Chapter 12: Coastal Ecosystems

Edited by Richard Alleman

SUMMARY

In the *2011 South Florida Environmental Report* (SFER) – *Volume I*, Chapter 12 is organized into Water Year 2010 (WY2010) (May 1, 2009–April 30, 2010) information on coastal ecosystems by region. This new framework facilitates a better focus on the specific estuarine areas where the South Florida Water Management District (SFWMD or District) has expended its work efforts. The purpose of this report is to provide environmental performance results, especially as they relate to District projects and criteria, and report significant findings that relate to the management of water. This chapter also serves as the annual report for the Caloosahatchee River Watershed Protection Plan and the St. Lucie River Watershed Protection Plan in accordance with the Northern Everglades and Estuaries Protection Program (Section 373.4595, Florida Statutes).

The coastal water bodies have been organized into four regions: (1) Northern Estuaries (St. Lucie River Estuary, Southern Indian River Lagoon, Caloosahatchee River Estuary, and Southern Charlotte Harbor; (2) Eastern Estuaries (Loxahatchee River Estuary, Lake Worth Lagoon, and the estuaries along the Intracoastal Waterway in Broward County), (3) Southern Estuaries (Biscayne Bay, the Florida Keys, Florida Bay, and the Ten Thousand Islands Estuary within Everglades National Park, and (4) Western Estuaries (Estero Bay, Naples Bay, Rookery Bay, and Fakahatchee Estuary). Highlights of key results for WY2010 are as follows:

- **Northern Estuaries.** The minimum flow criterion for the North Fork of the St. Lucie Estuary was met, and flows to the Caloosahatchee River Estuary did not fall below the target of 450 cubic feet per second for the first six months of 2010. Nutrient loads to the Caloosahatchee River Estuary were slightly lower in WY2010. Submerged aquatic vegetation increased by nearly 500 acres in Southern Indian River Lagoon since 2007. Live eastern oyster (*Crassostrea virginica*) densities greater than 1,200 per square meter in the Caloosahatchee River Estuary were observed, and densities increased throughout the year.
- **Eastern Estuaries.** For the most part, the minimum flow criterion for the Loxahatchee River was maintained in WY2010. Observed nutrient concentrations in the Loxahatchee River and Estuary in WY2010 were in line with interim targets. Nutrient concentrations in the Lake Worth Lagoon did not increase and declined in the North Fork of the New River Estuary. Some submerged aquatic vegetation recovered from previous lows in the lagoon, and eastern oyster densities increased in WY2010.
- **Southern Estuaries.** Salinity did not exceed 35 practical salinity units more than 5 percent of the time during WY2010 in neither the nearshore of south-central Biscayne Bay nor the Manatee Bay locations monitored and used by the SFWMD as indicators of ecosystem health. Nutrient concentrations were below normal in the nearshore of south-central Biscayne Bay. The observed fish populations along the western shoreline of southern Biscayne Bay remained stable. Freshwater flows into Taylor Slough were above normal in WY2010, as

was the coverage of submerged aquatic vegetation in the transition zone. The minimum flow criterion for Northeast Florida Bay was met for the most part in WY2010.

- **Western Estuaries.** The average size of eastern oysters in the Faka Union Estuary was larger in March 2010 compared to observations in August 2009. Freshwater inflows to Naples Bay from Golden Gate Canal were less variable than in WY2009.

INTRODUCTION

This chapter of the *2011 South Florida Environmental Report* (SFER) – *Volume I* highlights select coastal ecosystems or reports on the general condition of each estuary according to region (**Figure 12-1**). This year's chapter reorganization provides an emphasis on the areas where the South Florida Water Management District (SFWMD or District) has focused its resources on studies, programs, or projects that affect the coastal ecosystems within the region. Most of the projects are described in detail in the 2011 SFER Consolidated Project Report Database available on the District's website at www.sfwmd.gov/SFER under SFER Reports. Key findings are presented where appropriate and, in most cases, reflect District or District-sponsored research and monitoring efforts. However, the SFWMD works closely with other local, state, and federal organizations involved in studying these systems, and findings from these sources are included and duly recognized as well.

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

District strategies aimed at protecting or restoring estuaries include regulations and restoration projects. The freshwater quantity required by a VEC may form the basis for setting Minimum Flows and Levels criteria, establishing Water Reservation criteria, determining preferred flow or salinity envelopes that provide guidance for day-to-day management of freshwater discharges, or setting project performance targets. While each of the coastal systems may have its own specific set of VECs, common to almost all District estuaries are submerged aquatic vegetation (SAV) and eastern oysters (*Crassostrea virginica*). These VECs are routinely monitored in many systems by Restoration Coordination and Verification (RECOVER) as part of the Comprehensive Everglades Restoration Plan (CERP). Similar to previous SFERs, this chapter provides brief summaries on the status of key VECs in several estuaries related to current District priorities.

The Caloosahatchee River and St. Lucie River Watershed Protection Plans (CRWPP and SLRWPP, respectively) have been developed in accordance with the Northern Everglades and

Estuaries Protection Program (NEEPP) [Section 373.4595, Florida Statutes (F.S.)]. The NEEPP requires the District, in collaboration with the Florida Department of Environmental Protection (FDEP) and the Florida Department of Agriculture and Consumer Services (FDACS), and in cooperation with local governments, to develop (1) the Lake Okeechobee Watershed Construction Project Phase II Technical Plan (P2TP), (2) the SLRWPP, and (3) the CRWPP. The SLRWPP and CRWPP were submitted to the Florida legislature in January 2009. The status of these plans is provided in the *Northern Estuaries* section.

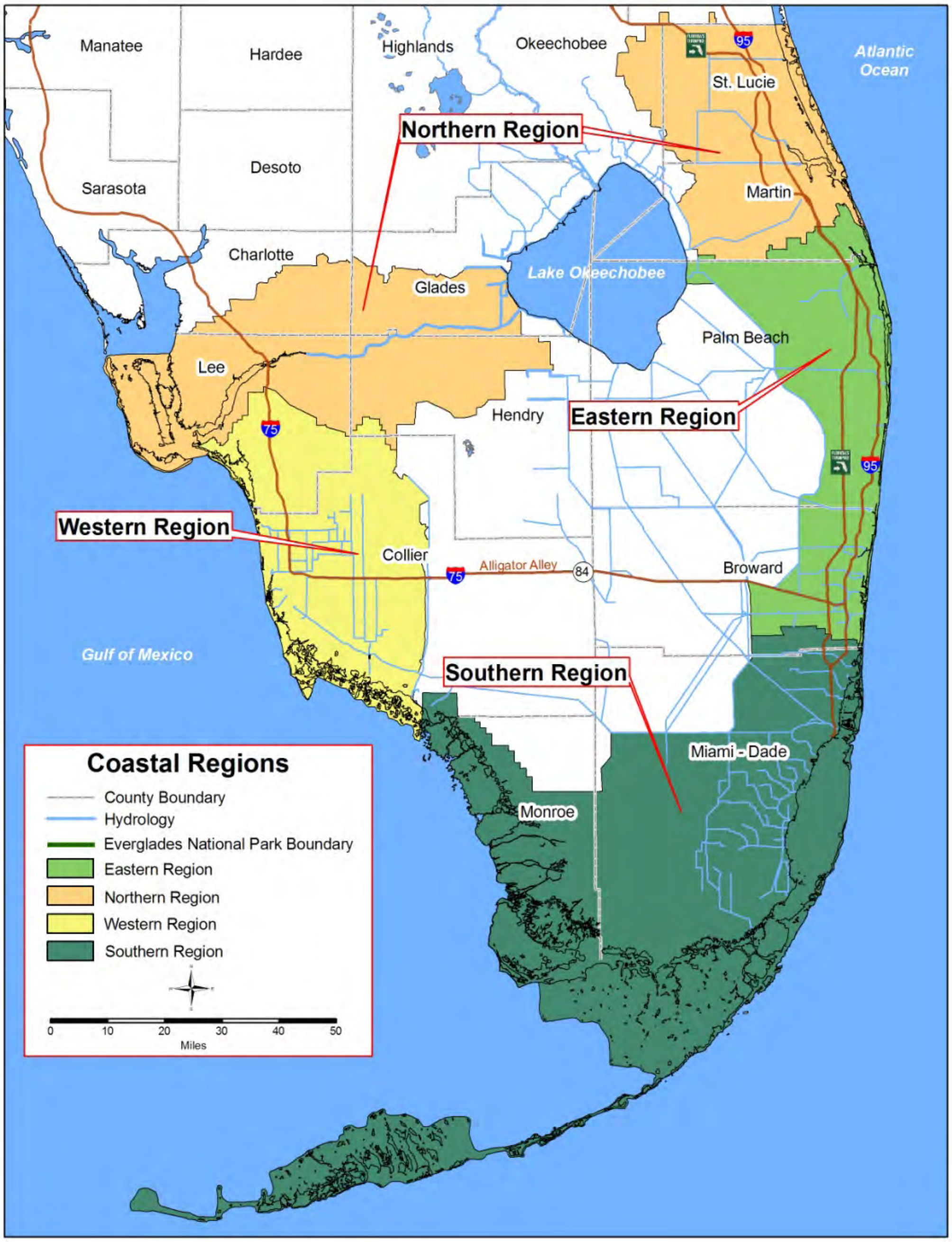

Figure 12-1. Four coastal regions within the South Florida Water Management District (SFWMD or District).

NORTHERN ESTUARIES

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DESCRIPTION OF NORTHERN ESTUARINE SYSTEMS, MAJOR PROJECTS AND ISSUES

The Northern Estuary Region consists of the St. Lucie River Estuary (SLE), Southern Indian River Lagoon (SIRL), the Caloosahatchee River Estuary (CRE), and Southern Charlotte Harbor (**Figure 12-1**). The SLE is a brackish water body on the east-central coast of Florida in Martin and St. Lucie counties, and a primary tributary to the Southern Indian River Lagoon.

The Caloosahatchee River (C-43 canal) is the major source of fresh water to the CRE, which extends about 70 kilometers [(km) or 43 miles] from Lake Okeechobee at Moore Haven (S-77) to the Franklin Lock and Dam (S-79) at Olga. The lock and dam marks the head of the estuary, which empties into San Carlos Bay in the southern portion of the Charlotte Harbor system.

Freshwater flow into these estuaries is a primary concern, particularly when water from Lake Okeechobee is discharged via the St. Lucie and Caloosahatchee rivers to the estuaries to maintain Lake Okeechobee’s regulation schedule. As a result, estuarine salinity often falls below healthy levels. By contrast, freshwater inflows can be so low at times during the dry season that salinity exceeds the levels needed to sustain key estuarine organisms such as tape grass (*Vallisneria americana*). In addition, nutrient enrichment in these estuaries is believed to cause phytoplankton blooms, which may periodically impact submerged aquatic vegetation (SAV) by attenuating down-dwelling light. Mortality of large numbers of phytoplankton may also depress dissolved oxygen (DO) concentrations (SFWMD et al., 2009a, 2009b).

Many of these issues are being addressed by the following District strategies:

- CRWPP and SLRWPP elements, which include a Watershed Construction Project; Watershed Pollutant Control Program, and Research and Water Quality Monitoring Program
- Tracking results associated with the minimum flow criteria for the North Fork of the St. Lucie River Estuary
- Adoption of a Water Reservation rule for the North Fork of the St. Lucie River
- Tracking results associated with the minimum flow criteria for the CRE
- The C-44 (St. Lucie Canal) Reservoir/Stormwater Treatment Area Project
- The C-43 (Caloosahatchee River) West Basin Reservoir Project

NORTHERN EVERGLADES AND ESTUARIES PROTECTION PROGRAM

St. Lucie River and Caloosahatchee River Watershed Protection Plans

The NEEPP (Section 373.4595, F.S.) legislation required the development of watershed protection plans for the three Northern Everglades watersheds: Lake Okeechobee Watershed, Caloosahatchee River Watershed, and St. Lucie River Watershed (**Figure 12-2** and **Figure 12-3**). Accordingly, the SFWMD completed these watershed protection plans in coordination with the

Florida Department of Protection (FDEP) and the Florida Department of Agriculture and Consumer Services (FDACS) (coordinating agencies), and in cooperation with Lee, Martin, and St. Lucie counties. The plans were submitted to the Florida legislature on January 1, 2009. The three main program elements of the watershed protection plans are (1) a Watershed Construction Project that identifies water quality and storage projects to improve hydrology, water quality, and aquatic habitats within the watershed; (2) a Watershed Pollutant Control Program with a multifaceted approach to reducing pollutant loads by improving management of pollutant sources within the watershed; and (3) a Watershed Research and Water Quality Monitoring Program to fill knowledge gaps and provide results about the progress of the programs and the health of the estuaries (**Figure 12-2**). The watershed protection plans build upon existing and planned programs and projects, and consolidate previous restoration efforts into a broader approach focused on restoring the entire Northern Everglades system. The watershed protection plans are currently being implemented (see Chapter 7 of this volume).

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

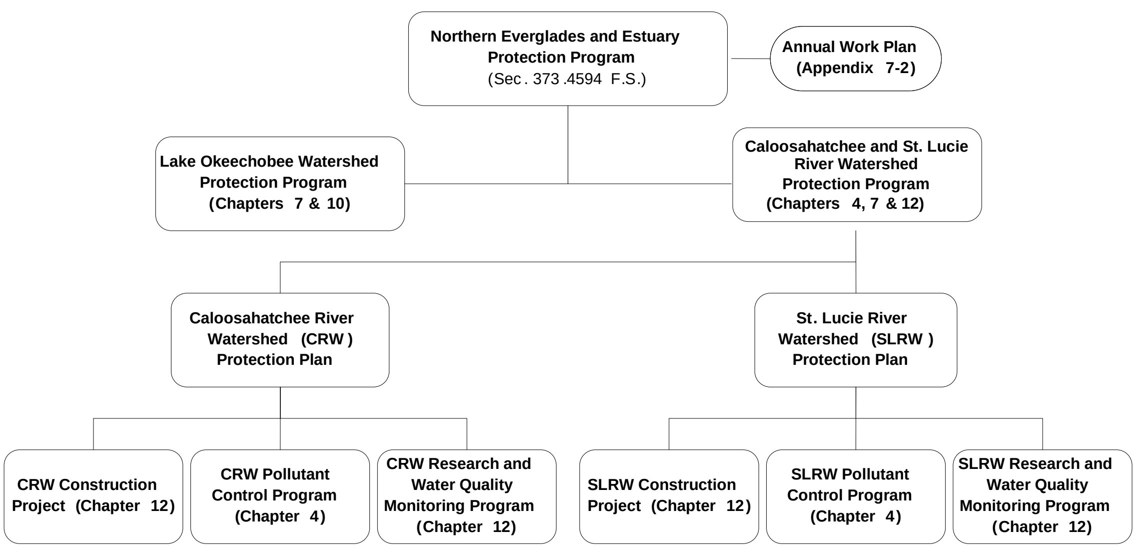

Figure 12-2. The Northern Everglades and Estuaries Protection Program (NEEPP) structure, outlining the Caloosahatchee and St. Lucie River Watershed Protection Program elements and chapters in the *2011 South Florida Environmental Report* (SFER) – *Volume I* where additional information is provided.

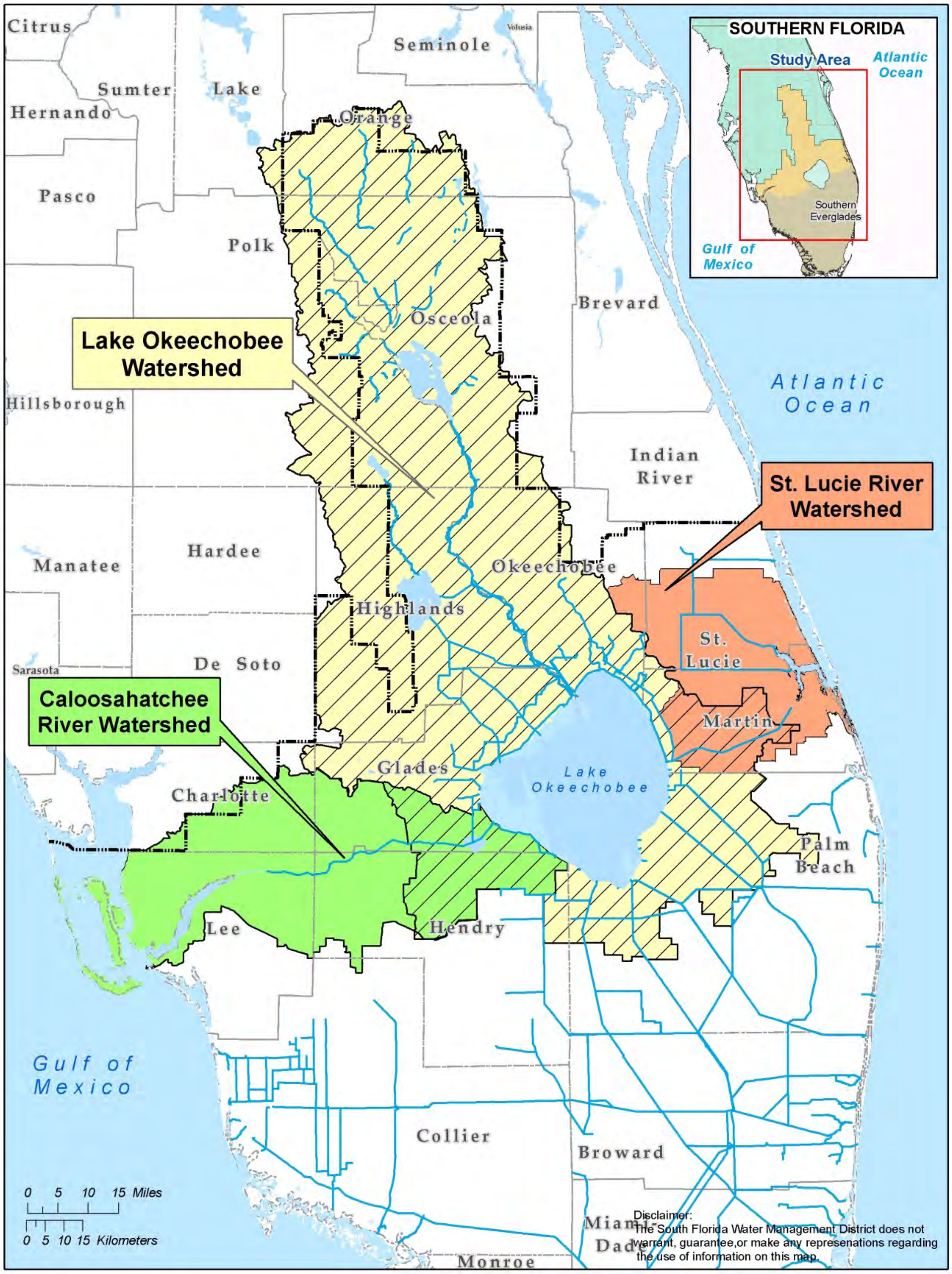

Figure 12-3. The NEEPP area as defined by the Florida legislature.

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

This section constitutes the required annual progress report for the CRWPP and SLRWPP and provides updates on the status of projects and activities being implemented under each plan by the District. Summaries of the conditions of hydrology, water quality, and aquatic habitat in the Caloosahatchee and St. Lucie river watersheds are also provided in the following *St. Lucie River Estuary and Southern Indian River Lagoon* section and *Caloosahatchee River Estuary and Southern Charlotte Harbor* sections. The Annual Work Plan for NEEPP is presented in Appendix 7-2 of this volume. In calendar year (CY) 2011, the coordinating agencies (SFWMD, FDEP, and FDACS) plan to initiate the three-year updates for the CRWPP and SLRWPP, which will be submitted to the Florida legislature in early CY2012.

Watershed Construction Projects

The St. Lucie River Watershed Construction Project includes the CERP Indian River Lagoon – South (IRL-S) Final Integrated Project Implementation Report projects, and an array of local projects. In addition, some local projects are being implemented through a cost-sharing approach using state, District, and Martin County funds.

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

St. Lucie River Watershed Construction Project

The following provides a status update of the four local projects, which aim to improve water quality in the St. Lucie River:

- **Old Palm City Phase 3 Stormwater Quality Improvement Project.** This project's objective is to improve water quality by developing a neighborhood stormwater quality management system. Although land acquisition was completed for all the required lots, a permit issue may potentially delay construction.
- **North River Shores Vacuum Sewer System.** This project provides sanitary sewer service to about 450 single-family and multi-family parcels of land in the North River Shores area. The project, which includes the construction of an underground collection system and a vacuum sewage collection and pumping facility, will enhance water quality in the North Fork of the St. Lucie River by eliminating nutrient loading from septic systems. In addition, the project will route wastewater to the North Wastewater Treatment Plant for conversion to irrigation-quality reclaimed water. Construction plans are complete as well as the required permits. The notice to proceed with construction was issued in March 2010, and construction is on target.

- **Manatee Creek Basin Water Quality Retrofit.** This project provides stormwater quality treatment for 135 of the 833 acres of residential, commercial, and industrial development that discharge into Manatee Pocket. Survey and redesign, as well as Phase II land acquisition, is complete. Phase III project layout has been reconfigured and all essential parcels have been acquired. Construction began in January 2010; however, delays were experienced due to erosion and sediment controls and dewatering for Phase II and III construction.
- **Manatee Pocket Dredging**. This project includes (1) dredging a navigation channel through the pocket measuring up to 10 feet (ft) deep and 100 ft wide, (2) removing accumulated muck in areas and at depths where seagrasses might recruit, and (3) adding signage and buoys. Public participation is ongoing. Permits were obtained from the FDEP and U.S. Army Corps of Engineers (USACE); however, modifications were requested to allow for additional dredging flexibility. The dredge material site was constructed and dredging began in July 2010.

Caloosahatchee River Watershed Construction Project

- **C-43 Water Quality Treatment and Testing Facility.** In September 2007, the District entered into an agreement with Lee County to develop a water quality treatment and testing facility in the Caloosahatchee Basin. Pursuant to the agreement, the District purchased about 1,770 acres to build the project. The Caloosahatchee River Basin Water Quality Treatment and Testing facility is located in Glades County, between State Road 80 and the Caloosahatchee River, about 8 miles east of the City of LaBelle. The purpose of the project is to provide nitrogen treatment, study nitrogen removal methods, and improve the quality of the on-site system. It is anticipated that a full-scale project will include a water quality treatment area consisting of natural system treatment cells and flow-ways, pump stations, hydraulic controls and spillway structures, and other ancillary structures. Several major tasks are complete including cultural resources fieldwork and Phase I and II Environmental Site Assessments, topographic surveys, and an initial conceptual design of the testing facility. Subsequent to the conceptual design, the District conducted a peer review of the test facility design and nitrogen treatment methodology in July 2010. Currently, the District, FDEP, and Lee County are reviewing the draft consolidated report recommendations from the peer-review panel. Prior to the design and construction of the full-scale project, a testing facility will be built to determine the best natural treatment methods for reducing and removing TN.
- **Spanish Creek/Four Corners Environmental Restoration Phase I.** Four Corners is an area in southwestern Florida where the four counties of Charlotte, Glades, Lee, and Hendry meet. The natural surface flow patterns in the region have undergone drastic change due to agricultural and some residential development. Phase I of the project is complete including (1) installation of monitoring wells and staff gauges to obtain initial data relative to existing surface water and groundwater levels within the project area; (2) surveys to obtain cross-sections of County Line ditch and associated infrastructure for use in modeling the existing flows; (3) permit coordination related to gopher tortoise (*Gopherus polyphemus*) relocation; and (4) working with Hendry County to coordinate County Line ditch clearance to improve flow conditions south of CR-78. The District gathered data from monitoring wells through September 2010. Local stakeholders are developing plans for future phases.

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

  Pilot project construction is complete, and influent and effluent data collection began in December 2008. The Quarterly Operational Report for Fourth Quarter, December 11, 2008, through December 10, 2009, provided cumulative results in which the average concentration reduction was about 19 percent for TP and 7 percent for TN. The Powell Creek ATS™ Pilot Final Report was revised and submitted for review on May 26, 2010. Acceptance of the final report and a formal recommendation by Lee County to proceed with a full-scale permanent facility are pending.

Watershed Pollutant Control Program

The Watershed Pollutant Control Program employs multifaceted approaches aimed at reducing pollutant loads. Approaches include the (1) design and deployment of targeted regulations; (2) development and implementation of BMPs; (3) improvement and restoration of hydrologic function of natural and managed systems; and (4) potential utilization of alternative technologies for pollutant reduction, such as cost-effective biologically based, hybrid wetland/chemical, and other innovative nutrient-control technologies.

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

In Fiscal Year 2009 (FY2009) (October 1, 2008–September 30, 2009), the District initiated the development of regulatory nutrient source control programs for each river watershed in response to NEEPP legislation. These programs are intended to establish a regulatory framework requiring the implementation of on-site source controls on all agricultural and non-agricultural lands within each river watershed. The St. Lucie and Caloosahatchee River Regulatory Nutrient Source Control programs will be implemented in four phases, (1) water quality monitoring, (2) data management and assessment, (3) BMP effectiveness performance measure development, (4) rulemaking and rule implementation.

Phases 1 through 3 consist of assessing the suitability of the existing water quality monitoring program and historical data for measuring the performance of a regulatory source control program, and developing performance measures to set benchmarks for evaluating the effectiveness of the collective source control programs. Phase 4 consists of amending Chapter 40E-61, Florida Administrative Code (F.A.C.), to include the St. Lucie and Caloosahatchee river watershed regulatory nutrient source control programs.

During Water Year 2010 (WY2010) (May 1, 2009–April 30, 2010), the District initiated Phases 1, 2, and 3 of the plan for development of river watershed regulatory nutrient source control programs. The District also initiated technical data evaluation and analyses to support future source control program development and completed action plans. The District is performing an inventory and evaluation of existing water quality data, which is slated for completion by February 2011. The rule development timeline is dependent on these findings. Chapter 4 of this volume provides more information about these source control efforts.

Research and Water Quality Monitoring Program

The CRWPP and SLRWPP contain Research and Water Quality Monitoring plans to identify information that will reduce key uncertainties in the pollutant load targets, freshwater inflow and salinity envelope criteria, and optimization of operational protocols. Studies and projects for each river watershed protection plan were described in detail in the 2010 SFER – Volume I, Chapter 12. The following provides a status update for WY2010.

St. Lucie Estuary Research and Monitoring Program Status

Estuarine Nutrient Budget Project. The exchange of nutrients between the sediments and water column is an important term in a nutrient budget. Nutrients stored in sediments represent a potential internal source that may mask anticipated improvements from reductions in external point and non-point sources. During the WY2008 dry season, about 50 sediment cores and overlying water samples were collected and incubated under light and temperature conditions representative of field conditions. The samples were taken from the area between the C-24 canal in the North Fork to the Palm City Bridge in the South Fork through the mid-estuary around Hell’s Gate to the estuarine mouth. Estimates of internal loadings [metric ton (mt) nitrogen (N) or phosphorus (P)/season; 1 mt = 1 x 10^6 grams (g)] to the entire estuary could be calculated using a spatially heterogeneous approach to interpolate observed benthic exchange rates. Estimates of daily exchanges of dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) under light and dark conditions were summed and multiplied by 180 to derive the seasonal estimates. Internal loads from the sediments were compared to nutrient loads supplied by surface waters through structures (S-48 + S-49 + S-80). Surface flow calculations assumed DIN = 0.2*(TN load) and DIP = 0.65*(TP load), with 33 percent of the annual loading assumed to occur during the dry season.

This study showed that internal loading of nitrogen through sediment efflux to the water column was 4.5 times surface loading to the SLE. Benthic DIN flux is a critical biogeochemical process as net exchanges could replace the water column DIN pool every 1.8 days, or about twice as fast as surface loading. This study also demonstrated the critical influence of light on exchange of nutrients across the sediment water interface. While 25 percent of surface light at the bottom is required for sediments to remove nutrients from the water, greater than 90 percent of the SLE benthos received less than 10 percent of surface light.

Dissolved Oxygen Dynamics Project. In WY2009, the spatial and temporal variability of bottom DO was examined using existing long-term monthly water quality monitoring measurements from 1991–2007, weekly samples collected in 2000, and high frequency (once per 30 minutes) samples collected in 2005. Major findings from this study are summarized in the 2010 SFER – Volume I, Chapter 12.

Low Salinity Zone Project. During WY2010, efforts focused on the analysis of previously collected data to support the St. Lucie River Water Reservation (SFWMD, 2009). Additional field efforts were not conducted for this project in WY2010.

Integrated Modeling Framework. Substantial efforts have been made to improve performance of the St. Lucie Estuary water quality model, which is one of the District's few comprehensive modeling efforts toward developing an integrated, sophisticated modeling system including hydrodynamic/salinity, sediment transport, and water quality modules. Tasks included:

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

Caloosahatchee Estuary Research and Monitoring Program Status

Estuarine Nutrient Budget Project. During the WY2008 dry season, about 50 sediment cores and overlying water samples were collected and incubated under light and temperature conditions representative of field conditions. The samples were taken from the area between the Franklin Lock and Dam and Shell Point. Estimates of internal loadings (mt N or P/season; 1 mt = 1 x 10^6 g) to the entire estuary could be calculated using a spatially heterogeneous approach to interpolate observed benthic exchange rates. Estimates of daily exchanges of DIN and DIP under light and dark conditions were summed and multiplied by 180 to derive the seasonal estimates. Internal loads from the sediments were compared to nutrient loads supplied by surface waters (S-79 for the Caloosahatchee). Surface flow calculations assumed DIN = 0.2*(TN load) and DIP = 0.65*(TP load) with 33 percent of the annual loading assumed to occur during the dry season.

This study showed that internal loading of nitrogen through sediment efflux to the water column was two times surface loading to the Caloosahatchee River Estuary (CRE). Benthic DIN flux is a critical biogeochemical process as net exchanges could replace the water column DIN pool every 1.8–3.8 days or about twice as fast as surface loading. This study also demonstrated the critical influence of light on the exchange of nutrients across the sediment water interface. When more than 25 percent of the surface light reached the bottom, sediments absorbed rather than released nutrients.

Dissolved Oxygen Dynamics Project. Continuous measurements of DO were taken at three sites in the Caloosahatchee Estuary from February through September 2008. One site was in the upper estuary, an area normally occupied by tape grass, and two sites were located in shoal grass (*Halodule wrightii*) beds in the more marine-oriented lower estuary. Data will be assessed during FY2011 to determine if an analysis is feasible.

Low Salinity Zone Project. Sampling was completed in WY2010. A preliminary data analysis and interpretation report completed in March 2010 focused on the effects of freshwater discharge on the distribution and abundance of planktonic organisms in the Caloosahatchee Estuary (Tolley et al., 2010). A final report was received in CY2010. The preliminary analysis indicated that:

- At low freshwater inflows during the dry season, juvenile bay anchovy (*Anchoa mitchilli*) and their prey, *Americamysis almyra*, are blocked from moving farther upstream by the Franklin Lock and Dam (S-79 structure). By obstructing movement upstream, the lock and dam truncates their upstream distribution, confining them to a narrow area and compressing their habitat. Habitat compression can result in increased predation and competition.

- At low dry season flows, many organisms moved up into the narrow portion of the estuary upstream of the I-75 bridge. This movement constitutes a second source of habitat compression.
- Gelatinous predators can negatively impact fish populations by feeding directly on eggs and larvae or competing with larvae for zooplankton prey. During the dry season, two gelatinous predators (a jellyfish, *Clytia*, and a comb jelly, *Mnemiopsis*) moved upstream where estuarine zooplankton also concentrated.

The analysis leads to the preliminary conclusion that during the dry season, ichthyoplankton, their zooplankton prey, and their potential predators and competitors may become concentrated in the narrow reaches of the upper estuary downstream of S-79. This may expose larval fish to increased competition and predation. Since the S-79 structure cannot be modified to allow additional space for animals without compromising salinity control in the upper basin, additional freshwater flow may be needed during these times.

Light Attenuation Project in San Carlos Bay. A resource-based method (Corbett & Hale, 2006) is being used to establish nutrient TMDLs in the Caloosahatchee Estuary. In this study, nutrient load reductions are based on limiting phytoplankton production to achieve water clarity in San Carlos Bay, allowing enough light penetration for seagrasses to grow to a depth of 2.2 meters (m).

Previous research has shown that colored dissolved organic matter (CDOM), turbidity, and phytoplankton [measured by chlorophyll *a* (Chl*a*)] are the major contributors to light attenuation in San Carlos Bay (Dixon and Kirkpatrick, 1999; Doering et al., 2006). Because nutrient load reductions strongly affect the concentration of Chl*a*, any significant improvement in water clarity through load reduction may only occur when phytoplankton density is the major attenuator of light rather than CDOM or suspended sediment.

The purpose of this study is to determine (1) the relative contribution of these parameters to light attenuation, and (2) how their concentrations and relative contributions vary with freshwater inflow. Sampling trips were conducted in June, August, September, and December 2009 and in February and April 2010.

Results indicate that, during the dry season, the concentration of CDOM is primarily controlled by the mixing of fresh and salt water and, during the wet season, the concentration of CDOM is reduced by photolysis. No bacterial degradation of CDOM was observed. Sufficient data were gathered from this study to begin the modeling process.

Integrated Modeling Framework. During WY2009, work began on formulating a watershed model (WaSH) for the Caloosahatchee Tidal Basin located west of the Franklin Lock and Dam. The tidal basin contributes about 15 percent of the total surface water inflow to the Caloosahatchee Estuary, but this is only a rough estimate. In WY2010, efforts focused on including recently collected inflow data for several tributaries in the tidal basin. In addition, the CH3D salinity/hydrodynamic model was recalibrated and can now simulate a full, 41-year period of record (POR) (1965–2005).

ECOSYSTEM STATUS

St. Lucie River Estuary and Southern Indian River Lagoon

Most of the St. Lucie River Watershed drains into the North and South Forks [6.4 square miles, (sq mi) or 16.6 square kilometers (km^2)]. The North and South Forks converge at the Roosevelt Bridge in Stuart, FL, and flow into the middle estuary (4.7 sq mi; 12.2 km^2) that extends east for about 5 miles [8 kilometers (km)] to the Southern Indian Lagoon (SIRL) and the Atlantic Ocean at the St. Lucie Inlet (**Figure 12-4**).

Historically, the SLE was a freshwater system exposed to ocean waters only when large storms opened ephemeral passes in the protective barrier islands. In 1892, however, the St. Lucie Inlet was opened, and has been maintained to provide a connection with ocean waters. The SLE is now a partially mixed micro-tidal estuary with a typical tidal range of 0.20 m and the dominant tidal constituent being M2 (= 12.42 h). Depending on the freshwater discharge, the residence time of the SLE was estimated to range from days to months (Ji et al., 2007).

To accommodate population growth and coastal development, the SLE Watershed has also been highly altered from a system of natural sloughs and wetlands into a complex of drainage canals. To control water levels in Lake Okeechobee, the South Fork of the estuary was connected to the lake in 1924. Between 1935 and 1960, drainage in the watershed was enhanced by dredging and channelizing the North Fork Narrows and constructing the C-23 and C-24 canals. These alterations have dramatically changed the quantity, quality, timing, and distribution of water flows to the estuary, exerting significant stresses on riverine and estuarine resources. For example, inflows can be excessive in the wet season. Periodic high-volume water releases from Lake Okeechobee or extreme runoff from the developed watershed can turn the estuary entirely fresh. Such conditions can last for days to months, causing considerable negative impacts. These changes in flow, and resultant variation in salinity and water quality, have degraded estuarine resources, such as SAV, oyster communities, and fisheries.

To protect and restore these resources, a Minimum Flows and Levels (MFLs) rule for the North Fork of the St. Lucie Estuary was established in 2002 (SFWMD, 2002). The minimum flow rule states that monthly average inflows should not fall below 28 cubic feet per second (cfs) [0.8 cubic meters per second (m^3/s)] for two consecutive months. Inflows lower than this threshold for two consecutive months would be considered an exceedance. The intent of this MFL rule is to protect the low salinity nursery zone in the North Fork of the St. Lucie River. To protect oyster beds in the middle estuary, a flow envelope was developed as part of the CERP Indian River Lagoon – South Project (RECOVER, 2007). Based on developed relationships between inflows and estuary salinity, preferred monthly average inflows from the watershed, groundwater, or from Lake Okeechobee should range from 350–2,000 cfs (~10–56 m^3/s). These flows will maintain salinity in the range of 8–25 practical salinity units (psu) at the Roosevelt Bridge (**Figure 12-4**).

To measure the health of the SLE and SIRL, and to assess effects of past and ongoing management and restoration efforts, the SFWMD has maintained a monitoring program since the early 1990s. Several parameters are surveyed on a monthly or bimonthly basis (**Figure 12-4**). These include physical and chemical parameters, such as salinity, freshwater inputs, nutrients, and abundances, as well as distributions of VECs such as SAV, the eastern oyster, and floodplain vegetation. The following sections summarize the ecosystem's overall status in WY2010, including hydrology, water quality, and aquatic habitats, using several key water quality indicators and VECs. Comparisons to WY2009 conditions and long-term averages are also made.

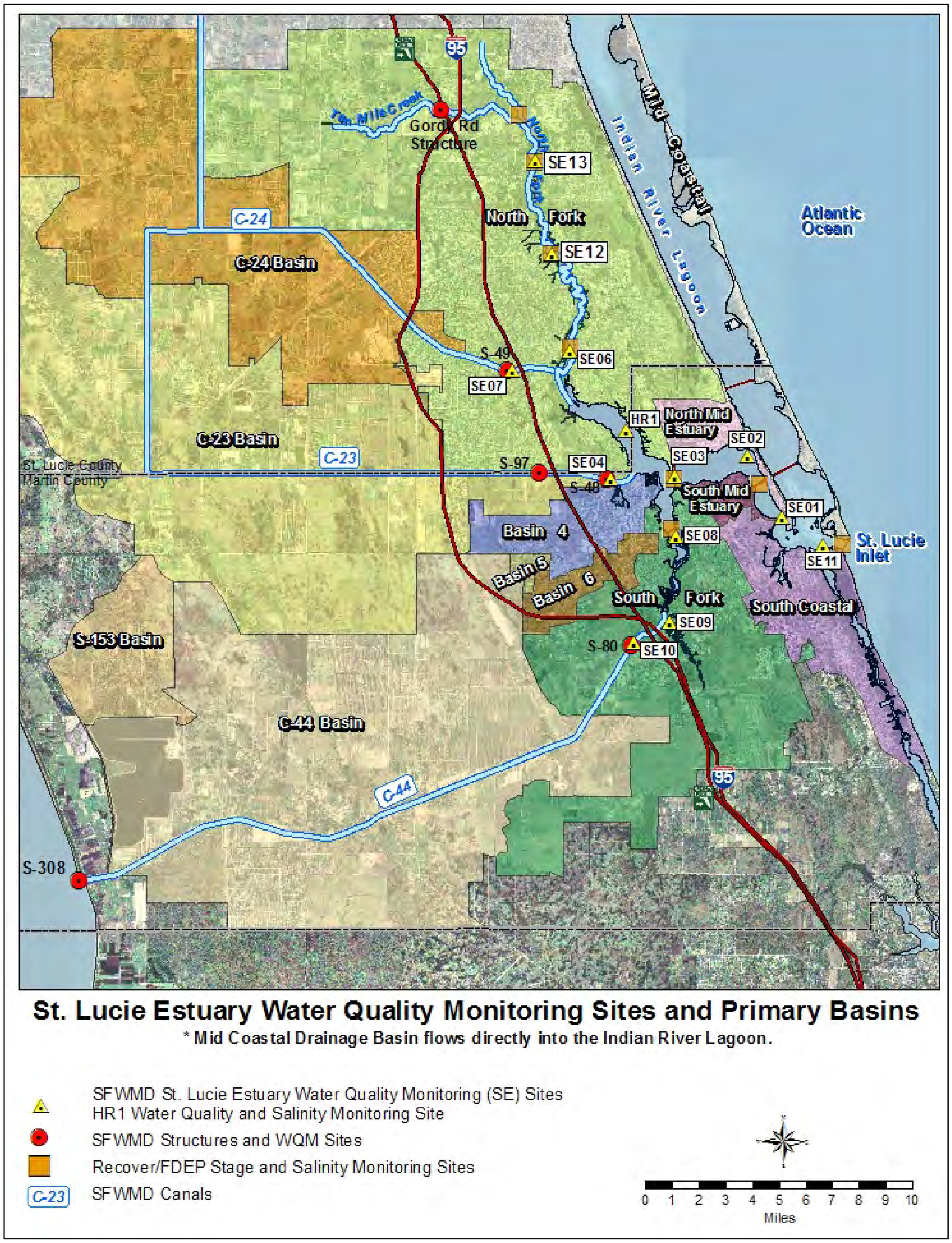

Figure 12-4. Structures and monitoring sites in the St. Lucie Estuary (SLE).

Salinity and Freshwater Inflows

Annual total freshwater inflow to the SLE in WY2010 was nearly the same as in WY2009 [approximately (~) 500×10^6 m^3 or ~ 400,000 acre-feet (ac-ft)], and in both water years, the total freshwater inflow was lower than the long-term average (**Table 12-1**). However, the flow rates in WY2009 and WY2010 show markedly different monthly distributions. In WY2009, almost all of the annual flow occurred during the wet season (**Figure 12-5**, panel A), which was dominated by watershed runoff from Tropical Storm Fay in August 2008 and ensuing flood control releases from Lake Okeechobee (**Figure 12-5**). By contrast, in WY2010, wet season flows were lower than in WY2009, but dry season flows were higher because of El Niño conditions. While discharge from Lake Okeechobee was below the long-term average during these two water years, discharge during WY2010 was less than half of that in WY2009 (**Table 12-1**).

Salinity responded to the freshwater inflows. The lower salinity at Roosevelt Bridge observed in August WY2009 and August WY2010 (**Figure 12-5**) coincided with the highest wet season flow rates. In WY2009, higher flows during the wet season resulted in lower salinity farther down the estuary at sites near the inlet. In WY2010, the lower salinity observed during the dry season corresponded to higher freshwater discharges. Given the proposed salinity envelope in the main estuary of 8–25 psu, it is likely that salinity in the SLE created unfavorable conditions for certain VECs in the upper and middle estuary, especially during the WY2010 dry season.

The MFL rule for the North Fork of the St. Lucie Estuary was met in WY2010. The flow rate did not fall 28 cfs (0.8 m^3/s) in any month (**Figure 12-6**). Thus, it supported the targeted oligohaline zone (0.5–5 psu) in the North Fork.

Table 12-1. Annual summary of estimated freshwater flows and nutrient loads to the SLE from gauged structures S-80, S-49, S-48, and S-308 (Lake Okeechobee) during Water Years 1992–2010 (WY1992–WY2010) (May 1, 1991–April 30, 2010).

Water Year	Total Inflow (1,000 m^3)	Inflow from LO (1,000 m^3)	Total TP (mt)	TP from LO (mt)	Total TN (mt)	TN from LO (mt)
1992–2008	886[1]	362[1]	234[1]	59[1]	1484[1]	616[1]
2009	517	126	234	23	891	221
2010	496	50	142	7.6	761	81

[1]Mean values

LO = Lake Okeechobee

m^3 = cubic meter

mt = metric ton

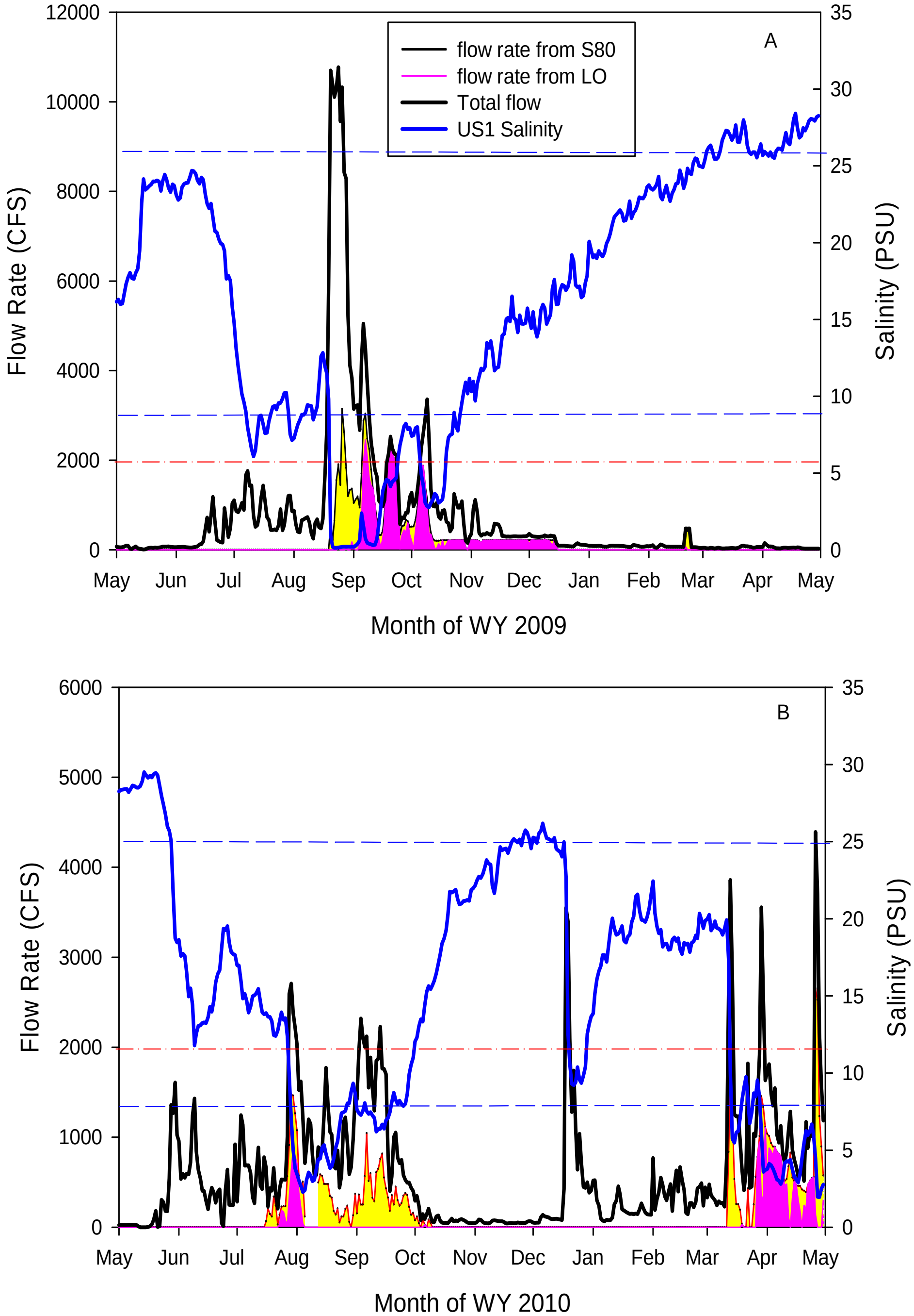

Figure 12-5. Total daily canal flows (cubic feet per second or cfs) (at structures S-80, S-48, S-49, and Gordy Road) and from Lake Okeechobee (S-308 structure) (see **Figure 12-4**). The blue solid line is surface salinity (~ 1.0 m depth, psu) at site US1 in (A) Water Year 2009 (WY2009) (May 1, 2008–April 30, 2009), and (B) Water Year 2010 (WY2010) (May 1, 2009–April 30, 2010), respectively. The blue-dashed lines represent the salinity envelope (8–25 psu) at US1, and the red dashed-and-dotted line represents a target flow rate of 2,000 cfs. Flow rates in the C-44 canal from Lake Okeechobee are depicted in the pink plot and from S-80 in the yellow plot.

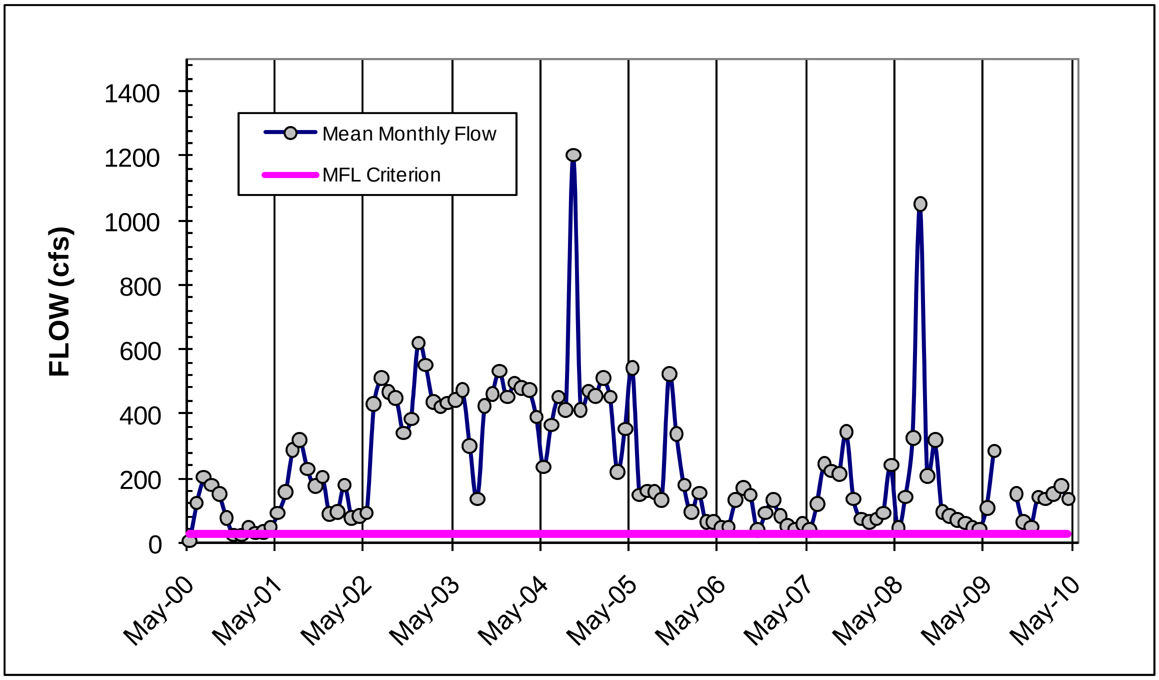

Figure 12-6. Estimated average monthly freshwater flow into the North Fork from the Gordy Road structure compared to the minimum flow criterion [28 cfs or 0.8 cubic meters per second (m^3/s), pink line]. An exceedance occurs when freshwater flow falls below 28 cfs for two consecutive months.

Nutrients

Total nitrogen and total phosphorus loads decreased in WY2010 compared to TN and TP loads in WY2009, with loads varying according to flow rates. In WY2010, TN and TP loads were generally higher throughout the wet season, but increased during the dry season in March and April 2010 when flows increased. A correlation between flows and loads can be made, because flows account for more than 80 percent variation in both TN and TP loads (Wan et al., 2003). However, the reduction in TP load was much greater compared to the freshwater inflow changes, (up to a 40 percent reduction of TP versus a 4 percent reduction of fresh water), resulting in a much lower flow-weighted mean (FWM) TP concentration in WY2010 [0.29 milligrams per liter (mg/L)] than in WY2009 (0.45 mg/L). No such large reduction was observed in TN loads between these two years. The differences between TP and TN loads relative to flow are related to seasonal changes in TN and TP concentrations from the canal discharges (RECOVER, 2010). TP concentrations tend to vary positively with increased flow rates, but TN concentrations tend to vary little regardless of inflow rates. Overall, TN and TP loads in WY2010 were below the long-term average.

Water quality in the SLE shows high spatial and temporal variation. To represent the water quality in the SLE, selected parameters from four segments — salinity, TP, TN, DIN, DIP, Chl*a*, and bottom DO — were summarized. The segments are located at the inlet (SE11); main estuary (SE01, SE02, and SE03); North Fork (SE04, HR1, SE06, and SE07); and South Fork (SE08, SE09, SE10) (**Figure 12-4**). In each segment, one site was chosen to represent water quality conditions in WY2009 and WY2010 and mean conditions during the POR (WY1997–WY2008). Sites were selected based on their location relative to the segments (e.g., HR1 is located the middle of the North Fork) and salinity gradients from the inlet to the upper estuaries. **Table 12-2** shows the statistical summaries of the selected parameters over the three time periods.

To further illustrate the changes of these parameters relative to long-term baselines, **Figures 12-7** and **12-8** show the monthly values of several parameters in the North Fork (HR1), middle estuary (SE03), and inlet (SE11) for WY2009 and WY2010.

In WY2010, a phytoplankton bloom occurred in June and July in the North Fork and middle estuaries (**Figures 12-7** and **12-8** and **Table 12-2**). Results from a non-parametric Mann-Whitney test indicated that the Chl*a* concentration was significantly higher ($p < 0.05$) at HR1 in WY2010 than in WY2009. The increase in Chl*a* coincided with significantly higher TN and DIN concentrations at this station. Overall, no significant changes were observed in TP and DIP at the selected sites. At SE11, where tidal flushing is a major driver, nutrients and chlorophyll concentrations ($p < 0.05$) have steadily decreased since the POR. Although annual nutrient loads were generally lower in WY2010 than in WY2009 (**Table 12-1**), annual maxima and medians in nutrient and chlorophyll concentrations did not reflect any differences in loading.

Corresponding with increased chlorophyll concentrations in the North Fork and middle estuary, lower bottom DO values were observed that usually occur within a lag time of one month. A close examination of water column stratification showed that the low values appear primarily as a result of preceding phytoplankton blooms, because there were no large changes in stratification conditions during the period of lower bottom DO in WY2010. While this relationship is evident in the upper and middle estuary, it does not seem to hold true near the inlet. Because of large variability in bottom DO concentrations, no statistically significant changes in DO were observed between WY2009 and WY2010 (**Table 12-2**).

Table 12-2. Statistical summary of selected water quality parameters in WY2009 and WY2010 and mean conditions from WY1997–WY2008 in the South Fork (SE09), North Fork (HR1), middle estuary (SE03), and mouth (SE11).

Site	TN (mg/L)			DIN (mg/L)			TP (mg/L)			OP (mg/L)			Chla (µg/L)			Bottom DO (mg/L)		
SE09	97-08	2009	2010	97-08	2009	2010	97-08	2009	2010	97-08	2009	2010	97-08	2009	2010	97-08	2009	2010
mean	1.22	1.05	1.07	0.22	0.14	0.18	0.193	0.154	0.184	0.114	0.082	0.129	12.13	12.83	12.17	5.78	5.57	4.77
median	1.13	1.03	1.06	0.17	0.17	0.18	0.173	0.152	0.202	0.099	0.073	0.130*	9.00	12.00	6.00	6.10	5.52	4.87
25th perc.	0.91	0.86	0.87	0.06	0.04	0.08	0.144	0.118	0.160	0.070	0.067	0.116	4.10	9.00	4.00	4.51	4.66	4.39
75th perc.	1.35	1.30	1.27	0.30	0.24	0.30	0.209	0.206	0.216	0.143	0.109	0.159	17.00	20.00	19.00	7.10	6.62	6.62
HR1																		
mean	1.02	0.90	0.98	0.12	0.08	0.12	0.225	0.183	0.225	0.167	0.130	0.166	12.15	8.00	17.33	5.37	5.66	5.01
median	0.95*	0.71	0.91*	0.06	0.02	0.12*	0.191	0.159	0.213	0.144	0.107	0.166	9.90	8.00	14.00*	5.70	6.21	5.79
25th perc.	0.74	0.55	0.65	0.02	0.01	0.01	0.143	0.132	0.149	0.092	0.100	0.114	5.80	4.00	6.00	4.00	4.22	4.19
75th perc.	1.25	1.06	1.32	0.22	0.14	0.23	0.270	0.242	0.284	0.210	0.179	0.216	13.70	11.00	22.00	6.69	6.83	6.72
SE03																		
mean	1.04	0.79	0.98	0.18	0.09	0.13	0.199	0.157	0.186	0.139	0.101	0.132	9.44	6.86	14.75	5.70	6.12	5.38
median	0.99	0.67	0.98	0.13	0.05	0.12	0.162	0.129	0.175	0.114	0.087	0.120	6.70	6.00	8.00	5.73	6.33	5.74
25th perc.	0.74	0.59	0.57	0.05	0.02	0.03	0.127	0.112	0.134	0.079	0.068	0.103	4.50	5.00	4.00	4.64	5.20	4.41
75th perc.	1.32	1.05	1.32	0.29	0.15	0.23	0.236	0.217	0.270	0.179	0.154	0.179	11.10	8.00	16.00	6.91	6.86	6.22
SE11																		
mean	0.67	0.35	0.18	0.10	0.06	0.01	0.078	0.049	0.027	0.049	0.027	0.012	3.89	2.25	2.50	6.32	6.85	6.62
median	0.64*	0.16	0.14	0.05*	0.01	0.01	0.048*	0.019	0.017	0.027*	0.006	0.006	3.00*	2.00	2.00	6.33	6.81	6.74
25th perc.	0.36	0.13	0.12	0.02	0.01	0.01	0.034	0.010	0.015	0.012	0.002	0.004	2.00	0.50	1.00	5.71	6.39	6.09
75th perc.	0.92	0.49	0.19	0.13	0.06	0.02	0.091	0.076	0.040	0.067	0.040	0.015	4.20	4.00	3.00	6.86	7.78	7.39

* significance at $p < 0.05$
Bottom DO – bottom dissolved oxygen
Chl*a* – chlorophyll *a*
DIN – dissolved inorganic nitrogen
mg/L – milligrams per liter
µg/L – micrograms per liter
OP – orthophosphate
TN – total nitrogen
TP – total phosphorus

(A) **(B)**

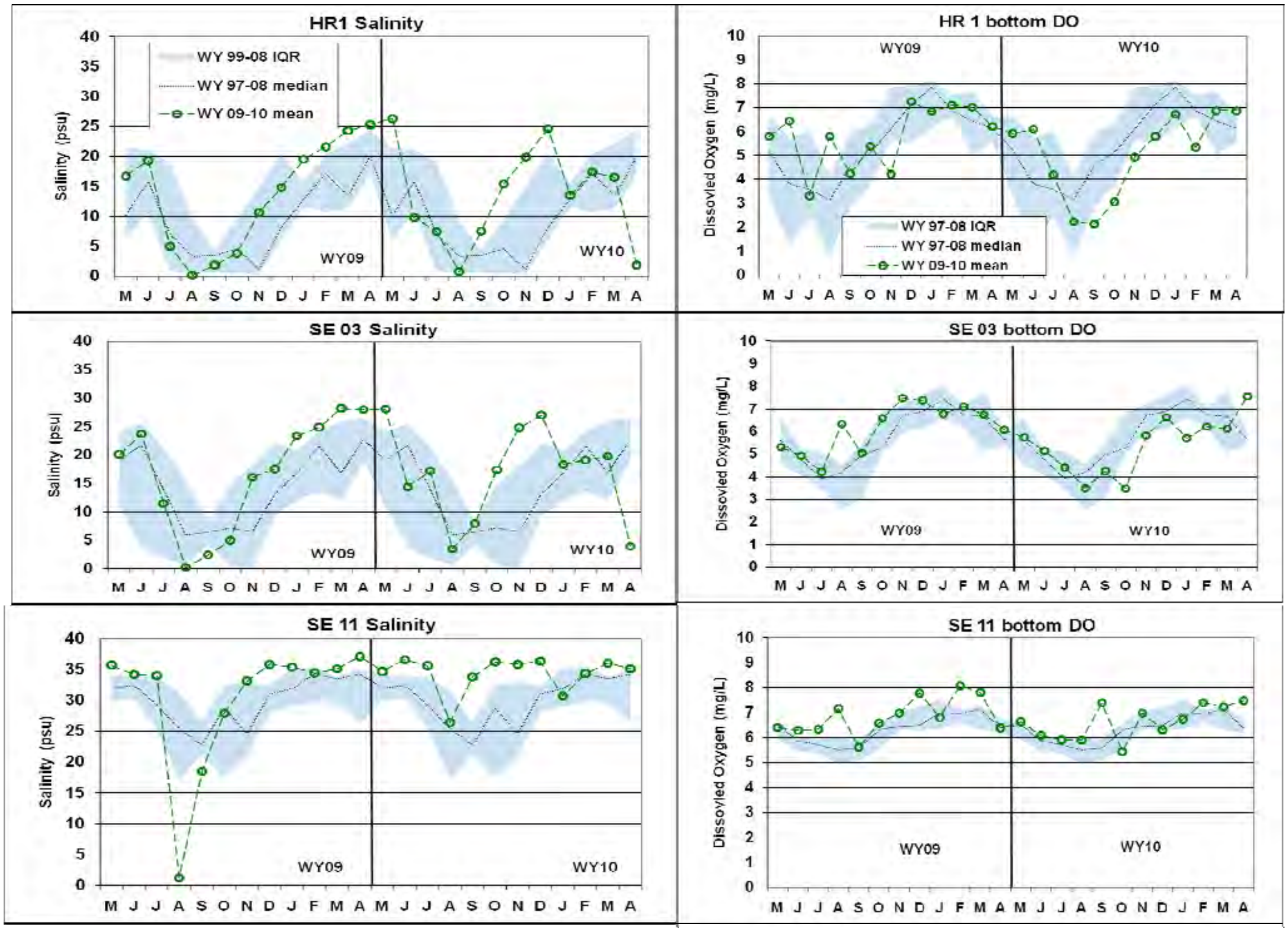

Figure 12-7. Monthly mean (A) salinity and (B) bottom DO in the North Fork (at HR1), middle estuary (SE03), and inlet (at SE11) during WY2009 and WY2010 compared to monthly median and interquartile range (IQR) for WY1997–WY2008.

(A) **(B)** **(C)**

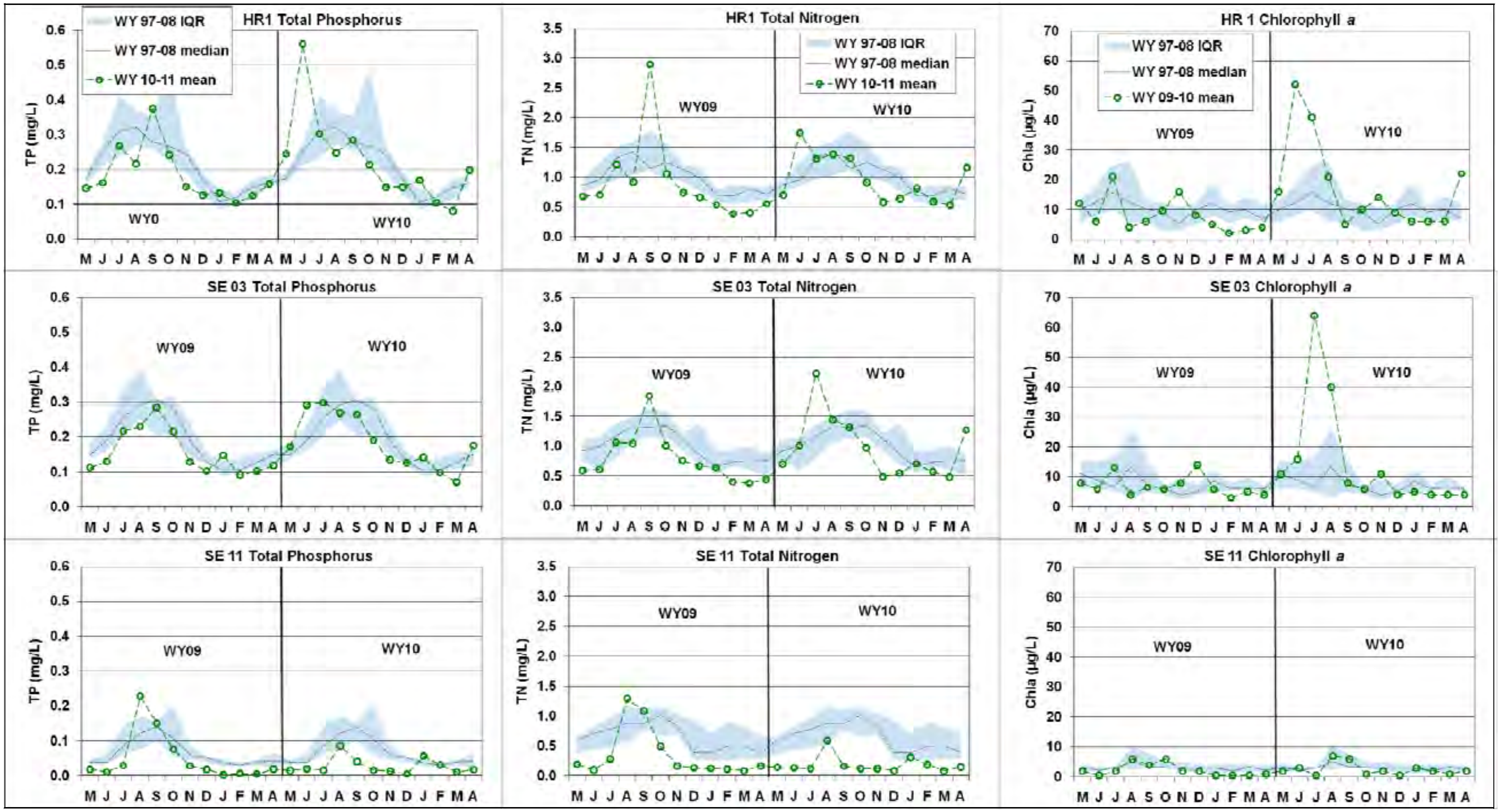

Figure 12-8. Monthly mean (A) total phosphorus (TP), (B) total nitrogen (TN), and (C) chlorophyll *a* (Chl*a*) in the North Fork (at HR1), middle estuary (SE03), and inlet (at SE11) during WY2009 and WY2010 compared to the long-term monthly median and IQR for WY1997–WY2008.

Submerged Aquatic Vegetation

Seagrasses, also described as submerged aquatic vegetation or SAV, are considered indicators of ecosystem health. Submerged aquatic vegetation and macroalgae mapping and monitoring data provide valuable information for assessing the health of an estuary, and for making water management decisions regarding the impacts of freshwater releases on marine resources (Doering et al., 2002; Thayer et al., 1984; Tomasko et al., 1996). SAV and macroalgae 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 or quadrats). The map data provide an estuary-wide picture of seagrass and macroalgae distribution, and facilitates evaluation of large-scale distribution changes (trends and natural variation) over time. Patch-scale monitoring provides the ability to detect small-scale changes over time. More importantly, in situ monitoring produces species-specific data and a level of detail that aerial maps cannot provide.

Preliminary seagrass restoration/preservation targets for the SIRL and SLE are based on depth targets for the deep edge of the bed. A 1994 study determined that a depth target of approximately 1.7 m was recommended for SAV restoration in the Indian River Lagoon (Steward et al., 1994). Depth targets vary throughout the lagoon according to how deep light can penetrate through the water column to support seagrass growth. Other depth targets under evaluation for the SIRL are 1.3 m (Crean et al., 2007) and 1 m for areas in and near the St. Lucie River (Steward et al., 1994). These targets were compared with past and current map data.

Since 1986, lagoon-wide seagrass and macroalgae cover mapping from aerial photography has been conducted every two to three years in partnership with the St. Johns River Water Management District (SJRWMD) to document trends over time. The 2010 SFER – Volume I, Chapter 12 presented results of the 2007 mapping project; this chapter includes the 2009 results (**Figure 12-9**, panel A). **Figure 12-9**, panel B presents a comparison of the two cover maps, which show the gains, losses, and areas of “no change” in seagrass coverage.

The mapping data were further examined by lagoon segments (**Figure 12-10**). To assess progress toward restoration, seagrass spatial coverage results were compared with lagoon bottom acreage associated with the seagrass depth targets. Seagrass acreage in the SIRL increased by almost 500 acres [202 hectares (ha)] from 2007 (8,847 acres or 3,580 ha) to 2009 (9,342 acres or 3780 ha). Much of this gain (about 350 acres or 142 ha) occurred in Segment 24 (**Figure 12-11**), which borders the north side of the St. Lucie inlet. As described in Chapter 12 of the 2010 SFER – Volume I, seagrass resources in this segment of the lagoon were heavily impacted by hurricanes. The eyes of Hurricanes Frances (September 5, 2004) and Jeanne (September 24, 2004) passed over this segment. In addition, discharges from Lake Okeechobee associated with Hurricane Wilma (October 24, 2005) influenced salinity and water clarity in this segment. In the 2010 SFER – Volume I, Chapter 12 reported evidence of seagrass recovery in Segment 24. The increased acreage mapped from 2007–2009 for this segment suggests continued recovery. Drought conditions, which led to improved water clarity and salinity conducive to seagrass growth, also likely supported this increase.

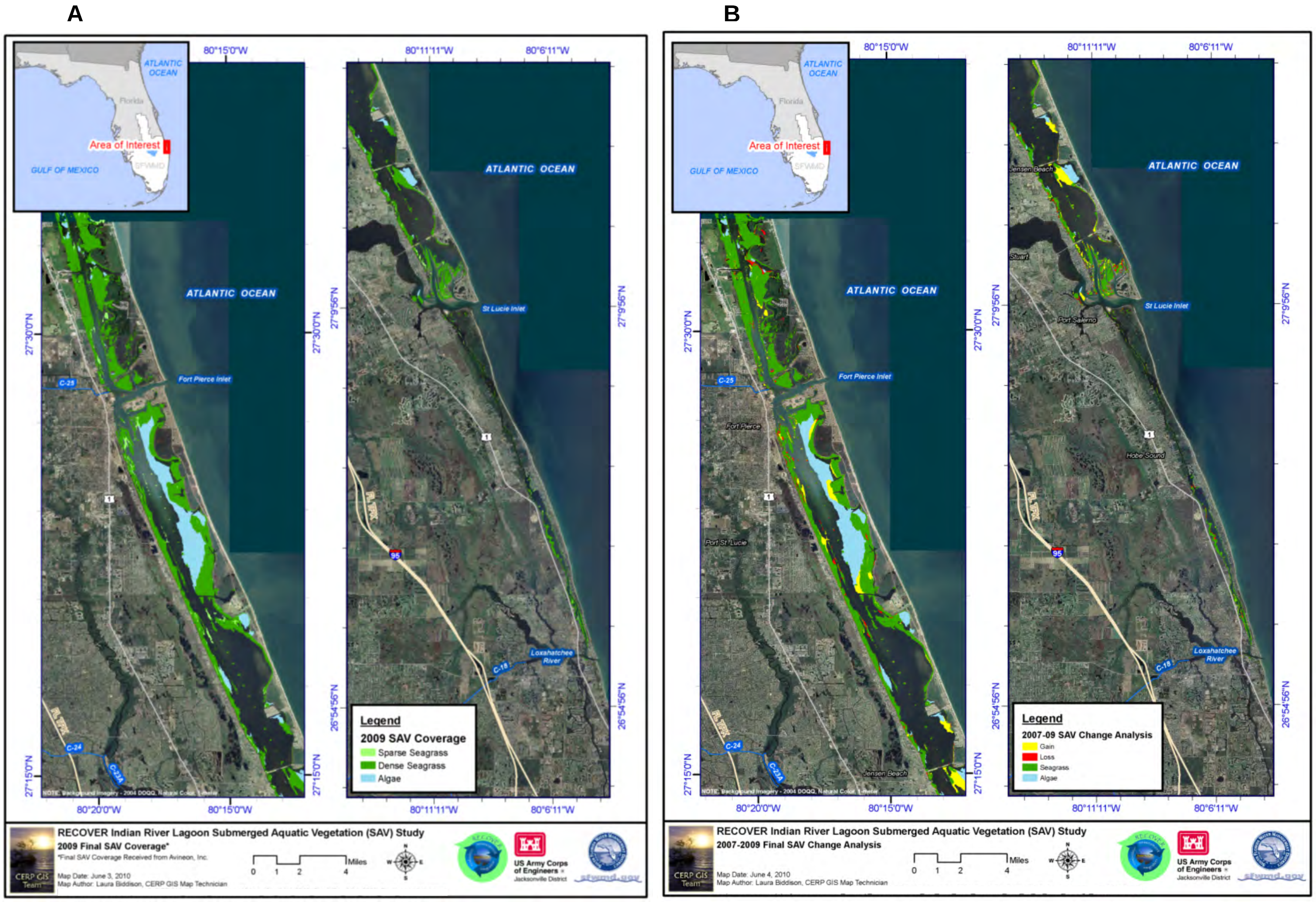

Figure 12-9. Indian River Lagoon (IRL) seagrass and macroalgae coverage based on interpretation of aerial photos during (A) summer 2009, and (B) a comparison of the mapping efforts in 2007 and 2009. Yellow areas show where seagrass acreage increased, red areas where seagrass acreage decreased, and green where seagrass distribution stayed the same.

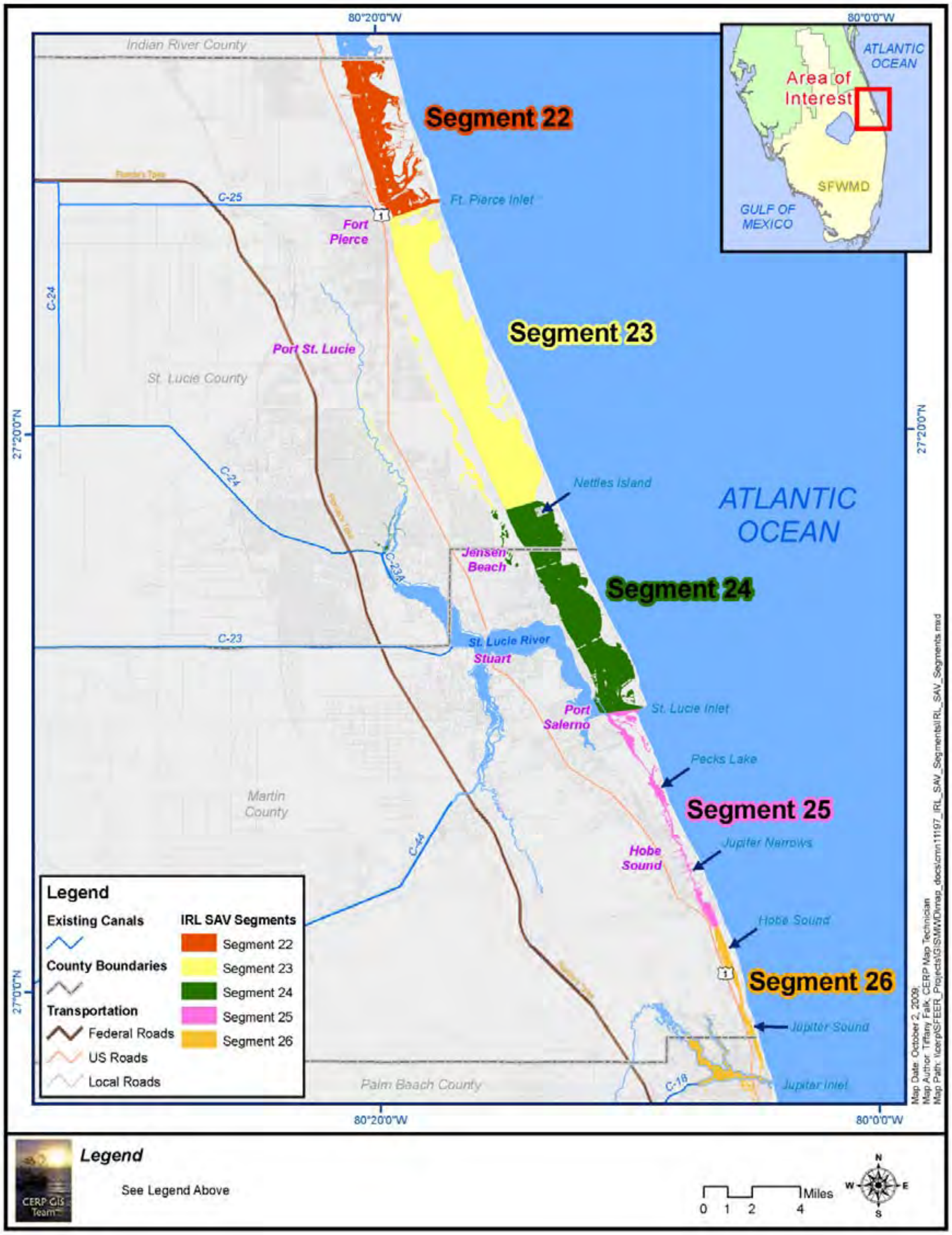

Figure 12-10. IRL seagrass management segments (areas with relatively homogeneous water quality).

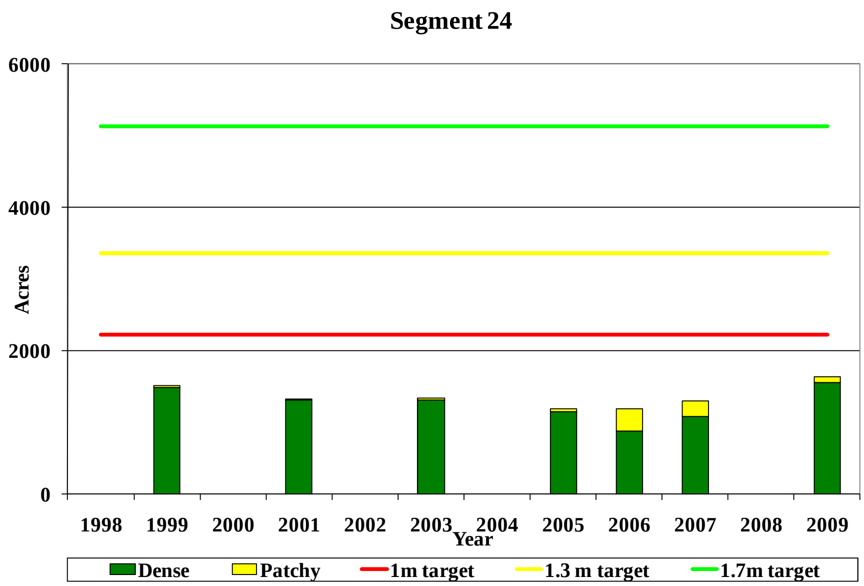

Figure 12-11. Seagrass cover acreage changes from 1999 through 2009 in Segment 24. Coverage is well below preferred targets.

In addition to aerial mapping in the SIRL, in situ monitoring was conducted bimonthly at 10 locations in the SIRL (**Figure 12-12**). This effort began in December 2008 (with testing of the method at some sites in 2007 and 2008) using a methodology being developed by an interagency RECOVER Quality Assurance Oversight Team to standardize SAV monitoring methods. Three of the 10 SIRL sites are monitored monthly, namely Boy Scout Island (BSI), Willoughby Creek (WILL_CK), and St. Lucie Inlet Southeast (SLI_SE). **Figure 12-13** shows the monitoring results for these three sites.

The BSI site has been monitored using various methods since 2002. A one-time comparison of the transect method used from 2002–2007 with the current, patch-scale method at the BSI site indicated that percent cover by seagrass species and percent occurrence results were similar between the two methods. This site supported a healthy manatee grass (*Syringodium filiforme*) bed prior to the 2004–2005 hurricane impacts, after which much of the manatee grass disappeared from the site. However, as reported in the 2010 SFER – Volume I, Chapter 12, manatee grass has since recovered. Currently, percent cover within this monitoring site is near 100 percent. The reestablishment of manatee grass may be inhibiting growth of both shoal grass and Johnson's seagrass (*Halophila johnsonii)*. The WILL_CK site has the most persistent, upstream seagrass bed in the SLE of shoal grass and Johnson's seagrass. Following a low salinity event in CY2008, both species declined in the study area, and Johnson's seagrass was largely eliminated from the site. Both species have since recovered to greater than 80 percent coverage. Finally, the SLI_SE site is a shallow, protected bed located behind small islands. This site supports shoal grass and Johnson's seagrass. Both species exhibit high percent cover at this location.

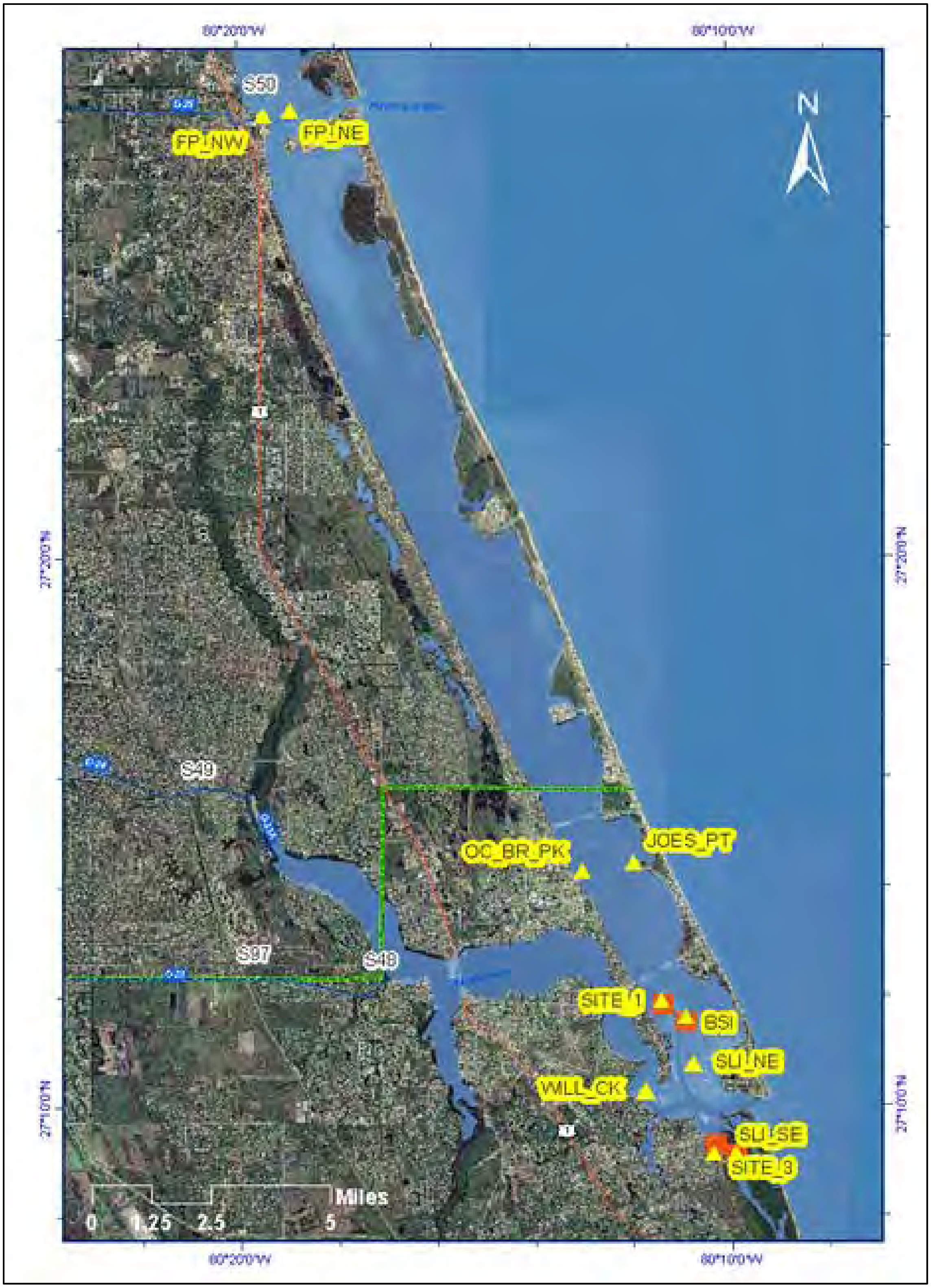

Figure 12-12. Seagrass monitoring locations. Yellow triangles depict the 10 bimonthly seagrass monitoring sites. Red squares indicate past monitoring sites.

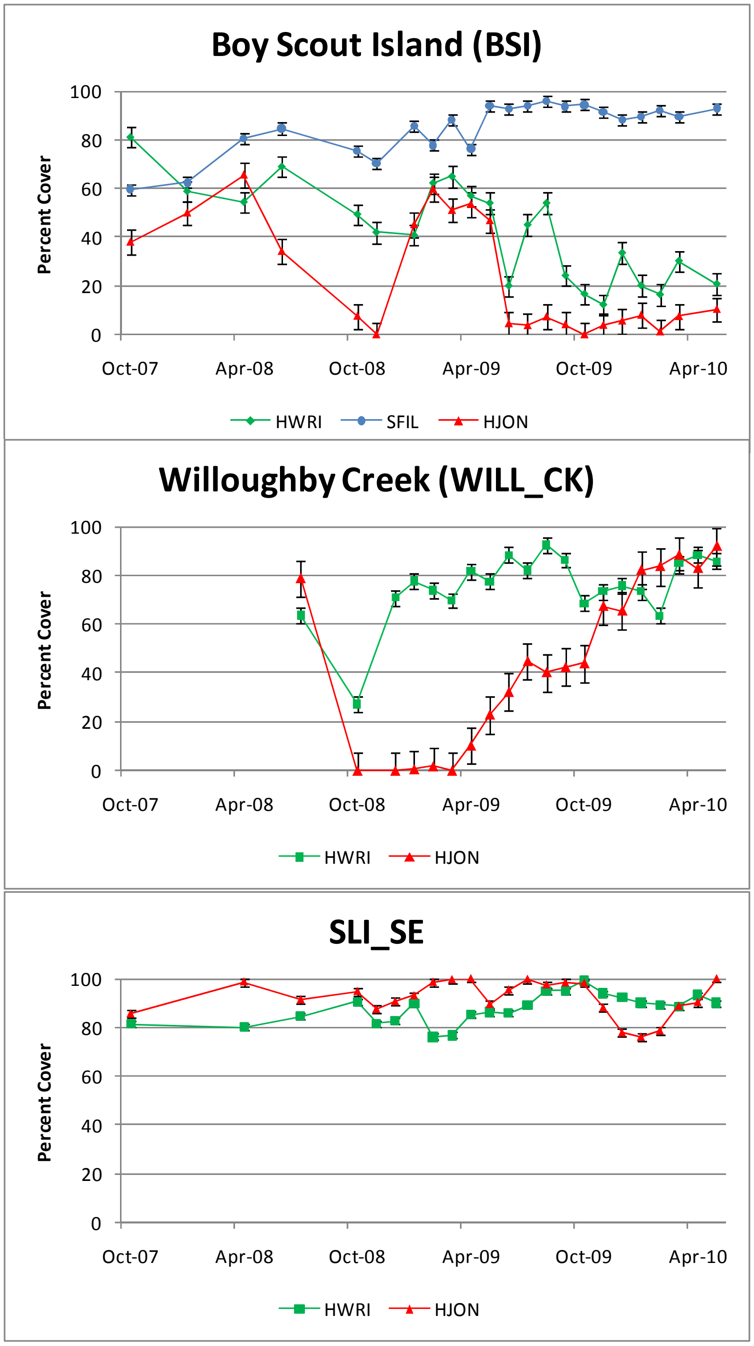

Figure 12-13. Average percent cover [± standard error (SE)] of seagrass species at three locations (see **Figure 12-12** for sites) near the mouth of the St. Lucie River. [HWRI – *Halodule wrightii* (shoal grass); SFIL – *Syringodium filiforme* (manatee grass); HJON – *Halophila johnsonii* (Johnson's seagrass)].

Eastern Oyster Abundance and Distribution

Reefs and beds of the eastern oyster provide various essential ecosystem functions including production of meat, stabilization of benthic environments, water filtration, bio-deposition, and habitat for various estuarine fauna. Oyster populations in South Florida estuaries have declined due to the effects of altered discharge and salinity. Generally, eastern oysters are not abundant when salinity is below 15 psu or greater than 30 psu. The distribution, density, and condition of oysters provide an excellent performance measure for watershed improvements related to CERP since their preferred salinity range overlaps many restoration targets in the estuaries.

As a measure of the status of estuarine oyster beds, the density of live and dead adult oysters is examined on a seasonal (wet, dry) basis. Implementation of wet and dry season oyster monitoring began in WY2005 at three stations — one each in the North, Central, and South Forks. All stations were aggregated for this analysis.

Overall, monitoring results indicate a strong, positive relationship between higher observed salinity and increased live oyster density (**Figure 12-14**). Oyster density was lower in WY2005, and then peaked through WY2006 to WY2007, before another dramatic decline during WY2007 and WY2008. After reaching minimum levels early in WY2008, live oyster numbers began to rebound throughout WY2009 and into WY2010 (**Figure 12-14**). These increases occurred despite low salinity in the wet seasons of WY2008 and WY2009.

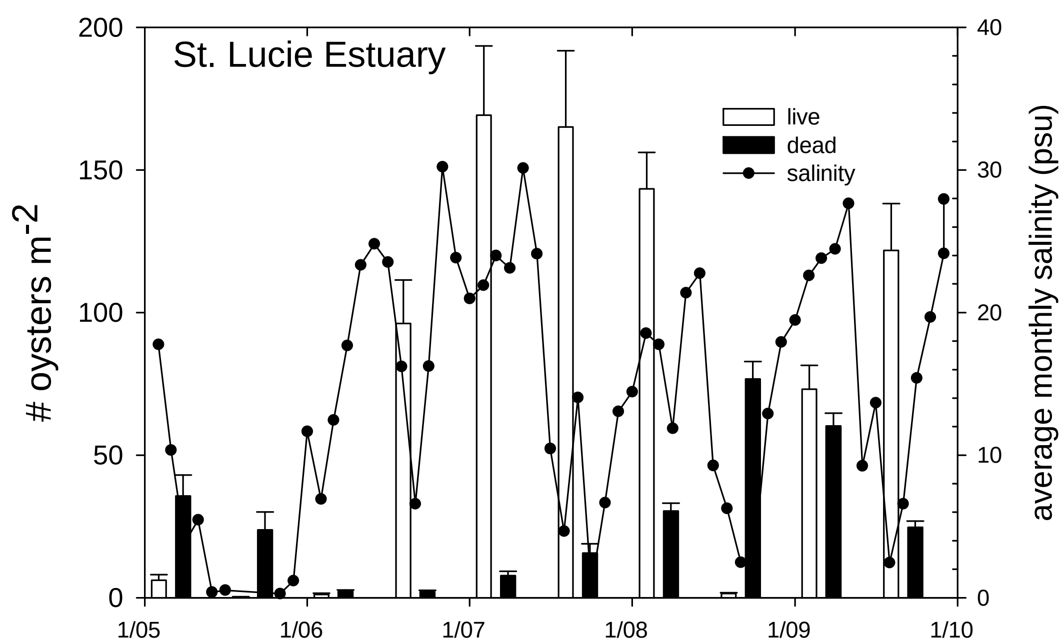

Figure 12-14. Live and dead oyster densities (left axis) and salinity (right axis) extending from the spring of 2005 (dry season) through the summer of 2009 (wet season) in the SLE.

Floodplain Vegetation

In February 2009, vegetation and soil studies were initiated on the North Fork of the St. Lucie River to obtain baseline information on floodplain communities. The first step in this process was to perform a pre-taxonomic survey to identify and verify plant identifications near the transect corridors prior to the enumeration of canopy, shrub, and groundcover species. Secondly, a dried and mounted reference plant collection was established for the study area. The studies identified a total of 163 species along the four transects (**Figure 12-15**). The percent of wetland indicator species ranged from 34 percent at Benchmark 4 (Miller Oxbow, riverine reach) to 59 percent at Benchmark 1 (Crowberry Drive, upper tidal reach). **Table 12-3** shows the relative number of wetland species listed as “facultative wet” or “obligate” for each transect based on the identification systems established in the 1996 National Wetlands Inventory or the 1998 Florida Wetlands Plants: An Identification Manual. Of the total transect flora, 23 are listed as invasive by the Florida Exotic Pest Plant Council. These species represented 14.3 percent of the total transect flora. See Chapter 9 of this volume for District-wide information about exotic vegetation.

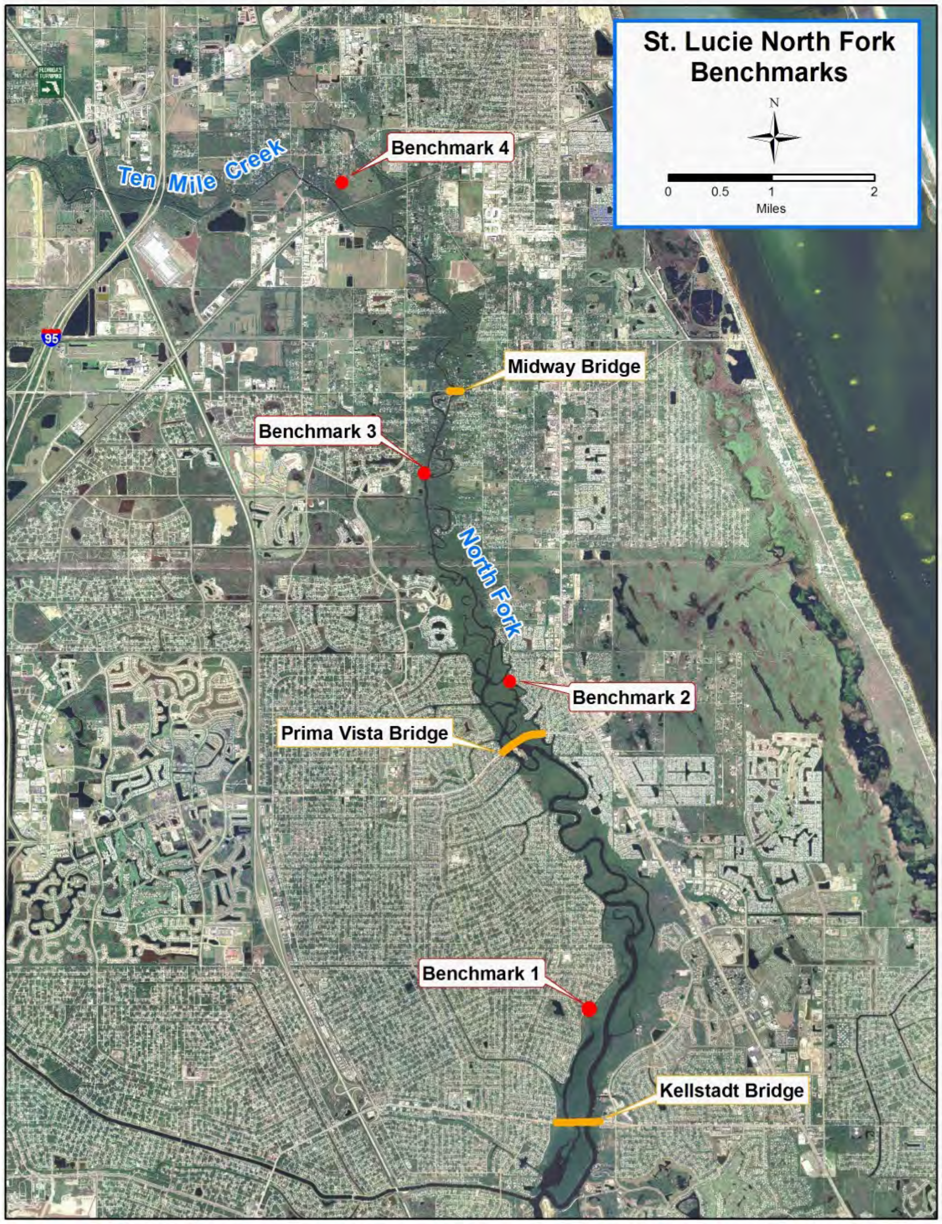

Figure 12-15. Vegetative benchmark transects (red dots) along the North Fork of the St. Lucie River.

Table 12-3. Relation of wetland indicator species at each transect, and the number of species with "facultative wet" or "obligate" wetland status, as they relate to the total number of species along each transect.

	Transect				All
Wetland Status	**Benchmark 4**	**Benchmark 3**	**Benchmark 2**	**Benchmark 1**	**Transects**
Facultative Wet	17	13	17	22	40
Obligate	9	12	18	13	31
Total species	76	44	87	59	158
% wetland spp.	34.2	56.8	40.2	59.3	44.9

Electrical conductivity (EC, cS/m) measurements of the soils and percent soil moisture (percent SM) were also collected to further interpret community composition and observe saltwater intrusion on the floodplain in areas with and without berms. Crowberry Drive [River Mile (RM) 17.6, bermed] and Beach Avenue (RM 19.5, partially bermed) transects are both located in the upper tidal reaches of the St. Lucie River while Rivers Edge (RM 20.5) appears to be in a transition area of fresh and saline waters and is partially bermed. Miller Oxbow (RM 30, bermed), located on Ten Mile Creek, is in the riverine reach. U.S. Geological Survey (USGS) salinity data collected in the channel of the North Fork show that the 14 psu isohaline at drier times of the year may go upstream of RM 20.

Geographic Information System (GIS) interpretation of Light Detection and Ranging (LiDAR) ground elevations and soil conductivity and SM can be used to examine spatial patterns and degree of saltwater intrusion. Higher ECs were associated with transitional young mangrove forested areas with remnant sawgrass/leather fern marsh on the Crowberry Drive transect while lower ECs were associated with freshwater swamp/bottomland hardwood and hammock areas. SM was generally higher by percentage in areas adjacent to the river channel; however, soils on the Miller Oxbow transect were much drier overall than on the other three transects. In early 2010, Miller Oxbow was the site of an oxbow restoration project by the Florida Fish and Wildlife Conservation Commission (FWC) to improve the floodplain hydroperiod. Plants and soils will be reexamined in the future on this site to determine the impact of restoring the hydroperiod and reconnecting floodplain areas behind the berms. These results suggest that opening berms and restoring the hydroperiod to floodplain areas may be an issue in the upper tidal reach of the river if freshwater flow is not available to maintain low salinity levels in the river channel of the North Fork.

Caloosahatchee River Estuary and Southern Charlotte Harbor

The Franklin Lock and Dam (S-79 structure) demarcates the head of the Caloosahatchee Estuary, where fresh and brackish waters meet. This structure prevents salinity encroachment into the watershed and controls the quantity of fresh water released downstream. From this point, the estuary extends about 42 km (26 miles) downstream to Shell Point, where it empties into San Carlos Bay in the southern portion of the greater Charlotte Harbor system (**Figure 12-16**).

The Caloosahatchee River Estuary (CRE) and Caloosahatchee River Watershed have been highly altered by human intervention and engineering. The Caloosahatchee River was once a sinuous river originating near Lake Flirt, about 3.2 km (2 miles) east of La Belle at Fort Thompson (**Figure 12-16**). Since the 1880s, the river has been connected to Lake Okeechobee; it has been straightened and deepened; and three water control structures have been added (Antonini et al., 2002). No longer free flowing, the river is operated as two pools: one at an elevation of about 3.3 m (11 ft) between structures S-77 and S-78, and the other between S-78 and S-79 at an elevation of about 0.9 m (3 ft). The river provides irrigation water, drainage, and potable water, as well as conveyance of regulatory releases of water from Lake Okeechobee. Lake Okeechobee's water level is regulated according to a seasonal schedule that sometime necessitates drainage of excess water (see Chapter 10 of this volume). Modifications to the Caloosahatchee River allowed development in the watershed. A network of secondary and tertiary canals now overlays the Caloosahatchee River Watershed. This network provides conveyance for both drainage and irrigation to accommodate citrus groves, sugarcane, cattle grazing, and urban development.

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

As a result of these changes, freshwater inflow to the estuary has a high seasonal variance. During the wet season, extreme flows can drive the system entirely fresh, causing mortality of marine organisms in the lower estuary and San Carlo Bay. By contrast, the lack of flows during the dry season can allow salt water to intrude up to the head of the estuary at S-79, sometimes reaching 20 psu. Salinity this high causes mortality of brackish water organisms that normally inhabit this area.

To better manage inflows to the estuary, the SFWMD has established preferred flow ranges for discharges at S-79 using freshwater SAV as an indicator or VEC (Doering et al., 2002; Chamberlain and Doering, 1998a; Chamberlain and Doering, 1998b). A considerable amount of work has demonstrated that these flows are not harmful to other components of the ecosystem including fish and shellfish, zooplankton, and ichthyoplankton (Volety et al., 2003; SFWMD, 2003; Chamberlain and Doering, 1998b). An MFL was established for the Caloosahatchee River and Estuary in 2001 (SFWMD, 2000) and reviewed in 2003 (SFWMD, 2003). The MFL has two salinity criteria, both measured at Fort Myers, that constitute an MFL exceedance: a 30-day average salinity above 10 psu or a daily average salinity above 20 psu. A detailed discussion of the MFL and preferred freshwater inflows at S-79 can be found in the 2009 SFER – Volume I, Chapter 12. In addition, District research has established that mean monthly flows between 450 cfs and 2,800 cfs at S-79 are generally protective of the estuarine ecology from S-79 to Shell Point.

To better address nutrient enrichment problems, the FDEP recently completed work on and proposed a TMDL for the Caloosahatchee River Estuary (Baily et al., 2009). As mandated by NEEPP (Section 373.4595, F.S.), the SFWMD completed the CRWPP (SFWMD et al., 2009a).

The major goals of the plan are to reduce nutrient loads to the estuary to meet any adopted TMDL and to reduce the frequency and duration of undesirable salinity ranges (SFWMD et al., 2009a).

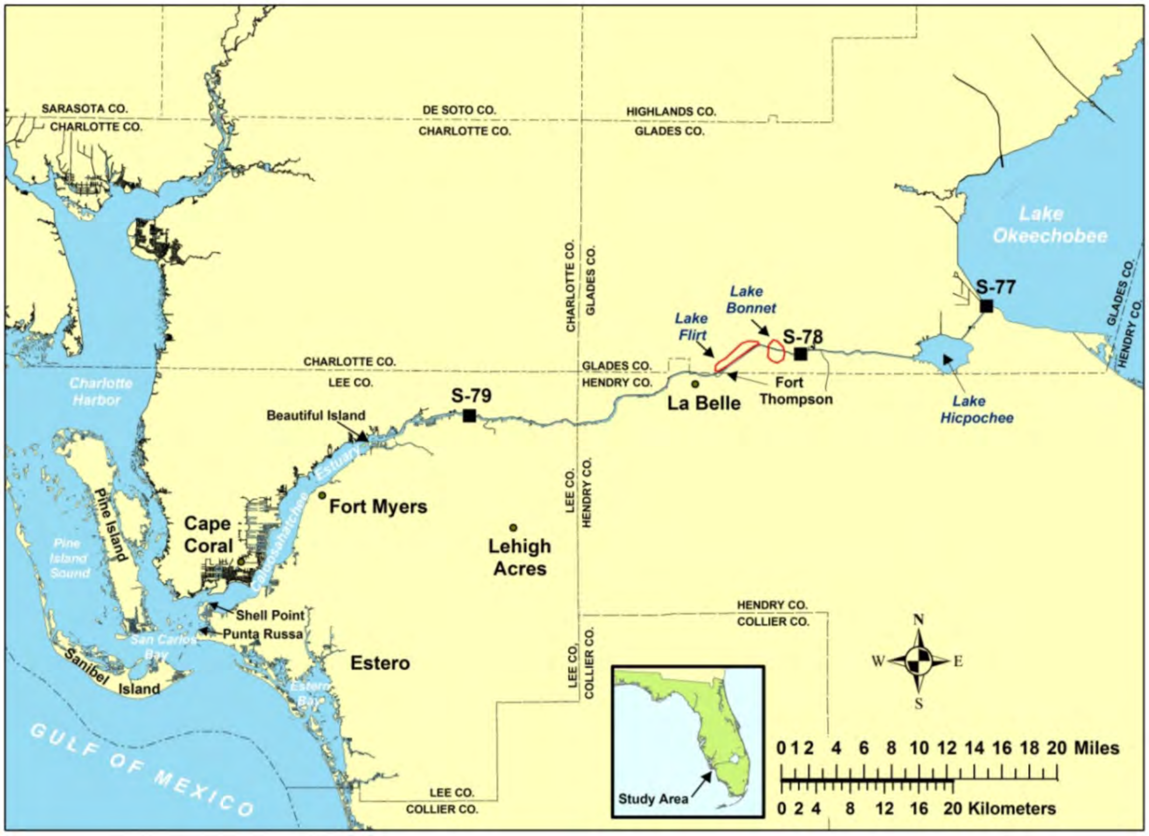

Figure 12-16. Caloosahatchee River and Estuary (CRE).

Salinity and Freshwater Inflows

Freshwater inflow to the CRE at S-79 during WY2010 was greater than in WY2009 but still below the POR long-term average (WY1991–WY2008) (**Table 12-4**). Inflow peaked during the wet season in June 2009 although there was considerable freshwater discharge in April 2010 (**Figure 12-17**). Releases of water from Lake Okeechobee comprised about 24 percent of the total discharge measured at S-79 in both WY2009 and WY2010 compared to the long-term average of 44 percent (**Table 12-4**).

Table 12-4. Total annual freshwater flow (acre-feet per year) observed at S-79 by water years (WY1991–WY2008, WY2009, and WY2010) and sources (C-43 Basin and Lake Okeechobee). Number in parentheses is the percentage of total annual discharge contributed by Lake Okeechobee.

POR	Discharge from C-43 Basin	Discharge from Lake Okeechobee (%)	Total Discharge at S-79
Average WY1991–WY2008	830.4	657.7 (44.2%)	1,488.2
WY2009	804.4	258.2 (24.3%)	1,062.6
WY2010	990.8	321.5 (24.5%)	1,312.3

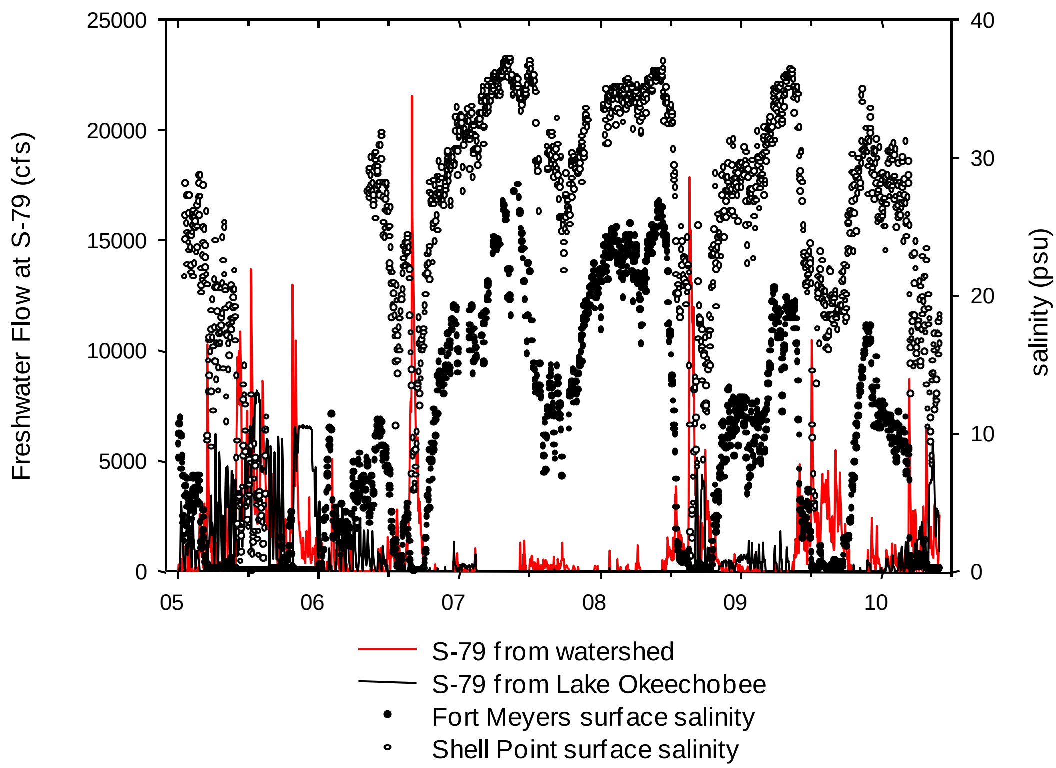

Figure 12-17. Time series of daily water discharge at S-79 from the watershed (C-43 Basin) (red) and Lake Okeechobee (dotted), and salinity observed at Fort Meyers (solid circles) and Shell Point (open circles) from WY2005–WY2010.

High frequency (15-minute interval) salinity monitoring was conducted at several sites (e.g., Fort Meyers, Cape Coral, and Shell Point) in the CRE (**Figure 12-18**). Salinity observed at Fort Meyers and Shell Point during WY2010 was slightly less than the salinity observed in WY2009 due to increased inflow (**Figure 12-17**). In particular, above-average precipitation and inflow during the WY2010 dry season lowered surface salinity values at the downstream Shell Point location. Compared to WY2009, dry season releases from Lake Okeechobee in WY2010 did not exceed watershed (C-43 Basin) inputs, and by May 2010, releases from both freshwater sources at S-79 were about the same.

WY2008 was extremely dry with average monthly discharge at S-79 less than 500 cfs and salinity at Fort Meyers greater than 12 psu, exceeding the MFL criterion for much of the year (**Figure 12-17**). By contrast, WY2009 discharges varied widely, from less than 500 cfs to greater than 5,000 cfs, and salinity followed suit, ranging from less than 2 psu to greater than 20 psu. Despite increased rainfall and inflow to the CRE in WY2009, mean monthly discharges approximating 1,000 cfs were required for average monthly salinity to approach 10 psu at Fort Meyers (**Figure 12-19**). This is likely due to reduced lateral inputs from the watershed and groundwater sources downstream of S-79 throughout WY2009. WY2010 inflow and salinity were more similar to long-term averages with a narrower range of values and salinity of 10 psu at discharges of 450 cfs. When constructed (completion date unknown), the C-43 (Caloosahatchee River) West Reservoir Project should alleviate some of the high salinity conditions (i.e., greater than 10 psu) that often occur in the upper estuary.

A comparison of mean monthly freshwater flows at S-79 per year (**Table 12-5**) indicates the flows were within the optimum range between 450 and 2,800 cfs more often (nine out of 12 months) than has been typical historically (average five out of 12 months). The unusual pattern in WY2010 was likely caused by the greater-than-normal rainfall during the dry season associated with El Niño conditions in combination with the new Lake Okeechobee regulation schedule.

Figure 12-18. Salinity sensors (orange squares) and water quality sampling stations in the CRE (red dots).

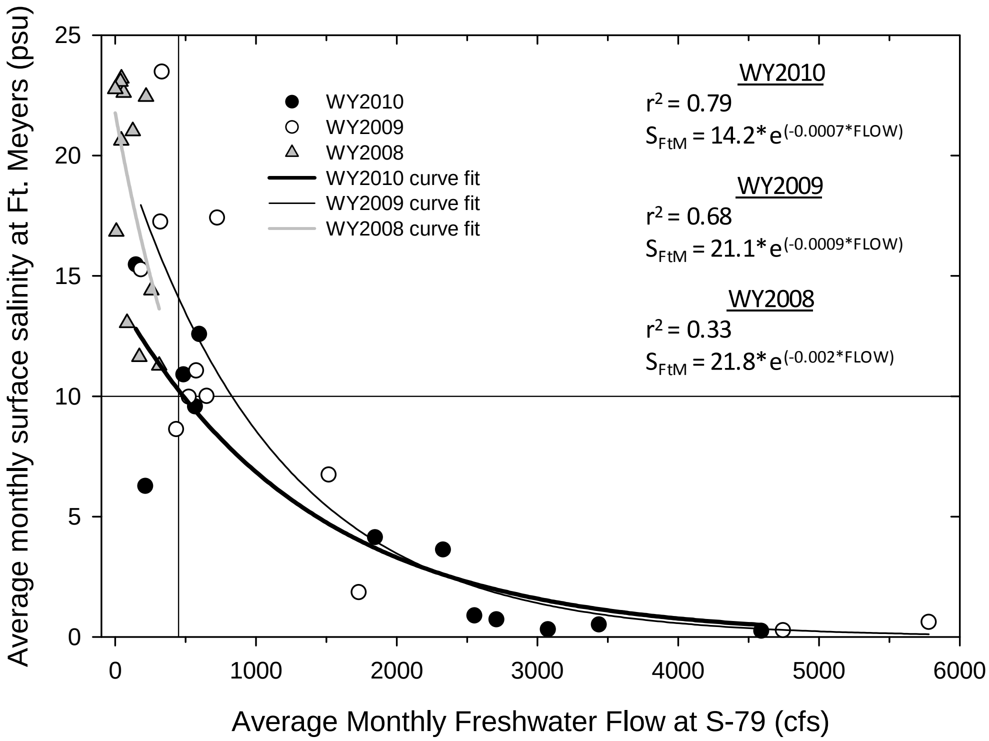

Figure 12-19. Negative exponential relationships between estimated freshwater flows at S-79 and surface water salinity at Fort Meyers in WY2008, WY2009, and WY2010. [Note: see curve fit equation and degree of fit parameter (r^2) for each water year.]

Table 12-5. Number of months when daily flows at S-79 were within one of three flow ranges.

	Number of Mean Monthly Flows Per Year at S-79		
Period	**< 450 cfs**	**450–2,800 cfs**	**> 2,800 cfs**
Average WY1967–2008	4.3	5	2.6
WY2009	5	5	2
WY2010	2	9	1

Nutrients

The annual TN load entering the CRE at S-79 was 2,031 metric tons per year (mt/yr) in WY2009 compared to 1,905 mt/yr in WY2010, a decrease of 6 percent (**Figure 12-20**). TN loading in WY2010 was also lower compared to the POR long-term average (2,706 mt/yr). The TP load in WY2010 (200 mt/yr) was also lower than in WY2009 (287 mt/yr), a decrease of 30 percent, and lower than the long-term average (239 mt/yr).

On average, about half the nitrogen load comes from the C-43 Basin and half from Lake Okeechobee. For phosphorus, long-term proportions are 70 percent from the basin and 30 percent from the lake. In WY2009, the basin proportion was relatively higher for nitrogen (66 percent) and phosphorus (75 percent).

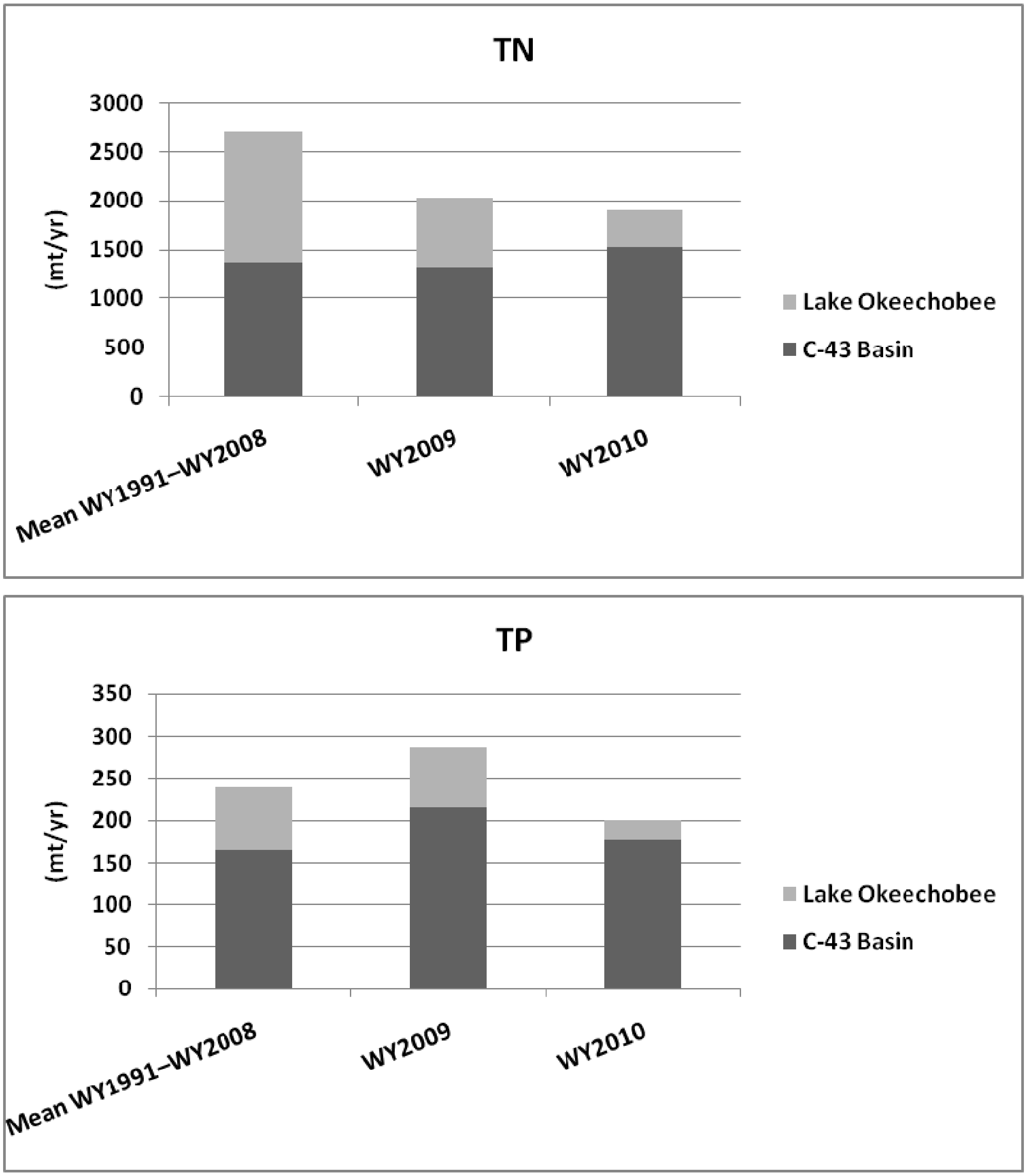

Figure 12-20. Estimated annual TN and TP loads to the CRE at the Franklin Lock and Dam (S-79) from Lake Okeechobee and C-43 Basin.

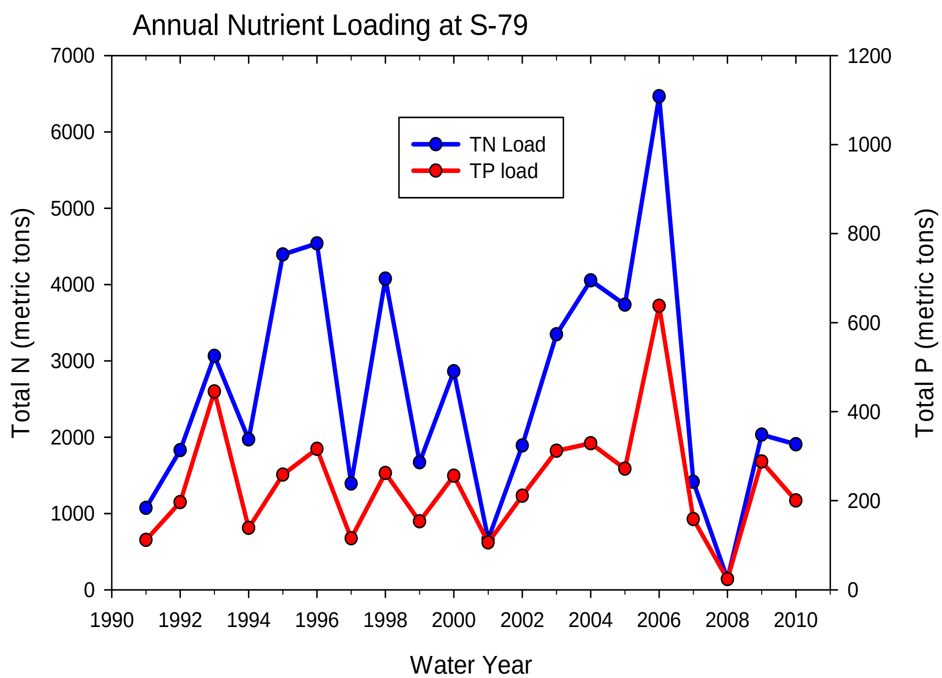

Figure 12-21. Annual loads of TN and TP to the CRE at the Franklin Lock and Dam (S-79).

Monitoring of the water column for TN and TP concentrations occurs at several sites (CES01, CES04, and CES06) in the CRE (**Figures 12-22** and **12-23**). Water column TN concentrations at CES01 in WY2010 were more consistent than in WY2009, staying at about 1.5 mg/L (**Figure 12-22**). At all three sites, monthly mean TN concentrations were primarily within the long-term inter-quartile range (IQR), defined as the range between the 25th and 75th percentiles of all observations from WY2000–2008. At CES04, TN peaked at about 5 mg/L in February 2010. TP concentrations at CES01 and CES04 exceeded the IQR early in WY2010 (**Figure 12-23**). Concentration ranges and patterns were largely similar to those in WY2009 at CES01 and CES06, but not at CES04 where TP peaked at 0.4 mg/L in February 2010.

Magnitudes and temporal and spatial patterns of Chl*a* in the water column are influenced by seasonality in temperature and freshwater inflow (Doering et al., 2006; **Figure 12-24**). Although the magnitude of Chl*a* concentrations experienced variable temporal patterns in WY2009 and WY2010 at CES01, Chl*a* concentrations remained within the long-term IQR. Chl*a* concentration was highest [approaching 45.0 micrograms per liter (µg/L)] in May 2009 at CES04 (**Figure 12-24**). Concentrations were greater than the IQR at this site throughout the late wet and early dry seasons in WY2010. Chl*a* concentrations at CES06 in WY2010 were generally lower compared to WY2009 although concentrations climbed upward from February 2010 to April 2010.

When completed (currently projected for September 2014), the C-43 Water Quality Treatment and Testing Facility is expected to reduce nutrient loads to the CRE. In addition, the facility will be used to test new approaches for removing nutrients.

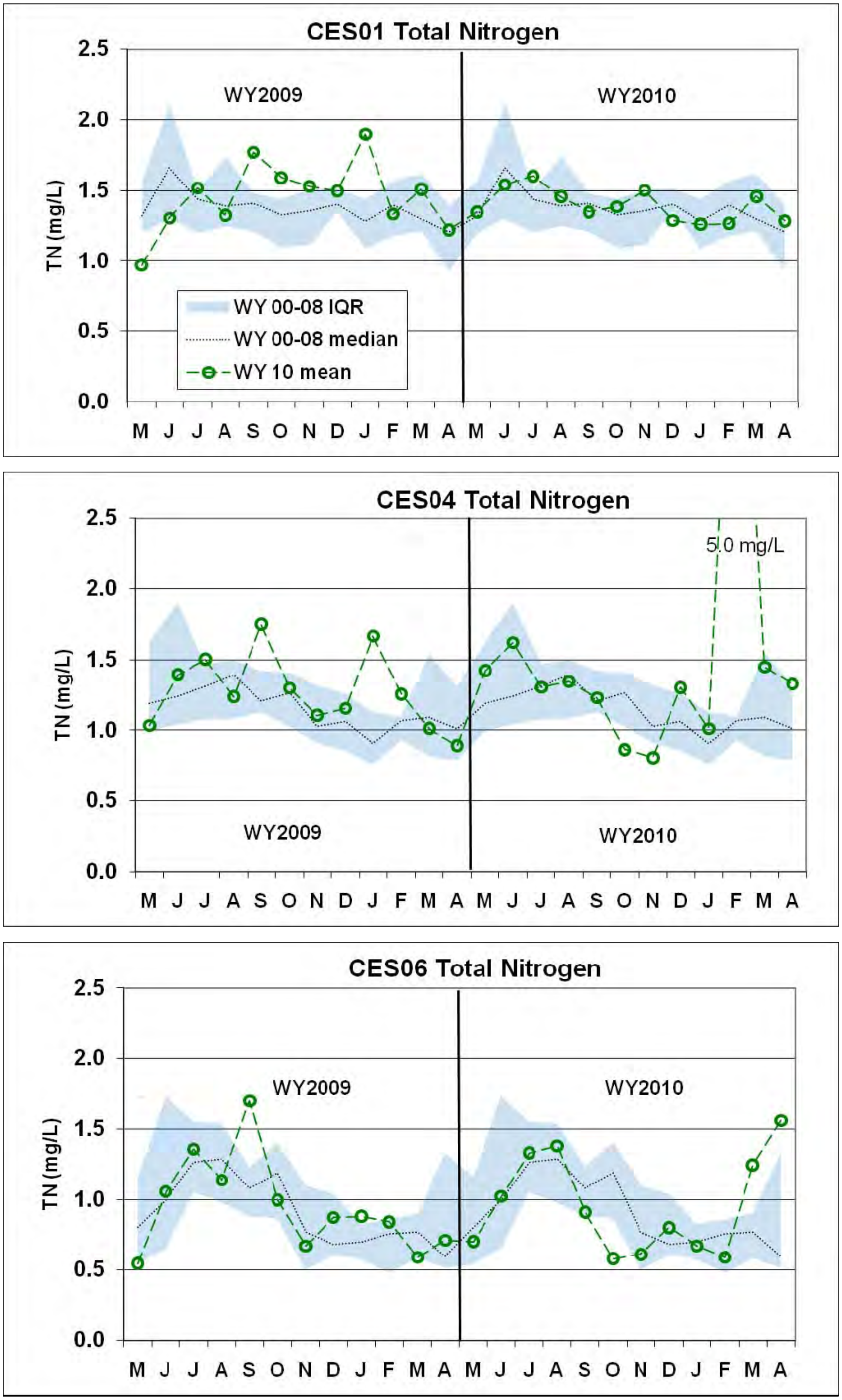

Figure 12-22. Water column TN concentrations (mg/L) at CES01, CES04, and CES06 monitoring sites in the CRE.

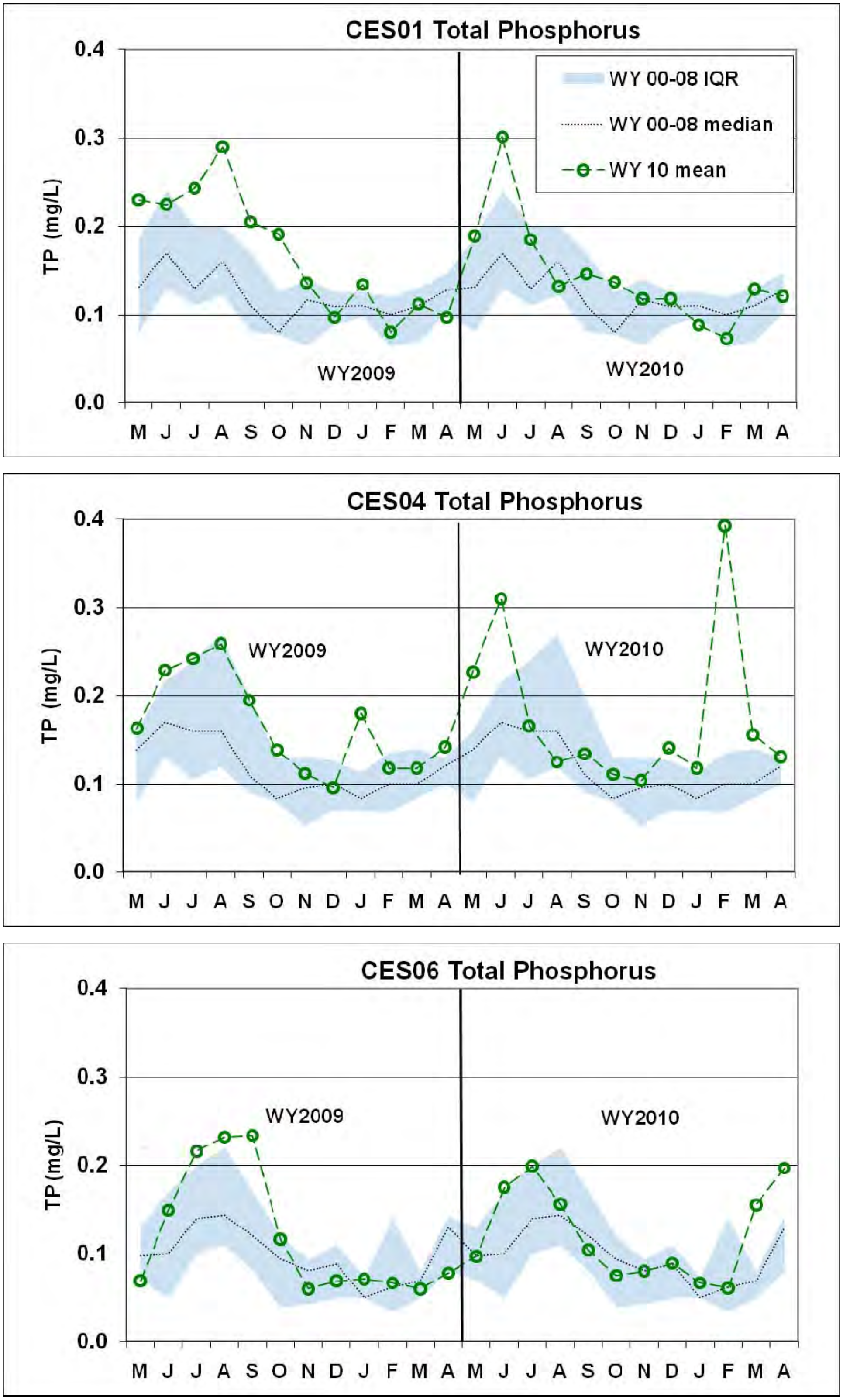

Figure 12-23. Water column TP concentrations (mg/L) at CES01, CES04, and CES06 in the CRE.

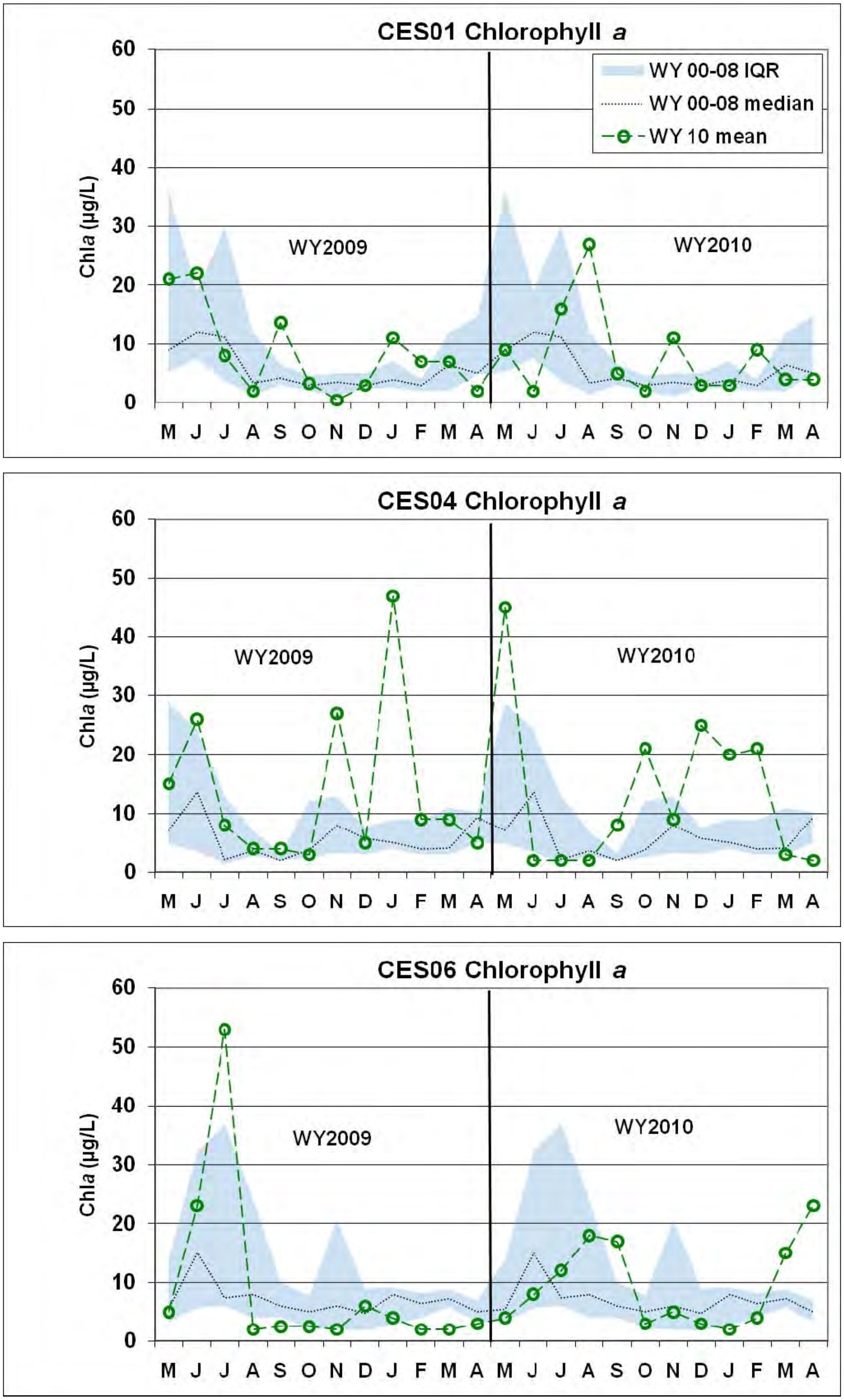

Figure 12-24. Water column Chl*a* concentrations (µg/L) at CES01, CES04, and CES06 in the CRE.

Submerged Aquatic Vegetation

SAV monitoring in the CRE is conducted at the patch scale using quadrats (< 10 m) and transects (> 100 m) (RECOVER, 2008). There are seven active SAV monitoring sites throughout the Upper CRE (Site 1 and 2), Lower CRE (Sites 5 and 6), and San Carlos Bay (Sites 7 and 8) (**Figure 12-5**). A subset of results is given in **Figures 12-26**, **12-27**, and **12-28**. The species composition of SAV in the Caloosahatchee Estuary changes along the main axis of the system due to land-to-sea gradients in salinity, submarine light availability, and nutrients. Tape grass, also known as American wild celery, has been the dominant species in the Upper CRE, and is often observed at less than 1 m of water depth due to light attenuation (Chamberlain and Doering, 1998a). Tape grass is a freshwater species that does not survive at salinity greater than 10 psu (Doering et al., 1999; French and Moore, 2003). *Ruppia maritime*, or widgeon grass, has a wide salinity tolerance and can survive throughout the CRE with occasional occurrence in the upper estuary (Kantrud, 1991). Shoal grass is an estuarine SAV that prefers mesohaline to euhaline conditions but can tolerate low salinity. It is usually found in the lower estuary (McMillan and Moseley, 1967). SAV habitat in San Carlos Bay is primarily composed of both shoal grass and the more marine turtle grass (*Thalassia testudinum*).

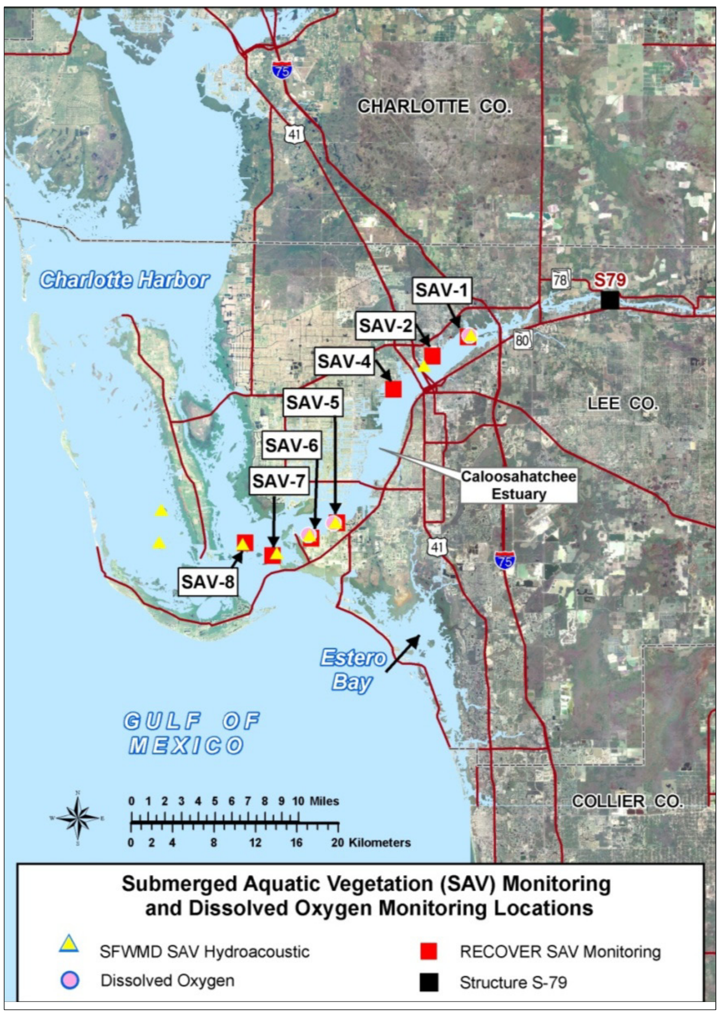

Figure 12-25. SAV monitoring sites in the CRE.

No tape grass has been observed at Sites 1 and 2 in the Upper CRE since January 2007 (**Figure 12-26**). In early 2007, salinity levels were greater than 10 psu for an extended period, which likely caused widespread loss of tape grass in aboveground biomass. While isolated rosettes were observed near Site 1, this key habitat has not recovered since 2007. Tape grass grows primarily upstream of Site 1. Despite a few observations, widgeon grass has been absent from the Upper CRE transects since 2004.

SAV habitats in the Lower CRE were dominated by shoal grass, and shoot densities generally increased with increased salinity (**Figure 12-27**). Average shoal grass shoot density decreased to < 50 per square meter (m^2) in CY2008 at Sites 5 and 6 in the Lower CRE. Despite a few observations, widgeon grass was largely absent from the lower estuary transects.

Both shoal and turtle grass shoot densities responded to inter-annual variations in salinity. Declines in both grasses coincided with freshwater discharge associated with Hurricane Wilma in 2005. Shoal grass recovered quickly and reached pre-hurricane levels in about 12 months. The turtle grass abundance has yet to recover fully. Shoal grass shoot density was about five times that of turtle grass and also had a greater range in values from CY2004–CY2010 (**Figure 12-28**). The increased freshwater discharge and reduced salinity in San Carlos Bay during the wet season of CY2008 may have caused shoot densities to decrease and a loss of habitat. It is not clear whether the beds were impacted primarily by low salinity or the increased light attenuation that can accompany freshwater discharges.

When constructed, the C-43 West Reservoir Project should reduce the occurrence of high salinity (i.e., > 10 psu), making the upper estuary more amenable for the growth of tape grass.

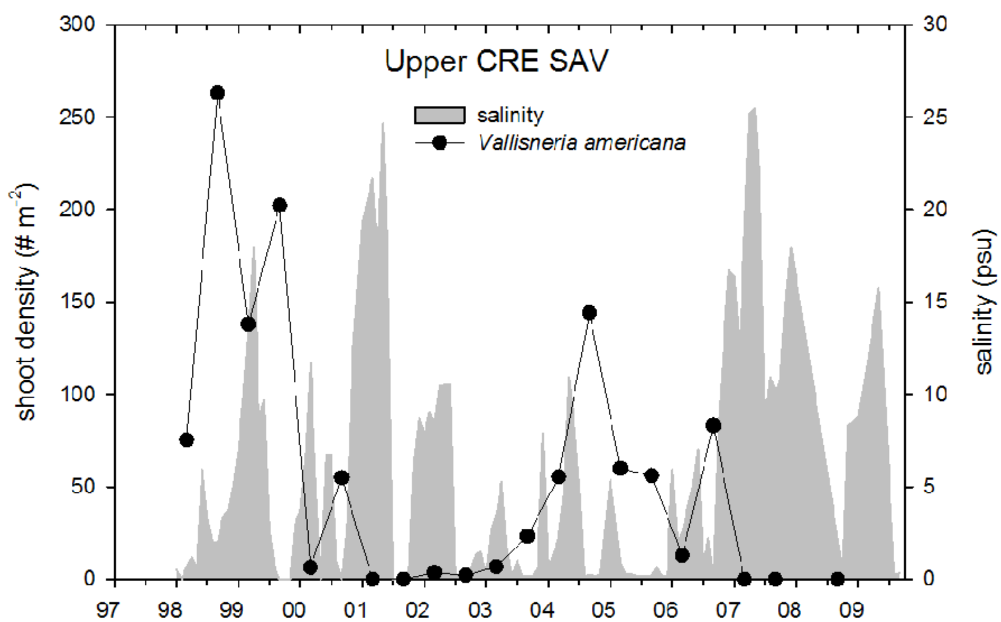

Figure 12-26. SAV shoot density (number per square meter) and salinity observed at Site 1 in the Upper CRE from calendar year (CY) 1998 through CY2009. Averages were derived from all transects sampled at seasonal intervals. Shaded area shows monthly average salinity.

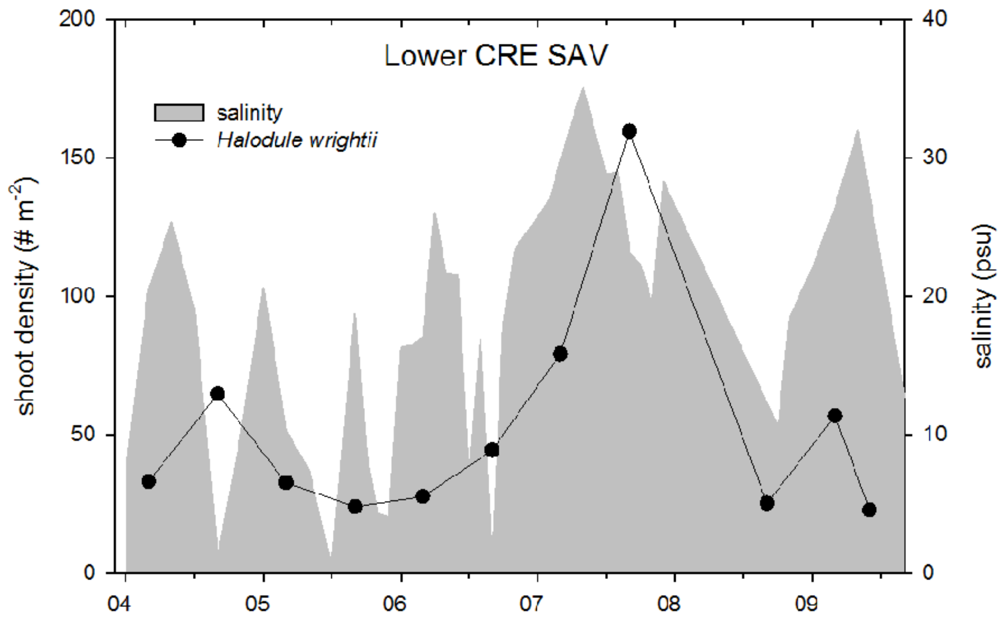

Figure 12-27. SAV shoot density (number per square meter) and salinity observed at Sites 5 and 6 in the Lower CRE from CY2004 through CY2009. Averages were derived from all transects sampled at seasonal intervals. Shaded area shows monthly average salinity.

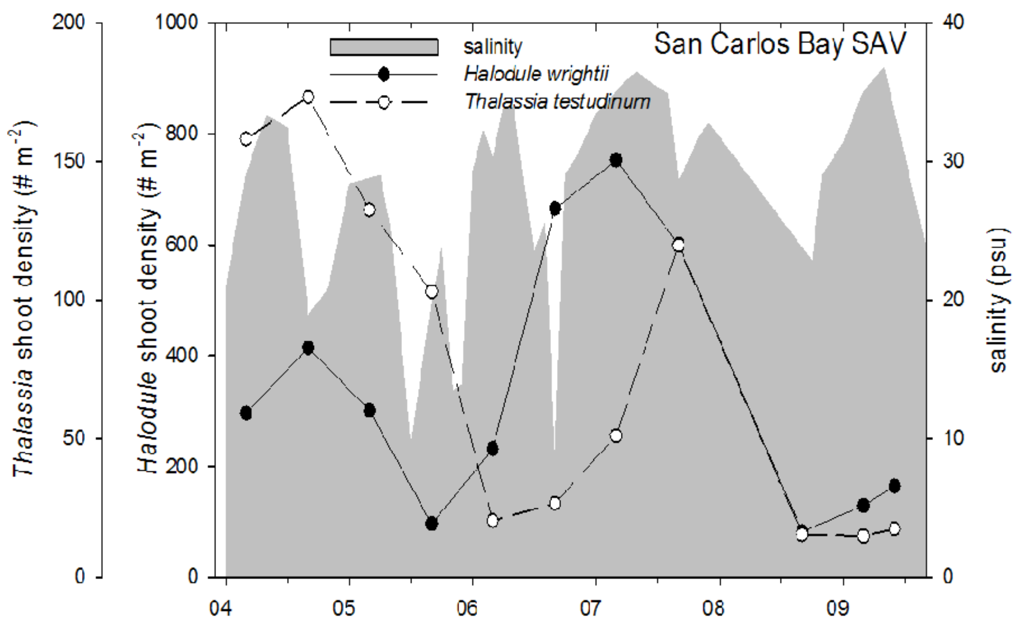

Figure 12-28. SAV shoot density (number per square meter) and salinity observed at Sites 7 and 8 in San Carlos Bay from CY2004 through CY2009. Averages were derived from all transects sampled at seasonal intervals. Shaded area shows monthly average salinity.

Eastern Oyster Abundance and Distribution

Wet and dry season monitoring of adult oyster conditions and spat fall in the Caloosahatchee Estuary was implemented in CY2000; however, a comprehensive monitoring program was not deployed until CY2003. The program tracks changes in oyster distribution, health, and abundance 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 12-29**). The density of live and dead adult oysters is sampled on a seasonal (wet, dry) basis and provides a measure to assess the status of estuarine oyster beds. In addition, monitoring of live oyster densities (number/m^2) at each site started in CY2006. Mean live oyster densities greater than 1,200/m^2 in the Lower CRE were observed in WY2010 (**Figure 12-30**). Station PTP was recently added, so insufficient results were available to include in analysis. The modest decrease in live oysters early in CY2010, which coincided with decreased salinity, is consistent with the strong relationship between higher observed salinity and increased live oyster density.

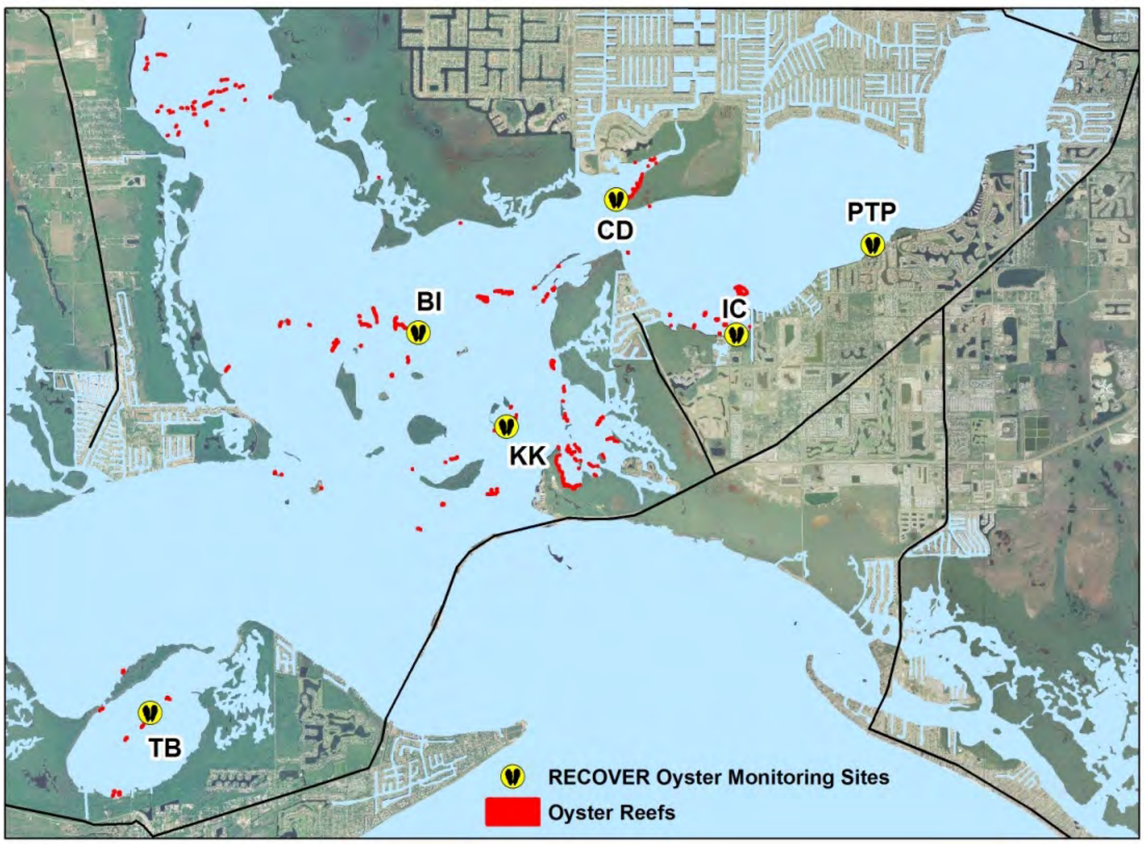

Figure 12-29. Oyster monitoring stations and locations of known oyster reefs within the Lower CRE and San Carlos Bay.

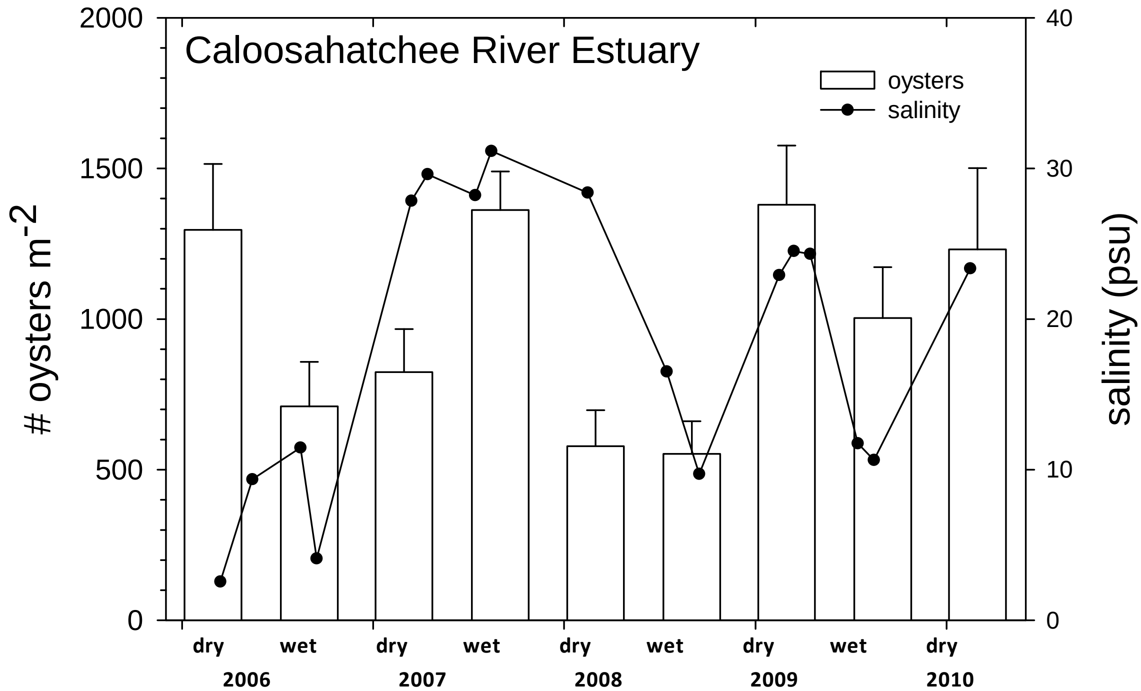

Figure 12-30. Average live oyster densities [standard error (S.E.) per square meter; left axis] at five sites, and average salinity (right axis) from spring 2006 to spring 2010 in the CRE.

FUTURE NORTHERN ESTUARY ACTIVITIES

The St. Lucie and Caloosahatchee River Watershed Protection plans will be updated in CY2011 and present new findings and information.

In 2008, a new regulation schedule for Lake Okeechobee went into effect. This schedule presents some challenges for management of discharges from the Lake Okeechobee to both the St. Lucie and Caloosahatchee rivers and estuaries. This new schedule, LORS2008, manages lake water levels at lower elevations than previous schedules. Because managing the lake at lower elevations reduces storage volume, LORS2008 could result in higher discharges to the St. Lucie and Caloosahatchee estuaries. To address this potential situation, LORS2008 includes a management range or "band" called the "Base Flow Band," in which discharges up to 450 cfs to the Caloosahatchee, and up to 200 cfs to the St. Lucie are allowed. In addition, the schedule is far more flexible regarding the amount of water that can be released, regardless of lake elevation. See Chapter 10 of this volume for more information.

The result is that water will be released from the lake to the estuaries more often than in previous schedules and in a variety of volumes. On a weekly basis, District staff are asked to recommend both the volume and temporal pattern of releases. The District has often recommended that water be released from the lake in pulses to mimic stormwater runoff, and this procedure was, in fact, specified in the previous schedule (Water Supply and Environment). Significantly, no systematic studies of such releases have been made. The short-term (week-to-week) effects of lake releases on estuarine ecology and water quality remain more qualitative than quantitative at this point.

Development of a coastal environmental operations program will continue in WY2011. Questions to be addressed include:

- What are the effects of pulse releases on stratification and DO in bottom waters?
- What are the effects of repetitive exposure to low salinity on oysters and seagrasses?
- Regarding the aerial extent of lowered salinity during high flow events, should discharges be constant or pulsed?
- How do dry season pulse releases alter the low salinity nursery zone?

EASTERN ESTUARIES

Fawen Zheng, Marion Hedgepeth, Rebecca Robbins,
Christopher Buzzelli, Zhiqiang Chen and Richard Alleman

DESCRIPTION OF EASTERN ESTUARINE SYSTEMS, MAJOR PROJECTS AND ISSUES

The Eastern Estuary Region consists of the Loxahatchee River Estuary (LRE) including the National Wild and Scenic Loxahatchee River, Lake Worth Lagoon (LWL), and the estuaries along the Intracoastal Waterway in Broward County (**Figure 12-1**), particularly the North Fork of the New River. Issues affecting these estuaries include modified freshwater inflows, saltwater intrusion as a result of open inlets to the Atlantic Ocean, and water quality degradation. The following District projects and activities are addressing these issues:

- Monitoring and other activities associated with the MFL rule for the Northwest Fork Loxahatchee River (LRE)
- L-8 Reservoir Project including structures G-160 and G-161 (LRE)
- Acme Basin B Discharge Project (LWL)
- North Fork of the New River Restoration Project (Broward County)

ECOSYSTEM STATUS

Loxahatchee River Estuary

The Loxahatchee River and Estuary lie between southern Martin County and northern Palm Beach County on the east coast of Florida (**Figure 12-31**). The Loxahatchee River is generally referred to as the “last free flowing river in Southeast Florida” and represents one of the last vestiges of native cypress river swamp within southeastern Florida. In 1985, 9.5 miles of the Northwest Fork was federally designated as Florida’s first National Wild and Scenic River. Large sections of the river’s watershed and river corridor are included within Jonathan Dickinson State Park, which includes outstanding examples of the region’s natural biological communities.

A system of inland wetlands, known locally as Grassy Waters Preserve and the Loxahatchee and Hungryland sloughs, forms the headwaters of the watershed and drains to the Northwest Fork of the Loxahatchee River. Floodplain plant communities, soils, and salinity regimes can be used to identify and characterize three distinct reaches: (1) riverine, (2) upper tidal, and (3) lower tidal along the river system (**Figure 12-31**). The Northwest Fork of the Loxahatchee River contains about 320 hectares [(ha); 791 acres] of riverine reach, 24 ha (59.3 acres) of upper tidal floodplain, and 45 ha (11.2 acres) of lower tidal floodplain (SFWMD and FDEP, 2009). The riverine reach is generally unaffected by salinity. The upper tidal reach experiences some saltwater intrusion during the dry season, and the lower tidal reach is highly influenced by tides and salinity in the water and soils.

Despite these enduring natural resources, the Loxahatchee Watershed was permanently altered by the construction of the Jupiter Inlet, which allows a larger tidal amplitude and saltwater intrusion. Drainage canal systems have also altered the natural pattern of freshwater inflow and inundation of the floodplain. Saltwater intrusion and reduced freshwater inflows to the riverine and upper tidal reaches of the Northwest Fork have particularly been issues. As a result, in 2003 the District adopted an MFL rule (Chapter 40E-8, F.A.C.) for the Northwest Fork of the Loxahatchee River. An MFL exceedance occurs when flow over the Lainhart Dam

(**Figure 12-31**) declines below 35 cfs (0.99 m^3/s) for more than 20 days or the average salinity at River Mile 9.1 (RM 9.1), expressed as a 20-day rolling average, exceeds 2 psu.

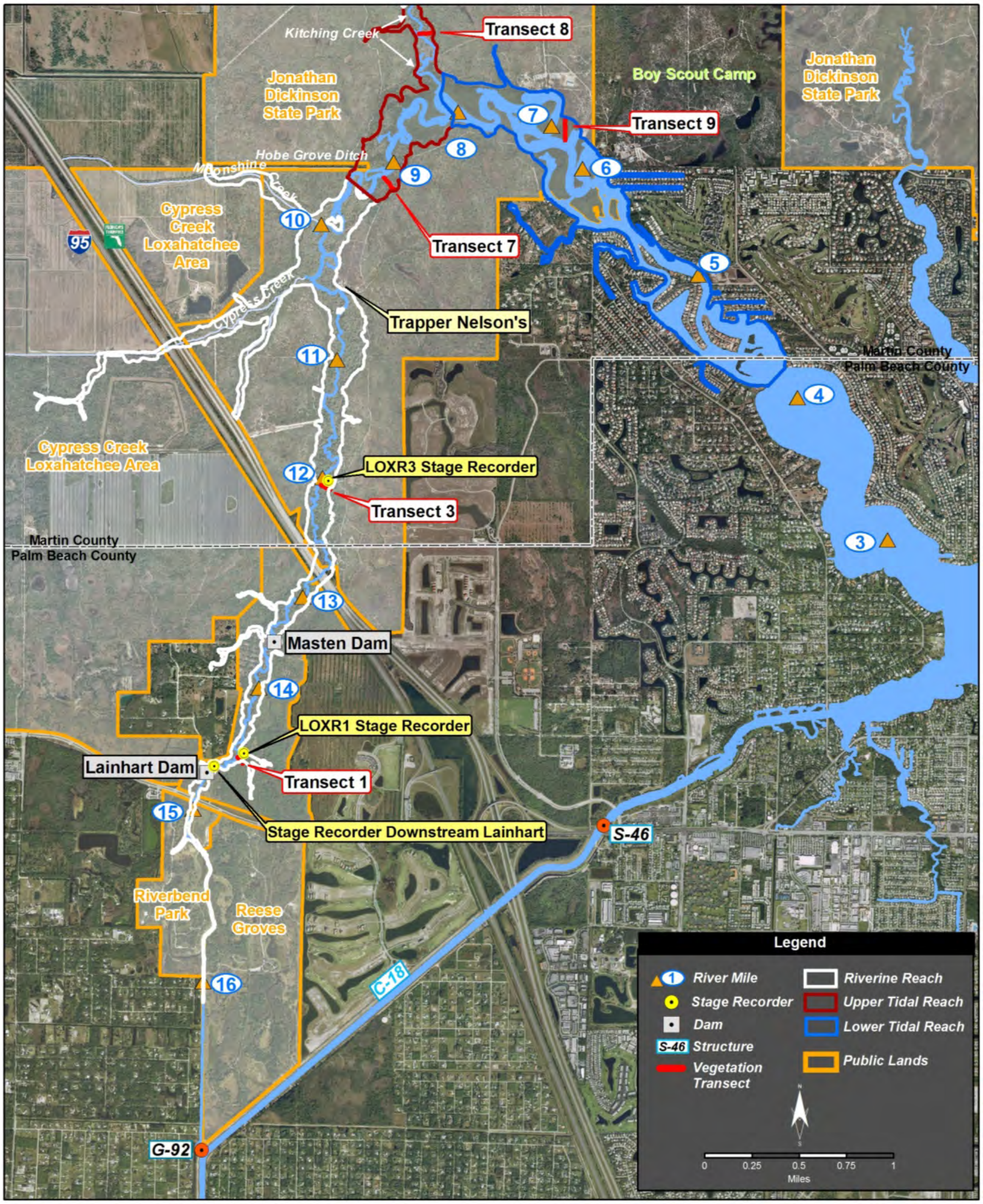

Figure 12-31. Reaches of the Loxahatchee River and monitoring locations.

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

A preferred "Restoration Flow Scenario" was selected by an interagency team that incorporated both dry and wet season hydrologic flow patterns, while providing the greatest ecological benefit to the freshwater riverine and tidal floodplains and with minimal impacts to the estuary. The Preferred Restoration Flow Scenario was established as "variable dry season flow between 50 cfs and 110 cfs (light blue line in **Figure 12-32**), with a mean monthly flow of 69 cfs over Lainhart Dam, providing an additional 30 cfs of flow from the downstream tributaries."

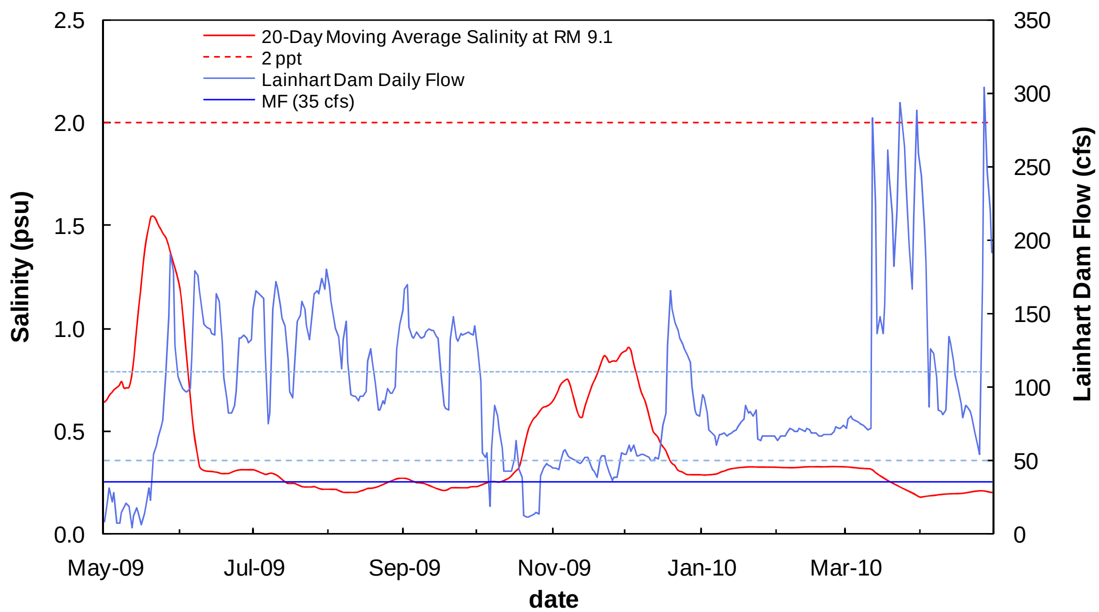

Figure 12-32. Flow at Lainhart Dam (light blue line) compared to the Preferred Flow Scenario (blue box) and minimum flow criterion (dark blue line) for WY2010.

Salinity and Freshwater Inflows

Five tide and salinity stations have been deployed in the Loxahatchee River since 2002, and were maintained in WY2010 to monitor salinity for compliance with the MFL rule, and assess the benefits of supplemental dry season flows in terms of salinity in the Northwest Fork and lower estuary. During the past water year, the flow over Lainhart Dam was mostly maintained above the MFL criterion of 35 cfs, except from April–May 2009 (25 days from April 27–May 20), and in October 2009 (eight days, October 6 and from October 20–26), (**Figure 12-32**). **Table 12-6** shows the monthly mean salinity at RM 9.1 and flow at Lainhart Dam. As a result of continuous freshwater inflow, the 20-day rolling average salinity at RM 9.1 did not exceed the 2 psu threshold throughout WY2010.

The L-8 Reservoir Project, a component of the CERP North Palm Beach County –Part 1 Project, is expected to provide 48,000 ac-ft of storage, which will increase dry season water availability to improve hydroperiods for the Loxahatchee Slough and provide restorative flows to the Northwest Fork. Structures G-161 and G-160 provide the necessary capacity for hydrologic and hydraulic connection within the basin. When the L-8 Reservoir is operational (projected for 2015), the project should deliver the necessary dry season flows to the Northwest Fork to meet the MFL requirement, and should maintain the desired salinity level along the river reach. The L-8 Reservoir Project is expected to improve the timing, distribution, and delivery of freshwater inflows to the Northwest Fork.

The Loxahatchee River District (LRD), a public utility, maintains a comprehensive water quality monitoring network, called River Keeper (started in 1991), in the freshwater and tidal segments of the Loxahatchee River (**Figure 12-33**) for about 30 parameters, including salinity, nutrients, chlorophyll, and bacteria (LRD, 2010). To explore temporal and spatial variations of water quality in the river, monthly mean salinity, Chl*a*, TN, and TP data for WY2009 and WY2010 were calculated for four areas: (1) riverine reach (using data from stations 67, 69, 95, and 100 in the Northwest Fork), (2) tidal reach (using data from stations 62 and 65 in the Northwest Fork), (3) station 72 in the Southwest Fork (to assess the impact of water from the C-18 canal through the S-46 structure), and (4) estuarine area (using data from stations 40 and 10) (**Figure 12-33**). WY2010 salinity monthly mean variations were relatively small compared to WY2009 mean variations, which were lower in August and September 2008 due to Tropical Storm Fay.

Table 12-6. Monthly mean flow at Lainhart Dam and salinity at River Mile 9.1 of the Northwest Fork of the Loxahatchee River.

Month-Year	Salinity at River Mile 9.1 (psu)	Flow at Lainhart Dam (cfs)
May–09	1.12	49.5
Jun–09	0.31	125.8
Jul–09	0.22	144.7
Aug–09	0.25	114.0
Sep–09	0.22	132.3
Oct–09	0.51	4461.8
Nov–09	0.80	48.0
Dec–09	0.32	85.9
Jan–10	0.32	72.9
Feb–10	0.33	69.5
Mar–10	0.23	168.9
Apr–10	0.20	127.4

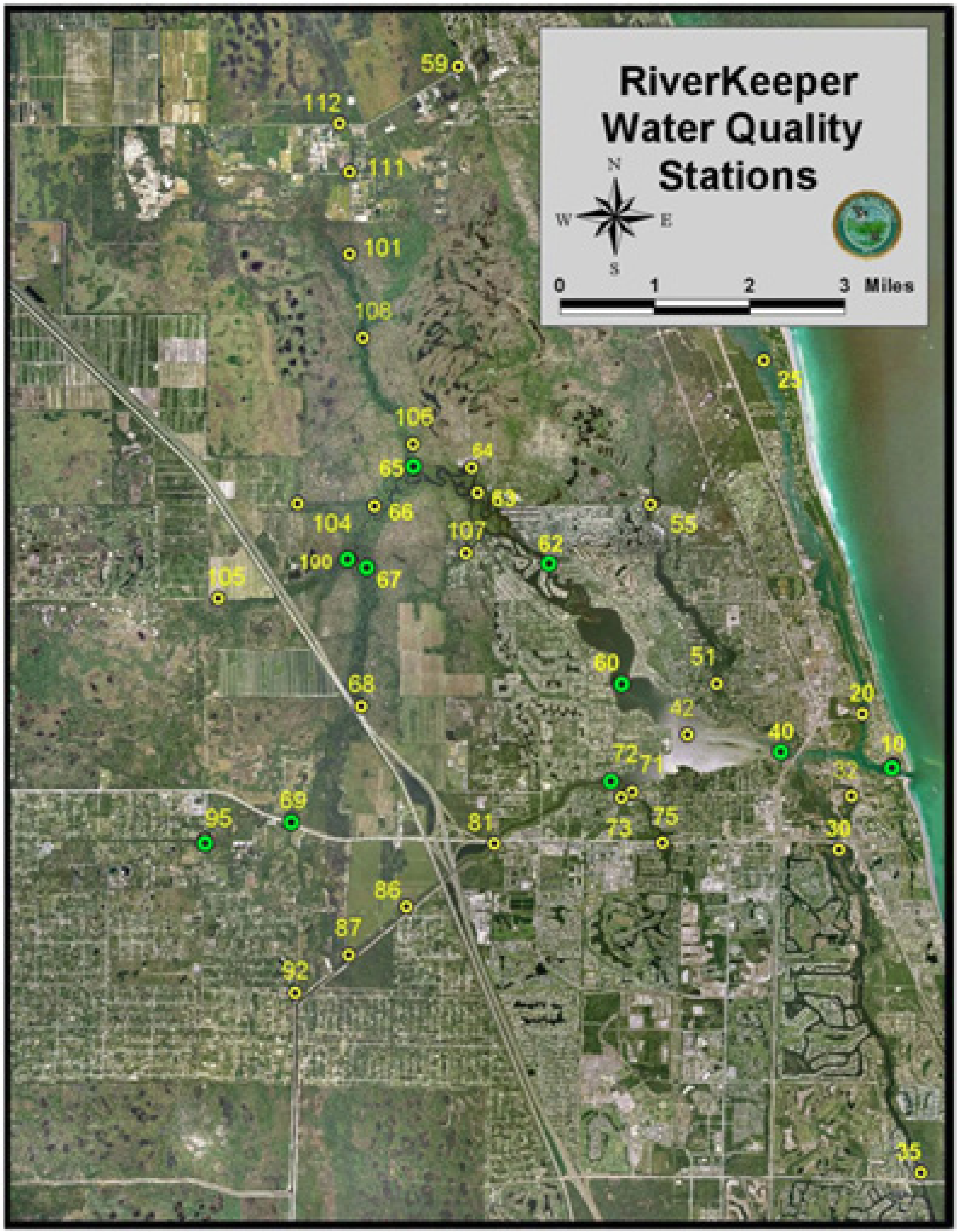

Figure 12-33. Loxahatchee River District RiverKeeper water quality monitoring sites. Green-colored stations are sampled monthly; yellow-colored sites are sampled bimonthly (LRD, 2010).

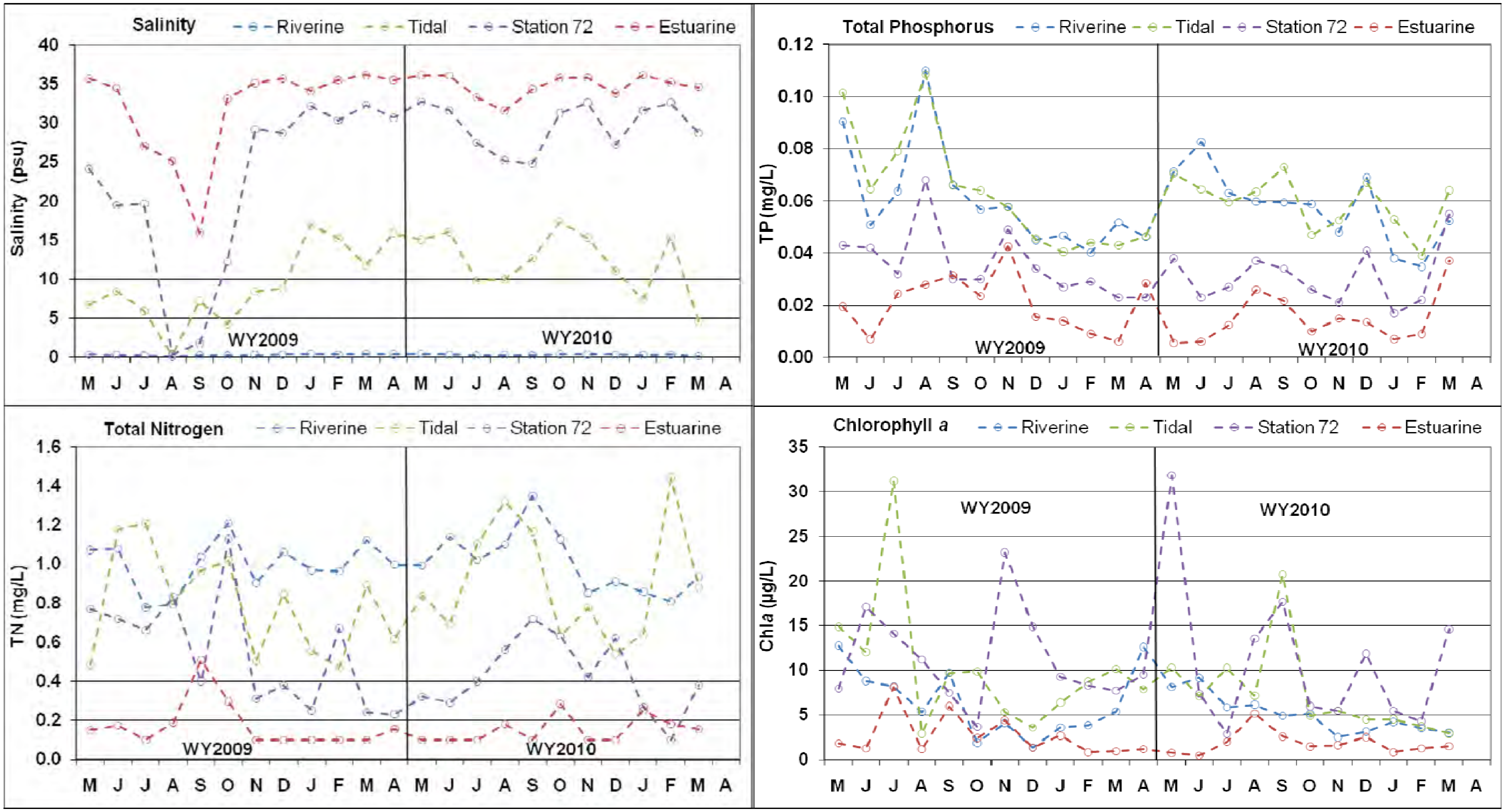

Figure 12-34. Comparison of monthly water quality over the past two years and at riverine, tidal, Southwest Fork (Station 72), and estuarine segments.

Nutrients

Qualitatively, based on the plots of monthly results, Chl*a* concentrations were generally the lowest in the estuarine area in both WY2009 and WY2010. Chl*a* concentrations were generally highest at station 72 in the Southwest Fork (**Figure 12-34**), although mean Chl*a* concentrations in the tidal area exceeded values at station 72 in July 2009 and September 2010. Mean Chl*a* concentrations in the riverine and tidal areas were generally between those at station 72 and in the estuary.

In general, the mean TN concentrations tended to be the lowest in the estuarine area, and highest in the riverine areas. The entire river system in WY2010 maintained almost the same TN concentrations as in WY2009 (**Figure 12-33**). TP concentrations followed the same general pattern as TN concentrations. These concentrations are in line with the interim water quality targets for the Loxahatchee River and Northwest Fork water quality monitoring sites (SFWMD, 2006). When the L-8 Reservoir is operational, some improvements in water quality are expected in the Northwest Fork.

Submerged Aquatic Vegetation

The most recent Loxahatchee Estuary seagrass map was completed by the LRD in 2007 (see the 2009 SFER – Volume I, Chapter 12). The LRD monitors five sites every other month (**Figure 12-35**), and plans to continue bimonthly monitoring at these sites for at least another year. Results from a previous monthly study and the bimonthly monitoring are shown in **12-36**. Two species of seagrass, shoal grass and Johnson's seagrass, dominated the upstream sites. Higher species richness and percent cover occurred farther downstream.

Hurricane impacts were observed at the two downstream monitoring sites during 2004–2005, Sand Bar and North Bay, where manatee grass was severely impacted and has yet to recover to pre-storm abundance. The transect monitoring method used prior to 2007 included point-intercept monitoring along four transects within each project area or site. The current patch-scale method uses the same general site boundaries but involves deploying 1 m^2 quadrats in a haphazard manner intended to represent the project area. Limited cross-calibration conducted by LRD staff at the North Bay site indicated that the methods are comparable in their ability to detect changes in coverage by seagrass species.

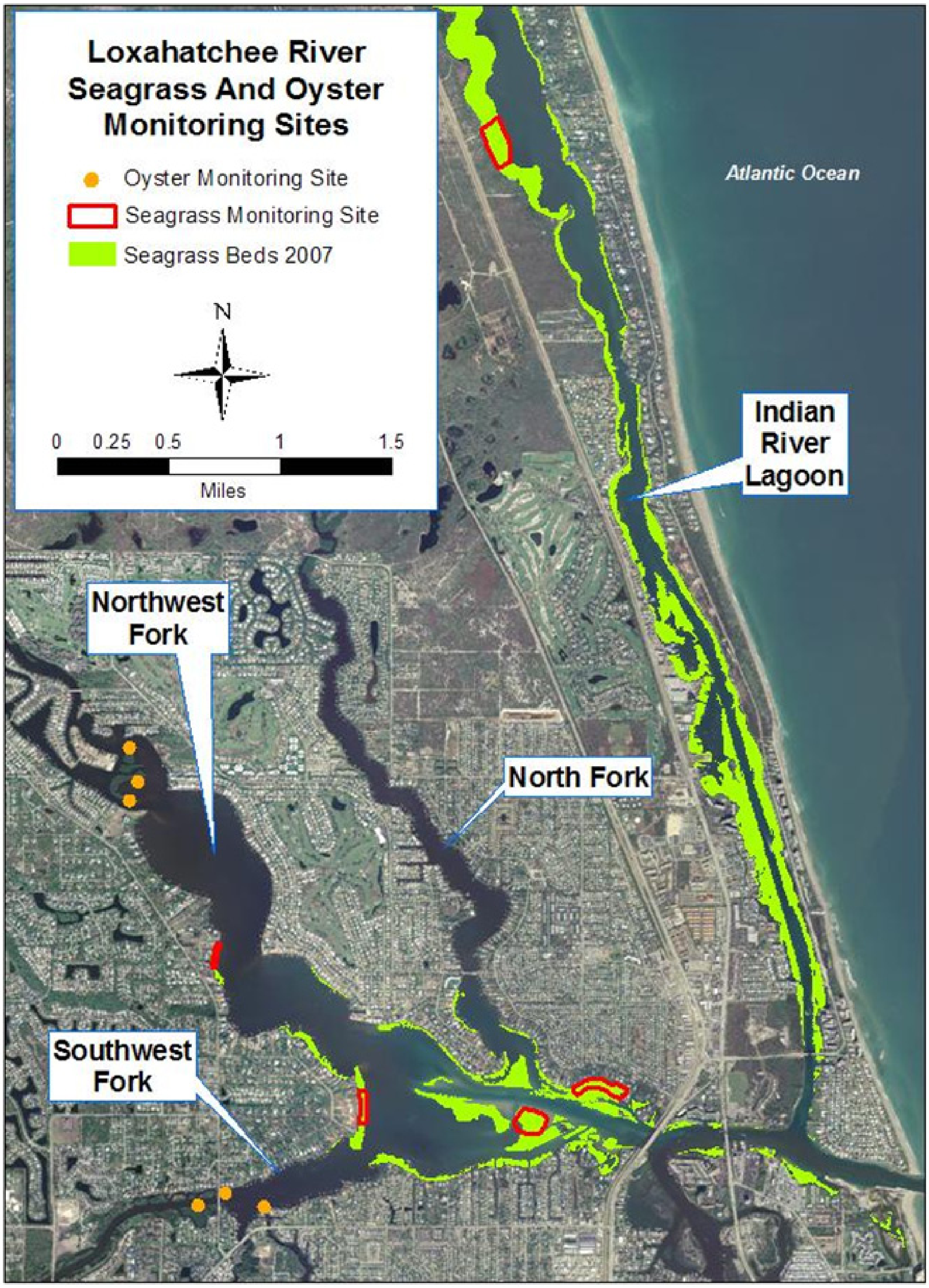

Figure 12-35. Seagrass and oyster monitoring locations [four Loxahatchee River Estuary (LRE) sites and one reference location in the Southern Indian River Lagoon (SIRL)].

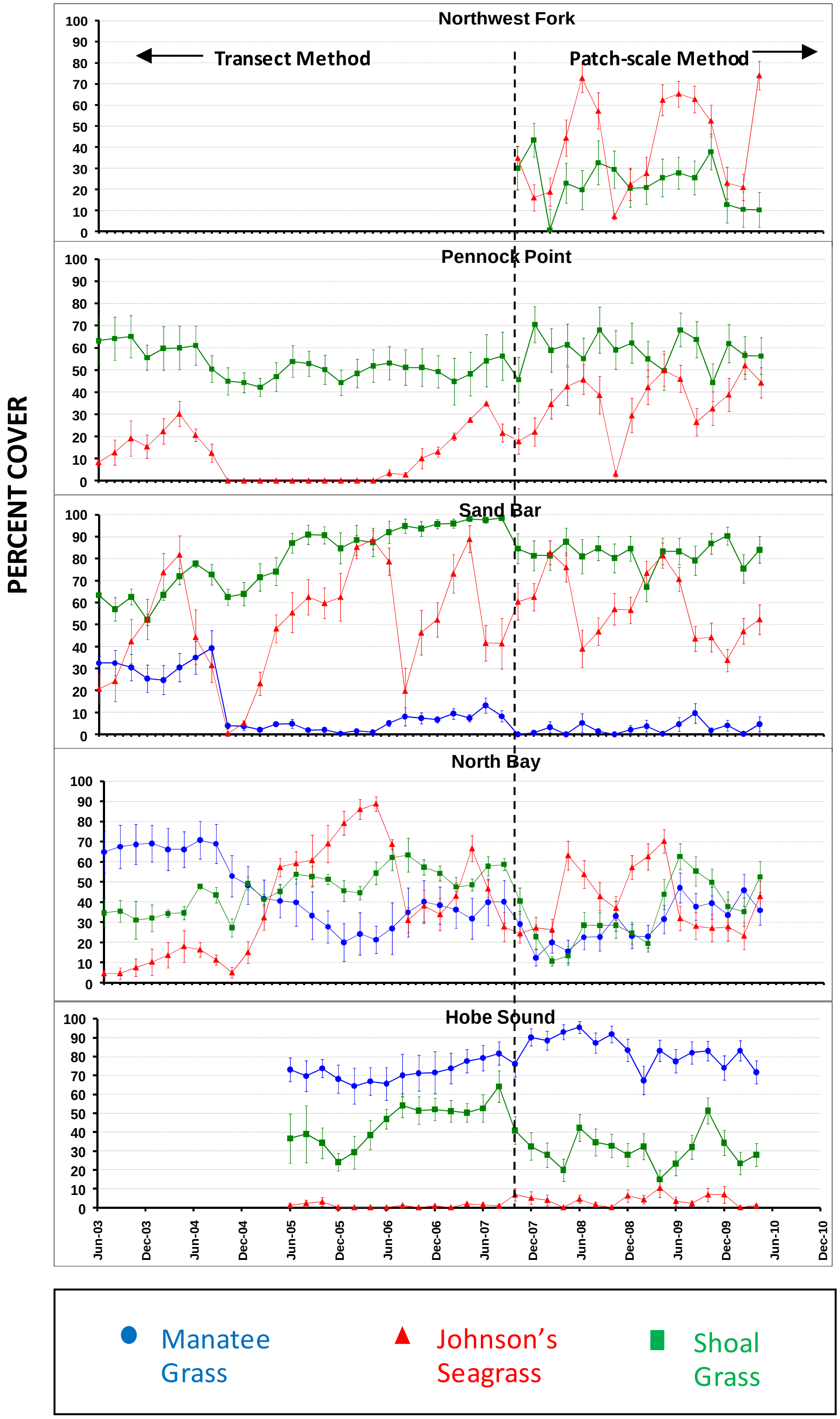

Figure 12-36. Summary of seagrass cover at five sampling sites from 2003 through 2009. Error bars represent ± 1 SE.

Eastern Oyster Abundance and Distribution

As a measure of the status of estuarine oyster beds, the District reports on the density of live and dead adult oysters, which are sampled on a seasonal (wet, dry) basis. Eastern oyster health and abundance have been monitored at three locations in both the Northwest and Southwest Forks since 2005. Stations were aggregated for this analysis (**Figure 12-35**).

Overall, monitoring results indicate a strong, positive relationship between higher observed salinity and increased live oyster density (**Figure 12-37**). The total number of oysters was depressed early in 2005. Oyster density peaked through 2006–2007 before another dramatic decline in 2007–2008. After reaching minimum levels early in 2008, live oyster numbers began to rebound throughout 2009 and into WY2010. These increases occurred despite low salinity in the wet seasons of WY2008 and WY2009.

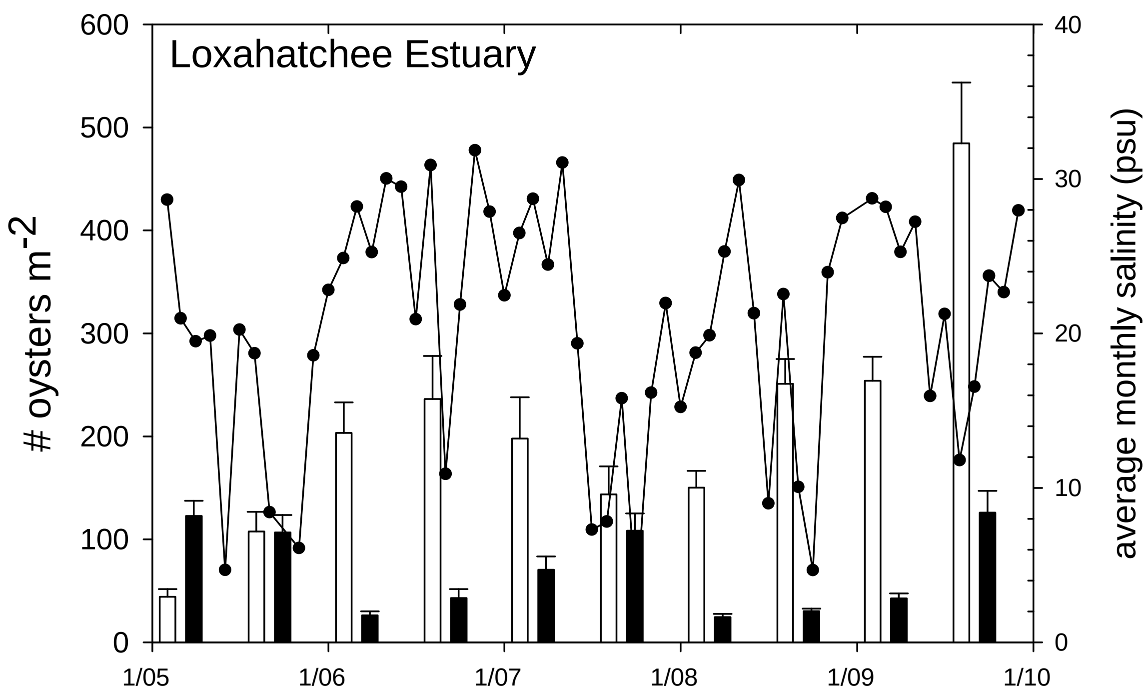

Figure 12-37. Live and dead oyster densities per square meter (left axis) and salinity (right axis) from spring 2005 to spring 2009 in the LRE.

Floodplain Vegetation

Reestablishment of sufficient hydroperiod (i.e., duration and depth of flooding) within the riverine floodplain forest in the upper portions of the Northwest Fork is a key objective. The major concern in the riverine reach is the lack of post-development inundation. This lack of inundation encourages the intrusion of native transitional, upland, and nonnative plant species; modifies the subcanopy vegetation into multiple forest types of communities; and reduces the utilization of the floodplain swamp by aquatic organisms. The tidal portions of the river have experienced a loss of freshwater vegetational species [e.g., bald cypress (*Taxodium distichum*)], and a shift to more saltwater-tolerant plants [e.g., red mangrove (*Rhizophora mangle*) and white mangrove (*Laguncularia racemosa*) swamp] associated with increases in salinity and tidal amplitude (Roberts et al., 2008). Similar community changes were noted in USGS studies of the Apalachicola River (Darst et al., 2008) and lower Suwannee River (Light et al., 2002). Using information from the Apalachicola River study and a review of scientific literature, the District developed a Floodplain Wetland and Salinity Index for the 27 canopy species of the Loxahatchee River (**Table 12-7**). Canopy communities were examined in 2003 and 2009, and shrub and groundcover communities were examined in 2003, 2007, and 2010 (SFWMD and FDEP, 2009).

In comparing results from the 2003 and the 2009 canopy surveys, several changes were noted in the abundance of canopy species along 10 monitoring transects (SFWMD, 2009) (**Table 12-8**). Losses occurred in freshwater species cabbage palm (*Sabal palmetto*) from 12.4 to 9.8 percent, bald cypress, from 9 to 7.6 percent, and red maple (*Acer rubrum*) from 3.5 to 2.4 percent. The abundance of saltwater-tolerant white mangrove increased from 22.5 to 29.3 percent and red mangrove increased from 14.2 to 17.9 percent. The freshwater species, pond apple (*Annona glabra*), also slightly increased from 13 to 14 percent. Some tree loss can be attributed to lasting impacts caused by Hurricanes Frances, Jeanne, and Wilma in 2004 and 2005. However, ground cover stem count results from the 2003, 2007, and 2010 surveys indicate that pond apple and bald cypress increased in 2010, presumably due to the wet winter months of 2009 and 2010, and several years of recovery from hurricane damage.

The likely main factors that affected changes in canopy between 2003 and 2009 in the Loxahatchee River floodplain were the 2004 and 2005 hurricanes and continued saltwater intrusion. The effects of Hurricanes Frances and Jeanne are summarized in a 2009 vegetation report (SFWMD and FDEP, 2009, Appendix K). Forty-eight percent of the trees examined in plots in the riverine reach were damaged by wind, while 42 and 54 percent of the trees on the upper and lower tidal reach, respectively, were damaged. Most of the damage consisted of broken branches, and broken trunks and tipovers occurred to a lesser degree. Eighteen deaths (mostly broken trunks) were reported in riverine plots, and 11 and five deaths were reported in upper and lower tidal plots, respectively. Cabbage palm and wax myrtle (*Morella cerifera*) had the highest number of mortalities (11 and 9 percent, respectively). Ten of the cabbage palm deaths appeared to be related to salinity, however. The increases observed in white and red mangroves are probably a result of the increase in post-hurricane light levels within the forest, followed by an increase in the remaining multi-trunk trees reaching canopy size (i.e., greater than 5 cm) by the 2009 survey. Abundance of exotic canopy species remains low on the Loxahatchee River floodplain due to the high abundance of native species and ongoing exotic eradication projects within Jonathan Dickinson State Park (SFWMD and FDEP, 2009). See Chapter 9 of this volume for information on nonindigenous and invasive species and their management.

Table 12-7. Vegetative species of the Loxahatchee River floodplain and associated wetland and salinity indexes.

Scientific Name	Common Name	*Wetland Indicator	Floodplain Indicator Category	Wetland Index Value	Salinity Index
Annona glabra	pond apple	OBL	sw	1	4
Fraxinus caroliniana	pop ash	OBL	sw	1	2
Laguncularia racemosa	white mangrove	FACW+	sw	1	5
Rhizophora mangle	red mangrove	OBL	sw	1	5
Taxodium distichum	bald cypress	OBL	sw	1	2
Acer rubrum	red maple	FACW	lo blh	2	2
Cephalanthus occidentalis	button bush	OBL	lo blh	2	2
Persea palustris	swamp bay	OBL	lo blh	2	2
Salix caroliniana	Carolina willow	OBL	lo blh	2	2
Syzygium cumini	java plum	FAC	lo blh	2	3
Carya aquatica	water hickory	OBL	hi blh	3	1
Chrysobalanus icaco	cocoplum	FACW	hi blh	3	2
Citrus spp.	citrus	FACU	hi blh	3	1
Psidium cattleianum	strawberry guava	FAC	hi blh	3	2
Quercus laurifolia	laurel oak	FACW	hi blh	3	1
Roystonea regia	royal palm	FAC	hi blh	3	1
Ficus aurea	strangler fig	FACW	h	4	1
Ficus microcarpa	Indian laurel fig		h	4	1
Myrica cerifera	wax myrtle	FAC+	h	4	2
Persea borbonia	red bay	FACW	h	4	2
Quercus virginiana	live oak**	FACU+	h	4	1
Rapanea punctata	myrsine	FAC	h	4	2
Sabal palmetto	cabbage palm**	FAC+	h	4	4
Pinus elliottii	slash pine	FACW	u	5	1
Quercus myrtifolia	myrtle oak		u	5	1
Schinus terebinthifolius	Brazilian pepper	FAC	u	5	2
Serenoa repens	saw palmetto	FACU	u	5	1

*National Wetlands Inventory (1996) or Florida Wetland Plants: An Identification Manual (1998)

OB = obligate wetland species

FAC = facultative equally likely to found in wetland and non-wetland

FACW = facultative wetland, usually wetland but sometimes not

FACU = facultative upland, usually upland, but sometimes not

** live oak = mesic hammock; cabbage palm = hydric

+ = more frequently found in wetter areas

Salinity Index: 5 = 30–20 practical salinity units (psu); 4 = 19–10 psu; 3 = 9–5 psu; 2 = 4 psu, 1 = 1–0 psu

Table 12-8. Total number (abundance) and relative abundance (percentage) of canopy species in the 2003 and 2009 surveys.

Species	Abundance Total #		Relative Abundance %Total	
	2003	2009	2003	2009
Annona glabra	228	285	13	14
Acer rubrum	61	48	3.5	2.35
Avicennia germinans		1		0.05
Carya aquatica	33	29	1.9	1.4
Chrysobalanus icaco		3		0.15
Cephalanthus occidentalis	3	9	0.2	0.44
Citrus aurantium	4	0	0.2	0
Ficus aurea	5	5	0.3	0.24
Fraxinus caroliniana	139	143	7.9	7.02
Ilex cassine	5	4	0.3	0.2
Laguncularia racemosa	396	598	22.5	29.34
Myrica cerifera	117	74	6.6	3.63
Morus rubra		1		0.05
Psidium cattleianum	4	1	0.2	0.05
Pinus elliottii	10	10	0.6	0.49
Persea borbonia	6	0	0.3	0
Persia palustris	1	2	0.1	0.01
Quercus laurifolia	18	17	1	0.83
Quercus virginiana	24	21	1.4	1.03
Rhizophora mangle	250	365	14.2	17.91
Rapanea punctata	1	1	0.1	0.05
Roystonea regia	4	4	0.2	0.2
Salix caroliniana	19	21	1.1	1.03
Syzygium cumini	3	3	0.2	0.15
Senna pendula	0	1	0	0.05
Sabal palmetto	219	200	12.4	9.81
Serenoa repens	1	2	0.1	0.01
Schinus terebinthifolius	49	29	2.8	1.4
Taxodium distichum	158	156	9	7.65
Toxicodendron radicans	0	1	0	0.05
Vitis shuttleworthii	1	4	0.1	0.2
Total	**1,760**	**2,038**	**100**	**100**

Lake Worth Lagoon

Bounded by barrier islands, LWL is located in eastern Palm Beach County (**Figure 12-38**). The estuary is about 35.4 km (22 miles) long and typically 1.8–3 m (6–10 ft) in depth. Tidal exchange with the Atlantic Ocean occurs at North Lake Worth (Palm Beach) and South Lake Worth (Boynton) inlets. The LWL Watershed encompasses about 1,165 km^2 (450 mi^2) of primarily urbanized land (Taylor Engineering, Inc., 2009).

Lake Worth Lagoon can be divided into three geographical segments (north, central, and south) based on factors such as water quality, circulation, and physical characteristics. The north segment includes waters north of Flagler Memorial Bridge to PGA Boulevard. The central segment includes waters form the Flagler Memorial Bridge to Lake Worth Bridge, and the south segment includes waters from Lake Worth Bridge to the Boynton Beach Bridge at Ocean Avenue (**Figure 12-38**). 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 C-51 canal discharge turns northward in the lagoon and about 25 percent turns southward (Chiu et al., 1970).

Figure 12-38. Lake Worth Lagoon (LWL).

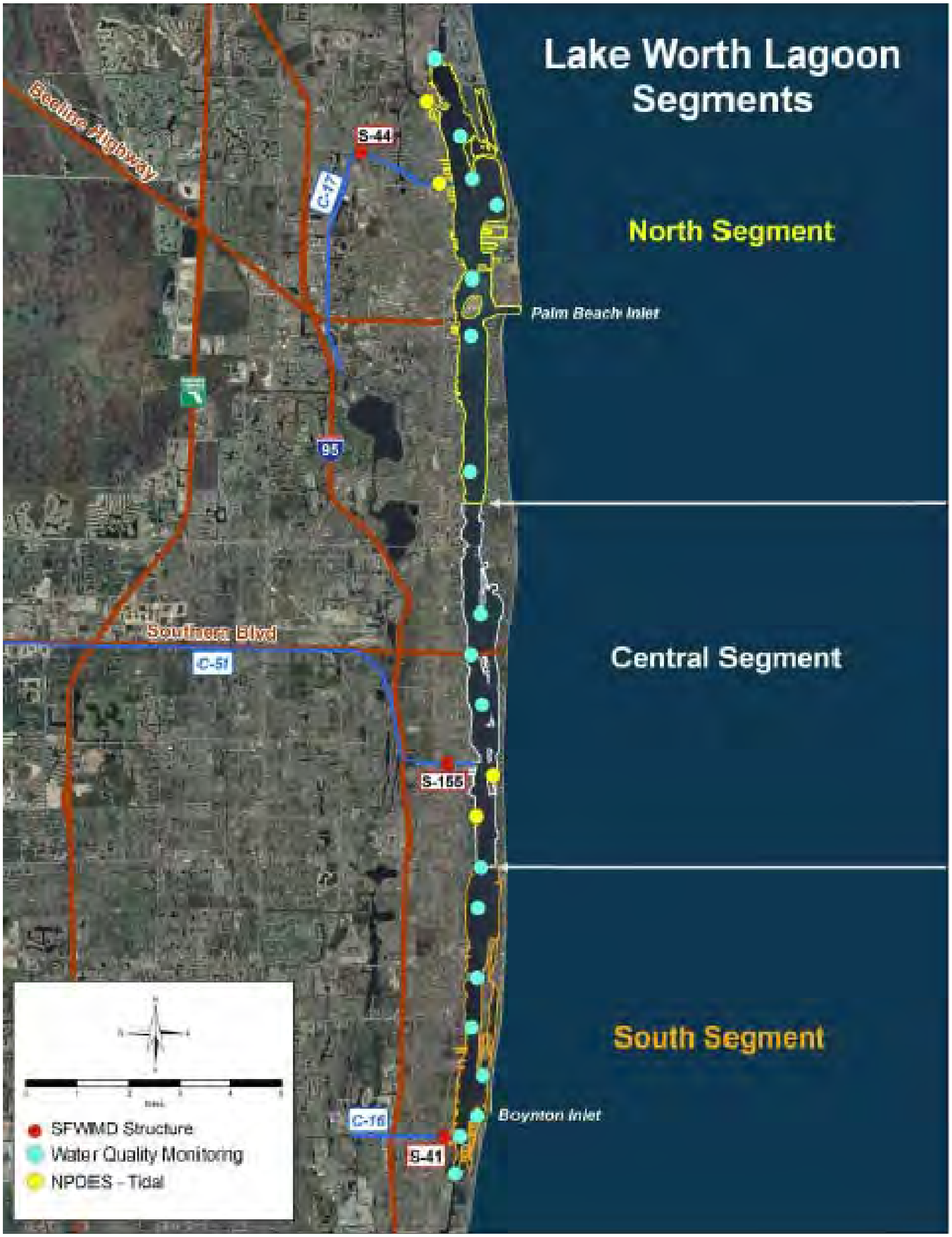

Figure 12-39. LWL segments and water quality stations established in 2007.

Basins on the east side of the LWL Watershed, where medium- and high-density residential land uses are most common (C-17, C-16, C-51 East, and LWL sub-basins), also showed elevated nutrient levels. In the C-17 Basin, where commercial and industrial land uses are most common, values of total Kjeldahl nitrogen (TKN) were among the highest reported (Taylor Engineering, Inc., 2009). The available data allowed the calculation of preliminary annual stormwater loads (with respect to specific land uses) from the three main canals (C-17, C-51, and C-16) that drain different parts of the basin and discharge to LWL. The annual loads from each canal varied significantly by year; however, year-to-year differences in annual loads did not vary consistently among the canals. The comparison between annual and year-to-year loads suggests that rainfall patterns within the basin as well as land use differences affected annual pollutant loading from different locations within the basin (Taylor Engineering, Inc., 2009).

Like many of South Florida's heavily urbanized coastal areas, anthropogenic changes have negatively affected LWL. Sedimentation and turbidity are problematic. The primary concern is that excessive fresh water is discharged at times into the lagoon. Differences observed in the macroinvertebrate community structure have been attributed to physical effects caused by the velocity of fresh water from the C-51 canal, and variable salinity in the lagoon (Criger, et al., 2005). The average daily flow is 419 cfs (912 m^3/s), but can reach more than 7,000 cfs (198 m^3/s). Salinity can be below thresholds considered optimum for key species, such as the eastern oyster and Johnson's seagrass. An evaluation target was established by an interagency team in 2007 to protect seagrasses and oysters near the outfall of the C-51 canal (SFWMD, 2007a). Therefore, current performance measures are targeted at limiting the discharges from the C-51 canal so that salinity does not stay below 15 psu for more than 26 days or less than 5 psu more than seven days from April–July each year.

Data review and exploratory analysis of the water quality data indicate that DO, TKN, orthophosphate (OP), and TP are the parameters of concern in the LWL Watershed. Water quality samples from basins west of the LWL Watershed (L-8, C-51 West, Acme B, and the C-16 North basins), where agricultural uses comprise a large fraction of the total land use, showed elevated nutrient inputs (NO_2 + NO_3, TKN, OP, and TP) (Taylor Engineering, Inc., 2009). These findings suggest that agricultural land uses (e.g., pasture, row crops, and citrus) tend to produce higher concentrations of nitrogen and phosphorus in runoff. A comparison of results from different seasons indicates that wet season concentrations generally exceed dry season values.

Salinity and Freshwater Inflows

Freshwater inflows and salinity plots for the three regions are shown in **Figures 12-40**, **12-41**, and **12-42**. Generally, the freshwater inflow in WY2010 to LWL is close to the historical average. The estuary was affected by relatively high inflows in March and April 2010, especially the central region where salinity was below 20 psu in April 2010. **Figure 12-43** shows the daily and long-term average flow in the C-51 canal at structure S-155. The higher dry season flows in WY2010 compared to dry season flows in WY2009 reflect the El Niño conditions experienced this water year.

Phase 1 of the Acme Basin B Discharge Project, which includes the C-51 pump station installations and C-1 canal improvements, was completed in 2010. This project diverts urban runoff in Palm Beach County to the C-51 canal, where it is then directed to Stormwater Treatment Area 1 East (STA-1E) for treatment before discharge to the Arthur R. Marshall Loxahatchee National Wildlife Refuge. Along with environmental and flood control benefits, this project may reduce some of the harmful discharges to the LWL, thereby reducing the frequency of low salinity events.

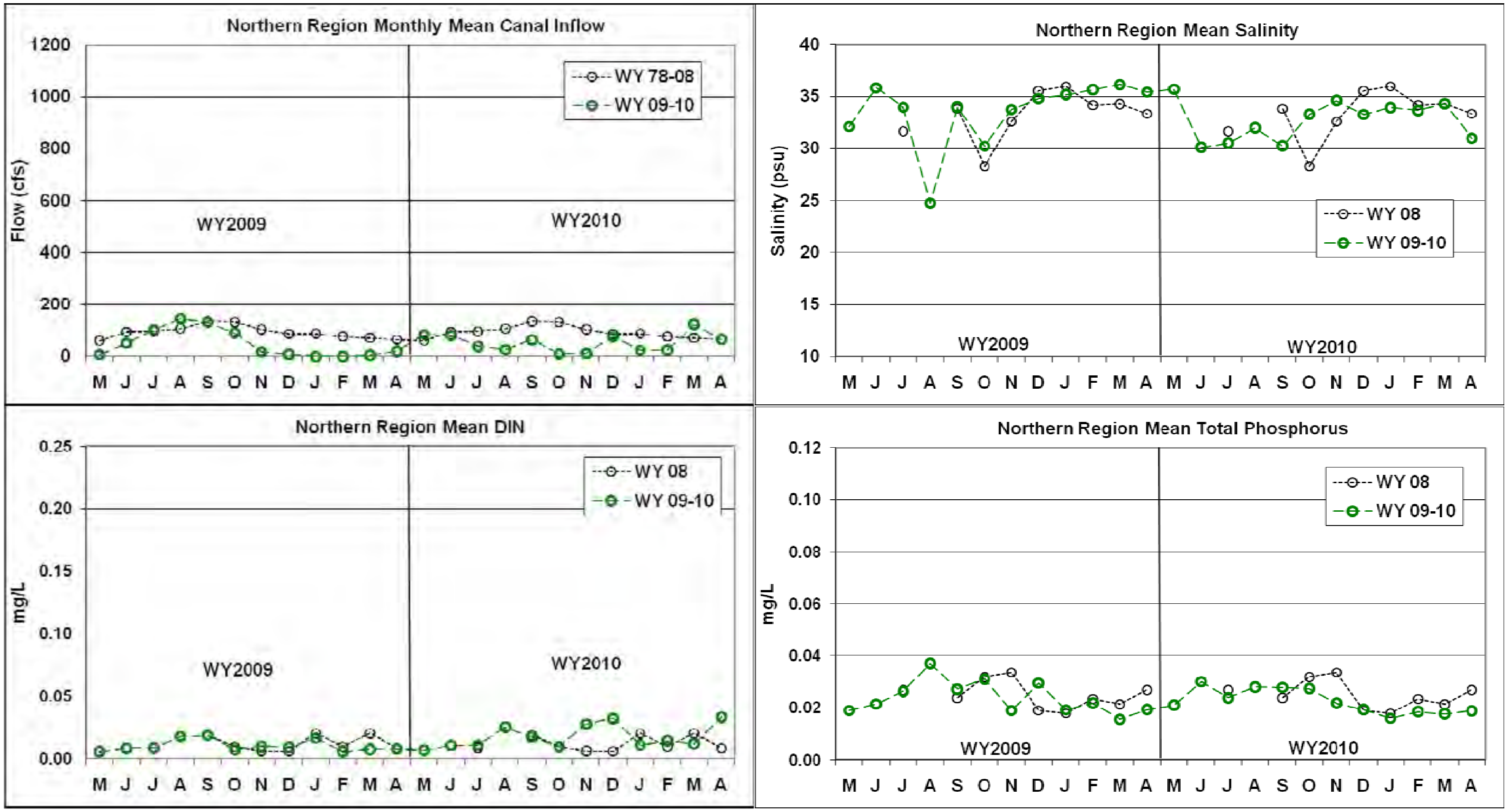

Figure 12-40. Monthly mean regional freshwater canal inflows and water quality in the northern region.

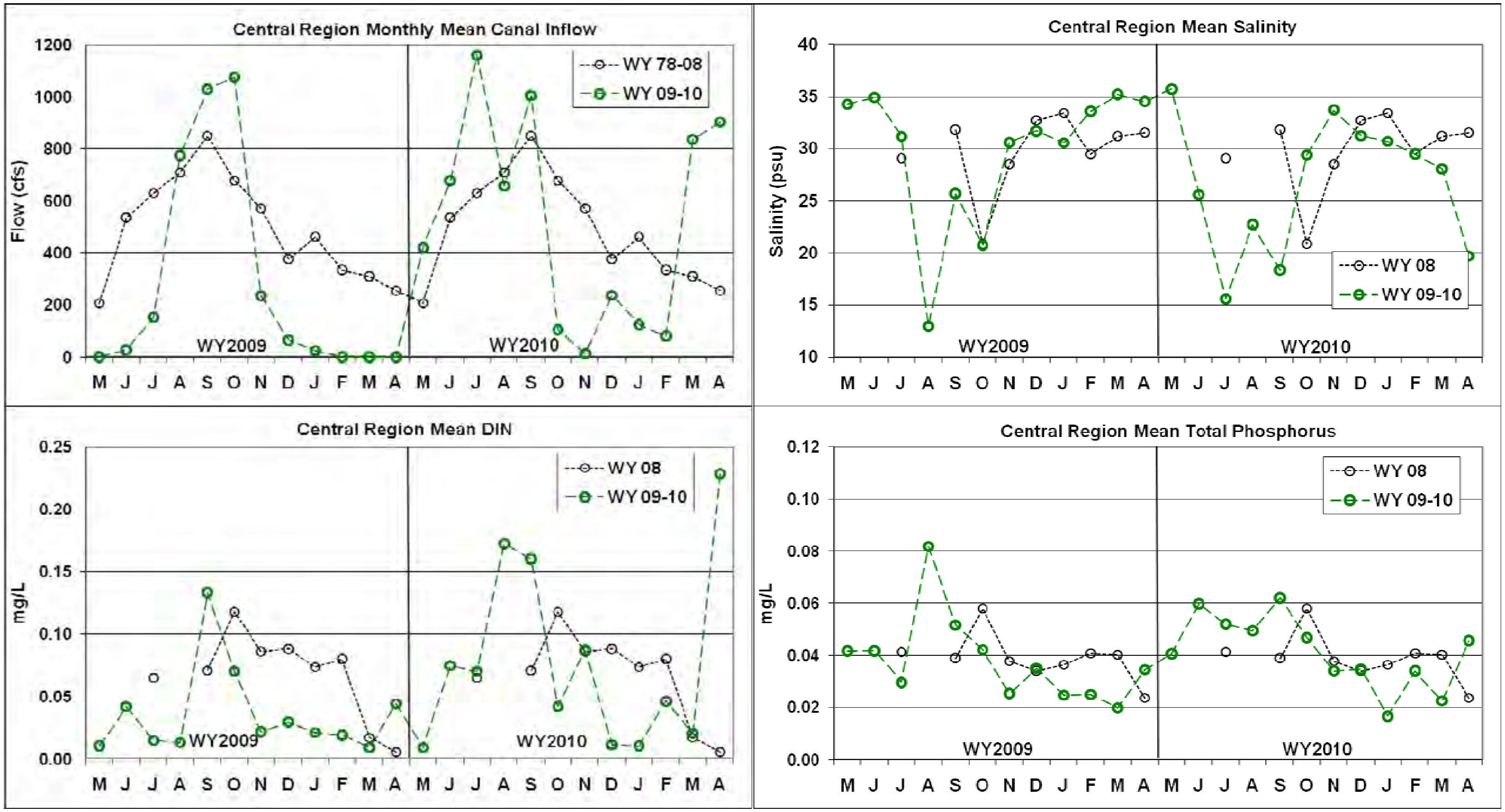

Figure 12-41. Monthly mean regional freshwater canal inflows and water quality in the central region.

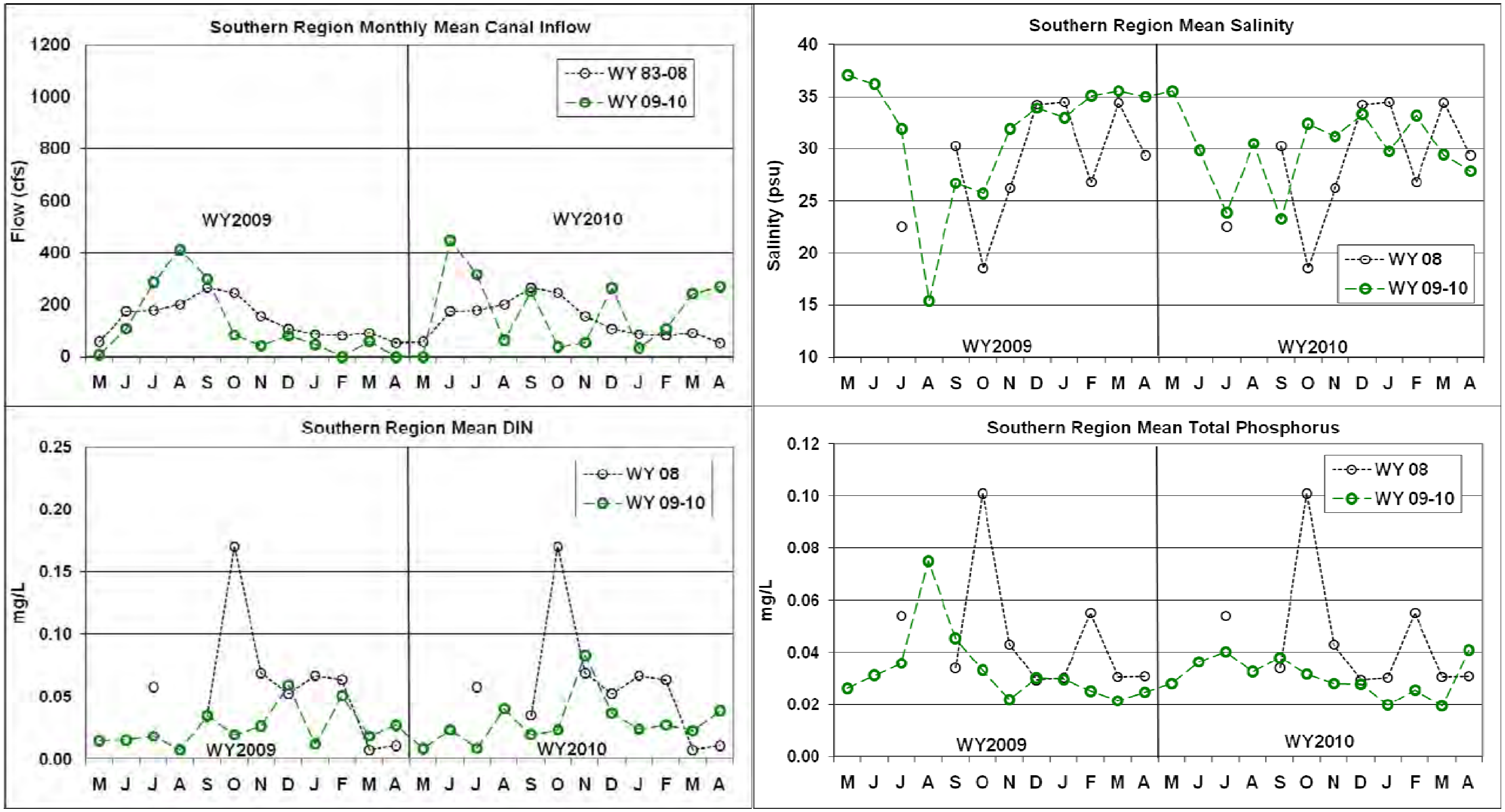

Figure 12-42. Monthly mean regional freshwater canal inflows and water quality in the southern region.

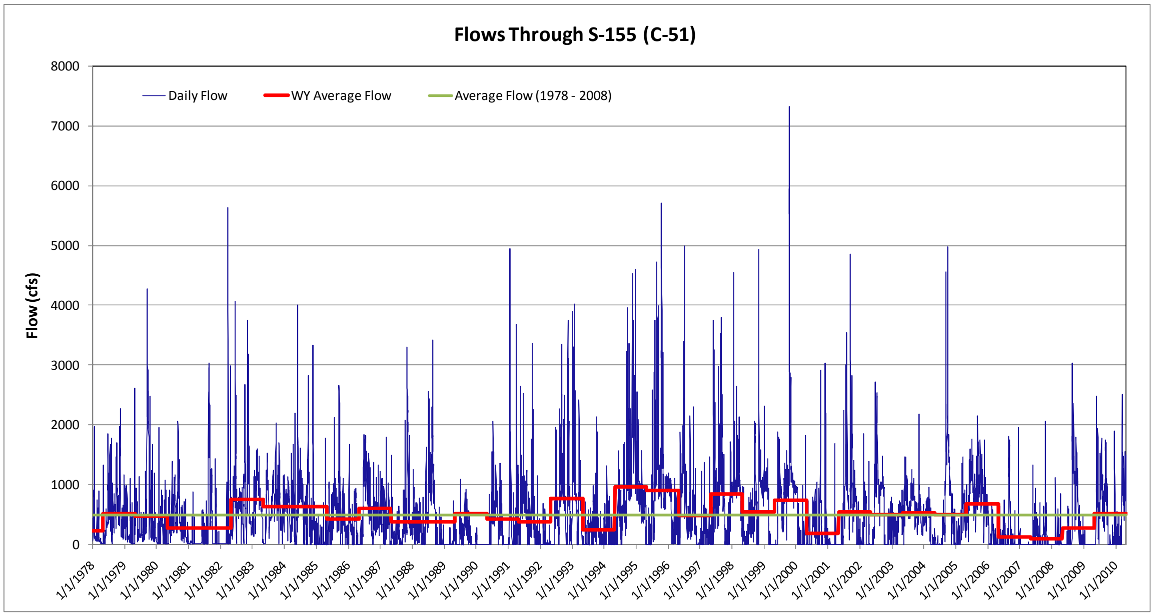

Figure 12-43. Long-term flow from the C-51 canal through S-155 into central LWL.

Nutrients

The LWL water quality monitoring program was revamped in 2007 when 12 stations were added to the existing network of 10 stations. Monthly mean nutrient concentrations were calculated for each LWL region (north, central, and south) (**Figures 12-40**, **12-41**, and **12-42)**. The plots indicate that both regional mean DIN and TP concentrations were lowest within the northern region of the lagoon. DIN and TP concentrations increased during times when freshwater inflows increased in each region. Qualitatively, neither DIN nor TP levels were substantially different in WY2009 compared to WY2010. The Acme Basin B Discharge Project is expected to improve water quality in the estuary.

Suspended Solids

Over the years, a layer of anaerobic muck has covered a large area of the lagoon. Muck sediments are thought to inhibit seagrass colonization and are associated with decreased diversity of benthic invertebrates. A portion of these sediments is very fine-grained and remains 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 total suspended solids (TSS) load from each canal was calculated using data from 1990–2008 (Taylor Engineering, Inc., 2009). **Table 12-9** presents the minimum, mid-range, and maximum loads from the C-17, C-51, and C-16 canals. The mid-range values were defined as the ninth of the all years' values ranked from lowest to highest (18 years for C-51; 19 years for C-17 and C-16). Minimum annual TSS loads from the three canals (**Figure 12-44** and **Table 12-9**) varied by less than a factor of 2, with the C-51 canal providing almost half the total loading to the LWL. Minimum, mid-range, and maximum annual per-acre loadings (**Table 12-9**) did vary widely and did not reflect strongly the differences in total areas drained by the canals. Note also that the minimum, maximum, and mid-point loadings did not occur in the same years for the different basins.

The number of TSS samples reported per year varied between three and 12 for the C-17 (no data for 1997) and C-51 (no data for 2003) canals, and between four and 12 for the C-16 canal (no data for 2006).

The construction and operation of water storage and treatment facilities in the C-51 Basin, in combination with the use of sediment traps, should reduce sediment inflow. The Acme Basin B Discharge Project may treat some of the runoff. These projects are expected to reduce TSS loads to the LWL through the C-51 canal.

Table 12-9. Total suspended solids (TSS) load summary for C–17, C–51, and C–16 canals.

	Minimum Load		Mid-Range of Loads		Maximum Load	
Canal	**Year**	**metric ton/yr (ac/yr)**	**Year**	**metric ton/yr (ac/yr)**	**Year**	**metric ton/yr (ac/yr)**
C-17	2002	2,449 (0.109)	2001	3,655 (0.162)	1994	10,259 (0.445)
C-51	2007	3,709 (0.033)	1993	19,434 (0.172)	2005	40,710 (0.359)
C-16	1996	2,251 (0.006)	1998	8,180 (0.239)	1999	12,709 (0.371)

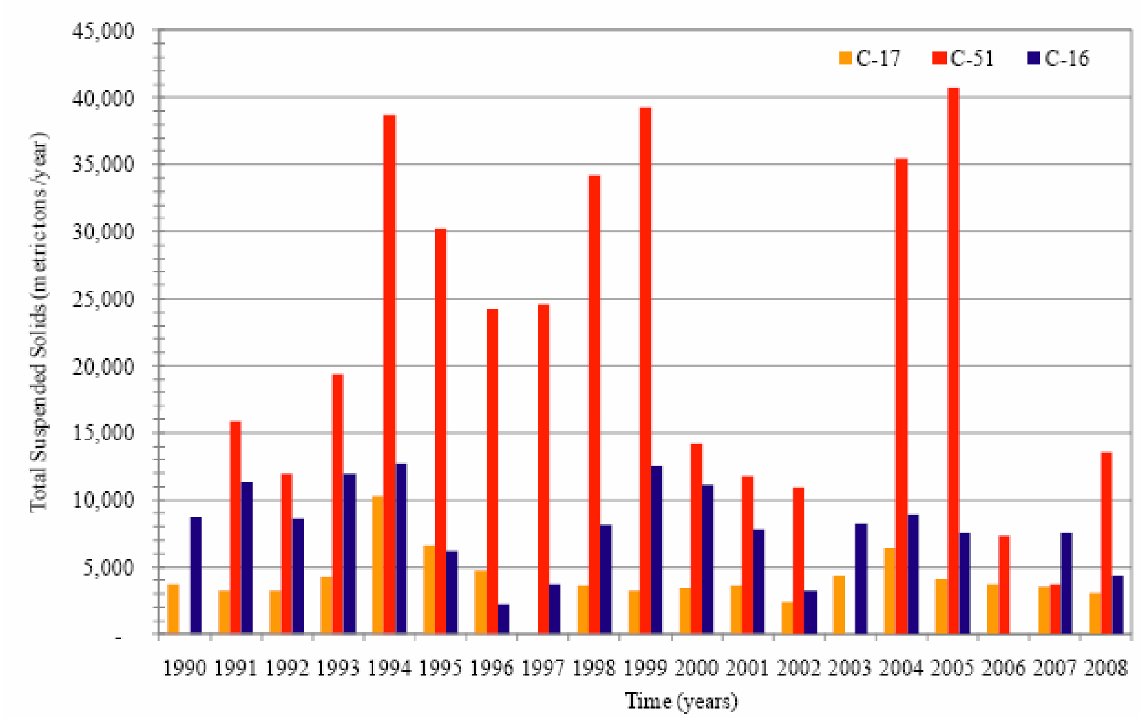

Figure 12-44. Total suspended solids annual load to the LWL from the C–17, C–51, and C–16 canals.

Submerged Aquatic Vegetation

Beginning in December 2008, SAV patch-scale monitoring was conducted bimonthly at five locations in the LWL (**Figure 12-45**). The sites were located near discharges from the C-17 and C–51 canals.

The C-17 sites were dominated by canopy-forming species (C-17A: manatee grass and C-17B: shoal grass), and the C-51 sites were dominated by Johnson's seagrass, a diminutive seagrass species whose canopy height is typically < 3 cm (**Figures 12-46** and **12-47**). At the C-17A site, percent cover of manatee grass remained at or above 80 percent. Percent cover at the C-17B site was consistently lower than at the C-17A location; with shoal grass percent cover ranging from 43 to 70 percent. Seagrass species differ in their response to water quality (Kenworthy and Fonseca, 1994; Woodward-Clyde, 1998).

Johnson's seagrass dominated all three of the C-51 sites with C-51C typically supporting the greatest percent cover (typically > 80 percent cover; the other two sites typically supported < 60 percent cover). It is interesting to note that sharp declines in Johnson's seagrass coverage in WY2009 were followed by recovery at all three locations in WY2010. The decline at C-51C occurred from October 2009 (93 percent) through December 2009 (38 percent). The steep declines at the other two sites occurred from June through August 2009. By April 2010, recovery was apparent at all sites.

Improved salinity and water clarity resulting from the Acme Basin B Discharge Project should improve seagrass densities within the lagoon.

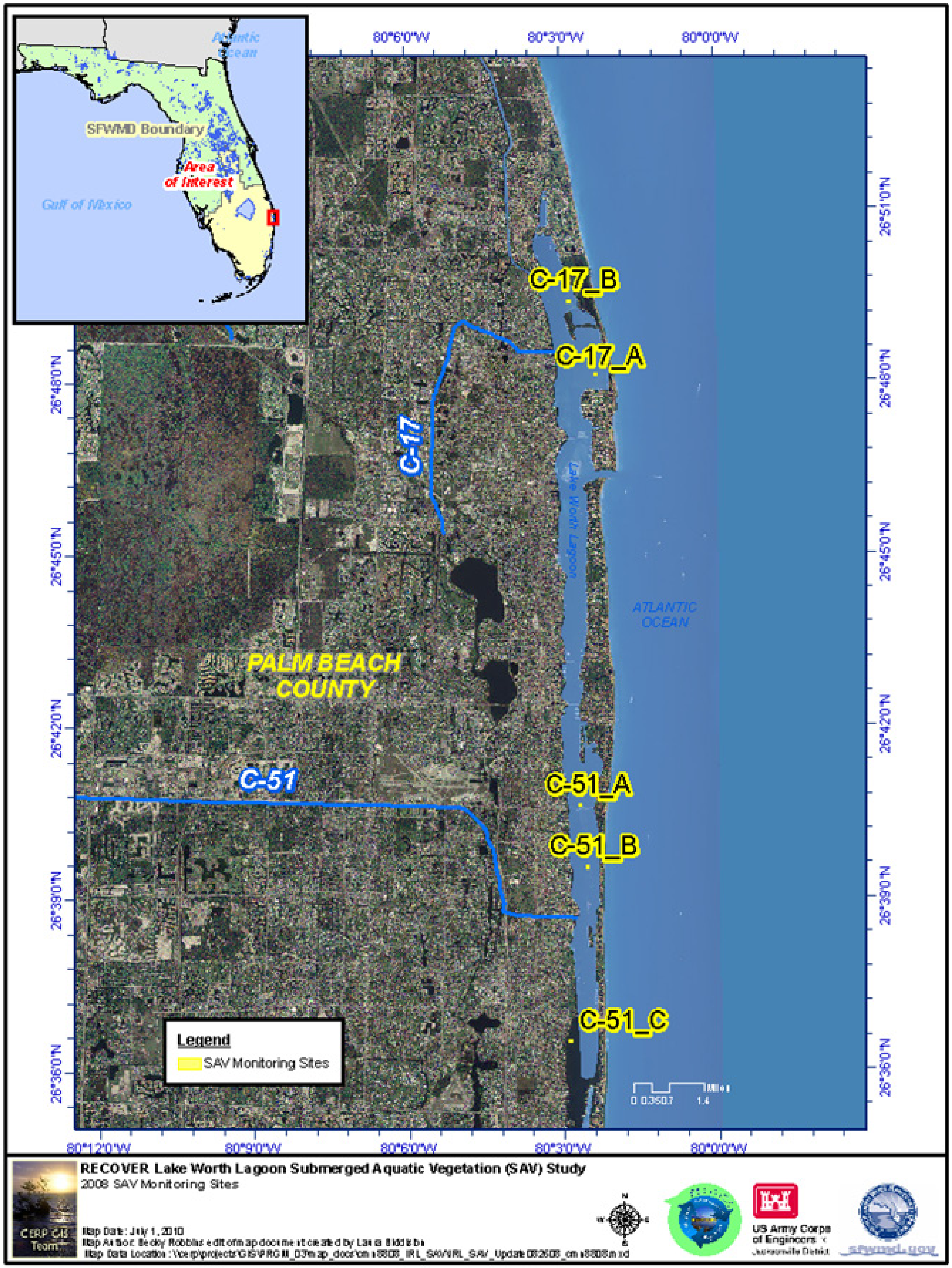

Figure 12-45. LWL seagrass monitoring locations (two near the C-17 discharge and three near the C-51 discharge).

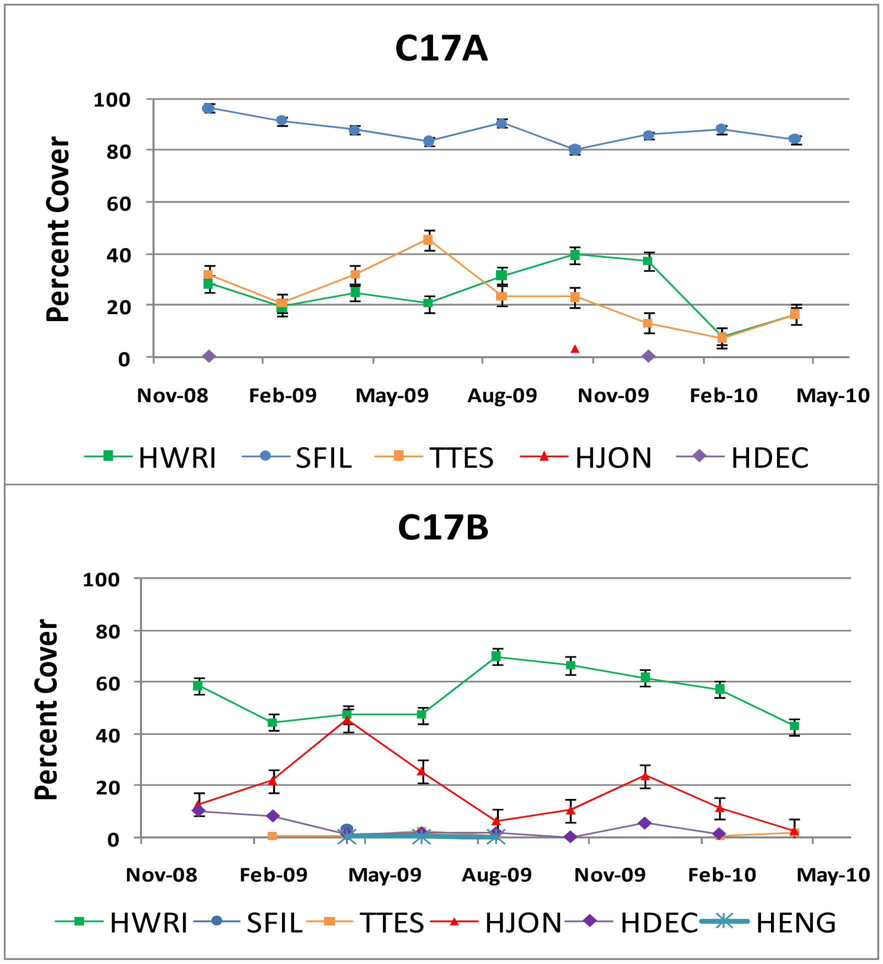

Figure 12-46. Summary of seagrass cover at the C-17 sites. Error bars represent ± 1 standard error (S.E.). HWRI – *Halodule wrightii* (shoal grass); SFIL – *Syringodium filiforme* (manatee grass); TTES – *Thalassia testudinum* (turtle grass); HJON – *Halophila johnsonii* (Johnson's seagrass); HDEC – *Halophila decipiens* (paddle grass); HENG – *Halophila engelmannii* (star grass).

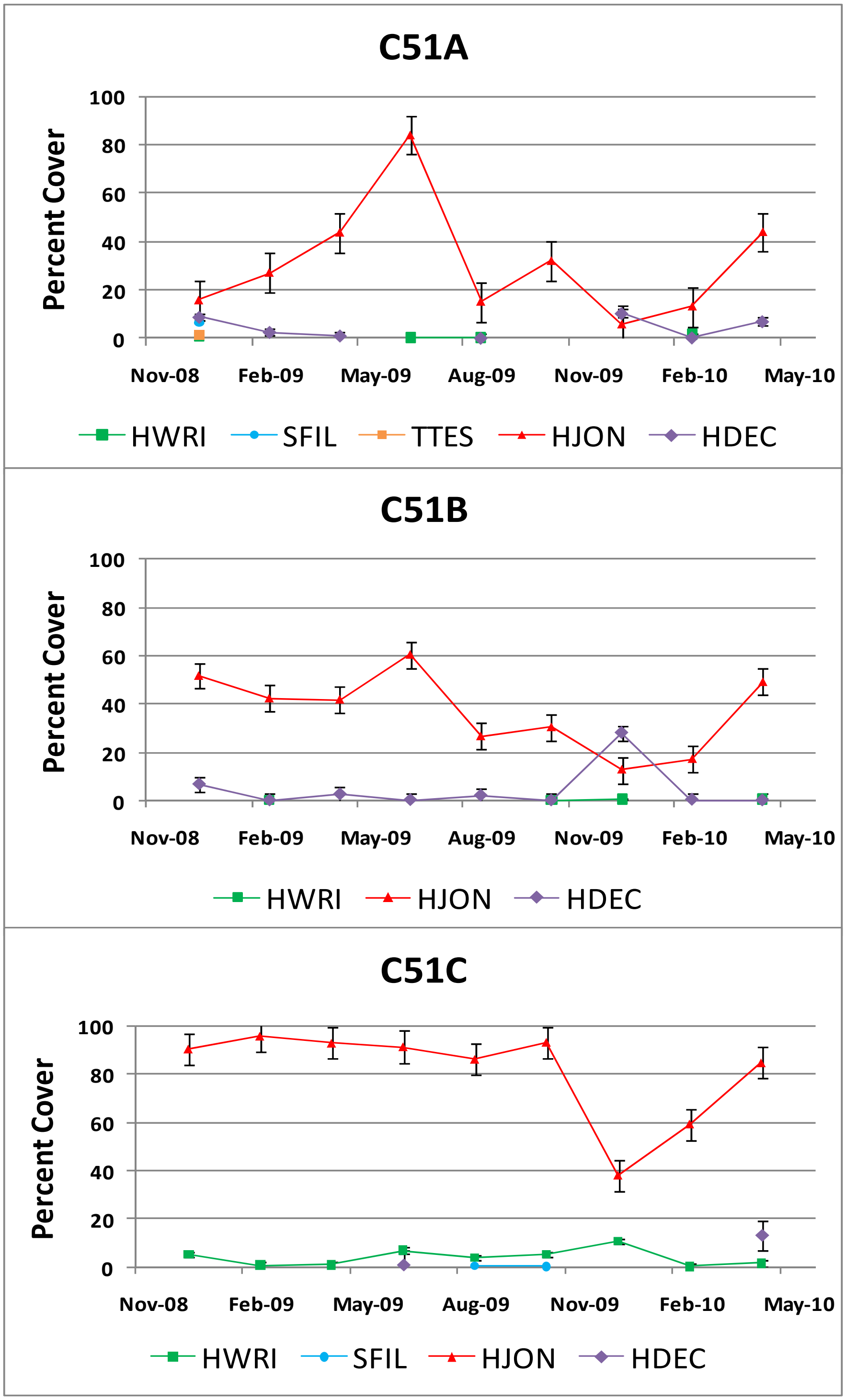

Figure 12-47. Summary of seagrass cover at the C-51 sites. Error bars represent ± 1 S.E. HWRI – shoal grass; SFIL – manatee grass; TTES – turtle grass; HJON – Johnson's seagrass; HDEC – paddle grass; HENG – star grass.

Eastern Oyster Abundance and Distribution

Wet and dry season oyster monitoring (once per season) was implemented at three stations in LWL in 2005 (FWC, 2010). Overall, there was a strong qualitative relationship between higher observed salinity and increased live oyster density (**Figure 12-48**). Total number of oysters was depressed early in 2005. Oyster density peaked through CY2006–CY2007 before another dramatic decline in CY2008. After reaching minimum levels in late CY2008, live oyster numbers began to rebound through spring 2009. These increases occurred despite low salinity in the wet seasons of WY2008 and WY2009.

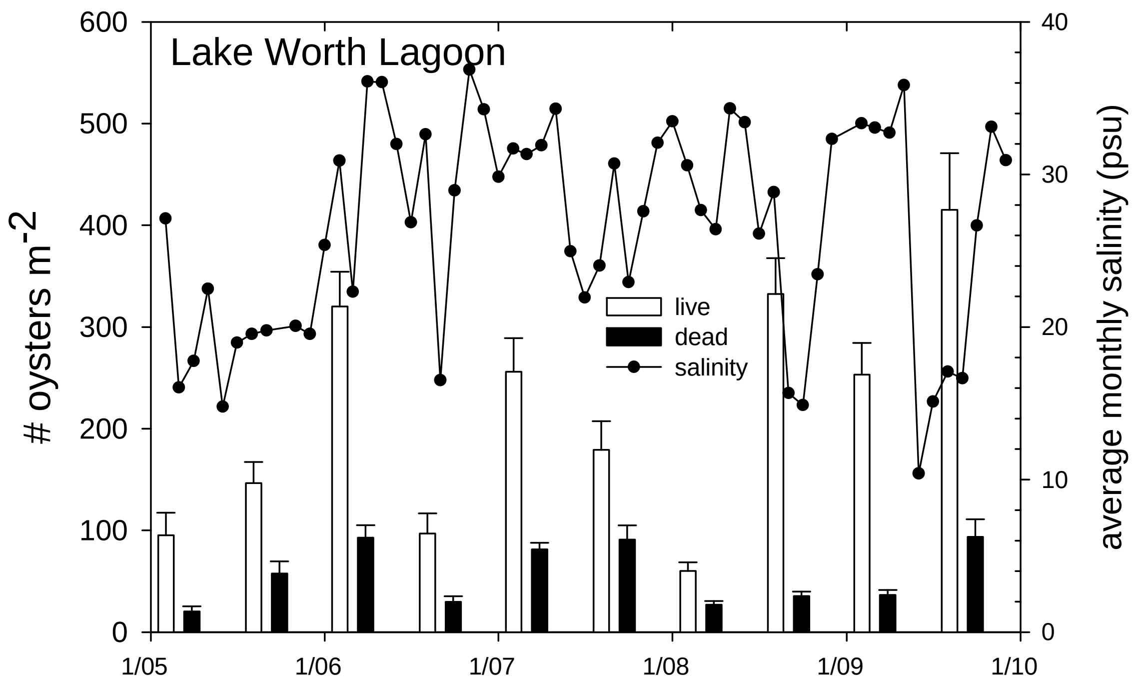

Figure 12-48. Live and dead oyster densities per square meter (left axis) and salinity (right axis) from spring 2005 to spring 2009 in LWL.

North Fork of the New River Estuary

The North Fork of the New River is a remnant tributary that drained the eastern Everglades, and now flows through the City of Fort Lauderdale, where it eventually joins the main branch and empties into the Atlantic Ocean (**Figure 12-49**). Hydrologic alterations and urbanization of the surrounding watershed have degraded the water quality in this tributary. Restoration efforts have focused on improving water quality, reestablishing a more consistent flow regime, improved management of stormwater runoff, sediment removal, shoreline revegetation, and trash and debris removal. Restoration projects, especially redirecting water from areas of excess (C-12 and C-13 canals) into the North Fork, is expected to lower salinity, phosphorus, and Chl*a* concentrations within the estuary (BCDPEM, 2003). The Broward County Environmental Protection Department has conducted quarterly monitoring within the North Fork for many years. Monitoring results provided in the following sections are from station 16 for the wet (June–October) and dry seasons (November–May) from 2000 to 2010 dry season. Station 16 is in the estuary downstream of the restoration project. Qualitatively, nutrient concentrations at site 16 from 2000–2010 have generally been lower since the 1974–1997 period, and salinity and TP concentrations, in particular, may be continuing to trend downward.

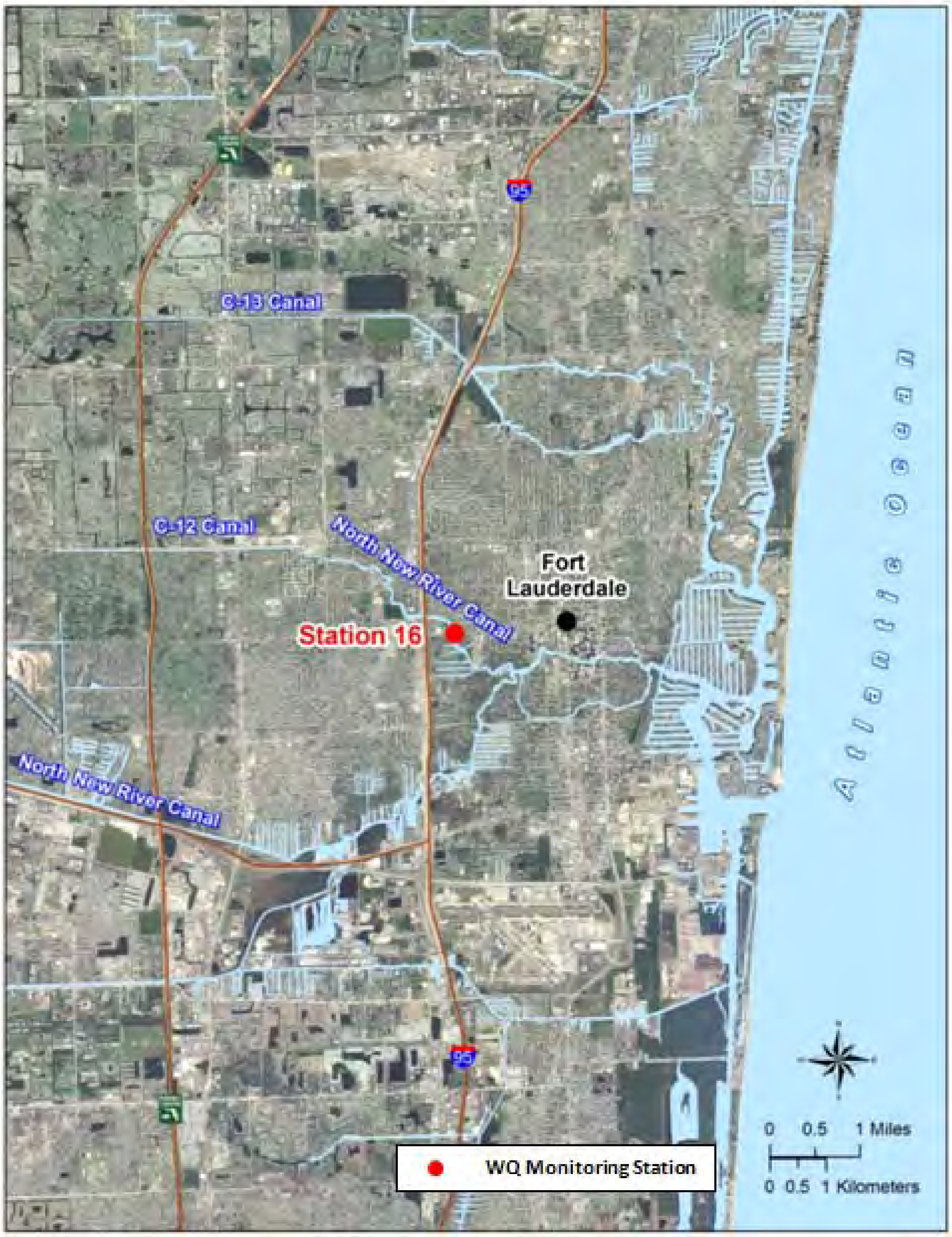

Figure 12-49. North Fork of the New River Canal and monitoring station 16.

Salinity

On average, salinity has been lower at station 16 in the North Fork since 2000 compared to the historical average (WY1974–WY1997) when salinity ranged from 18 to 32 psu (BCDPEM, 2003) (**Table 12-10**). WY2009 dry season median salinity was higher compared to the WY1999–WY2008 results, but median salinity in 2010 was within the typical seasonal range (**Figure 12-49**).

Table 12-10. Average water quality concentrations at station 16 for different water year periods and number of observations (n).

Parameter	1974–1997	2000–2008	2009	2010
Salinity (psu)	4 (136)	6 (38)	12 (2)	1 (5)
TP (mg/L)	0.72 (106)	0.09 (37)	0.07 (2)	0.08 (5)
DIN (mg/L)	0.77(68)	0.25 (38)	0.08 (2)	0.28 (5)
Chla (µg/L)	NA[1]	20 (38)	52 (2)	26 (5)

[1]NA = data not collected.

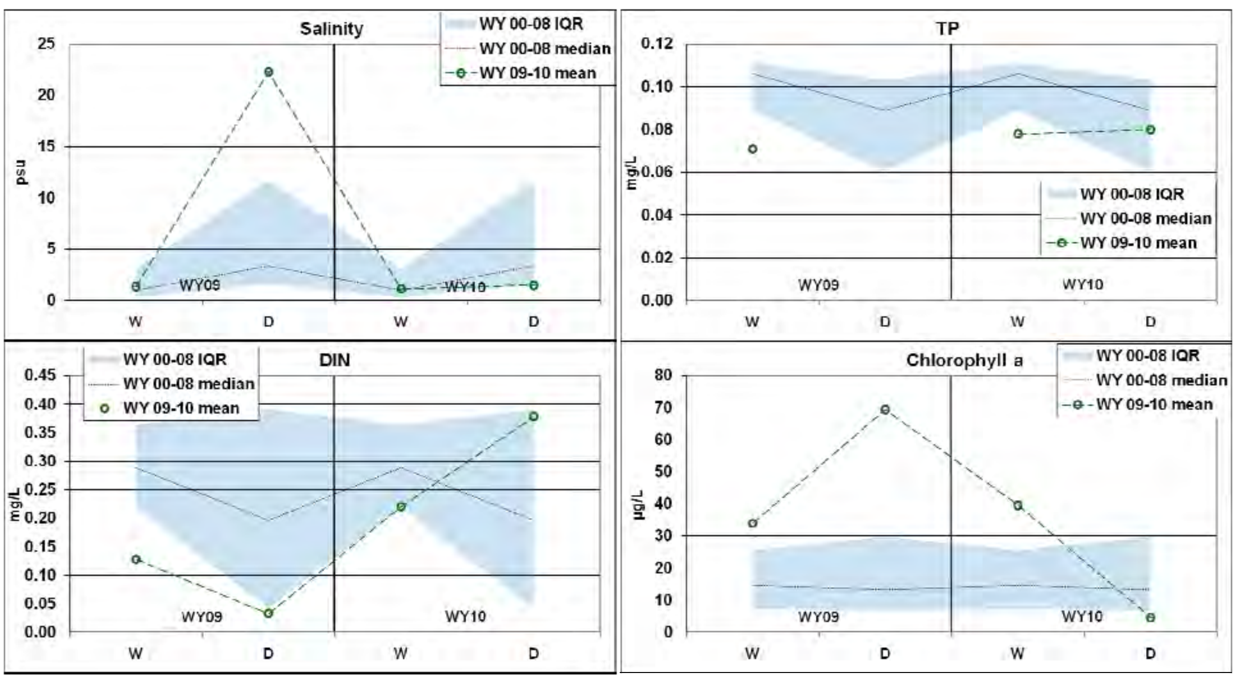

Figure 12-50. Seasonal water quality concentrations at monitoring station 16 in the North Fork of the New River. IQR = interquartile range.

Nutrients

According to a qualitative comparison of average concentrations, TP has become more moderate since the WY1974–WY1997 period when concentrations reached 2.4 mg/L (BCDPEM, 2003) (**Table 12-10**). Average seasonal values in WY2009 and WY2010 also appear to be at or below typical values. No samples were collected in the WY2009 dry season (**Figure 12-50**).

Dissolved inorganic nitrogen concentrations have also become more moderate since the WY1974–WY1997 monitoring period (**Table 12-11**). Average seasonal concentrations were generally below typical the values from WY2000–WY2008, except for the WY2010 dry season (**Figure 12-50**).

Chl*a* concentrations were not measured until WY2000 at station 16. Average seasonal values were generally higher than typical for the last two years, except in the WY2010 dry season (**Figure 12-50**).

FUTURE EASTERN ESTUARY ACTIVITIES

The Loxahatchee River District plans to update a seagrass cover distribution map for the Loxahatchee River Estuary. In addition to mapping seagrass species, fieldwork will include generalized mapping of the substrate and more detailed estimates of species density than conducted in 2007. Results will be used to generate a coverage map and a cover change analysis.

The Restoration Plan for the Northwest Fork of the Loxahatchee River (SFWMD, 2006) recommended the development of a science plan for the Loxahatchee Watershed to (1) monitor effects of restoration efforts to support adaptive management of the system, and (2) fill knowledge gaps critical to successful restoration. The Loxahatchee River Interagency Science Plan Team (LIST) team was formed in 2008 to provide details and focus to the Loxahatchee River Science Plan. The LIST is composed of representatives from the SFWMD, the FDEP Florida Park Service, LRD, Martin County, Palm Beach County Environmental Resources Management, and Florida International University. The science plan is designed to establish and support monitoring programs that gather information on a structured, focused basis that provide information about the effects of water quantity, water quality, timing, and distribution. Information will be used for modeling, predictive analysis, and evaluation purposes, which will form the basis for adaptive management decision making (SFWMD, 2008b). A draft of the science plan has been completed.

Phase 2 of the Acme Basin B Discharge Project, involving the design of the Section 24 Impoundment, is ongoing. The SFWMD work is substantially complete. When the project is fully complete, it should capture some of the excess water discharged from the C-51 canal into Lake Worth Lagoon.

SOUTHERN ESTUARIES

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

DESCRIPTION OF SOUTHERN ESTUARINE SYSTEMS, MAJOR PROJECTS AND ISSUES

The Southern Estuary Region consists of Biscayne Bay, the Florida Keys, Florida Bay, and the Ten Thousand Island Estuary that lies within Everglades National Park (**Figure 12-54**). This region also includes parts of Biscayne National Park and the Florida Keys National Marine Sanctuary. Freshwater inflow patterns into Biscayne Bay, Florida Bay, and the Ten Thousand Island area have been disrupted due to water management practices. In particular, typically low volumes of freshwater inflows at the end of the dry season each year cause salinity to exceed nearby Atlantic Ocean salinity (about 35 psu). Salinity nearshore within southern Biscayne Bay and Florida Bay can vary from 15 to 42 psu or more within a year. Historically (i.e., circa 1900), salinity in these nearshore areas is believed to have remained below 35 psu throughout the year as runoff from the vast Everglades Watershed slowly drained throughout the dry season. Many of the typically estuarine species were extirpated or now occur in reduced numbers. The abundance of species, such as pink shrimp (*Farfantepenaeus duorarum*), has been linked to salinity in theses estuaries (Browder et al., 2002; Browder et al., 2005). In addition, runoff is now discharged through a series of drainage canals that diverts and concentrates freshwater inputs at a few locations along the east coast, thereby changing historical salinity patterns that once emanated from a more widely distributed runoff system of small creeks and overland flow. These systems were also typically oligotrophic historically, but excessive nutrients have caused phytoplankton blooms occasionally in southern Biscayne Bay and Florida Bay. While phosphorus is usually the limiting nutrient in these systems for phytoplankton productivity, excessive inorganic nitrogen discharged into south-central Biscayne Bay may contribute to the growth of macroalgae nearshore (Biber, 2002).

The following District projects and activities are addressing these issues:

- Minimum flow criteria for Northeast Florida Bay
- C-111 Spreader Canal Western Project (Florida Bay)
- Biscayne Bay Coastal Wetlands Project

ECOSYSTEM STATUS

Biscayne Bay

Biscayne Bay is a shallow, subtropical estuary located along Florida's southeastern coast (**Figure 12-51**). The bay covers about 711 km^2 (275 sq mi), and the watershed is about 2,201 km^2 (850 sq mi). Most of the northern and central areas of the watershed are urban, with Miami being the largest city. Large portions of the Southern Everglades Watershed are dominated by agricultural land uses such as row crops, tree crops, and nurseries.

The SFWMD manages and maintains a primary drainage network consisting of 16 outfalls into the bay that regulate water levels within the watershed for flood control and water supply. Drainage of the watershed has primarily changed the location and timing of freshwater inputs to the bay. Timing affects runoff velocity on both an annual scale and during rainfall events occurring over several days. The concentration of runoff into canals that historically flowed into the bay through small rivers, streams, and groundwater flux has altered distribution. In addition, the opening of artificial inlets and construction of artificial islands and channels, particularly in the northern area, have contributed to the bay's transition from a freshwater estuary to more of a marine lagoon.

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

Water quality in Biscayne Bay has been impacted by raw sewage discharges, a practice that ceased in the 1950s, and increasing stormwater runoff from developed lands. More recently, water quality has been improving, and despite some dramatic physical and chemical changes, the bay supports extensive submerged aquatic vegetation (SAV) and hardground communities. On the other hand, some fisheries that were once abundant, such as redfish or red drum (*Sciaenops ocellatus*), mullet (*Mugil* sp.) and spotted seatrout (*Cynoscion nebulosus*), have declined substantially. The bay still supports a large recreational fishery and viable commercial pink shrimp fishery. Eastern oysters were abundant prior to the changes in Biscayne Bay, and oyster bars were relatively common. Now oyster bars are rare, and individuals are primarily found on mangrove prop roots and bulkheads.

Large areas of coastal wetlands have been filled, and most of the remaining coastal wetlands are in the central and southern areas of Biscayne Bay. These wetlands have been largely starved of fresh water because of diversion of the freshwater flows. The Biscayne Bay Coastal Wetlands Project will restore some overland freshwater flow to coastal wetlands in southern Biscayne Bay (see Chapter 7 of this volume) (USACE and SFWMD, 2010), and likely result in some incidental reduction of nutrient loads to the bay. A pilot project, which concluded in 2003, found that (1) nutrients were retained within the wetlands; (2) mangroves trees were unaffected; and (3) periphyton composition shifted to an assemblage of species more tolerant of fresh water (Ross et al., 2003).

Two components of the Biscayne Bay Coastal Wetlands Project consist of the design and construction of the Deering Estate Flow-way and L-31E culverts. Four culverts along the L-31E will divert water that would normally discharge from the S21A and S20F outfall structures into coastal wetlands upstream of stations BB53 and BBCW10 (**Figure 12-51**). Construction began on all four culverts in 2010 with completion of the L-31E culvert in March 2010. Construction of the Deering Estate Flow-way began in 2010 and is expected to be completed in 2011.

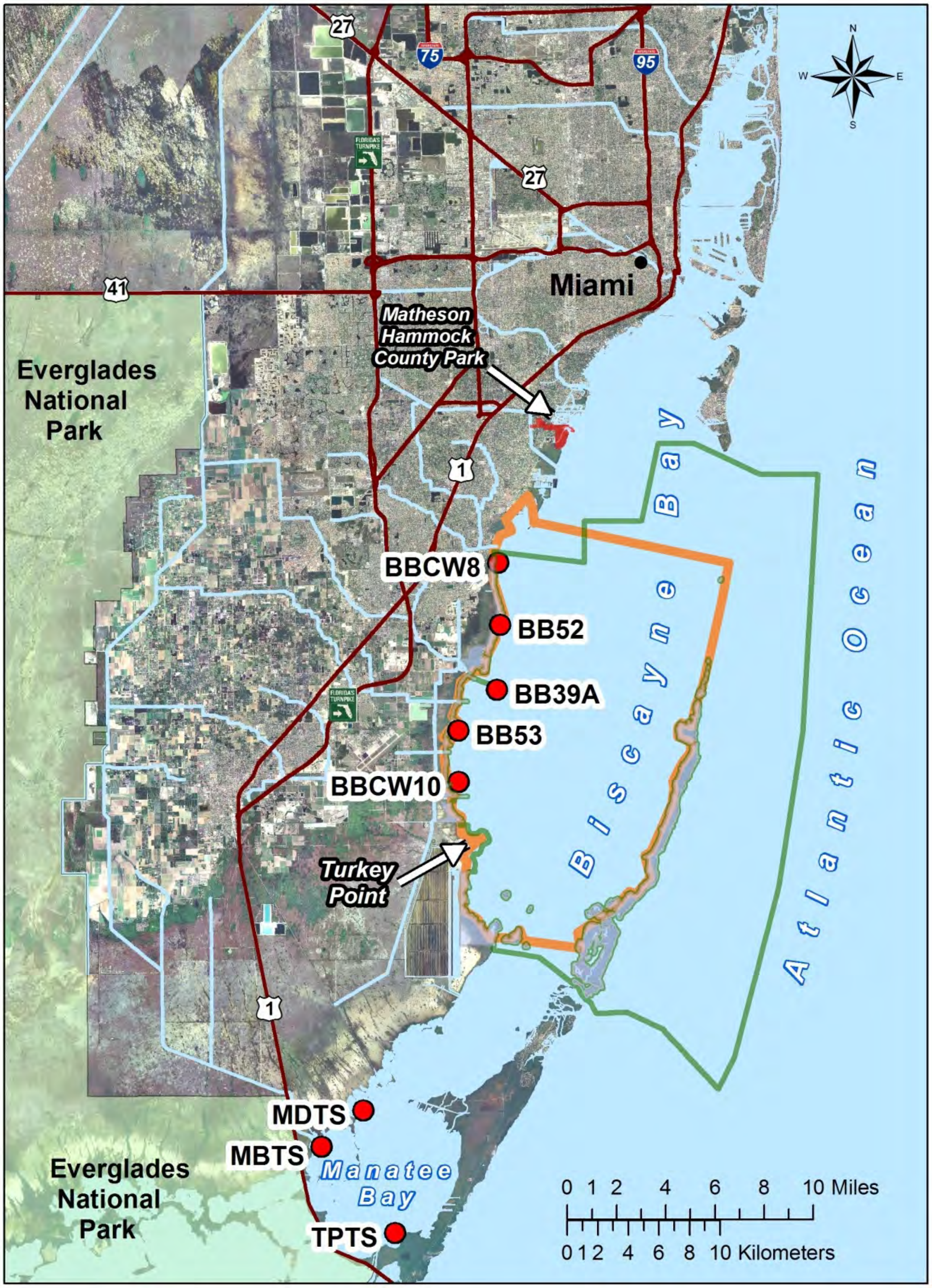

Figure 12-51. Biscayne Bay and selected monitoring stations.

Salinity and Freshwater Inflows

A primary concern has been both seasonal excursions of hypersalinity and annual variability of salinity near the western shore of south-central Biscayne Bay and within Manatee Bay. Hypersalinity in Biscayne Bay is defined by the SFWMD as any value greater than 35 psu. The current target is 5 percent of the annual daily mean values measured at certain points; the annual period is June through May to capture an entire wet/dry cycle. Daily mean salinity (calculated from 15-minute results) exceeded 35 psu on five days (1 percent) at SFWMD station BBCW8 from June 2009 through May 2010, and 10 days (3 percent) at SFWMD station BBCW10 (**Table 12-11**). Most of the values greater than 35 psu occurred during the wet season at BBCW10. High water temperatures cause evaporation, and in combination with a lull in rainfall, can increase salinity within a few days. Since these sites became active around April 2009, no long-term results are available. **Figure 12-52** shows the long-term results for Manatee Bay at SFWMD station MBTS. The percentage of days that daily mean salinity (calculated from 15-minute intervals) exceeded 35 psu was less than one from June 2009 through May 2010. By contrast, salinity exceeded 35 psu 48 percent of the time during the drought in 2005 with most of the values occurring during the dry season (November–May). Dry season rainfall was lowest in 2005, and lower-than-average values continued until 2010. The lower dry season rainfall from WY2007 through WY2009 may partly explain the higher percentages of hypersaline days in those years.

The Biscayne Bay Coastal Wetlands Project is expected to alter nearshore salinity patterns of south-central Biscayne Bay (see Chapter 7 of this volume). The project does not add any water into the system, but will redistribute fresh water currently discharged through four canals. It should result in lower average salinity along the shore between canal outfalls, with higher salinity at the coastal outfalls. Overall, salinity patterns should be more uniform once the project is complete. Salinity sampled monthly at stations BB52, BB39A, and BB53 by the Miami-Dade Department of Environmental Resources Management (DERM) averages 19 to 33 psu over the long term (**Figure 12-53**). Average salinity was above normal at the end of WY2009, but close to normal at the end of WY2010. Future CERP projects are to add some water storage (Biscayne Bay Coastal Wetlands Phases 1 and 2), and increase water availability during the dry season (South Miami-Dade Reuse).

Table 12-11. Mean daily salinity greater than 35 psu at stations BBCW8 and BBCW10.

Period of Record	Station	Number days salinity > 35 psu	Percent days salinity > 35 psu
June 2009–May 2010 (Annual)	BBCW8	5	1
	BBCW10	10	3
November 2009–May 2010 (Dry Season)	BBCW8	3	1
	BBCW10	1	<1

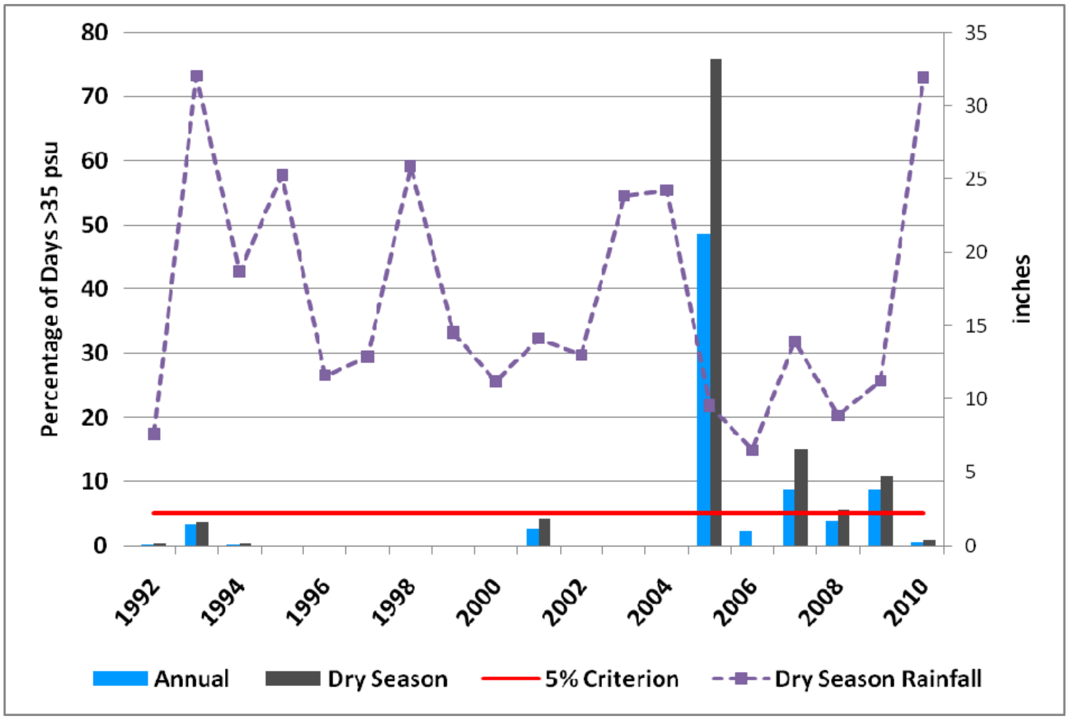

Figure 12-52. Percentage of days salinity was greater than 35 psu at station MBTS in Manatee Bay (blue columns are annual; black columns are dry season only) Purple-colored dashed line indicates dry season total rainfall (November–May).

Nutrients

Phosphorus loading is of particular concern for Biscayne Bay, since it is typically the limiting nutrient (Brand, 1988). Monthly long-term concentrations averaged between 0.003 and 0.007 mg/L at stations BB52, BB39A, and BB53 (**Figure 12-53**). Mean monthly TP concentrations in the past two years were lower than average at the selected locations downstream of the Biscayne Bay Coastal Wetlands Project, particularly in WY2010 (**Figure 12-52**). While phosphorus concentrations are typically quite low in southern Biscayne Bay, nitrogen concentrations are elevated in the southern part of the project area due to agricultural runoff (Alleman et al., 1995). Station BB53 is located within the influence of the higher nitrogen loading and therefore only values from this station are shown in **Figure 12-53**. Long-term total inorganic nitrogen (TIN, unfiltered samples) monthly values averaged between 0.14 mg/L and 1.1 mg/L (**Figure 12-53**). The highest concentrations generally occurred during the wet season when runoff was greatest. This is consistent with the higher rates of flow from canals in the area, such as C-102 and C-103, which typically contain average nitrate/nitrite concentrations of 2.3 and 4.1 mg/L (DERM, 2005). Values in WY2009 appear typical, but in WY2010, nitrogen concentrations spiked in January and February (**Figure 12-52**). The cause of the nitrogen spike is not clear. Average Chl*a* concentrations at the Biscayne Bay stations range from 0.3 to 0.7 mg/m^3 (DERM, 2005). The Biscayne Bay Coastal Wetlands Project is expected to reduce some of the inorganic nutrient loads to Biscayne Bay, because some canal water will be directed though wetlands where natural processes can remove them. Results from a pilot project conducted from 1997 through 2003 did not detect any impacts to Biscayne Bay or emergent vegetation from diverted canal water (Ross et al., 2003).

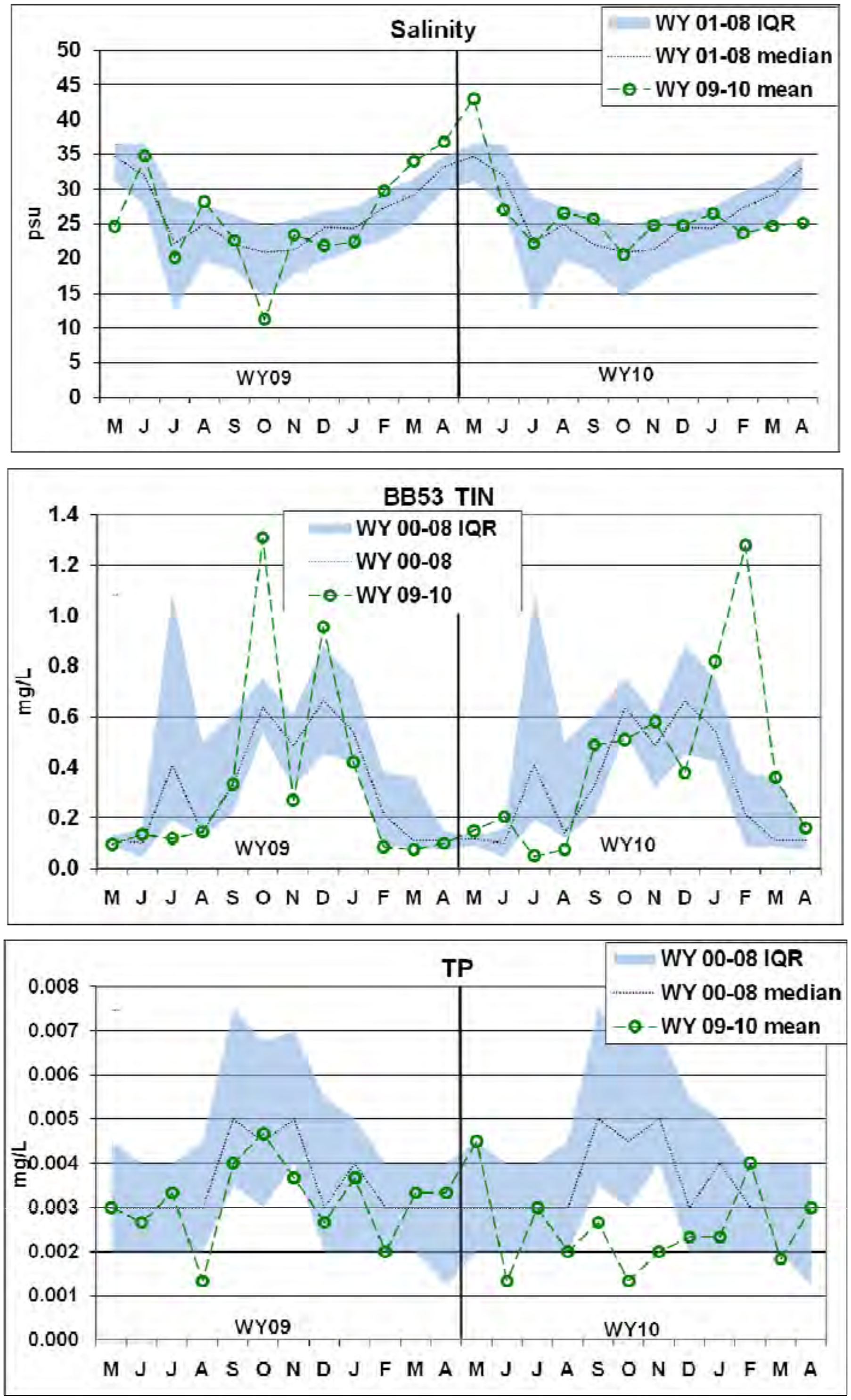

Figure 12-53. Mean long-term water quality results for WY2009 and WY2010 at stations BB52, BB39A, and BB53. Total inorganic nitrogen is only shown for station BB53.

Epibenthic Habitats

The bottom community in Biscayne Bay is dominated by seagrasses, but a large area of hard ground exists in the south-central region. The predominant seagrass is turtle grass, but shoal grass and manatee grass are also commonly found, and paddle grass and widgeon grass are present as well. Within south-central Biscayne Bay, shoal grass occurs mostly along the southwestern shoreline within roughly 1 km of the shore. Shoal grass out-competes turtle grass in these areas due to the variable salinity (Lirman and Cropper, 2003). More than 200 species of macroalgae are present in Biscayne Bay (Biber, 2002), and macroalgae comprise a significant portion of the bottom vegetative community. In fact, in the western nearshore areas of southern Biscayne Bay (i.e., from Matheson Hammock Park to Manatee Bay), macroalgae is more abundant than seagrasses (**Figure 12-54**). Macroalgae dominated by *Laurencia* are prolific nearshore of south-central Biscayne Bay, and exhibit a seasonal growth pattern. Biber (2002) tied growth rates to excessive nitrogen loads in this area. Some species appear to be sensitive to salinity (Lirman and Serafy, 2009). For example, *Chara hornemanii* was consistently found in lower and variable salinity areas nearshore (Lirman and Serafy, 2009). The Biscayne Bay Coastal Wetlands Project is expected to change the abundance and coverage of shoal grass, particularly. Altered salinity patterns should favor shoal grass over turtle grass in some areas. Currently, shoal grass abundance is patchy and most dense near canal outfalls, but may become more widely distributed as a result of lower and more uniform salinity along the shoreline.

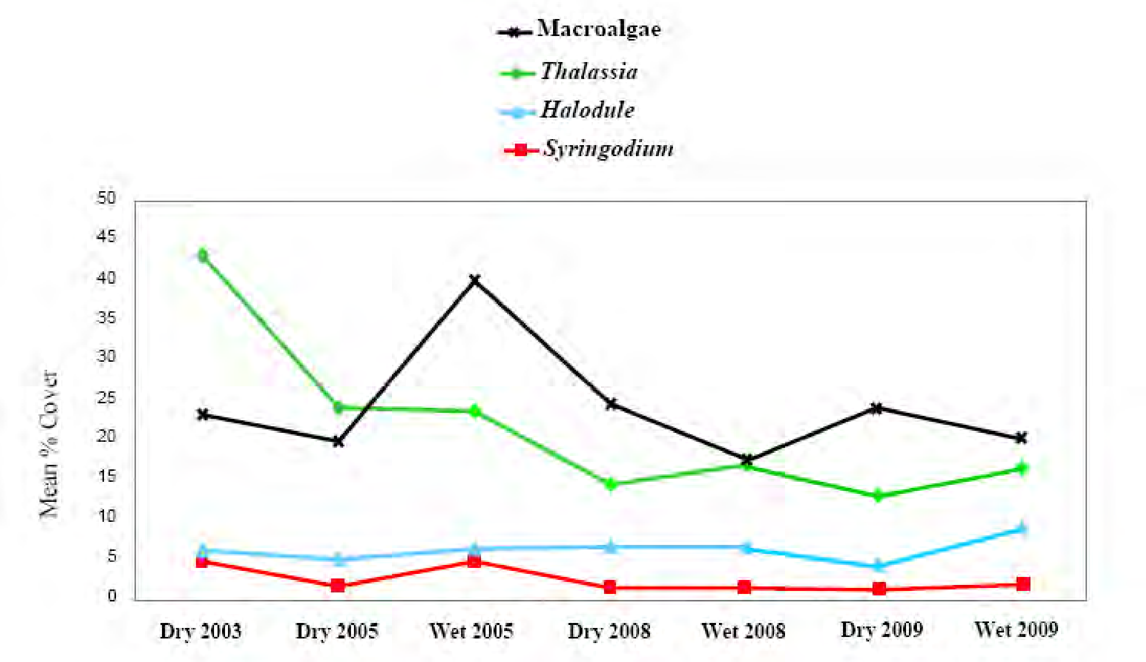

Figure 12-54. Mean percent cover of seagrasses and macroalgae along the southwestern nearshore zone (i.e., within 500 meters of shore) in southern Biscayne Bay (from Lirman and Serafy, 2009).

Eastern Oyster Abundance and Distribution

Historically, eastern oysters were so common in Biscayne Bay that their abundance was described as "luxuriant" (Smith, 1896). It is known that eastern oyster reefs were present in the past near the outlets of the natural rivers and streams (Meeder et al., 1999). Small numbers of eastern oyster are still present throughout Biscayne Bay close to the western shorelines. The current total population is unknown. A recent survey along the western shoreline within Biscayne National Park documented the presence of a few small oyster bars adjacent to the mouths of small creeks, and small numbers of live oysters (e.g., 6–15 per m^2) were common on mangroves (Bellmund et al., 2009). Systematic monitoring of the eastern oyster population in south-central Biscayne Bay was suspended in 2007 over concerns that taking of individuals for analyses may negatively affect sustainability. Monitoring is to resume when conditions become more favorable. The Biscayne Bay Coastal Wetlands Project is expected to improve eastern oyster habitat by lowering salinity in some critical areas. This will be confirmed through salinity monitoring by Biscayne National Park.

Fish Communities

The fish community in Biscayne Bay is diverse and supports large recreational and some commercial fisheries. Pink shrimp, in particular, are harvested commercially in the central region of the bay. The abundance of some species, such as red drum, spotted seatrout, and striped mullet, has declined over time. Spotted seatrout are more common in the northern region. Most of the central and southern regions of Biscayne Bay favor marine fishes, but salinity gradients that set up in the wet season along the western shoreline influence fish communities. The lower salinity along the western nearshore increases the probability that species, such as spotted seatrout, will occur. By contrast, when salinity exceeds 36 psu, fish communities tend to be less diverse with reduced assemblage structure (Serafy et al., 2008). The fish community is currently monitored by visual census, and has been relatively stable since 1998 (Serafy and Johnson, 2010). Key indicator species that have been observed most frequently in the lower salinity zone along the shoreline include great barracuda (*Sphyraena barracuda*), yellowfin mojarra (*Gerres cinereus*) and small morjarras (*Eucinostomus* spp.) The Biscayne Bay Coastal Wetlands Project is expected to shift the community so that these species may become more abundant in other areas along the shoreline.

Coastal Wetlands

Some relatively large areas of coastal or salt-intruded wetlands remain in the central and southern regions of Biscayne Bay. Prior to artificial drainage and subsequent saltwater intrusion, the saltwater wetlands were smaller and hugged the shoreline. Overland runoff formed a series of creeks and small rivers that passed through the wetlands to the bay, similar to the morphology still present in Florida Bay (see *Florida Bay* section of this chapter). This ecotone consisted of meso- and oligohaline habitats. The Biscayne Bay Coastal Wetlands Project will restore freshwater flow to some of these wetlands, and is expected reestablish creek systems. Monitoring will include vegetation along transects, water level, and salinity.

Florida Bay

Florida Bay lies at the southern tip of the Florida peninsula, forming an estuarine-marine lagoon between the Everglades and the Florida Keys (**Figure 12-55**). The shallow bay, covering a triangular area of 850 sq mi (2,200 km^2), has an average depth of about 3.3 ft (1 m). About 80 percent of the estuary lies within Everglades National Park (ENP or Park). Waters are generally clear, and most of the bottom is covered by seagrass, which is beneficial habitat for many invertebrate and fish species. Since 1987, when a widespread seagrass die-off occurred, Florida Bay has experienced additional seagrass die-off events, algal blooms and high turbidity, widespread mortality of sponges, and decreases in some other invertebrates and fish species (Fourqurean and Robblee, 1999). Major factors considered to have led to these changes are the reduction of freshwater inflow and increasing salinity in the estuary (Fourqurean and Robblee, 1999). More recently, nutrient pulses have contributed to algal blooms in areas of the bay (Rudnick et al., 2009). The major premise of the Everglades restoration strategy for Florida Bay is that the loss of freshwater inflow from the Everglades has contributed to destabilization of the ecosystem and an ecological cascade of harmful impacts (Rudnick et al., 2005).

The CERP C-111 Spreader Canal Western Project (C-111 SCWP), which aims to reduce water losses from Taylor Slough through the eastern boundary of the Everglades, began implementation in 2010. This project features the creation of a hydrologic ridge along the eastern border of Taylor Slough, designed to retain more water within the slough and increase the flow of water to Florida Bay. As project implementation proceeds, important changes to the hydrology and ecology of the Southern Everglades wetland, the mangrove ecotone, and Florida Bay are expected, and the SFWMD will follow the course of ecosystem responses in the Southern Everglades and Florida Bay. Monitoring and research in the area has been ongoing for the past decade, instrumental in designing the project and projecting expected consequences. Baseline data have been gathered in the wetlands, creeks, and the bay. As the C-111 SCWP progresses, the District will track the benefits accruing to the system during and after project implementation (USACE and SFWMD, 2009).

MFL criteria for Florida Bay are being reevaluated and refined based on several years of additional research and data since establishment of the initial MFL rule in 2006. Salinity monitoring has expanded from a single point to multiple reference points across the landscape, and data from these transition zones are being used to develop modeling tools to better forecast the bay's salinity regime. A recent algal bloom that began in fall 2005 in eastern Florida Bay and southern Biscayne Bay subsided in WY2009 and showed no sign of return in WY2010. Hurricane disturbance, water management, and construction along the Florida Keys' Overseas Highway (U.S. Highway 1) are hypothesized to have contributed to the bloom. Efficient nutrient recycling and relatively low flushing rates sustained the bloom for three years until the material sustaining the bloom was substantially flushed from the system. Modeling calculations were used to assess the dynamics of the bloom and predict its rate of its dissipation.

The District has developed an integrated program of monitoring, research, and modeling in Florida Bay in support of RECOVER, MFLs for Florida Bay, and the C-111 SWCP to (1) better understand the importance of water management impacts on ecological changes, (2) improve the ability to forecast the impacts of changing water management, and (3) improve management structures and operations for the protection and restoration of the Florida Bay ecosystem. In this section, results from major monitoring projects are highlighted, emphasizing hydrologic and salinity conditions, water quality, seagrass habitat, and upper trophic levels, including fish and roseate spoonbills. Updates on research and modeling activities and research planning are also provided.

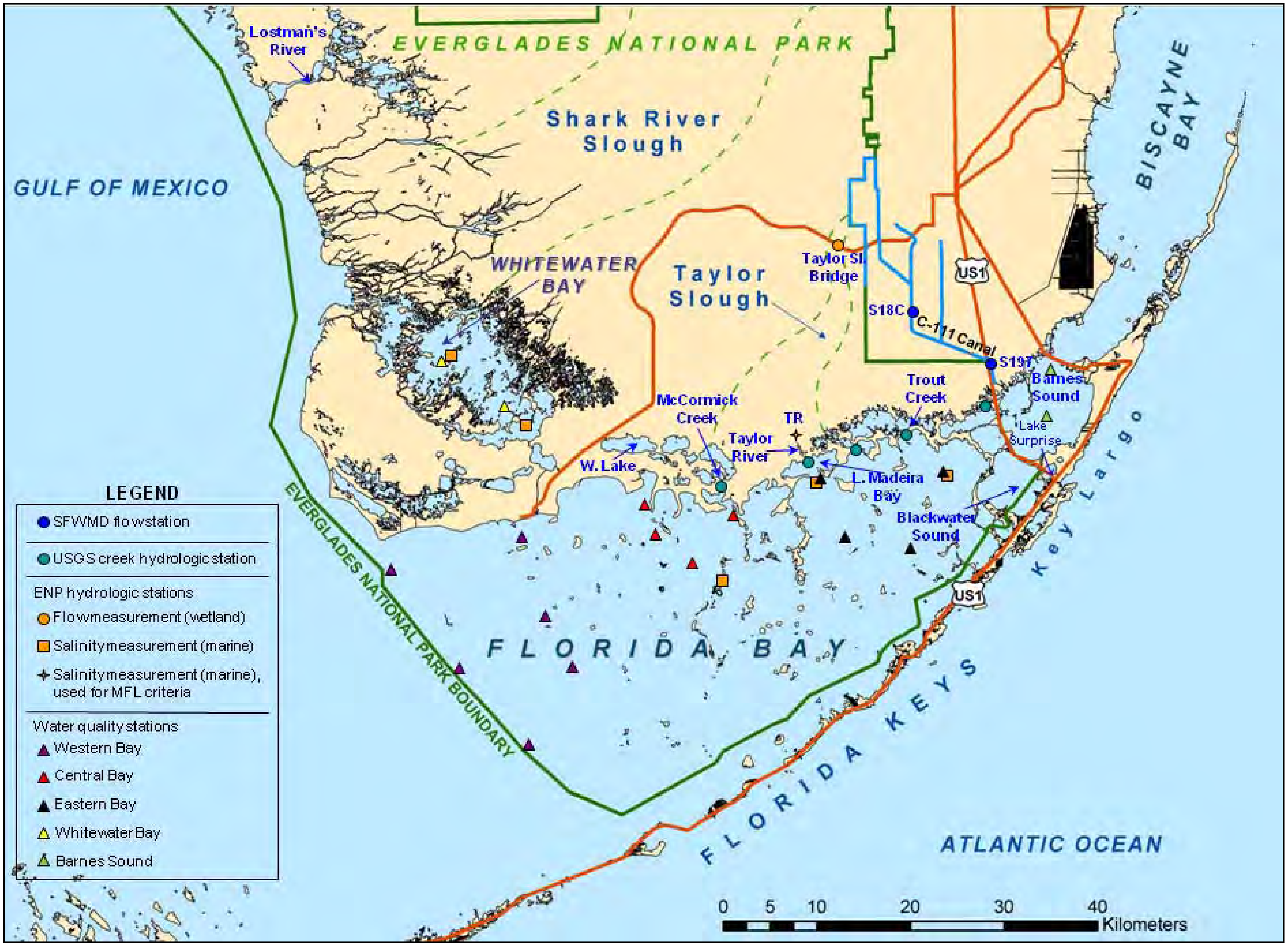

Figure 12-55. Florida Bay and research/monitoring sites.

Rainfall and Freshwater Inflows

Rainfall in eastern Florida Bay was calculated on a daily basis as the mean precipitation measured at several eastern bay stations: (1) the ENP, Little Madeira Bay, Duck Key, Long Sound, and Highway Creek maintained by the ENP, (2) Joe Bay maintained by the SFWMD, and (3) West Highway Creek maintained by the USGS. Rainfall in the central bay was computed as the daily mean precipitation of sites at Whipray Basin and Terrapin Bay (ENP). Both areas of the bay received above-average rainfall in WY2010 with annual precipitation totaling 53.6 inches in the eastern bay and 47.4 inches in the central bay. During the period of record from WY1997–WY2008, rainfall averaged 43 inches (109 cm) in the eastern bay and 45 inches (114 cm) in the central bay. The ENP wetlands, where rainfall is typically higher than in the open bay, also experienced above-average annual precipitation (60 inches; 152 cm) in WY2010 (see Chapter 2 of this volume). Though the wet season began in May with above-average rainfall (9 inches or 23 cm) in the eastern and central basins, rainfall declined in the latter part of the wet season due to a lack of tropical activity. In comparison, precipitation in May from WY1997–WY2008 averaged 2 inches. An El Niño event in the WY2010 dry season, however, more than compensated for the wet season deficit, with both basins receiving 20 inches (51 cm) of precipitation, more than double the long-term dry season average of 9.5 inches (24 cm).

Temporal patterns of flow measured through the C-111 canal and at Taylor Slough Bridge (TSB), two major paths of water for eastern and central Florida Bay, show some important trends over recent years, especially in WY2010 (**Figure 12-56**). Freshwater delivery to Florida Bay through the C-111 canal (calculated as the difference in discharge between S-18C and S-197, which empties into adjacent Manatee Bay) was well above average for the entire year, totaling 234,400 ac-ft [289 millions of cubic meters (Mm^3); WY1997–WY2008 average = 128,200 ac-ft], which approached values observed in the very wet WY1995. Overall annual flow at TSB (71,300 ac-ft; 88 Mm^3) was also above the long-term average (64,300 ac-ft) for WY2010, supported by wet season flows through September, after which discharge dropped to or slightly below average levels, despite abundant regional rainfall received through the WY2010 dry season. In recent years, Taylor Slough has received less flow, proportionally, compared to that measured through the C-111 canal toward eastern Florida Bay (**Figure 12-57**). It is notable that TSB flows have not increased at the rate observed in the C-111 canal for the past three water years, and patterns in C-111 and TSB flows were significantly different in the WY2010 dry season (**Figure 12-56**). Such trends point to the importance of implementing projects such as the CERP C-111 SCWP, the first phase of which is designed to keep more water in Taylor Slough and allow less seepage into the adjacent C-111 canal.

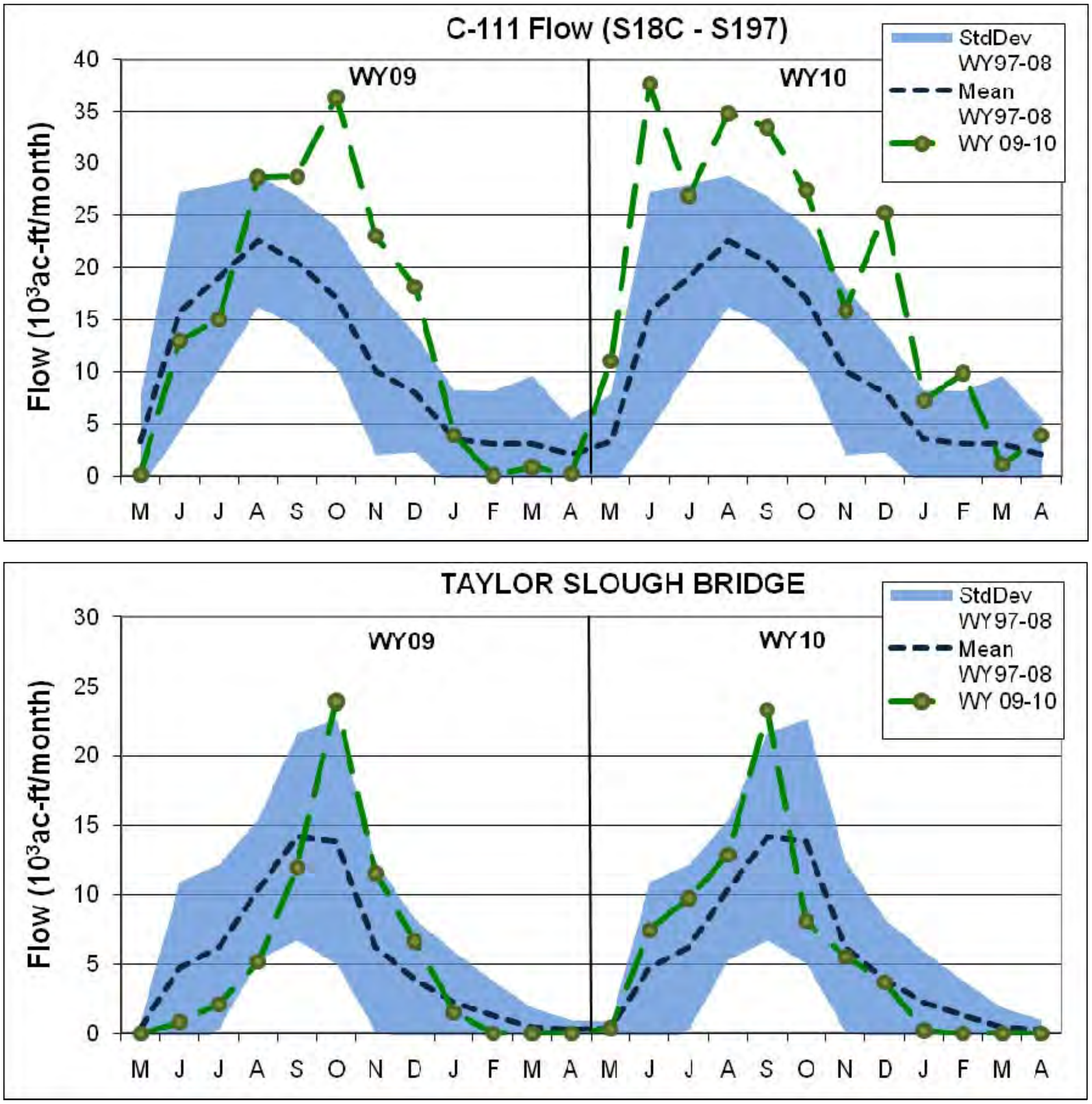

Figure 12-56. Monthly cumulative discharge from the C-111 canal (measured as the difference of flow between structures S-18C and S-197) and from Taylor Slough Bridge (TSB) into the Southern Everglades in WY2009 and WY2010 compared to mean monthly discharge from WY1997–WY2008.

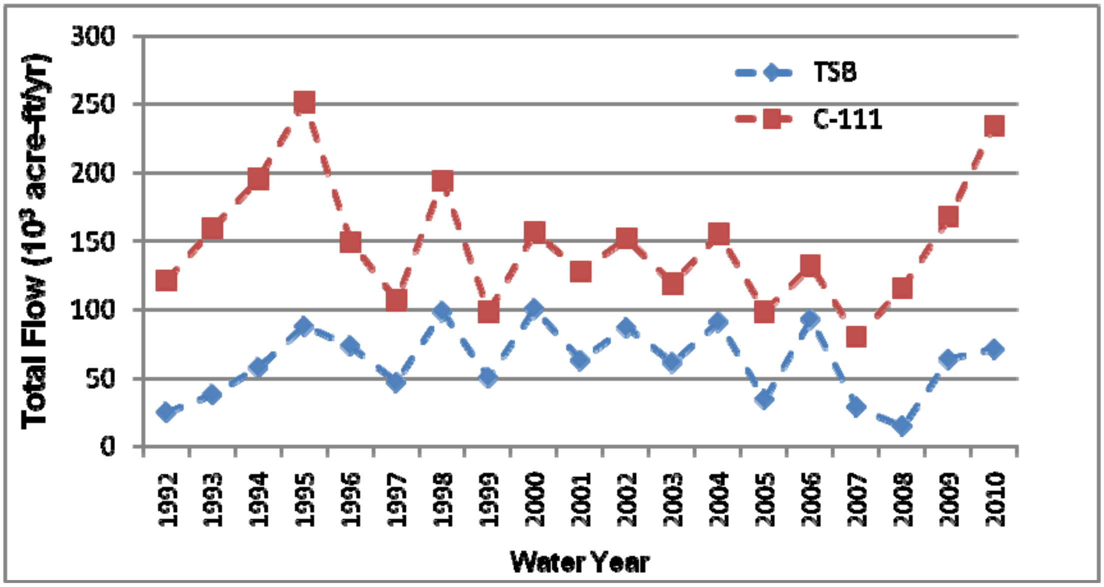

Figure 12-57. Time series of annual cumulative discharge from the C-111 canal and TSB from WY1992–WY2010.

Flow results from three major creeks discharging into the bay, Trout Creek and Taylor River (into the eastern bay) and McCormick Creek (into the central bay), are shown in **Figure 12-58**. Based on USGS measurements of nine creeks flowing into northern Florida Bay, three creeks are estimated to account for 60 percent of all creek flow (Hittle et al., 2001). As the major contributor of flow into the bay, Trout Creek had an annual discharge of 205,800 ac-ft (254 Mm^3) in WY2010, an increase of 40 percent from the long-term (WY1997–WY2008) average annual discharge of 146,900 acre-feet (181 Mm^3). To the west, Taylor River annual discharge was also 40 percent above average (40,100 ac-ft or 50 Mm^3; WY1997–WY2008 average = 29,500 ac-ft), as was flow into the central bay through McCormick Creek [WY2010 = 25,000 ac-ft (31 Mm^3); WY1997–WY2008 average = 17,800 ac-ft]. The temporal trend for these creek discharges through the year is consistent with the rainfall pattern: flows were high early in the wet season and then well above average again for much of the dry season El Niño event. Total annual discharge to the bay in WY2010 from five major creeks (three identified, plus Mud Creek and West Highway Creek) was nearly 11 percent greater than the long-term mean of 255,900 ac-ft (316 Mm^3). Discharge is monitored as part of the Florida Bay MFL criteria. The 365-day cumulative discharge from the five creeks remained well above the 105,000 ac-ft threshold specified in the Florida Bay MFL rule for the entire WY2010.

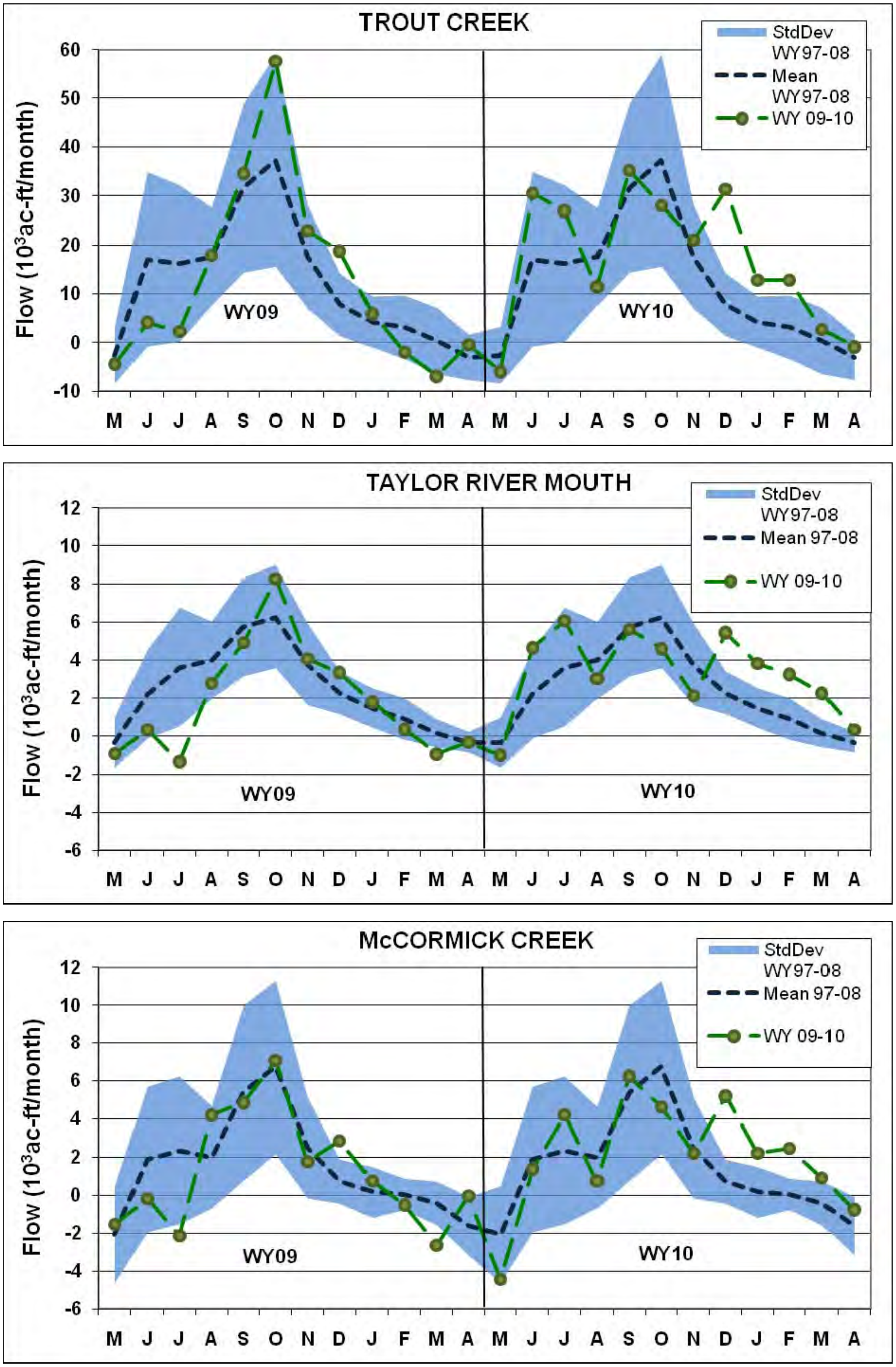

Figure 12-58. Monthly cumulative discharge to Florida Bay through three creeks in WY2009 and WY2010 compared to mean monthly discharge from WY1997–WY2008. Data after September 2009 are provisional, supplied courtesy of USGS.

Interesting trends emerge from a comparison of flows in the upstream sites (TSB and C-111) with creek inflows. A westward shift in the creek flow rates, first described in the SFER published in 2008, seems to contradict the trends described above for flow through TSB versus C-111 routes to Florida Bay over recent years. **Figure 12-59** shows a plot of proportional flow of both upstream sources and for the three westernmost creeks into Florida Bay. The trend for both curves through 2004 is a shifting of water discharge toward the west, but after 2006 this trend was not sustained. Moreover, a comparison of upstream flows with the two creeks that make up the dominant proportion of the downstream input into Florida Bay (Trout Creek and Taylor River), shows a positive relationship between C-111 and Trout Creek (**Figure 12-60**), but a less significant relationship between flows at TSB and the mouth of Taylor River (**Figure 12-61**). These results point to shifting hydrologic patterns, perhaps as a result of operational modifications along the L-31N canal as part of the C-111 Project. Further examination of these data is needed to better understand these changes and to provide an accurate assessment of baseline (pre-construction) conditions for the C-111 SCWP.

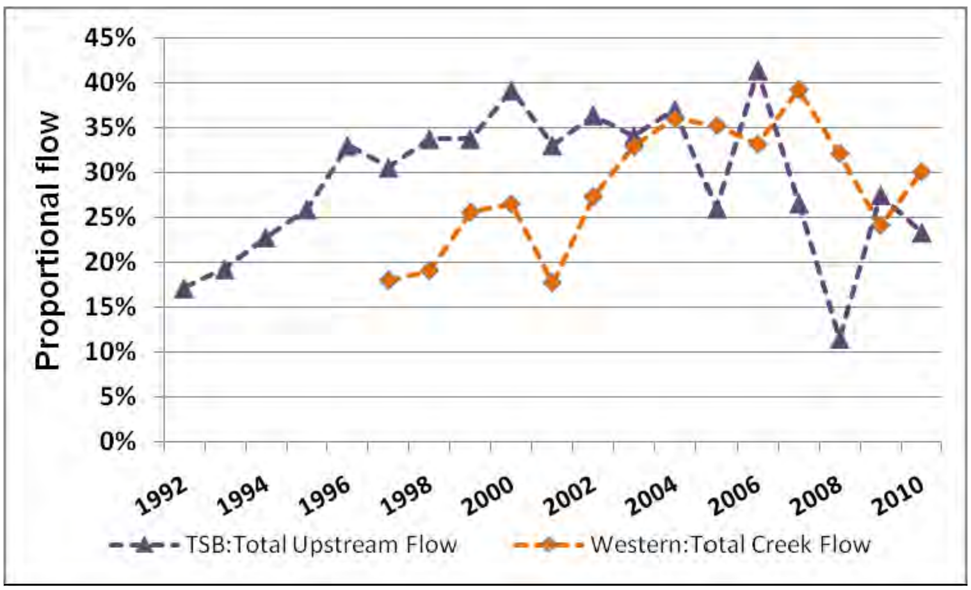

Figure 12-59. Ratio of annual flows at TSB to total upstream flows (TSB plus C-111 canal) (triangles), and the ratio of annual western creek flows (in three western creeks) to total creek flow (in five creeks east to west) (diamonds).

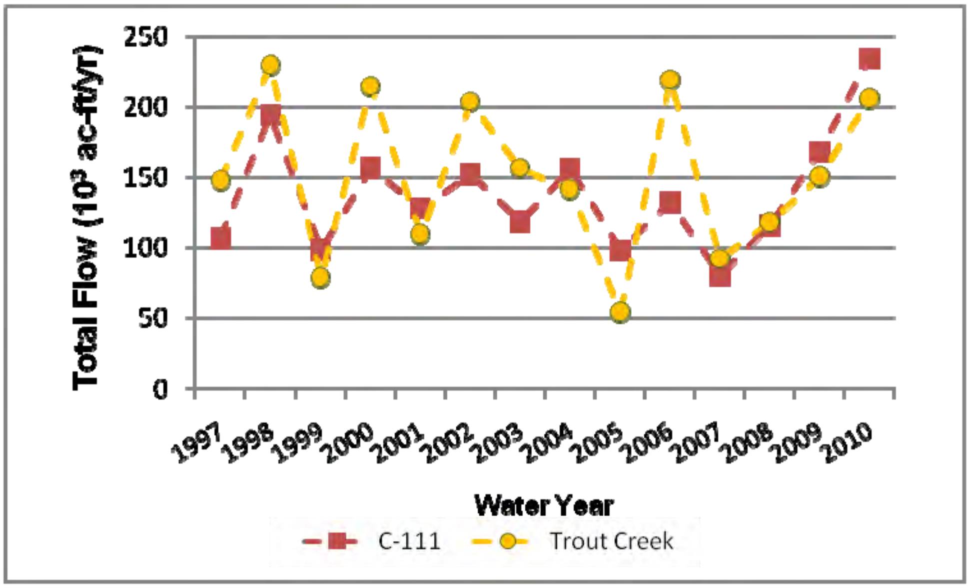

Figure 12-60. Time series of annual cumulative discharge from the C-111 canal and its dominant outflow into Florida Bay, Trout Creek, from WY1997–WY2010.

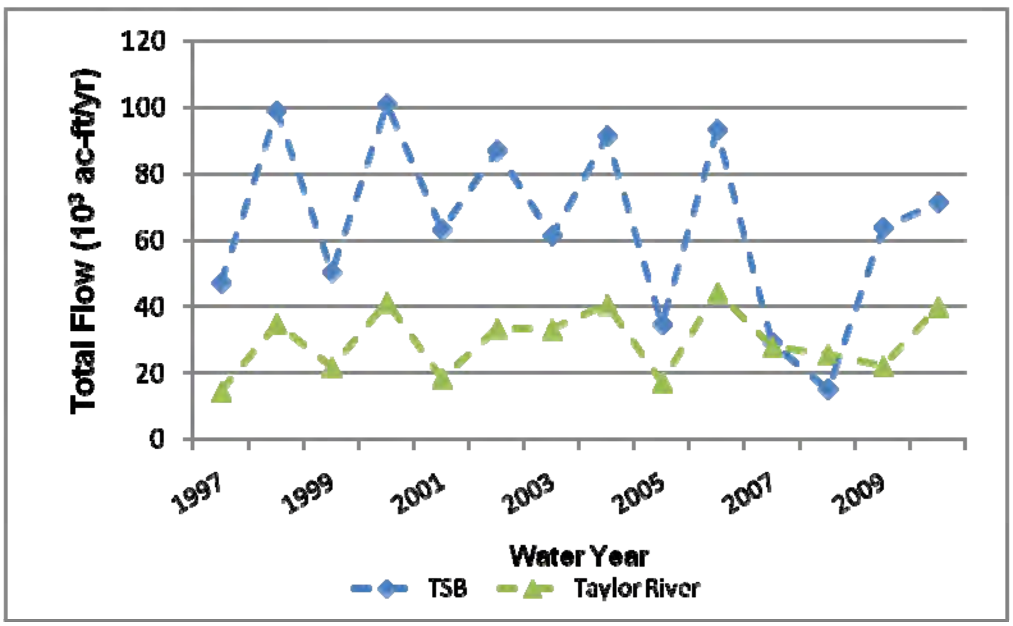

Figure 12-61. Time series of annual cumulative discharge measured at TSB and downstream at the mouth of Taylor River from WY1997–WY2010.

Salinity in Florida Bay and Whitewater Bay

Salinity dynamics in Florida Bay and Whitewater Bay are determined by multiple factors: freshwater flow from the Everglades, precipitation, evaporation, groundwater exchange, 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, the bay is susceptible to rapid and abrupt changes in salinity and to hypersalinity events that affect its biology and chemistry. Data are collected continuously at stations in the ENP's Marine Monitoring Network (ENP-MMN), continuously at creek mouth stations monitored by the USGS, and monthly under the SFWMD's coastal water quality monitoring network, providing information on spatial and temporal trends in salinity. Monthly average salinity for representative ENP-MMN and USGS sites (Clearwater Pass and Whitewater Bay East for Whitewater Bay; Trout Creek, Duck Key, and Little Madeira Bay for eastern Florida Bay; and Whipray Basin for central Florida Bay) were averaged with monthly grab salinity data collected in the corresponding months and regions.

Despite above-average rainfall and inflows to the bay in WY2010, salinity in both eastern and central Florida Bay remained above the long-term average for much of WY2010 (**Figure 12-62**). This reinforces the importance of antecedent conditions to this system, where there can be a lag of months before upstream inputs can affect the bay proper. Conditions at the end of WY2009 were very dry, allowing for development of hypersaline conditions (above 40 psu) in the bay by May 2009. Seasonal rainfall after that point caused salt concentrations to decline somewhat, but it took abundant El Niño precipitation (and resultant creek inflows) to reduce salinity to seasonable levels in Florida Bay during the last few months of the water year. Salinity in Whitewater Bay displayed a similar trend to that of Florida Bay, but not having reached hypersaline conditions during the latter months of WY2009, concentrations in Whitewater Bay declined more quickly through WY2010 (**Figure 12-62**). Thus, salinity in Whitewater Bay remained near its long-term average (WY1997–WY2008) throughout much of WY2010.

In WY2010, contrasting salinity patterns were observed for the transition zone north of Florida Bay. During the drought in WY2009, hypersalinity spatially developed in concert with the flow pattern of the bay water. Under drought conditions, water often flows northward into the transition zone, reinforcing high salinity conditions. Salinity was well above the 30 psu threshold stipulated in the Florida Bay MFL Rule (measured as the 30-day running average from the Taylor River (TR) station in the transition zone; see **Figure 12-63**). This exceedance occurred in April 2009 and lasted until the rainy season arrived in May 2009. Abundant precipitation and sustained creek inflows resulted in a salinity decline, and it remained below average in the transition zone through the year. Though there was a brief, wind-induced flow reversal in November 2009, no additional MFL salinity exceedances occurred in WY2010 at the TR platform.

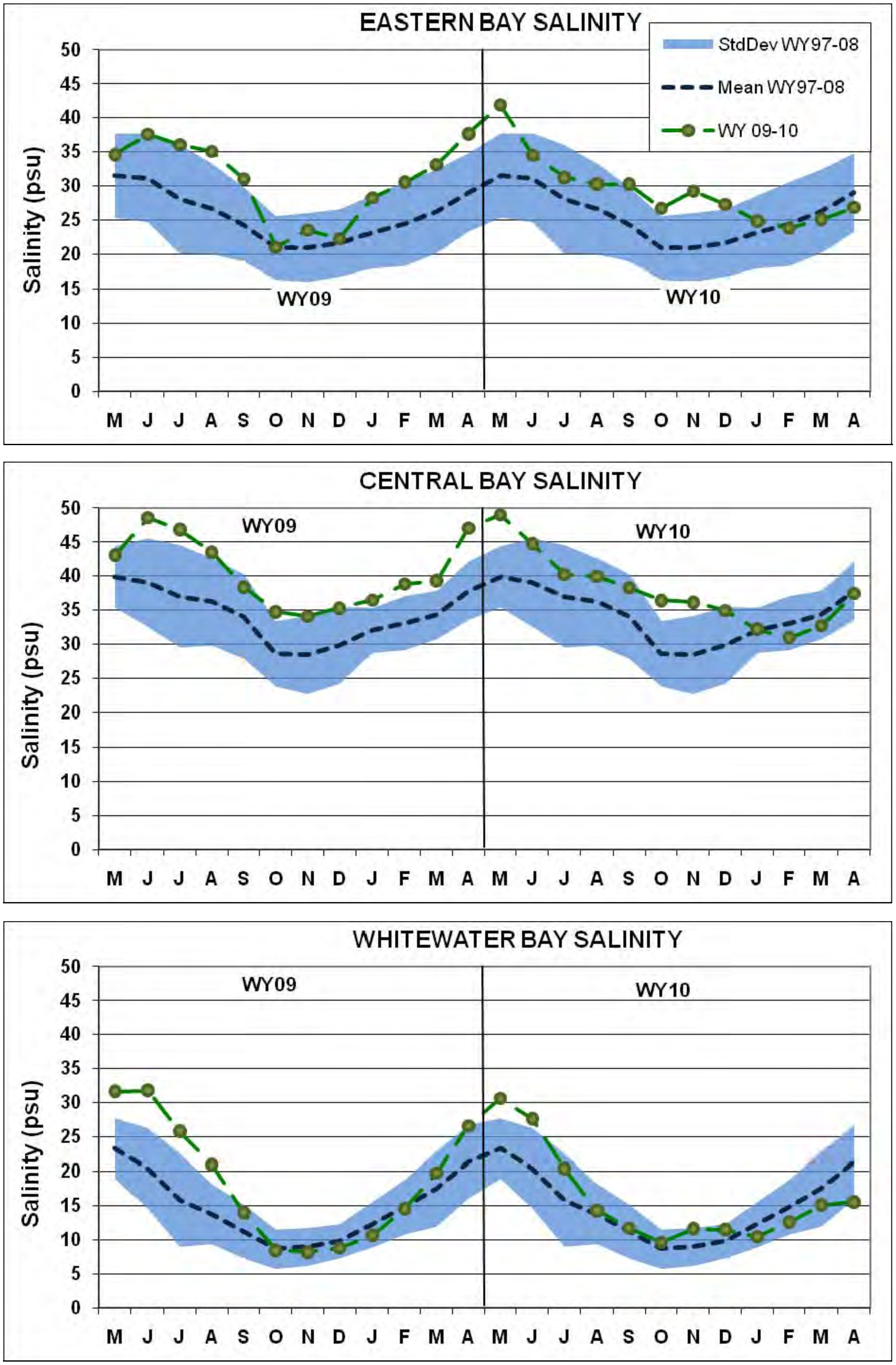

Figure 12-62. Mean monthly salinity values in eastern and central regions of Florida Bay, and Whitewater Bay in WY2009 and WY2010, compared to monthly means from WY1997–WY2008.

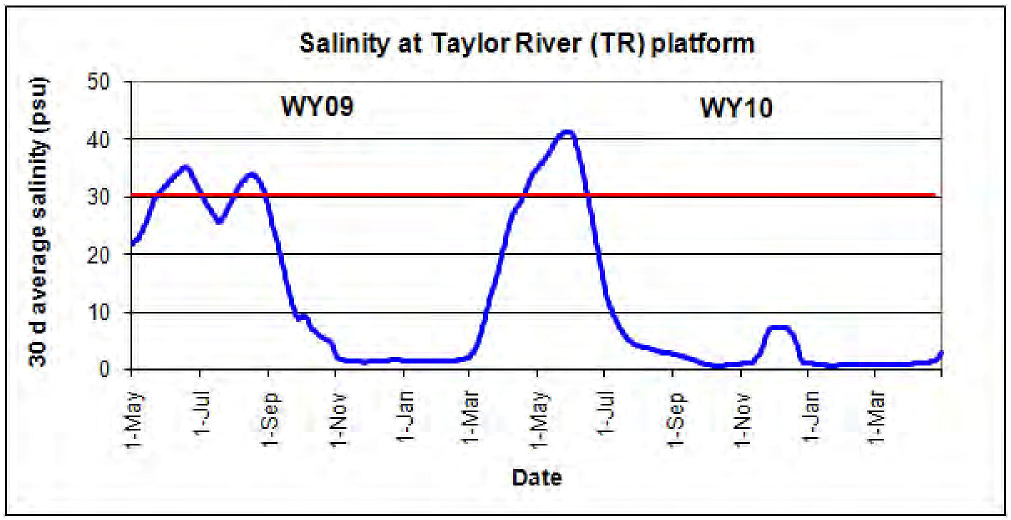

Figure 12-63. Salinity at the Argyle-Hendry pond (Station TR) in upper Taylor River for WY2009 and WY2010 compared to daily mean values from WY1997–WY2008. An exceedance of the Florida Bay MFL occurs when the running average exceeds 30 psu within a calendar year. Exceedances occurred in both CY2008 and CY2009.

Nutrients

CERP performance measures for Florida Bay and the other southern coastal systems require assessments of water quality parameters to ensure that District operations and projects protect and restore the ecosystem. Chl*a* concentration, an indicator of algal blooms, as well as the nutrient inputs that initiate and sustain blooms, have been measured throughout the system since 1991. For the 2011 SFER, this chapter reports on water quality in Florida Bay as well as the coastal systems to the west (Whitewater Bay) and east (Barnes Sound in Biscayne Bay). In previous SFERs, Chapter 12 documented the combined spatial and temporal monthly means of select water quality parameters without including the variance around these means. This report, however, presents both the temporal median of the monthly spatial means and the interquartile range (IQR) for the entire period of record. Information on the status and trends of water quality in Florida Bay can be found in previous SFERs. The following briefly describes the water quality parameters in Whitewater Bay and Barnes Sound.

During WY2010, Chl*a* concentrations were near or below the long-term (WY1992–WY2007) median in the eastern and central regions of the bay (**Figure 12-64**). Chl*a* concentrations in the western bay were relatively high at the start of the WY2010 wet season, but near the median for the rest of the water year (**Figure 12-64**). Results were similar for TP and turbidity. Interestingly, both parameters in the eastern and central bay were at or below the 25th percent quartile for all of WY2010 (**Figure 12-64**).

Long-term annual average (WY1992–WY2008) Chl*a* and TP concentrations in Whitewater Bay and Barnes Sound are shown in **Figure 12-65**. Both are higher in Whitewater Bay than in Barnes Sound, the latter of which has the lowest turbidity of all regions. In WY2009 and WY2010, TP and Chl*a* were below or near the long-term median in Barnes Sound (**Figure 12-66**) with TP staying below the 25th percent quartile for most of this period. TP in Whitewater Bay has been lower while TN has been higher since the WY2009 dry season, and Chl*a* was lower during the start of the WY2010 wet season (**Figure 12-66**).

TN in the eastern and central bay was higher in WY2010 than the long-term median and near or above the 75^{th} percent quartile, while TN in the western bay was near the long-term median. All three regions have shown an increase in annual average TN since WY2005.

Dissolved inorganic nitrogen (DIN) was near or below the long-term median in all three bay regions, except at the end of the dry season in the eastern bay and a peak concentration in December 2009 in the central bay due to one exceptionally high ammonium concentration at a single station. DIN in Barnes Sound has been elevated since April 2008 and above the 75^{th} percent quartile since October 2009. In Whitewater Bay, TOC, DIN, and turbidity were below or near the long-term median during WY2009 and WY2010.

Total organic carbon (TOC) was near or below the long-term median in the eastern and western bay, and near the long-term median in the central region. All three regions had lower TOC than the long-term average. In Barnes Sound, TOC was also below or near the long-term median through October 2009 and then rose above the 75^{th} percent quartile for the remainder of WY2010. TOC in Whitewater Bay is higher than all other regions.

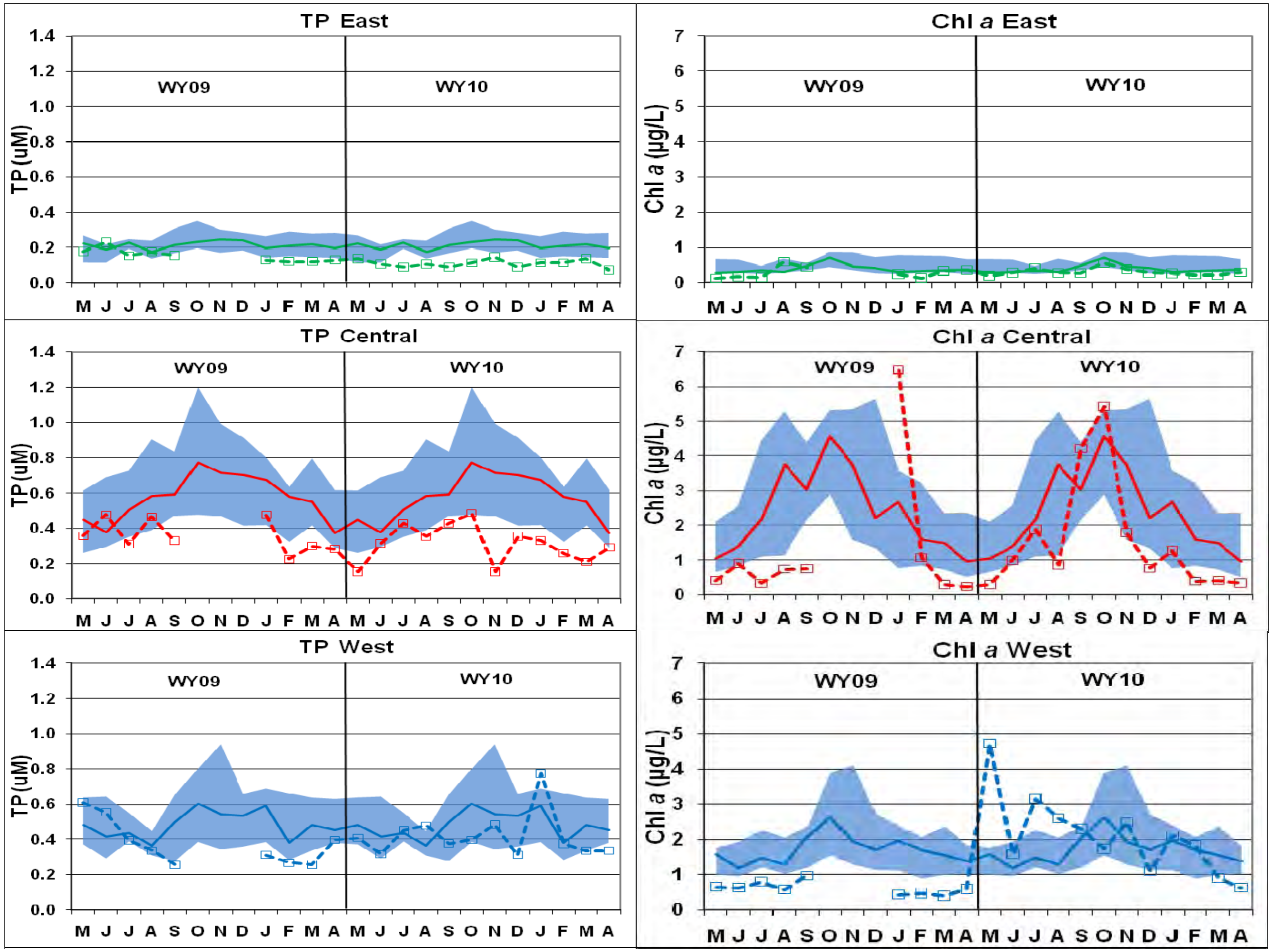

Figure 12-64. Monthly TP [1 micromol (µM) = 31 µg/L] and Chl*a* concentrations in the three regions of Florida Bay during WY2009 and WY2010 (dashed line with open symbols) compared to median and IQR of monthly means from WY1992–WY2008 (solid line and blue shading).

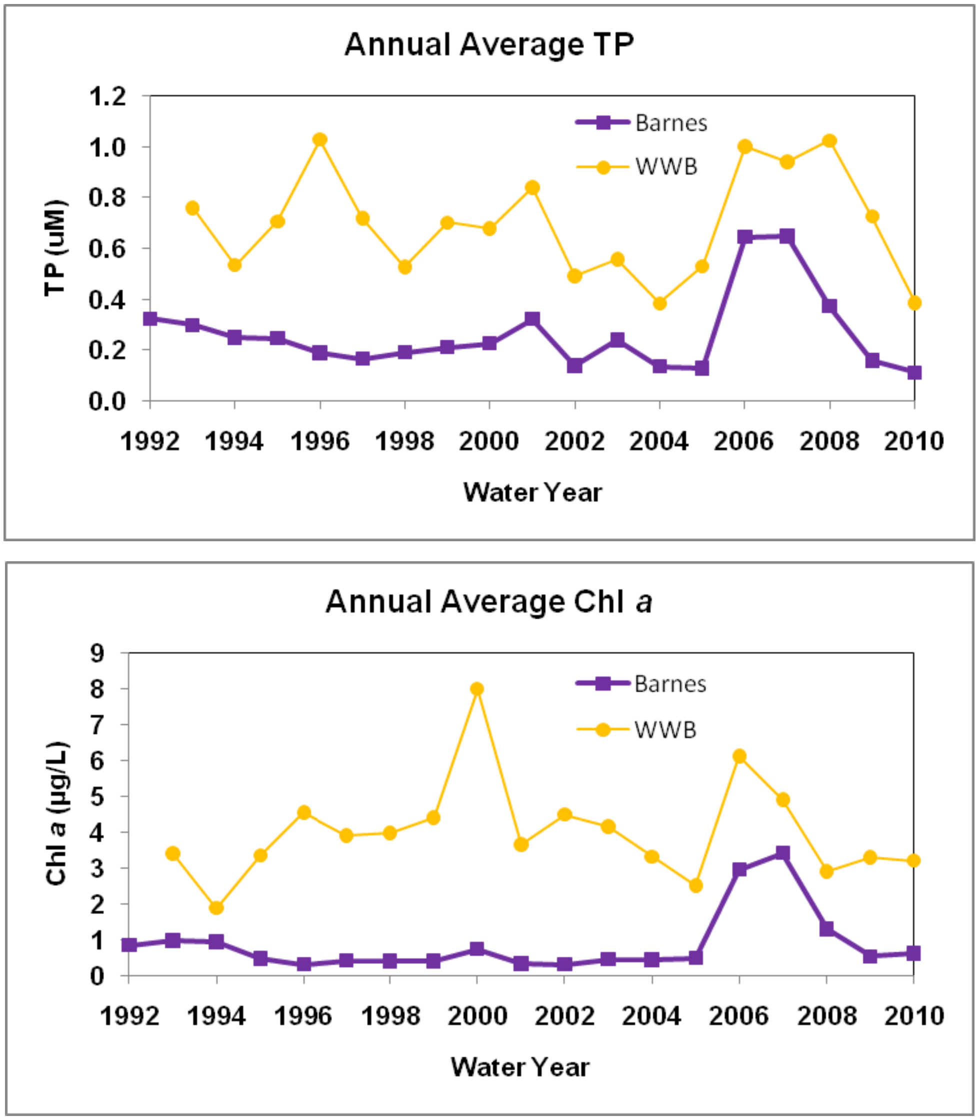

Figure 12-65. Annual average TP (1 µM = 31 µg/L) and Chl*a* concentrations in Barnes Sound (Barnes) and Whitewater Bay (WWB).

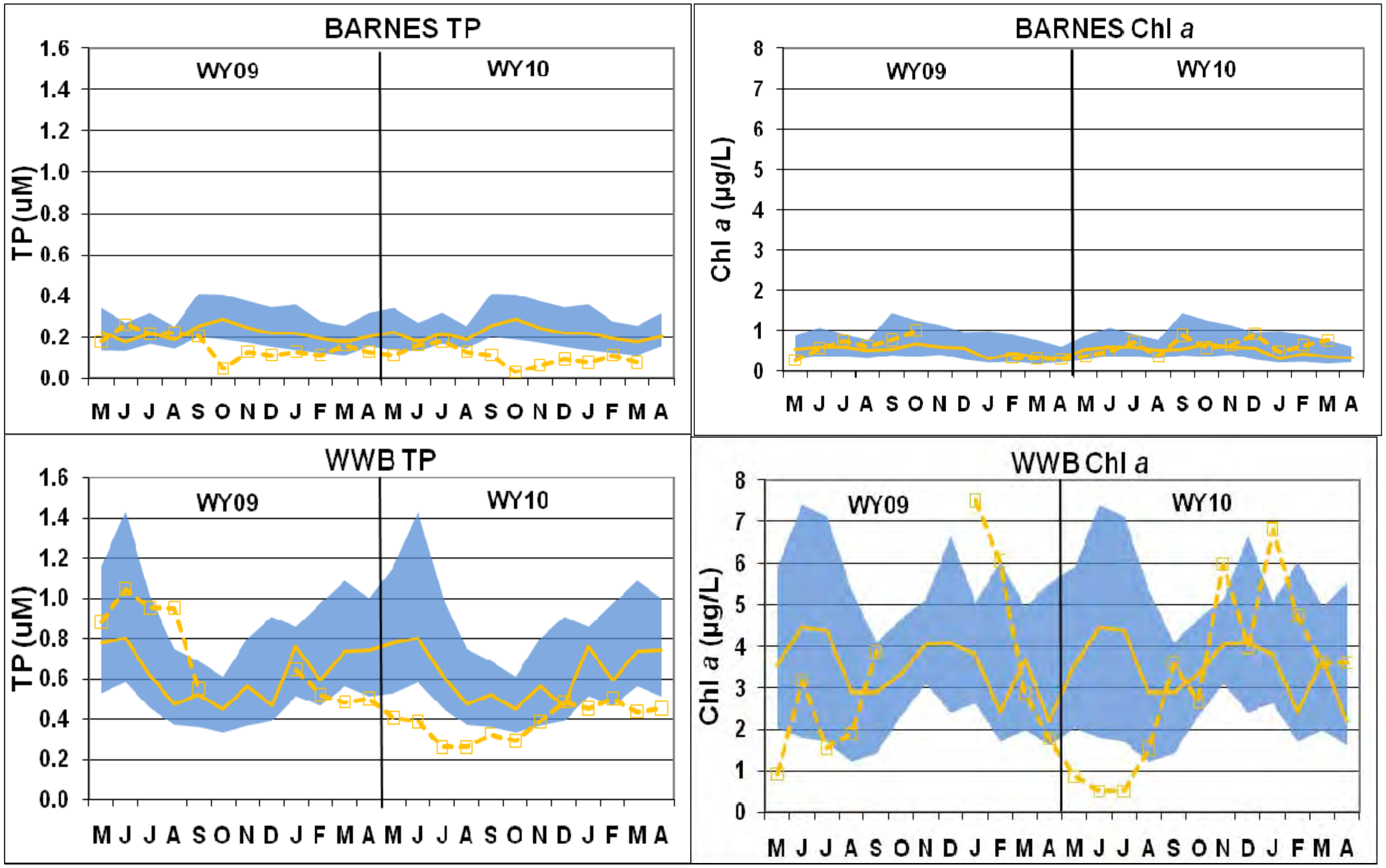

Figure 12-66. Monthly TP (1 µM = 31 µg/L) and Chl*a* concentrations in Barnes Sound and Whitewater Bay during WY2009 and WY2010 (dashed line with open symbols) compared to median (solid line) and IQR (blue shading) of monthly means from WY1992–WY2008.

Submerged Aquatic Vegetation

U.S. Highway 1 and Lake Surprise Area. U.S. Highway 1 between Florida City and Key Largo (also known as "the 18-mile Stretch") has been undergoing roadway widening and improvement by the Florida Department of Transportation (FDOT) since 2005 (**Figure 12-55**). Activities from WY2009–WY2010 include the following:

- Removal of the old Jewfish Creek drawbridge and causeway across Lake Surprise
- Completion of a new fixed bridge spanning Jewfish Creek and Lake Surprise
- Start of construction on a new fixed bridge across the C-111 canal
- Installation of culverts under U.S. Highway 1 allowing water and wildlife to pass between Long Sound and Little Blackwater Sound to the west and Manatee Bay and Barnes Sound to the east

Currently, construction activities have largely shifted northward along U.S. 1 into the wetland areas near Florida City. Work also continues on the C-111 bridge.

Lake Surprise experienced an unprecedented algal bloom that affected much of Northeast Florida Bay from fall 2005 through 2008, but was especially strong in the lake. Regional water quality monitoring reported higher nutrients, higher phytoplankton biomass (Chl*a* concentration), and decreased water clarity (Abbott et al., 2007) relative to long-term averages, likely due to a combination of road construction and soil disturbance, hurricane-induced losses of SAV, and managed canal water releases in 2005. Lake Surprise was subjected to particularly intense road construction activities during most of this period with major activity on the causeway and bridges from 2005–2008. Causeway removal began in November 2008, and the roadbed and fill were excavated, graded, and capped with new fill material to a height of 2 feet below mean low water level, restoring the hydrologic connection between the divided lake for the first time in over 100 years. Despite extensive containment efforts, construction resulted in sediment resuspension and increased turbidity (FDOT, unpublished data). Frequent short-term hypoxic events (low dissolved oxygen) were also measured during construction (SFWMD, unpublished data), raising concerns about the negative effects on benthic macrophytes.

Removal of the causeway was completed in early December 2008. Nutrient and Chl*a* concentrations in the lake returned to historical baseline levels within a few months, along with a general decline in bloom conditions throughout the northeastern bay region. Removal of the causeway may have increased flushing and decreased water residence time in the lake, and these factors could be important in the dissipation of the bloom and decrease in turbidity. The impacts of the prolonged algal bloom and construction disturbance on the Lake Surprise benthic community were unknown as data on SAV prior to the start of the algal bloom in 2005 are sparse. However, a rapid survey conducted in 2007 documented significant SAV in the lake during the bloom (Cunniff et al., 2007).

The fate of SAV in Lake Surprise is important to Northeast Florida Bay water quality due to the nutrients sequestered in sediments and SAV biomass. Collapse of the seagrass community could serve as a source of significant nutrient loading to adjacent basins from decomposing tissues and porewater nutrient release. District staff and contractors assessed Lake Surprise SAV over five sample time points to investigate the response of the system to the restoration action: (1) fall 2008 (immediately preceding causeway removal), (2) spring 2009, (3) summer 2009, (4) fall 2009, and (5) spring 2010. For each sample, frequency of SAV presence and bottom cover (which is used as a proxy for density) was measured using the Braun-Blanquet Cover Abundance Index (BBCA) at 32 sites in eight randomly located 0.25 m^2 quadrats per site. SAV and macroalgae were observed with very high frequency with at least one species present in 98–100 percent of all quadrats sampled from fall 2008 through spring 2010, demonstrating a widespread distribution of benthic vegetation in the lake. Total vegetation cover and relative density were higher in spring than fall. Total SAV coverage increased slightly but density declined from fall 2008–spring 2010 (**Figure 12-67**). Seagrass, rather than macroalgae, predominated in terms of presence and density. Seagrasses were observed with high frequency at all time points (91.8–96.5 percent), and density displayed the same seasonal trend of higher BBCA values in spring versus fall. Comparing seasonal time points for seagrass only, fall presence and density declined from 2008–2009, and spring density declined from 2009–2010. Total seagrass presence increased but density declined from fall 2008–spring 2010 (**Figure 12-68**). In comparing seasonal time points for macroalgae, presence and density declined in fall 2008 to fall 2009, and presence increased but density declined from spring 2009 to spring 2010. Total macroalgae presence and density increased slightly from fall 2008–spring 2010 (**Figure 12-69**).

Lake Surprise features a diverse assemblage of benthic vegetation with four species of seagrass (turtle grass, shoal grass, star grass, and widgeon grass) and 17 species of macroalgae, both calcareous and non-calcareous. The number of species observed per quadrat (driven mostly by macroalgae) averaged 3.5 and 3.9 in spring samples and 3.2 in fall samples for both years as shown in **Table 12-12**. The average number of seagrass species observed was generally consistent (1.3–1.5) and increased from fall 2008 to spring 2010. Macroalgae species diversity was higher than seagrass in general, higher in the spring (2.1–2.4) than fall (1.7–1.9), and increased from fall 2008 to spring 2010. Of particular interest was the apparent increase in turtle grass and shoal grass frequency from 71.8–80.5 percent and 59.8–68.4 percent from fall 2008 to spring 2010, respectively (**Figure 12-70**).

Overall, Lake Surprise seagrass + macroalgae presence increased, and density decreased during the study period. By component, seagrass cover increased but density decreased, whereas both cover and density increased for macroalgae. It is unclear whether these relatively short-term changes were influenced by the improved water quality conditions that occurred following causeway removal late in 2008 (after the first sampling event). The results suggest that increased turbidity and stress associated with causeway excavation did not negatively impact this community. The community may be shifting its structure toward being less patchy, lower density, and higher diversity.

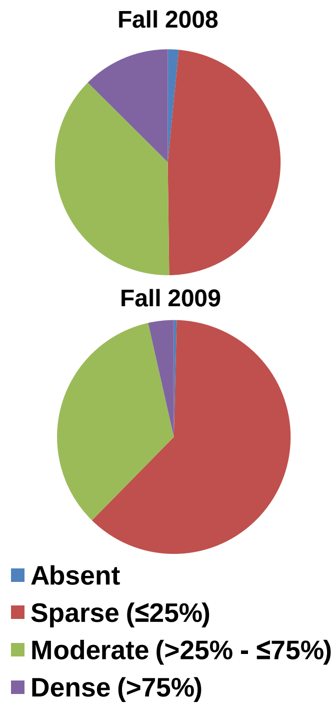

Figure 12-67. Lake Surprise total seagrass and macroalgae density. Data are pooled by sample time point from equally weighted individual Braun-Blanquet Cover Abundance Index (BBCA) quadrat observations ($n_{observations}$ = 1,024).

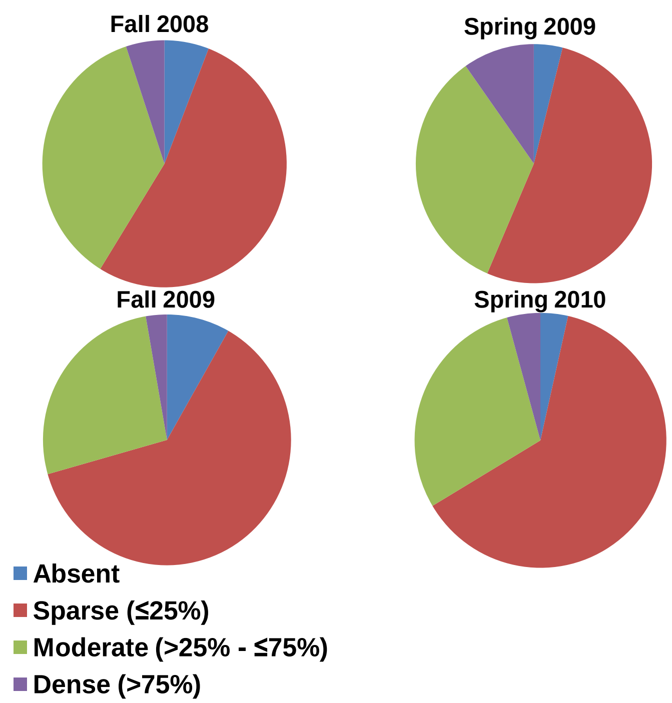

Figure 12-68. Lake Surprise seagrass density. Data are pooled by sample time point from equally weighted individual BBCA quadrat observations ($n_{observations}$ = 1,024).

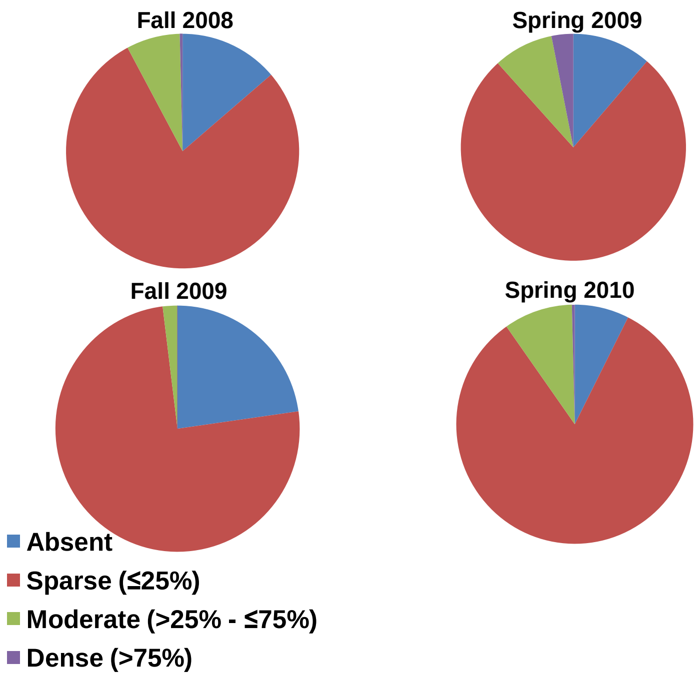

Figure 12-69. Lake Surprise macroalgal density. Data are pooled by sample time point from equally weighted individual BBCA quadrat observations ($n_{observations}$ = 1,024).

Table 12-12. Average number of observed seagrass and macroalgae species per quadrat. Number given in parentheses represents the maximum number of observed species in a quadrat.

	Total Species	Seagrass Species	Macroalgae Species
Fall 2008	3.2 (8)	1.3 (2)	1.9 (6)
Spring 2009	3.5 (7)	1.4 (2)	2.1 (6)
Fall 2009	3.2 (7)	1.5 (3)	1.7 (5)
Spring 2010	3.9 (8)	1.5 (3)	2.4 (6)

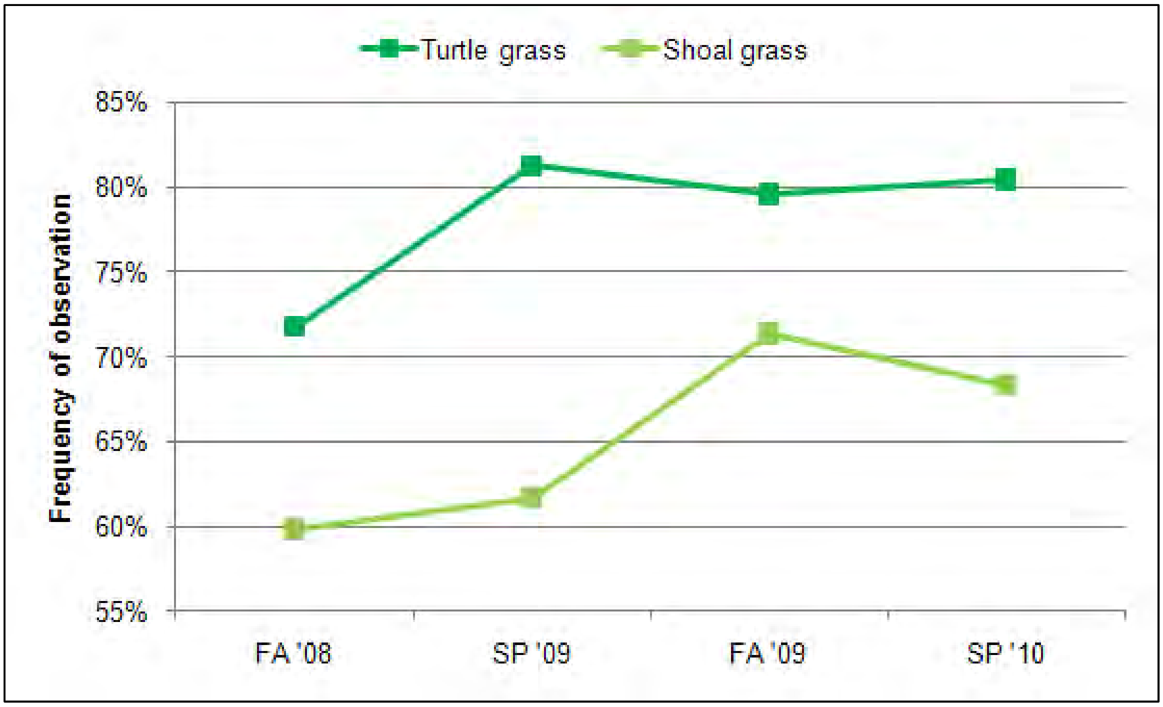

Figure 12-70. Turtle grass and shoal grass frequency of observation per quadrat, pooled by sample time point ($n_{observations}$ = 1,024).

A separate epibenthic investigation in the area of the Lake Surprise causeway cap (over the footprint of the original causeway) was conducted in spring 2010 to document the status of macrophyte recruitment since completion of the excavation and filling project. FDOT would be compelled to take steps toward transplantation if natural macrophyte recruitment does not occur within in two years after project completion. District staff and contractors employed the BBCA index at 15 random points along a 770 m transect, along the length of the cap, and placed five quadrats evenly spaced across the cap from side to side (ranging from 10–30 m) perpendicular to the transect for a total of 75 equally weighted observations. At least one SAV species was present in 97.3 percent of observed quadrats, and macroalgae were observed more frequently and in higher density compared to seagrass (**Figure 12-71**). These preliminary results suggest that epibenthic plants are recruiting on the cap, and continued monitoring is planned.

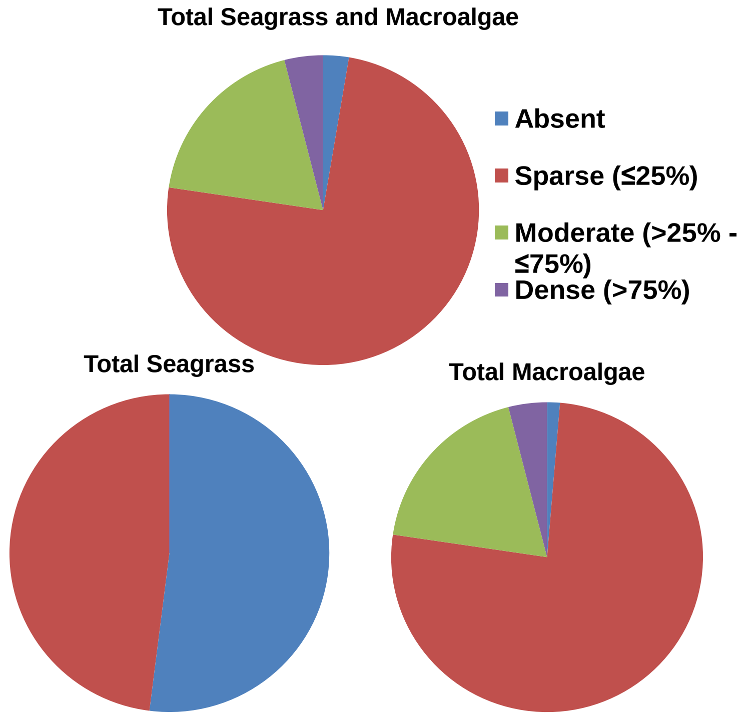

Figure 12-71. Lake Surprise causeway cap seagrass and macroalgal density ($n_{observations}$ = 75).

Florida Bay Benthic Habitat. The status of SAV habitat is the central performance measure for Florida Bay assessment and restoration (Rudnick et al., 2005). The sustainability of mixed-species seagrass beds with moderate-to-dense cover through most subregions is the primary restoration target for the bay. Performance measures defining optimal SAV species composition are documented for RECOVER. 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. Three groups receive funding from the District to monitor SAV status in the Florida Bay area: Miami-Dade DERM, FWC, and Audubon of Florida (Audubon).

DERM conducts benthic habitat surveys in eastern Florida Bay and southern Biscayne Bay, quarterly within 12 monitoring basins. The technique uses a modified BBCA (Fourqurean et al., 2001), where benthic cover is visually estimated by bottom occlusion. Four or 12 randomly selected sites (depending on basin size) are sampled in each basin area using four haphazardly thrown 0.25 m^2 quadrats per site, aggregated to the basin level for analysis.

The FWC Fisheries Habitat Assessment Program (FHAP) has sampled 10 basins in Florida Bay since 1995, and in 2004, the program expanded to 17 basins from Lostman's River in the western bay to Barnes Sound on the east side of U.S. Highway 1. Sampling was conducted annually in May using the same methodology and BBCA scale as DERM at 30 sites within each sampling basin (with eight haphazardly thrown 0.25 m^2 quadrats per site). The higher spatial resolution within the basins facilitates analysis of spatial distributions within the individual basins, but the coarse temporal resolution precludes the assessment of intra-annual trends.

Audubon monitors SAV upstream in the creeks that discharge to Florida Bay at six stations along nine transects extending from the freshwater marshes upstream to near the shoreline of Florida Bay (Frezza et al., 2010b). Cover is estimated with a point-intercept method because visibility is often too poor to use the BBCA method. A 0.25 m^2 quadrat containing 25 intercept points is deployed within 12 quadrats per site. Monitoring is conducted every six weeks.

This report focuses on the mangrove ecotone, also known as the transition zone, which borders northern Florida Bay. This area receives freshwater runoff and, in the case of Manatee Bay, canal discharges, so presumably it is also the most affected by water management activities. Audubon reported above-normal SAV cover upstream in the creeks through much of the year including high numbers of fresh to brackish water algal species As of March 2010, the typical SAV decline observed during the dry season did not occur, likely prevented by above-average rainfall (Lorenz, 2010). A high abundance of widgeon grass (*Ruppia maritima*) in some of the sites was observed, and though not previously observed in the area, the freshwater algal species, *Spirogyra* sp. was noted during the spring sampling.

In the nearshore embayments (from east to west: Manatee Bay, Highway Creek, Long Sound, Trout Cove, Joe Bay, Davis Cove, Alligator Bay, Little Madeira Bay, and Madeira Bay), widgeon grass has been absent since February 2007, with the exception of two observations in Highway Creek in February 2008 and in Joe Bay in December 2009. Prior to 2005, widgeon grass was found routinely at nearly every time point in Highway Creek, Joe Bay, and Little Madeira in an average of 22 percent of quadrats. One expectation of restoration in Florida Bay is the reestablishment of widgeon grass with an expansion of its spatial extent in the transition zone and into the bay.

In the 2010 SFER – Volume I, Chapter 12 reported that shoal grass density had declined in Little Madeira Bay during WY2009, a trend that continued in WY2010. While the shoal grass frequency slightly increased (occurred in an average of 73 percent of quadrats in WY2010 compared to 61 percent in WY2009), the frequency of observations containing greater than 5 percent shoal grass coverage did not increase (averaging 12 percent in WY2010 compared to 13 percent in WY2009). In March 2010, shoal grass was observed only once in Little Madeira Bay where coverage was more than 5 percent. The likely cause of this decline in shoal grass was above-average salinity in Little Madeira Bay that persisted through much of WY2010 (**Figure 12-72**). This negative response of shoal grass abundance is consistent with predictions simulated using the Florida Bay Seagrass Ecosystem Assessment and Community Organization Model (SEACOM), described in the following *Integration of Research, Monitoring and Modeling* section (Madden and McDonald, 2009).

In Madeira Bay, the 2010 SFER – Volume I, Chapter 12 reported that turtle grass frequency had declined during WY2009, while shoal grass frequency and density had increased. Results from May 2009 show that shoal grass frequency continued to increase in WY2010 (occurring in 65 percent of observations compared to 49 percent in May 2008) (**Figure 12-72**). Although shoal grass frequency increased in WY2010, average density has decreased year to year. Turtle grass frequency increased slightly from 74 percent in WY2009 to 79 percent in WY2010, but it has not yet regained the levels observed during WY1999–WY2006. The cause of the shoal grass increase is unknown because no systematic water quality or salinity monitoring was conducted in the area. However, water quality data during this period suggest that salinity has decreased year to year. Unfortunately, these data are collected once per year, so inferences concerning salinity patterns and seagrass responses are not possible. A salinity station has been proposed for this basin as part of the C-111 SCWP monitoring plan.

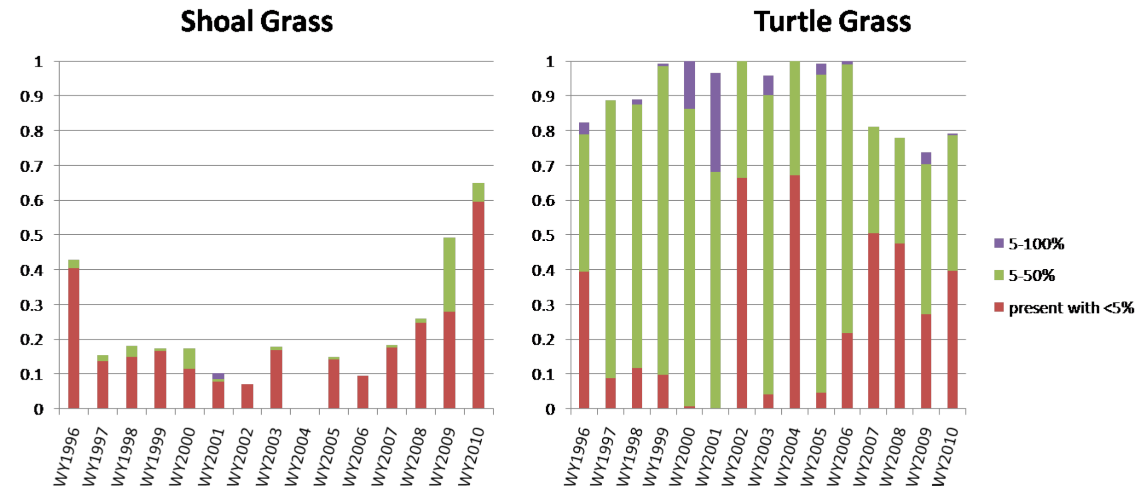

Figure 12-72. Seagrass cover data for shoal grass and turtle grass (from WY1996–WY2010) in Madeira Bay showing the changing frequency distribution of bottom cover categories. Bottom cover is a proxy for density. Data are collected by the FWC Fisheries Habitat Assessment Program annually in May.

Higher Trophic Levels

Record cold temperatures, low dissolved oxygen, and above-average water levels made WY2010 a difficult year for Florida Bay and Whitewater Bay fauna. In July and again in September 2010, thousands of mostly prey base fish [especially striped mullet (*Mugil cephalus*), and pinfish (*Lagodon rhombiodes*)] were found floating along with seagrass wrack near Buoy Key and Snake Bight in northern Florida Bay.

Effects of an extended cold spell in January 2010 were widespread across the Greater Everglades, including the southern ENP estuaries. Air temperatures dropped to the coldest levels in nearly two decades, reducing water temperatures in Florida Bay and Whitewater Bay. Audubon (Tavernier Science Center) recorded a new low water temperature, 1.3°C (34.3°F), at Highway Creek on January 11 (Frezza et al., 2010a). Water temperatures at this station and stations in the network were unusually low (single-digit Celsius values) for over a week in early January. The long January cold spell depleted the few thermal refuges that remained in southern ENP. These conditions caused several cold-sensitive, marine game fish species [snook (*Centropomus undecimalis*), tarpon (*Megalops atlanticus*), bonefish and ladyfish (Albulidae), and several species of snapper, grouper, and sharks] to suffer losses of tens, if not hundreds, of thousands (Hallac et al., 2010). It may take years for these sport fish populations to rebound. The FWC imposed additional fishing restrictions on the species most impacted, such as snook, tarpon, and bonefish. One positive outcome was that populations of exotic freshwater fish, such as Mayan cichlids (*Cichlasoma urophthalmus*), also experienced heavy losses from the cold temperatures, allowing more cold-tolerant native species, such as sunfish (*Lepomis* spp.), to flourish (Audubon status report, Hallac et al., 2010).

Cold temperatures also impacted manatees and crocodiles in Florida Bay and Whitewater Bay, killing individuals who could not escape the low temperatures. ENP staff reported at least 60 West Indian manatees (*Trichechus manatus*) and 50 American crocodiles (*Crocodylus acutus*) perished from the cold, and this is likely an underestimate. Manatees cannot thermoregulate well in water below 20°C (68°F).

Roseate spoonbill (*Platalea ajaja*) nesting in Florida Bay was impacted by both cold temperatures and poor foraging conditions in WY2010. The cold spell came at an inopportune time in the spoonbill breeding cycle (extending roughly from November–April), especially for northwestern Florida Bay colonies where many nests had newly hatched chicks in early January (nest monitoring done by Audubon of Florida). Water depths across the Southern Everglades (where adult spoonbills forage) remained above the prey concentration threshold of 4.9 inches (12.5 cm) where prey is concentrated for efficient spoonbill foraging for almost the entire breeding season. These conditions yielded very low nest success bay-wide with each monitored colony producing well below the one chick/nest value used by Audubon as the determinant of nest success or failure. WY2010 nest numbers were the lowest observed in Florida Bay since the 1960s, and the low nesting success and effort resulted in a poor season for spoonbill productivity in Florida Bay.

Integration of Research, Monitoring and Modeling

Research, monitoring, and modeling programs in Florida Bay and the Southern Everglades are essential in order to develop an integrated understanding of ecosystem function and responses to natural and human effects, especially resulting from District operations and restoration efforts. The integration of multiple areas of study provides the information needed to form a coherent synthesis of the ecology of Florida Bay, and contributes to restoration strategies, project design, and goal-setting for restoration. These research focus areas include hydrologic, water quality, and habitat components, with specific analysis of nutrient cycling in the Everglades wetlands and loading to Florida Bay. These studies integrate seagrass community and population dynamics, seagrass reproduction (seed germination response to environmental conditions), seagrass species composition and health research, monitoring of the estuarine salinity regime, synoptic water quality patterns, water column nutrient levels, and phytoplankton community characteristics in the bay. Additional studies address algal bloom dynamics, estuarine sediment-water fluxes, wetland macrophyte community processes and species composition, wetland hydroperiod, and the effects of soil salinity on periphyton and macrophytes. Information gained from these activities is integrated using a number of synthesis tools, such as conceptual models, numerical ecosystem models, hydrologic/hydrodynamic models, Geographic Information System (GIS), and statistical analysis.

The primary projects supported by these products are federally and state-mandated: RECOVER, the CERP C-111 SCWP, and MFLs for Florida Bay. Additionally, these research efforts support other important projects, such as tracking and understanding algal blooms and harmful algal blooms in Florida Bay, tracking low dissolved oxygen events that can lead to fish kills, identifying mechanisms for seagrass stress and die-off, and understanding species succession and its consequences in the estuarine ecosystem. Many of the individual research activities discussed in this section support multiple projects; all Everglades projects are supported by the growing knowledge base formed by the synthesis of these and other efforts. During WY2010, several projects focused on the Florida Bay ecosystem, and findings from these projects and studies appear under the activity to which they primarily contribute.

Minimum Flows and Levels for Florida Bay. An MFL peer review in 2006 provided a basis for an MFL update research plan (described in the 2008 SFER – Volume I, Chapter 12), following initial rulemaking in 2006. The scientific basis for the Florida Bay MFL rule is currently being reviewed. Based on this review, the rule may be refined or updated, if applicable, which would be submitted to the SFWMD and the FDEP in 2011. Current program activities are focused on improving information about bottom plant community habitat responses to freshwater flow (and associated salinity) and resultant higher trophic level responses. The primary focus of the MFL rule and recent research in Florida Bay is on the tolerant *Ruppia maritima* community and the freshwater macroalgal consortium (e.g., *Chara* sp.) that historically provided high-quality habitat in the variable salinity mangrove transition zone. Seaward, the MFL rule is designed to protect the seagrass community in northern Florida Bay proper.

The MFL is based on a salinity criterion that is evaluated against a threshold value of 30 psu, at a single salinity station in Taylor River, to determine compliance with the rule. The salinity regime is simulated using models for much of northern Florida Bay where salinity variability and hypersalinity are the critical parameters evaluated for protectiveness of the seagrass resource within the northern bay. For the MFL update, the effectiveness of the current rule is being evaluated, and the SFWMD is investigating the possible spatial expansion of salinity reference sites to the east and west of the current single site in Taylor Slough. To support this goal, the SFWMD and Florida Atlantic University (FAU) are employing a combination of mesocosm and field experiments, field monitoring of seagrass and macroalgae, and ecosystem simulation modeling. Through collaboration with Audubon, the District is engaged in statistical analysis of long-term data on hydrologic variables, seagrass and macroalgae density, and prey fish density and biomass.

An important result found by Koch et al. (In prep.) is exemplified in **Figure 12-73,** which shows the transition in vegetation through time at a representative transition zone site in Joe Bay during the wet and dry seasons of WY2010. *Halodule*, a marine macrophyte species, is the predominant cover in a shallow creek until the onset of rains and declining salinity leads to replacement by the freshwater species *Ruppia*. A decline in *Ruppia* (significant) begins in January 2010 after a period of salinity increase and temperature decline. Understanding the factors that control and enhance *Ruppia* survival is important to the goal of sustaining habitat in the transition zone.

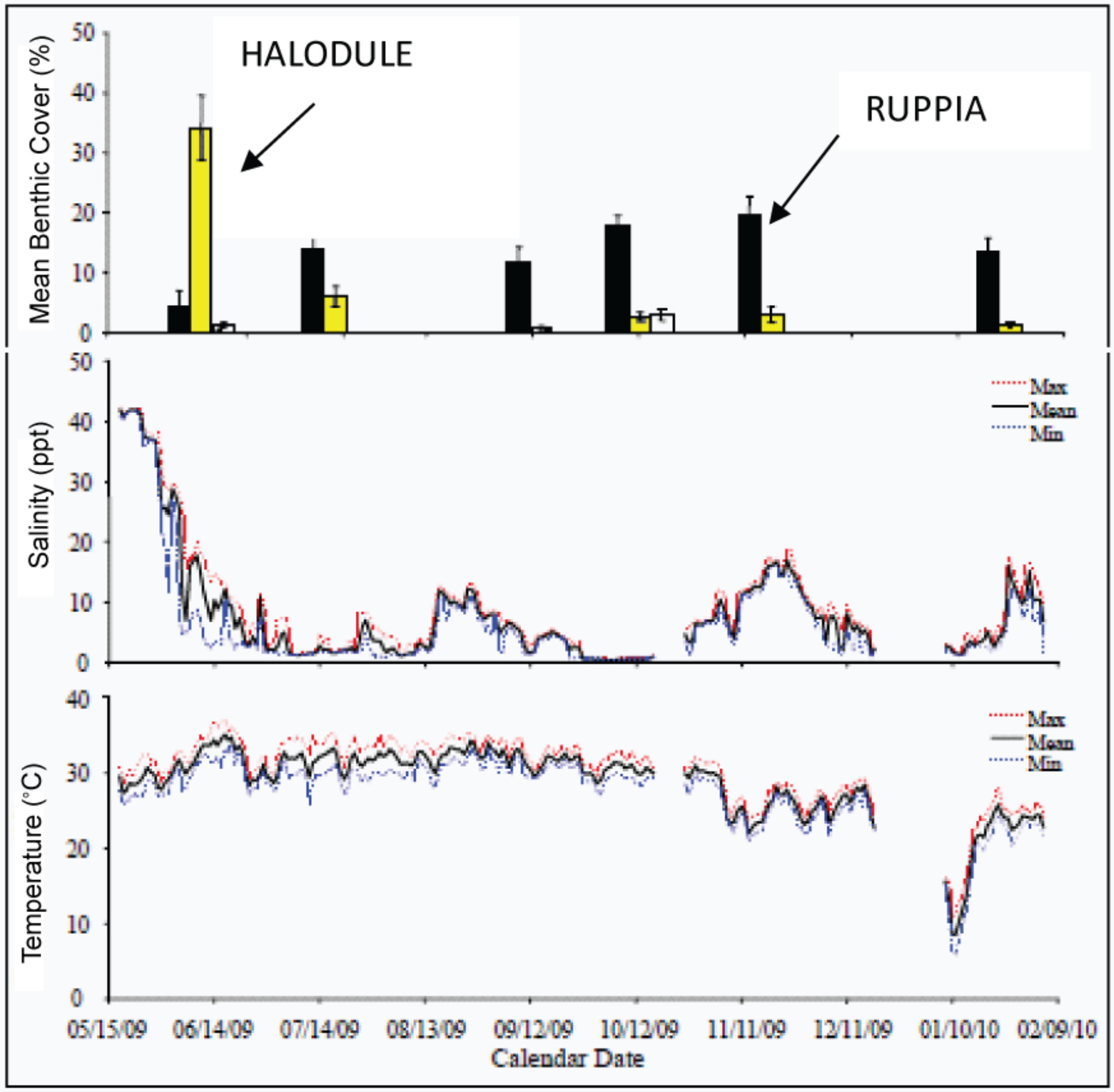

Figure 12-73. Time course of two important seagrass habitat species in a transition zone site in Joe Bay from May 2009–February 2010. Environmental factors of temperature and salinity that may be important in controlling abundance patterns are continuously measured by deployed sonde. (Koch et al., In prep.).

It is also important to know the conditions required to successfully germinate *Ruppia* seed and promote seedling survival to recruit new adult plants. Ongoing surveys along six transects show that intact germinated seeds are found throughout the area, from Barnes Sound to West Lake, with the locus of major seedling production (both numbers of seeds per meter and percent germinated) in more western sites (**Figure 12-74**). Most germination occurs in the middle to upper (fresher) sites in each transect.

Another major finding of District-funded research in the mesocosm facility at FAU indicates that pre-conditioning of *Ruppia* seeds by exposure to high salinity for a time prior to germination will increase the probability of germination. Germination does not occur, however, until salinity falls below 30 psu (Koch et al., In prep.), the threshold established for statutory MFL requirements. Statistical models (Fourqurean et al., 2001) predict that with increased freshwater input from restoration implementation of the C-111 SCWP, *Ruppia* will expand southward into

Florida Bay. SEACOM, a mechanistic model of the Florida Bay seagrass community (Madden and McDonald, 2009), predicts that the enhanced freshwater input to the bay will also modify community composition in a favorable direction by increasing diversity toward a more stable mix of *Thalassia-Halodule* species. SEACOM is described in the *Modeling* section of this chapter.

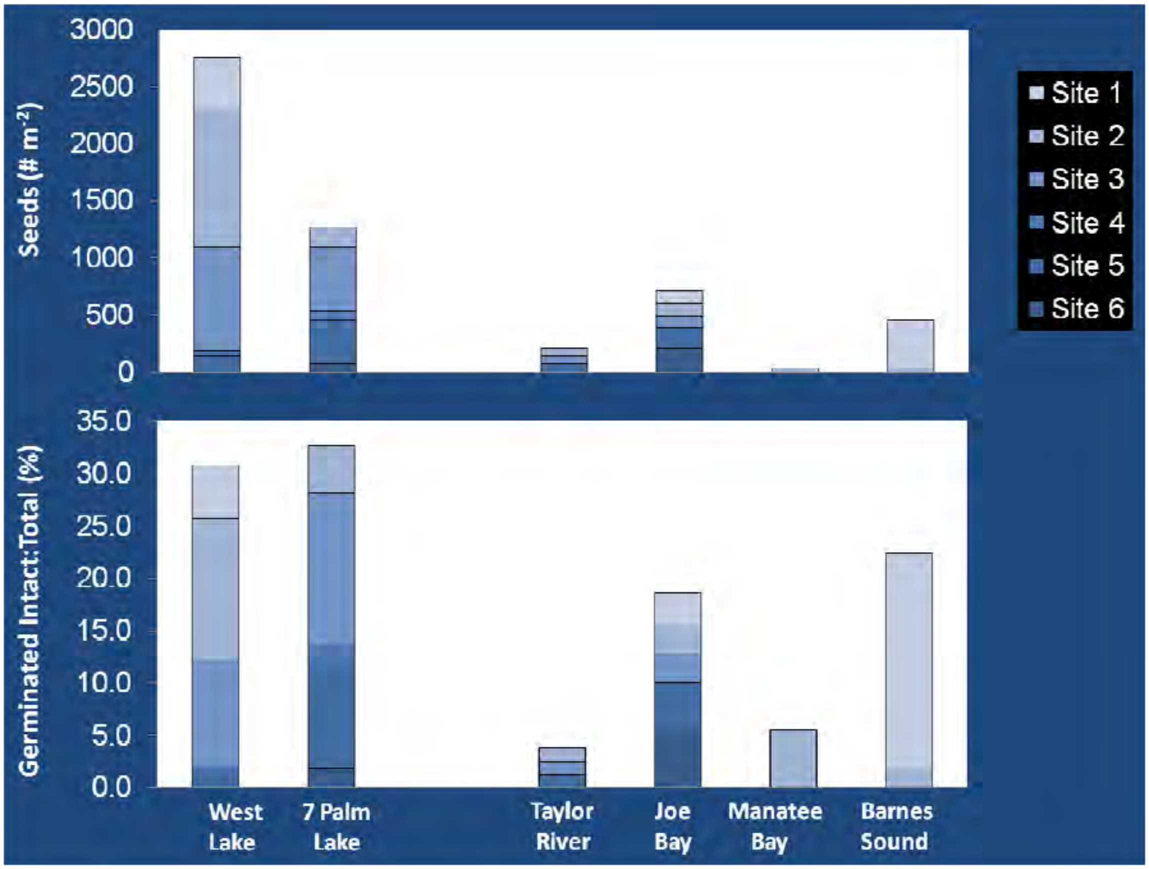

Figure 12-74. Number of widgeon grass (*Ruppia*) seeds per square meter and percent seeds germinated by site for six fresh-salt transects in the transition zone of Florida Bay. Site 1 is the farthest upstream, and Site 6 is most bayward (Koch et al., In prep.).

Synoptic Mapping of Water Quality. The District produces maps of water quality results in northern Florida Bay at intervals of three to four months to track conditions. High-resolution contour maps of salinity, chlorophyll, dissolved organic material, and water clarity have a spatial resolution of about 50 m. The results are used in various ways, including calibration of simulation models that project the effects of salinity thresholds used in MFL rules and the monitoring of algal blooms and other phytoplankton patterns. Of recent interest is the fate of a long-term (2005–2008) phytoplankton bloom that occurred in the eastern bay and sporadic blooms that occur in the central bay. For example, **Figure 12-75** shows the chlorophyll and salinity patterns at the end of the wet season and the end of the dry season in WY2010. Chl*a* has returned to low, pre-bloom levels in the eastern bay, and the central bay exhibits a moderate bloom in October 2009 when the saline lakes also reflect the presence of chlorophyll. Salinity is lower at the end of the wet season in October 2009, primarily in the lakes and transitional bays while it is elevated there during the dry season in April, despite unusually high precipitation due to an El Niño event.

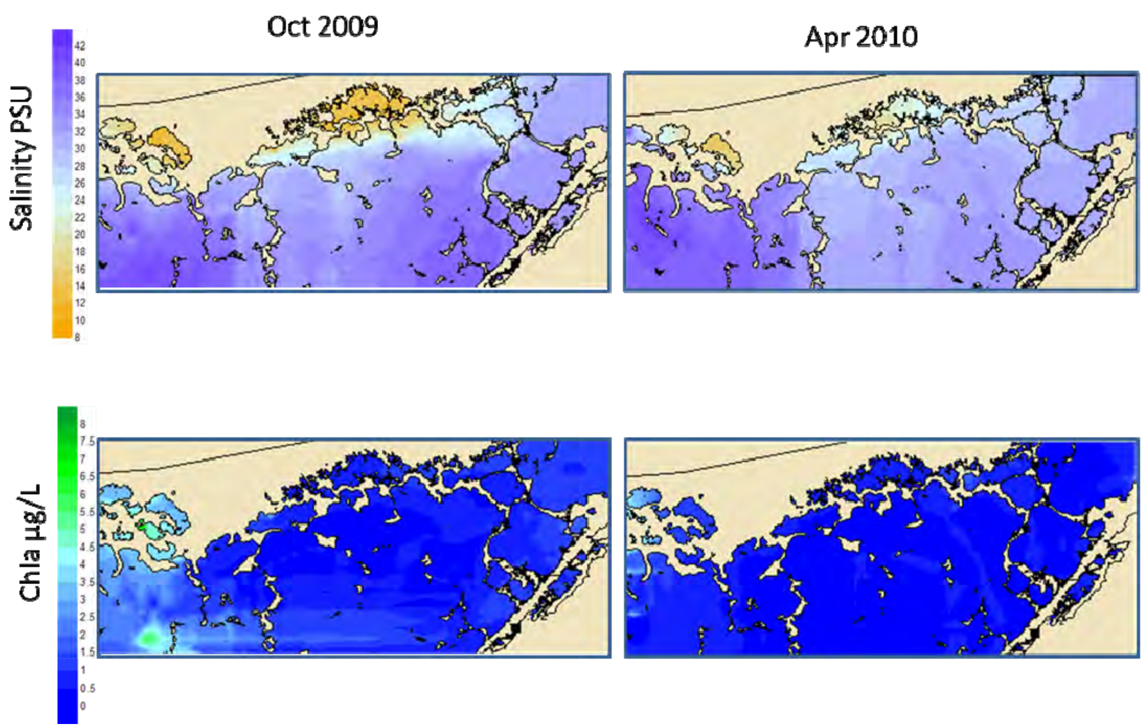

Figure 12-75. Synoptic dataflow maps of salinity and Chl*a* for northern Florida Bay for the dry season and wet season in WY2010.

C-111 Spreader Canal Western Project. The SFWMD conducts monitoring and research in support of restoration activities in the Southern Everglades in Taylor Slough and the C-111 Canal Basin. Both Taylor Slough and the C-111 Canal Basin hydrology will be affected by the C-111 SCW Project, a component of CERP. A three-year monitoring and assessment program for the area that will be affected by hydrologic restoration was initiated in WY2010 to understand how changes in quantity, timing, and quality of water deliveries will affect the downstream wetlands and estuary. The monitoring has enabled the District to gather baseline data for operational and restoration planning prior to implementation of a hydrologic seepage barrier (see **Figure 12-76**) designed to retain water in central Taylor Slough. Following project implementation, continued monitoring will track the impacts of the C-111 SCWP on the wetland and estuary ecosystems. Analysis of these data will be used for evaluating and refining restoration performance measures and targets, and developing improved simulation models for operational needs.

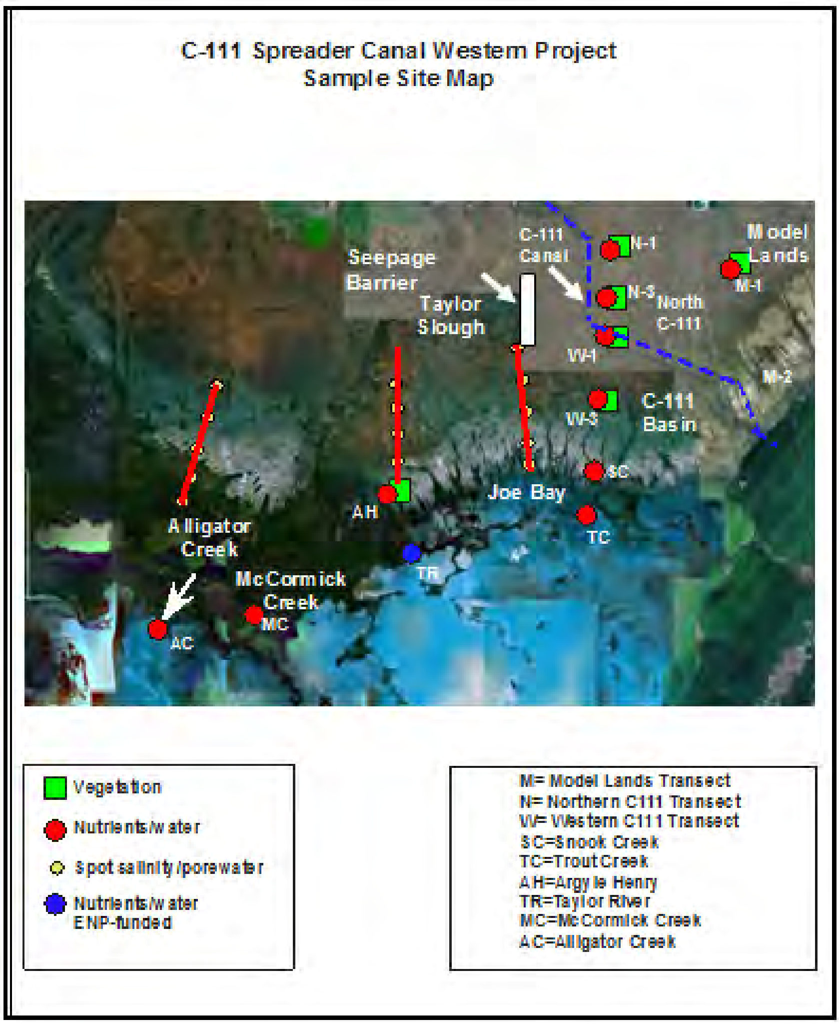

Figure 12-76. C-111 Spreader Canal Western Project monitoring stations and transect lines for biogeochemistry assessment and measurement of nutrient loading.

The baseline C-111 SCWP studies, 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, will continue after project implementation to monitor and quantify the impact of the project. This work is being conducted through collaborations with multiple agencies and institutions, including the USACE, USGS, ENP, Audubon, Florida International University (FIU), and FAU. The work is also providing improved understanding of the relationship of hydrologic conditions, bottom plants, prey base fish, and wading bird status. The District's planning for the C-111 SCWP includes studies to document the ecological benefits of the project with regard to restoring more natural flows through Taylor Slough to Florida Bay and investigations of short-term and long-term water quality consequences.

Water quality parameters (TN, TP, inorganic nutrients, and salinity in overlying water, and porewater TN, TP, inorganics and salinity) are measured in a network of 11 permanent sites and 12 temporary sites throughout the C-111 SCWP footprint using a combination of autosamplers and monthly surveys. The network encompasses sites within the Model Lands Basin, C-111 Basin, and Lower Taylor Slough including the lower fresh marsh, the degraded mangrove habitat area known as the "white zone," the extant mangrove ecotone, the buttonwood ridge, and the creeks discharging into Florida Bay (**Figure 12-76**). Results will be used to assess progress toward project goals.

The C-111 SCWP is designed to move water westward toward Taylor Slough and the lakes region (including Seven Palm Lake, Middle Lake, Monroe Lake, Terrapin Bay, West Lake, Long Lake, the Lungs, and Garfield Bight) by maintaining a seepage barrier on the eastern border of Taylor Slough. In advance of hydrologic changes, the District is monitoring the discharge of water from major creeks into Florida Bay and their associated nutrient load. Three important creeks that are expected to increase in flow rate are Taylor River Mouth, McCormick Creek, and Alligator Creek at the western boundary of the C-111 SCWP. As discharge increases, it is important to monitor the loading of materials and nutrients to Florida Bay. **Figure 12-77** shows that during the period from 2008–2010, TP is about 3–4 times higher and TN is 1.5–2 times higher in Alligator Creek than in Taylor River. As the project is implemented, and discharge may increase asymmetrically in both flow-ways, the rate of materials export to the bay and any downstream impacts will continue to be monitored and evaluated.

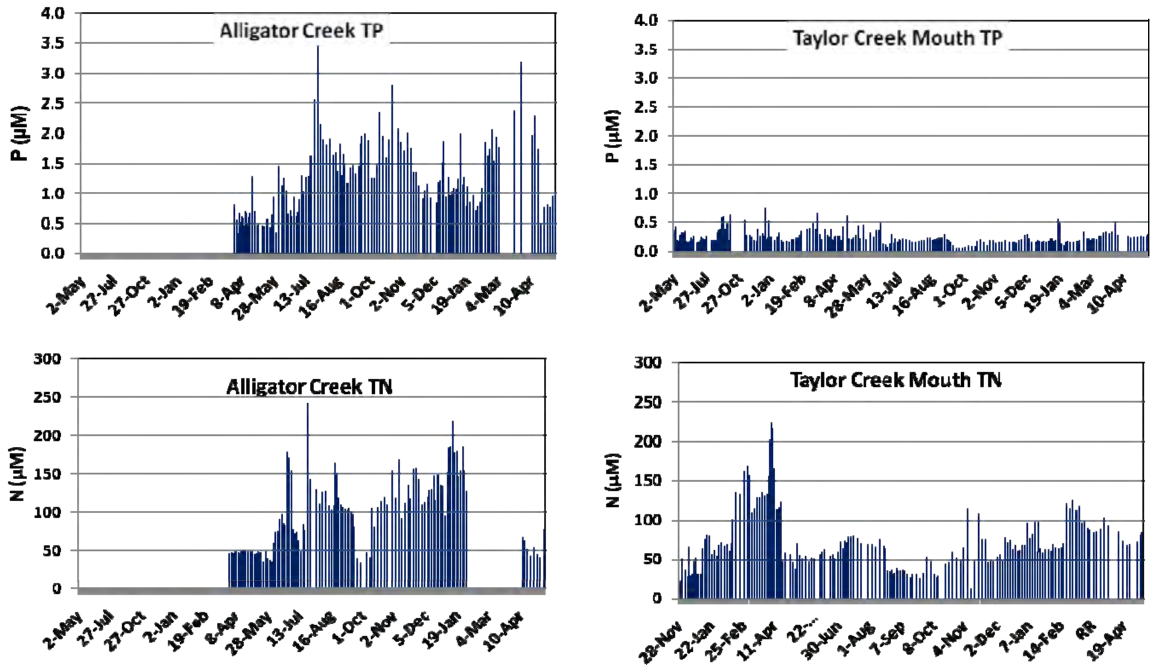

Figure 12-77. Composited 1.5-day concentrations of TN (1 µM = 14 µg/L) and TP (1 µM = 31 µg/L) at Alligator Creek mouth and Taylor River mouth in WY2010.

Central Lakes Region Sediment-Water Nutrient Fluxes. The District began a new initiative designed to understand the character and dynamics of the western boundary of Taylor Slough (the lakes region between Seven Palm Lake and West Lake), which is a little-studied area that will be critical to evaluation of CERP restoration projects (**Figure 12-78**). 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 high nutrient and Chl*a* concentrations compared to Everglades wetlands (upstream of the lake region) or Florida Bay (downstream of the lakes region). As part of the research underlying CERP activities, it is important to understand the water column and sediment processes that will be affected by increased freshwater input to the transition zone. These processes will have potential impacts downstream in terms of nutrient transformation and loading, and phytoplankton growth response. Water management operational plans and restoration plans of the past decade intend to improve the timing and distribution of freshwater flow through the Everglades to Florida Bay. These hydrologic changes could increase (at least temporarily) nutrient transport to the bay and potentially stimulate phytoplankton blooms in the bay. An area of specific interest is the north-central bay, located downstream of a set of relatively nutrient-rich saline lakes where algal blooms have been most common.

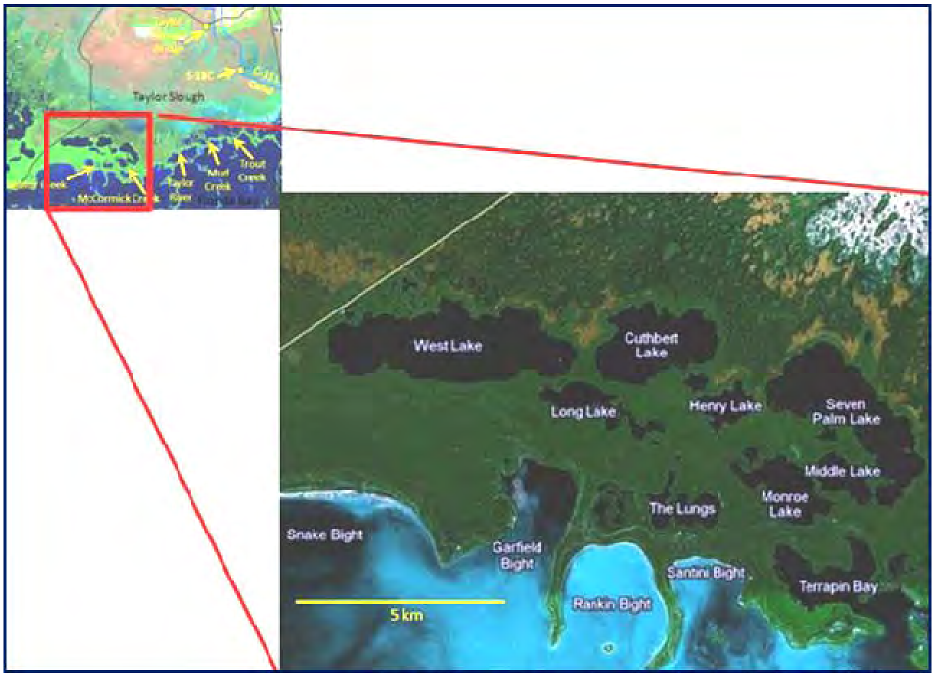

Figure 12-78. Study location of saline lakes north of central Florida Bay.

Recent studies by Frankovich and Fourqurean (2010) measured TP concentrations of 24 µg/L and Chl*a* concentrations of 3.1 µg/L in the Seven Palm Lake-Middle Lake-Monroe Lake chain of lakes, and TP of 86 µg/L and Chl*a* of 23 µg/L in the West Lake-Long Lake-Lungs chain of lakes. With the ongoing effort to shift freshwater flow from the C-111 Basin toward its natural pathway through Taylor Slough, the proportion of water flowing through the central saline lakes toward Florida Bay increased over a 10-year period through WY2007 (**Figure 12-58**) as previously noted in Chapter 12 of the 2010 SFER. To assess the potential water quality effects of altered freshwater flow through these lake systems on downstream water quality, the sources of nutrients within these lakes and their potential to release nutrients to the bay must be determined. Part of this determination is documenting the rate of nutrient exchange between lake sediments and the overlying waters.

The objective of the lakes study program is to quantify rates of benthic nutrient and metabolic gas fluxes from sediment cores taken from Seven Palm Lake, Middle Lake or Munroe Lake, Terrapin Bay, West Lake, Long Lake, and Garfield Bight. Results from these measurements, combined with results from the analysis of surface sediment composition, will be used to make an initial assessment of the magnitude of sedimentary nutrient sources to overlying waters that can be transported downstream.

Central Lakes Region Phytoplankton Processes. The availability of nutrients and nutrient species composition are major factors controlling the phytoplankton community in Florida Bay waters. Consequently, the process of phytoplankton nutrient uptake affects nutrient dynamics and ecological processes in the estuary. Among the affected ecosystem components are water transparency, benthic plant community, grazer communities, sponges, and nutrient availability for other producers. Blooms of cyanobacteria have been shown to be associated with high organic:inorganic nitrogen ratios. Blooms of diatoms are associated with high inorganic:organic nitrogen.ratios. Differing nutrient composition ratios are a consequence of varying source inputs. Bioassays at four sites in the central lakes in April 2010 show that additions of ammonium mildly stimulated algal growth over 24- and 48-hour incubations, and additional phosphate increased algal concentrations two- to threefold over the same time period (**Figure 12-79**).

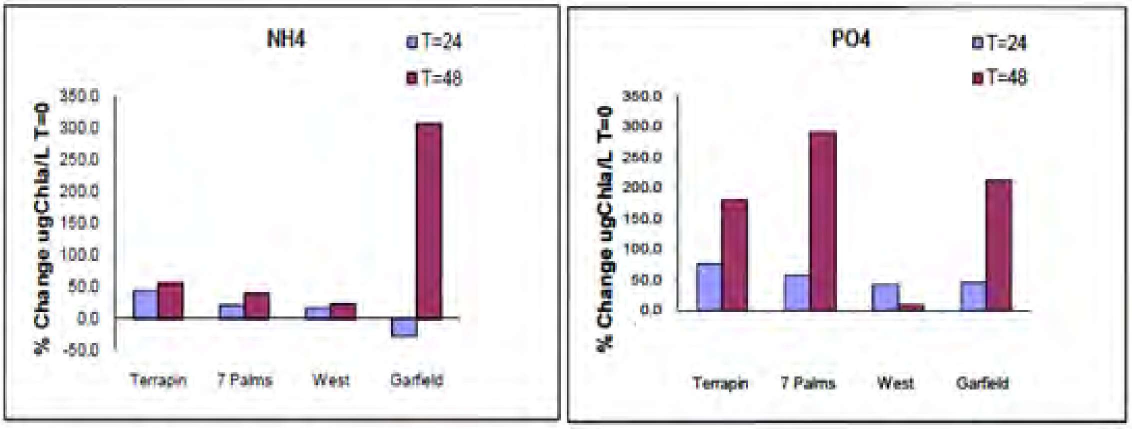

Figure 12-79. Percent increase in Chl*a* in bioassay incubations with additions of ammonium (left) and phosphate (right) for several lakes sites in northern Florida Bay.

In response to intense and persistent phytoplankton blooms in central Florida Bay and upstream lakes in the mangrove ecotone, the District will continue studying the sources and fates of nutrients in the central lakes region and downstream waters during wet and dry seasons as the C-111 SWCP is brought online. This information is of interest in (1) determining the kinds, intensity, timing, and characteristics of phytoplankton communities occurring in the lakes and central Florida Bay; (2) determining the triggers of blooms in the lakes and downstream waters; (3) calculating budgets of nutrients and organic matter in the bay; and (4) understanding how such blooms affect other aspects of bay ecology, such as habitat and trophic dynamics.

Florida Bay Ecosystem Assessment Indicators. As ecosystem restoration proceeds in South Florida and additional fresh water is discharged to Florida Bay, it is important to make regular assessments of seagrass community health. A suite of seagrass indicator metrics was developed to evaluate four essential measures of seagrass community status for Florida Bay (Madden et al., 2009). The measures are based on several years of District-sponsored monitoring data using the BBCA scale to derive information about seagrass spatial extent, abundance, species diversity, and presence of target species. Indicator metrics are calculated at the basin spatial scale, and scores are aggregated to five larger zones representative of areas of the bay with distinguishable characteristics: Northeast, Central, West, South and Transition. Three summary index metrics are derived for each by combining two underlying indicator values. The summary indices are then aggregated to derive a single, bay-wide system status score standardized on the System-wide Indicator protocol (Doren et al., 2008). The indicators provide a way to assess progress toward restoration goals or to reveal areas of ecological concern. Each indicator, index, and overall system status score is reported in a stoplight format, providing information in a readily accessible form for mangers, policy makers, and stakeholders in planning and implementing an adaptive management strategy.

For WY2009, the Composite Index that summarizes overall system status for seagrass in Florida Bay shows an improvement to good in the Central Zone (May 2008–April 2009) compared to the previous assessment in 2007 (**Figure 12-80**). All other zones had the same overall scores in 2009 as in 2007, despite both positive and negative changes in the underlying indicator metrics. The Composite Index for 2009 was good (green) in the Northeast and Western Zones, and fair (yellow) in the Transition and Southern Zones.

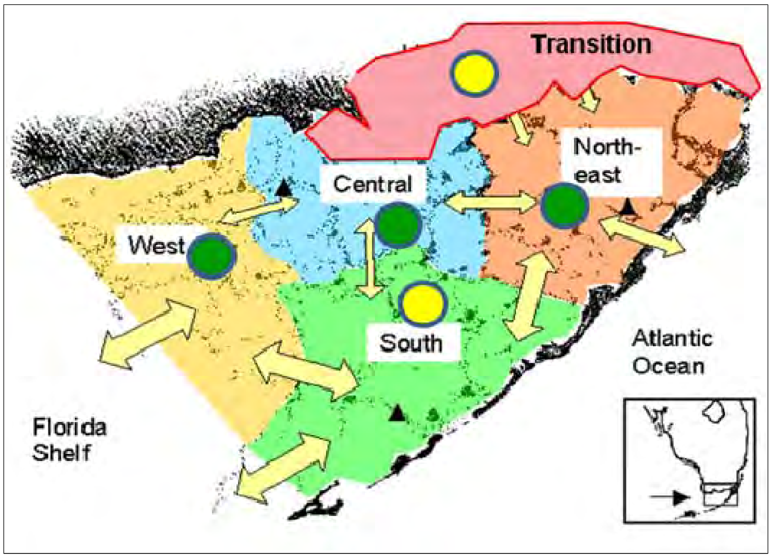

Figure 12-80. System status indicators assessing abundance and species composition for seagrasses in five zones for WY2009.

The underlying Abundance Index (combining both spatial coverage of bottom area and average density indicators) was good in the Northeast and Western zones, fair in the Central and Transition, and poor in the Southern Zone. Underlying indicators reflect good spatial coverage of seagrass in almost all basins throughout the bay but mixed results in the density indicator, reducing the overall index scores for some basins. Abundance was poor in both Madeira Bay and Twin Key Basin.

The Target Species Index, which in turn combines underlying indicators for species diversity and presence of desired species, showed continued good status in the Northeast, Central, and Western zones, and improvement from poor to fair in the Southern Zone, reflecting increased community diversity. Only the Transition Zone showed continued weakness in target species, with Target Species Index scores of fair for each year from 2006–2009. Most zones showed scores of good for presence of target species, but the Transition Zone had an aggregate score of poor due to lack of community diversity.

Basins in the Northeast Zone have generally good seagrass density and good spatial coverage scores. In some basins, density is generally low, but due to the oligotrophic nutrient character of the region, low productivity is considered normal and these levels qualify for good scores for the Abundance Index. However, Northeast basins that were affected by an algal bloom from 2005–2008 (chiefly Barnes and Blackwater Sounds) were negatively impacted, with reductions in both density and spatial extent of seagrass. The affected basins showed some improvement in both indicators toward pre-bloom status as of 2009 although not yet significant. In the Transition Zone, it is notable that Little Madeira Bay formerly scored consistently in the good range for the

Target Species Index, but fell to the poor range in 2009, scoring poor in the underlying target species and the species diversity indicators.

Modeling. Florida Bay has been altered by diminished freshwater inflow and reduced circulation, which in the past, resulted in seagrass die-off, species declines, and algal blooms. Hydrologic restoration calls for increased freshwater discharges to Florida Bay. Changes in nutrient and freshwater delivery regimes, N:P ratios, and substrate can combine to potentially influence light, salinity and nutrient regimes; affect productivity; and influence species composition of the system. A major mechanism for synthesis of the multidisciplinary projects focused on the Southern Everglades and Florida Bay is a complex simulation model of the seagrass-phytoplankton community in the estuary. A numerical model of Florida Bay, the SEACOM, simulates coupled benthic-water column regimes, integrating physics, geochemistry, and biology, in support of restoration strategy. A hydrologic transport mass-balance model (FATHOM) links to SEACOM to create a landscape framework for calculating flushing rates and salinity distributions. SEACOM simulates biomass, production, and community structure for three dominant seagrass species, *Thalassia testudinum*, *Halodule wrightii*, and *Ruppia maritima*; geochemical processes in the sediments and water column; and three phytoplankton functional groups. The integrated model framework tests hypotheses about drivers and stressors on the ecosystem and outcomes of restoration activities.

SEACOM provides analysis of how flushing rates and nutrient cycling rates affect phytoplankton growth and in turn how algal blooms, salinity regime, and sediment geochemistry impact seagrasses (**Figure 12-81**). The integrated upstream-downstream model framework enables forecasting of community response to watershed management, ecological thresholds, and potential shifts in benthic-pelagic dominance.

Increasingly oscillatory behavior of Florida Bay producers between seagrass and phytoplankton dominance may indicate an incipient regime shift. The model has been applied via sensitivity analysis to identify potential tipping points for changes in the benthic system. These calculations are critically important to MFLs for Florida Bay and in developing CERP strategies, targets, and performance measures as additional freshwater is directed to the estuary and water quality may be altered.

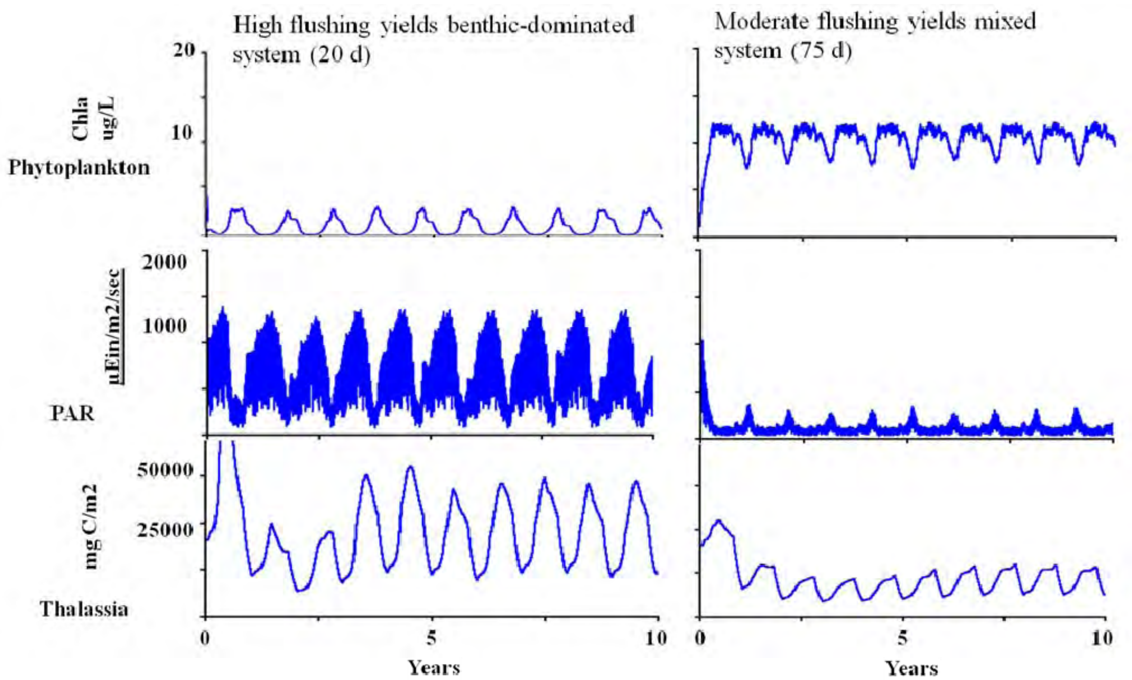

Figure 12-81. SEACOM model output showing effects of three flushing rates on phytoplankton biomass, light at seagrass canopy height, and seagrass response. Results shown are from a model version calibrated for Barnes Sound.

FUTURE SOUTHERN ESTUARY ACTIVITIES

Two of three components of the Biscayne Bay Coastal Wetlands Project and the entire C-111 SCWP are scheduled for completion in WY2011. Additional project-specific monitoring will start up at that time. For example, vegetation transects will be established in the wetlands within the Biscayne Bay Coastal Wetlands Project area, and some additional water quality monitoring. Project monitoring will begin for the C-111 SCWP. The District will examine the latest results to determine if the minimum flow for Northeast Florida Bay is still appropriate. The entire expedited portion (versus Phase 1) of the Biscayne Bay Coastal Wetlands Project is projected to be completed in 2016.

WESTERN ESTUARIES

Patricia Goodman and Richard Alleman

DESCRIPTION OF WESTERN ESTUARINE SYSTEMS, MAJOR PROJECTS AND ISSUES

The Western Estuary Region consists of Estero Bay, Naples Bay, Rookery Bay, and the Fakahatchee Estuary (**Figure 12-82**). The Estero Bay Watershed includes central and southern Lee County and parts of northern Collier and western Hendry counties. Naples Bay is on the coast of Collier County. Estuaries within the Rookery Bay/Ten Thousand Islands region include the following river/bay systems, from west to east: Royal Palm Creek/Palm Bay, Blackwater River/Blackwater Bay, Whitney River/Buttonwood Bay, Pumpkin River/Pumpkin Bay, Wood River, Little Wood River, Faka Union Canal/Faka Union Bay, and Fakahatchee Bay (Savarese et al., 2004). Collectively, these estuarine areas comprise the Fakahatchee Estuary.

All three of these estuarine systems have experienced changes to their natural hydrology and salinity regimes due to water management activities. Changes in the natural river systems around Estero Bay and the Fakahatchee Estuary resulted from intensified development in the 1960s. Today, all receive water from basins that have grown in size as a result of canal system improvements for urban development and flood protection. In the past, the slow, sheet flow patterns of the Estero Bay and Fakahatchee Estuary basins distributed nutrients over broad areas of wetland vegetation, and the seasonal rainfall fluctuations created flow that facilitated the necessary salinity regime for good estuarine productivity.

The following current District projects are addressing these issues:

- Picayune Strand Restoration Project (Fakahatchee Estuary)
- Picayune Strand Water Reservation (Fakahatchee Estuary)
- Golden Gate Weir No. 3 Relocation (Naples Bay)

ECOSYSTEM STATUS

Fakahatchee Estuary

The Big Cypress and Everglades watersheds are the exclusive drainage basins entering the Ten Thousand Islands. The Big Cypress Watershed drains the majority of Collier County, supplying fresh water to the estuaries of the Ten Thousand Islands through a series of tributaries. Prior to anthropogenic impacts, flat topography, marly soils, and seasonal rainfall were principal influences on the hydrology of the Picayune Strand area. This natural sheet flow system absorbed floodwater, promoted groundwater recharge, sustained wetland vegetation, rejuvenated freshwater aquifers, assimilated nutrients, and removed suspended materials. Fresh water reached the Ten Thousand Islands estuaries and associated acres of salt marshes and mangrove swamps through a combination of overland sheet flow and groundwater seepage (USACE and SFWMD, 2004). The quantity and timing of freshwater inflows determined many characteristics of estuarine habitat by establishing salinity, other aspects of water chemistry, and dynamics of currents and water exchange. This slow, year-round influx of fresh water maintained salinity in the natural range that estuarine species require (SFWMD, 2008).

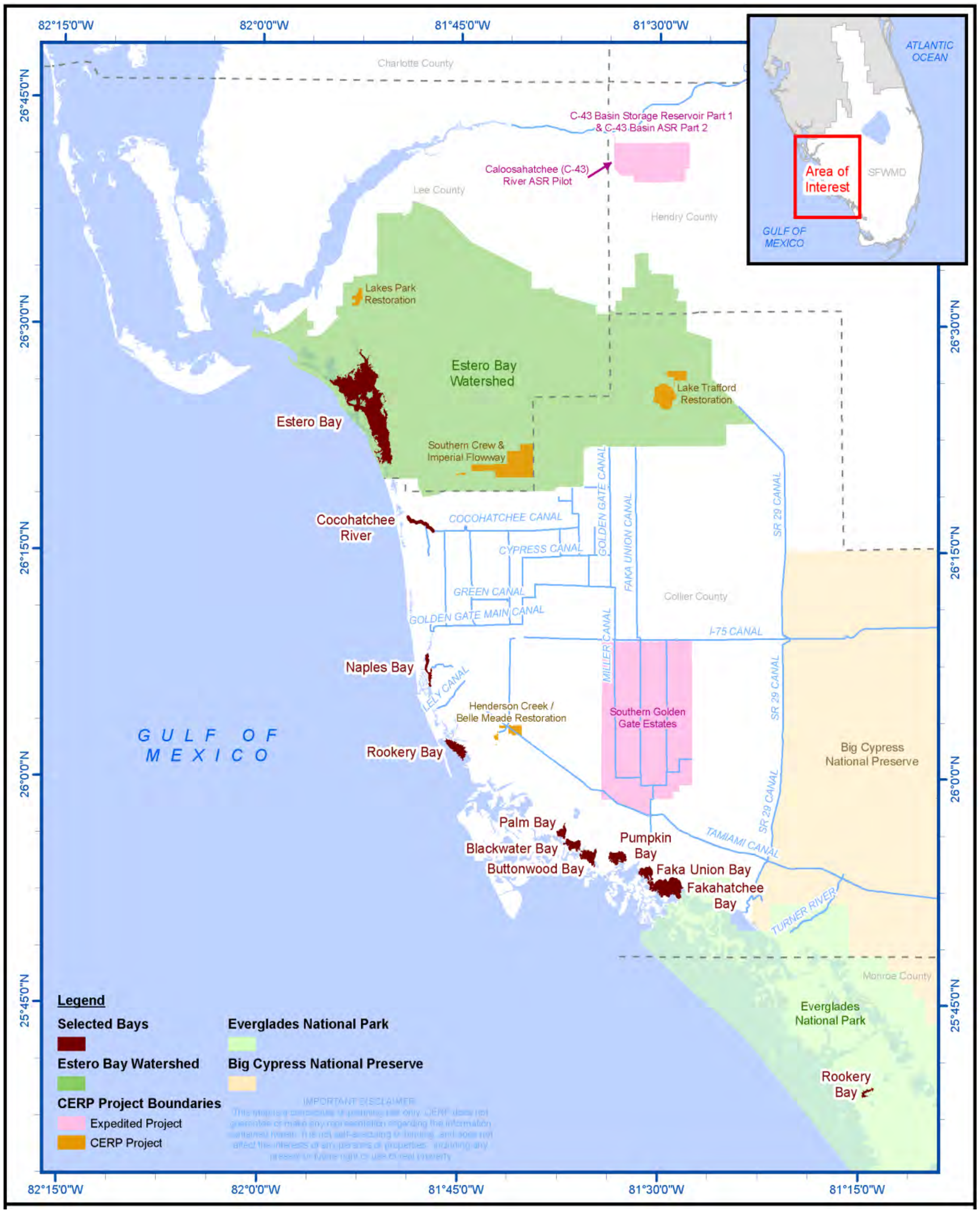

Figure 12-82. Western Estuary Region.

The Picayune Strand Restoration Project, an Expedited Everglades Restoration Project (**Figure 12-82**), involves rehydrating a failed 1960s subdivision, known as Southern Golden Gate Estates (SGGE), by removing the infrastructure of roads and canals and restoring its pre-drainage hydrology. Located in southwestern Collier County, Picayune Strand is surrounded by preserves and wildlife areas that will be linked to and enhanced by the restored conditions within the project area. This single, connected regional ecosystem will encompass estuaries, freshwater wetlands, and uplands (see Chapter 7 of this volume).

To develop the 55,247-acre (94 square miles) subdivision, an extensive canal system was excavated to drain surface waters and provide fill for the road system. Within the project area, four large drainage canals flow from north to south: the Miller, Faka Union, Merritt, and Prairie canals. These canals have drained the area, resulting in the reduction of aquifer recharge; increased freshwater point source discharges to Faka Union Bay (**Figure 12-83**); decreased freshwater overland flow and seepage into the remaining receiving estuaries; invasion by nuisance vegetation; loss of ecological connectivity and associated habitat; and increased frequency of forest fires. Expected improvements include:

- Reversal to historic plant and animal communities
- Reestablishment of sheet flow through Picayune Strand toward coastal estuaries
- Reduction of harmful surge flows through Faka Union Canal into Faka Union Bay
- Improved freshwater overland flow and seepage into other bays of the Ten Thousand Islands region
- Improved aquifer recharge
- Decreased frequency and intensity of forest fires
- Improved habitat for fish and wildlife including threatened and endangered species
- Reductions in invasive native and exotic species
- Increased spatial extent of wetlands

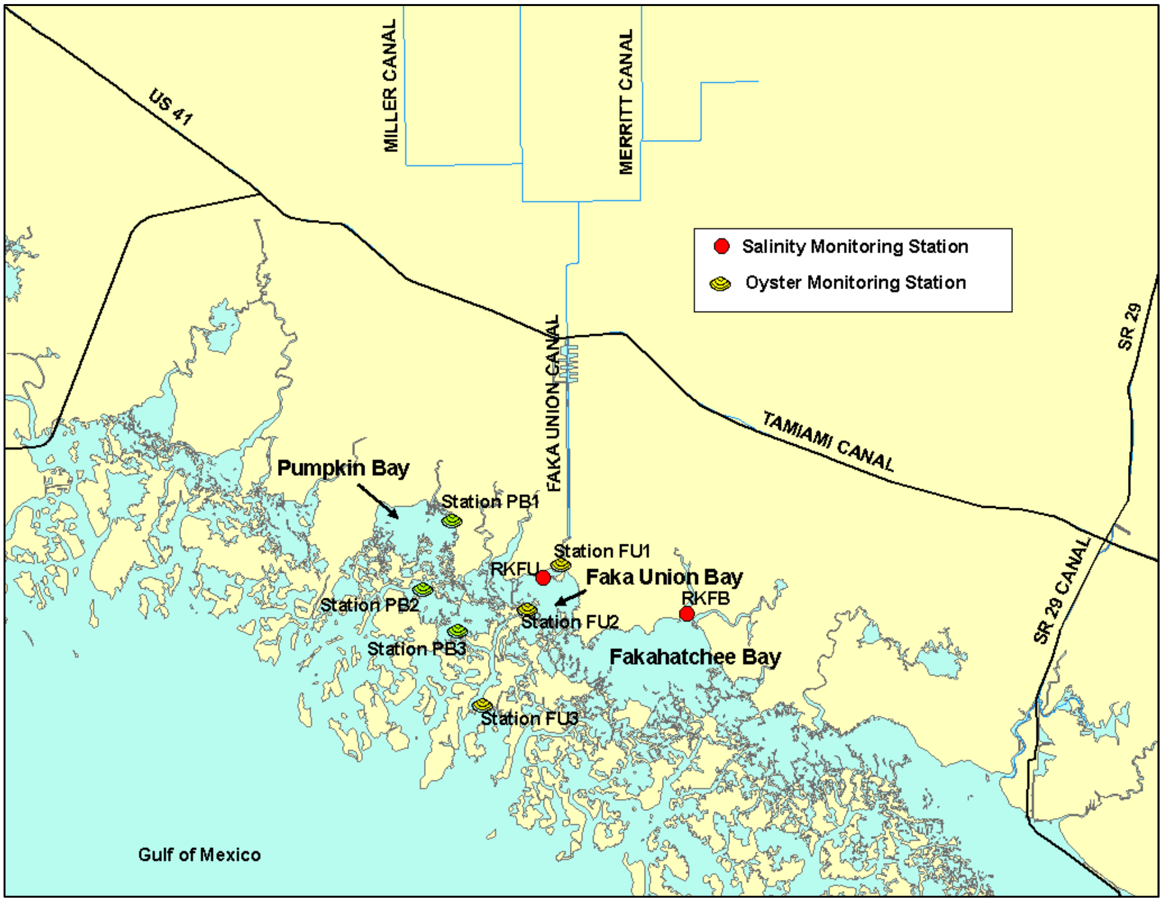

Figure 12-83. Fakahatchee Estuary and monitoring locations.

Salinity and Freshwater Inflows

Increased freshwater inflow volumes from Faka Union Canal have greatly altered the hydrology of the Fakahatchee Estuary, affecting salinity conditions for oyster health and recruitment (see the *Eastern Oyster Abundance and Distribution* section of this chapter). In March 2009, a monitoring project was initiated to compare the status and responses of oysters in relation to water quality in Faka Union Bay (stations FU1, FU2, and FU3) and Pumpkin Bay (stations PB1, PB2, and PB3) (**Figure 12-83**) (Volety, 2010).

During the study period from March 2009–March 2010, salinity exhibited typical seasonal variation with lower salinity prevailing during the warm summer months and higher salinity during the dry winter months. In Pumpkin Bay, salinity ranged from 15 psu (September 2009, PB3) to 45.6 psu (April 2009, PB2). In Faka Union Bay, salinity ranged from 1.7 psu (September 2009, FU1) to 45.2 psu (April 2009, FU3). Salinity at Pumpkin Bay's downstream station (PB3) was lower compared to the upstream (PB1) and mid-stream stations (PB2). Overall, salinity was observed to be higher in Pumpkin Bay compared to Faka Union Bay (Volety, 2010).

The Pumpkin Bay and Faka Union Bay downstream monitoring sites are located where the bays converge in the Fakahatchee Estuary; therefore, the PB3 station may be influenced by freshwater inputs into the bay from the Faka Union Canal (Volety, 2010). Browder et al. (1989) previously noted a reverse salinity gradient into Pumpkin Bay during part of the year, probably due to the large amount of fresh water entering the Ten Thousand Islands through Faka Union

Bay. Because of the SGGE development, freshwater inflows to Pumpkin Bay have been limited; however, this bay should experience a downstream shift of oyster reef development in response to increased freshwater inputs following completion of the Picayune Strand Restoration Project.

During WY2010, the Rookery Bay National Estuary Reserve also monitored salinity at Faka Union Bay (site RKFU) (**Tables 12-13** and **12-14**). Results indicate that a seasonal shift creates a less-than-desirable environment for the eastern oyster because of the number of days salinity exceeds 25 psu (186 days or 51 percent of the time in WY2010) (**Table 12-13**). Additionally, freshwater pulses from the Faka Union Canal provide flood relief for the entire basin, resulting in salinity values lower than 10 psu on occasion (**Table 12-14**).

To proceed with the Picayune Strand Restoration Project, a Water Reservation for the protection of fish and wildlife for the Picayune Strand and Fakahatchee Estuary ecosystems was adopted that seeks to maintain flows in the Faka Union Canal between 50 and 500 cubic feet per second (cfs) (SFWMD, 2008). Ideally, flows should not be outside this range more than about 8.3 percent over the long-term average. Flow values for Faka Union Canal are available beginning in August 2009. From August 8, 2009, through April 2010, daily mean flow was outside the ideal range about 26 percent of the time with flows greater than 500 cfs.

Table 12-13. Mean daily salinity greater than 25 psu at Rookery Bay National Estuary Reserve station RKBFU.

Period of Record	Station	No. days salinity > 25 psu	% days salinity > 25 psu
June 2009–May 2010 (Annual)	RKBFU	186/365	51
November 2009–May 2010 (Dry Season)	RKBFU	130/212	61

Table 12-14. Mean daily salinity less than 10 psu at Rookery Bay National Estuary Reserve station RKBFU.

Period of Record	Station	No. days salinity < 10 psu	% days salinity < 10 psu
June 2009–May 2010 (Annual)	RKBFU	8/365	2
June 2009–Nov 2009 (Wet Season)	RKBFU	0/212	0

Eastern Oyster Abundance and Distribution

Oyster resources within the Ten Thousand Islands region associated with the Picayune Strand Restoration Project were the subject of a study conducted by Drs. Aswani Volety and Michael Savarese of Florida Gulf Coast University between July 1999 and May 2001 (Volety and Savarese, 2001). The study was designed to document the spatial distribution, secondary productivity, recruitment, and health of the eastern oyster within Ten Thousand Islands estuaries of various states of anthropogenic alteration. Their work focused on three estuaries: one pristine that served as the control (Blackwater River), and two whose watersheds were managed and scheduled for restoration (Henderson Creek and Faka Union).

Volety and Savarese assessed the variability in oyster reef distribution, oyster growth, recruitment and productivity, and disease susceptibility and intensity among populations within the three estuaries. These results were helpful but, in general, inconclusive when considering data that are appropriate for use in determining a baseline or pre-implementation condition due to the short duration of the study. Oyster productivity was likely influenced by the climatic events that have occurred since the sites were last surveyed. In the seven years following the last monitoring event, the southwest coast of Florida has experienced the most intense drought period recorded to date, as well as the landfall of several hurricanes or intense tropical storms. Additionally, the study did not include the effects of predation, which during the 2007–2008 drought season, was observed to be heavily influenced by periods of prolonged higher salinity on the Caloosahatchee River and severely impacted oyster larval recruit (Volety, 2010).

As discussed in the previous section, a year-long monitoring project was initiated in March 2009 to compare the status and responses of oysters in relation to water quality in Faka Union Bay. In Faka Union Bay. oyster reef development is limited along mangrove margins due to extreme wet season discharges from the Faka Union Canal. In the ensuing dry season, generally high salinity conditions occur because the watershed has been drained and freshwater sheetflow can only be supplied by rainfall.

In addition to salinity conditions, *Perkinsus marinus* infection affects the density of live eastern oysters. During the study period (from March 2009–March 2010), the prevalence of oysters with *Perkinsus marinus* infection varied between sampling months and sampling locations, ranging from 20–100 percent in both Pumpkin Bay and Faka Union Bay oysters. The mean prevalence of infected oysters from all Pumpkin Bay sites ranged from 36.5–97.8 percent, and mean prevalence in Faka Union oysters ranged from 38–89 percent. Overall, Pumpkin Bay oysters had a higher prevalence (70.8 percent) compared to 63.6 percent in Faka Union oysters; however, insufficient results were available to apply statistical tests to the data.

Volety (2010) noted that intensity of infection (on a scale of 0–5) also varied between sampling months and sampling locations. Intensity ranged from 0.27–2.67 in Pumpkin Bay, and from 0.53–2.53 in Faka Union oysters at various sampling locations. Mean infection intensity (averaged for all stations) ranged from 0.59–2.04 in Pumpkin Bay and from 0.69–1.49 in Faka-Union oysters. Corresponding to the prevalence of *Perkinsus marinus* infection, Pumpkin Bay oysters had higher infection intensity (1.27) compared to Faka-Union oysters (1.13).

Oyster spat recruitment occurred between June and December in both estuaries. This is consistent with reproductive patterns of oysters in other Southwest Florida estuaries (Volety, 2008; Volety et al., 2009). Spat recruitment (spat/shell/month) in Pumpkin Bay ranged from 0–3.56, and recruitment in Faka Union Bay ranged from 0–3.94. While these numbers are lower compared to those in Estero Bay and Caloosahatchee Estuary (Volety et al., 2009), long-term comparisons cannot be made given the short duration of the study. While Faka Union Bay had a slightly higher spat recruitment (0.42 spat/shell/month) compared to Pumpkin Bay (0.31 spat/shell/month), the overall low spat recruitment should be viewed with caution. Given the study's one-year time frame, it is difficult to predict the causes for low spat recruitment (lower larval supply versus higher predation), and its association to freshwater canal releases (Volety, 2010).

Mean oyster densities in both estuaries significantly varied between stations, while no seasonal differences were noted (wet versus dry). Living oyster density was significantly higher ($p < 0.001$) at the Pumpkin Bay mid-estuary location (PB2) compared to both upstream and downstream locations (PB1 and PB3) (**Figure 12-84**). Mean living density of oysters in Pumpkin Bay during the dry season was 821 oysters per square meter (m^2) compared to 706 oysters/m^2 during the wet season.

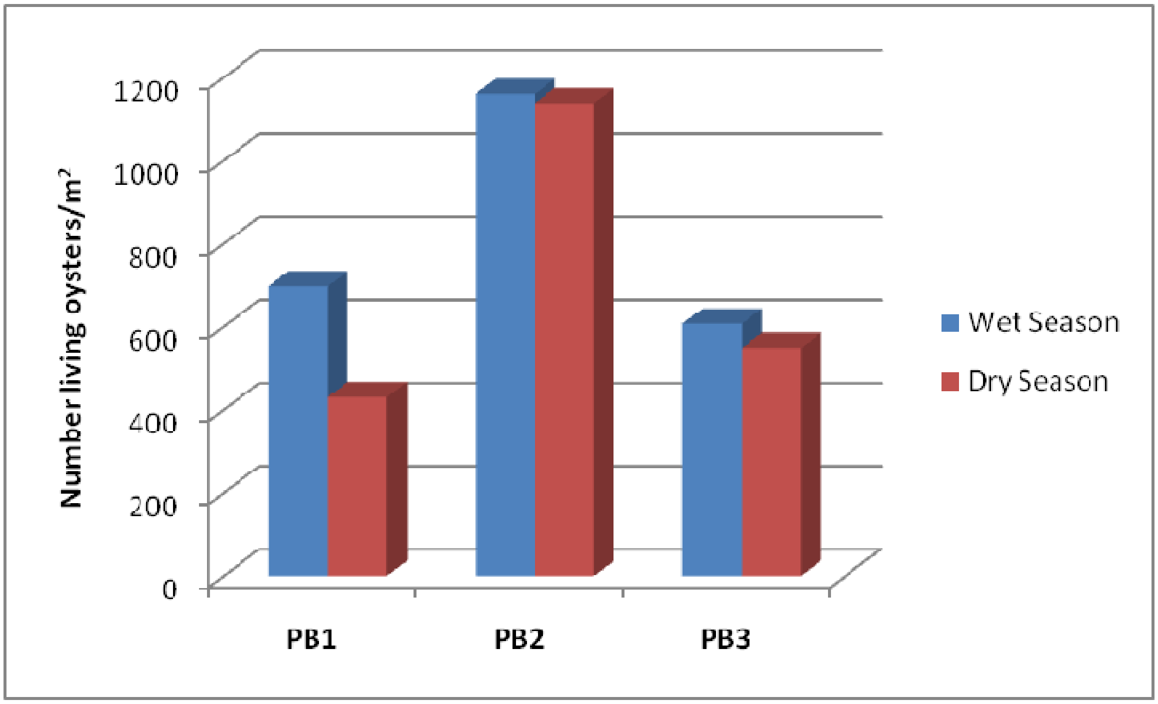

Figure 12-84. Mean density of living oysters in Pumpkin Bay along a gradient from upstream (PB1) to downstream (PB3) monitoring stations.

In contrast to Pumpkin Bay, Faka Union Bay had significantly higher living densities of oysters at the downstream location (FU3) compared to the upstream (FU1) and midstream (FU2) locations. No significant differences were noted between sites FU1 and FU2 ($p = 0.071$) and between sites FU2 and FU3 ($p = 0.082$). Overall, Pumpkin Bay had a living oyster density of 764 oysters/m^2 compared to 1,019 oysters/m^2 in Faka Union. Mean size of oysters at the end of the study period (March 2010) was higher compared to mean oyster size in August 2009. Mean size of oysters in Faka Union at the end of the study was 51.53 millimeters (mm) compared to 42.19 mm in Pumpkin Bay (Volety, 2010). It is expected that oyster health in general and densities within Pumpkin and Faka Union bays will improve with implementation of the Picayune Strand Restoration Project. This will be confirmed through salinity and oyster monitoring funded by the project following completion of construction.

Naples Bay

Naples Bay is a long, narrow estuary located within a flat, low elevation region on the coast of Collier County (**Figure 12-85**). The bay is a shallow, north-south oriented water body formed by the confluence of the Gordon River and other small tributaries that empty through Gordon Pass into the Gulf of Mexico. The Naples Bay Basin lies within the Big Cypress Basin. The bay once received drainage from about 10 square miles, but with the construction of the Golden Gate Canal system, the basin expanded to about 120 square miles (SFWMD, 2007b). Naples Bay Basin is bounded by the Gulf of Mexico to the west (terminating within the northwestern corner of the Rookery Bay Reserve), and shares borders with the Corkscrew-Cocohatchee Basin to the north, Faka Union Canal Basin to the east, and the Henderson Creek and District VI Basins along the southeast.

Tidal exchange occurs through Gordon Pass at the southern end of the bay. Average daily tide range at Gordon Pass is 2.1 ft. The highest tides occur every two weeks during the "spring tides" at full and new moons. Spring tide average is 2.8 ft at Gordon Pass. Tidal ranges increase slightly, moving north from Gordon Pass to the U.S. 41 Highway Bridge in downtown Naples due to amplification caused by the elongated shape of Naples Bay. Tidal ranges decrease in the Gordon River north of the bridge where tidal flow is limited by the constricted shape of Naples Bay near the bridge.

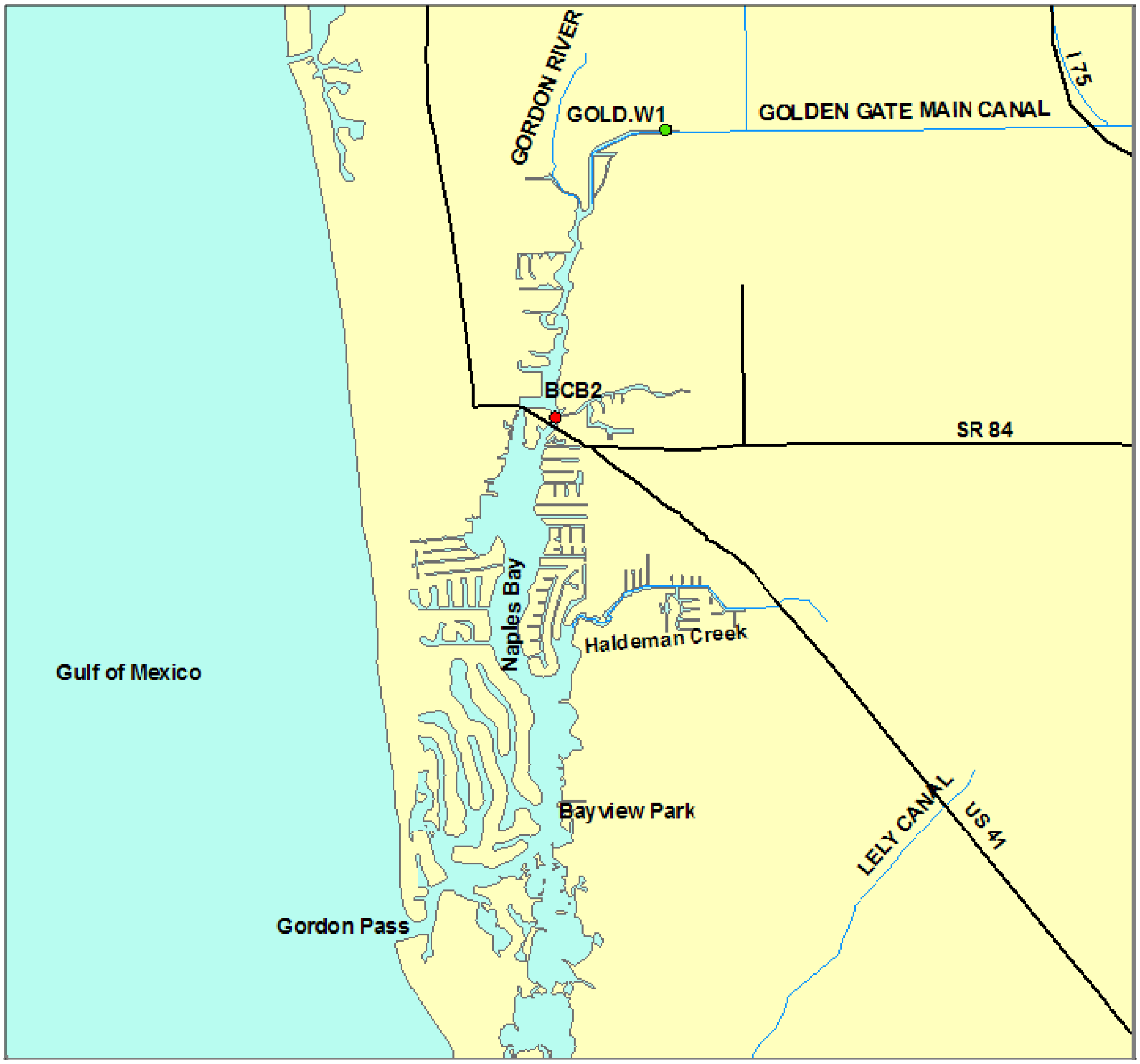

Figure 12-85. Naples Bay and monitoring locations.

Salinity and Freshwater Inflows

Salinity in Naples Bay varies both seasonally (wet and dry) and daily driven by tidal cycles (**Figure 12-86**). As an example, average salinity near the U.S. Highway 41 Bridge (station BC2) ranged from 0–10 psu in the wet season and occasionally exceeded 35 psu (the salinity of the open Gulf) in the dry season. Presumably, salinity at this location is affected by flows from the Golden Gate Canal, but also by some runoff from Rock Creek. Salinity in the Gulf of Mexico near Gordon Pass is typically 35 psu. The largest range in daily salinity is most often seen in the area of Bayview Park in Naples Bay. Low salinity surface layers move into this area during outgoing tides. Incoming tides force the low salinity waters north and inhibit the discharge of tributaries such as Haldeman Creek.

Much of the freshwater input occurs through the Golden Gate Canal. Systematic flow monitoring of the canal at station GOLD.W1 by the SFWMD was suspended for about six years and resumed in 2008. **Figure 12-87** depicts the total monthly flows into Naples Bay where data are available for the last two water years. In WY2009, very little water was discharged during the dry season, which explains the high salinity observed during those months. Flows in WY2010 were more moderate.

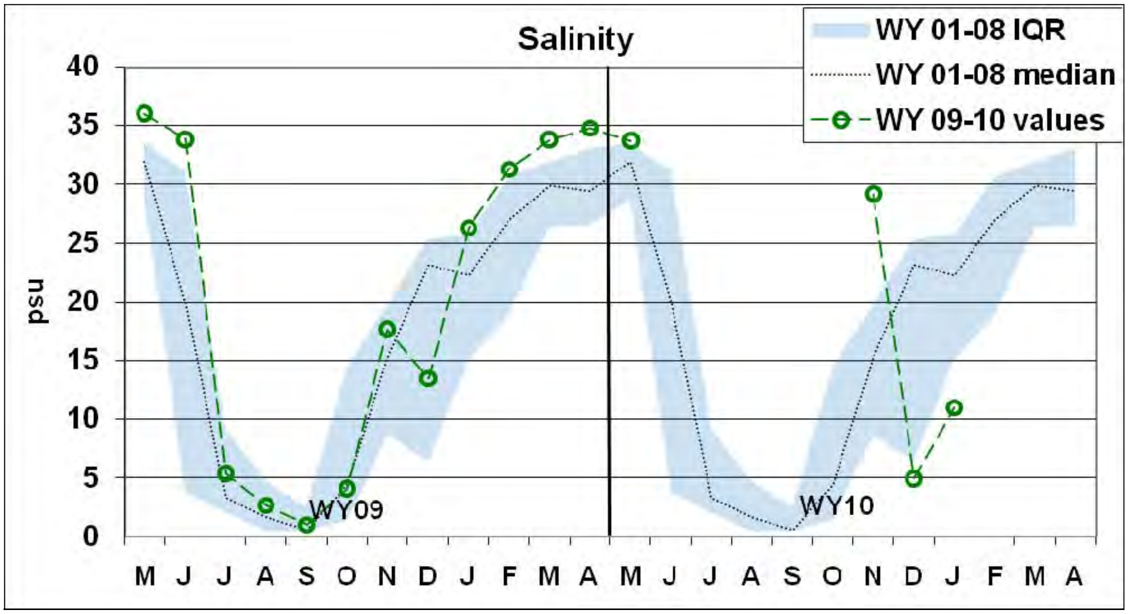

Figure 12-86. Salinity results (psu) in Naples Bay at station BC2 for WY2009 and WY2010 compared to the long-term average. Only surface salinity results are available.

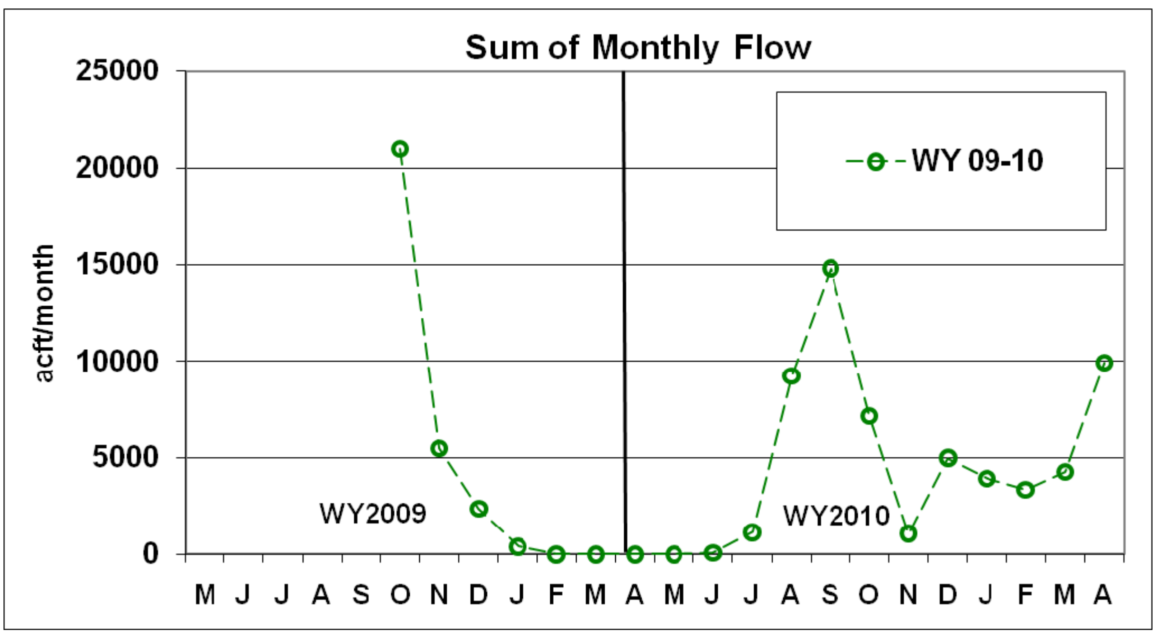

Figure 12-87. Monthly total flow results (acre-feet/month) at station GOLD.W1 in the Golden Gate Canal for WY2009 and WY2010.

During the wet season, the deeper portions of northern Naples Bay become stratified and form layers of different salinity water. Low salinity water flowing out of the Golden Gate Canal and other tributaries moves over denser, higher salinity bay waters, resulting in a series of horizontal layers that increase in salinity from the surface to the bottom. In the northern bay, these layers often do not mix. This lack of mixing between the upper layers, where oxygen is produced, and lower layers results in low bottom oxygen concentrations.

Stratification problems are believed to have increased due to increased freshwater flow and construction of deep, dead-end canals. Stratification is less of a problem in the lower bay where horizontal mixing from tidal currents is greater (Simpson et al., 1979). Golden Gate Weir 3 improvements, currently under construction, will divert a portion of Golden Gate Main Canal flows into Henderson Creek to help reduce freshwater discharges that affect water quality in Naples Bay.

FUTURE WESTERN ESTUARY ACTIVITIES

Six water quality and flow monitoring stations in the Ten Thousand Islands, which were temporarily disabled, will become operational under RECOVER's monitoring program. These are essential to monitor hydrologic changes and are part of the ecological monitoring plan for the Picayune Strand Restoration Project. The District will begin work on a hydrodynamic and salinity model for Naples Bay.

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