estuary and the Caloosahatchee River Estuary are included in the newly implemented Northern Everglades and Estuaries Protection Program (NEEPP). A primary objective of the District is to ensure that an appropriate pattern of fresh water is supplied to the estuaries. This requires knowledge about (1) the current conditions and ecology of each one of the water bodies and watersheds, (2) appropriate water quality and ecological end points with a means to predict potential changes to the freshwater inflow patterns, and (3) impacts to the ecosystems. **Table 12-1** lists the priority estuaries and a summary of facts about each estuary. **Table 12-2** summarizes the status of the development of tools, such as required models, for each of the estuaries presented in this chapter.

The Caloosahatchee and St. Lucie River Watershed Protection Plans (CRWPP and SLRWPP, respectively) have been developed in response to the recent state legislation, which authorized the NEEPP [Section 373.4595, Florida Statutes (F.S.)]. The NEEPP legislation requires development of watershed protection plans for the three Northern Everglades watersheds: (1) the Lake Okeechobee Watershed, (2) the Caloosahatchee River Watershed, and (3) the St. Lucie River Watershed. Specifically, the legislation requires coordinating agencies, including the SFWMD, the Florida Department of Environmental Protection (FDEP), and the Florida Department of Agriculture and Consumer Services (FDACS), in cooperation with Lee, Martin, and St. Lucie counties and affected municipalities, to submit the watershed protection plans to the Florida legislature by January 1, 2009. There is ongoing coordination between the development teams of the Caloosahatchee and St. Lucie River Watershed Protection Plans and the development teams of the Lake Okeechobee Watershed Construction Project (LOWCP) Phase II Technical Plan. Refinements of the Coastal Ecosystem Science Plan over the past water year have been concentrated on the Caloosahatchee River and Estuary and St. Lucie Estuary to support the NEEPP.

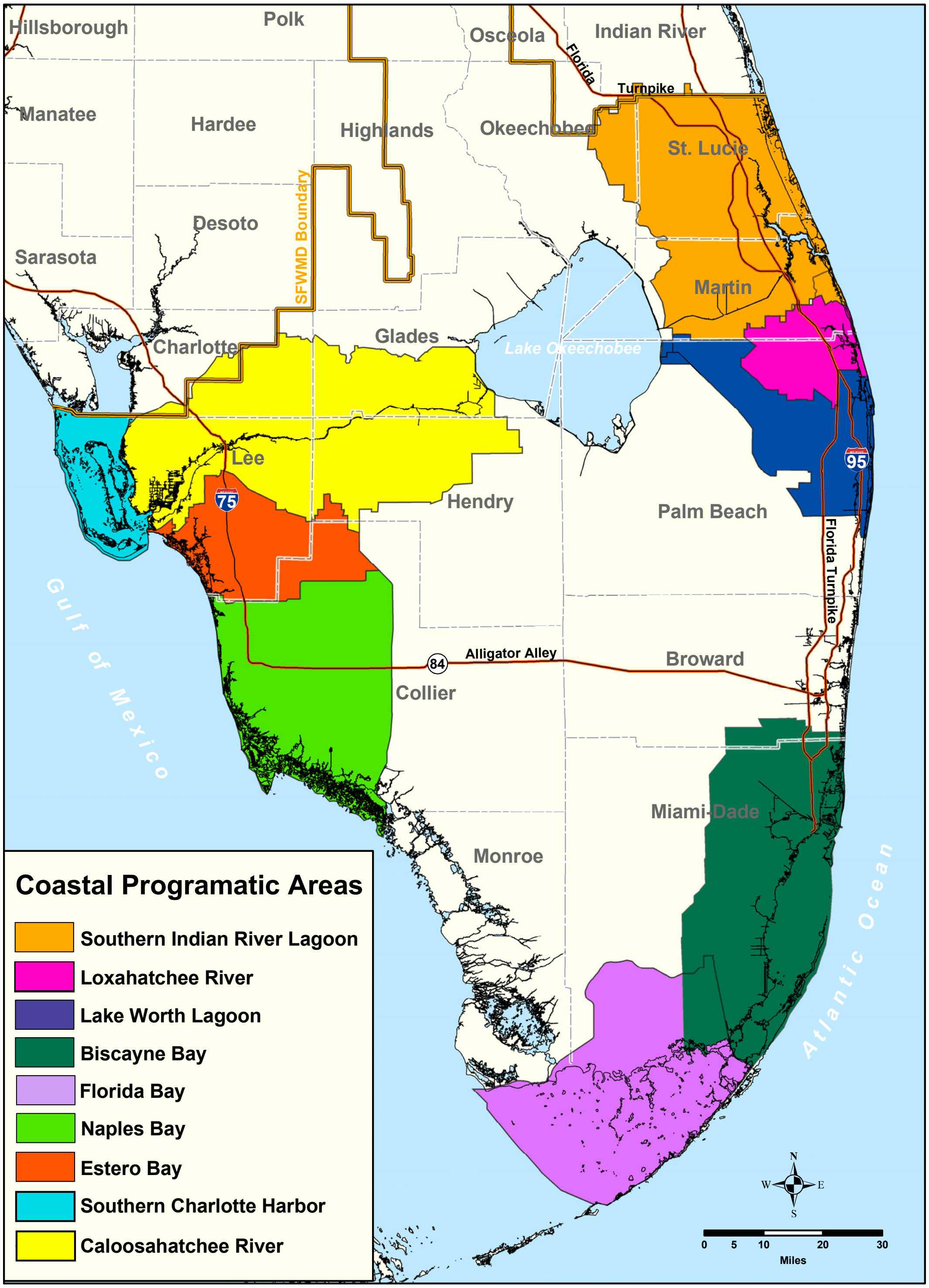

Figure 12-1. Priority coastal watersheds within the South Florida Water Management District (SFWMD or District).

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**	**Past Conditions**
St. Lucie River and Southern Indian River Lagoon	(1) Calibrated WASH Model for hydrology. Field data for inflows and water quality being collected for verification (2) WASH water quality component under development (FDEP)	Hydrological Simulation Program Model hydrology simulations completed
Loxahatchee River	Calibrated WASH Model for hydrology Groundwater model under development	Regional Simulation Model under development. Will be converted to hindcast conditions
Lake Worth Lagoon	Lower East Coast Sub-regional ModFlow Model	NA
Biscayne Bay	South Florida Water Management Model used, but not appropriate for all applications. RSM developed	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	(1) HSPF (hydrology and water quality) and EFDC (hydrodynamic and water quality) under development (FDEP) (2) Calibrated MIKE SHE Regional Model for stage and flow (hydrology) (3) Northern Everglades Regional Simulation Model under development (4) 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; integrated surface and groundwater model under development	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 Mode.	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 calibrated	CH3D Model calibrated	NA	NA
Caloosahatchee River Estuary	CH3D Model calibrated EFDC Model under development (FDEP)	CH3D Model calibrated and regression models used to estimate salinity EFDC Model under development*	EFDC water quality component under development (FDEP) WASP Model under development (FDEP)	NA
Southern Charlotte Harbor	EFDC Model under development (FDEP)	EFDC Model under development (FDEP)	EFDC and WASP models under development (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 *Thalassia/Halodule (turtle and shoal grass)* competition	NA	Salinity HSI models for shoreline fish	NA	Wading bird abundance based on water levels
Florida Bay	Dynamic seagrass community 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; spoonbill *(Ajaja ajaja)* statistical model; documentation under way
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, 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
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	NA
Estero Bay	NA
Caloosahatchee River Estuary	Caloosahatchee River (C-43) West Basin Storage Reservoir (CERP) and Southwest Florida Feasibility Study
Southern Charlotte Harbor	

AFSIRS – Agricultural Field Scale Irrigation Requirements
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
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
RMA – Resource Management Associates hydrodynamic model
RSM – Regional Simulation Model
SFWMM – South Florida Water Management Model
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

ST. LUCIE RIVER AND CALOOSAHATCHEE RIVER WATERSHED PROTECTION PLANS

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The St. Lucie River and Caloosahatchee River Watershed Protection Plans have been developed in response to state legislation adopted in June 2007, authorizing the Northern Everglades and Estuaries Protection Program Section 373.4595, F.S. The NEEPP legislation requires development of watershed protection plans for the three Northern Everglades watersheds: (1) the Lake Okeechobee Watershed, (2) the Caloosahatchee River Watershed, (3) and the St. Lucie River Watershed (**Figure 12-2**).

Specifically, the legislation requires coordinating agencies, including the SFWMD, FDEP, and FDACS, in cooperation with Lee, Martin, and St. Lucie counties and affected municipalities, to submit the SLRWPP and CRWPP to the Florida legislature by January 1, 2009. The LOWCP Phase II Technical Plan was completed in February 2008 and is available on the District's web site at www.sfwmd.gov, under the *Northern Everglades* tab. With the support of coordinating agencies and other partners, the District is currently preparing the Caloosahatchee and St. Lucie River Watershed Protection Plans. In accordance with the legislative reporting requirements, the following section constitutes the required annual progress report on the SLRWPP and CRWPP, supplemented by updates on the LOWCP Phase II Technical Plan and expenditure of funds from the Save Our Everglades Trust in Chapters 10 and 13 of this volume, respectively.

The objective of this section is to provide an overview of the Water Year 2008 (WY2008) (May 1, 2007–April 30, 2008) status and future planned activities associated with the CRWPP and SLRWPP, which include the following three components:

Caloosahatchee and St. Lucie River Watershed Construction Projects. The purpose of the CRWPP and SLRWPP construction projects is to improve hydrology, water quality, and aquatic habitats within the river watersheds by (1) identifying potential water quality and quantity projects, (2) formulating alternatives based on the projects identified, and (3) identifying a preferred alternative for each watershed that results in the most benefit to the Caloosahatchee and St. Lucie estuaries.

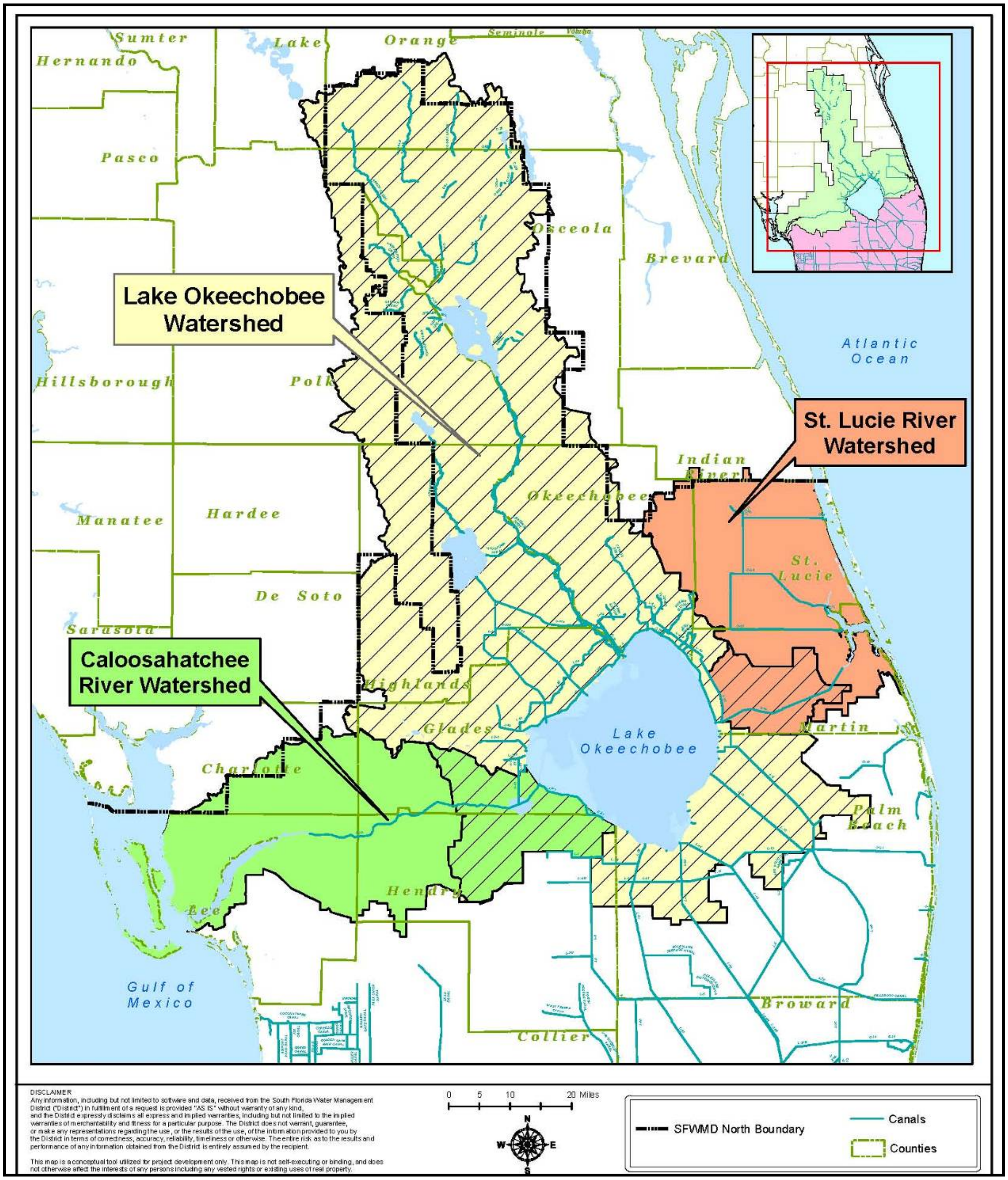

Figure 12-2. Northern Everglades and Estuaries Protection Program (NEEPP) area as defined by the Florida legislature.

Caloosahatchee and St. Lucie River Watershed Pollutant Control Programs. These programs are designed to be multifaceted approaches to reducing pollutant loads by improving the management of pollutant sources within the river watersheds through (1) the implementation of regulations and Best Management Practices (BMPs); (2) the development and implementation of improved 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. The coordinating agencies will facilitate the utilization of federal programs offering opportunities for water quality treatment, including preservation, restoration, or creation of wetlands on agricultural lands.

Caloosahatchee and St. Lucie River Watershed Research and Water Quality Monitoring Programs. The Research and Water Quality Monitoring programs will build upon the District's existing research programs, and are intended to carry out, comply with, or assess the plans, programs, and other responsibilities created by the Watershed Protection Plans. Under these Research and Water Quality Monitoring programs, assessments will be conducted of the water volumes and timing from the Lake Okeechobee Watershed, Caloosahatchee River Watershed, and St. Lucie River Watershed, and their relative contributions to the estuaries.

The District is conducting a comprehensive, systematic planning process to develop the Watershed Protection Plans. This process involves extensive stakeholder input through working team and stakeholder meetings as well as informal interaction. Specific aspects of the planning process include:

- Characterization of existing conditions
- Determination of planning problems, objectives, and constraints
- Selection of performance measures and management measures
- Formulation and evaluation of alternatives
- Selection and processing of the preferred plan

In the context of this plan, problems are considered undesirable conditions. Identified problems include excess regulatory discharges from Lake Okeechobee into the estuaries, excess discharges resulting from watershed runoff, excess nutrient loads to fresh and estuarine portions of the river, undesirable low flows to the estuary, and undesirable salinity ranges and associated effects on aquatic habitats.

The SLRWPP and CRWPP's objectives are intended to (1) solve the identified problems, and include maximizing nitrogen (N) and phosphorus (P) load reductions to meet the respective Total Maximum Daily Loads (TMDLs) once they are established for the Caloosahatchee and St. Lucie estuaries; (2) manage Lake Okeechobee flows and watershed discharges to meet desirable salinity ranges for the estuaries; and (3) establish Research and Water Quality Monitoring programs sufficient to implement the Watershed Protection Plans. Constraints include maintaining the existing levels of flood protection and water supply for affected water basin users, and Minimum Flows and Levels (MFLs).

Management measures are features or activities that can be implemented at a specific site within the study area to address one or more planning objectives. Management measures are building blocks of alternative plans. A comprehensive list of management measures was prepared, evaluated, and screened to eliminate features or activities that did not contribute to meeting the planning goals and objectives. This comprehensive list included many features and activities that are already under way or imminent that will contribute to achievement of the planning objectives. Management measures considered for capturing and storing stormwater runoff in the river watersheds included aboveground reservoirs, alternative water storage facilities and Aquifer Storage and Recovery wells. Examples of water quality focused management measures included source control, such as BMPs, Stormwater Treatment Areas (STAs), stormwater retrofits, and hybrid wetland treatment technologies. The intent of these plans is to build upon and dovetail with ongoing restoration activities; therefore, the plan will consolidate many previous restoration efforts and determine whether additional management measures are necessary to achieve the planning objectives.

For water quality, each sub-watershed within the Caloosahatchee and St. Lucie rivers and watersheds is evaluated with respect to its current nutrient load, concentration, land use, and other relevant factors. For water quantity, excess water (i.e., stormwater runoff) is identified in each sub-watershed based on hydrologic simulations. Hydrologic simulations of current conditions were compared to ecologically based flow targets to determine the quantity and timing of excess flows, which were used to calculate storage targets. Four alternative plans are currently being formulated and evaluated by the planning team. Alternative 1 includes common elements consisting of all the ongoing or imminent projects in the Caloosahatchee and St. Lucie rivers and watersheds and is included in all subsequent alternatives. Alternative 2 is formulated to maximize storage benefits, and Alternative 3 is formulated to maximize water quality benefits. Alternative 4 incorporates a combination of management measures from the other alternatives, and is intended to optimize both storage capacity and N and P load reductions. Performance of each individual alternative plan will be assessed based on water quantity and quality analyses, and then performance measures will be used to compare the performance of each alternative plan to one another. The alternatives evaluation will culminate in identification of a preferred plan. In the future, progress toward meeting the water quantity and quality goals of the SLRWPP and CRWPP will be measured, and necessary revisions will be incorporated into the plans every three years.

In addition to the Caloosahatchee and St. Lucie River Watershed Construction projects and Pollutant Control programs, the Caloosahatchee and St. Lucie River Watershed Research and Water Quality Monitoring programs are currently under development. Evaluation and assessment of existing monitoring and research have been conducted by a working team established for this purpose. These plans include the current state of knowledge regarding hydrology, water quality, and aquatic habitat and reviews of nutrient loading, salinity envelopes, and effects of Lake Okeechobee on delivery of water to the Caloosahatchee and St. Lucie systems. A summary of existing monitoring programs for hydrology, water quality, and aquatic habitat will be included. These monitoring programs will be evaluated based on their ability to meet program goals and potential improvements will be identified. A recommended monitoring plan, along with associated costs of implementation will be described. Lastly, ongoing research and modeling applicable to program goals will be described, and future research and modeling needs will be identified and prioritized.

The formulation and evaluation of all three components of the CRWPP and SLRWPP (i.e., construction projects, Pollutant Control Program, and Research and Water Quality Monitoring programs) are ongoing. The draft CRWPP and SLRWPP were released for public comment in fall 2008, followed by their presentation to the District's Governing Board in December 2008. Once approved, they will be submitted to the Florida legislature by January 1, 2009, in accordance with the mandated deadline.

In accordance with the legislation, the preferred plan shall be updated every three years. More specifically, the legislation requires the District, in cooperation with coordinating agencies, to conduct an evaluation of pollutant reduction goals and any other specific goals stated in the CRWPP and SLRWPP by 2012 and every three years thereafter. This requirement defines an adaptive management feedback loop that allows information generated by monitoring, modeling, and research to assist and support the periodic assessments and identify potential modifications. The Research and Water Quality Monitoring programs and associated projects will generate results to determine if nutrient reduction goals are being met and if frequency and duration of undesirable salinity ranges are declining. Furthermore, information gathered from monitoring, modeling, and research can be used to identify refinements to performance measure targets, changes to facility operations and implementation priorities, and make improvements to predictive models.

STRATEGY OVERVIEW

Three major management goals for the St. Lucie River and Caloosahatchee River estuaries are to (1) reduce pollutant loads to non-harmful levels, (2) ensure that freshwater loads sustain a healthy estuary, and (3) maintain appropriate salinity envelopes. Research to address and support attainment of these overarching goals is described below for pollutant loads, salinity envelopes, freshwater inflows, and environmental operations.

Pollutant Loads

A goal of the research program is to provide robust scientific support for — and to reduce the uncertainty — in estimating the appropriate level of pollutant loads. The program should quantify (1) the relationship between the biological resources upon which a load may be based (e.g., seagrass) and aspects of water quality that load targets seek to improve, and (2) the roles of nutrient loading and the dynamic biogeochemical processes in controlling water quality parameters (e.g., chlorophyll *a*, dissolved oxygen, and nutrients).

Salinity Envelopes and Freshwater Inflow Targets

These provide the basis for management of the quantity of fresh water discharged to the St. Lucie and Caloosahatchee estuaries. The goal of the research is to reduce the uncertainty of these resource-based targets, and to quantify not only what are undesirable flows and salinity patterns, but also to identify the critical periods when meeting these targets is most ecologically beneficial.

Environmental Operations

To improve environmental conditions in the estuary, protection plans may call for the construction of facilities designed to help meet pollutant load targets, and freshwater inflow and salinity targets by attenuating and storing stormwater runoff, and to reduce nutrient loads. Operation of these facilities will be vital to meet environmental objectives, and monitoring and short-term studies will be required to adaptively manage these facilities.

Adaptive Management

Research conducted within the context of an environmental protection program supports and informs adaptive management. Adaptive management is the iterative and deliberative process of applying the principles of scientific investigation to the design and implementation of a program to better understand the ecosystem and predict its response to implementation, and to reduce key uncertainties. The basis of adaptive management is the use of feedback loops that iteratively feed new information into the decision making process for planning, implementation, and assessment of project components. A tri-annual assessment will provide this feedback loop and ensure the incorporation of adaptive management in management of the estuary.

Research to support adaptive management will use a combination of models (conceptual to numeric), and observational and experimental studies to reduce uncertainty in the pollutant load targets and salinity/flow targets; improve the operations of water storage and water quality projects; and increase predictive capability. The role of modeling is to provide a mechanism for synthesis, hypothesis specification and preliminary testing; and to enhance predictive capability.

SOUTHERN INDIAN RIVER LAGOON AND ST. LUCIE RIVER ESTUARY

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INTRODUCTION

The St. Lucie Estuary (SLE) 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). 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) that extends east for about 5 miles (8 km) to the Indian River Lagoon (IRL) and the Atlantic Ocean at the St. Lucie Inlet.

The SLE and its watershed (**Figure 12-3**) have been highly altered to accommodate human development. During recent history, the freshwater St. Lucie River 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 dug and maintained, allowing for the current brackish water system. 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. Periodic high-volume flood control discharges from the lake have turned 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. Major effects of this drainage system include reductions in groundwater levels and evaporation, and rapid watershed drainage manifested by changes in the quantity, quality, timing, and distribution of inflows to the estuary. Discharges from the lake, altered watershed hydrology, and water quality have degraded estuarine resources such as submerged aquatic vegetation (SAV), oyster communities, and fisheries.

STATUS OF THE ST. LUCIE ESTUARY

The SFWMD monitors several health indicators of the St. Lucie River Estuary and Southern Indian River Lagoon. These include the biological VECs such as SAV, Eastern oyster (*Crassostrea virginica*) abundance and distribution, and floodplain vegetation, as well as physical and chemical indicators such as salinity, freshwater inputs, and nutrients.

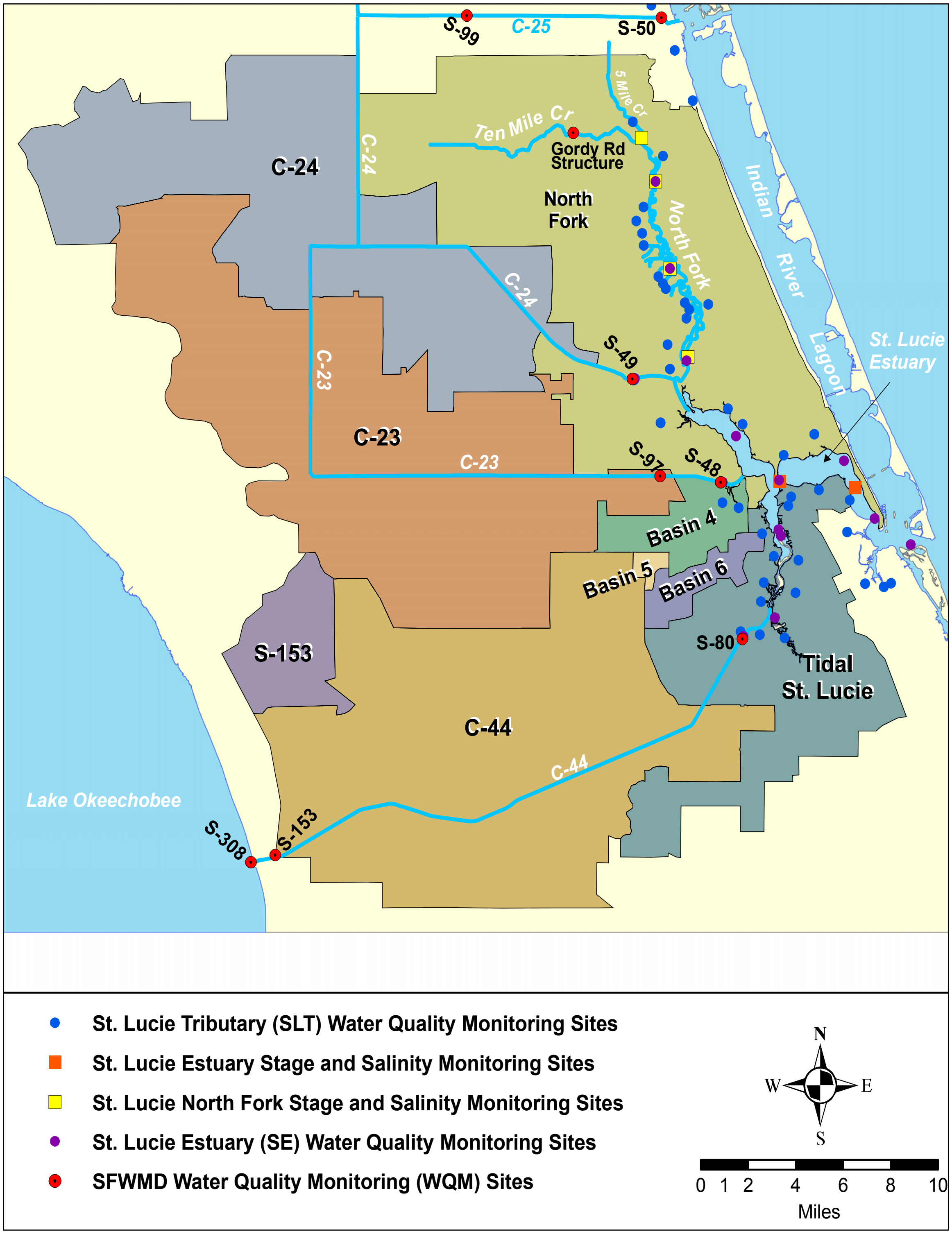

Figure 12-3. St. Lucie Estuary (SLE) water quality monitoring network.

Submerged Aquatic Vegetation

Seagrasses, often referred to as submerged aquatic vegetation, 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; Tomasko et al., 1996; Thayer et al., 1984). 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 allows 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. Additionally, this in situ monitoring provides species-specific data — a level of detail that cannot be obtained from maps created by using aerial photographs.

Submerged Aquatic Vegetation Mapping

Indian River Lagoon. Lagoon-wide SAV mapping from aerial photographs is normally done in partnership with the St. Johns Water Management District every two to three years to document trends over time. The 2007 SAV map is shown in **Figure 12-4**. Changes in Southern Indian River Lagoon SAV acreage and distribution between 1986 and 1999 are documented in Robbins and Conrad (2001). A change analysis using the 2007 information is currently in progress.

Lagoon-wide SAV maps, based on aerial photographs, provide an overall understanding of the SAV coverage and distribution in the entire Indian River Lagoon. 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 the southern part of the IRL (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 is the focus of a 2007/2008 species-specific mapping test project using extensive field work and sub-meter accuracy Global Positioning System (GPS) technology. Results of this project are expected to be available in 2009.

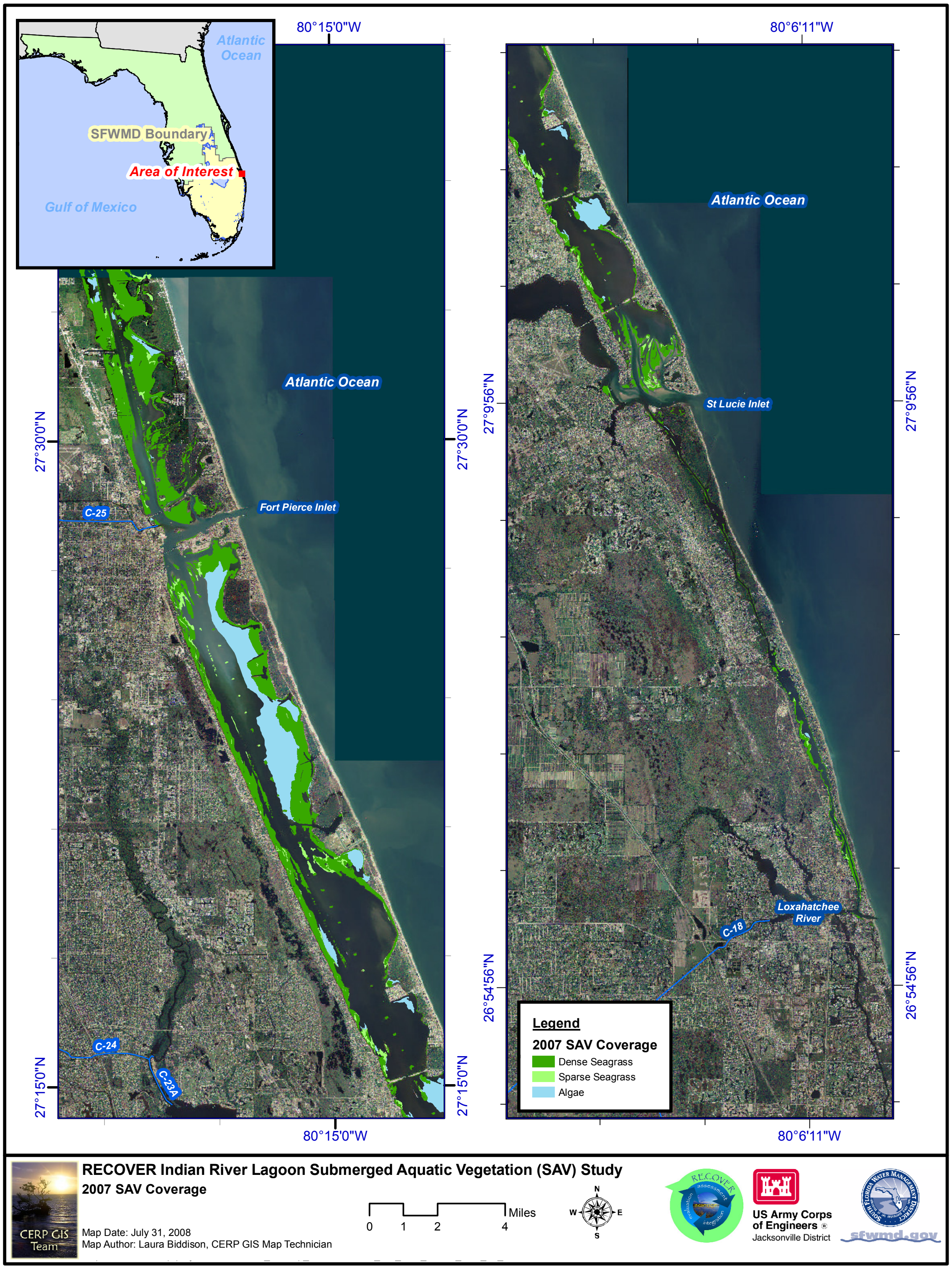

Figure 12-4. Results of Indian River Lagoon submerged aquatic vegetation (SAV) mapping project conducted in summer 2007.

St. Lucie Estuary. Due to the dark water in the SLE, it is not possible to map SAV from aerial photographs. Instead, intensive field work coupled with sub-meter accuracy GPS technology was used to map SLE SAV during the summer of 2007 (Ibis Environmental, Inc., 2007). Most areas inspected did not support SAV. Very sparse [less than (<) 10 percent cover in most areas] SAV was present in the lower and mid-estuary, but not in either of the Forks. Three seagrass species occurred within the project boundary: (1) shoal grass (*Halodule wrightii*), (2) Johnson's seagrass (*Halophila johnsonii*), and (3) paddle grass (*Halophila decipiens*). The majority of the SAV occurred in small isolated patches. The dominant SAV species in the project area in calendar year 2007 (CY2007) was Johnson's seagrass. It also extended farther upstream than any other SAV species.

Johnson's seagrass is a diminutive species [< 3 centimeters (cm) blade length] that grows on a variety of substrates in the SIRL and SLE. Limited data suggest that this species survives and grows best at salinity near 30 practical salinity units (psu) (Irlandi 2006). Of particular note, Johnson's seagrass is the only seagrass 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.

In 1940, seagrass beds extended all the way up into the North Fork along the shoreline by some accounts (URS Greiner Woodward Clyde, 1999). A 1994 study determined that a depth target of about 1 meter (m) was recommended for SAV restoration in the SLE (Steward et al., 1994). **Figure 12-5** shows that meeting this depth target may result in a thin fringe of SAV throughout much of the estuary. Restoration efforts will likely focus on meeting oyster salinity requirements in the middle estuary, so seagrasses with similar requirements should thrive. Widgeon grass (*Ruppia maritima*) is the most likely SAV species to be successful in the North and South Forks once the restoration salinity regime is in place (lower salinity conditions). The middle estuary will most likely support SAV species such as shoal and Johnson's seagrasses. The lower estuary, where highest salinity (and clearest water) will occur, will most likely continue to support shoal and Johnson's seagrasses, and may eventually support manatee grass (*Syringodium filiforme*) (as observed by Phillips and Engle, 1960).

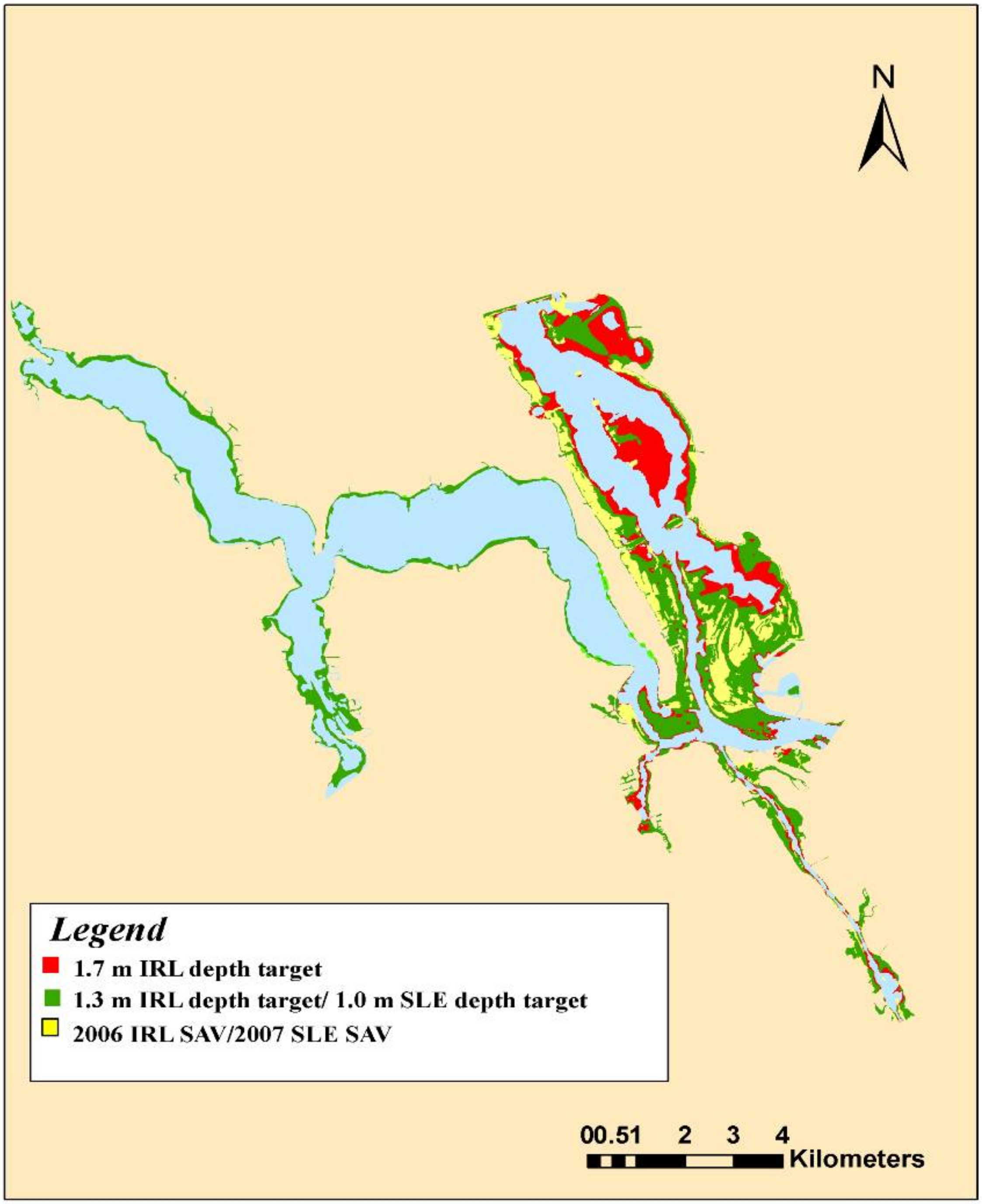

Figure 12-5. Potential SAV depth targets and 2006/2007 SAV distribution.

Submerged Aquatic Vegetation Monitoring

Monthly and semiannual seagrass monitoring in the SIRL continued in 2007 (**Figure 12-6**). The monthly monitoring was a five-year project, which concluded in August 2007. The purpose of the monthly monitoring was to better understand (1) the natural seasonal variability of seagrass and macroalgae in the study area, and (2) the response of the seagrass community to freshwater discharge. The semiannual monitoring is part of a lagoon-wide, multiple agency effort initiated in 1994 to document long-term seagrass trends.

The seagrass monitoring sites near the St. Lucie Inlet showed significant signs of damage from hurricane impacts in 2004 and 2005. During 2006 and 2007, monitoring documented seagrass recovery. Detailed data analysis is not complete; however, in general, recovery began with colonization of bare substrate by the smallest seagrass species (Johnson's seagrass and paddle grass). Additionally, attached macroalgae (*Caulerpa* sp.) abundance increased at some of the sites. Recovery has been slower for the more robust seagrass species.

A new SAV monitoring initiative began in summer 2008 using a methodology developed by an interagency Restoration Coordination and Verification (RECOVER) SAV sub-team. The monitoring will be conducted every two months at sites shown on **Figure 12-6**. Sites formerly included in the monthly monitoring will now be monitored every other month using the new methodology.

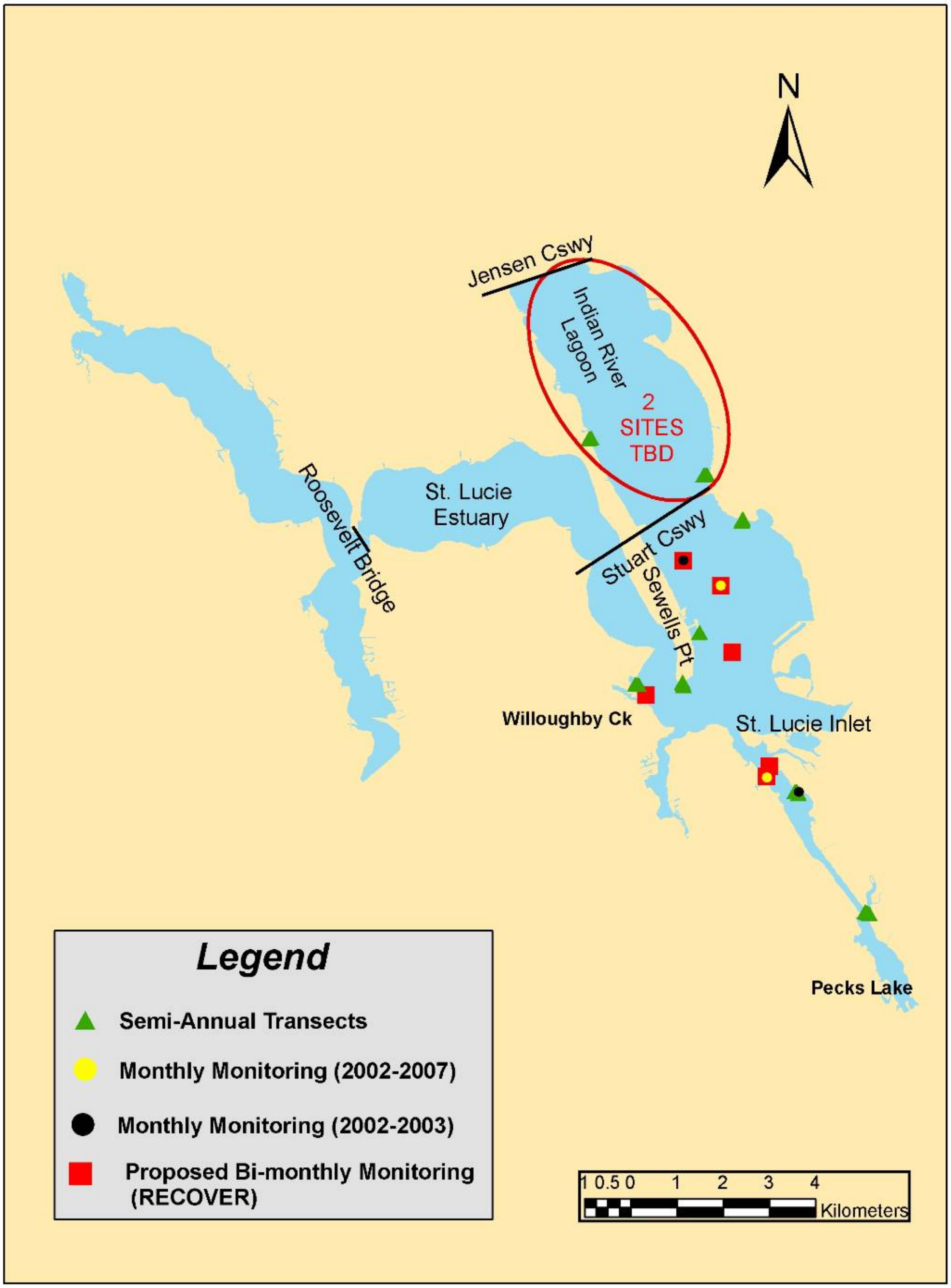

Figure 12-6. Southern Indian River Lagoon seagrass monitoring sites located in and near the mouth of the St. Lucie River.

Eastern Oyster Abundance and Distribution

The SLE has experienced severe alterations of the distribution, quantity, and timing of freshwater inflows as a result of water management infrastructure and practices. These alterations have in turn caused stressful, and at times lethal, changes in salinity for the Eastern oyster communities in the estuary.

It is predicted the SLE will experience improvements in water quality and inflow characteristics due to the implementation the Comprehensive Everglades Restoration Plan (CERP) Indian River Lagoon – South Project. The Monitoring and Assessment Program (MAP) component of CERP is designed to provide a diverse approach to documenting and describing the impacts of these changed freshwater inflows on the flora and fauna inhabiting inland landscapes and coastal waters. Because of the oyster's wide distribution, and essential habitat value, it is considered an indicator of estuarine health (VEC) by the SFWMD. Therefore, the distribution and abundance of oysters will be monitored. A long-term monitoring program of the Eastern oyster in the SLE was implemented in 2004 through a contract with the Florida Fish and Wildlife Conservation Commission (FWC). Oyster monitoring occurs at three locations: in the inner estuary at both the North and South Forks, and in the central estuary (**Figure 12-7**). Each site is monitored for (1) spatial and size distribution of adult oysters; (2) distribution and frequency of the oyster diseases *Perkinsus marinus* ("dermo") and *Haplosporidium nelsoni* (MSX); (3) reproduction and recruitment; and (4) juvenile oyster growth and survival. The change in spatial extent and health of the oyster beds is a key performance measure that will help assess the success of CERP. Yearly summary reports are analyzed to determine if the health and spatial extent of the oysters are improving over time.

Overview of Current Oyster Monitoring Program

Adult oysters are sampled in the SLE by the FWC. Recruitment is monitored by examining the density of spat collected from oyster-shell cultch. Reproductive development and disease occurrence is assessed by analyzing adult oyster samples using standard histological and microscopic analyses. Juvenile oyster growth is estimated from measurements of wild oysters recruited to artificial substrate and tracked for about one year beginning with the early post-settlement phase. In addition, water quality data (temperature, salinity, conductivity, pH, dissolved oxygen, and turbidity) are collected monthly. The size and vitality of adult oysters are sampled semiannually from randomly located quadrats at each station. Sampling is conducted to assess oyster recruitment reproduction condition, density of live oysters, shell height, and disease prevalence. Some of the most informative data from this project is presented.

Recruitment of oyster larvae (**Figure 12-8**), as represented by the presence of oyster spat on shell collectors in the inner and central estuary, did not occur in 2005 when salinities were very low (near 0 psu) during the spring and summer. However, under more normal salinity conditions in 2006 and 2007, major recruitment occurred in July and June, respectively, with the South Fork having the least recruitment of all sites. Even though no live oysters were obtained in the inner estuary in 2005, recruitment in summer 2006 during more favorable salinity conditions allowed oysters to re-populate the inner estuary as documented in fall 2006. Once established in the inner estuary, the mean height incrementally increased. Densities of live oysters were always significantly higher in the central estuary and reached a near 400 oysters/square meter (m^2) in fall 2007 before decreasing to about 170 oysters/m^2 during spring 2008 (**Figure 12-9**).

Oyster Mapping. The District conducts baseline mapping of the density of living oyster reef distribution in the SLE. A map of oyster reefs in 1997 identified 208 acres of living oyster habitat, while a more recent survey in 2003 documented only 117 acres. A map of oyster reefs will be created every five years and will include size, distribution, and density of living oysters. Water inflow management and the addition of hard substrate (cultch) resulting from implementing CERP is expected to restore suitable oyster habitat back to perceived historical distributions of about 890 acres within the inner and central estuaries.

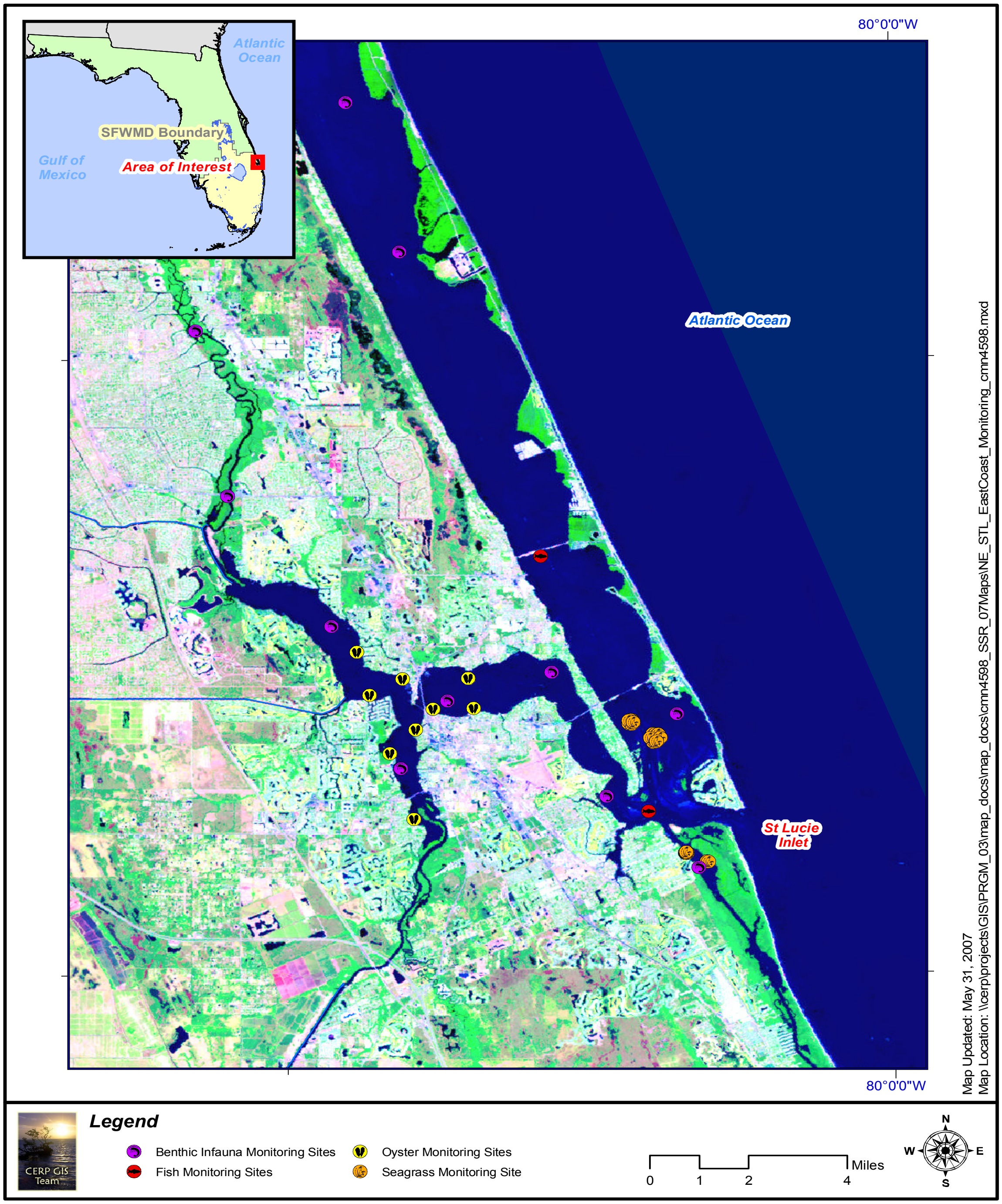

Figure 12-7. SLE monitoring sites.

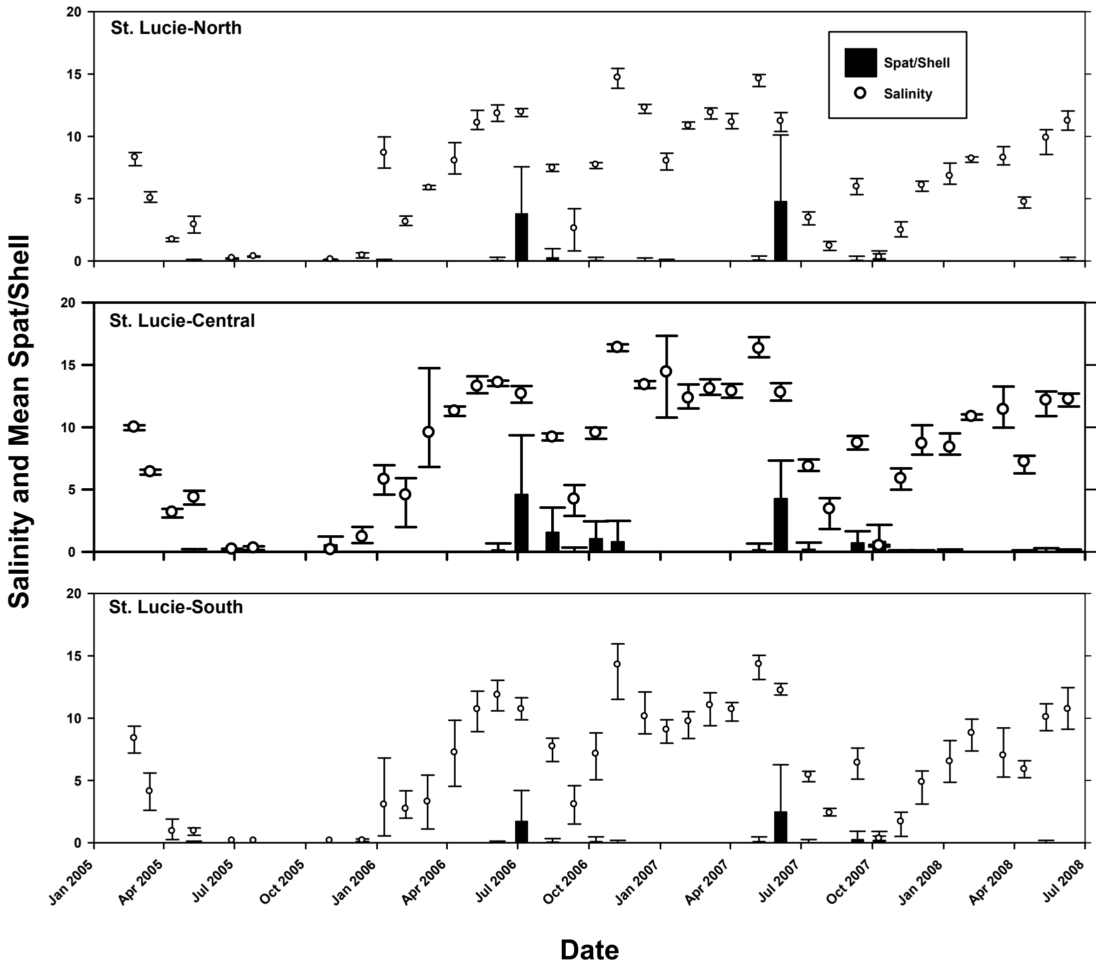

Figure 12-8. Mean (± S.D.) number of oyster recruits collected per shell each month and the mean, maximum and minimum salinity recorded each month. The first retrieval of recruitment collectors occurred in March 2005.

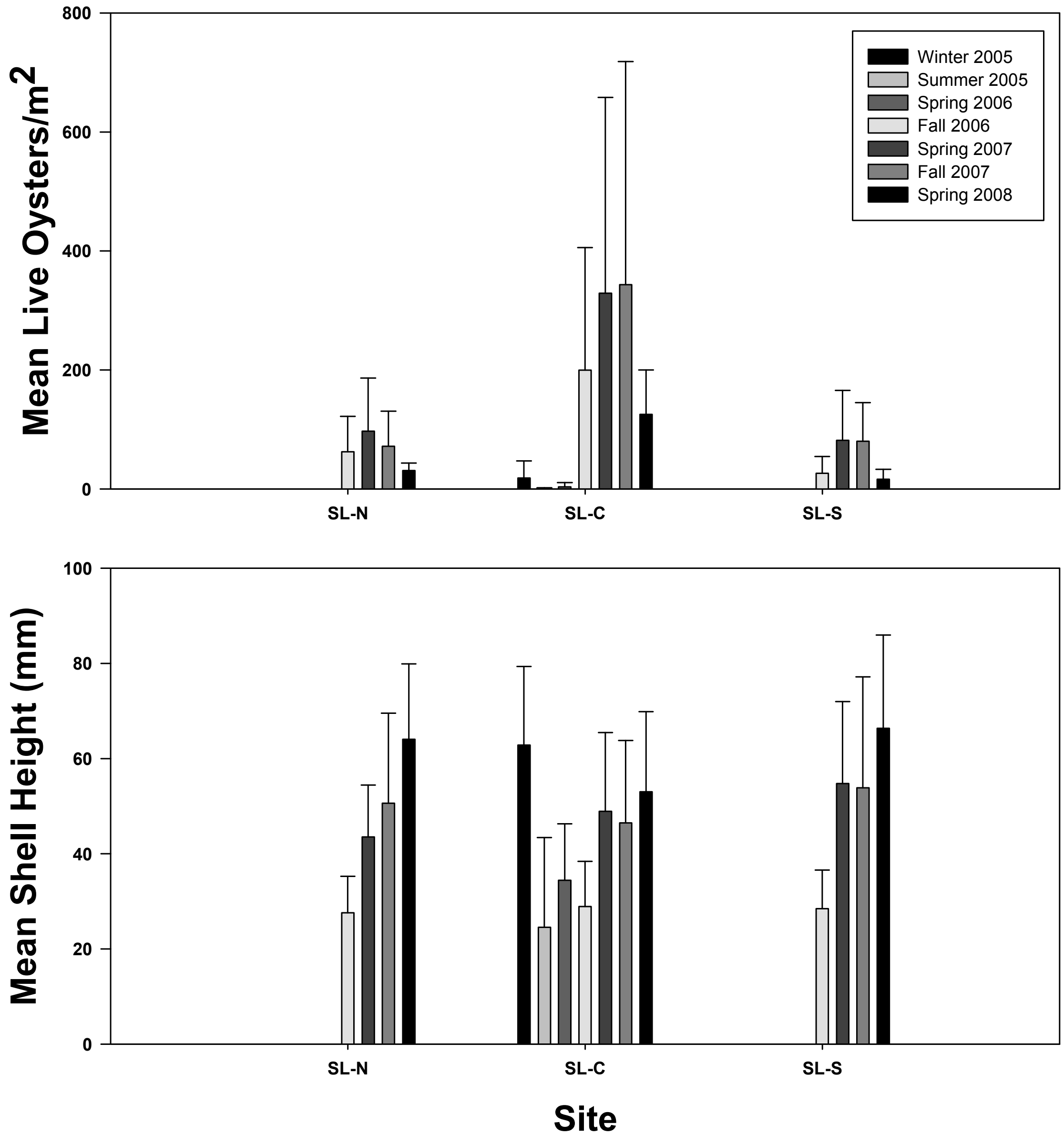

Figure 12-9. Mean number of live oysters sampled and the mean shell height (millimeters) of oysters present during each survey in the SLE. (SL-N = St. Lucie-North, SL-C = St. Lucie-Central, SL-S = St. Lucie-South).

Floodplain Vegetation

A study has been initiated by the District to identify historical and current floodplain vegetation communities, examine their current health, and make recommendations regarding the impact of enhancing current freshwater flow and salinity patterns in the North Fork of the St. Lucie River. Three vegetative transects have been identified, and benchmarks have been established to examine canopy, shrub and ground cover communities along segments of the North Fork and Ten Mile Creek. Better management of flow will improve water quality and reduce sediment deposition in the St. Lucie Estuary. It is important for the District to examine ways to protect and enhance hydrological conditions on the remaining river floodplain communities. This information will also be helpful when developing adaptive management of flows from the Ten Mile Creek Water Preserve Area and the improved management of flows from future reservoirs or STAs.

Topographical Analysis of the Floodplain Using LiDAR Technology

One of the most important datasets for understanding the hydrology and hydrodynamics of this river is elevation. Elevation data from the North Fork of the St. Lucie River are being evaluated (1) to identify the extensive system of berms created when the river was dredged for flood control from the 1920s to the 1940s; (2) to identify potential areas for oxbow or floodplain reconnections; (3) to determine the current levels of inundation across the floodplain; and (4) to assist in the identification of changes in vegetative types. Light Detection and Ranging (LiDAR) technology was the most cost-effective way of acquiring the amount of elevation data required for this type of analysis of the river and its floodplain. LiDAR data are being used for floodplain mapping and the creation of a Digital Elevation Model of the project area (**Figure 12-10**).

Inflows and Salinity in the St. Lucie Estuary

To protect a key region of the estuary, a Minimum Flows and Levels (MFLs) rule for the North Fork of the St. Lucie Estuary was established on November 6, 2002 (SFWMD, 2002). The rule states that inflows should not fall below 28 cubic feet per second (cfs) (0.8 cubic meters per second, or m^3/s), monthly average, at the inland Gordy Road structure for two consecutive months. Inflows lower than this threshold for two consecutive years would be considered an exceedance. **Figure 12-11** shows flows at this structure from the year 2002 to the present with no exceedances. Potential impacts near the location of discharges make releases of water through the C-23, C-24, and C-44 canals an ineffective means of providing freshwater inflows to prevent significant harm from occurring to the North Fork of the St. Lucie River and Estuary, so are not figured into meeting the MFL criterion.

District scientists have developed relationships between inflows and salinity. To ensure that salinity at the U.S. Highway 1 bridge does not decrease below 7 psu, inflows from the watershed, groundwater, and/or flood control monthly average releases from Lake Okeechobee should not exceed about 2,000 cfs (56.6 m^3/s). The bridge is at the confluence of the North and South forks and, therefore, salinity at this location indicates the integrated salinity effects of the majority of inflows into the system. **Figure 12-12** indicates that the maximum inflow guideline was not exceeded during WY2008. A salinity and water stage monitoring site was established in May 2007, in cooperation with the FDEP, on the north side of the St. Lucie Inlet to collect additional data in this area.

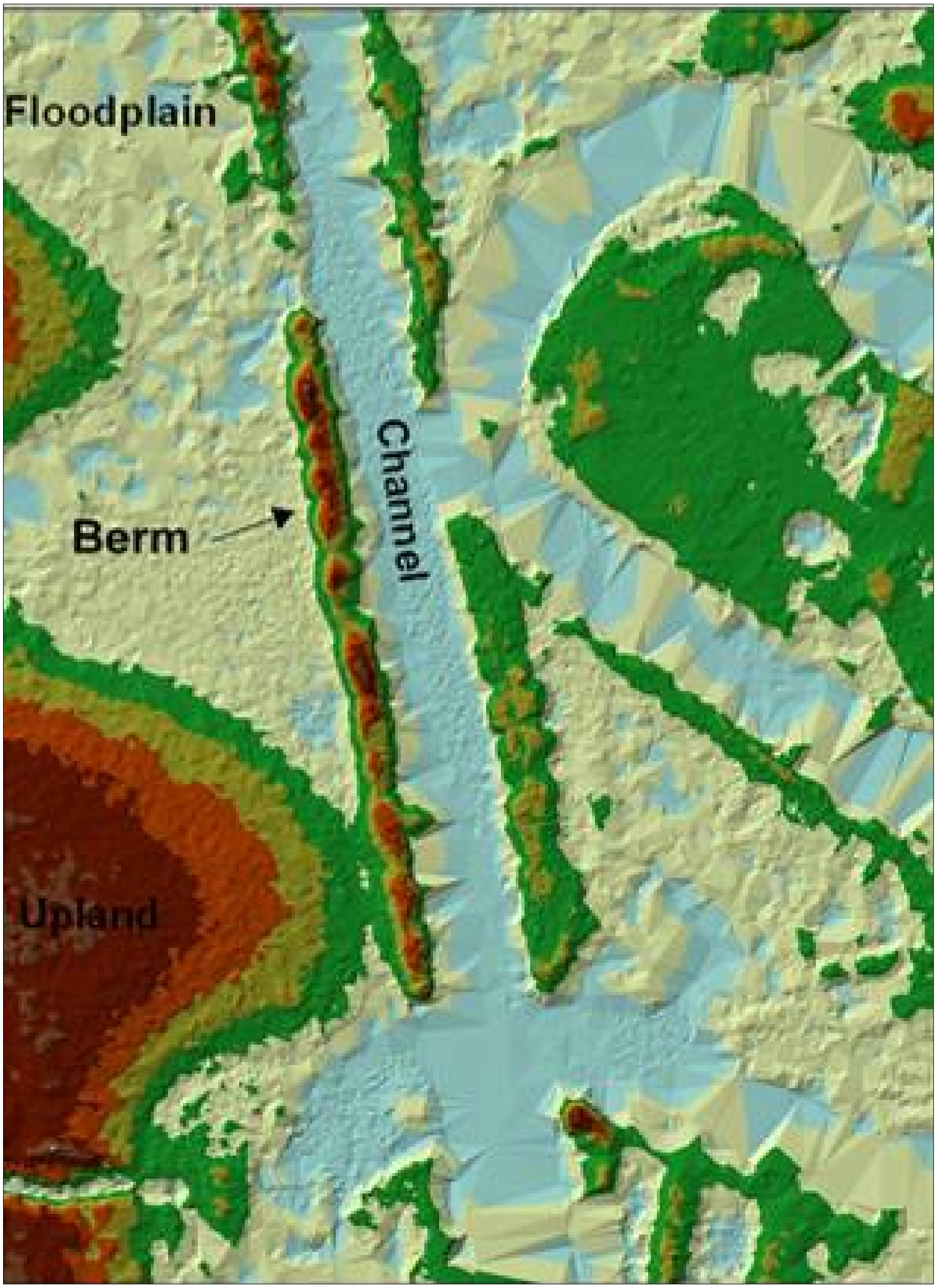

Figure 12-10. Processed LiDaR data from the North Fork of the St. Lucie River illustrating the changes in elevation in the floodplain and surrounding upland areas.

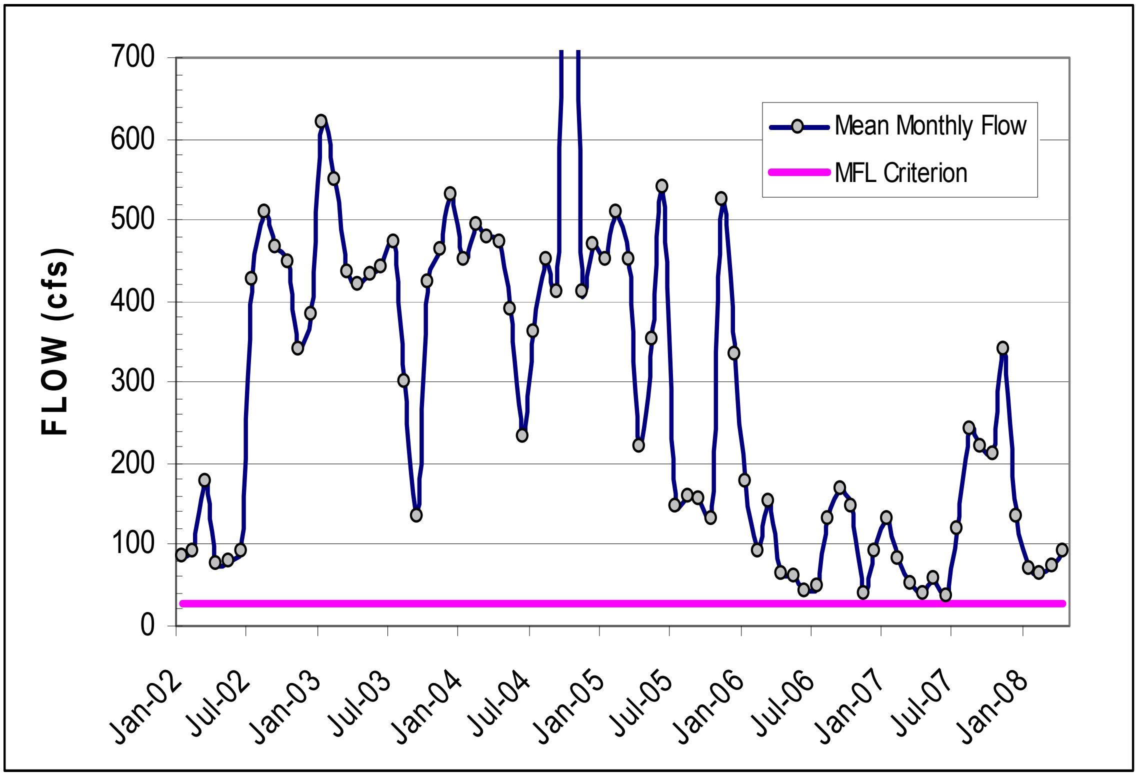

Figure 12-11. Average monthly freshwater flow to the North Fork (Gordy Road structure) compared to the minimum flow criterion [28 cubic feet per second (cfs)] [0.8 cubic meters per second (m^3/s)]. A violation occurs when freshwater flow falls below 28 cfs for two consecutive months and two consecutive years. The Y scale is truncated to show detail.

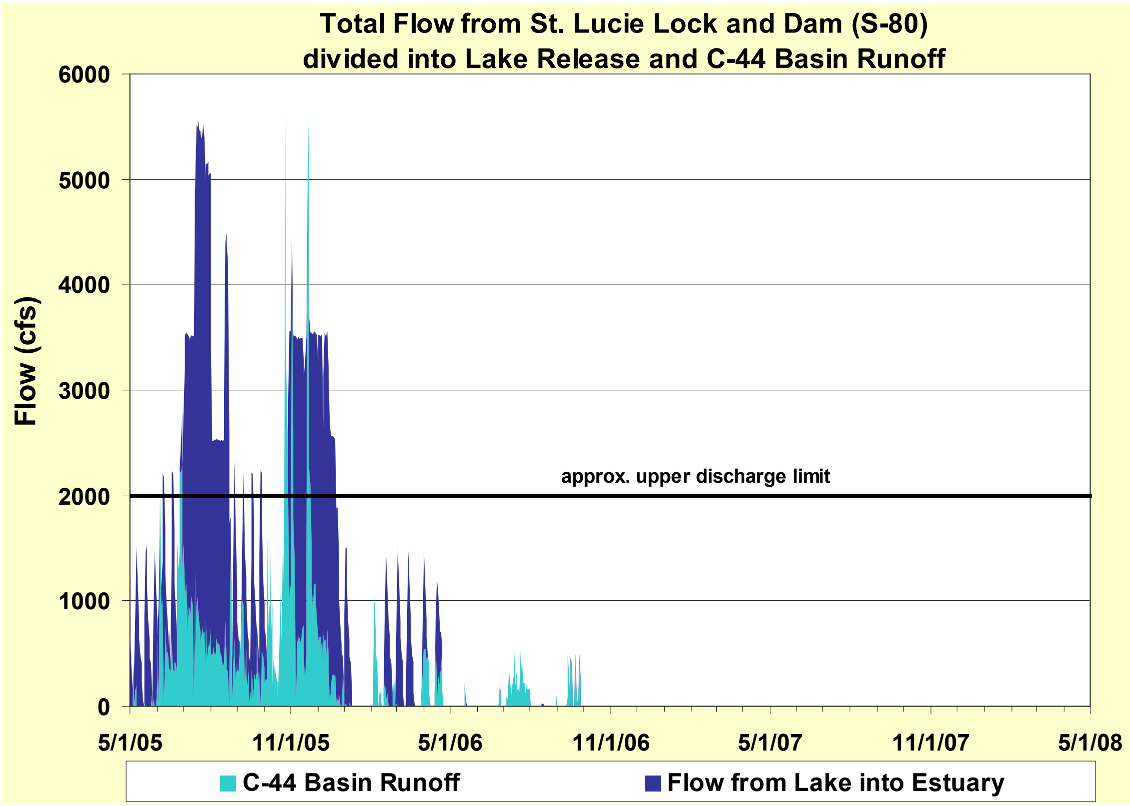

Figure 12-12. Flow results from C-44 compared to the 2,000 cfs total inflow upper limit guideline.

Water Quality

Estuary

The District began monitoring water quality on a monthly basis at 10 locations in the SLE in 1990 (**Figure 12-3)**. An eleventh station was added in the St. Lucie inlet in 1997. Long-term average and median concentrations for the whole estuary and for individual regions are given in **Table 12-3**. Dissolved oxygen (DO) at mid-depth and Secchi disk depth increase in proximity to the ocean. Color and nutrient concentrations decrease.

Comparisons of wet and dry season concentrations show that salinity and DO are higher in the dry season than in the wet season. All other parameters [Color, total nitrogen (TN), total phosphorus (TP), and chlorophyll *a*] have higher concentrations in the wet season related to freshwater inflows. Most monitoring sites are hypoxic part of the time. Stations located near water control structures tended to have a higher incidence of hypoxia and anoxia. This is believed to be a result of stratification between fresh and brackish waters under low- or no-flow conditions.

Table 12-3. Statistical summary of selected water quality parameters in the SLE from July 1992 through December 2006.

Parameter	Mean	±	Standard Deviation	Minimum	Percentiles 5th	25th	50th	75th	95th	Maximum
South Fork										
Salinity (PSU)	3.8	±	5.1	<0.1	0.1	0.2	0.4	6.3	15.5	23.6
Dissolved Oxygen (mg/L)	6.1	±	2.1	<0.1	2.0	4.8	6.4	7.5	9.0	21.3
Apparent Color (PCU)	72.1	±	47.5	0.5	27.0	37.0	55.0	93.8	167.6	314.0
Secchi disk depth (m)	0.8	±	0.4	<0.01	0.2	0.5	0.8	1.0	1.4	7.5
Total Nitrogen (mg/L)	0.75	±	0.63	<0.05	<0.05	0.20	0.63	1.23	1.75	7.09
Total Phosphorus (µg/L)	192.2	±	84.8	72.0	99.0	136.0	174.0	220.0	352.8	710.0
Chlorophyll *a* (mg/m^3)	10.4	±	9.5	0.3	1.6	3.9	7.8	13.3	29.1	73.3
North Fork										
Salinity (PSU)	7.1	±	7.2	<0.1	0.1	0.5	4.9	12.2	20.9	39.0
Dissolved Oxygen (mg/L)	5.6	±	2.2	<0.1	1.5	4.1	5.8	7.1	8.7	20.2
Apparent Color (PCU)	85.1	±	64.5	11.0	25.0	38.0	60.0	115.0	220.0	383.0
Secchi disk depth (m)	1.0	±	0.4	0.1	0.5	0.7	1.0	1.2	1.6	10.0
Total Nitrogen (mg/L)	0.65	±	0.58	<0.05	<0.05	0.13	0.47	1.10	1.65	4.68
Total Phosphorus (µg/L)	236.5	±	120.7	49.0	101.4	159.0	207.0	280.0	466.2	1040.0
Chlorophyll *a* (mg/m^3)	12.2	±	11.4	0.5	2.0	5.0	9.2	16.0	30.9	157.0
Main Estuary										
Salinity (PSU)	17.4	±	10.3	<0.1	0.4	8.6	18.6	26.1	32.4	36.4
Dissolved Oxygen (mg/L)	6.2	±	1.3	<0.1	4.0	5.4	6.2	7.0	8.4	11.6
Apparent Color (PCU)	52.8	±	46.6	0.5	9.0	19.0	35.0	74.0	160.5	216.0
Secchi disk depth (m)	1.0	±	0.4	0.1	0.3	0.7	1.0	1.3	1.7	4.8
Total Nitrogen (mg/L)	0.55	±	0.53	<0.05	<0.05	0.11	0.35	0.90	1.50	3.37
Total Phosphorus (µg/L)	154.4	±	94.0	8.0	54.0	86.0	131.0	200.0	333.0	631.0
Chlorophyll *a* (mg/m^3)	8.3	±	7.7	<0.3	2.0	3.9	6.0	10.0	23.9	63.3
Inlet										
Salinity (PSU)	27.2	±	7.9	0.6	9.6	22.9	29.6	33.3	35.7	36.5
Dissolved Oxygen (mg/L)	6.4	±	1.1	2.6	4.8	5.8	6.4	6.9	8.0	12.6
Apparent Color (PCU)	25.0	±	31.3	0.5	0.7	6.0	11.0	35.3	91.8	156.0
Secchi disk depth (m)	1.1	±	0.5	0.2	0.4	0.8	1.1	1.4	1.9	2.5
Total Nitrogen (mg/L)	0.43	±	0.41	<0.05	0.02	0.06	0.30	0.73	1.17	2.03
Total Phosphorus (µg/L)	82.5	±	71.9	7.0	22.0	36.0	53.0	106.0	265.0	341.0
Chlorophyll *a* (mg/m^3)	4.1	±	3.4	0.5	1.3	2.0	3.0	4.4	11.1	23.1
Entire Estuary										
Salinity (PSU)	11.0	±	10.5	<0.1	0.1	0.6	8.2	19.1	31.0	39.0
Dissolved Oxygen (mg/L)	5.9	±	1.9	<0.1	2.4	4.9	6.1	7.2	8.7	21.3
Apparent Color (PCU)	69.6	±	56.5	0.5	12.0	31.0	50.0	95.0	186.0	383.0
Secchi disk depth (m)	1.0	±	0.4	<0.01	0.3	0.7	1.0	1.2	1.6	10.0
Total Nitrogen (mg/L)	0.64	±	0.58	<0.05	0.01	0.14	0.45	1.07	1.64	7.09
Total Phosphorus (µg/L)	194.3	±	110.4	7.0	61.0	124.0	174.5	235.0	410.0	1040.0
Chlorophyll *a* (mg/m^3)	10.2	±	9.9	<0.3	1.8	4.0	7.0	13.0	28.1	157.0

Watershed Trends

The District commissioned trend analyses of nutrient concentrations observed in the St. Lucie River watershed on the following nutrient species: nitrite plus nitrate nitrogen (NO_X–N), nitrite nitrogen (NO_2–N), nitrate nitrogen (NO_3–N), ammonia nitrogen (NH_4–N), total Kjeldahl nitrogen (TKN), orthophosphate phosphorus (PO_4–P), and TP. Full results have been published in Qian et al. (2007). The parametric Tobit Test was employed when a dataset contained more than 5 percent censored results; otherwise, the nonparametric Seasonal Kendall Test was used for trend detection.

During the 1979 to 2004 period, some selected nutrient species exhibited significant trends ($p < 0.1$). The pattern of trends was found to vary by both individual nutrient species and the location of monitoring stations. Overall, more positive trends were detected than negative trends. For example, in the C-23 basin at station S-48, NO_3–N, NH_4–N, PO_4–P, and TP annual concentration trends were positive, while no trends were detected for other species. At S-80 on the C-44 canal, NOx–N (1979–2002), NH_4–N (1979–2002), PO_4–P (1979–2004), and TP (1979–2004) annual concentration trends were positive, while TKN (1979–2004) concentrations were negative. Negative trends dominated at S-49 on the C-24 canal for all the nutrient species except NO_3–N (no trend) from 1979–2004.

Despite some negative annual trends of nutrient concentrations, such as at S-49, many positive trends in other basins imply that during the past years, N and P concentrations were increasing overall. The elevated nutrient concentrations contribute partly to the degradation of water quality conditions of the estuary (e.g., Doering et al., 2006). Analyses of land use coverage data indicate that in basins C-23, C-24, and C-44, agricultural and urban land use increased about 10 percent from 1988–1999, while forest and wetland decreased 11 percent during the same period. It was reported in Graves et al. (2004) that agricultural and urban land uses/land covers in these basins tend to result in significantly higher concentrations of inorganic nitrogen species and phosphorus in surface waters than wetland or forest cover types due to fertilizer application and/or domestic wastes. The substantial change in land use might, in part, account for the increasing concentrations of inorganic nitrogen (NO_X–N, NO_2–N, NO_3–N, or NH_4–N) and phosphorus (TP or PO_4–P) at monitoring sites S-48 and S-80. Additional investigation is needed to understand why the two adjacent basins of C-23 and C-24 present opposite trends in nutrient concentrations. Differences in implementation of BMPs, land application of wastewater sludge, and irrigation practices may be among the factors contributing to this difference.

Nutrient Loading

Loadings of TN and TP to the SLE from canal inflows were estimated using inflow and nutrient concentration data collected by the District from 1995–2005. In the tributary basins, where flow data are not available, the St. Lucie Watershed Water Quality model was used to predict the corresponding flow and nutrient concentration to estimate the load (Wan et al., 2003). **Figure 12-13** shows the annual TN and TP canal loading into the estuary from 1995–2005. The average annual loading from canals totaled 2,221 metric tons per year (mt)/year for TN and 376 mt/year for TP during this period of record (POR). Assuming a total surface area for the St. Lucie Estuary of 34 km^2, the unit area loadings were 64,360 kg/km^2 TN and 10,816 kg/km^2 TP. Annual loadings varied widely from year to year with wet or dry conditions. For example, 1995, 2004, and 2005 were wet years, when higher annual nutrient canal loadings of about 4,000 mt for TN and 600 mt for TP were observed. Loadings in dry years, such as 1996, 1997, and 2000, were down to about 1,000 mt for TN and 100-170 mt for TP. The nutrient loading rate from surface waters is controlled by both water influx (canal discharge rates) and nutrient concentrations in the canal water. Regressions between total annual flow and annual loadings indicate that annual loading is largely controlled by flow rates, and explains about 81 percent of the variation for both TN and TP loads. Nutrient loads from canal inputs are likely the largest source of inorganic nutrients to the estuary.

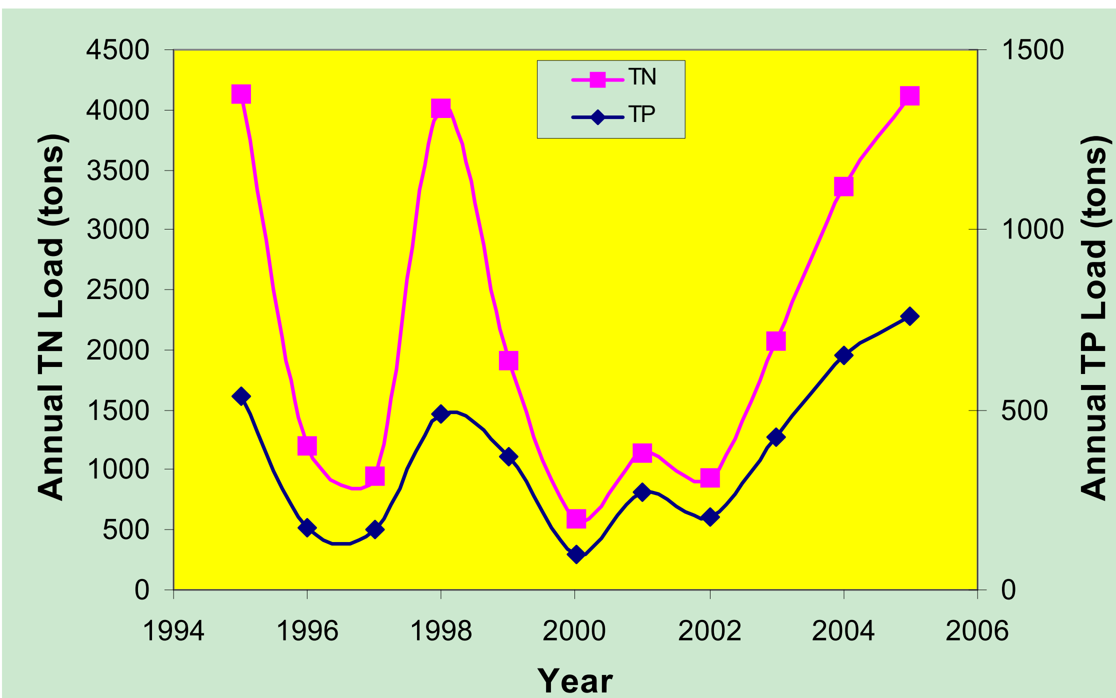

Figure 12-13. Annual loading of total nitrogen (TN) and total phosphorus (TP) from canals into the SLE from 1995–2005.

STRATEGIES FOR THE ST. LUCIE ESTUARY

Research projects are intended to reduce or eliminate key uncertainties in the load targets as well as in flow and salinity envelopes, and optimize the operation protocols. Four research projects are presented in order of priority. Each project is accompanied by a table of project elements or components along with an assessment of how information will be obtained (e.g., new measurements, existing data, or estimates from a model). The *Southern Indian River Lagoon and St. Lucie River Estuary, Integrated Modeling Framework* section of this chapter describes existing watershed, estuarine, and ecological models, and summarizes additional modeling requirements.

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 St. Lucie Estuary and a problem for estuaries worldwide (Gray, 1992). In the SLE, elevated levels of chlorophyll *a* (used to estimate algal biomass), and low dissolved oxygen concentrations have indicated nutrient enrichment (Chamberlain and Hayward, 1996). The scientific foundation for the management of over-enrichment rests on the concept of nutrient limitation (Smith et al., 1999); that is, the nutrient present in the environment in the least quantity relative to plant demands will limit growth. Controlling the effects of over-enrichment should be accomplished by restricting the loading of this key nutrient to the ecosystem (Smith et al., 1999). As a general rule, nitrogen most often limits algal growth in marine systems, while phosphorus is limiting in fresh waters (Smith et al., 2006). While dissolved inorganic forms of nitrogen and phosphorus are readily available for plant growth, some organic forms can be taken up directly or converted to forms that can be taken up (Seitzinger et al., 2002). Therefore, the distribution of the nutrient load among available inorganic and organic forms (and unavailable organic forms) is an important consideration in quantifying the load to be controlled or restricted.

A well-constrained nutrient budget is critical to understanding the origin, magnitude, and management of problematic nutrient loads. A nutrient budget is simply an accounting or summing up of nutrient inputs, outputs, and permanent losses (e.g., Nixon et al., 1995). Internal cycling terms are often included. For nutrients, inputs include among others, stormwater runoff and atmospheric deposition. Outputs include, among others, export to the Atlantic Ocean. Burial in the bottom sediments is an example of a permanent loss term, and the flux of nutrients out of the bottom sediments constitutes an internal cycling term.

Management Objective

The nutrient budget analysis project supports the goal of achieving the appropriate nutrient loads for the St. Lucie Estuary (yet to be determined) by quantifying the magnitude of nutrient loads from various sources so BMPs can be prioritized.

Application of Results

Nutrient budget tools assist in determining appropriate nutrient reduction approaches, and in evaluating and optimizing project effectiveness. Meeting the load targets relies on reducing nutrient loads that can be controlled. The relative magnitude of controllable and uncontrollable sources limits the extent of improvement that can be achieved. Since a nutrient budget comprises both types of sources, it provides the basic information required to quantify this limit. Including internal cycling terms as constraints (such as the regeneration of nutrients by bottom sediments) allows for estimating the time scale of system response to external load reductions. Results of this project can be used to support water quality modeling efforts, which will reduce the uncertainty of the appropriate targets and increase the capability to predict effects of various management measures, including BMPs.

Methodological Approach

This project will construct nutrient budgets of nitrogen and phosphorus for the St. Lucie 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 loads from C-23, C-24, and C-44). Others, such as stormwater runoff from ungauged portions of the watershed, may be available only from models. Still other terms, such as the flux of nutrients out of bottom sediments, may require direct measurement (**Table 12-4**).

Table 12-4. Input, internal cycling, and output terms included in the nutrient budget for the SLE. Also given is the status of data required for each term and need.

INPUTS	STATUS
C-23, C-24, C-44	**Data Available**
Ungauged Areas	
Surface Flows	Watershed model and measurements
Groundwater	Watershed model and measurements
Atlantic Ocean	Requires modeling project
Atmospheric Deposition	Data Needed
Nitrogen Fixation	Requires new measurements
INTERNAL CYCLING	**STATUS**
Primary Productivity	Requires new measurements
Water Column Respiration	Requires new measurements
Benthic Nutrient Flux	One dry season data available; need more dry and wet season data
OUTPUTS	**STATUS**
Export to Ocean	Requires modeling project
Burial in Sediments	Some sedimentation rate data exist
Denitrification	One dry season data available; need more dry and wet season data
Biomass	
Migration	Data needed
Harvesting	Data needed

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Nutrient Limitation of Phytoplankton Growth. Indirect evidence suggests that nitrogen most often limits the growth of phytoplankton in the St. Lucie Estuary (Doering, 1996), but no existing experimental studies have examined nutrient limitation. Therefore, a year-long study was initiated in April 2007.

The focus of this study was to examine the response of the phytoplankton community to shifting salinity and nutrient conditions in the estuary. The responses were evaluated within the context of spatial and temporal patterns in the abundance and composition of the phytoplankton community and nutrient elements, and variability in physical-chemical characteristics of the water column, including salinity, temperature, and light availability. To evaluate the potential responsiveness of the phytoplankton community to changes in nutrient load, the nutrient limiting status of the community was determined in controlled bioassay experiments.

Nutrient limitation/growth bioassay experiments for phytoplankton were performed on a monthly basis for the five sampling sites. The experimental design was based on methods described by Aldridge et al. (1995) and Phlips et al. (1997). Assays were done under laboratory conditions in 500-milliliter (ml) Erlenmeyer flasks with 400 ml of whole water. Treatments (in triplicate) consisted of a control (no additions), N addition [400 micrograms (µg) N l-1], 2N addition (800 µg N l-1), P addition (40 µg P l-1), N + P addition (400 µg N l-1 + 40 µg P l-1), and N+P+Si addition (400 µg N l-1 + 40 µg P l-1 + 400 µg Si l-1).

Incubations were done in temperature-controlled water baths with bottom illumination. Incubation temperatures were near ambient temperatures recorded on each sampling date. Light intensity was fixed at 80 µE m^{-2} s^{-1}. Photoperiods were 12/12 10/14 dark/light from April–September. Algal biomass was estimated by net in vivo fluorescence of Chl-a (IVF) using a Turner Designs fluorometer at time intervals over a 14–21 day incubation period. Fluorescence values were compared to extracted chlorophyll values at selected intervals for ground-truthing.

A nutrient was considered limiting when the addition of that nutrient, or a combination of nutrients, resulted in significantly greater growth than the control. When algal growth in the control treatment increased relative to the initial control, it was concluded that surplus bioavailable nutrients were present at the time of sampling.

Five sites in the St. Lucie Estuary were sampled on a weekly basis from April 2007–April 2008. Controlled bioassay experiments were conducted on a monthly basis:

- Site 7 was located in the North Fork of the inner estuary, near the inflow of Ten Mile Creek
- Site 8 was located in the South Fork of the inner estuary, near the inflow of the St. Lucie Canal (C-44 canal)
- Site 9 was located in the middle estuary, near the confluence of the North Fork and South Fork
- Site 10 was located several kilometers from the St. Lucie Inlet
- Site 11 was located just inside the inlet to the Atlantic Ocean

Preliminary results indicate that nitrogen most often limits phytoplankton production. Silica is also sometimes limiting, which suggests that, at times, diatoms (which require silica) may be at a competitive disadvantage to other species.

From a temporal perspective, diatoms were important components of the phytoplankton biomass (i.e., biovolume, a measure of biomass) in spring 2007 and winter 2008, at all five sites. In the summer, dinoflagellates became the dominant phytoplankton group at Sites 7–9, forming blooms in July and early August. Later in summer 2007, cyanobacteria replaced dinoflagellates as the dominant bloom species. In the late winter resurgence of phytoplankton, diatoms initiated the increase, followed by dinoflagellates in spring 2008. The major bloom-forming species of phytoplankton were different in the inner (i.e., Sites 7–9) and outer portions of the estuary (i.e., Sites 10–11). In the inner estuary, dinoflagellates headed the list of top bloom-forming species, including *Akashiwo sanguineum*, *Gyrodinium instriatum*, *Ceratium hircus* and *Prorocentrum micans*. Some diatoms were also on the list of top bloom-formers, including *Odantella regia* and *Pseudonitzschia calliantha*. In the outer estuary, diatoms head the list of top bloom-forming phytoplankton, including *Pseudonitzschia calliantha*, *Leptocylindrus danicus*, *Coscinodiscus sp*., *Skeletonema costatum*, and *Rhizosolenia setigera*. Along with diatoms and dinoflagellates, a spherical picoplanktonic cyanobacterium was observed at bloom-levels [i.e., greater than (>) 3 x 106 µm3 ml-1] at some point in time at all five sampling sites. Picoplanktonic phytoplankton are clearly a potentially important element of the food web in the estuary.

Short-Term Water Quality Analysis. To improve monitoring flexibility and obtain critical continuous data, the District began designing and constructing two identical floating monitoring platforms in 2006. The platforms, named the Marine Environmental Research Laboratory for In-Situ Sampler (MERLIN), are designed to collect high-frequency time-series water quality data, and meet all quality assurance objectives. Testing of the platforms and validation of the results have been started.

The design includes various sensors connected to a flow-through water system. Onboard sensors measure several variables including nutrients (nitrate, phosphate, silicate, and ammonia), water temperature, dissolved oxygen, pH, salinity, and turbidity. MERLIN also records meteorological data including air temperature, precipitation, barometric pressure, relative humidity, and wind speed and direction.

The high-resolution data acquisition capabilities and in situ nutrient analysis results collected by MERLIN are expected to provide the information to understand processes leading to phytoplankton blooms in the SLE on short time scales that can be used to set loading targets. MERLIN will be deployed initially in the North Fork.

Benthic Nutrient Fluxes. In shallow coastal estuarine systems, such as the SLE, the water column and sediments can be tightly coupled with respect to the biogeochemical cycles of nitrogen and phosphorus. Sediment can function as a sink (i.e., permanent burial), or a source (i.e., inputs of nutrients to the estuary) through the transfer, or flux, of nutrients between the water column and sediments. Inorganic nutrients are produced during the microbial remineralization of organic matter within the sediments. Loads of nutrients from sediments can contribute significantly to the total nutrient load in subtropical estuaries. A recent study of benthic fluxes in an estuary in northwestern Florida identified sediments as a significant source of inorganic nitrogen and phosphorus to the water column relative to inputs from the main freshwater source during drought conditions (DiDonato et al., 2006).

Due to lack of information about benthic nutrient fluxes available for this system, two studies were conducted in February 2008 to estimate benthic fluxes of nitrogen and phosphorus

(Howes et al., 2008; Cornwell et al., 2008). The goals of the first study were to (1) provide estimates representative of system-wide benthic nutrient flux rates in the SLE, (2) identify "hot spots" of benthic nutrient fluxes, and (3) provide data in support of current and future water quality modeling efforts. System-wide estimates were based on measurements from sediment cores collected from 50 sites distributed throughout the estuary. The goals of the second study were to identify the contribution of diffusive and advective fluxes in the SLE by comparing fluxes measured from cores in the laboratory with fluxes measured in the field with chambers. The results will guide future research and monitoring efforts in the application of appropriate methodology for measuring benthic nutrient fluxes. These initial measurements were taken in February 2008, which occurred during the dry season and happened to be within a drought year. Additional measurements during wetter periods are required to determine the relative contribution of the sediments to the total nutrient load.

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 SLE (Chamberlain and Hayward, 1996). The FDEP has determined that the SLE is impaired for dissolved oxygen concentration (FDEP, 2004). Causative agents for the DO impairment are believed to be both a biological oxygen demand (BOD) and chlorophyll *a* (i.e., excessive phytoplankton). The two causative agents suggest different origins as causes for the DO impairments. BOD levels are higher than what would be expected based on internal cycling, and suggest that some of the oxygen demand may be caused by labile organic matter loads from sources external to the lagoon. Chlorophyll *a* can exceed 100 micrograms per liter (µg/L) during the summer. As the phytoplankton decay, DO is consumed. The two scenarios lead to different management actions.

Management Objective

This project supports the management goal of improving dissolved oxygen concentrations in the St. Lucie Estuary.

Application of Results

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.

Methodological Approach

To determine if lower nutrient loads will improve DO concentrations in the SLE, it is necessary to quantify the relative importance of factors that control DO, and how they interact to exert that control. This study will examine the role of internal and external factors in determining the concentration of DO (**Table 12-5**). Factors include stratification, algal blooms, SOD, and BOD loading and re-aeration. Emphasis will be on measuring diel (daytime-nighttime) fluctuations of DO in surface and bottom waters in different seasons, and over a range of freshwater inflows, and algal bloom conditions. The interpretation of these observations will be aided by measurements of SOD and BOD in the water column.

Table 12-5. Sources, sinks, and other measurements required to quantify the dynamics of dissolved oxygen (DO) in the SLE.

SINKS	STATUS
External BOD Load	Monitoring planned
Benthic Sediment Oxygen Demand (SOD)	One dry season data available; need more dry and wet season data
Water Column Respiration	Requires new measurements
SOURCES	**STATUS**
Primary Productivity	Requires new measurements
Re-aeration	Modeled
PHYSICS	**STATUS**
Stratification	Requires new measurements
CONCENTRATION TIME SERIES	**STATUS**
Dissolved Oxygen (DO)	Requires new measurements
Chlorophyll *a* Biomass	Requires new measurements
Light Extinction	Requires new measurements

Progress in WY2008

Benthic Oxygen Fluxes. Initial measurements of SOD were taken along with nutrient flux measurements. Further measurements are required and currently planned for 2009.

Low Salinity Zone Project

Overview and Background

One of the management goals for the St. Lucie River Estuary is to minimize the occurrence of undesirable salinity patterns in certain areas. Low freshwater inflow requirements of the SLE have been based on salinity tolerances of the Eastern oyster, which prefers meso- to polyhaline waters (14–28 psu) (Montagna et al., 2007). Generally, this species currently inhabits the middle regions of the estuarine system of the SLE.

Typically located near the head of an estuary, the low salinity zone (0–10 psu, Holmes et al., 2000) is highly productive, serving as a nursery area for early life stages of economically important fish and shellfish (Day et al., 1989). Survival of these economically important fish stocks is dependent on the survival of juveniles within these low salinity nursery habitats, which in turn depend on sufficient freshwater inflow. Whether low flow targets based on salinity requirements of the Eastern oyster in the middle estuary are sufficient to maintain the nursery function in the upper estuary has yet to be determined.

Estuaries are characterized by high primary and secondary productivity (Nixon et al., 1986; Nixon, 1988). It is generally agreed that freshwater input maintains this production (Fisher et al., 1988; Day et al., 1989; Montagna and Kalke, 1992). A common view deems the nutrients carried to estuaries by freshwater inflows as beneficial, with higher freshwater inflows leading to higher yields of desirable species (Loneragan and Bun, 1999). Yet the relationship between freshwater input and estuarine productivity is not completely understood (Livingston et al., 1997). While productivity is often positively correlated with the quantity of freshwater discharge, both reductions and increases in discharge can result in reduced productivity (Wilbur, 1992; Livingston et al., 1997; Turner, 2006).

In a recent review of recruitment of fish and other nekton, Petersen (2003) unified the dynamic-stationary habitat overlap hypothesis of Browder and Moore (1981) with Cushing's (1990) match/mismatch hypothesis. Peterson (2003) noted that successful recruitment depends first on larvae approaching their physiological optima (salinity, temperature, and dissolved oxygen) in the surrounding water (dynamic habitat), and then having available the appropriate habitat structure (e.g., grass bed, sediment type, and stationary habitat) for other life requirements. Chief among these other requirements is the overlap between fish larvae and their prey. Annual variation in temporal and spatial overlap (match/mismatch) is reflected in subsequent recruitment. The dual role of freshwater inflow in positioning larvae with respect to physical habitat and food and supplying the nutrients to grow the food is evident.

Estuaries typically trap sediment in high concentrations at localized regions within the low salinity zone, called the estuarine turbidity maximum (ETM). The ETM is a unique dynamic habitat that provides protection and nutrients to planktonic and larval fish (Roman et al., 2005; North and Houde, 2003). In Southwest Florida, Peebles et al. (1996) demonstrated that estuarine-dependent fish, such as perch (*Bairdiella chrysoura*) and bay anchovy (*Anchoa mitchilli*), spend the juvenile phase of their life-cycle foraging in the ETM. Despite its importance to the ecology of the estuary, little or no work has been done to examine the dynamics of the ETM in the SLE.

Management Objective

Mid-estuarine salinity envelopes at the Roosevelt Bridge and at the A1A Bridge were designed primarily based on providing tolerable physiological and ecological conditions for the Eastern oyster in the middle estuary. The relationship between freshwater inflow and estuarine productivity has not been described in the SLE. It is not known whether freshwater inflow and salinity envelopes based on physiological tolerances also adequately support estuarine productivity.

The Low Salinity Zone 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 SLE as a nursery area. The relationship between freshwater discharge and the nursery function of estuaries is not understood well enough to provide generic information relevant to the management of freshwater inflow to estuaries. Site-specific determination of flows adequate to support and/or enhance the nursery function in the SLE is required to maintain a healthy ecology.

Application of Results

Results of this study will be used to refine the salinity envelope ranges and to provide environmental guidelines for delivery of freshwater to the North and South Forks of the St. Lucie Estuary.

Methodological Approach

Constituents that have been shown to respond to variations in inflow within the low salinity zone will be measured. Emphasis is on the linkage among inflow and primary and secondary productivity related to the fish nursery function of the estuary. The estuary will be divided spatially into several zones. At present, the following collections in each zone are anticipated. Collections will be on a monthly basis:

- Zooplankton (plankton net)
- Phytoplankton (plankton net)
- Benthic macrofauna
- Juvenile fish
- Water-column chlorophyll *a* (in situ fluorometry)
- Estuarine turbidity maximum (location and strength)
- Colored dissolved organic matter [(CDOM) fluorometry]
- Standard water quality measurements (i.e., salinity, conductivity, temperature, nutrients, and dissolved oxygen profiles)

Progress in Water Year 2008

Estuarine Turbidity Maximum. A short-term preliminary study of the St. Lucie ETM was initiated in 2008. Four sampling trips were completed from October 2007–April 2008. Results indicate that ETMs occurred most often just upstream of the freshwater-saltwater interface.

The objective of this study was to identify and evaluate the vertical and horizontal density and turbidity structure(s) with respect to DO, salinity, and/or chlorophyll *a* stratification. The results of this project can be used for the calibration of a numerical sediment transport model to evaluate light conditions in the estuary. The project also has implications in environmental operations for better management of freshwater releases to improve the ecosystem health in the Low Salinity Zone and for refinement of salinity and flow envelopes.

Research Projects and Priorities

Each major project can be broken down into several component parts. These parts are given in separate tables, such as **Table 12-5**, and others that follow the listing of research projects. Examination of the component parts of each project shows that several projects may have common components. The commonalities between components of the various projects may be integrated to obtain more than one type of data, as summarized in **Table 12-6**. For the individual projects, the source of data for each component is given (existing data, new measurements, model, etc). Items funded in any given year may be prioritized according to the number of projects to which they belong.

Table 12-6. Major research projects in the SLE and watershed. Their components and commonalities among studies are indicated by cross-hatched cells in the table.

	RESEARCH PROJECTS			
RESEARCH COMPONENT	***Nutrient Budget***	***D.O. Dynamics***	***Low Salinity Zone***	**SOURCE**
		Inputs		
Canal Loads (C-23, C-24, C-25)				Monitoring
Ungauged Surface Flow Groundwater				From model analysis of data
Ocean Input				Concentration from literature Flow from model
Atmospheric Input				Literature/data search
		Internal Cycling		
Primary Productivity/ Water Column Respiration				New measurements
Organic Matter Decomposition, including DON				New measurements
Benthic Flux				New measurements
D.O. Time Series				New contract in-house
		Outputs		
Export to Ocean				Model
Denitrification				Benthic Flux Project
North and South Fork Narrows: Larval /Juvenile fish Species, size, number, and gut content				
Adult Fish Movement, spawning				New measurements
Zooplankton Species, stage, reproductive state				
Benthos Species, feeding type, number				
Phytoplankton Species and size				

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. 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 following describes the applications of each type of model:

- 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

The District has been using this approach for several years in addressing MFLs and restoration projects, both for feasibility studies [e.g., Indian River Lagoon – South and Southwest Florida Feasibility Study (SWFFS)] and at the project level.

The modeling tools summarized above make a critical contribution toward achieving the management goals of the SLE 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 for urban and agricultural lands, to large filter marshes 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 reservoirs and other facilities. The contribution of models to the adaptive management process is also critical. Models can be used to synthesize information and generate testable hypotheses that will refine targets or performance measures, and the plan to achieve them. **Table 12-2** summarizes the models developed to date and their applications.

Modeling Needs and Strategies for the St. Lucie Estuary

To provide the needed technical support for adaptive management, and implementation of management measures, an integrated modeling approach is preferred along with some specific new work to refine or update the existing models described in the previous section. This integrated modeling and resource assessment framework can be applied at different levels of complexity to provide the information required for sound, science-based management. The short-term modeling needs based on existing modeling tools are discussed in this chapter. In the future, a comprehensive modeling framework for the Northern Everglades (Kissimmee River and Watershed, Lake Okeechobee and Watershed, integrated with the St. Lucie and Caloosahatchee rivers, estuaries, and watersheds) would be ideal.

Watershed Hydrology and Water Quality Modeling. The short-term watershed modeling needs based on existing modeling tools are summarized in **Table 12-7**.

The Northern Everglades Regional Simulation Model will continue to serve as a regional hydrological model to simulate the hydrologic interaction of the St. Lucie River Watershed (WASH Model) with other components of the NEEPP (Kissimmee River and Watershed and Lake Okeechobee and Watershed). Reservoirs and STAs are currently treated as a combined system. The model can be refined to represent reservoirs and STAs explicitly to enhance the treatment capability of the facilities. Water quality components need to be developed. Numerical integration with the St. Lucie Reservoir Optimization Model 6 (OPTI6) may also need to be added to enhance the operation capability.

The OPTI Model is currently being used as a planning-level tool. The dry season flow requirement to sustain the Low Salinity Zone in the North Fork can be included in the objective function of the model. Currently, reservoirs and STAs are treated as a combined system for storage. The model can be refined to separate reservoirs and STAs to enhance the operation for water quality treatment purposes. The OPTI Model also has a potential application to support the day-to-day operation of the water control structures and water storage facilities in the watershed. Since the operational rules generated by OPTI involve many interactions of generic algorism and fuzzy logic, a web-based Graphical User Interface (GUI) will be helpful in day-to-day operation.

To properly integrate the watershed loadings and operation management with estuary water quality and ecological impacts, the current WASH Model will need to be updated to reflect the recent sub-basin delineation and inter-basin transfers. The model will also need to be refined with additional calibration to better simulate nutrient cycling and DO dynamics in major canals. Data collected by the monitoring activities will be used for this purpose. Once these updates are completed, the model will need to be extended temporally to support projects proposed for estuary research and evaluation.

Table 12-7. Short-term watershed modeling needs for the St. Lucie system.

MODEL	HYDROLOGY	WATER QUALITY	WATER MANAGEMENT PRACTICES
RSM	1. Represent reservoirs and STAs explicitly. 2. Calibrate in same time frame as other models for proper integration.	1. Needs to be developed. 2. Calibrate in same time frame as other models for proper integration.	Numerical integration with OPTI6 may also need to be added to enhance the operation capability.
OPTI			1. Update the code to include the dry season North Fork Low Salinity Zone flow requirement into the model's objective function. 2. Update the code to include the water quality treatment requirements by STAs into the model's objective functions. 3. Modify the code to allow for concurrent diversion and pump out from reservoirs on the same day to reflect the need for water quality treatment requirement. 4. Modify the code to allow for day-to-day operational schedules for all the reservoirs, STAs, and discharging structures in the basin to meet the objective of coastal ecosystem restoration and water quality treatment. 5. Develop a web-based Graphical User Interface for application of facility operators.
WASH	1. Update rainfall and evapotranspiration data, particularly in the tidal basins where monitoring flow data are not available. 2. Update recent basin delineation to reflect current and future land development. 3. Simulate flow diversion between C-23, C-24, and C-25. 4. Simulate groundwater seepage into the estuary. 5. Calibrate in same time frame as other models for proper integration.	1. Refine the calibration of nutrient concentration and loading prediction for same calibration period as estuary models and ecological models from each of the land use types and sub-basins with newly collected data. 2. Refine model calibration for same calibration period as estuary models and ecological models of the in-stream processes with newly collected data of diurnal DO, SOD, BOD, and nutrients. 3. Calibrate in same time frame as other models for proper integration.	Need to implement reservoirs and STAs in the watershed to simulate the operation and anticipated nutrient reduction of these management practices.

Estuary Hydrodynamic Water Quality and Ecological Response Modeling. The short-term estuarine modeling needs based on existing modeling tools are summarized below and in **Table 12-8.**

A curvilinear-grid hydrodynamics 3D hydrodynamic/salinity model (CH3D) was successfully calibrated and verified with observed tidal and salinity data from 1997–2005 for the SLE. The model can be further enhanced by including seasonal groundwater seepage and refining turbulence schemes to better simulate the stratifications and mixing in the estuary. A sediment transport model is also necessary for the understanding of the ETM, which is an indicator of the nursery function of the low salinity zone in the estuary. Coupled with the hydrodynamic/salinity model, the sediment model can be used to study the location, spatial range, and temporal variation of the ETM zone. Since wind-generated waves are considered to be important for sediment resuspension and, therefore, have significant impact on turbidity, the wind-generated wave impact will be investigated using the sediment transport model. To establish a nutrient budget and understand the different pathways of nutrients and, hence, the impact on ecosystems, the water quality component/model will need to be updated with newly collected data including benthic flux results, diel DO concentrations, sediment and turbidity. Calibration and refinements on nutrient cycling processes, stratification, and DO dynamics need to be made when data are available.

In addition to Eastern oysters in the middle estuary, another VEC in the SLE is the seagrass growing in Indian River Lagoon near the inlet. Seagrasses in this area are sensitive to freshwater inflows. Unpublished data also suggest there is a low-flow requirement by fish larvae in the low salinity zone of the estuary. Future efforts in the estuarine ecologic response modeling should simulate the habitats for seagrass, oyster, and fish larvae to represent the entire spectrum of the valued ecosystems in the estuary. These VECs may serve as performance measures for future environmental operation during different climatic and seasonal conditions. A set of ecological performance measures representing habitats for fish larvae in the low salinity zone, oyster in the mesohaline zone, and seagrass in the polyhaline zone will be needed by the operation model to direct operation for both the dry season and wet season. These performance measures will also need to be integrated into an index-type model along with a GUI to aid in future applications. Eventually, a community-level ecological response model should be developed to predict the ecosystem change with the anticipated improvement in the habitats.

Table 12-8. Short-term estuarine modeling needs for the St. Lucie system.

HYDRODYNAMIC/ SEDIMENT TRANSPORT	WATER QUALITY	ECOLOGICAL
1. Include groundwater seepage as the input data. 2. Refine the turbulence scheme for better simulation of stratification and mixing. 3. Add bathymetry data for South Fork and floodplain. 4. Integrate wind-generated wave impact. 5. Calibrate in same time frame as other models for proper integration.	1. Refine the representation of nutrient cycling processes, particularly the benthic flux with newly collected data. 2. Balance the influence of stratification and the sources and sinks of DO kinetic relationships. 3. Obtain time-series sediment data for model calibration and proper simulation of the ETM dynamics with sediment resuspension and transport. 4. Calibrate in same time frame as other models for proper integration.	1. Include the seagrass and fish larvae. 2. Develop a community-level ecological response model. 3. Develop a web-based graphic user interface. 4. Calibrate in same time frame as other models for proper integration.

CALOOSAHATCHEE RIVER ESTUARY AND SOUTHERN CHARLOTTE HARBOR

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INTRODUCTION

The Caloosahatchee River Estuary (CRE) and Southern Charlotte Harbor are located on the southwest coast of Florida. The major source of fresh water to the Caloosahatchee River Estuary is the Caloosahatchee River, which runs 65 km (40 mi) from Lake Okeechobee to the head of the estuary at the Franklin Lock and Dam (S-79). Geographically, the estuary extends about 42 km (26 mi) downstream to Shell Point, where it empties into San Carlos Bay at the lower end of Southern Charlotte Harbor (**Figure 12-14**).

Charlotte Harbor 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 meadows of submerged aquatic vegetation, 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, San Carlos Bay, and almost all of Pine Island Sound and Matlacha Pass. Large fluctuations in flows from the Caloosahatchee between the wet and dry seasons affect its salinity, other water characteristics, and natural resources. Major environmental concerns for the estuary that can extend into Southern Charlotte Harbor are altered freshwater inflows, nutrient enrichment, and habitat loss (SFWMD, 2005; SFWMD, 2006).

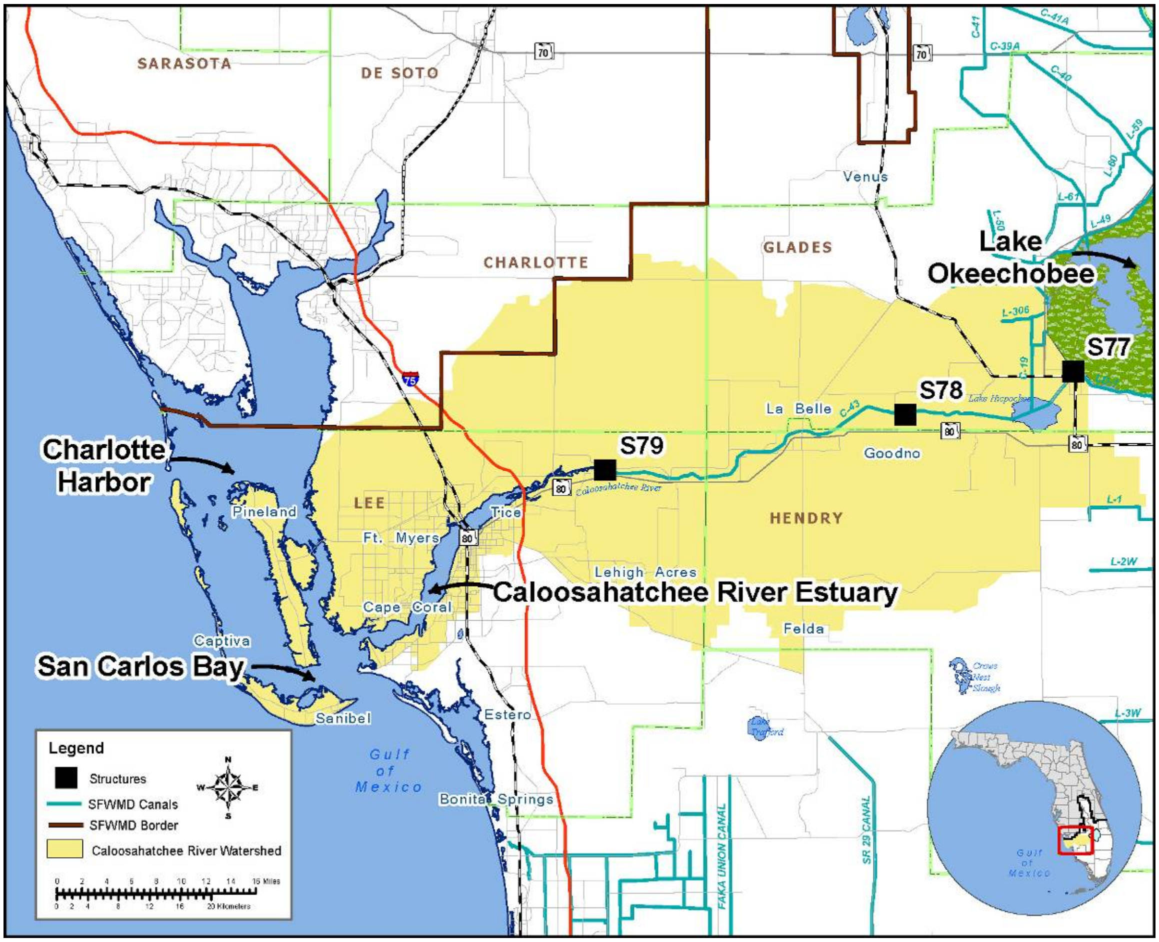


Figure 12-14. Location of the Caloosahatchee River Estuary (CRE) and Southern Charlotte Harbor.

STATUS OF THE CALOOSAHATCHEE RIVER ESTUARY AND SOUTHERN CHARLOTTE HARBOR

Submerged Aquatic Vegetation

Submerged Aquatic Vegetation Mapping

Within the CRE, a District effort is under way to evaluate the dynamics of SAV over a large (landscape) scale (**Figure 12-15**). These efforts include the acquisition of aerial photographs that are 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 dynamics at an estuarine scale by identifying areas of change (loss or gain), and stability. In the CRE, image acquisition is being conducted every two to five years. There have been five aerial-photograph surveys conducted since 1999. The resulting information has been used by various organizations to evaluate incremental and long-term changes throughout the entire region and within major sections of the system. A full description of existing SAV monitoring is expected to be provided in the CRWPP.

Because of the tannin color of the river above its mouth, identifying SAV beds from aerial images is not possible. To overcome this logistical difficulty, the SFWMD obtains information, such as percent cover, mean canopy height, and edge of bed location for tape grass (*Vallisneria americana*) using a hydroacoustic approach. 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 U.S. Army Corps of Engineers (USACE) in 1996 and continued through 2004. These data continue to be collected tri-annually by the SFWMD.

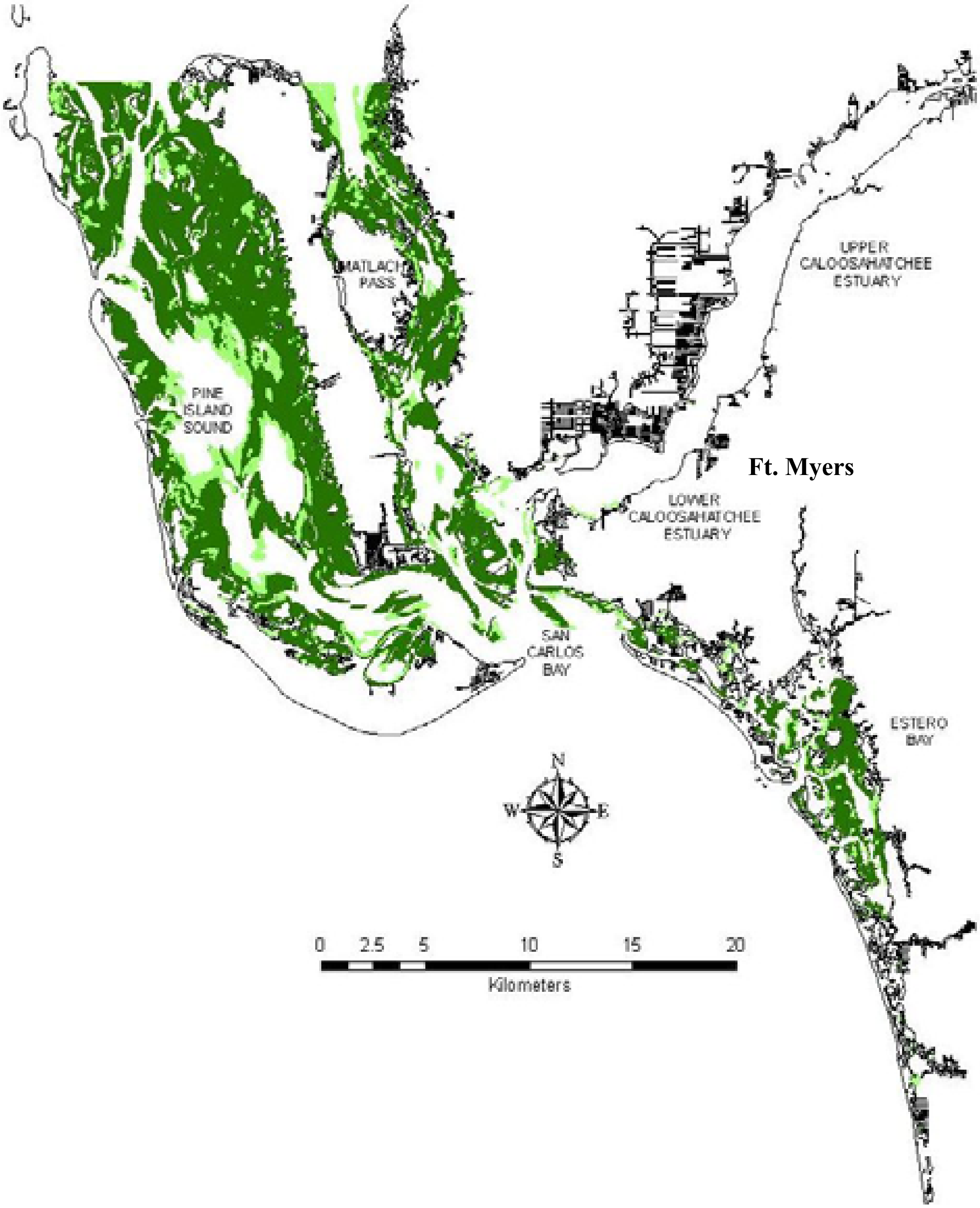


Figure 12-15. SAV areal extent and distribution in Southern Charlotte Harbor, CRE, and Estero Bay, as delineated from 2006 aerial photographs.

Submerged Aquatic Vegetation Monitoring

There are currently six SAV monitoring efforts in the tidal waters within the CRWPP boundaries. **Figure 12-16** depicts the sampling stations associated with the monitoring conducted by (1) the Sanibel-Captiva Conservation Foundation, (2) the FDEP, (3) Estero Bay Aquatic Preserve, and (4) the SFWMD Hydroacoustic Monitoring Program. In addition to the stations depicted in **Figure 12-16**, an additional 18 stations in Southern Charlotte Harbor are annually monitored by staff from the Charlotte Harbor Aquatic Preserve — identified as potentially important to this effort (within the boundaries of the CRWPP). Three of these stations are also sampled quarterly by the FDEP.

Densities of shoal grass (*Halodule wrightii*) in WY2008 matched or exceeded WY2007 densities during the growing season (May 2007–September 2007) before decreasing below WY2007 dry season levels at three of four stations perhaps due to continued drought conditions (**Figure 12-17,** panel A). Turtle grass (*Thalassia testudinum*) densities in WY2008 also exceeded WY2007 densities at stations 7 and 8 (**Figure 12–17,** panel B), as might be expected due to the generally higher salinity that occurred during the drought.

Upstream of Ft. Myers is the highest concentration of the fresh-brackish water plant tape grass. It requires a minimum flow of fresh water to maintain salinity below its upper tolerance limits (30-day average 10 psu). During the last major drought (WY2001–WY2002), the plant disappeared from the estuary, but began to reappear in WY2004. The development of drought conditions in WY2007 caused salinity in the upper estuary to exceed 25 psu, resulting again in the total loss of the plant from the estuary (SFWMD, 2008b). As a result of continued drought conditions, salinity at the Ft. Myers station remained above 10 psu for most of the year, falling below 10 psu only occasionally during August and September 2007. Tape grass has not been observed at any of the District's SAV monitoring stations since December 2006. In an effort to facilitate the reestablishment of tape grass in the CRE, a planting event was conducted on April 28, 2008, just upstream of S-79 in fresh water, to establish a seed population for growth downstream of S-79 (tape grass monitoring stations 1 and 2) once drought conditions cease. It is expected that once salinity becomes more favorable downstream of S-79, seeds from the grass population upstream will repopulate beds downstream.

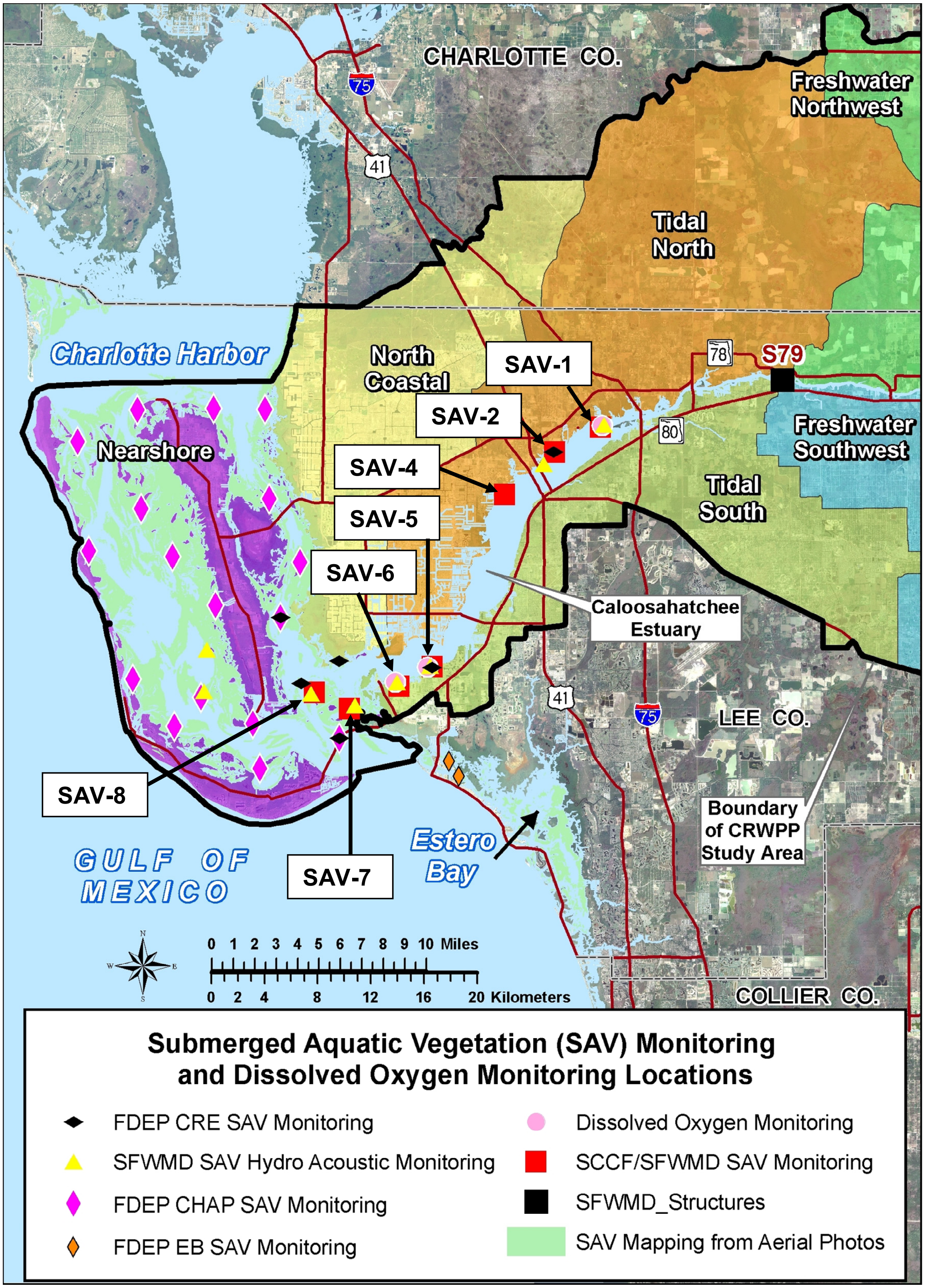
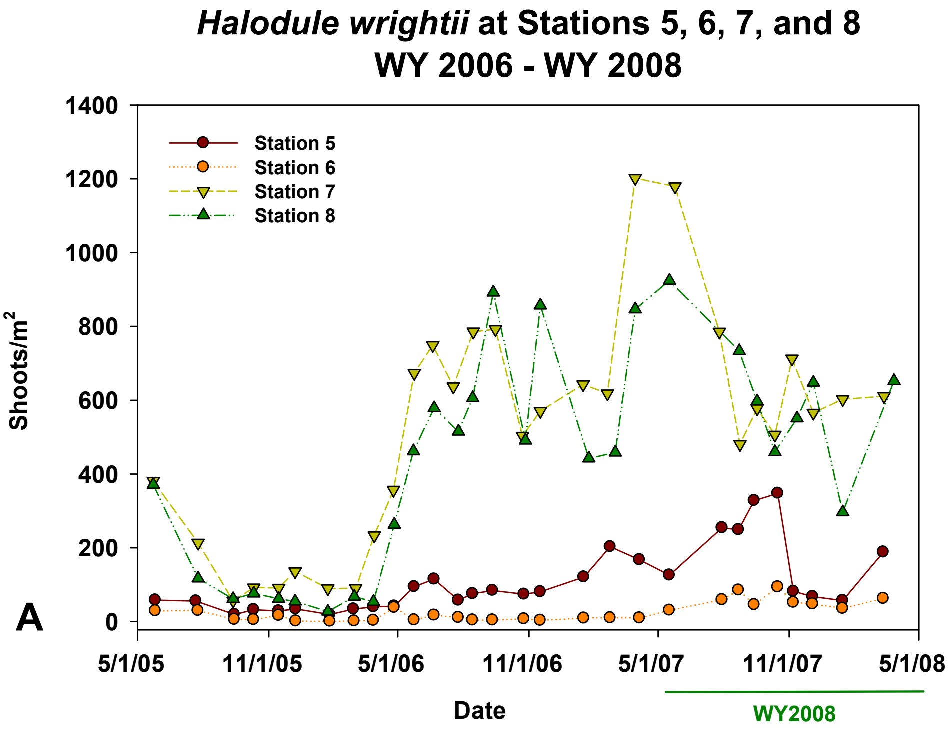


Figure 12-16. Monitoring stations for SAV and DO in the CRE.



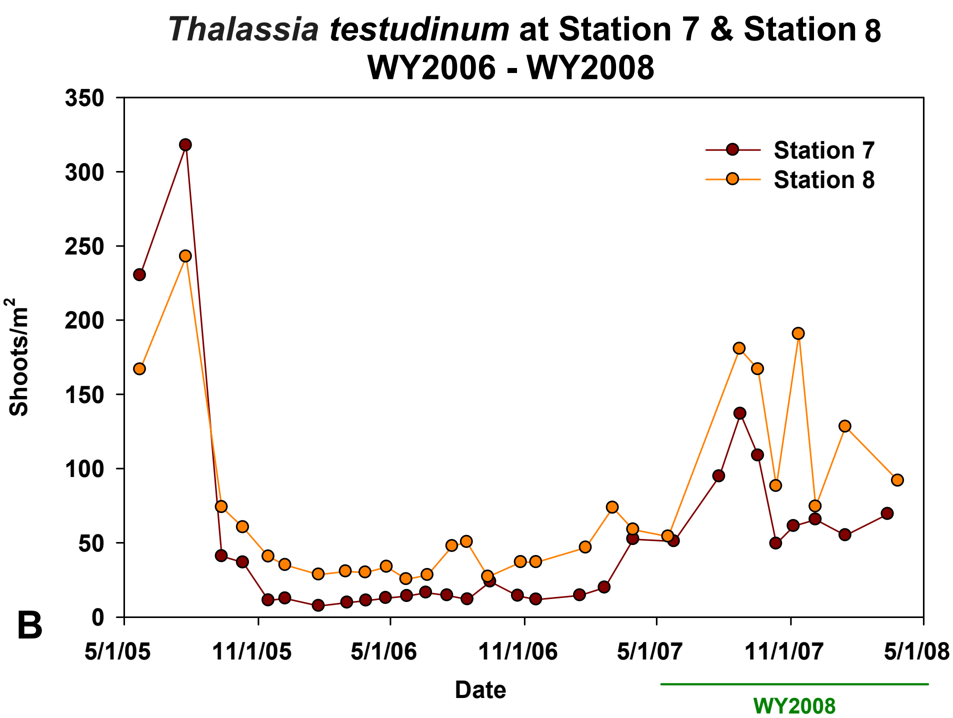


Figure 12-17. Mean density of seagrass: (panel A) shoal grass (*Halodule wrightii*) and (panel B) turtle grass (*Thalassia testudinum*) in the CRE and San Carlos Bay. Data collected by the Sanibel-Captiva Conservation Foundation.

EASTERN OYSTER ABUNDANCE AND DISTRIBUTION

Oyster Monitoring

The CERP Monitoring and Assessment Plan (MAP) is designed to provide a diverse approach to documenting and describing the impacts of changed freshwater flow to the flora and fauna inhabiting inland landscapes and coastal waters. Because of its wide distribution, historical context, and essential habitat value, the Eastern oyster is included as a target species for monitoring. The Caloosahatchee Estuary Oyster Monitoring Program, implemented in 2003, tracks changes in oyster distribution, health, and abundance within the CRE (**Figure 12–18**). Furthermore, the MAP anticipates that mapping of oyster reefs to determine actual reef acreage needs to take place every three to five years (RECOVER, 2007a). The target for the CRE, predicted with the full project implementation, is "to provide about 400 acres of suitable oyster habitat with at least 100 acres of living oyster reefs" (RECOVER, 2007a).

The main objective of the MAP effort is to implement a long-term monitoring program for Eastern oysters in South Florida estuaries. Five aspects of oyster ecology are monitored at monthly or seasonally frequencies (**Table 12–9**), 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). This monitoring is currently in progress at six stations in the CRE: Pepper Tree Point (PTP), Iona Cove (IC), Cattle Dock (CD), Bird Island (BI), Kitchel Key (KK), and Tarpon Bay (TB) (**Figure 12-18)**.

RECOVER's Performance Measure (RECOVER, 2007a) for living oyster densities is being assessed, but a plan to map the extent of oyster reef development (spatial coverage in acres) every five years, beginning in Fiscal Year 2009 (FY2009) (October 1, 2008–September 30, 2009), has been proposed (P. Sime, personal communication). Extent of oyster coverage is described as an interim goal, thus oyster mapping should be conducted on a five-year schedule that corresponds to the interim goal schedule.

Oyster density in the CRE over the past five years has been relatively stable. Mean density (averaged for all the sampling locations) over the sampling period ranged between 765–1,795 oysters/m^2. These densities are relatively high compared to other estuaries on the east coast of Florida. Oyster reef coverage was about 18 acres in 2004 when it was last mapped. While oyster mapping has not taken place recently, based on WY2007 density and recruitment data, oyster distribution probably has expanded upstream given the estuarine conditions prevailing during the past two water years of drought.

As a result of recent higher salinity conditions, disease and predation on oysters increased. For example, larval recruitment was an order of magnitude lower in CY2007 compared to previous years, probably because of predation. With the exception of the past two dry calendar years, there is too much freshwater inflow into the CRE in the summer months, and too little freshwater inflow into the estuary in the winter months, disrupting natural patterns and estuarine conditions. The oysters in the Caloosahatchee Estuary are still being impacted by this unnatural water delivery pattern. Too much fresh water impacts reproduction, larval recruitment, survival, and growth, while too little fresh water impacts the survival of oysters due to higher disease prevalence (dermo) and intensity of predation.

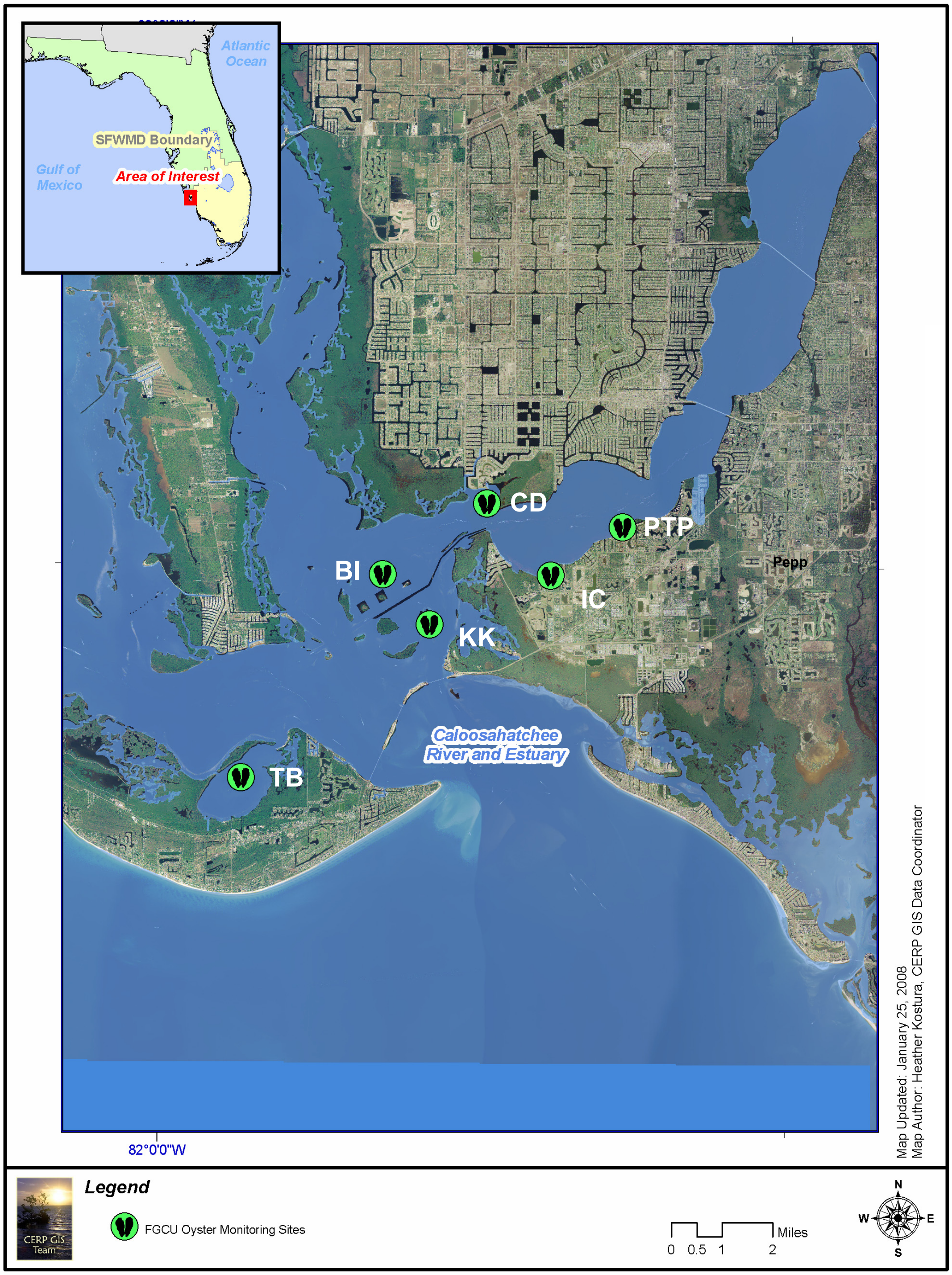


Figure 12-18. Oyster monitoring stations in the CRE.

Table 12–9. Parameters measured in RECOVER's Oyster Monitoring Program, CRE (Volety, 2007).

MEDIUM	PARAMETERS	STATIONS	FREQUENCY	COLLECTION
Water	Dissolved oxygen, pH, salinity, conductivity, and temperature	All	Monthly	YSI/Hydrolab
Oysters (Adults)	Density of living adults/m^2	All	Winter	Quadrat counts and in situ measurements
Oysters	Gonadal Index, Gonadal conditions	All	Monthly	Histology and image analysis from collected samples
Oysters (Spat)	Oyster spat recruitment and growth upon settlement	All	Monthly	Count spat on oyster settling apparatus and measure growth
Oysters (Juveniles)	Juvenile oyster growth and survival	All	Monthly	Measure 50 random juvenile oysters from wire mesh bag; examine percent survival of all juvenile oysters

Freshwater Inflows and Salinity in the Caloosahatchee River Estuary

Freshwater inflow to the CRE was greatly reduced relative to previous water years due to drought conditions from October 2006–May 2008. Flows from the S-79 structure (which discharges to the estuary via the C-43 canal) totaled about 86,895 acre feet (ac-ft) [107,180,805 cubic meters (m^3)] during WY2008[1]. The contribution of Lake Okeechobee to the total flow was nominal, about 413 ac-ft (508,888 m^3) (0.5 percent) of the total flow to the estuary. The WY2008 total was about 12.5 percent of the 693,391 ac-ft (855,285,204 m^3) that were discharged in WY2007, of which 93,153 ac-ft (114,902,533 m^3) were contributed by the lake. The long-term average discharge at S-79 is about 1.3 million ac-ft (1.6 billion m^3). Daily S-79 inflows consisted of sub-level 1 pulses from the lake that began in June, peaked at 1,836 cfs (52 m^3/s) in mid-June, and persisted until early October (**Figure 12-19**).

Six continuous salinity sensors are located in the CRE (**Figure 12–20**). The salinity from the Ft. Myers and Shell Point recorders are depicted in **Figure 12-19**. Salinity at both locations was much different during WY2008 compared to WY2007. In WY2007, salinity at Shell Point was forced to less than 10 psu for a period of several days during peak discharges from August 31–September 11, 2006, after which it steadily climbed above 25 psu (within the ideal salinity range of 25–35 psu for oysters in this area) by mid-October. Salinity continued to trend up to above 35 psu through the end of WY2007. Salinity remained above 30 psu for much of WY2008, oscillating into the optimal range for oysters at Shell Point for a total of 133 days between July 2007 and January 2008, and remaining above 35 psu through the end of April 2008.

Description of Flow Criteria, Status and Trends

In September 2001, a Minimum Flow and Level (MFL) rule for the Caloosahatchee River and CRE was established [Chapter 40E-8.221(2) Florida Administrative Code (F.A.C.)]. The rule states that:

> Caloosahatchee River. A minimum mean monthly flow of 300 CFS is necessary to maintain sufficient salinities at S-79 in order to prevent a MFL exceedance. A MFL exceedance occurs during a 365 day period, when:
>
> (a) A 30-day average salinity concentration exceeds 10 parts per thousand (sic) at the Ft. Myers salinity station (measured at 20% of the total river depth from the water surface at a location of latitude 263907.260, longitude 815209.296; or
>
> (b) A single, daily average salinity exceeds a concentration of 20 parts per thousand (sic) at the Ft. Myers salinity station. Exceedance of either paragraph (a) or (b), for two consecutive years is a violation of the MFL.

Beginning in November 2007, and for most of WY2008, the MFL rule (a) was exceeded, except for a brief 20-day period in October 2007 (**Figure 12-19**). Exceedance of MFL rule (b) was not as severe, occurring sporadically for 159 days in WY2008.

MFL flows of about 300 cfs (8.5 m^3/s) were not harmful to zooplankton and ichthyoplankton or to Eastern oysters living in the downstream higher salinity portions of the estuary. However,

[1] Note: Calculations in this chapter that incorporated flows from the S-79 structure used 86,893 ac-ft (107,180,937 m^3), because the 86,895 validated value was not available at the time calculations were done.

lower flows (less than 300 cfs) have been associated with phytoplankton blooms in the upper estuary. These blooms could result in water quality problems such as depressed oxygen levels. While evidence indicates that low flows in the 300 cfs range are not harmful, high flows above the 2,500–3,000 cfs (70.8-85 m^3/s) range appear detrimental. This high-flow limit agrees with previous estimates (Chamberlain and Doering, 1998; Doering et al., 2002).

Research and modeling conducted by the District since 2001 have resulted in the identification of an average monthly flow distribution between 450 (12.7 m^3/s) and 2,800 cfs (79.3 m^3/s) to protect and promote desirable estuarine biota and resources. This distribution has been adopted as a performance measure target for discharge at S-79 by CERP and the SWFFS. In an ordinary year, flows less than 450 cfs occur during 4.2 months and are greater than 2,800 cfs for 2.6 months. As a result of continued drought conditions, the 30-day average flow fell below the preferred range (i.e., < 450 cfs) for the entire 12-month period of WY2008. Occurrences of daily inflows after October were rare, maintaining the 30-day average flow below the preferred flow range.

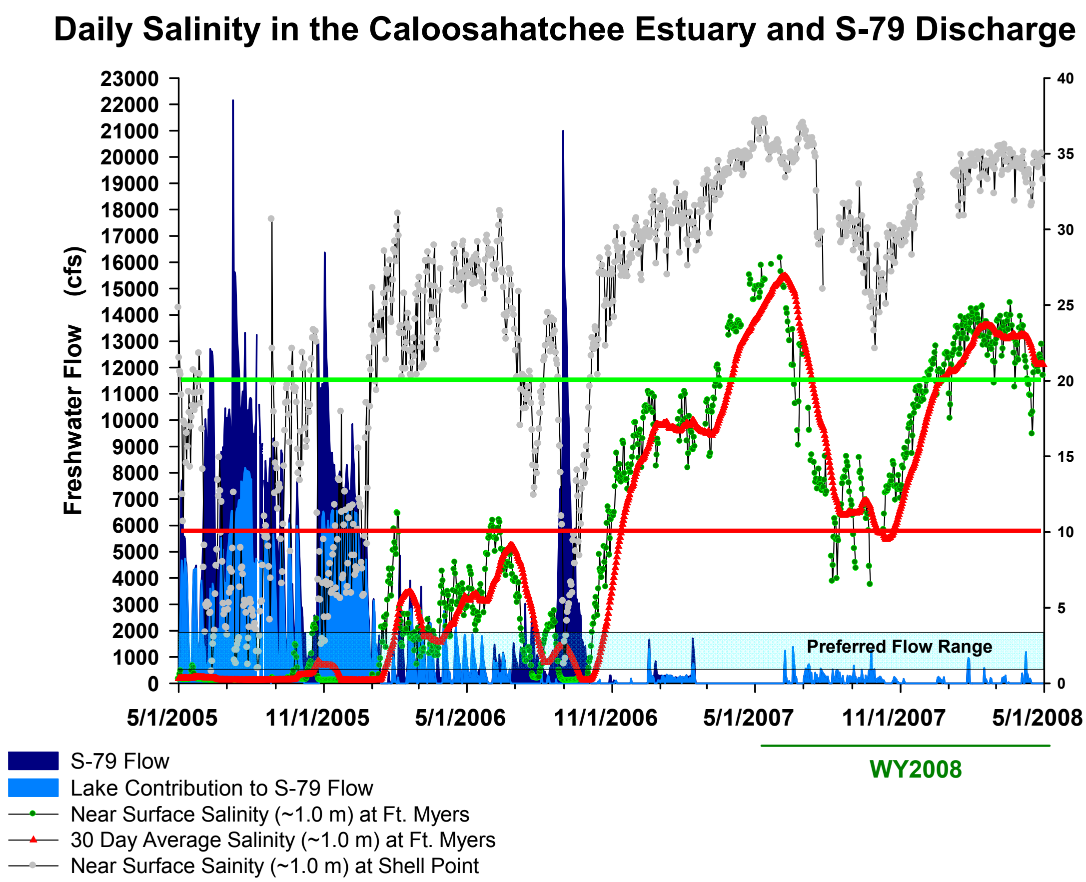


Figure 12-19. Daily freshwater flows to the CRE and its salinity.

Water Quality Trends

A recent effort (RECOVER, 2007c) summarized water quality in the CRE at seven stations from upstream at S-79 to Shell Point for the POR 1994–2006 (**Table 12-10**). Hand (2004) established the median concentrations chlorophyll *a* (7.2 µg/L), TN (0.67 mg/l), and TP (100 µg/l) in Florida's estuarine waters. Median TN concentrations in the first 30 km (18.6 mi) downstream of S-79 exceeded the median for Florida's estuaries (**Table 12-10**). Median concentrations of TP exceeded the Florida median only within the first 10 km (6.2 mi). Median chlorophyll *a* concentrations in the three regions of the estuary were all below the Florida median. Dissolved oxygen concentrations falling below the state standard of 4 mg/L (instantaneous minimum) for Class III salt waters, or the generally accepted threshold for hypoxia (2 mg/L), were relatively rare and confined to the upper reaches of the CRE (RECOVER, 2007c), although data do not include bottom measurements or any taken during dark conditions.

Trends in water quality were analyzed for the Charlotte Harbor National Estuary Program (Janicki Environmental, 2003, 2007) using the nonparametric seasonal Kendall test. A key finding is that salinity decreased in all regions of Southern Charlotte Harbor from the CRE to Pine Island Sound. Nitrate and/or nitrate + nitrite and TKN concentrations have also increased at a minimum of one station in each region. Similar trends in concentration were not observed just upstream of S-79 in the Caloosahatchee River (CES01). Since river water has a higher concentration of nitrogen species than Gulf water, the increase in nitrogen may be due to the increase in the fraction of fresh water as indicated by the decrease in salinity. The increase in nitrate + nitrite in the downstream estuary described in the Janicki Environmental (2007) report is consistent with the increase in dissolved inorganic nitrogen loading apparent in the results reported by RECOVER (2007c).

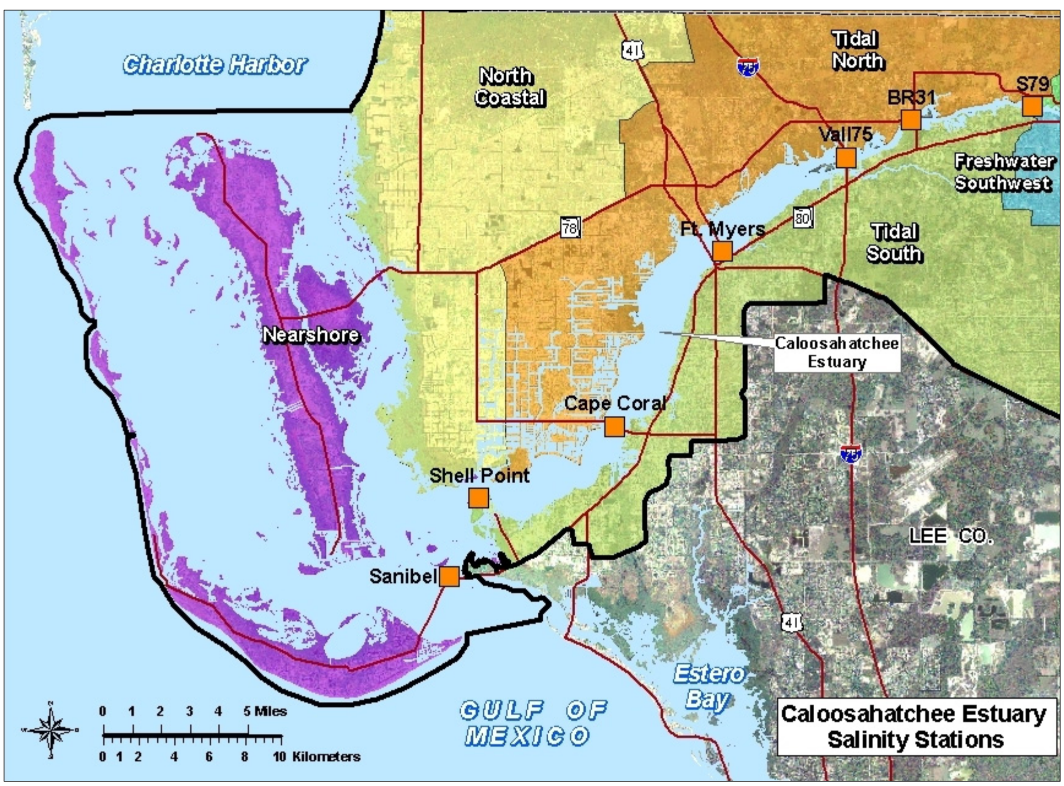


Figure 12-20. Locations of CRE continuous salinity monitoring stations.

Table 12–10. Summary of water quality (depth = 0.5 m) in four reaches of the Caloosahatchee River, 1994–2006 (RECOVER, 2007c; SFWMD, 2008a).

Parameter	Mean	±	Standard Deviation	Minimum	Percentiles					Maximum
					5th	25th	50th	75th	95th	
Station ~0.6 km upstram of S-79 (C-43)										
Salinity (PSU)	0.3	±	0.1	<0.2	<0.2	<0.2	0.2	0.3	0.5	2.3
Apparent Color (PCU)	103.8	±	53.8	40.0	49.8	64.0	80.4	134.3	213.8	260.0
Dissolved Oxygen (mg/L)	5.6	±	1.9	0.2	2.8	4.1	5.6	7.4	8.4	10.4
Total Phosphorus (µg/L)	115.9	±	57.8	15.0	27.8	77.8	110.0	140.0	230.0	360.0
Total Nitrogen (mg/L)	1.35	±	0.32	<0.05	0.91	1.17	1.36	1.51	1.86	2.43
Chlorophyll *a* (mg/m^3)	8.3	±	13.5	0.3	1.1	2.5	4.2	8.2	32.0	80.7
Stations 0 - 10 km from S-79 (Region1)										
Salinity (PSU)	1.3	±	3.0	<0.2	<0.2	0.2	0.3	0.5	7.2	22.2
Apparent Color (PCU)	103.1	±	57.2	20.4	41.8	60.7	80.2	138.0	221.5	282.0
Dissolved Oxygen (mg/L)	5.6	±	2.1	0.1	2.6	3.9	5.5	7.2	8.7	13.3
Total Phosphorus (µg/L)	125.3	±	83.7	15.0	37.0	72.0	110.0	160.0	280.8	680.0
Total Nitrogen (mg/L)	1.26	±	0.37	<0.05	0.64	1.08	1.26	1.49	1.86	2.36
Chlorophyll *a* (mg/m^3)	8.7	±	10.2	0.3	1.1	2.7	5.0	9.9	33.1	50.0
Stations 10 -30 km from S-79 (Region 2)										
Salinity (PSU)	4.7	±	6.4	<0.2	0.2	0.2	0.8	7.7	18.3	30.9
Apparent Color (PCU)	88.3	±	58.9	6.1	27.0	44.3	67.6	118.0	208.1	379.0
Dissolved Oxygen (mg/L)	6.6	±	1.9	0.4	3.6	5.1	6.8	7.9	9.4	13.4
Total Phosphorus (µg/L)	111.6	±	74.2	15.0	25.0	63.8	100.0	140.0	240.0	730.0
Total Nitrogen (mg/L)	1.04	±	0.47	<0.05	0.30	0.71	1.03	1.33	1.84	2.69
Chlorophyll *a* (mg/m^3)	11.8	±	17.5	0.3	1.5	3.2	5.8	12.4	40.9	119.0
Stations >30 km from S-79 (Region 3)										
Salinity (PSU)	17.9	±	10.6	<0.2	0.6	8.1	19.6	27.0	32.7	38.1
Apparent Color (PCU)	45.3	±	44.1	3.5	8.0	19.0	30.0	53.0	136.2	274.0
Dissolved Oxygen (mg/L)	6.6	±	1.4	2.7	4.1	5.7	6.7	7.6	8.8	12.7
Total Phosphorus (µg/L)	100.4	±	131.2	16.0	25.0	36.0	70.0	120.8	266.5	1130
Total Nitrogen (mg/L)	0.55	±	0.50	<0.05	<0.05	0.16	0.38	0.84	1.40	2.51
Chlorophyll *a* (mg/m^3)	6.1	±	6.7	0.2	0.9	2.6	4.0	7.2	17.3	51.1

Nutrient Loading

Recently, RECOVER (2007c) calculated nutrient loads at S-77, S-78, and S-79 for WY1991–WY2006 (**Table 12-11**). Observed inter-annual variation is large. For example, the maximum annual TN load at S-79 [6,521 mt nitrogen] is almost seven times greater than the minimum (850 mt nitrogen). Annual fluctuations in the magnitude of both total and inorganic loads were primarily driven by fluctuations in annual discharge. Doering and Chamberlain (2005) found similar results for annual and daily TN and TP loads at S-79. Depending on the nutrient, statistical analysis indicated that the volume of discharge explained between 50 and 90 percent of the daily variation. Variation in concentration, the other component of load, explained between 2 and 25 percent of the daily load variation (Doering and Chamberlain, 2005).

Significant increasing trends in some or all of the loads were observed at all structures, but not in freshwater discharge. Whether these trends are a function of the length of the POR (WY1991–WY2006) is unclear. Loads of TP increased at S-77 and S-78, perhaps reflecting the increase in TP concentration at these sites. The loads of inorganic nitrogen and phosphorus to the estuary at S-79 appear to have increased during the POR. Doering and Chamberlain (2005) analyzed calendar year loads from 1981–2002 and found no trends in total or inorganic nutrient loads at S-79. If the present POR is truncated at CY2002, all trends at all structures disappear. The result suggests that the increasing trends observed between 1991 and 2006 are due to loads that occurred in the four most recent water years. On average, about 50 percent of the TN load and 30 percent of the TP load at S-79 comes from Lake Okeechobee through the S-77 structure.

Table 12-11. Hydraulic and nutrient loads and flow-weighted mean concentrations at S-79 from WY1991 through WY2006.

Water Year	Inflow Volume	Nutrient Loads				Flow-Weighted Mean Concentration			
		Total Phosphorus	Soluble Reactive Phosphorus	Total Nitrogen	Dissolved Inorganic Nitrogen	Total Phosphorus	Soluble Reactive Phosphorus	Total Nitrogen	Dissolved Inorganic Nitrogen
	(m^3 X 10^6)	(metric tons)				(µg/L)	(µg/L)	(mg/L)	(mg/L)
1991	576	112	64.1	1,072	157	194.1	111.2	1.86	0.27
1992	1,126	197	146	1,828	414	174.6	129.5	1.62	0.37
1993	1,783	445	180	3,064	399	249.6	101.2	1.72	0.22
1994	958	139	61.1	1,968	692	144.9	63.8	2.05	0.72
1995	2,815	264	178	4,521	647	93.7	63.1	1.61	0.23
1996	3,497	274	182	4,097	754	78.3	52.2	1.17	0.22
1997	954	115	81.4	1,384	264	120.4	85.3	1.45	0.28
1998	3,077	262	199	4,076	658	85.3	64.6	1.32	0.21
1999	1105	154	124	1,665	359	139.3	112.0	1.51	0.32
2000	2,020	335	235	3,129	811	165.8	116.2	1.55	0.40
2001	593	97.1	76.4	850	251	163.7	128.7	1.43	0.42
2002	1,153	245	219	1,852	465	212.2	189.8	1.61	0.40
2003	2,232	353	232	3,798	738	158.3	103.8	1.70	0.33
2004	3,039	316	217	4,169	839	104.0	71.5	1.37	0.28
2005	2,503	279	190	3,303	712	111.4	75.9	1.32	0.28
2006	4,331	540	319	6,251	1,448	124.7	73.6	1.44	0.33

STRATEGIES FOR THE CALOOSAHATCHEE RIVER ESTUARY

Research projects are intended to reduce or eliminate key uncertainties in the load targets, as well as in flow and salinity envelopes, and optimize the operation protocols. Four research projects are presented in order of priority. Each project is accompanied by a table of project elements or components along with an assessment of how information will be obtained (e.g., new measurements, existing data, or estimates from a model). The *Caloosahatchee River Estuary, Integrated Modeling Framework* section of this chapter describes existing watershed, estuarine, and ecological models, and summarizes additional needs.

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 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 algae blooms, red tides, and massive accumulation of drift algae (Lapointe and Bedford, 2006) have been taken as an indication that nutrient loads to the Caloosahatchee are too high and the system suffers from eutrophication.

For more details about the scientific background of this project, see the *Strategies for the St. Lucie Estuary, Estuarine Nutrient Budget Project* section of this chapter. The rationale for the CRE nutrient budget parallels the SLE's nutrient budget.

Management Objective

The nutrient budget analysis project supports the goal of achieving the appropriate nutrient loads for the Caloosahatchee Estuary by quantifying the magnitude of nutrient loads from various sources so BMPs can be prioritized.

Application of Results

Nutrient budget tools assist in determining appropriate nutrient reduction approaches, and in evaluating and optimizing project effectiveness. Meeting the load targets relies on reducing nutrient loads that can be controlled. The relative magnitude of controllable and uncontrollable sources limits the extent of improvement that can be achieved. Since a nutrient budget comprises both types of sources, it provides the basic information required to quantify this limit. Including internal cycling terms as constraints (such as the regeneration of nutrients by bottom sediments) allows for estimating the time scale of system response to external load reductions. Results of this project can be used to support water quality modeling efforts, which will reduce the uncertainty of the appropriate targets and increase the capability to predict effects of various management measures, including BMPs.

Methodological Approach

This project will construct nutrient budgets of nitrogen and phosphorus for the CRE. 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 the Franklin Lock and Dam). 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 (**Table 12-12**). Priorities for evaluating the terms in the budget were determined by identifying terms that can be calculated without further data collection or new modeling efforts. Terms for which data collection was partially complete also received high priority.

Table 12-12. Input, internal cycling, and output terms included in the nutrient budget for the CRE. Includes the status of data required for each term and priority for funding.

INPUTS	STATUS
Franklin Locks	Data available, but frequency and profiling could be improved
Tidal Basin	
Surface Flows	Requires modeling project
Groundwater	Requires modeling project
Wastewater Treatment Facilities	Data available
Gulf of Mexico	Requires modeling project
Atmospheric Deposition	Lee County data for Estero Bay
Nitrogen Fixation	Requires new measurements
INTERNAL CYCLING	**STATUS**
Primary Productivity	Requires new measurements
Water Column Respiration	Requires new measurements
Benthic Nutrient Flux	Dry season data available; need wet season data
OUTPUTS	**STATUS**
Export to Gulf	Requires modeling project
Burial in Sediments	Some sedimentation rate data exist
Denitrification	Dry season data available; need wet season data
Biomass	
Migration	Data needed
Harvesting	Data needed

Progress in Water Year 2008

Nutrient Limitation of Phytoplankton Growth. Although indirect evidence suggests that nitrogen is limiting in the Caloosahatchee, no recent studies have experimentally determined whether nitrogen or phosphorus limits algal production in this system. Measurements from monitoring programs indicate that much of the nitrogen load is organic, but the extent to which this organic fraction can support algal production is not known.

This project examines nutrient limitation of algal growth at four stations in the CRE through nutrient addition and dilution bioassays. It also examines the availability of organic nitrogen. This information supports development of water quality targets, indicates which nutrient (nitrogen or phosphorus) needs to be controlled, and, thus, guides the development of TMDLs and the nutrient load reduction strategies required achieve those load limits.

This project began in 2006 and includes sampling over a two-year period. The final report is still undergoing quality assurance/quality control and review; however, preliminary results indicate nitrogen limitation.

Degradation of Riverine Dissolved Organic Nitrogen (DON). Monitoring data indicate that about 80 percent of the nitrogen load at S-79 is organic, much of which must be remineralized before becoming available to phytoplankton, although some phytoplankton have the ability to use organic nitrogen directly. Most of the organic nitrogen is dissolved, and how much can become available to support phytoplankton production is unknown. The amount that can become available will determine whether control of DON will be required to achieve the nitrogen TMDL for the Caloosahatchee system.

The District has funded a project to examine how much of the DON in the downstream estuary can be remineralized. There are many possible sources of DON to the downstream estuary, including tidal creeks, seepage, and effluent from wastewater treatment facilities. This study builds on previous work by characterizing the largest source: DON from the freshwater Caloosahatchee River and determining how much can become available to phytoplankton. Experiments on the role of bacteria and photolysis follow those of Seitzinger and Sanders (1997) and Vahatalo and Zepp (2005).

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, DON did not appear to be converted to inorganic nitrogen by bacteria and did not form particulate aggregates upon mixing with seawater. Further studies during wet conditions are required.

Benthic Nutrient Fluxes. In shallow coastal estuarine systems such as the CRE, the water column and sediments can be tightly coupled with respect to the biogeochemical cycles of nitrogen and phosphorus. Sediment can function as a sink or a source through the flux of nutrients between the water column and sediments. Inorganic nutrients are produced during the microbial remineralization of organic matter within the sediments. Loads of nutrients from sediments can contribute significantly to the total nutrient load in sub-tropical estuaries. A recent study of benthic fluxes in an estuary in northwestern Florida identified sediments as a significant source of inorganic nitrogen and phosphorus to the water column relative to inputs from the main freshwater source during drought conditions (DiDonato et al., 2006).

Due to lack of information about benthic nutrient fluxes available for this system, two studies were conducted in February 2008 to estimate benthic fluxes of nitrogen and phosphorus in the CRE (Howes et al., 2008; Cornwell et al., 2008).

The goals of the first study were to: (1) provide estimates representative of system-wide benthic nutrient flux rates in the CRE, (2) identify "hot spots" of benthic nutrient, and (3) provide data in support of current and future water quality modeling efforts. System-wide estimates were based on measurements from sediment cores collected from 50 sites distributed throughout the estuary.

The goals of the second study were to identify the contribution of diffusive and advective fluxes in the CRE by comparing fluxes measured from cores in the laboratory with fluxes measured in the field with chambers. The results will guide future research and monitoring efforts in the application of appropriate methodology for measuring benthic nutrient fluxes.

Initial measurements were taken in February 2008 during the dry season in a drought year. Additional measurements are required to determine the relative contribution of the sediments to the total nutrient load.

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 has been listed as impaired for DO and nutrients by the FDEP. Causative agents for the dissolved oxygen impairment were identified as both a high BOD and high levels of chlorophyll *a* (FDEP, 2004). The two causative agents suggest different origins for the DO impairments. By contrast, elevated levels of chlorophyll suggest that excess nutrient loading leads to internal production of algae, which consume dissolved oxygen when they die and decompose. The two scenarios lead to different management actions.

Management Objective

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

Application of Results

This project will identify the factors causing the DO impairment in the CRE. 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.

Methodological Approach

To determine if lower nutrient loads will improve DO concentrations in the CRE, it is necessary to quantify the relative importance of factors that control DO, and how they interact to exert that control. This study will examine the role of internal and external factors in determining the concentration of DO (**Table 12-13**). Factors include stratification, algal blooms, SOD, and BOD loading. Emphasis will be on measuring diel (daytime-nighttime) fluctuations of DO in surface and bottom waters in different seasons — and over a range of freshwater inflows and algal bloom conditions. The interpretation of these observations will be aided by measurements of SOD and BOD in the water column.

Table 12-13. Sources, sinks, and other measurements required to quantify the dynamics of DO in the CRE.

SINKS	STATUS
External BOD Load	Monitoring planned
Benthic Sediment Oxygen Demand (SOD)	Requires new measurements
Water Column Respiration	Requires new measurements
SOURCES	**STATUS**
Primary Productivity	Requires new measurements
Re-aeration	Modeled
PHYSICS	**STATUS**
Stratification	Requires new measurements
CONCENTRATION TIME SERIES	**STATUS**
Dissolved Oxygen	Requires new measurements
Chlorophyll *a* Biomass	Requires new measurements
Light Extinction	Requires new measurements

Progress in Water Year 2008

Sediment Oxygen Demand. Measurements of SOD were taken along with the nutrient flux measurements described above. These were obtained during the dry season of a drought year (CY2008). Further measurements are required.

Dissolved Oxygen Time Series. In February 2008, continuous measurements of DO were initiated in the upper CRE (**Figure 12-16**). 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 northern estuaries have been based on salinity tolerances of organisms (e.g., Eastern oyster) living in low-salinity regions located near the head of these systems.

Typically located near the head of an estuary, the low salinity zone (0-10 psu, Holmes et al., 2000) is highly productive, serving as a nursery area for early life stages of economically important fish and shell fish (Day et al., 1989). Whether low flow targets based on the salinity requirements of the Eastern oyster (whose survival in these regions is used as an indicator of ecosystem viability) are sufficient to maintain this nursery function have yet to be determined.

Estuaries are characterized by high primary and secondary productivity (Nixon et al., 1986; Nixon, 1988). It is generally agreed that freshwater input maintains this production (Fisher et al., 1988; Day et al., 1989; Montagna and Kalke, 1992). An agricultural paradigm deems the nutrients carried to estuaries by freshwater inflows as beneficial, with higher freshwater inflows leading to higher yields of desirable species (Loneragan and Bun, 1999). Yet the relationship between freshwater input and estuarine productivity is not completely understood (Livingston et al., 1997). While productivity is often positively correlated with the quantity of freshwater discharge, both reductions and increases in discharge can result in reduced productivity (Wilbur, 1992; Livingston et al., 1997; Turner, 2006).

In a recent review of recruitment of fish and other nekton, Petersen (2003) unified the dynamic-stationary habitat overlap hypothesis of Browder and Moore (1981) with Cushing's (1990) match/mismatch hypothesis. Peterson (2003) noted that successful recruitment depends first on larvae approaching their physiological optima (salinity, temperature, and dissolved oxygen) in the surrounding water (dynamic habitat), and then having available the appropriate habitat structure (e.g., grass bed, sediment type, and stationary habitat) for other life requirements. Chief among these other requirements is the overlap between fish larvae and their prey. Annual variation in temporal and spatial overlap (match/mismatch) is reflected in subsequent recruitment. The dual role of freshwater inflow in positioning larvae with respect to physical habitat and food and supplying the nutrients to grow the food is evident.

Estuaries typically trap sediment in high concentrations at localized regions within the low salinity zone, called the ETM. The ETM is a unique dynamic habitat that provides protection and nutrients to planktonic and larval fish (Roman et al., 2005; North and Houde, 2003). In Southwest Florida, Peebles (1996) demonstrated that estuarine-dependent fish (such as perch and bay anchovy) spend the juvenile phase of their life-cycle foraging in the ETM. Despite its importance to the ecology of the estuary, little or no work has been done to examine the dynamics of the ETM in the CRE.

Management Objective

Much of the work that supports estimates of minimum and maximum freshwater inflow requirements to the CRE is based on the salinity tolerances of freshwater and marine organisms that inhabit the system. Inflows targets are primarily based on providing tolerable physiological conditions. The relationship between freshwater inflow and estuarine productivity has not been described in the CRE. It is not known whether freshwater inflow and salinity envelopes based on physiological tolerances also adequately support estuarine productivity.

This project examines elements of the estuarine food web, including planktonic and benthic algae as well as zooplankton and fish larvae within the ETM 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. It supports the establishment of water quantities that are protective of fish and other wildlife. Results can be applied to establishing water reservations, to refining flow and salinity envelopes, and to providing guidelines for delivery of fresh water to the CRE.

Application of Results

Results of this study will be used to refine salinity and flow envelopes for the CRE and to provide guidelines for delivery of fresh water at S-79.

Methodological Approach

The study area consists of the lower Caloosahatchee River and Estuary (**Figure 12-21**). A total of seven zones will be sampled from San Carlos Bay to just below the Franklin Lock and Dam. The locations for phtyo- and zooplankton sampling will be fixed (nonmoving) for all collections. Collection locations will be located using GPS, and the collection vessel's position will be recorded using GPS chart plotters. This method will give quality-control personnel records of the collection locations visited by the vessel during individual collection efforts.

Sampling and data collection will be conducted at night. In comparable studies, flood tides have been used as the standard condition for plankton-net sampling. Dates for plankton-net sampling will be determined according to the presence of flood tides in order to reduce variability caused by organisms' reactions to differences in tide direction. Existing data indicate that during flood tides, the estuarine water column tends to contain more organisms that are moving upstream or are trying to maintain position, whereas ebb tidal waters tend to contain more organisms that are in the process of leaving the estuary. Transects will be conducted on two consecutive nights, if necessary, in order to ensure that sampling and data collection fall within a similar tide. The following samples and data will be collected within each zone of the study area:

- Zooplankton (plankton net)
- Phytoplankton (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)

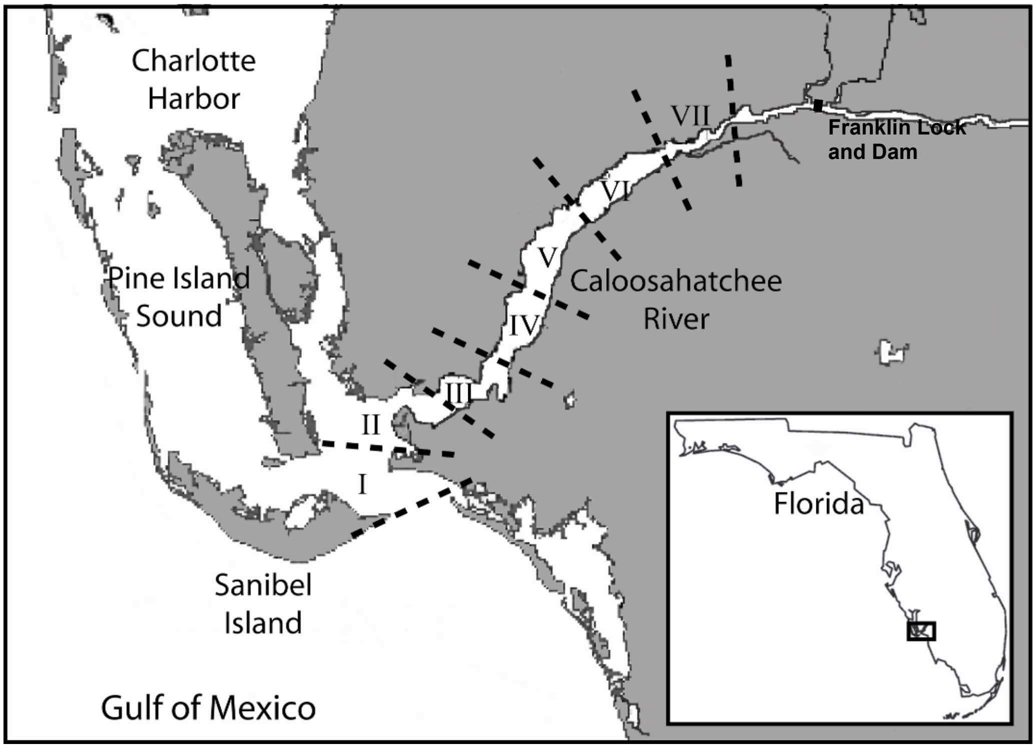


Figure 12-21. Map of the Low Salinity Zone Project study area indicating zones selected for biological and water quality sampling.

Progress in Water Year 2008

Estuarine Turbidity Maximum. A short-term preliminary study of the CRE ETM was initiated in 2008. The goal of this study was to identify and evaluate the vertical and horizontal density and turbidity structure(s) with respect to DO, salinity, and/or chlorophyll *a* stratification. The results of this project can be used for the calibration of a numerical sediment transport model to evaluate light conditions in the estuary. The project also has implications in environmental operations for better management of freshwater releases to improve the ecosystem health in the low salinity zone and for refinement of salinity and flow envelopes.

Four longitudinal transects were made during two trips on February 7, 2008, and March 16, 2008. This project produced some of the first high-spatial-resolution measurements of turbidity, DO, and chlorophyll *a* in the Caloosahatchee River. During low discharge periods, the ETM is located upstream around 14–18 km from the Franklin Lock.

Low Salinity Zone Demonstration Project. A demonstration project was initiated in CY2008. The work is being conducted by investigators from Florida Gulf Coast University (FGCU) and the University of South Florida (see previous *Low Salinity Zone Project, Overview and Background* section for project description). Because this is a demonstration project, sampling is limited to two events, one during a seasonally dry month (April or May) and one during a seasonally wet month (September) in 2008.

Light Attenuation Project in San Carlos Bay

Overview and Background

A resource-based method (Corbett and Hale, 2006) is being employed to establish nutrient load targets in the CRE. Nutrient load reductions will be based on achieving a level of water clarity in San Carlos Bay that allows enough light for seagrasses to grow in water of up to 2.2 m (7.2 ft) depth. McPherson and Miller (1994) identified three major water quality constituents that attenuate light in Southern Charlotte Harbor: (1) turbidity, (2) CDOM, and (3) chlorophyll *a*. The major assumption of this resource-based approach is that nutrient load reductions will result in chlorophyll reductions sufficient to achieve the water clarity goal.

While there has been no comprehensive investigation of light attenuation in San Carlos Bay, existing evidence suggests that in some years, CDOM may account for most of the light attenuation, while chlorophyll may dominate during other years (Dixon and Kirkpatrick, 1999; Doering et al., 2006). This suggests that a target might meet its resource goal in some years and not others, regardless of external water management activities.

CDOM is measured as color using a platinum-cobalt (Pt-Co) standard scale. The long-term (1994–2006) average concentration of color in the Caloosahatchee Estuary varies spatially, ranging from 103 Pt-Co units (PCU) at the head of the estuary (0–10 km downstream of S-79) to 45 PCU near the mouth (30–40 km downstream of S-79). CDOM concentration also varies seasonally, typically higher during wet seasons and wet years, and lower during dry seasons and dry years.

Management Objective

The management objective is to reach a water clarity goal through nutrient load reduction. This project tests whether this objective is achievable.

Application of Results

Information from this study will better define controls on light attenuation in San Carlos Bay, and the relationship between nutrient load targets and resource goals. Results can be used to determine when, and under what conditions, resource light attenuation goals may be met.

Methodological Approach

This study will determine how the relative contributions to total light attenuation of chlorophyll *a*, CDOM, and turbidity vary with season and freshwater inflow in San Carlos Bay. Water quality samples will be taken at several stations in the estuary and San Carlos Bay, where the light extinction coefficient will be measured (**Table 12-14**). Light attenuation will be modeled following McPherson and Miller (1994). The model will allow the contribution of each constituent to total light attenuation under different seasonal and flow conditions to be calculated. The estuarine mixing behavior of CDOM from various sources will also be investigated.

Table 12-14. Elements of the Light Attenuation Project in San Carlos Bay.

INPUTS	STATUS
Franklin Locks	
Flow	Data available
Color	Data available
Turbidity	Data available
Chlorophyll	Data available
TSS	Data available
Tidal Basin	
Surface Flows	Requires modeling project
Color	Project/measurements
Turbidity	Data available
Chlorophyll	Data available
TSS	Data available
INTERNAL CYCLING	**STATUS**
Mixing Behavior	Requires new measurements
Sediment Resuspension	Requires new measurements
CONCENTRATION TIME SERIES	**STATUS**
San Carlos Bay	
Color	Requires new measurements
Turbidity	Requires new measurements
Chlorophyll	Requires new measurements
TSS	Requires new measurements
PAR	Requires new measurements

Progress in Water Year 2008

Routine monitoring data useful to the project have been collected during CY2008, but no specific research has been initiated. The Charlotte Harbor National Estuary Program is reevaluating the optical model employed by Corbett and Hale (2006).

Research Projects and Priorities

Each major project can be broken down into several component parts. These parts are given in separate tables, such as (**Table 12-14)**, and others that follow the listing of the research projects**.** Some projects have common components. The commonalities between components of various CRE projects are summarized in **Table 12-15**. As in the individual project tables, the source of data for each component is given (existing data, new measurements, model etc.). The components funded in any given year may be prioritized according to the number of projects to which they belong.

Table 12-15. Major research projects in the CRE with their components and commonalities.

	RESEARCH PROJECTS				
RESEARCH COMPONENT	***NUTRIENT BUDGET***	***D.O. DYNAMICS***	***LOW SALINITY ZONE***	***LIGHT ATTENUATION***	**SOURCE**
INPUTS					
Franklin Lock (S-79) Loads	X	X	X	X	Monitoring
Tidal Basin Loads	X	X	X	X	
Surface Flow	X	X	X	X	Model measurements
Ground Water	X	X	X	X	Model measurements
Wastewater Treatment Facilities	X	X	X	X	New measurements
Gulf of Mexico	X				Model for flow Literature/ concentration
Atmospheric Input	X				Literature data analysis
INTERNAL CYCLING					
Primary Productivity/ Water Column Respiration	X	X	X	X	New measurements
Organic Matter Decomposition, including. DON	X	X			New measurements
Benthic Nutrient Flux	X	X			New measurements
D.O. Time Series		X	X		New contract ***Eastern oyster*** in-house
San Carlos Bay				X	
Color				X	New measurements
Turbidity				X	New measurements
Chlorophyll				X	New measurements
TSS				X	New measurements
PAR				X	New measurements
OUTPUTS					
Export to Gulf	X				Model
Denitrification	X				Benthic Flux Project
Biomass				X	
Larval/ Juvenile Fish				X	New measurements
Zooplankton				X	New measurements
Benthic microalgae				X	New measurements
Phytoplankton (species/groups)				X	New measurements

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. For a detailed discussion of this approach in the CRE, see the *Southern Indian River Lagoon and St. Lucie River Estuary, Integrated Modeling Framework* section of this chapter.

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

Although substantial progress has been made in Caloosahatchee modeling efforts, an overall assessment of the needs of each modeling component is necessary to plan future work with budget-limited resources, and to provide the needed technical support for adaptive management and implementation of the CRWPP. The integrated modeling and resource assessment framework can be applied at different levels of complexity to provide the information required for sound, science-based management. Such a well-calibrated and validated modeling system can be implemented as an essential tool to quantify the impacts of watershed modification. It can also be used to evaluate restoration alternatives and to assess management targets.

The modeling needs described below are based on an examination of both quick simulations with long-time steps and rigorous modeling with short-time steps. On the one hand, there will always be a need to come up with quick solutions for pressing management needs. On the other hand, long-term, rigorous solutions built upon sound and defendable science are needed. In the future, a comprehensive modeling framework for the Northern Everglades will be evaluated and developed.

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**).

The NERSM model can serve as a regional hydrological model to simulate the hydrologic interactions across the Northern Everglades watersheds, but would require additional refinements and integration with a water quality component and optimization component. The MIKE SHE, AFSIRS/WATBAL, and HSPF models can be used as the sub-regional models to simulate the detailed hydrology of the watershed. These models will need to be further evaluated and refined with additional calibration to better simulate nutrient cycling and DO dynamics in major canals. A longer period of calibration and validation are also needed. Data collected by the monitoring activities described in Chapter 4 of the *2009 South Florida Environmental Report* (2009 SFER) – Volume I can be used for this purpose. A user-friendly GUI is also necessary for management of the geo-spatial data (such as land use change and irrigation demands). To manage freshwater discharge upon implementation of the C-43 reservoirs, it is critical to have a reliable operation model to meet the salinity envelope target in the estuary.

Estuary Hydrodynamic Water Quality Modeling. One of the major objectives of the Caloosahatchee River projects is to identify and answer the priority science questions to reduce the uncertainties. One of the science questions is: How will the change in the quantity, quality, timing, and distribution of watershed inflows improve water quality and aquatic habitats in the estuary? The estuary hydrodynamic, water quality, and ecological models, when integrated with the watershed models, will serve as critical Eastern oyster tools in evaluating the many hydrodynamic and water quality issues, such as stratification, nutrient cycling, and DO dynamics.

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, and 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 Southwest Feasibility Study. 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 EFDC and WASP7 models for establishing Caloosahatchee TMDLs are under development and should be available in FY2009. The EFDC Model has a short calibration period (one calendar year). The water quality component of the EFDC and WASP7 models used water quality data collected in CY2003 for calibration and CY2004 for validation. In order to simulate the impact in the estuary from watershed loading for adaptive management, the water quality model will need to be updated with newly collected data including benthic flux, diel DO concentrations, and sediment and turbidity data. Calibration and refinements on nutrient cycling process, stratification, and DO dynamics need to be done when such data are available. The empirical relationships of important water quality processes and their control factors need to be explored further. The simulation period needs to be extended to cover a longer time period, for example, from CY2000 through CY2007. To develop a better integrated modeling system for the Caloosahatchee River and Estuary, these models will be evaluated and assessed in the future.

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. These components may serve as performance measures for future environmental operation during different climatic and seasonal conditions. To achieve this goal, a set of ecological performance measures, representing different habitats for fish larvae, oysters, and seagrasses, will be needed to direct operations for South Florida's annual dry season and wet season. These performance measures will also need to be integrated into an index-type model along with a GUI to aid in future applications. Eventually, a community-level ecological response model should be developed to predict how the ecosystem would change with the anticipated improvements in the habitats. A GUI will also need to be developed to provide explicit linkage between management objectives and predicted improvements with restoration actions. Spatial maps and temporal dynamic graphics demonstrate system-wide visual comparisons and enhance effective communications. Such GUI tools could be applied to showcase modeling results with maps, time-series plots, animation, and movies.

Habitat Suitability Index (HSI) Models. The existing HSI Model is a static-parameter based model that does not contain dynamic processes. It provides a quick, overall assessment of whether estuary conditions are favorable for SAV or oysters. HSI models should be incorporated into a geographical information system to portray responses spatially and temporally; this portrayal of responses will facilitate policy decisions. The HSI models were developed principally with literature, expert knowledge, and currently available field data. These models use deterministic indices that combine independent variables without explicit consideration of variable interactions or dynamic processes. The models need to be further validated with comprehensive monitoring data. A comprehensive assessment is also necessary to evaluate the model type for both long-term and short-term applications. The advantage of HSI models is that they can be developed in the early stages of a project because they require less data. The HSI Model, when validated, can be used as a forecasting tool that brings research and monitoring together with ecosystems assessment. Such an approach fits well into an adaptive management framework for the evaluation and refinement of alternative plans.

SAV Models. The existing tape grass model for the CRE was developed using Stella® (Structural Thinking Experiential Learning Laboratory with Animation), an icon-based software package specifically designed for dynamic systems modeling. The model should be converted to a common platform, such as Fortran, with linkages to Microsoft Excel or another user-friendly interface to increase computation efficiency. For broader applications, the SAV model needs to be expanded to include other SAV species, such as shoal grass and turtle grass. A numeric ecological model will need to be set up for each species and calibrated with field monitoring data. A broad range of tests will also need to be conducted under different salinity, light, and water temperature conditions. Additionally, there are no current water quality linkage applications with SAV models, which would need to be established.

LOXAHATCHEE RIVER ESTUARY

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DESCRIPTION OF THE LOXAHATCHEE RIVER ESTUARY AND MAJOR ISSUES

The Loxahatchee River and Estuary are located along the lower east coast of Florida. This watershed drains an area of about 210 sq mi (544 km^2) within northern Palm Beach and southern Martin counties, and connects to the Atlantic Ocean through the Jupiter Inlet. (**Figure 12-22**). In May 1985, 9.5 mi (15.3 km) of the Northwest Fork of the Loxahatchee River, between River Mile (RM) 6 and RM 15.5, was federally designated as Florida's first National Wild and Scenic River. Other unique resources of the river and estuary include designations of Aquatic Preserve, Outstanding Florida Waters, and Jonathan Dickinson State Park.

Originally, the Loxahatchee River was a freshwater system, the headwaters of which originated in what is known as the Grassy Waters Preserve, the Loxahatchee Slough, and Hungryland Slough. Most of the watershed was drained by the Northwest Fork of the Loxahatchee River. During the past century, the natural hydrologic regime of the Loxahatchee Watershed was altered by human activities: the permanent opening of the Jupiter Inlet in 1947, the operation of the C-18 canal, and drainage activities associated with urban and agricultural development. Hydrologic changes, which have occurred in the Loxahatchee River and Estuary due to navigation, drainage, and flood control activities, have significantly altered the volume, timing, and distribution of freshwater flow. This network of canals and barriers has reduced water storage in natural areas, reduced dry season flows to natural systems, and increased wet season discharges to the Loxahatchee River Central Embayment and Estuary areas.

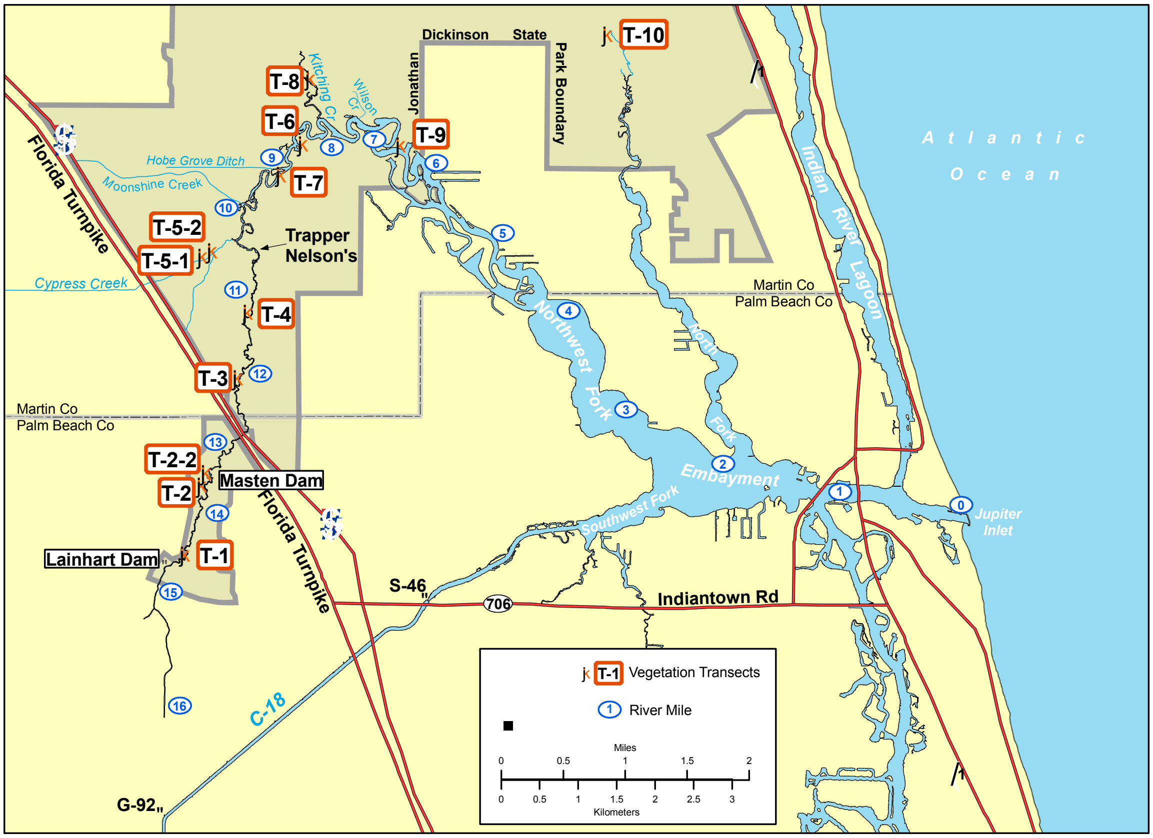


Figure 12-22. Location of the Loxahatchee River Estuary (LRE) with river miles and vegetation transects.

In April 2003, the District adopted a Minimum Flows and Levels Rule [Chapter 40E-8 (F.A.C.)], with a minimum flow of 35 cfs (0.99 m3/s) for the Northwest Fork of the Loxahatchee River. As required by legislation, a recovery strategy was incorporated into the MFL rule, which included a commitment by the SFWMD to develop, in partnership with the FDEP, "a practical Restoration Plan and goal" for the Northwest Fork of the Loxahatchee River. On April 12, 2006, the District's Governing Board adopted the Restoration Plan for the Northwest Fork of the Loxahatchee River. After an analysis of historic and current flora and fauna communities, five VECs for the Northwest Fork ecosystem were identified:

1. Cypress swamp and hydric hammock in the freshwater riverine floodplain (RM 16 to RM 9.5)
2. Cypress swamp in the tidal floodplain (RM 9.5 to RM 5.5)
3. Fish larvae in the low salinity zone (RM 9.5 to RM 5.5)
4. Oysters in the mesohaline zone (RM 6.0 to RM 4.0)
5. Seagrasses in the polyhaline zone downstream (RM 4.0 to RM 0.0)

Performance measures for each VEC were developed to relate flow and stage in the floodplain and salinity in the river, to the ecological health of the VECs, and were used to evaluate the relative biological effects of each restoration flow alternative.

STATUS AND TRENDS IN THE LOXAHATCHEE RIVER

Salinity and Freshwater Inflows

The five tide and salinity stations that have been deployed in the Loxahatchee River since 2002 were maintained in WY2008 to monitor salinity for compliance with the MFL rule, and to assess the benefits of supplemental dry season flows in terms of salinity in the Northwest Fork and lower estuary. The MFL rule established a minimum flow of 35 cfs over the Lainhart Dam to the Northwest Fork of the Loxahatchee River during the dry season. In the past water year, the flow over the Lainhart Dam was mostly maintained above the MFL criterion of 35 cfs except in the month of May 2007 (**Table 12-16**). As a result of the low freshwater flow, salinity at RM 9 exceeded the 2 psu threshold in May 2007, and the first few days of June 2007. With the completion of the L-8 Reservoir, G-160, G-161, and other CERP North Palm Beach County projects, the system will be able to deliver more fresh water to the Loxahatchee River and further improve the salinity condition in the Northwest Fork.

Figure 12-23 shows the daily flow over Lainhart Dam and corresponding salinity at RM 9 in WY2008. As previous studies have demonstrated, monitoring in the past year indicated that the salinity in the Northwest Fork is highly sensitive to the freshwater flow. When flow at Lainhart Dam was below the 35 cfs threshold, the salinity at RM 9 increased and exceeded 2 psu.

Table 12-16. Monthly mean flow at Lainhart Dam and salinity at River Mile 9 of the Northwest Fork of the Loxahatchee River.

MONTH-YEAR	SALINITY AT RIVER MILE 9 (PSU)	FLOW AT LAINHART DAM (CFS)
May-07	5.71	24.5
Jun-07	0.59	71.2
Jul-07	0.22	192.5
Aug-07	0.20	203.9
Sep-07	0.21	192.7
Oct-07	0.19	181.9
Nov-07	0.21	159.3
Dec-07	0.22	124.9
Jan-08	0.28	72.8
Feb-08	0.30	70.6
Mar-08	0.26	112.5
Apr-08	0.38	98.7

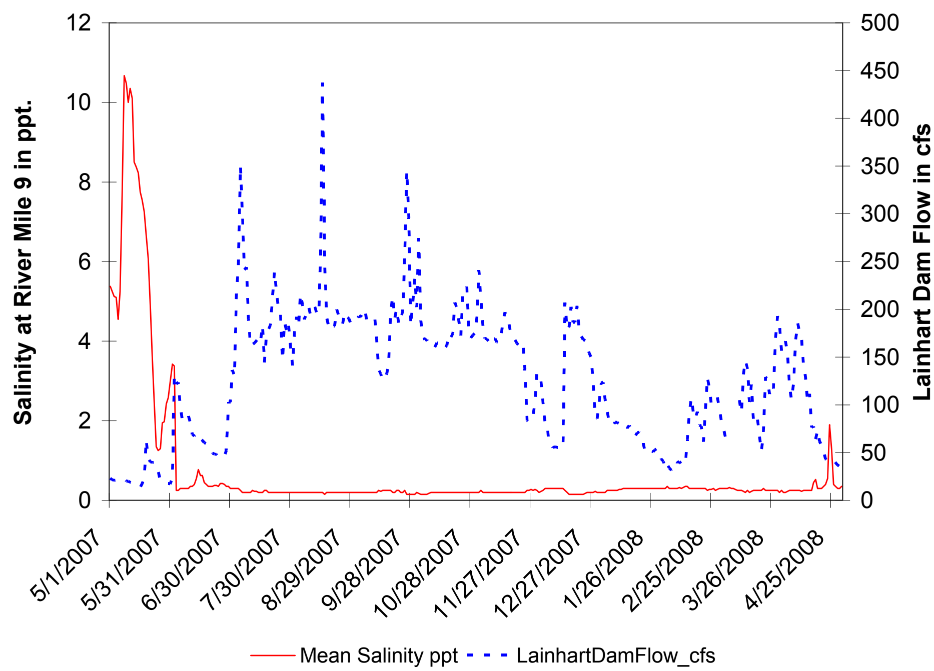


Figure 12-23. Flow over Lainhart Dam and salinity at River Mile 9 of the Loxahatchee River in Water Year 2008 (WY2008) (May 1, 2007–April 30, 2008).

Nutrients

The Loxahatchee River District (LRD) has established a comprehensive water quality monitoring network at approximately 40 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 trends analysis and predictive analysis. From May 2007–April 2008, the average concentration of total nitrogen in the estuary and the tributaries was 0.86 mg/L. The average concentration of total phosphorus at the same sites was 0.05 mg/L. These concentrations are in line with the interim water quality targets for the Loxahatchee River and Northwest Fork water quality monitoring sites.

Submerged Aquatic Vegetation

Seagrass cover in 2007 is depicted in **Figure 12-24**. Loxahatchee River Estuary (LRE) seagrass communities were heavily impacted during the 2004 and 2005 hurricane seasons (Ridler, et al., 2006). Ongoing monitoring by the LRD is documenting the recovery process.

Eastern Oyster Abundance and Distribution

Surveys from 2003 identified about 10 acres (4 hectares) of oyster reef in the LRE, and this information will be updated in WY2009. Field observations have shown that Eastern oysters are largest within certain ranges of the LRE. For example, in the Northwest Fork, the largest living oysters (standard length 80–90 mm) occurred between RM 4.0 and RM 6.0, where the average high tide surface salinity ranged between 7 and 22 psu, and total range between 2 and 28 psu. A river delta ("S-Bar") located near RM 4.5 plays a controlling role in upriver salinity, and is the most active oyster ground (Law Environmental, Inc., 1991).

Oysters were monitored at two sites (three stations each) within the LRE through a cooperative project between the District and FWC. Juvenile oysters were planted at the monitoring stations to assess growth and mortality in 2005 and 2006. Planted juveniles were cultured from parent broodstock collected from the local estuary, or collected from natural stock in the wild. During 2006, juvenile oysters were planted at a size of 2–5 mm to obtain a better understanding of growth and survival patterns for the smallest possible size class. During 2005, juvenile oysters grew most rapidly in the South Fork of the LRE compared to the other estuaries (RECOVER, 2007a). Overall, growth rates were remarkably rapid, and most juvenile oysters planted achieved a shell height of at least 45 mm within a year. A cooperative project between LRD and the SFWMD includes additional monitoring of oyster communities upstream and downstream of the FWC sites.

An oyster restoration project is being led by LRD in cooperation with several local agencies, the SFWMD, and local community members. The targeted locations are in the Northwest Fork between RM 3.5 and RM 5.5, and in the Southwest Fork between Island Way Bridge and the Loxahatchee River Bridge. Substrate consisting of limestone boulders and rocks, bags of oyster shells, and reef balls will be tested.

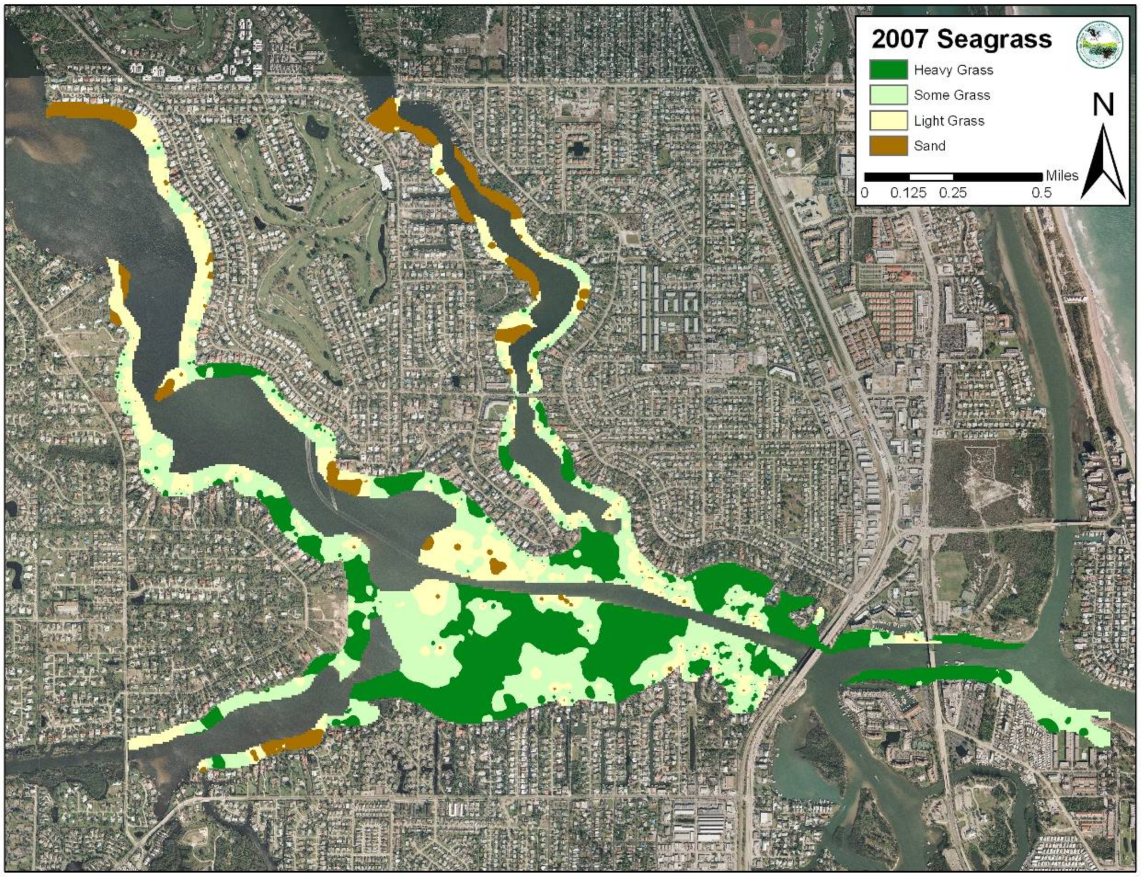


Figure 12-24. Relative seagrass cover in the LRE in 2007 created by interpolation of more than 1,000 direct observation points.

Fish Communities

Periodic inundation of floodplains, sloughs, and wet prairies may be closely linked to the overall biological productivity of the Loxahatchee River Watershed ecosystem. Inundation of these aquatic habitats typically expands the habitat and food resources available for fishes and their food resources. Information about fish in the middle and upper Northwest Fork of the Loxahatchee River or its tributaries was unavailable. Therefore, a baseline fish survey of the watershed was conducted between June 2007 and March 2008 by a multiagency research team comprising representatives from the SFWMD, FDEP, FWC, U.S. Fish and Wildlife Service, and CSA International, Inc. Sampling gear included backpack and boat mounted electroshockers, seines, cast net, and underwater video (**Figures 12-25** and **12-26**). In addition, a comprehensive review was conducted of the scientific and technical literature on the effects of water levels on fish populations, with special reference to Florida fishes and their habitats. Information was also obtained on the extent of distribution and abundance of exotic and nuisance fish species in the Loxahatchee River Watershed.

With 18 sampling sites in the Northwest Fork river corridor between Hobe Grove Ditch and just upstream of Trapper Nelson's Interpretative Site, 31 fish species were collected. Of these species, five were categorized as exotic. Of the exotics, spotted tilapia (*Tilapia mariae*), walking catfish (*Clarias batrachus*), and brown hoplo (*Hoplosternum littorale*) were the most common representatives within the Loxahatchee River Watershed. With regard to native South Florida fish species, mosquitofish (*Gambusia holbrooki*) and bluegill sunfish (*Lepomis macrochirus*) exhibited the highest frequencies of occurrence and abundance. Data collected during CY2006 from the Loxahatchee Slough prior to this study added an additional eight species to the survey list. Currently, a new study is being conducted to observe fish species distribution at low flows. The new study will (1) obtain data on fish presence/absence, abundance, and biomass in response to flow and stage changes in the river channel during the dry season; (2) examine fish distribution patterns in the river channel with regard to temperature, conductivity, dissolved oxygen, and water depth, flow velocity, and habitat type; and (3) summarize the current status of endangered, threatened, or species of special concern, and exotic fish species in the river and how these species would be affected by changes in flow and stage levels.

Figure 12-25. Crew with backpack electroshockers collecting fish in the Loxahatchee River (photo by the SFWMD).

Figure 12-26. Counting and measuring fishes after beach seining and cast netting in the Loxahatchee River (photo by the SFWMD).

Floodplain Vegetation

Using data from the 10 vegetative belt transects consisting of 138 vegetative plots and four environmental variables (river mile, elevation, soil type, and forest type) on the Loxahatchee River and its major tributaries, the software package PC-ORD was used to run the following analysis: Principal Components Analysis (PCA), Canonical Correspondence Analysis (CCA), and Detrended Correspondence Analysis (DCA). Results were graphed as a scatterplot (**Figure 12-27**). A more detailed account of the ordination analysis will appear in an upcoming report produced by the SFWMD, FDEP, and Florida Park Service, entitled Riverine and Tidal Floodplains of the Loxahatchee River and Its Major Tributaries. For canopy, datasets were available for abundance, frequency of occurrence, and basal area, while datasets for shrubs consisted of percent cover and frequency of occurrence. Datasets for ground cover consisted of frequency of occurrence and stem counts.

As reported in earlier South Florida studies, mixed groups of forest types were prevalent on the floodplain of the Loxahatchee River and its tributaries (Davis, 1943). In a PCA analysis of the 2003 canopy frequency of occurrence dataset, the resulting algorithm identified two major canopy groups (upland/hammock and bottomland hardwood/swamp) with six sub-groups consisting of mesic and hydric hammock, upland/hammock mix, riverine swamp, riverine bottomland hardwood and swamp mix, tidal swamp, and tidal hammock mix. The largest group, identified as the mixed swamp and bottomland hardwoods group, also had overlap with the upland and hammock groups. Additional ordination results also suggested that, particularly in the riverine reach, hydroperiods may not be adequate in depth and duration to exclude intrusion of non-hydric and exotic plant species, and landscape displacement of the hydric species.

Additional work is continuing on comparing shrub and ground cover datasets from 2003 and 2007, canopy cover analysis using densitometer and hemispheric photography, and, photographic points of the transect plots.

AR	*Acer rubrum*
AG	*Annona glabra*
CA	*Carya aquatica*
CO	*Cephalanthus occidentalis*
CI	*Chrysobalanus icaco*
CS	*Citrus sp.*
FA	*Ficus aurea*
FC	*Fraxinus caroliniana*
IC	*Ilex cassine*
LR	*Laguncularia racemosa*
MC	*Myrica cerifera*
PB	*Persea borbonia*
PP	*Persea palustris*
PE	*Pinus elliottii*
PC	*Psidium cattleianum*
QL	*Quercus laurifolia*
QM	*Quercus myrtifolia*
QV	*Quercus virginiana*
RP	*Rapanea punctata*
RM	*Rhizophora mangle*
RR	*Roystonea regia*
SP	*Sabal palmetto*
SaC	*Salix caroliniana*
ST	*Schinus terebinthifolius*
SR	*Serenoa repens*
SC	*Syzygium cumini*
TD	*Taxodium districhum*

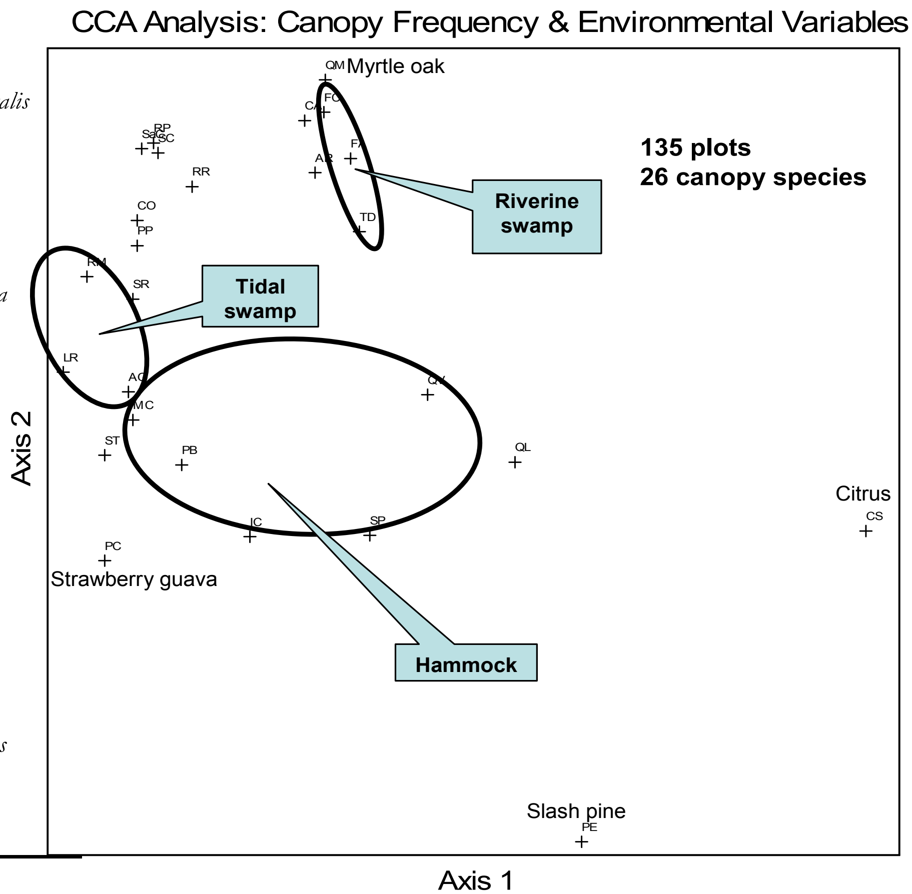


Figure 12-27. Canonical Correspondence Analysis of the Loxahatchee River floodplain canopy species illustrating the relationships between species that were found in the hammock, riverine, and tidal swamps along with outliers that had little relationship with the other communities.

RESEARCH STRATEGIES FOR THE LOXAHATCHEE RIVER ESTUARY

The Northwest Fork Loxahatchee River Restoration Plan identified the following research projects. Progress was made in the past water year to move several projects forward.

Vegetation Response to Severe Storms or Droughts

The high winds and flooding in the Northwest Fork floodplain from Hurricanes Frances and Jeanne in 2004 and Hurricane Wilma in 2005 destroyed canopy trees, understory vegetation, and ground cover. Routine assessments of the impacted vegetative communities by the Florida Park Service at Jonathan Dickinson State Park will help document system response and recovery from these types of extreme weather events. A hurricane damage assessment project was conducted in 2005 by the SFWMD and Florida Park Service. A report of the results was prepared and published by *Florida Scientist* (Roberts et al., 2008).

Cypress Seedling Studies

This study, being conducted by the University of Florida (UF), is designed to determine how cypress seedlings are affected by salt water. Because salinity levels in the riverine floodplain will likely decrease when restoration flows are implemented, the salt tolerance of bald cypress (*Taxodium distichum*) seedlings is an important aspect of restoration to determine if salinity will be low enough for this species. In 2005 and 2006, the SFWMD funded contracts with UF to study the effects of salinity and altered hydrology on bald cypress seedlings under laboratory and field conditions. In 2007, the Florida Park Service funded the continuation of the project and added studies utilizing pond apples (*Anona glabra*). In FY2008 (October 1, 2007–September 30, 2008), the SFWMD funded the last project to study the effects of using oxygenated fertilizer to enhance the survival of bald cypress seedlings. It is anticipated that the results of this study will be reported in the 2010 SFER – Volume I.

System Response to Rainfall Events and Droughts

Special studies are necessary to document short-term changes of water quantity and quality of watershed runoff from various rainfall events. This information, collected concurrently with estuarine water quality, will provide data needed to calibrate an estuarine water quality model to develop Pollution Load Reduction Goals and TMDLs.

Mesocosm Studies

This plan has demonstrated the importance of understanding salinity tolerances of seagrass species to evaluate the potential impacts of alternative inflow regimes. A recent, extensive literature search provided sufficient seagrass salinity tolerance information for several species to conduct this evaluation; however, it has also revealed a paucity of information on several important species, such as Johnson's seagrass and manatee grass. Controlled laboratory studies need to be conducted to determine the response of these species to various salinity regimes. With this additional information available, the existing monitoring and mapping efforts — in concert with the discovered salinity tolerances of these species — will reveal the level of detailed data needed to better evaluate restoration flow scenarios.

Oysters

The distribution and abundance of oysters relative to salinity have been determined for the Northwest Fork. During preparation of the Northwest Fork Loxahatchee River Restoration Plan, simulations were conducted of an oyster model, which predicts that the preferred restoration flow alternative will move the suitable salinity environment downstream with minimum impact on the majority of oyster beds. However, mitigation for the loss of oyster beds upstream from RM 4.0 can be addressed by providing substrate (cultch) in the area near RM 4.0. An investigation needs to be undertaken to determine the locations and sizes of oyster beds that can be created. Once implemented, the outcome of this oyster bed creation project should be documented.

Fish Larvae

The preferred restoration flow scenario augments dry season flows in a pulsing fashion that simulates the hydrograph of a small rainstorm event to benefit estuarine fish larvae. This is one of the most important, and frequently used, water management techniques recommended in this plan. However, an appropriate, environmentally sensitive way to implement this concept has not been determined. A special study to document the riverine floodplain response to short-term changes in water levels and the impact on fish larvae dynamics within the low salinity zone during the dry season should be conducted during controlled pulse releases from Lainhart Dam.

KEY SFWMD PROJECTS IN THE LOXAHATCHEE RIVER ESTUARY

Implementation of the Northwest Fork Loxahatchee River Restoration Plan with its Preferred Restoration Flow Scenario is being achieved through important plans and projects, which are currently under way within the Loxahatchee River Watershed. These include:

- Initial and Project Water Reservations for the Northwest Fork of the Loxahatchee River (SFWMD)
- Implementation of CERP 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 (FPS)
- Loxahatchee River Watershed Action Plan (FDEP)
- Loxahatchee River Preservation Initiative
- Loxahatchee River National Wild and Scenic River Management Plan 2000
- Continued community participation through the Loxahatchee River District (LRD)

In June 2003, the LRD, in partnership with the SFWMD, began a project to monitor seasonal trends in seagrass at three sites along a salinity gradient in the Central Embayment of the Loxahatchee Estuary to better understand the natural seasonal variability of seagrass in the study area and the response of the seagrass community to freshwater discharge. A fourth site, Hobe Sound, is removed from the direct influence of the Loxahatchee River and is considered a reference site. Monitoring is conducted monthly and includes shoot counts, canopy height, percent cover, species diversity, species shifts, and species depth distribution.

In July 2003, the SFWMD began mapping seagrasses in the Central Embayment using benthic mapping methods consistent with those used for the adjacent Indian River and Lake Worth lagoons (mapping from aerial photographs by simultaneously interpreting/rectifying the habitat polygons using an analytical stereoplotter). The study includes a reference site at Hobe Sound that is not influenced as greatly by large discharges of fresh water. Mapping was also conducted in 2004, 2006, and 2007. Additionally, the LRD conducted detailed ground-truthing using submeter accuracy GPS technology to produce a species-specific seagrass map of the Loxahatchee Estuary in summer 2007.

KEY NON-SFWMD PROJECTS IN THE LOXAHATCHEE RIVER ESTUARY

The LRD has established a comprehensive water quality monitoring network at 40 sites in the freshwater and tidal segments of the Loxahatchee River for about 30 parameters, including salinity, nutrients, chlorophyll, and bacteria. Monitoring frequency is monthly at some of the key sites, which should result in improved trends analysis and predictive analyses. The District is currently in the process of working with LRD to determine the long-term trend in water quality in the Loxahatchee River and Estuary.

LAKE WORTH LAGOON

Michael Gostel[2] and Rod Braun

DESCRIPTION OF LAKE WORTH LAGOON AND MAJOR ISSUES

Lake Worth Lagoon (LWL) is an estuary located in eastern Palm Beach County (**Figure 12-28**) bounded by barrier islands. Lake Worth Lagoon is about 22 miles (35.4 km) long and typically 6 to 10 feet (1.8−3 meters) 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 Lake Worth Lagoon watershed is about 450 sq mi (1,165 km^2) with most of the land urbanized. Communities include North Palm Beach, Lake Park, Riviera Beach, Mangonia Park, Palm Beach Shores, West Palm Beach, Palm Beach, South Palm Beach, Lake Worth, Lantana, Hypoluxo, Manalapan, Boynton Beach, and Ocean Ridge.

Lake Worth Lagoon is divided into three geographical segments (north, central, and south) based on hydrological factors including water quality, circulation, and physical characteristics (**Figure 12-29**). 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 to the lagoon. Studies indicate that about 75 percent of the canal discharge turns northward in the lagoon and about 25 percent southward (Chui et al., 1970).

Similar to many of South Florida's heavily urbanized coastal areas, LWL has been negatively impacted by anthropogenic changes. Sedimentation and turbidity are primary concern in LWL. 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 depressed below thresholds considered optimum for key species such as the Eastern oyster and Johnson's seagrass. Therefore, current performance measures are targeted at limiting the discharges from the C-51 canal so that salinity does not stay below 15 psu more than 26 days or less than 5 psu more than seven days from April–July each year.

[2] Retired from the District as of June 2008

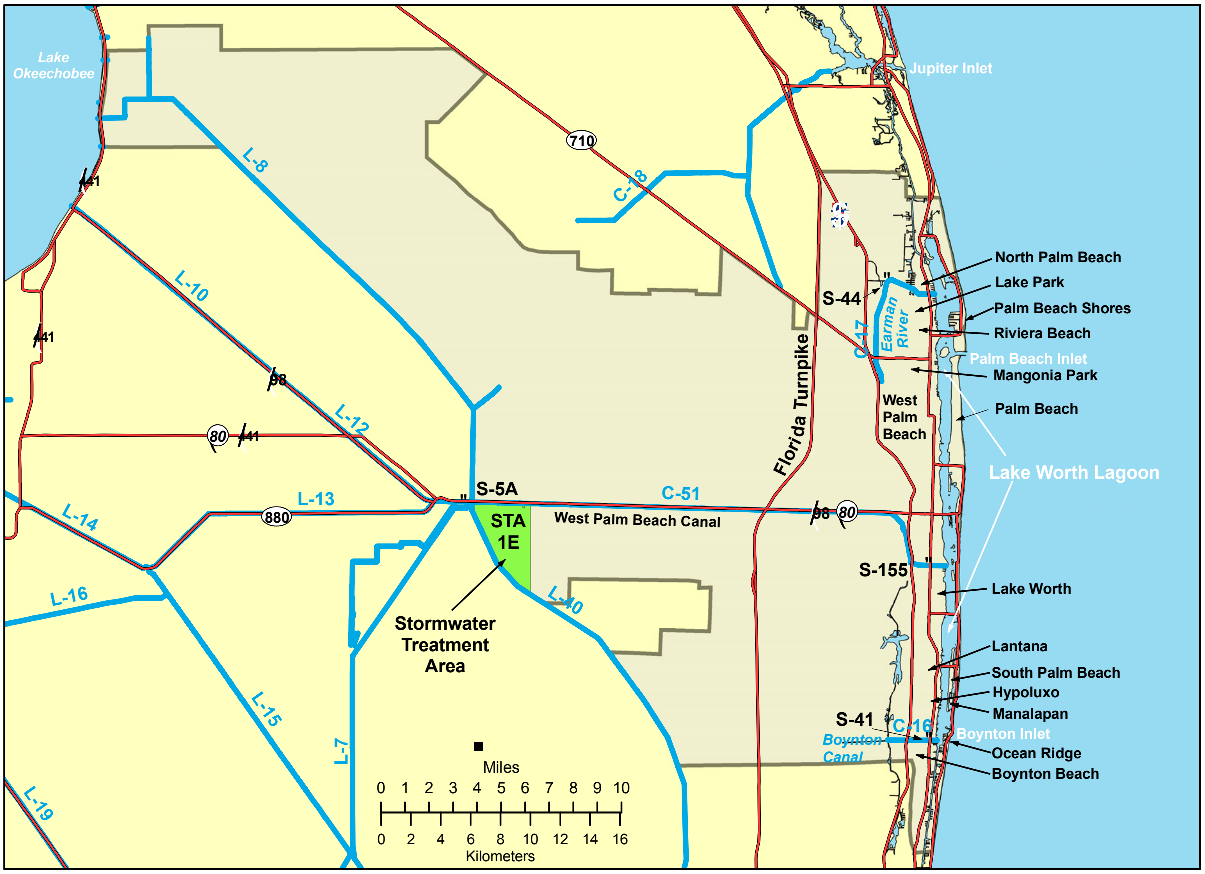


Figure 12-28. Location of Lake Worth Lagoon (LWL).

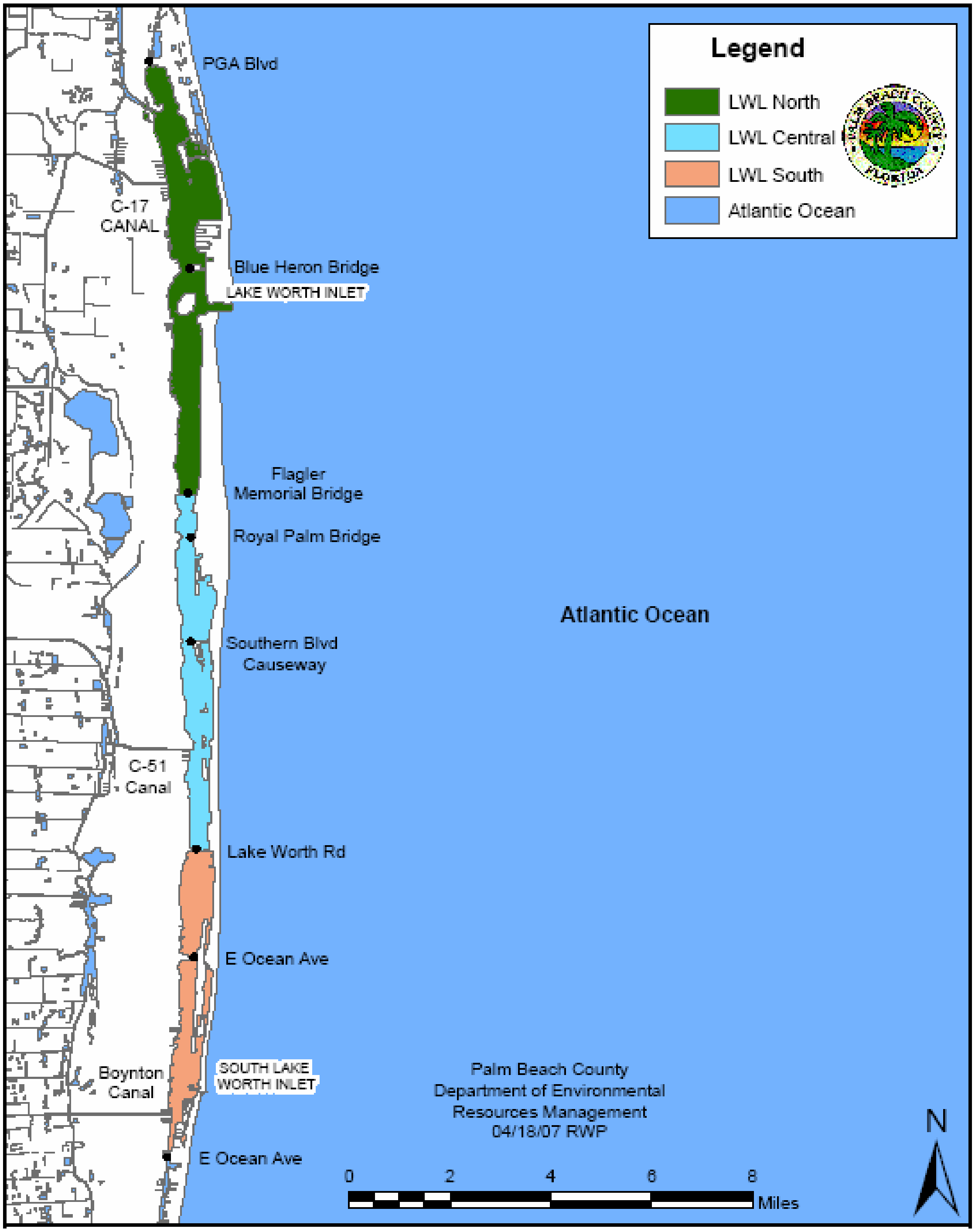


Figure 12-29. Northern (green), central (blue), and southern (pink) LWL segments.

STATUS AND TRENDS IN LAKE WORTH LAGOON

Salinity and Freshwater Inflows

WY2008 was affected by an ongoing regional drought; therefore, reduced canal discharge conditions may have been favorable for reestablishment of seagrass. No freshwater MFL or Water Reservation has been developed for LWL to date. The primary concern is that excessive fresh water is sometimes discharged into the lagoon. For example, an evaluation target was established by an interagency team in 2007 to limit salinity to a minimum of 15 psu to protect seagrasses and oysters near the outfall of the C-51 canal (SFWMD, 2007). A new salinity monitoring program designed to evaluate the new target was established in CY2007, so long-term salinity results at the new sites are not available. Results from two salinity monitoring sites in the lagoon that are near the C-51 canal (**Figures 12-30** and **12-31**) suggest that salinity may not be changing over the long term at these locations. Average inflows from C-51 also appear to be level over the long term, although frequent large peaks occur within this average (**Figure 12-32**).

Water Quality

The LWL monitoring network has changed over time. Stations have been added or discontinued, with few site locations possessing relatively long datasets. Originally, the LWL Water Quality Monitoring Program consisted of 10 sampling stations among the three segments of the lagoon (north, central, and south) sampled on a monthly basis. Eight fixed stations are located within the LWL proper and two fixed stations are located at SFWMD control structures or within tidally influenced canal confluences. Twelve new stations have been added to the monitoring network (implemented in October 2007), for a total of 22 sites (**Figure 12-33**). Several parameters will be analyzed on a monthly basis including DO, pH, salinity; TKN, ammonia nitrogen (NH^4), nitrite-nitrate nitrogen (NOx), TP and orthophosphorus (OPO_4), turbidity, and chlorophyll *a*. Metals such as arsenic (As), copper (Cu), cadmium (Cd), and lead (Pb) will also be collected. Additionally, five high-frequency in-situ sondes (multi-parameter sampling units) will be deployed to augment the monitoring network.

The newest water quality monitoring network is a joint effort with the Palm Beach County Department of Environmental Resources Management (PBCERM). The network will provide an estuary-wide assessment of the chemical and physical conditions of LWL. For the purpose of this baseline, only some of the parameters were analyzed due to the limited long-term consistency of the data. The POR includes data from 1994–2006 and does not include data collected after October 2007. Data collected prior to 1994 was not included because of inconsistent frequency of collection. Station location, parameters analyzed, and the POR analyzed are summarized in **Table 12-17**.

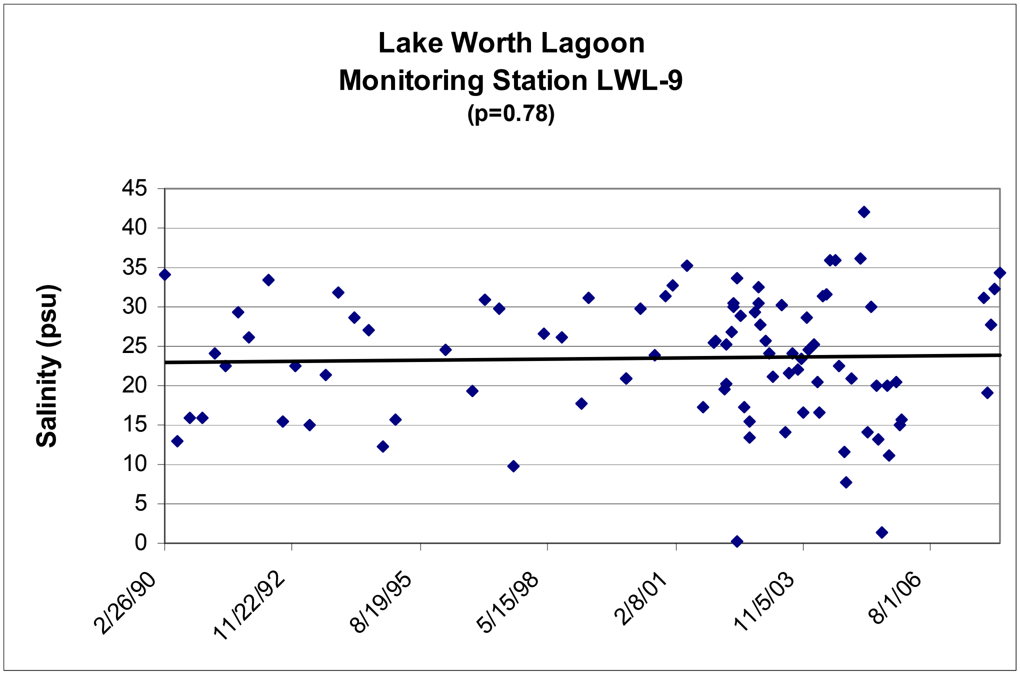


Figure 12-30. Long-term salinity results at monitoring station LWL-9 in LWL north of the outfall of the C-51 canal.

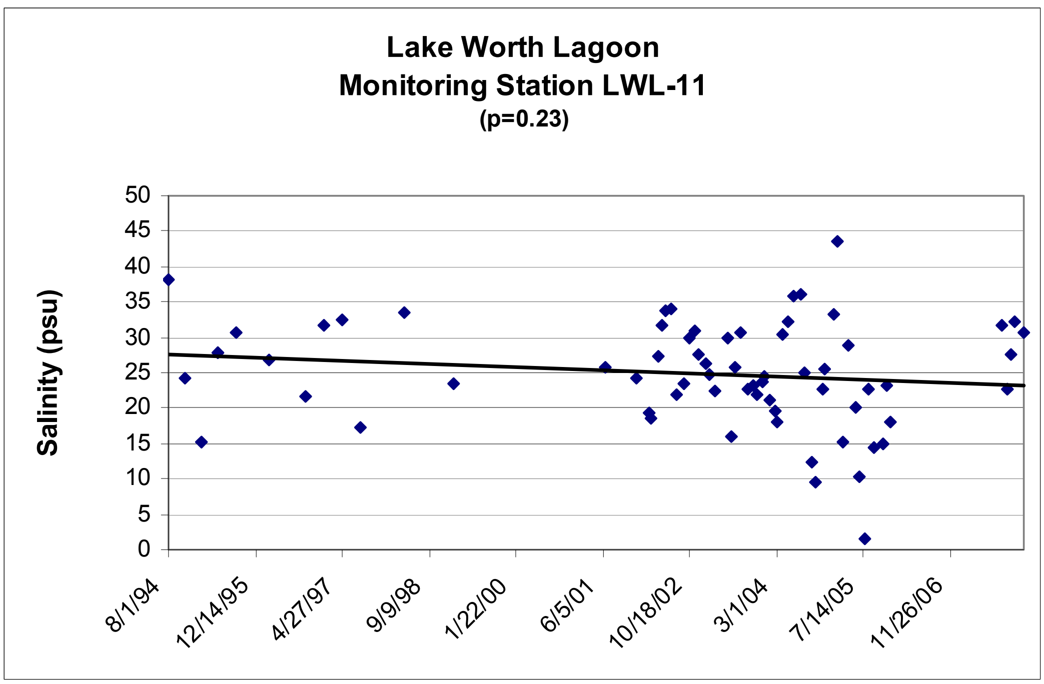


Figure 12-31. Long-term salinity results at monitoring station LWL-11 in LWL south of the outfall of the C-51 canal.

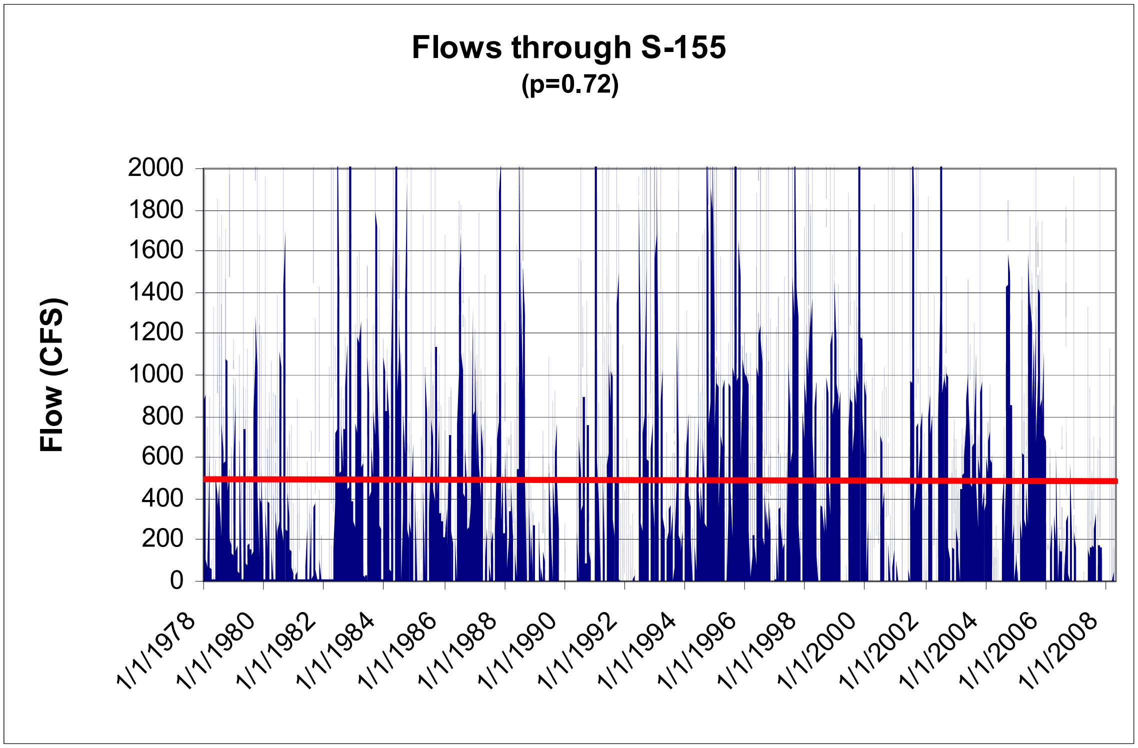


Figure 12-32. The long-term flow rate from the C-51 canal into LWL with a fitted regression line. (Y scale is truncated to show detail).

Figure 12-33. Current LWL water quality monitoring stations.

Table 12-17. Frequency and parameters analyzed for LWL surface water samples.

STATION NAME	FREQUENCY	PERIOD OF RECORD	PARAMETERS
11, 13, 18C, 18D[1]	12x/Year	1994–2006	DO, salinity, TKN, TP, turbidity, chlorophyll *a* (corrected), As, Cu metals were collected quarterly.
LWL 1, LWL 3, LWL 9, LWL 11, LWL 13, LWL 18[2]	12x/Year	1994–2006	DO, salinity, TKN, TP, turbidity, chlorophyll *a* (corrected), As, Cu metals collected quarterly.

1. Collected by PBCDERM.
2. Formerly collected by the FDEP and renamed in 2007. Currently collected by PBCERM.

Water Quality Results

Water quality results from LWL are available in time-series graphs and statistical box plots in the Lake Worth Lagoon Management Plan Update (PBCERM, 2008). For statistical purposes, monthly and yearly data were considered to establish trends. In the occurrence where multiple samples were collected within a given month, arithmetic means were calculated. Correlations between data were determined by the nonparametric Spearman rank method, which was deemed significant only in those cases where the 95 percent confidence interval determined by bootstrap resampling circumscribed critical values all possessing p values less than 0.05 (statistical significance); in those cases where this criterion was met, the p value reported is that determined by the statistic (Zar, 1998). Trends were evaluated utilizing the nonparametric Seasonal Kendall Trend test, using each of the 12 months as individual seasons. Results of the water quality baseline for the 1994–2006 POR are summarized below:

Dissolved oxygen concentration was not categorized as a concern in the LWL with mean (average) and median concentrations of 5.8 mg/L and 6.0 mg/L, respectively. The surface water quality standard for Class III Marine criteria is 4.0 mg/L. However, the results do not include measurements taken near the bottom, or during darkness.

TP showed mean and median concentrations of 0.138 mg/L and 0.067 mg/L, respectively. The mean and median values reflect obvious outliers in the earlier data reaching up to 22 mg/L for the 1994–1999 POR. Evaluating only the data within the 2000–2006 time frame; however, results in mean and median TP concentrations of 0.061 and 0.057 mg/L, respectively, with no apparent trend. These values are below the median TP value among Florida estuaries of 0.100 mg/L (Hand, 2004).

TN showed mean and median concentrations of 0.83 mg/L and 0.72 mg/L, respectively, above the median value among other Florida estuaries of 0.67 mg/L (Hand, 2004). A statistically significant increase in TN was observed from 2002–2006. The active hurricane seasons of 2004 and 2005 might have had an effect on the trend, but trends may be difficult to infer with less than about 10 years of data.

Chlorophyll *a* data are only available from 2001. Results showed an apparent upward trend with mean and median concentrations of 4.4 µg/l and 3.2 µg /l, respectively. Mean and median turbidity concentrations are 4.6 and 3.1 NTU, respectively. Turbidity apparently increased lagoon-wide from 2001–2006. Salinity levels indicated that the increasing freshwater discharges from the C-51 canal decrease conductivity, leading to a freshening of the lagoon and causing a salinity drop in the surrounding areas.

TN, TP, turbidity, salinity, and chlorophyll *a* are significantly correlated with flow discharges from the C-51 canal at the S-155 structure. TN and turbidity, in fact, showed a significant increase near the C-51 canal. The inverse correlation of salinity with TN, TP and turbidity, with TN ($N = 427$, $\rho = -0.555$, $p < 0.001$), TP ($N = 639$, $\rho = -0.261$, $p < 0.001$), and turbidity ($N = 691$, $\rho = -0.309$, $p < 0.001$), suggests that C-51 canal discharges result in increases in these constituents. These effects are more pronounced as the distance to the C-51 canal mouth decreases.

Results of Cu and As analyses showed some concentration exceedances of state water quality standards for Cu and no exceedances for As. Overall mean and median concentrations for Cu were below water quality state criteria of 3.7 µg/L. Exceedances of Cu have been reported just south of the LWL. Mean and median concentrations of As were below the state water quality criteria of 50 µg/L (PBCERM, 2008).

Submerged Aquatic Vegetation

A 1990 Palm Beach County survey estimated there was a total of 2,010 acres (813 hectares) of seagrass within the lagoon. Results of a 2001 mapping project indicated that seagrass beds covered at least 1,631 acres (660 hectares 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 varies throughout the lagoon, with more percentage bottom seagrass cover in the north end than in the south end of the lagoon. Aerial images were collected in 2007 as part of the 2007 Habitat Classification and Mapping Project. The project includes mapping of seagrasses, mangroves, oysters, and cord grasses (*Spartina* spp.) within the estuarine boundaries of Palm Beach County. Preliminary data indicate an increase from 646 (262 hectares) to 725 acres (292 hectares) from 1985–2007. This represents a 12 percent increase in the acreage of mangroves. Preliminary data comparing 2001 seagrass coverage to 2007 seagrass coverage show a 62-acre increase of seagrass. The increase was observed predominantly in the southern segment of LWL and the Intracoastal Waterway in Palm Beach County (**Figure 12-34**). Final results were expected in late CY2008, and will provide the first opportunity to investigate a quantitative temporal trend in seagrass coverage.

Figure 12-34. 2001 and 2007 seagrass coverage in LWL in the vicinity of South Lake Worth Inlet.

Eastern Oyster Abundance and Distribution

As part of the 2007 SAV mapping effort, PBCERM determined locations of existing oyster bars/reef in LWL. About 4.2 acres of oyster bar/reef were delineated (**Figure 12-35**).

Oysters in the LWL have been monitored as part of RECOVER since 2005 under contract with the FWC. Three oyster reefs are sampled within the LWL monthly for spat recruitment, reproduction (CI and reproductive development), and disease (prevalence and intensity), and yearly juvenile growth and mortality (within open and closed cages). Water quality sampling is also collected monthly. Adult sampling — the counting of live versus dead oysters including measurements of live oysters' shells — occurs twice a year in March and September. Data from the three years of monitoring are presented in **Figure 12-36**.

It is anticipated that changes from CERP restoration projects will occur for salinity and water quality, spat recruitment, growth of juvenile oysters, and living densities; CI should increase; and disease intensity should remain at the same levels or slightly increase. This, however, can be mitigated by releases of fresh water during times of high temperatures.

Figure 12-35. Location of existing oyster reef habitat in LWL.

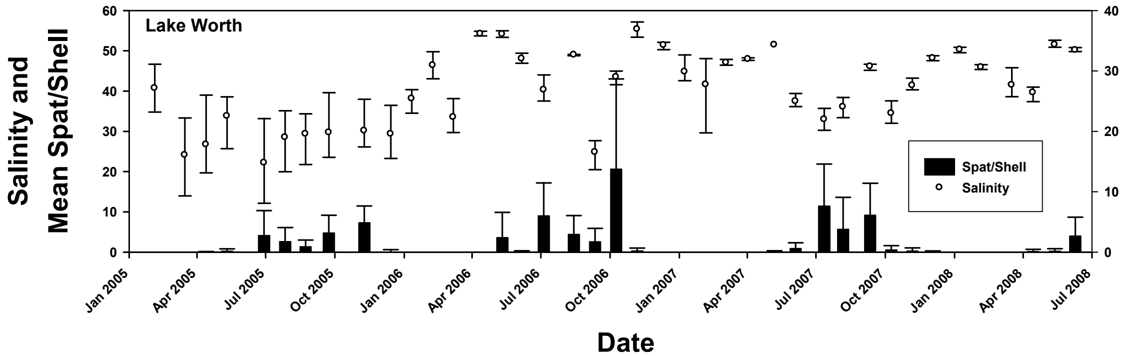


Figure 12-36. Mean (± S.D.) number of oyster recruits collected per shell each month and the mean, maximum, and minimum salinity recorded each month in LWL. The first retrieval of recruitment collectors occurred in March 2005.

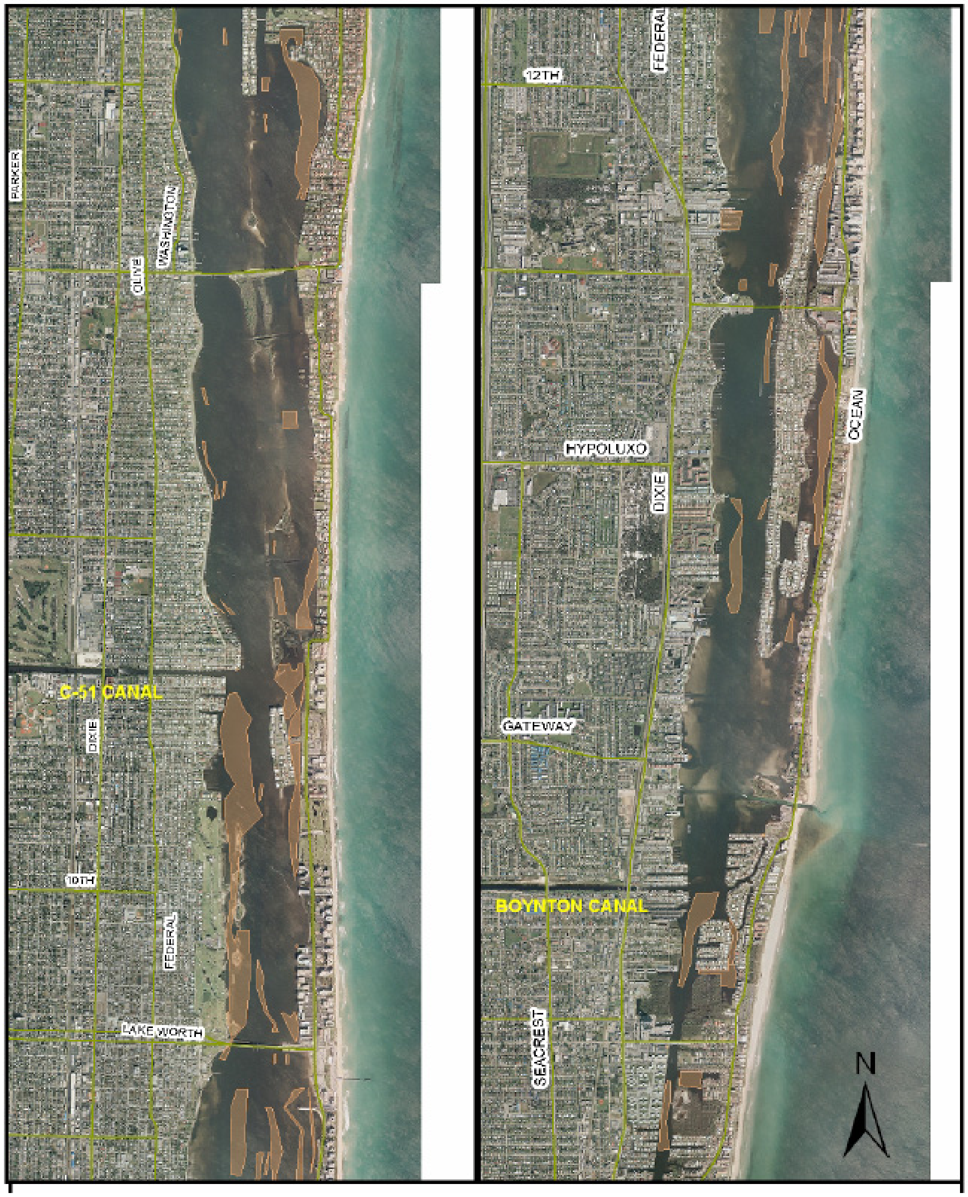


Figure 12-37. Existing muck sediments greater than 0.3 meters in depth (brown-shaded polygons) within LWL in 2003.

Sediments

The accumulation of sediments over the years has blanketed a large area of the lagoon with a layer of anaerobic muck, resulting in a decreased diversity of benthic invertebrates, and inhibiting colonization of seagrasses, an important component of the estuarine community. PBCERM and the U.S. Geological Service (USGS) collected data on sediment loading from the C-51 canal to LWL. Preliminary results are expected in 2009. In 2003, muck sediment maps were produced by PBCERM and indicate where muck sediments are greater than 0.3 m (1 ft) in depth (**Figure 12-37**). 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.

RESEARCH STRATEGIES FOR LAKE WORTH LAGOON

Water quality monitoring has not been consistent in the past, but the monitoring program was expanded last year to provide reliable data that can be used to detect changes as projects are completed, such as the Northern Palm Beach County – Part 1 Project.

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

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 CY2008 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 Lake Worth Lagoon. It is anticipated after one year of monitoring (October 2009), the results will be analyzed.

The Northern Palm Beach County Project – Part 1 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 tradeoffs 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 miles 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. 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 seagrasses and benthic communities. The elimination of the organically enriched sediment from the C-51 canal discharge will provide for long-term improvements to the lagoon and enable success for additional habitat restoration and enhancement projects planned by Palm Beach County.

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. The District is committed to ongoing collaboration efforts, short-term implementation projects, and longer-term infrastructure and operational projects consistent with the Coastal Watersheds Program Strategies that are included in the current SFWMD Strategic Plan.

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 performing aerial mapping of seagrasses in Lake Worth Lagoon.

Eastern oyster monitoring in LWL is monitored by PBCERM and the District. The new PBCERM monitoring was initiated in March 2008, and is planned as a three-year effort depending upon funding. Monitoring of oysters in LWL began in 2005.

BISCAYNE BAY

Richard Alleman

DESCRIPTION OF BISCAYNE BAY AND MAJOR ISSUES

Biscayne Bay is a shallow, subtropical estuary located along Florida's southeastern coast (**Figure 12-38)**. The bay is about 275 sq mi (711 km^2), and the watershed is about 850 sq mi (2,201 km^2). Most of the northern and central areas of the watershed are urban, with Miami being the largest city. Everglades National Park (ENP or Park) borders the southwestern part of the watershed and shares some of it. Biscayne National Park encompasses a large area of the central region of Biscayne Bay, and Card and Barnes sounds are within the Florida Keys National Marine Sanctuary. Biscayne Bay is designated an Outstanding Florida Water.

Development of the watershed has altered the delivery of freshwater inflows into the bay. Northern Biscayne Bay and central Biscayne Bay have been strongly affected by the urban development associated with the growth of the associated metropolitan area. Southern Biscayne Bay is influenced by drainage from the ENP and runoff from the southern watershed, which includes some urban and agricultural land uses. The SFWMD manages and maintains a primary drainage network that includes 16 outfalls into the bay. About half of the freshwater inputs consist of discharges from the canals that regulate water levels within the watershed for flood control and water supply, and discharge about 1.4 million ac-ft (1.73 billion m^3) per year on average. Additional significant sources of fresh water include rainfall that averages about 60 inches per year (1.37 million ac-ft/year; 1.68 billion m^3), and groundwater flux, which is estimated to be roughly 5 percent of surface water inputs (Langevin, 2001). Drainage of the watershed has primarily changed the location and timing of freshwater inputs to the bay. Timing refers to the increased velocity of runoff (because of the reduced storage in the watershed) and affects runoff velocity on both an annual scale and during rainfall events that occur over days. Distribution has been altered by concentration of the runoff into canals that historically flowed into the bay through small rivers, streams, and groundwater flux. 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. Even in the southern area of the bay, salinity has increased since about 1900, especially along the western nearshore areas (Wingard et al., 2004).

Water quality has been impacted in Biscayne Bay, but in some ways has improved significantly over time. Despite dramatic physical changes to Biscayne Bay, it supports extensive SAV and hardground communities. Fish communities have been altered, but still support a large recreational fishery and viable commercial pink shrimp (*Farfantepenaeus duorarum*) fishery.

Eastern oysters were more abundant prior to the changes to Biscayne Bay. Large areas of coastal wetlands have been filled. Most of the remaining wetlands are in the central and southern areas of Biscayne Bay. These wetlands have been largely starved of freshwater flow as a result of diversion of the flow.

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).

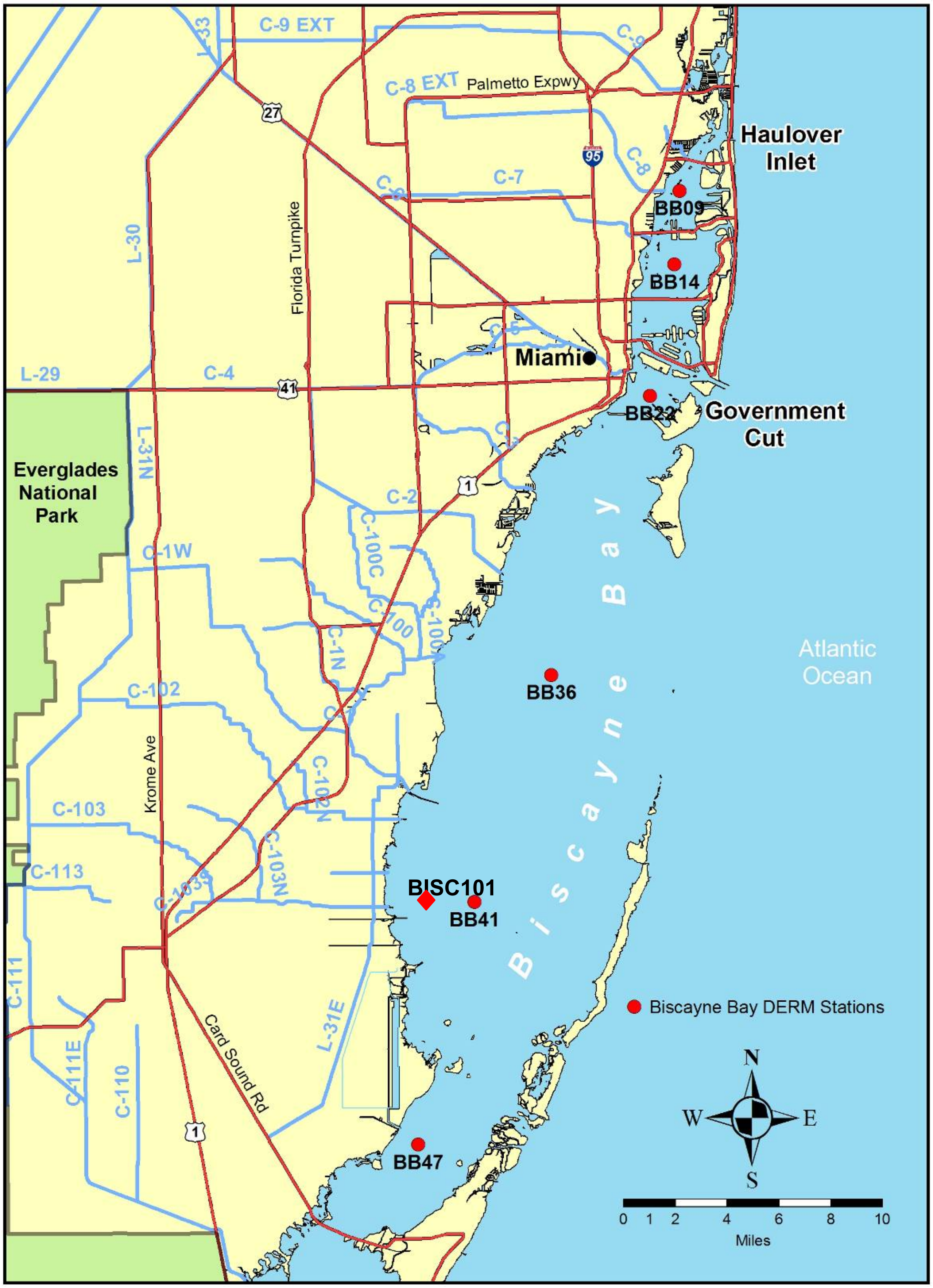


Figure 12-38. Biscayne Bay and selected monitoring sites.

STATUS AND TRENDS IN BISCAYNE BAY

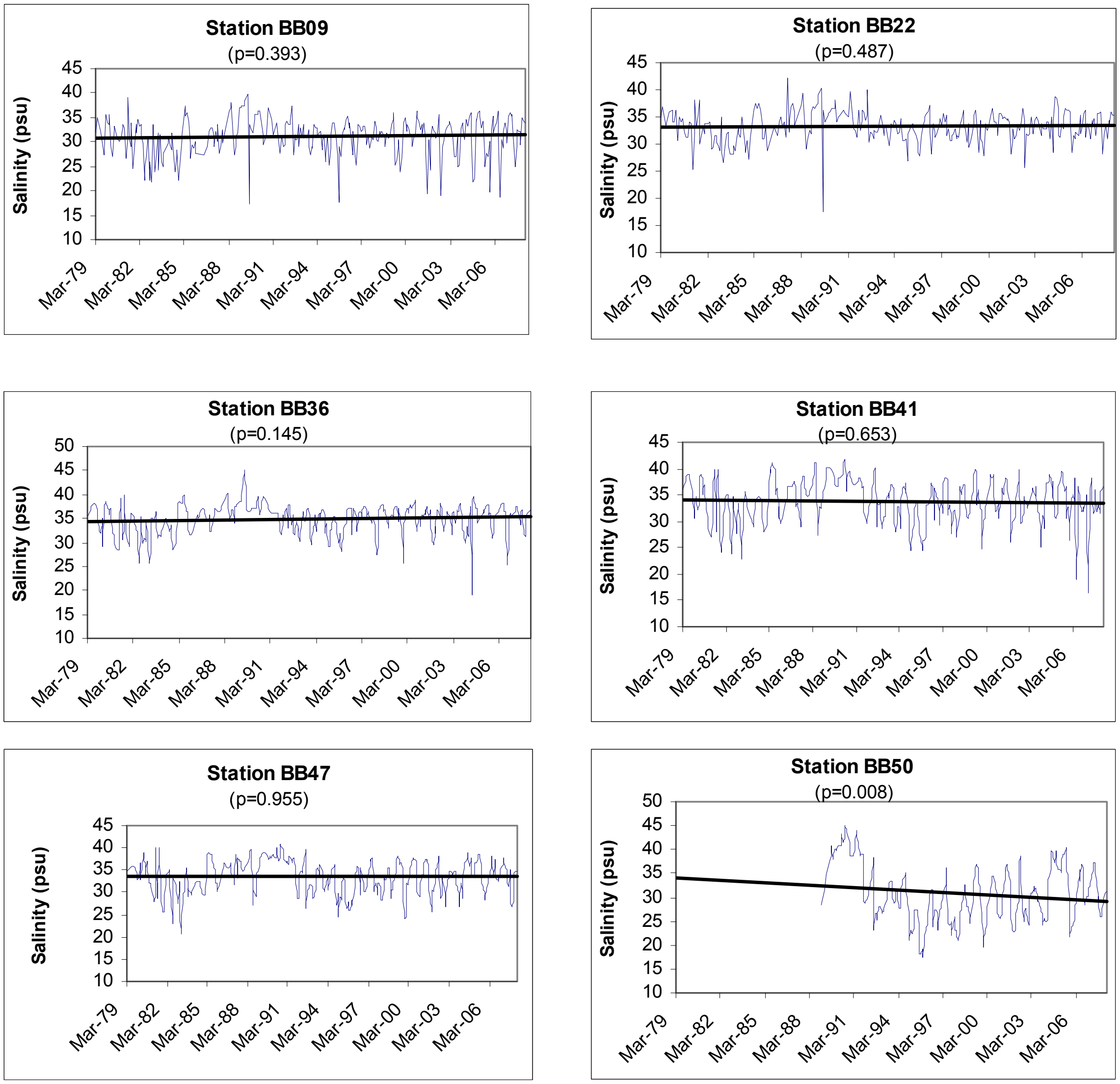
Salinity and Freshwater Inflows

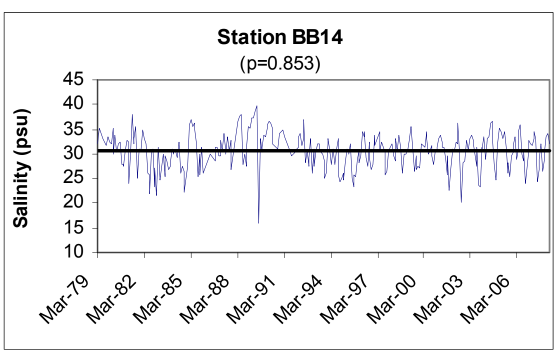
No MFL criteria have been formally adopted for Biscayne Bay to date, nor any specific quantities of water reserved. The SFWMD is proceeding, however, to develop a reservation of water for the Biscayne Bay Coastal Wetlands – Phase 1 Project (see Chapter 7A of this volume) in accordance with the Water 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 (Marshall et al., 2008) summarizes the relationships of salinity in the different regions of Biscayne Bay to freshwater inputs.

Systematic and spatially comprehensive salinity monitoring in Biscayne Bay began in 1979 by the Miami-Dade Department of Environmental Resources Management (DERM), and has continued to date. Examination of these data records reveals that no significant increase of salinity has occurred in Biscayne Bay over the past 28 years as represented by a few selected stations (**Figure 12-39)**. An area of interest is along the mainland nearshore within Biscayne National Park. For example, at station BISC101 [collected by Florida International University (FIU)], bottom salinity exceeds 35 psu most years, usually at the end of the dry season, even though the average salinity is 29.6 psu (**Figure 12-40**). Station BISC101 is located 2 km east of the shoreline. Salinity values tend to be highest close to the shoreline. Freshwater inputs from the canals in the area typically cease to flow at the end of the dry season each year, and groundwater flux is at the lowest because of low water stages in the watershed.

Nutrients

Mean total inorganic nitrogen (TIN) concentrations at the DERM monitoring stations indicated in **Figure 12-38** range from about 0.07 to 0.10 mg/L. Of these, the only location that may be increasing in TIN concentrations is station BB09. The amount of increase is small and the cause unclear. Monitoring data from nearby canals do not indicate increased concentrations over time. Phosphorus is considered to be a limiting nutrient in Biscayne Bay (Brand, 1988). Mean TP concentrations at the DERM stations depicted in **Figure 12-38** range from about 0.004 to 0.007 mg/L. Phosphorus and chlorophyll *a* concentrations are higher in Northern Biscayne Bay than in Southern Biscayne Bay. A decreasing phosphorus trend throughout Biscayne Bay was first reported by Alleman (1985) and this trend is continuing (Miami-Dade County, 2005).





Station	Mean Salinity (psu)
BB09	31.12
BB14	30.59
BB22	33.18
BB36	34.89
BB41	33.73
BB47	33.44
BB50	30.66

Figure 12-39. Long-term salinity observed at key stations in Biscayne Bay with fitted linear regression lines.

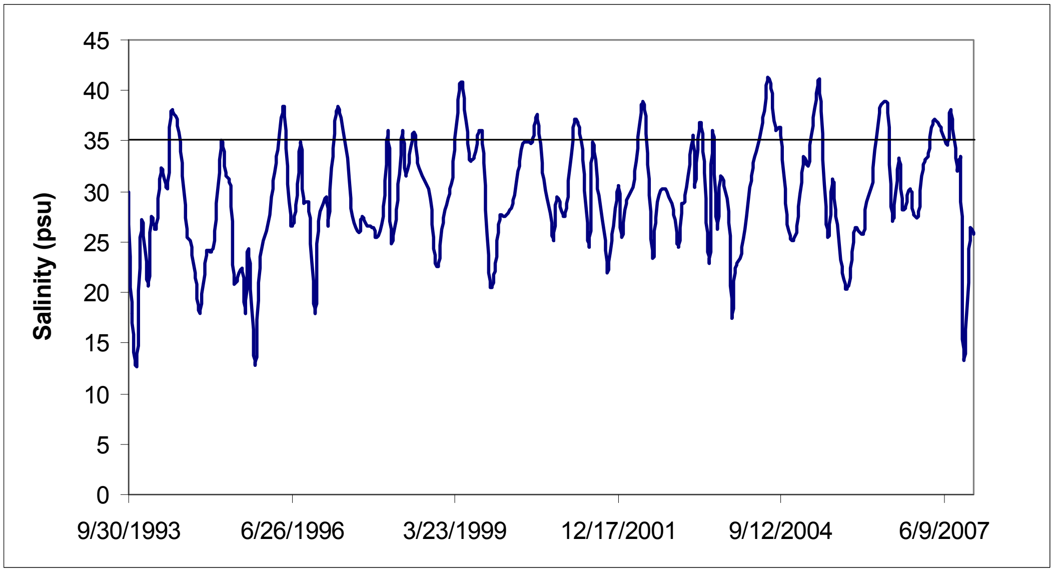


Figure 12-40. Long-term salinity results at monitoring station BISC101 indicating when salinity exceeded 35 practical salinity units (psu).

Epibenthic Habitats

The bottom community in Biscayne Bay is dominated by seagrasses, but a large area of hardground exists in the south-central region. The predominant seagrass is turtle grass, but shoal grass and manatee grass are also common. Paddle grass and widgeon grass are also present. 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* is prolific nearshore of the south-central area of Biscayne Bay, and exhibits a seasonal growth pattern. Biber tied growth rates to excessive nitrogen loads in this area, but it does not seem to exclude seagrasses in most areas. It is not clear whether macroalgae cover has changed overall in Biscayne Bay. Seagrass cover in Biscayne Bay is stable — 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.

Hardground communities typically occur in southern Biscayne Bay on exposed limestone or where less than 15 cm (6 in) of sediment occurs, and make up roughly 10 percent of the epibenthic community of the bay overall. Hardbottom communities consist primarily of sponges, alcyonarians, and estuarine corals. Water quality in these areas typically consists of clear, oligotrophic water with a stable salinity greater than 30 psu.

Eastern Oyster Abundance and Distribution

Small numbers of Eastern oyster are present throughout Biscayne Bay close to the western shorelines. The current population is unknown, although an existing study will attempt to quantify the distribution and abundance along the mainland shoreline within Biscayne National Park. It is known that Eastern oyster reefs were present in the past near the outlets of the natural rivers and streams, but perhaps the only place where reefs still exist is near the outlet of Snake Creek (the C-9 canal).

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 (*Sciaenops ocellatus*), spotted seatrout (*Cynoscion nebulosus*), and mullet (*Mugil* sp.) have apparently declined over time according to largely anecdotal information. 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).

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 in size 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. This ecotone consisted of meso- and oligohaline habitats. The District and 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 along several key performance indicators, such as hydrology, wetland vegetation, salinity, SAV, oysters, and fishes. The monitoring plan is part of a draft Project Implementation Report that is scheduled to be published in the Federal Register for comments in WY2009.

RESEARCH STRATEGIES FOR BISCAYNE BAY

Systematic water quality monitoring in Biscayne Bay has been important to characterize the system and evaluate trends, and will be key to evaluating possible changes to the distribution of freshwater inflows from restoration projects within and nearby the watershed. This includes continuous salinity monitoring in critical areas of Biscayne Bay to characterize the response and variability of salinity to inflows.

Freshwater inflow quantities from surface water are largely known because of methods the District utilizes to estimate flows that pass through the coastal outfall structures, but groundwater inflows can be only roughly estimated. Although the overall proportion of groundwater to surface water is perhaps 5 to 10 percent, groundwater influx is believed to play an important role in dry season nearshore salinity patterns, because of the absence of surface inflow. The quantity of groundwater flux varies widely along the interface, because of the water stage elevations maintained in the watershed and the structure of the aquifer. In addition, the fresh water mixes with salt water at varying rates due to tidal pumping, hydraulic forces upstream, and resistance encountered within different strata of the Biscayne aquifer. A numerical model that includes these factors, and interfaces with a hydrodynamic model, could provide insight about the linkage of water management in the watershed and salinity patterns in Biscayne Bay.

The ecological effects of the frequent hypersaline events that occur in Biscayne National Park are largely unknown. Studies that investigate specific changes to communities or species abundance and distribution will be needed to document possible impacts.

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 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 2, which is the entire project as described as the Alternative O. During FY2008, the Tentatively Selected Plan was identified for Biscayne Bay Coastal Wetlands – Phase I, and preparation of the draft PIR is under way. As of April 2008, one permit was issued by the FDEP (No. 0271729-001) for the expedited construction of four culverts through levee 31 east between canals 102 and 103. Construction has not yet commenced on any part of the project. Once construction begins, required results will be summarized 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 commenced in WY2008. A mass-balance analysis of freshwater inflows and salinity in Biscayne Bay was completed that describes how general salinity patterns relate to inflows in different areas of Biscayne Bay (Marshall et al., 2008). In addition, several years of fish observation data collected nearshore were related to salinity conditions (Serafy et al., 2008).

A proposed reservation of water is being developed for the Biscayne Bay Coastal Wetlands – Phase I Project, and will be included in the draft Project Implementation Report. Also, the District partnered with FIU and DERM to collect monthly water quality grab samples throughout Biscayne Bay. These datasets are important for describing trends, validating model results, and characterizing response.

KEY NON-SFWMD PROJECTS IN BISCAYNE BAY

Miami-Dade County constructed a weir within the Cutler Slough channel at the Deering Estate, which will be an essential feature to impound fresh water within wetlands. The weir is also part of the Biscayne Bay Coastal Wetlands Project. In addition, the USACE funded a cooperative project with Biscayne National Park to maintain about 40 continuous salinity recorders in the nearshore area of central and southern Biscayne Bay. The Park instituted monitoring in 2004, which has been essential to fill geographic gaps in salinity results in this variable and dynamic environment near the canal discharges.

NAPLES BAY

Chenxia Qiu

DESCRIPTION OF NAPLES BAY AND MAJOR ISSUES

Naples Bay and its watershed are located in western Collier County. It is a relatively narrow and shallow estuarine system. Its width ranges from 100–1,500 ft (30−457 m), and its depth varies from 1–13 ft (0.3−4 m). It is 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, is connected to Rookery Bay through a shallow waterway with a dredged channel (**Figure 12-41**). Naples Bay is typical of estuarine systems along the coast of Florida that have 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 Haldeman Creek to the east and from Golden Gate Canal, Gordon River, and Rock Creek to the north. Urban runoff surrounds the bay. In the 1960s, the construction of the Golden Gate Canal system increased the Naples Bay watershed from 10 sq. mi to 130 sq. mi (26−337 km^2), resulting in a 20 to 40 times increase in freshwater inflow. 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 impacted 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).

STATUS AND TRENDS IN NAPLES BAY

Salinity and Freshwater Inflows

No minimum flow criteria or reservation of water have been established for Naples Bay to date. The inflow from Golden Gate Canal, a key inflow point, during 1994−2002 was recorded, and this monitoring resumed in April 2008. Provisional results from the Golden Gate Canal monitoring station are depicted in **Figure 12-42**. Since a prolonged dry period persisted during WY2007 and WY2008, no flow was released to the bay from May to June 2008, except for a couple of events. The data presented below serves as an example of the product of the ongoing monitoring work and is still subject to validation.

Monthly salinity grab samples collected by FIU since 1999 in Dollar Bay indicate a mean bottom salinity of 33.6 psu with wide ranges from 9–38 psu. It is not clear that a monthly sampling frequency can adequately characterize salinity due to potential variability within the small embayments, especially during wet periods.

Figure 12-41. Naples Bay, Dollar Bay, and Rookery Bay on the southwest coast of Florida.

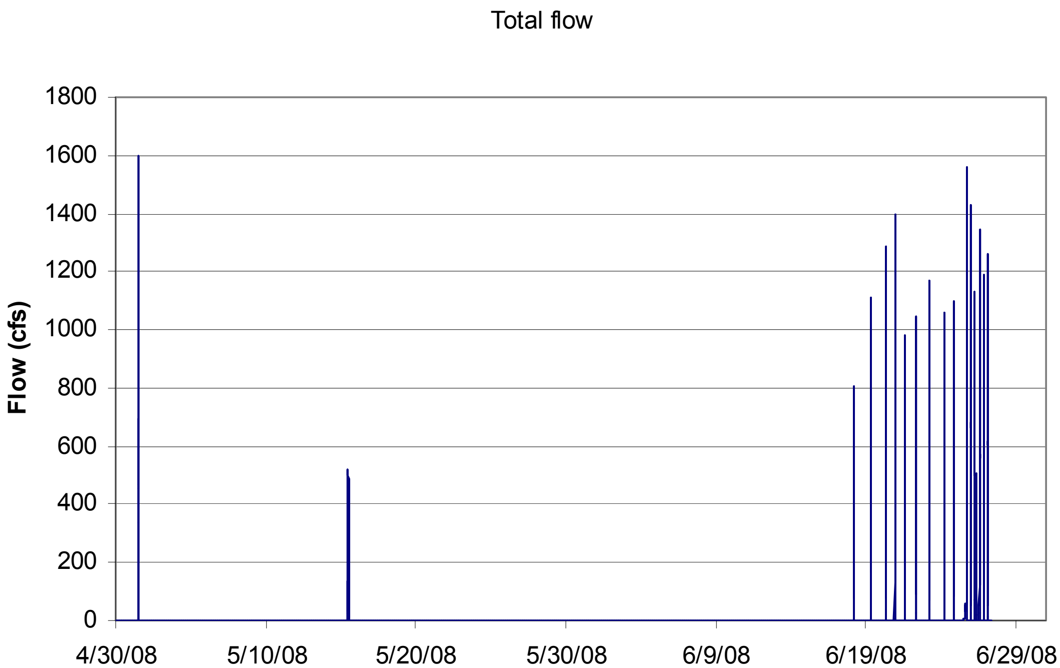


Figure 12-42. Two months of available flow data from Golden Gate Canal.

Nutrients

The City of Naples established 16 water quality monitoring sites in 2005, and collects samples bimonthly from Gordon Pass to the Gordon River (**Figure 12-43**). The water quality parameters being monitored include DO, pH, salinity, temperature, BOD, TOC, chlorophyll *a*, pheophytin, TKN, nitrate and nitrite, ammonia, TP, orthophosphate, sulfate, Secchi disk depth, color, turbidity, copper, lead, calcium, and zinc. Nitrogen, phosphorus, and chlorophyll *a* concentrations exhibited strong seasonal patterns in 2006 and 2007, with highs in the wet season and lows in the dry season (**Figure 12-44**), according to data collected by the City of Naples. For example, total nitrogen concentration was less than detectable levels in the dry season, and peaked at 0.9 mg/L in the wet season. Similarly, chlorophyll *a* varied from below detectable levels in the dry season to 15 µg/L in the wet season. This pattern is likely associated with the seasonal change of nutrient loading brought by freshwater inputs. Nutrient concentrations tend to decline gradually from the upper bay toward Gordon Pass inlet, possibly due to the dilution by ocean water. The flushing effect of the inlet on phosphorus is more notable than on nitrogen.

Secchi disk depths, indicating water transparency, followed the opposite seasonal trend of nutrients. Greater light penetration was observed in the dry season. However, Secchi disk depth decreased to less than 1 m in the wet season, possibly due to the elevated levels of turbidity and color (data not shown). In the lower Naples Bay (NBAYBV), Secchi disk depths were improved by tidal flushing through the inlet, and light was able to reach the bottom most of the time.

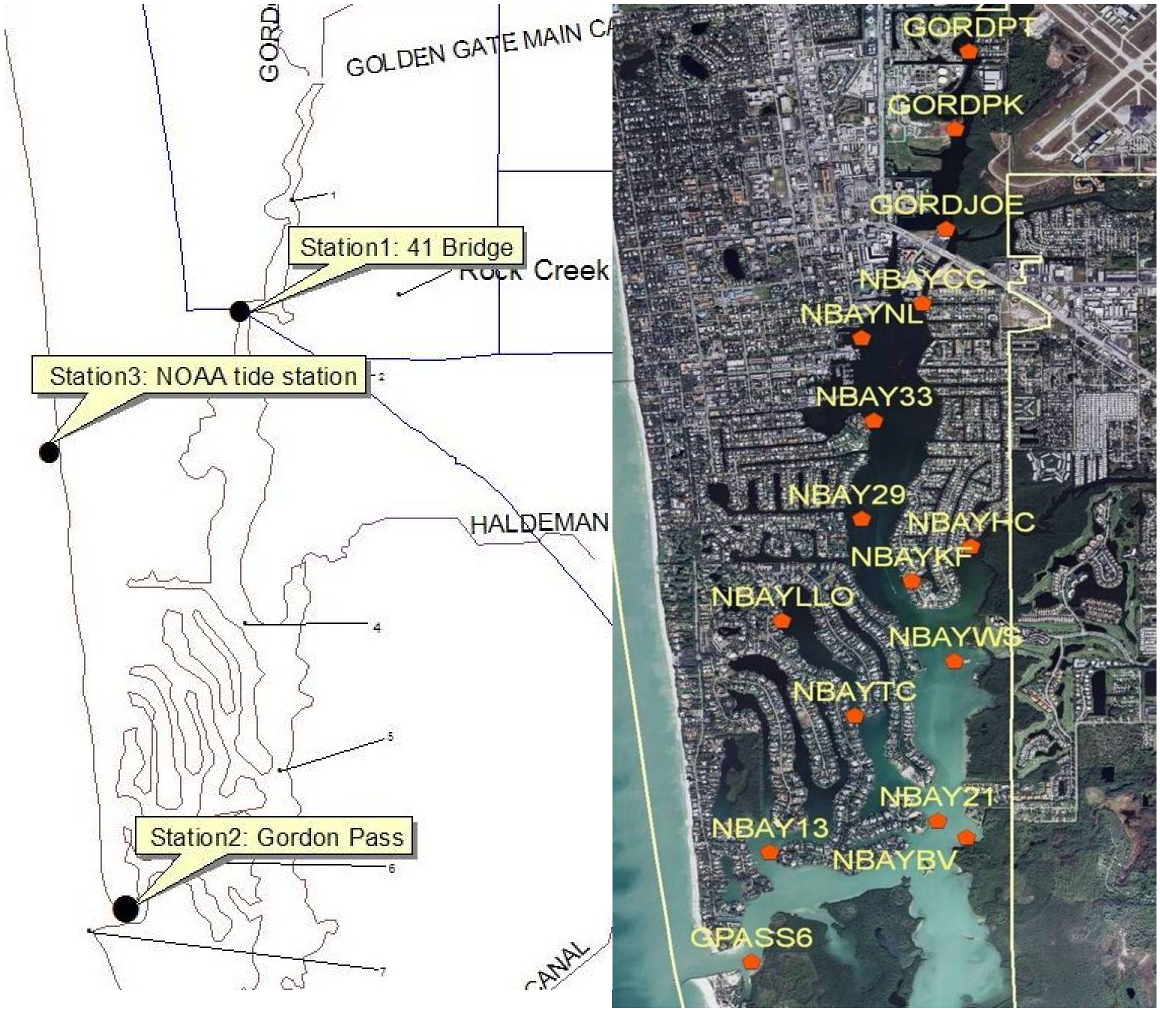


Figure 12-43. Naples Bay monitoring stations and canals. Salinity and tide stations (left); water quality stations (right).

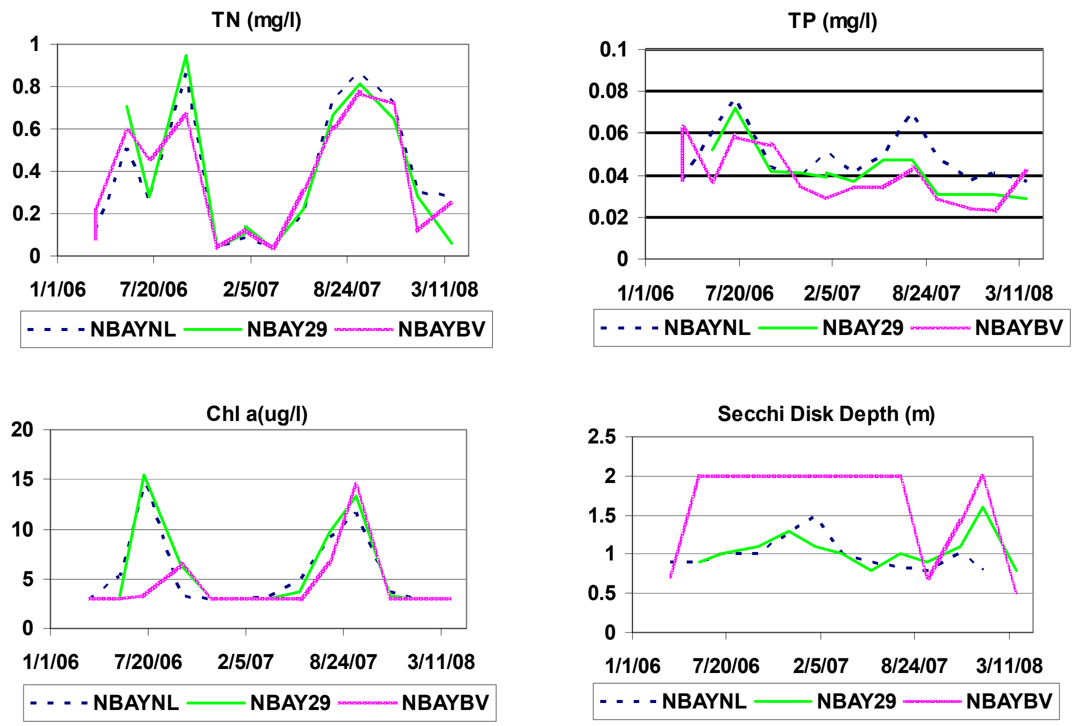


Figure 12-44. Water quality results from January 2006–March 2008 as collected bimonthly by the City of Naples: NBAYNL, NBAY29, and NBAYBV represent conditions in upper, middle, and lower bay, respectively.

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 59 acres (24 hectares) of seagrasses. In 2005, an inventory revealed that about 4 acres (1.7 hectares) of sparse seagrass remained. Epibenthic monitoring by the City of Naples along five transects south of Bayview Park indicates that seagrass cover has been stable since 2005. Primary species include shoal grass and paddle grass.

Eastern Oyster Abundance and Distribution

A study by Schmid et al. (2006) estimated that about 52 acres (21 hectares) of historical Eastern oyster habitat has shrunk to 12 acres (5 hectares) currently. An oyster reef restoration demonstration project conducted by FGCU and the FDEP was completed in 2007 to test the suitability of water quality for oyster reef development (Savarese et al., 2007). Two shell cultch reef substrates were manufactured at two localities within Naples Bay: at an upstream site within the heart of the Naples Bay adjacent to Naples Landing with lower salinity (site 1), and at a downstream site south of the confluence with Haldeman Creek with higher salinities (site 2). Two hundred biodegradable mesh bags filled with fossil shell were used at each site to construct the substrate.

The influence of substrate effects was tested by the monitoring of natural recruitment and living density (i.e., the number of living individuals found attached to the mesh bags). Density was monitored every three months for a nine-month period that spanned the wet to dry season transition. Living densities were low for all monitoring efforts at both sites, though densities were slightly higher at site 2. Counts ranged from four to 53 individuals per bag, which are one or two orders of magnitude lower than what has been recorded from other restoration projects in estuaries with ideal water quality and sustainable brood stocks. The results suggest that the lack of appropriate substrate and poor water quality is limiting the development of oyster reefs in Naples Bay. Monitoring continues.

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 characterize salinity variability, high-frequency time-series salinity results are needed. Currently, data are either monthly or bimonthly frequency.

Long-term SAV abundance and response is 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 began monitoring three sites in CY2008 within Naples Bay to obtain salinity values at a high frequency. The data will be used to characterize salinity throughout the bay, calibrate and verify a hydrodynamic/salinity model, and compare monthly grab sample results collected by the City of Naples and FIU. A CH3D model has been created for the bay. Thus far, simulated results for water levels agree with observed data.

Water flow rates were also recorded at two locations in CY2008: the U.S. Highway 41 Bridge and Gordon Pass.

KEY NON-SFWMD PROJECTS IN NAPLES BAY

The City of Naples is continuing to monitor recruitment and growth of Eastern oysters on cultch placed in the bay to assess the long-term viability of oyster reef restoration. Naples is also monitoring five seagrass transects. The city began monitoring water quality in the bay in 2005 at eight locations. Parameters include: DO, pH, salinity, water temperature, BOD, TOC, chlorophyll *a*, phaeophytin, TKN, nitrate/nitrite, ammonia, TP, orthophosphate, sulfate, Secchi disc depth, color, turbidity, copper, lead, calcium, and zinc.

ESTERO BAY

Beth Orlando

DESCRIPTION OF ESTERO BAY AND MAJOR ISSUES

Estero Bay is a small, long and narrow, shallow bar-built estuary located on the southwest coast of Florida (**Figure 12-45**). The watershed of the bay includes central and southern Lee County and parts of northern Collier and western Hendry counties. The bay is oriented along a north-south axis with barrier islands separating it from the Gulf of Mexico. Estero Bay is Florida's first Aquatic Preserve, designated by the state in 1966. In general, the FDEP is the lead organization for Estero Bay, because of its Aquatic Preserve status.

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. Much of the flow from this river may enter the Gulf of Mexico quickly through Big Hickory Pass.

Because the tributaries also are estuarine, salinity gradients in the bay and within the tributaries can form a complex temporal and spatial mosaic. Estero Bay is dynamic: opening, closing, and migration of inlets due to storms, and long-shore erosion and deposition have been documented. Both oysters and seagrasses are considered valuable ecosystem components and are being monitored.

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 are based on the salinity tolerances of the Eastern oyster and are used to define flow envelopes that maintain appropriate salinity at river mouths where oysters are located. The preferred inflow ranges result in salinity levels (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 result in salinity below 5 psu are considered lethal to juvenile oysters (**Table 12-18)**.

Freshwater inflows to the three major tributaries were examined regarding their current and historical deviation from the recommended flows to maintain appropriate salinity as described in the previous section at the river mouths for the Eastern oyster adults (**Table 12-19)**. **Figure 12-46** depicts the mean annual salinity observed at three locations within Estero Bay.

Figure 12-45. Location of Estero Bay.

Table 12-18. 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

Table 12-19. Comparison of historical and WY2008 tributary inflow in Estero Bay.*

TRIBUTARY CONTROL STATION	HISTORICAL MEAN (DAYS) 1988–2007	DAYS IN WY2008
Imperial River		
8-26 cfs >94 cfs	139.6 ± 14.2 105.0 ± 14.0	309 16
South Estero		
3-9 cfs >31 cfs	67.6 ± 8.8 43.2 ± 6.8	15 3
Ten Mile Canal		
4-50 cfs >215 cfs	144.7 ± 8.7 31.3 ± 6.9	162 5

*Note: The number of days in WY2008 when flow was within the minimum flow range is compared to the historical mean ± 95% confidence Interval (C.I.). The number of days in WY2008 when flow exceeded the recommended maximum is compared to the historical mean ± 95 percent C.I.

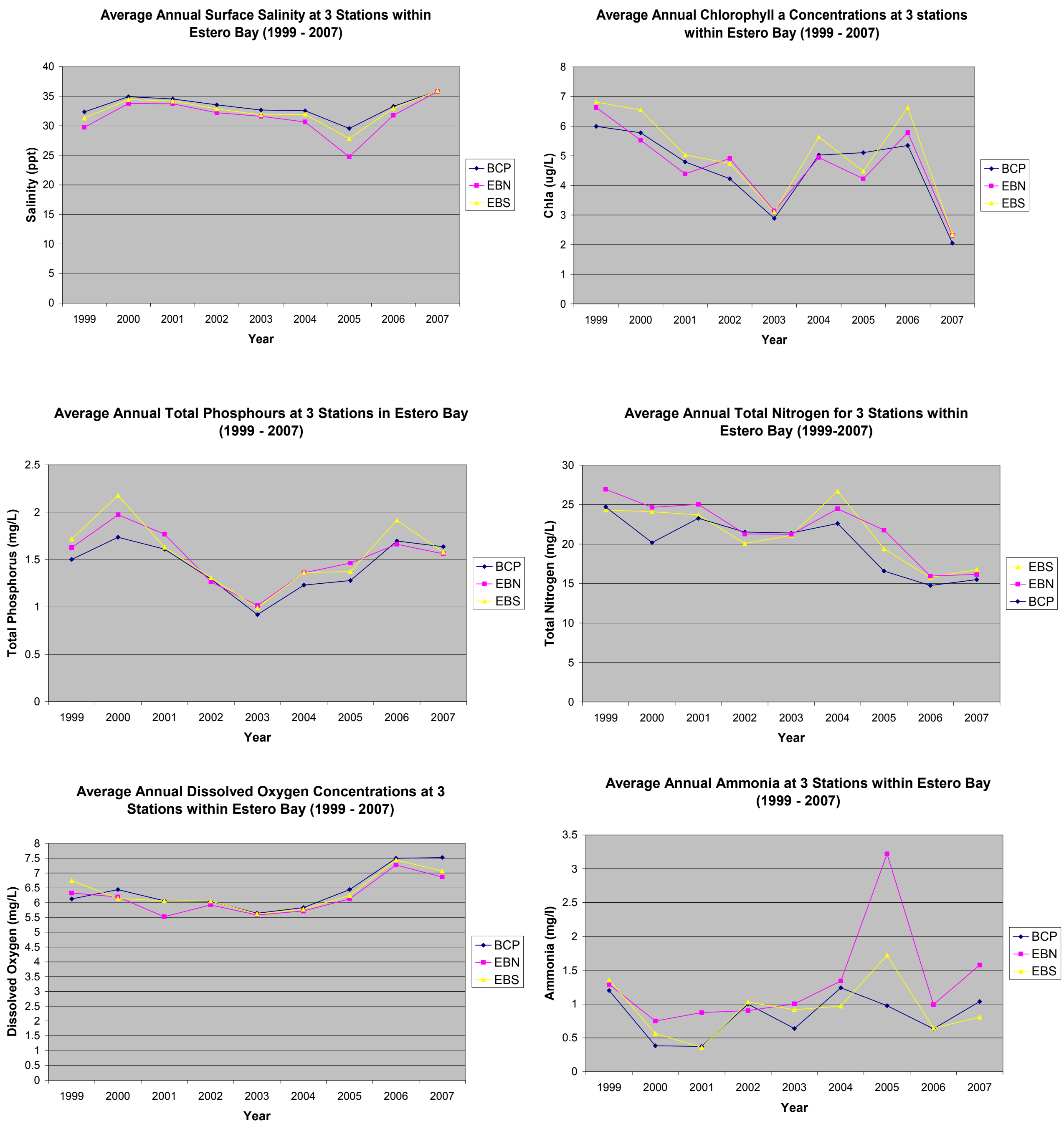


Figure 12-46. Mean annual water quality results at three monitoring stations in Estero Bay.

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. Since January 1999, four stations in Estero Bay [Estero Bay North (EBN), Estero Bay South (EBS), Big Carlos Pass (BCP), and Outer Clam Pass (OCP)] are sampled monthly (**Figure 12-45**). Variables currently being collected include salinity, chlorophyll *a*, DIN and TP (**Figure 12-46**). DIN and soluable reactive phosphorus show spikes in concentration in 2005 and 2006, respectively, which may be related to increased watershed runoff and lake releases after an active hurricane season.

Since 1999, water quality has been sampled monthly within the tributaries of Estero Bay in a collaborative effort between Lee County Environmental Lab and Estero Bay Aquatic Preserve. 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, total nitrogen, turbidity and fecal coliform bacteria. Continuous water quality monitoring efforts include three data sondes located throughout the bay. Information form 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 dissolved oxygen levels. Water quality data have also shown higher turbidity levels in Estero Bay than in Charlotte Harbor.

Submerged Aquatic Vegetation Habitats

Aerial photography was used by the District to quantify distribution and response of seagrasses to freshwater inflows in 1999, 2003, 2004, and 2006. According to WY2007 bottom vegetation maps, 44,562 acres (18,033 hectares) of SAV cover (including macroalgae) was identified at the time of the survey. Cover increased by 6,347 acres (2569 hectares) from 1999–2006. The majority of this increase [5,043 acres (2,041 hectares)] occurred before the 2004/2005 hurricane seasons. The comparatively lower increase in vegetative coverage between 2004 and 2006 [1,304 ac (528 hectares)] may have been a result of increased freshwater flows following each of the two very active hurricane years.

Eastern Oyster Abundance and Distribution

Historical information on the aerial extent of oyster reefs in Estero Bay is limited. Based on WY2004 data, there were about 60 acres (24 hectares) of live oyster habitat in Estero Bay, and another 8,269 acres (3,346 hectares) 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. Ongoing oyster projects are designed to characterize the utilization of creek mouth oyster beds by fish. Through its restoration program, FGCU continues monitoring oyster reefs in Estero Bay for spat recruitment, growth rates, predation, and disease.

Fish Communities

To determine the influence of various physical factors, such as river flow, salinity, and dissolved oxygen on fish community structure and habitat, the SFWMD funded an expansion of the FWC Fish and Wildlife Research Institute's Fisheries-Independent Monitoring (FIM) program to include water bodies directly affected by the implementation of ongoing restoration projects. The three-year dataset includes information about the distribution and abundance of juvenile and small adult fishes, turtles, and swimming invertebrates, collectively known as nekton. Changes in nekton community structure in the Estero Bay estuary appeared to coincide with changes in freshwater inflow.

The period from 2005 to 2007 had extreme variations in flow conditions. Correlations between monthly change in nekton community structure and seasonal and physicochemical changes in the Estero Bay estuary were moderate. For nekton communities of the Estero Bay tributaries (Hendry Creek, Mullock Creek, and Imperial River), correlations with physiochemical conditions were greater than those for regular annual cycles, with measures of shoreline depth, salinity, bottom DO, and bottom temperature being variables providing the best fit to explain monthly changes in nekton community structure.

For the nekton communities of Estero Bay proper, correlations with regular annual cycles were greater than for physiochemical conditions, suggesting that the seasonality and intrinsic spawning periods of the fishes present in the open bay are more important determinants in shaping the communities.

Species-specific analyses investigating the response of nekton abundance to varying freshwater inflows revealed significant relationships for several river-associated transient species and for economically important species. Species whose life histories are closely associated with rivers, such as hogchoker (*Trinectes maculates*), naked goby (*Gobiosoma bosc*), and striped mojarra (*Eugerres plumieri*), exhibited positive linear responses, indicating that abundance increased with increasing inflow. Species more typical of habitats in the open estuary [e.g., pinfish (*Lagodon rhomboids*)] exhibited negative linear responses, indicating that abundances in the tributaries increased with decreasing freshwater inflow.

Benthic Invertebrate Community

Characterization of benthic invertebrates has been performed both within the bay and near freshwater tributaries. These organisms are being evaluated as potential indicators of inflow response and as indicators of sediment and water quality. Thus far, results have been inconclusive.

RESEARCH STRATEGIES FOR ESTERO BAY

Previous projects have focused on developing a CH3D hydrodynamic/salinity model within the bay and evaluating various organisms or groups of organisms as potential VECs. Issues of concern include (1) degraded estuarine water quality, (2) altered freshwater inflow, (3) altered sedimentation, and (4) loss of biotic resources within the bay (such as seagrass beds and oyster bars). With continued development in the watershed, scrutiny and scientific investigation of Estero Bay is increasing. However, perceptions of environmental degradation, such as loss of seagrass beds and events of low DO, remain either anecdotal or have not been tied to anthropogenic disturbance. Thus, key strategies for current research are synthesizing data to include quantification of the responses of Estero Bay biota to changes in salinity and freshwater inflow, and extending modeling capabilities. This includes both upgrading existing models and integrating or linking modeling efforts (i.e., hydrodynamic, watershed, water quality, and ecological). The potential VECs being evaluated include seagrasses, oysters, fishes, and benthic macroinvertebrates.

Submerged Aquatic Vegetation

Seagrasses are being assessed by aerial photography to quantify distribution and response to freshwater inflow. As a result of theWY2008 aerial surveys, the creation of updated seagrass maps is scheduled for completion in 2009.

Eastern Oysters

Ongoing oyster projects are designed to characterize the utilization of creek mouth oyster beds by fish. Through funding by the District, FGCU was expected to begin an oyster restoration program in 2008.

Fish Communities

Fish communities are being characterized to understand community composition and how the assemblage changes in response to seasonal influences.

KEY SFWMD PROJECTS IN ESTERO BAY

The District and FWC have cooperatively conducted independent (versus recreational or commercial) fishery monitoring in Estero Bay.

The Comprehensive Review Study for the Central and Southern Florida (C&SF) Project (Restudy) has important implications for Southwest Florida. Among its recommendations to Congress in July 1999, the Restudy recommended a feasibility study to identify Southwest Florida water resource conditions and to develop potential solutions to any problems that may be identified. The SWFFS is being conducted by the USACE and the District. The study area also includes all of Lee County, as well as Estero Bay and its watershed. The SWFFS is an important first step and offers the opportunity to use USACE and District resources to plan for proper infrastructure before (or as) development occurs, by providing a water resources plan for the entire Southwest Florida area that considers ecosystem and marine/estuary restoration and protection, environmental quality, flood protection, water supply, and other water-related purposes. Therefore, the SWFFS will provide a framework to address the health of aquatic ecosystems (water flows, water supply, wildlife, biological diversity, and natural habitat); the region's economic viability; and property rights. The study will also investigate nonstructural alternatives, maximize regional benefits through multipurpose land use, ensure consistency with local planning initiatives, and improve water quality.

The SWFFS will be accomplished using a two-phase study process. The first phase, scoping, has been completed. It identified problems, opportunities, and potential solutions. The second phase, feasibility, which is near completion, will evaluate proposed water management alternatives, and the best scenario will be developed in more detail so a viable plan can be authorized and funded.

Currently, all alternatives have been identified and the evaluation process will begin as soon as the predicted (model) hydrology is provided, which will include estimated freshwater flows to Estero Bay and the changes in nitrogen loading associated with each alternative. Flows and loading will be compared to established performance measures for the tributaries, and a habitat suitability model developed by UF will be employed to assess benefits/harm to important estuarine biota.

The District's Governing Board authorized $255,000 to the San Carlos Estates Water Control District (SCEWCD) for a project that will enhance flood protection for its residents and improve the quality of water discharged to Spring Creek.

This project will include removal of exotic vegetation, planting of native species, and stabilization and restoration of canal banks. SCEWCD is matching the District's funds to cover the total cost of $510,000. The Spring Creek project is part of a $10 million capital improvement initiative by the SCEWCD to enhance its overall level of service.

The SCEWCD Capital Improvement initiative includes rebuilding and paving all roads located within the water control district, reconstructing roadside swales, installing a control structure at discharge points to perimeter canals, and installing two weirs. This is the SFWMD's second contribution to the initiative. In January 2007, the District's Governing Board authorized $250,000 to create a wetland to provide additional water quality treatment and create a more natural environment in the project area.

The Ft. Myers Beach Stormwater Management Study will implement the first of a two-phase comprehensive stormwater management plan for Estero Island. The initial phase will identify and map existing infrastructure, assess water storage and treatment alternatives, and develop an island-wide stormwater management strategy.

KEY NON-SFWMD PROJECTS IN ESTERO BAY

Lee County has been monitoring water quality at 14 locations within Estero Bay for 22 parameters.

FLORIDA BAY

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

DESCRIPTION OF FLORIDA BAY AND MAJOR ISSUES

Florida Bay covers a triangular area of 2,200 849 sq mi (km^2) at the southern tip of the state, between the Everglades and the Florida Keys (**Figure 12-47**). About 80 percent of this estuary is within the ENP and part of the Everglades Protection Area (EPA). The bay is shallow, with an average depth of about 3.3 ft (1 m). Most of the bay's bottom is covered by seagrass, which is habitat for many invertebrate and fish species. Starting in the late 1980s, a series of ecological changes were apparent, including widespread seagrass die-off, the occurrence of algal booms and high turbidity in what had been clear waters, widespread mortality of sponges, and decreases in some other invertebrates and fish species (Fourqurean and Robblee, 1999). A major hypothesis of Everglades restoration 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). Since fall 2005, an algal bloom has been sustained at the eastern boundary of Florida Bay and in southern Biscayne Bay. Hurricane disturbance, water management, and construction along the Florida Keys' Overseas Highway (U.S. 1) have been hypothesized to be interactive causes of this bloom.

The District has sustained a program of Florida Bay monitoring, research, and modeling 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. This section highlights results from major monitoring projects associated with hydrologic and salinity conditions, water quality, seagrass habitat, and roseate spoonbill *(Ajaja ajaja*) nesting, as well as brief updates regarding research and modeling activities and research planning. It also summarizes key results related to water management operations near the ENP, Florida Bay Minimum Flows and Levels, and CERP [C-111 Spreader Project, Florida Bay and Florida Keys Feasibility Study (FBFKFS), and RECOVER].

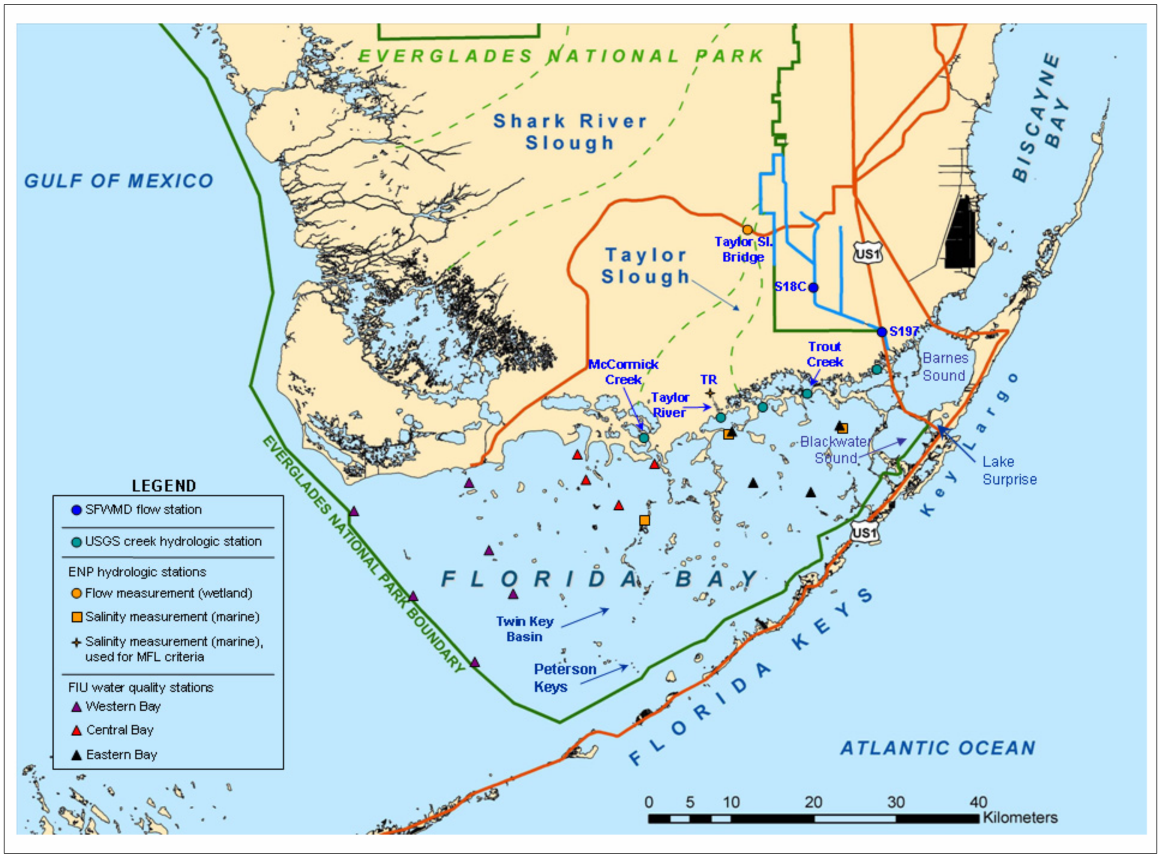


Figure 12-47. Florida Bay and major features.

STATUS AND TRENDS IN FLORIDA BAY

Key restoration targets adopted by RECOVER and the FBFKFS include salinity levels (with paleoecological studies providing a basis for formulation), seagrass cover and community structure, water quality (with the goal of preventing harm, particularly with regard to algal blooms), and fauna (including juvenile pink shrimp, juvenile lobsters (*Panulirus argus*), pre-adult spotted seatrout, American crocodiles (*Crocodylus acutus*), and roseate spoonbill reproductive success).

Salinity and Freshwater Inflows

Florida Bay rainfall was calculated on a daily basis as the mean precipitation measured at several platforms in the eastern bay (mean of Little Madeira, Duck Key, Long Sound, and Highway Creek) and central bay (mean of Whipray Basin and Terrapin Bay). With annual precipitation totals of 57.2 and 50.6 inches (145 and 129 cm), respectively, both eastern and central Florida Bay saw above-average rainfall [WY1997–WY2006: 45 inches (114 cm) in both basins] in WY2008. The ENP wetlands, which typically receive more precipitation than Florida Bay, also received above-average annual precipitation [61 inches (155 cm); for additional details, see Chapter 5 of this volume]. Totals for the wet season months were particularly high in WY2008 (except in August), while dry season accumulations fell below the long-term average by 1–3 inches (2.5-7.6 cm).

Flows from three major creeks that flow into the bay, Trout Creek and Taylor Creek (flowing into the eastern bay) and McCormick Creek (flowing into the central bay), are shown in **Figure 12-48**. Based on USGS measurements of nine mangrove creeks flowing into northern Florida Bay, the three creeks were estimated to account for about 60 percent of all creek flow (Hittle et al., 2001). Serving as the major contributor of flows into the bay, Trout Creek saw an annual discharge of 118,400 ac-ft (146 Mm^3) in WY2008, down nearly 25 percent from its long-term (WY1997–WY2006) average annual discharge of 155,300 ac-ft (192 Mm^3). To the west, Taylor River annual discharge was 15 percent below average (WY2008 = 25,800 ac-ft (32 Mm^3); WY1997–WY2006 average = 30,100 ac-ft). Flow into the central Bay through McCormick Creek remained well above (37 percent) the long-term average annual discharge (WY2008 = 22,400 ac-ft (27.7 Mm^3); WY1997–2006 average = 16,300 ac-ft).

Total annual discharge from five major creeks that feed into Florida Bay (three described above, plus Mud Creek and West Highway Creek), a quantity that is monitored as part of the Florida Bay MFL criteria, was down by nearly 15 percent in WY2008 from the decadal mean of 263,000 ac-ft (324 Mm^3). Flow was particularly low during the dry season (November–April) in the two easternmost creeks, West Highway and Trout, both of which had decadal lows for total dry season flow. High wet season flows earlier in the year helped offset these poor dry season flows, so at no time in WY2008 did the 365-day cumulative discharge from the five creeks go below the 105,000 ac-ft specified in the Florida Bay MFL rule.

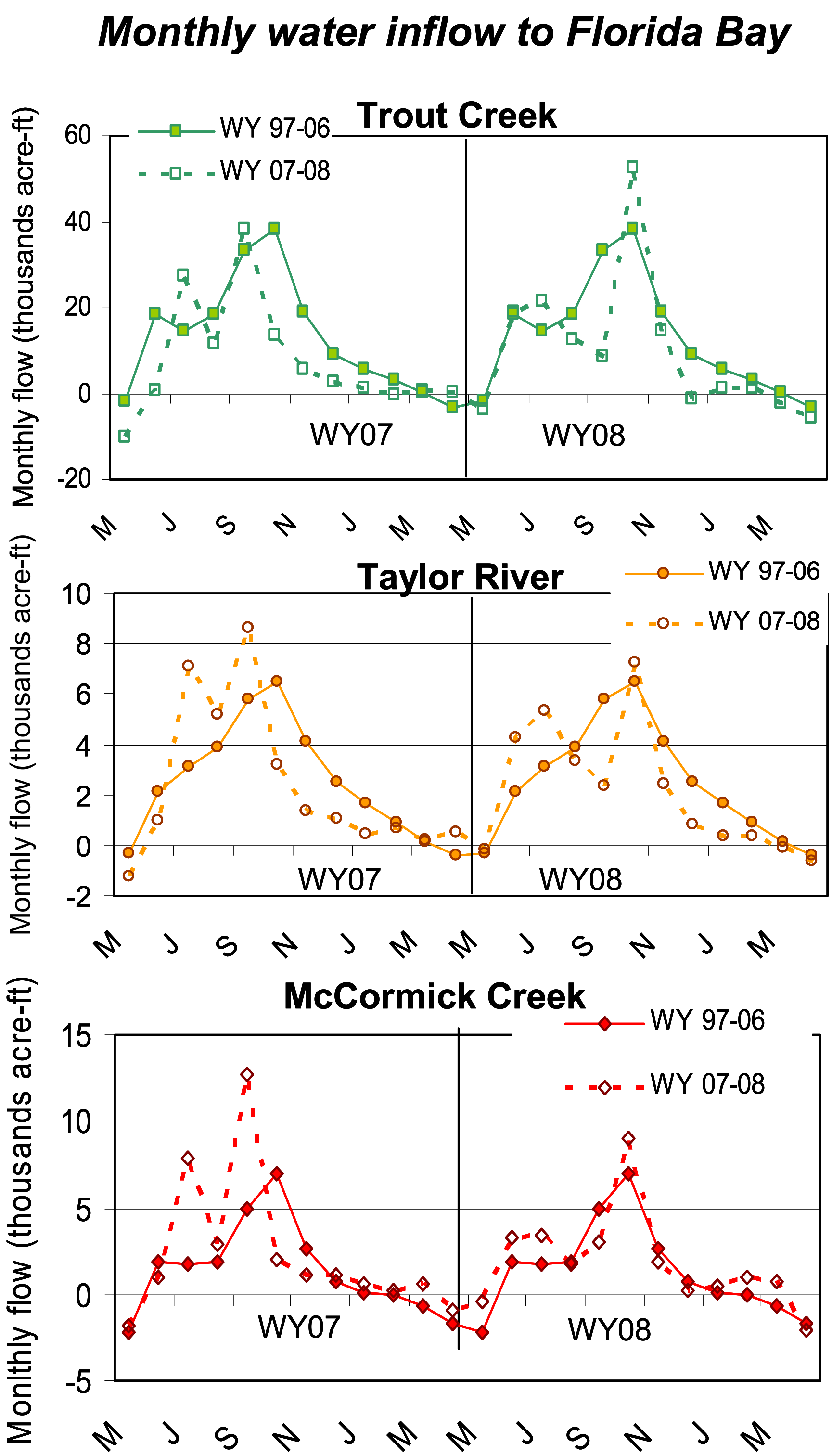


Figure 12-48. Monthly cumulative discharge to Florida Bay via three creeks in WY2007 and WY2008, compared to mean monthly discharge during the previous decade. Data for WY2008 are provisional. Creek flow data provided by USGS.

The spatial pattern of creek flows in WY2008 continued to support 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. This proportion of discharge, contributed to the bay through three central creeks (Mud Creek, Taylor River, and McCormick Creek), has increased relative to discharge from the easternmost creeks of the group (Trout Creek and West Highway Creek) (**Figure 12-49**). Though the five-creek discharge total has been below the long-term mean over the past two water years (particularly because flow through Trout Creek has been well below average), this spatial pattern is still evident. 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, which is designed to decrease easterly seepage of water from the ENP.

Salinity dynamics in Florida Bay are determined by multiple factors: freshwater flow from the Everglades, precipitation, evaporation, groundwater exchange, and exchange with the 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 extreme hypersalinity that affects the biology and chemistry of the bay. Data are collected continuously at stations in the ENP's Marine Monitoring Network (MMN), continuously at creek mouth stations monitored by USGS, and monthly as part of the SFWMD's water quality monitoring (contract with FIU), 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 FIU data collected in the corresponding months and regions.

Salinity across both eastern and central Florida Bay remained near the long-term decadal means for much of WY2008 (**Figure 12-50**). A peak above 40 psu in the central bay in September 2007, followed unusually low rainfall in August. Other than that anomaly, salinity remained near average across the system, including in the mangrove ponds north of Florida Bay. The Florida Bay MFL rule specifies a threshold salinity of 30 psu calculated as a 30-day running average concentration from a station in the mangrove transition zone (Taylor River); there was no exceedance of the MFL threshold during WY2008 (**Figure 12-51**). Corresponding with low inflows from the eastern creeks, WY2008 sustained a trend for increasing dry season salinity in the eastern nearshore embayments of Long Sound and Joe Bay (areas not used for data shown in **Figure 12-50**). A similar trend has not been evident in nearshore areas fed by central/western creeks, further supporting a spatial shift in creek flow distribution over recent years.

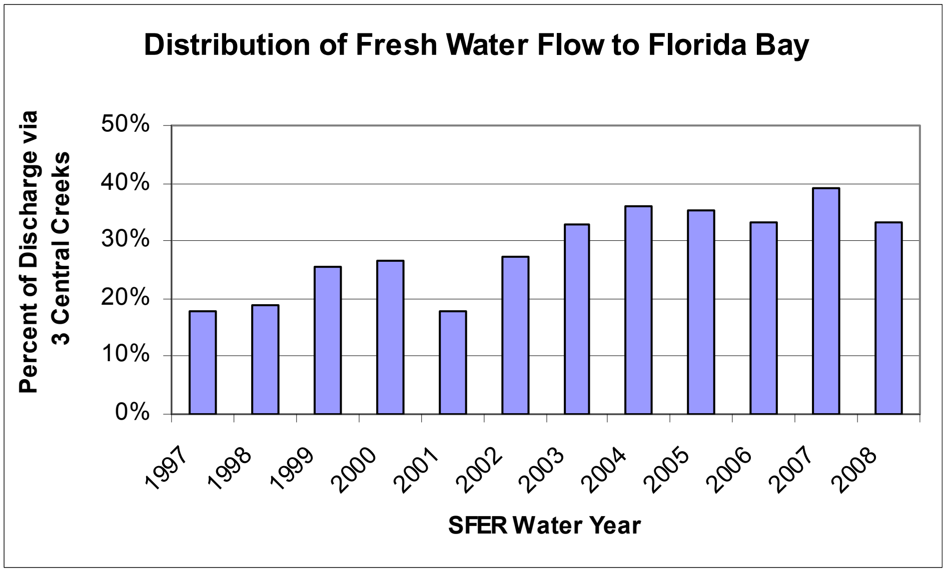


Figure 12-49. The proportion of annual creek discharge to Florida Bay (measured in five creeks) via the three most western creeks (McCormick Creek plus Taylor River plus Mud Creek).

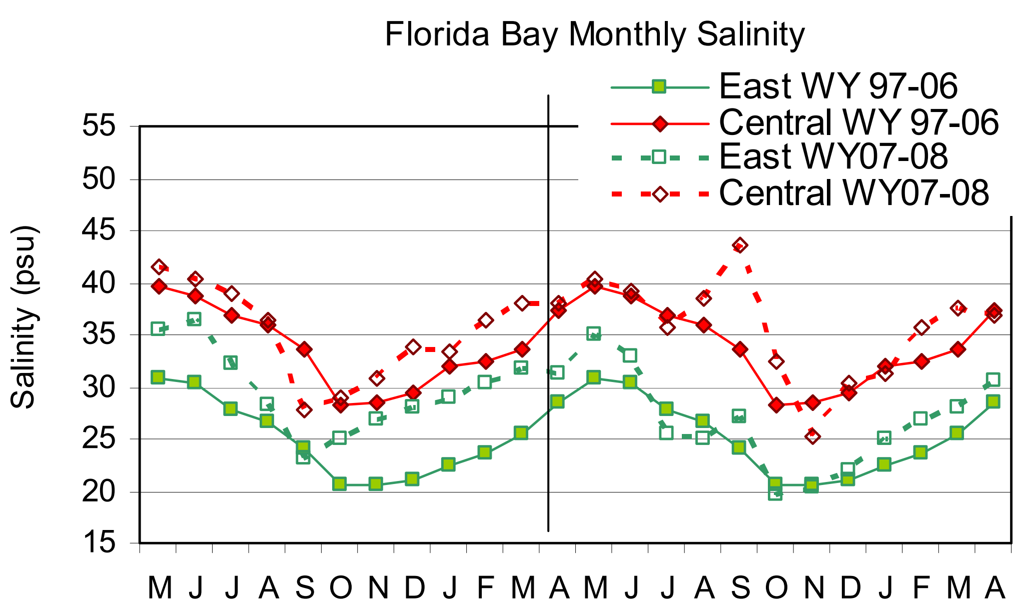


Figure 12-50. Mean monthly salinity values in eastern and central regions of Florida Bay in WY2007 and WY2008, compared to monthly means during the previous decade.

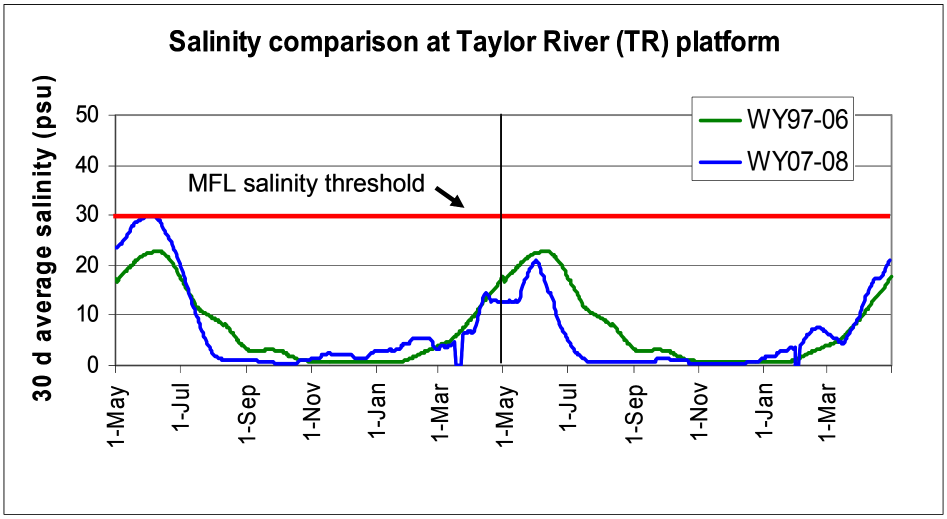


Figure 12-51. Salinity (30-day running average) at the Argyle-Hendry pond (Station TR) in upper Taylor River for WY2008 and mean daily values over the previous decade. The Florida Bay MFL threshold for an exceedance is the occurrence of this running average exceeding 30 psu within a calendar year. No exceedance occurred in WY2007 or WY2008.

Nutrients and Algal Blooms

Assessment of water quality in Florida Bay, which is part of the EPA, is necessary in order to ensure that District operations and projects protect and, to the extent possible, restore the ecosystem. CERP performance measures (in RECOVER and the 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 (1991). Water quality is thus considered a constraint on restoration efforts, with the objective of doing no harm.

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 and TOC concentrations and turbidity) decreased markedly in WY2008. While these concentrations remained above long-term means, both the magnitude and spatial extent of the algal bloom that began in fall 2005 greatly decreased by spring 2008. For details on the initiation, sustenance, and possible causes of this unprecedented bloom, see the 2008 SFER – Volume I, Chapter 12, *Florida Bay* section. **Figure 12-52** presents the WY2008 changes in two basins that have been at the center of this bloom, Blackwater Sound and Barnes Sound, with values from March 1991 through March 2008. The WY2008 chlorophyll *a* concentration range in these two basins was 0.6 μg/L to 3.2 μg/L, with mean concentrations of 1.7 μg/L in Blackwater Sound and 1.6 μg/L in Barnes Sound. This compares to a long-term, pre-bloom (WY1992–WY3005) mean chlorophyll *a* concentration of 0.5 μg/L in each basin. Spatial mapping of the bloom using the Dataflow Continuous Flow and Multiprobe System (Madden and Day, 1992), showed both decreased bloom magnitude and spatial extent (**Figure 12-53**). The location of the bloom in WY2008 has remained centered near U.S. 1 and Key Largo since bloom initiation in 2005. Likely due to its shallow depth and low flushing (long residence time), Lake Surprise had the highest concentrations associated with this bloom.

Other water quality parameters in the eastern bloom area also decreased in WY2008, approaching or returning to pre-bloom concentration ranges (**Figure 12-52**). Concentrations of TP, which closely follow chlorophyll *a* concentrations (with much of the TP being associated with algal cells), decreased to a mean of 0.37 micromolar (μM) [11.5 parts per billion (ppb)] in each basin, still above the pre-bloom (WY1992–WY2005) mean of 0.22 μM (6.8 ppb) in each basin. Total organic carbon concentrations, which increased to very high levels during the bloom in WY2005, were well within the range of pre-bloom concentrations in WY2008. While turbidity decreased from WY2007–WY2008 (data not shown; annual mean decrease of 21 percent in Blackwater Sound and 31 percent in Barnes Sound), it remained relatively high in both basins; WY2008 mean values were about double pre-bloom (WY1992–WY2005) means.

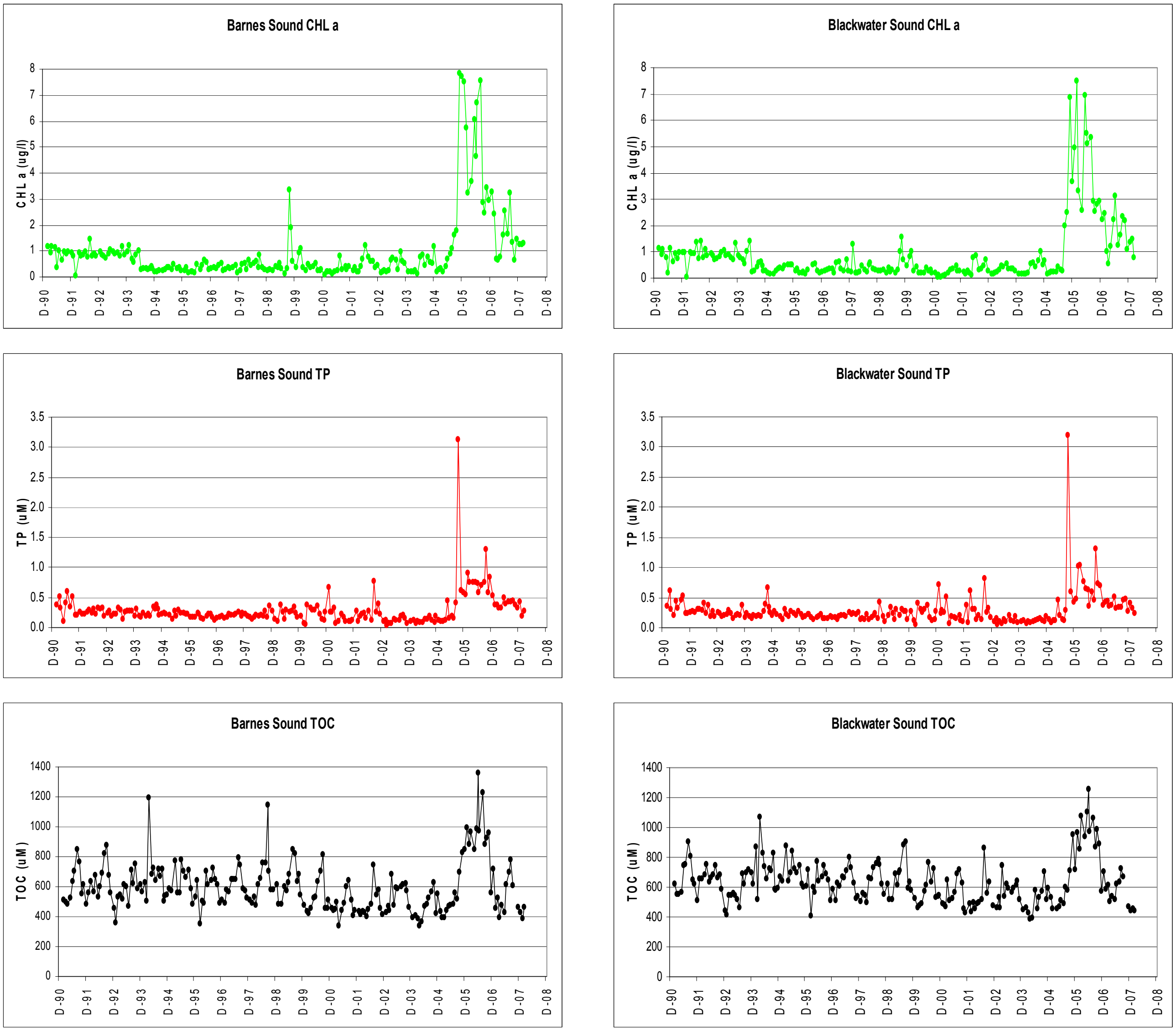


Figure 12-52. Monthly chlorophyll *a*, TP, and total organic carbon (TOC) concentrations at SFWMD/FIU monitoring sites in Barnes Sound and Blackwater Sound. The sharp TP peak, associated with algal bloom initiation, occurred in October 2005.

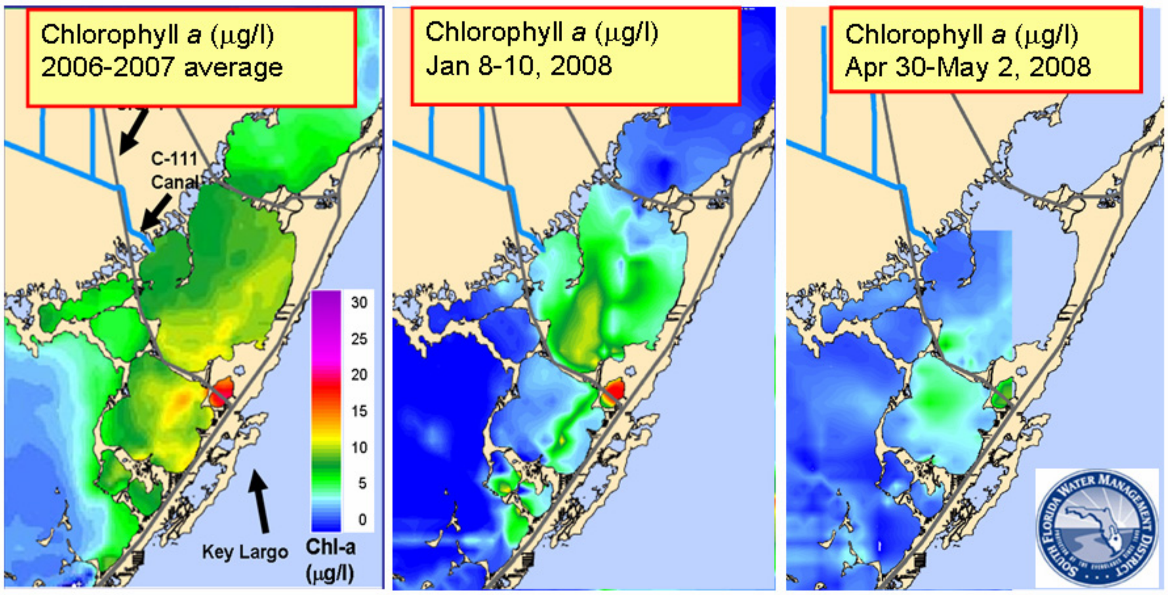


Figure 12-53. Status of phytoplankton bloom in eastern Florida Bay. chlorophyll *a* concentration maps estimated from Dataflow surveys of *in vivo* fluorescence. Each survey through the area shown includes tracks with several thousand data points. The first panel is an average of 10 surveys during calendar years 2006 and 2007. Other panels are from January and April 2008 surveys.

The status of water quality elsewhere in Florida Bay was near long-term (WY1992–WY2006) averages, except along the bay's southern boundary with the Florida Keys. Monthly chlorophyll *a* and TP concentrations in the eastern bay were low and near average, while these concentrations in the central and western bay were lower than average (**Figure 12-54**). However, an algal bloom was observed near the Florida Keys. This bloom drew public attention in summer 2007 because of the extensive mortality of sponges (see the *Benthic Habitat* section below). Only two stations (Twin Key Basin and Peterson Key; **Figure 12-47**) in the SFWMD-FIU water quality monitoring network were near areas with this bloom. Chlorophyll *a* concentrations have been elevated in this area since November 2005, but mean annual concentrations remained below 2 μg/L (**Figure 12-55**). Maximum concentrations in WY2008 were 5.5 μg/L in these two basins during July or August 2007. During the past three years, turbidity was at its highest level since the early 1990s (**Figure 12-55**). The relative increase in turbidity since WY2005 (versus WY1996–WY2004) was greater than the relative increase in chlorophyll *a*. It is notable that a major sponge mortality event also occurred in this region in the early 1990s (Butler et al., 1995). The algal blooms, dominated by cyanobacteria, may have been a cause of this mortality — and decreased sponge grazing then may have resulted in larger, sustained algal blooms.

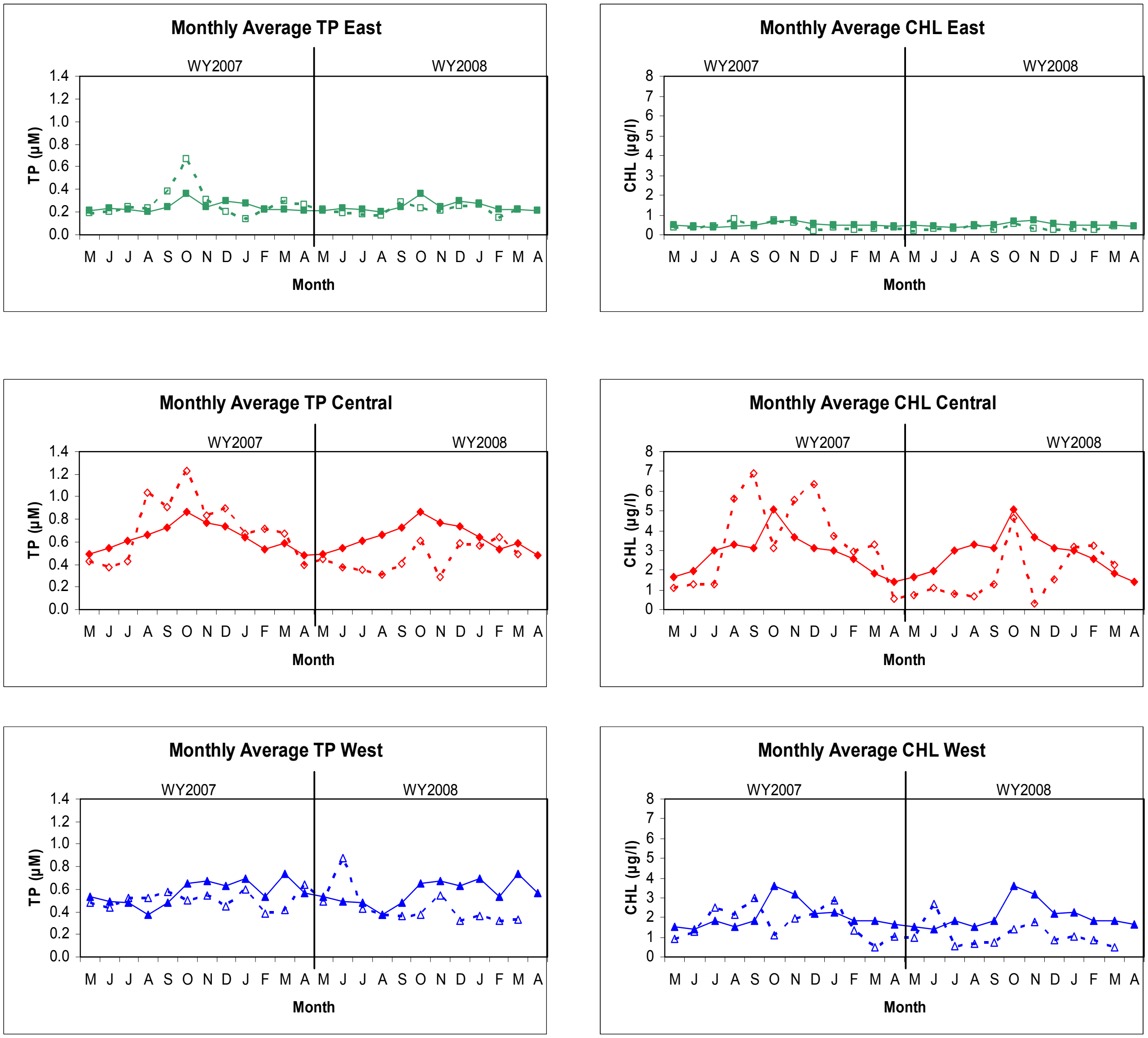


Figure 12-54. Monthly TP and chlorophyll *a* concentrations in regions of Florida Bay during WY2007 and 2008 (dashed line with open symbols) compared to monthly means from WY1992–WY2006 (solid line with closed symbols).

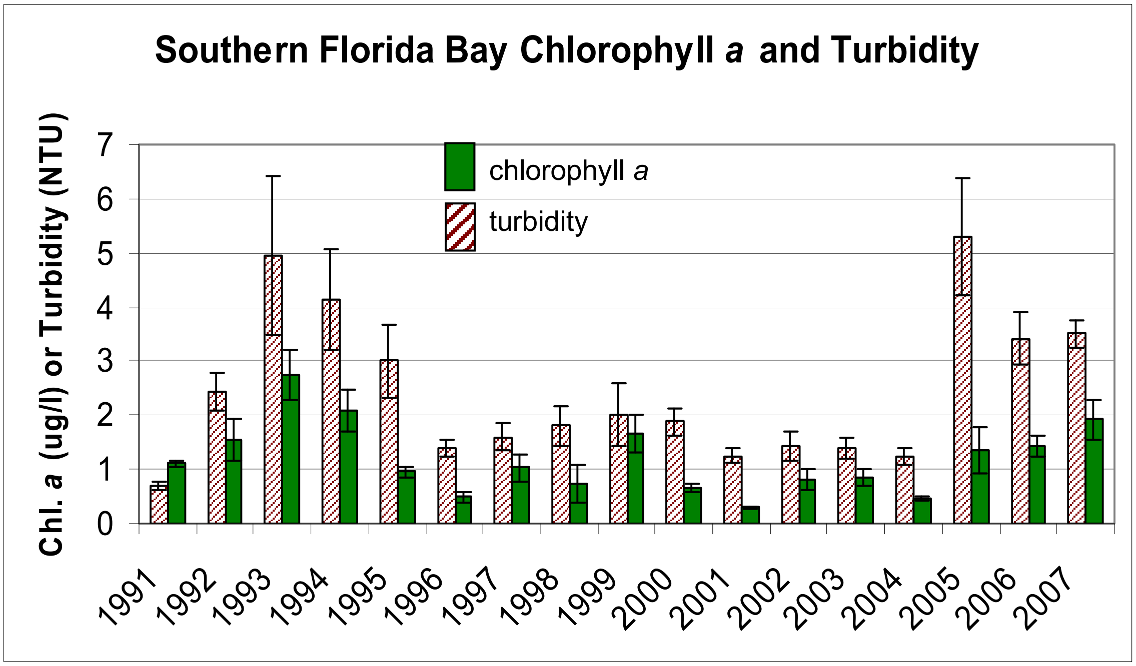


Figure 12-55. Mean annual (±SE) chlorophyll *a* concentrations and turbidity in southern Florida Bay, averaging values from Twin Key Basin and Peterson Keys stations.

Benthic Habitat

Submerged Aquatic Vegetation and Sponges

Submerged aquatic vegetation (SAV) habitat is the central performance measure for Florida Bay assessment and restoration (Rudnick et al., 2005). A restoration target for the bay (performance measures documented for RECOVER and the FBFKFS) is the sustainability of mixed-species seagrass beds with moderate to dense cover through most subregions. 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. For this report, data from benthic habitat surveys conducted by Miami-Dade DERM and the FWC are used to assess the status of Florida Bay SAV. Both entities currently receive funding from the District to conduct these surveys.

DERM conducts benthic habitat surveys in eastern Florida Bay and southern Biscayne Bay. These surveys are conducted 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 estimated by bottom occlusion. Four to 12 randomly selected sites are sampled in each basin area using four haphazardly thrown 0.25 m^2 quadrats. These data are aggregated to the basin level for analysis and can be used to determine intra- and inter-annual trends in benthic habitat cover.

The Fisheries Habitat Assessment Program of the FWC has been sampling in 10 basins of Florida Bay since 1995. In 2004, RECOVER began funding the program and expanded the region to include Whitewater Bay, Coot Bay, Lostman's River, and nearshore Biscayne Bay for a total of 20 sampling basins. Sampling is currently conducted in May of each year 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.

The focus of SAV reporting for this chapter is on only two areas of Florida Bay where algal blooms have been reported: Twin Key Basin and the eastern boundary of Florida Bay (U.S. 1 corridor). Twin Key Basin has been a turtle grass-dominated environment since monitoring began, occurring in 80 percent or more of all observations in this basin. Shoal grass, in contrast, has consistently had a low frequency of occurrence. The maximum frequency of occurrence for shoal grass in existing data occurred in May 1997 and 1998, with shoal grass present in 20 percent of all observations, but then became rarer (frequency < 5 percent from 2004–2006). However, in May 2007, frequency of occurrence increased to 16 percent. It should also be noted that shoal grass in Twin Key Basin had low density (when observed) from 2000–2006, with no single quadrat having a density of > 5 percent bottom occlusion. However, in 2007, 29 percent of shoal grass observations fell in the category of > 5 percent bottom occlusion. Given that shoal grass has a lower light requirement than turtle grass (Dunton and Tomasko, 1994; Fourqurean and Zieman, 1991), recently increased shoal grass cover is consistent with the occurrence of algal blooms. Shoal grass changes could also be a response to changing nutrient availability (Fourqurean et al., 1995).

As reported the 2008 SFER – Volume I, Chapter 12, *Florida Bay* section, an algal bloom (dominated by *Synechococcus* spp., which are cyanobacteria) began in fall 2005 along the eastern boundary of Florida Bay in association with the onslaught of three hurricanes and construction along U.S. 1. Elevated chlorophyll *a* was measured in Manatee Bay and Barnes Sound (southern Biscayne Bay) in September 2005, but the bloom expanded regionally with higher chlorophyll *a* concentrations measured that November (**Figures 12-52** and **12-53**). SAV losses, coincident hurricane disturbance, and bloom occurrence were reported for Barnes Sound and Blackwater Sound. Updated DERM SAV results from these and other nearby basins (**Figure 12-56**) show a regional decrease in SAV cover at this time, then evidence of increased SAV cover (mostly green algae) in WY2007 and WY2008. However, turtle grass recovery is not evident. In WY2008, shoal grass increased in frequency and density in Barnes Sound.

Upon further examination of DERM benthic data for this region, it was found that no sponges were observed from October 2005–June 2007 (**Figure 12-57**). A prolonged absence of sponges has never been recorded before in Blackwater Sound, Barnes Sound, or Manatee Bay (with sampling since 1996), making this finding particularly noteworthy. Sponge mortality between July and October 2005, could have been caused directly by the cyanobacteria bloom (Butler et al., 1995), but bloom intensification was not measured regionally until November. Mortality could have been associated with more localized blooms, decreased salinity, and low DO concentrations. Daytime water quality monitoring of DO did not detect hypoxia or anoxia, but with high rainfall and runoff from Hurricanes Katrina and Rita in August and September 2005, water column stratification with nighttime benthic oxygen depletion may have triggered sponge mortality and also released nutrients to the water column, promoting further algal blooms. Sponge mortality, with resultant decreased grazing on plankton, also likely increased the potential for algal blooms.

It should also be noted that benthic monitoring in southern Florida Bay by other agencies found widespread and near-complete mortality of sponges in hardbottom areas near the Florida Keys during summer 2007. A workshop co-sponsored by the Florida Keys National Marine Sanctuary and the District was convened in March 2008, and included presentations with extensive evidence linking this mortality to cyanobacteria blooms.

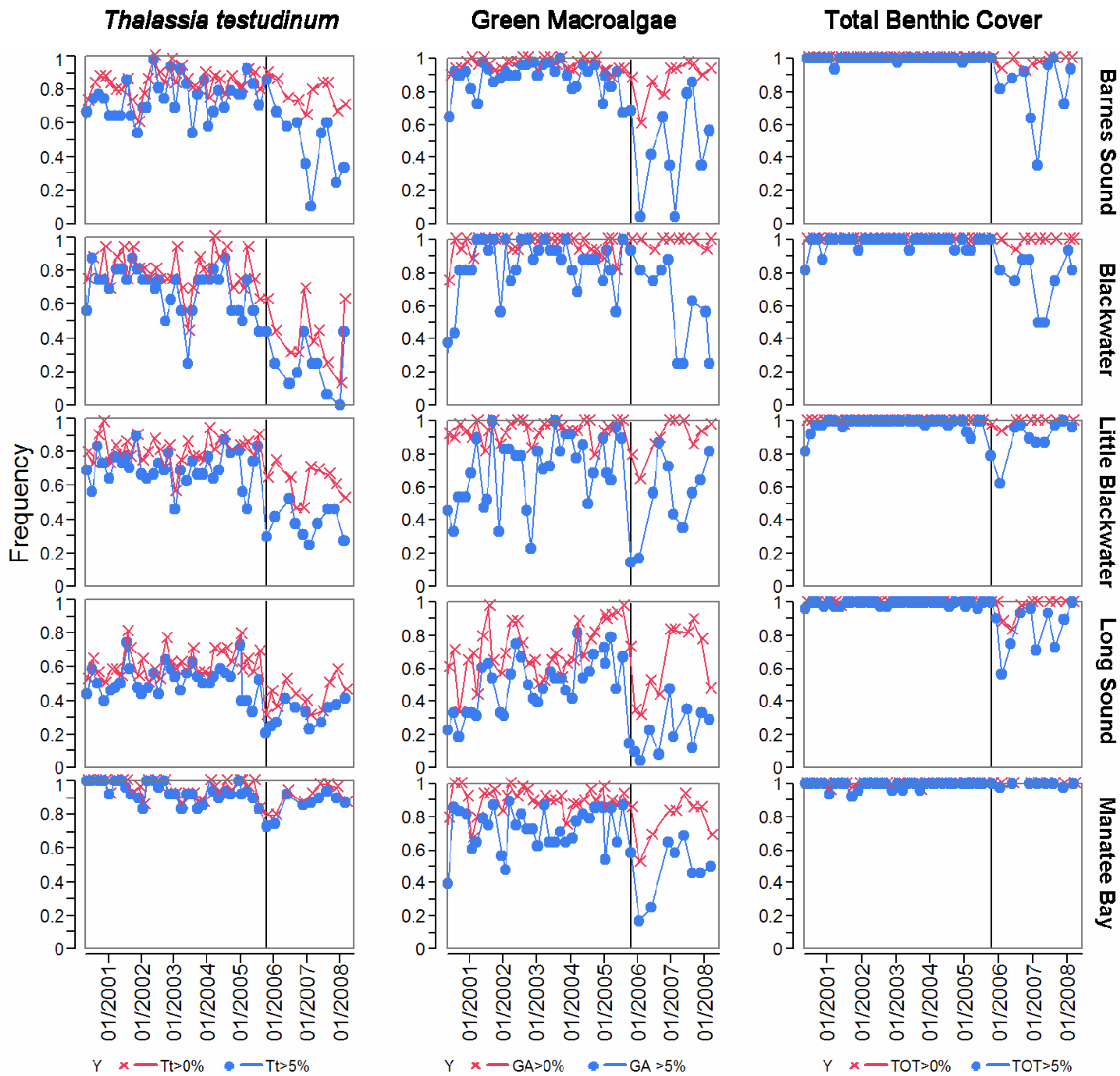


Figure 12-56. Benthic cover data for WY2001 through WY2008 sampled on a quarterly basis by DERM. Data are collected using a Braun-Blanquet Cover Abundance Index (BBCA), reported as frequencies. The red x's are the total frequency of occurrence for *Thalassia* (Tt), green macroalgae (GA), and total cover (where BBCA score > 0). Blue circles are the frequency of occurrence for bottom occlusion greater than 5 percent (where BBCA score ≥ 2). A vertical line marking October 2005, after which most of the SAV loss occurred, is drawn.

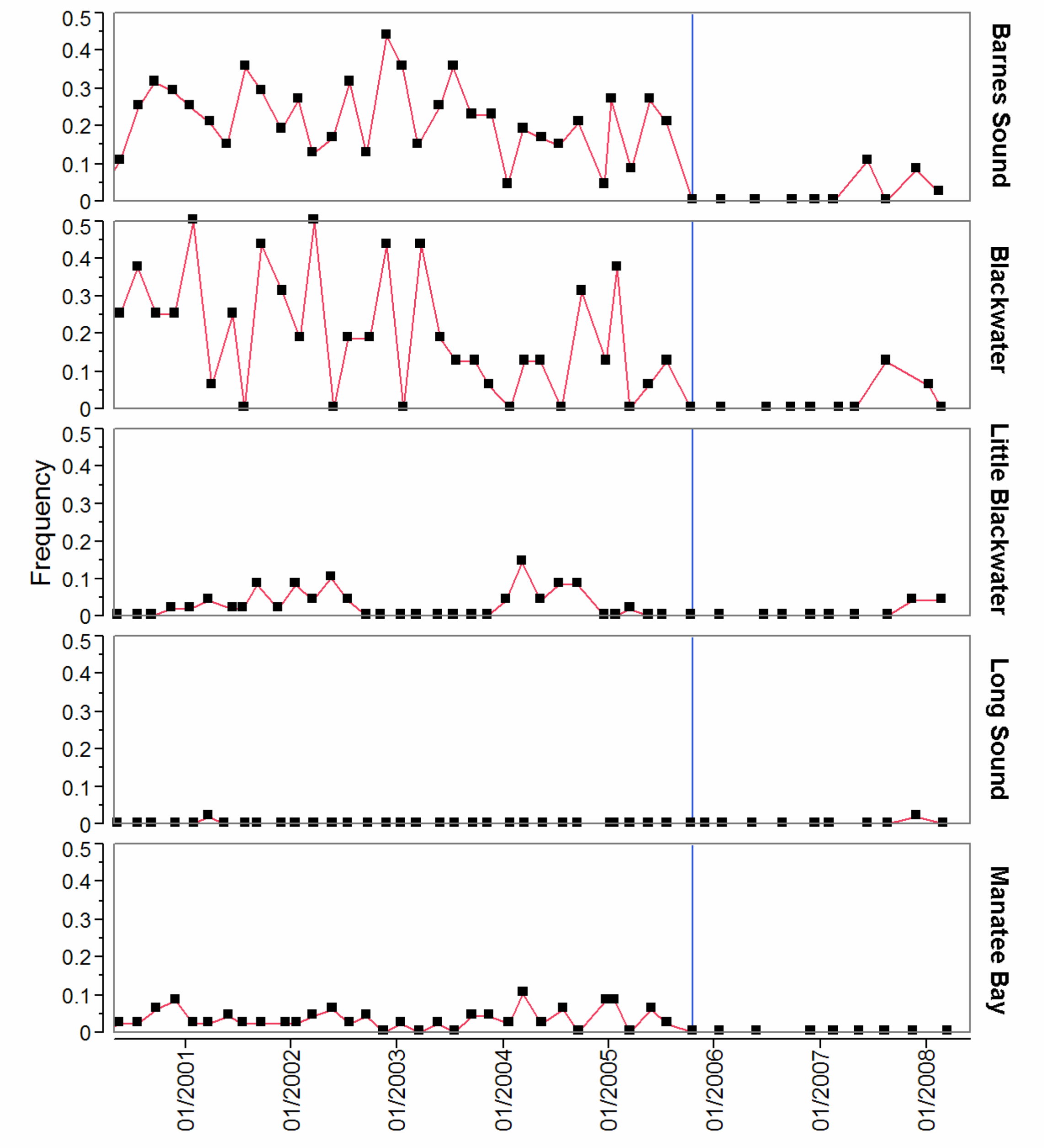


Figure 12-57. Frequency of occurrence for sponges along the U.S. 1 corridor from data collected by DERM from WY2001–WY2008. The vertical reference line marks October 2005, which is the first sampling event where all basins in this region had no sponges observed in any of the observations.

Higher Trophic Levels

Roseate Spoonbills

Roseate spoonbills are listed by the state of Florida as a species of special concern. Florida Bay represents one of the primary spoonbill nesting areas in the state (Bjork and Powell, 1993). The bird's survival strategies (nesting away from mainland predators, feeding in a way that requires shallow water, and timing their nesting period with the seasonal drawdown of water in the coastal wetlands) have all narrowed the ecological niche of spoonbills, and facilitated their use as a sentinel species of South Florida's changing ecosystem (Lorenz et al., 2002). While many factors have been cited as affecting the selection and distribution of spoonbill nests in Florida Bay, Lorenz et al. (2002) presented evidence for how habitat loss and water manipulations in spoonbill foraging areas have played a major role in affecting the location, abundance, and success of their nests.

The SFWMD has collaborated with staff from Audubon of Florida's Tavernier Science Center to monitor spoonbill reproductive success in Florida Bay as a function of hydrologic conditions across the Everglades mangrove transition zone, where adult spoonbills feed. In WY2008, Audubon prepared a report for the SFWMD that included data analysis for nearly 20 spoonbill nesting seasons. Highlights from this report include:

- Estimation of an optimal water level (approximately 5 inches, 12.5 cm) for spoonbill feeding in the southeastern Everglades mangrove transition zone (foraging area most influenced by water management activities)
- Development of a statistical model using water levels and recession rates in the southeastern Everglades to provide near real-time predictions for when spoonbills will be cued to nest in northeast Florida Bay (Tern Key colony)
- Comparison of nesting success between northeast and northwest Florida Bay colonies — the former is influenced by water management and the latter is not so influenced
- Recommendations regarding how water management can minimize disturbance of reproductive timing (delayed or early nesting) and minimize un-natural chick mortality (often caused by water level reversals and prey dispersal)

The WY2008 spoonbill nesting season was historically poor across the bay despite what appeared to be good hydrologic conditions for foraging during the early dry seasons when spoonbills nest (notably earlier than most other wading birds described in Chapter 6 of this volume). Audubon data (**Figure 12-58**) indicate that water levels in the southeastern Everglades were just below the long-term average at the time of nest initiation (November–December 2007) and very similar to levels measured in past years with nesting success on Tern Key in northeastern Florida Bay. However, in WY2008, no nests were found on this key. The number of nests in this region of the bay were exceptionally low (**Figure 12-59**). Chick production per nest was > 1 in these northeastern nests (defined by Audubon staff as a successful nesting effort), further suggesting that hydrologic conditions in the southeastern Everglades were suitable for the spoonbills nesting in this region. Information about prey abundance in foraging areas is not available at the time of this publication.

Decreases in spoonbill nest abundance in northeastern Florida Bay over the past two decades have coincided with increases in northwestern Florida Bay. However, during the last two calendar years, fewer birds nested in the northwestern Bay as well. In WY2008, for example, Audubon noted almost complete colony failure on several keys in the northwestern part of the bay — typically the most productive spoonbill subregion. It is unclear why fewer birds are nesting across Florida Bay. Some birds appear to be migrating northward, from the ENP to Tampa Bay. This movement away from the ENP reflects a regional downward trend described in Chapter 6 of this volume for the number of wading birds nesting and foraging in the southern Everglades estuaries, a pattern targeted for reversal through the implementation of CERP.

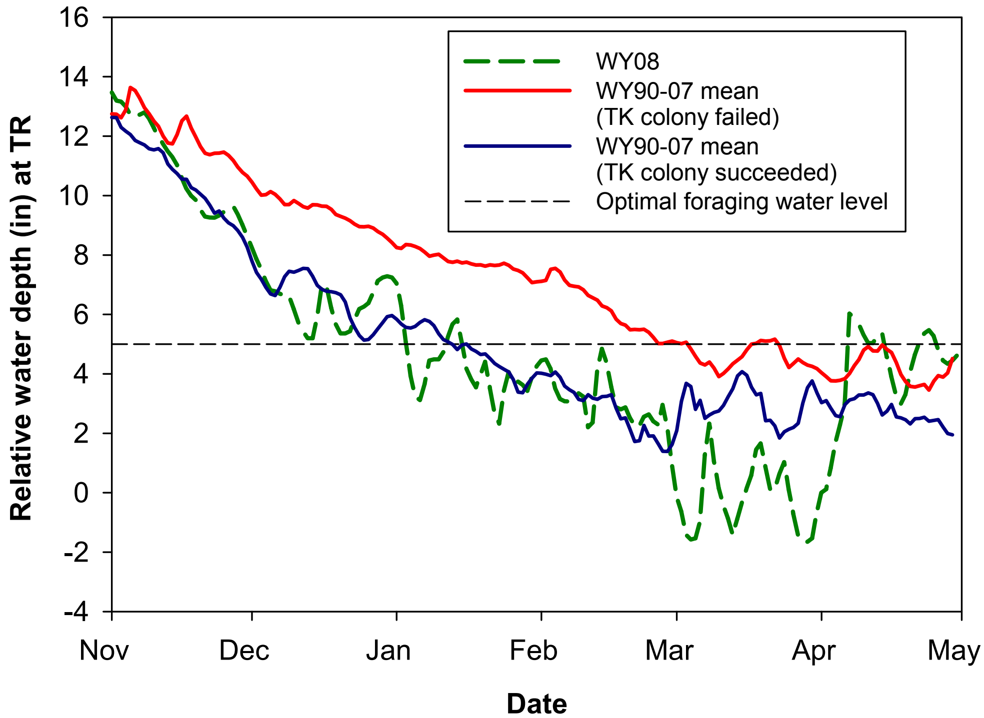


Figure 12-58. Nesting season water depth at Audubon's Station TR (Taylor River) during WY2008. Also shown are long-term (WY1990–WY2007) mean depths for seasons when nesting on Tern Key succeeded or failed. Data provided by Audubon of Florida Tavernier Science Center.

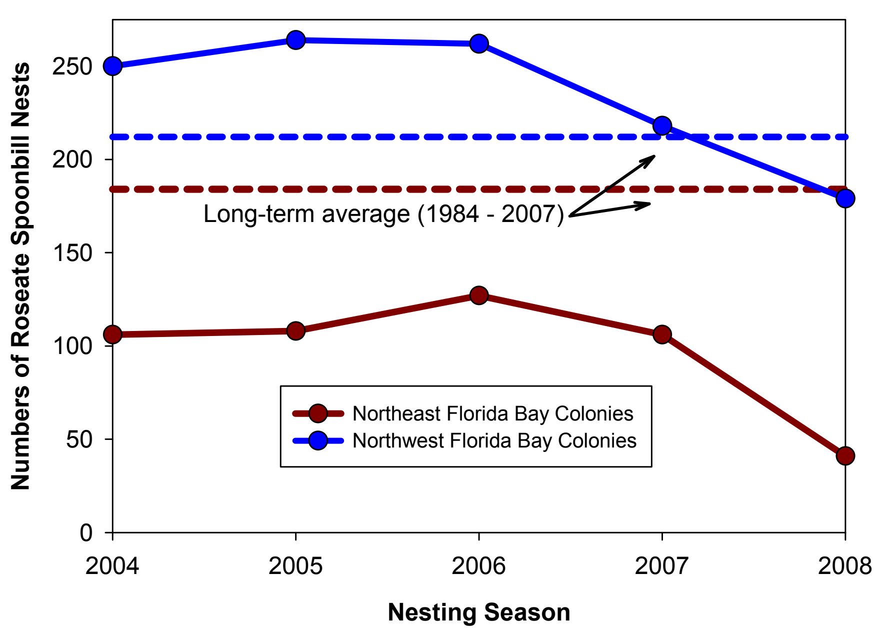


Figure 12-59. Number at spoonbill nests counted in two regions of Florida Bay. Data from Audubon of Florida.

RESEARCH ACTIVITIES AND STRATEGIES

Research activities in WY2008 focused on meeting 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 Florida Department of Transportation regarding causeway removal in Lake Surprise, establishing an ecological baseline for Phase I of CERP's C-111 Spreader Project and RECOVER. A research strategy, which focused on increased integration of Florida Bay research with upstream mangrove zone research, was included in the 2008 SFER – Volume I, Appendix 6-1. Below are brief updates on WY2008 activities.

Groundwater Mapping and Nutrients

Three surveys of potential groundwater sources in eastern Florida Bay and southern Biscayne Bay, conducted by contracted USGS and FIU researchers, were completed in WY2008. These surveys used continuous mapping of ^{222}Rn (radon) and resistivity profiles, time series of ^{222}Rn, water seepage measurements, and analysis of nutrients in wells. Preliminary results indicate considerable surface water-groundwater exchange in Florida Bay; groundwater discharge appears to be recycled bay water. Areas with the highest discharge appear to be near the Florida Keys and northern coast of the bay.

Dissolved Organic Matter Bioavailability

Research conducted by SFWMD staff and external scientists was reviewed and discussed at a workshop sponsored by the agency. This workshop included participants from many national universities and agencies, including experts in dissolved organic matter chemistry and microbial ecology. A summary report of this workshop, which identifies key points of current understanding and information needs, will be posted on the District's web site at http://www.sfwmd.gov under the *What We Do, Watershed Management, Everglades/Florida Bay Documents* tabs.

Algal Bloom Studies

In addition to documenting the spatial patterns of the eastern algal bloom using Dataflow (**Figure 12-53**), the SFWMD focused on documenting conditions in and near Lake Surprise and providing recommendations to the Florida Department of Transportation regarding mechanisms and timing of causeway removal. This work included sediment, SAV, and water quality surveys (most importantly documenting diel DO dynamics, as a concern is that excavation could increase turbidity, decrease light and photosynthesis, while increasing oxygen demand). The District continued to collaborate with scientists researching bloom dynamics (nutrient limitations and grazing), and continued to collaborate with scientists (P. Glibert and C. Heil) who are researching bloom dynamics (nutrient limitations and grazing). Their work is being incorporated into and synthesized via the Florida Bay SAV Model. The District also co-sponsored (with the Florida Keys National Marine Sanctuary) a two-day workshop on regional algal blooms that included many agencies, universities, and stakeholders. Scientists presented information about all aspects of the *Synechococcus* blooms in Florida Bay, from potential causes to the cyanobacteria's physiology and impacts on biota. The workshop discussed bloom history, contextualizing the current *Synechococcus* blooms in Florida Bay with similar blooms in the 1990s, as well as larger ecosystem impacts. Presentations were followed by a discussion of bloom causes, and current and future management responses to blooms, especially in light of research conducted since the 1990s *Synechococcus* blooms.

Florida Bay Seagrass Community Research and Model Development

A sector-based, coupled seagrass-phytoplankton model was developed during WY2008 and is being parameterized based on field experiments, bioassays, and monitoring data. The model 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 demonstrates 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 (**Figure 12-60**). The model is currently being updated with the most recent data on nutrient uptake kinetics by bay sector.

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. Prior to this update, turtle grass and shoal grass were modeled interactively. The widgeon grass module is being parameterized with data from field and laboratory experiments on seed germination rates and salinity tolerance. Data show that salinity has a major control on the ability of widgeon grass seeds to germinate in Florida Bay (**Figure 12-61**). Although adult plants tolerate high salinity well, seeds rarely germinate above 30 psu (Koch, 2008), potentially explaining the restricted distribution of widgeon grass in the bay. The seagrass model is being refined to include this recruitment mechanism so it can be used to project the ecosystem responses during restoration planning. It is anticipated that the widgeon grass and phytoplankton modules will be fully integrated into the primary ecological model and calibrated in 2009.

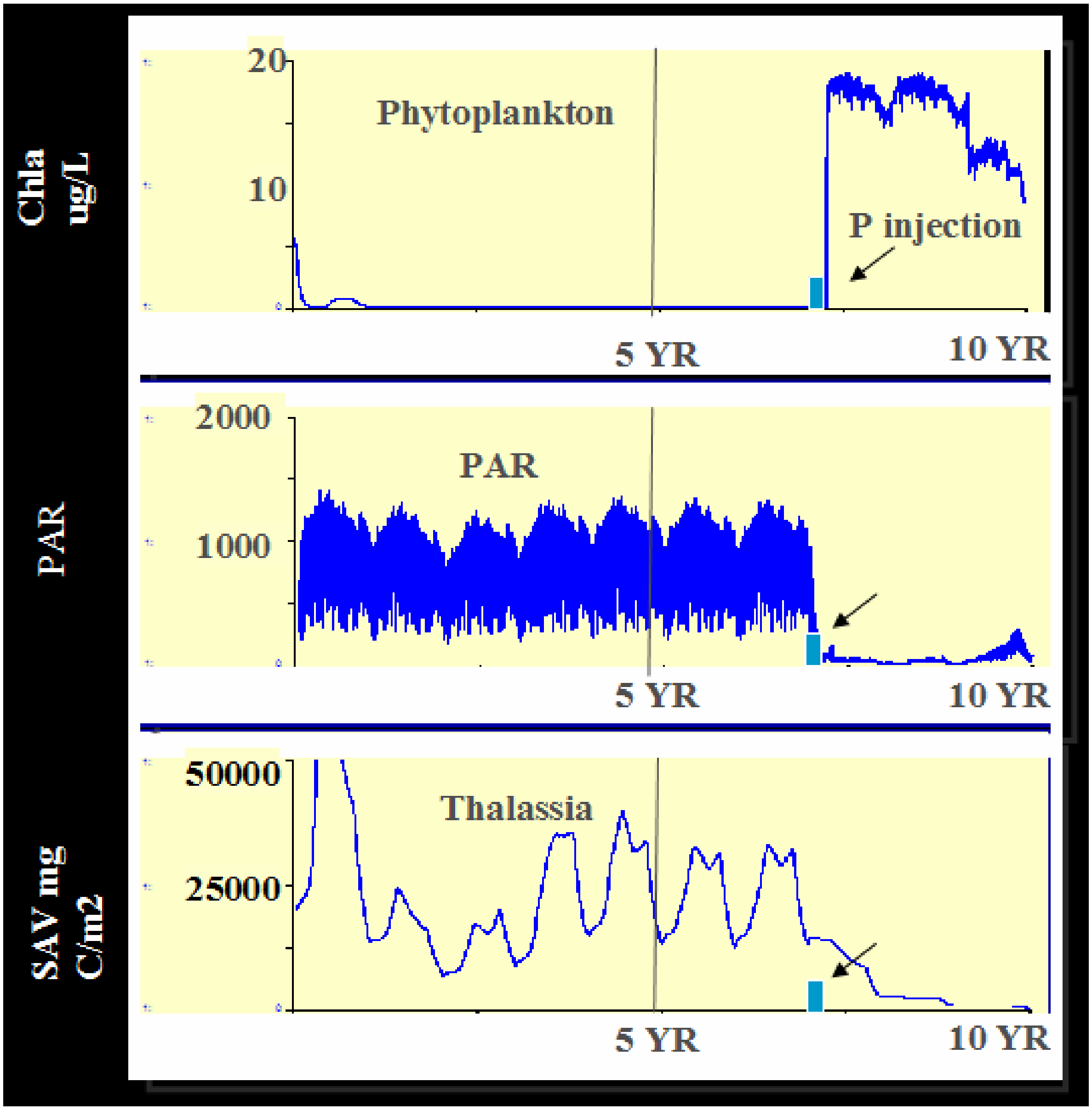


Figure 12-60. Output of seagrass-phytoplankton community model for Florida Bay. After a five-year stabilization period, output for phytoplankton biomass, light at canopy height (middle panel) and seagrass (bottom panel) showed results typical for eastern Florida Bay. With a simulated injection of phosphorus at the beginning of Year 7 over a period of three months, there was sufficient "fuel" to initiate a phytoplankton bloom of similar magnitude to that observed in 2005. The effect of the bloom on light attenuation and seagrass loss is shown. The bloom was reduced to only half within three years.

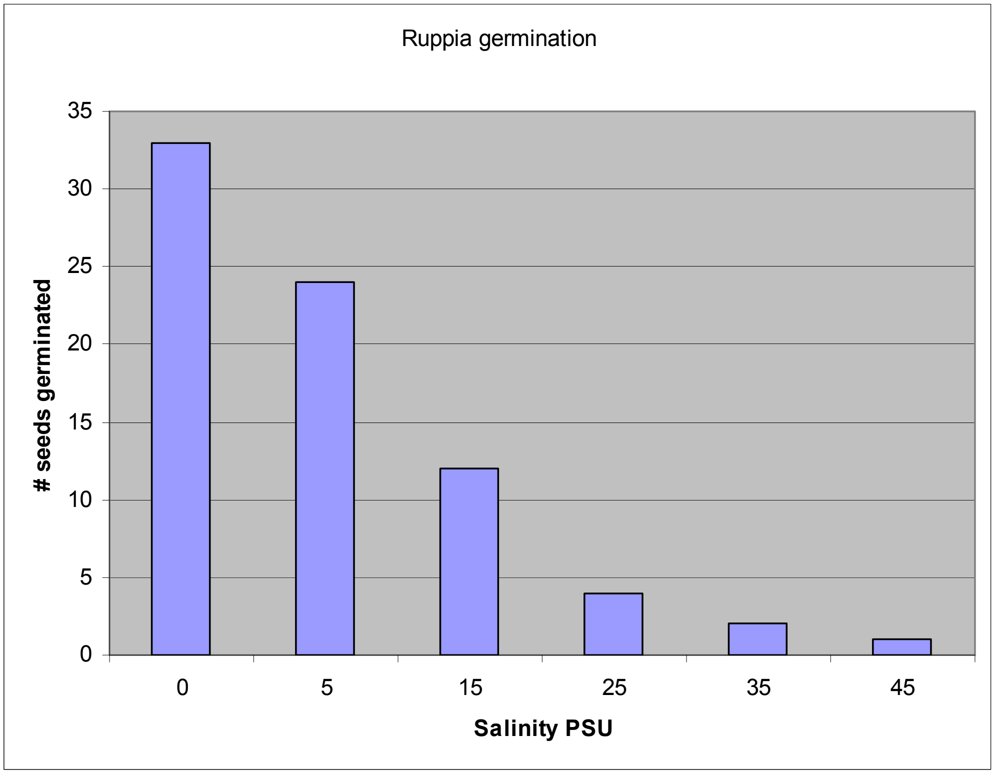
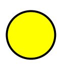
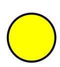
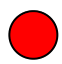
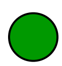
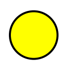
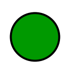


Figure 12-61. Germination frequency of seeds incubated at salinities from 0–45 psu.

Florida Bay Ecosystem Assessment Indicators

A set of indicators of system status and trends has been developed for Florida Bay seagrasses and will be published in the scientific literature as part of a suite of ecological indicators for Florida Bay. The seagrass indicators are based on quantitative monitoring data, enabling a means of rapidly assessing and a standard way of comparing several seagrass parameters related to community health and restoration targets, such as areal expanse and density of beds, species diversity, and target species presence. The current bay-wide assessment reflects improved SAV abundance from WY 2006–WY2007, and a good 10-year trend, although abundance declined within the central and southern areas of the bay (example of central bay indicators in **Table 12-20**). The Target Species Index in the mangrove transition zone is poor, reflecting the absence of widgeon grass in WY2006 and WY2007 while most other areas of the bay show increased diversity. Aggregated index scores show fair status in the transition, central and southern zones, and good status in the northeastern and western zones.

Table 12-20. Example of stoplight indicators for central Florida Bay for WY2007 depicting the combined spatial extent and density scores (upper row) and combined diversity and target species presence scores (lower row).

Zone/Performance Measure	[1]Last Status	[2]Current Status	2-Year Prospects	[2]Current Status	2-Year Prospects
Central Bay					
Abundance	 	 	 	Abundance in Central basins were marked by low scores throughout, based mostly on low density, trending lower in several basins in this zone in recent years. Spatial coverage was generally very good.	Caution is indicated for this area as it is prone to hypersalinity and algal blooms that can reduce SAV cover. Restoration is designed to improve conditions but two years is likely too short a time to manifest positive impacts.
Target Species				Increasing presence of secondary target species (*Halodule*) has improved in this region though a slight reduction in species evenness was noted.	Prospects for continuing improvements in diverse species composition are good even under current conditions.

1. 2006 data
2. 2007 data; all zones for which calculations are made are based on 10 year datasets

Planning for the C-111 Spreader Project

Phase I of 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 Florida Atlantic University. Increased collaboration and contracting with Audubon of Florida is also providing improved understanding of the relationship of hydrologic conditions, SAV, prey base fish, and roseate spoonbill 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 concentrations compared to Everglades wetlands (upstream of the lake region) or Florida Bay (downstream of the lakes region). Therefore, the District's planning for the C-111 Project includes not only studies to document the ecological benefits of the project with regard to restoring more natural flows through Taylor Slough to Florida Bay, but also 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 FDEP in 2011, seeks to improve a scientific basis for the current rule (and potential revision). A minimum flows and levels 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 WY2008. Collaboration with Audubon 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.

Florida Bay and Florida Keys Feasibility Study Evaluations

This CERP project is tasked with evaluating the sufficiency of current CERP plans to meet the needs for Florida Bay restoration. Hydrologic (TIME) and hydrodynamic (EFDC) models have been developed and base runs (current operations and future) have been completed. However, water quality components of the hydrodynamic model have not been fully completed or reviewed by the Interagency Modeling Center (IMC) and may not be available for this feasibility study. Ecological models (for SAV community, juvenile pink shrimp, and juvenile lobster) to evaluate performance measures have been developed and reviewed by the IMC. Delays in TIME/EFDC output and issues regarding water quality evaluations have caused delays in performance-measure and CERP evaluations.

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