Chapter 10: Coastal Priorities

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SUMMARY

This chapter focuses on two Northern Everglades estuaries, the St. Lucie and Caloosahatchee river estuaries. Annual reporting on these estuaries is mandated under the Northern Everglades and Estuaries Protection Program (NEEPP; Section 373.4595, Florida Statutes). For both the St. Lucie Estuary (SLE) and Caloosahatchee River Estuary (CRE), outflows from Lake Okeechobee have a profound influence on circulation and transport, water quality, and biotic resources. In addition to an update on relevant watershed construction projects, this chapter contains a summary of estuary monitoring and associated research that link watershed freshwater inflow to estuarine ecological patterns and trends.

The first part focuses on current efforts in the watershed to improve the quality, quantity, timing, and delivery of water to the estuaries. A description of watershed construction projects provides the vehicle to outline these efforts. Secondly, the current physical (water quality and hydrology) and ecological [oysters and submerged aquatic vegetation (SAV)] condition of the two estuaries were evaluated relative to rainfall, freshwater inflows, nutrient loading, salinity attributes, and benthic habitats (submersed macrophytes and oysters). Monitoring data were analyzed at three basic scales including dry (November–April) versus wet (May–October) seasons, over the last three water years, and relative to inter-annual periods of record. The final component describes a finer-scale estuarine study designed around adaptive protocols for the Lake Okeechobee regulation schedule that allows for low level discharges to the CRE during the dry season.

ST. LUCIE ESTUARY

Water Year 2013 (WY2013) (May 1, 2012–April 30, 2013) represented an average year for rainfall and freshwater inflow to the SLE. However, while both rainfall and inflow were reduced in the dry season, they increased in the wet season. Extreme values during Tropical Storm Isaac in September 2012 contributed to the observed totals. The dry and wet season contributions of Lake Okeechobee declined to 3 and 13 percent of total inflow compared to the long-term values of ~20 percent. The SLE watershed provided 86-96 percent of the total inflow in WY2013 compared to the long-term average of ~79 percent. Total nitrogen (TN) and total phosphorus (TP) loading to the SLE follow patterns of freshwater inflow. While TN and TP loads in WY2013 exceeded those of WY2011–WY2012, they were approximately 50 to 60 percent of the long-term

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1 Contributed as SFWMD staff during the draft SFER production cycle.
average values. Overall, the contribution of Lake Okeechobee to annual TP and TN loadings were much reduced in WY2011–WY2013 due to the decreased outflow from the lake. As with freshwater inflow, the SLE watershed accounted for a relatively greater fraction of TP and TN loading in WY2013.

Concentrations of TN, TP, and Chla in WY2013 exceeded the targets for total maximum daily loads (TMDL = 0.72 milligrams TN per liter, 0.081 milligrams TP per liter) and the Impaired Waters Rule (IWR) (11.0 micrograms Chla per liter) in the upper SLE, but not the lower estuary near the St. Lucie Inlet. While concentrations at site HR1 in the North Fork were similar to the long-term averages, those at sites SE03 and SE11 in the lower estuary were depressed. Inter-seasonal variations in water column Chla concentration were not as predictable as those observed for TN and TP.

The reduced contribution of Lake Okeechobee was evident as salinity critical for oyster survival was maintained at the US 1 Bridge much of the time. The St. Lucie Watershed had a greater influence on the maintenance of critical salinity than outflows from Lake Okeechobee. The percentage of days with salinity favorable for oysters (8 to 25) was greater than the long-term average. The exception was the high freshwater inflow in September 2012 that suppressed live oyster density in the SLE. The reduction in oyster density was greater in the North Fork and South Fork than the middle segment. This event led to reduced spat abundance and the intensity of dermo infection in WY2013. Increasing salinities across the lower SLE and SIRL promoted a more salt-tolerant seagrass community from WY2011–WY2012. However, the high freshwater inflow in September 2012 led to reductions in the prevalence of these species including a large negative impact on seagrass habitat inside the St. Lucie Inlet at Willoughby Creek.

**CALOOSAHATCHEE RIVER ESTUARY**

Total rainfall in WY2013 was similar to the long-term average. Lower than average rainfall in the dry season combined with higher than average rainfall in the wet season approximated the long-term value. The respective contributions of Lake Okeechobee and the Caloosahatchee River Watershed upstream of S-79 to total freshwater inflow were within range of the long-term averages. As with rainfall, reduced inflow in the dry season was offset by increased inflow in the wet season. Releases from the lake to accommodate the increased water level associated with Tropical Storm Isaac in September 2012 were an important component to wet season total inflow.

Average daily salinity at Fort Myers was generally low in WY2013, with peak values in May–June 2012, followed by decreased salinity nearing 0 by September 2012, and increases to 10 to 12 in early 2013. Daily salinity conditions were greater than 10 at Fort Myers for about 37 percent of the days, which was similar to the long-term average. Salinity was enhanced as only 29 percent of days were below the critical value of 5 compared to 48 percent of days in the long-term record. The Caloosahatchee River Watershed downstream of S-79 was comparatively dehydrated in WY2013 as more inflow at the head of the estuary was required to maintain target salinities at Fort Myers.

While total TP and TN loads in WY2013 were similar to the long-term values (WY1996–WY2013), they were almost twice those observed in WY2011 and WY2012. TN and TP concentrations in the estuary were similar to the long-term averages. Exceptions occurred when TN increased in the upper CRE in May–June 2012 and in the lower CRE in October–November 2012. Increased values early in 2012 resulted from a phytoplankton bloom in April 2012, while the downstream increases later in 2012 were associated with the tropical storm-induced inflow in September 2012. WY2013 concentrations of Chla in the entire CRE [8.4 micrograms per liter (µg L⁻¹)] were less than the critical value of 11.0 µg L⁻¹.
Salinity conditions at Shell Point in the lower CRE were generally favorable for oyster habitat. Live densities were greater than 1,000 oysters per square meter (m²) at all sampling locations. Larval abundance measured as the number of spat per shell decreased throughout WY2012–WY2013. While a large percentage (80–90 percent) of the oysters sampled was positive for an oyster-specific parasitic infection in WY2012–WY2013, overall infection intensity was comparatively low. The effects of drought and increasing salinities throughout WY2011–WY2012 helped to account for the decline of freshwater SAV (tape grass and widgeon grass) in the upper CRE and increased prevalence of marine SAV species in the lower CRE. However, increased freshwater inflow in the WY2013 wet season, particularly in September 2012, led to decreased percentages of seagrasses [shoal grass (Halodule wrightii) and turtle grass (Thalassia testudinum)] in the lower CRE.

**ADAPTIVE PROTOCOL RELEASE STUDY**

The Adaptive Protocol Release Study presented a unique opportunity to evaluate the potential effects of different short-term inflow strategies on water quality and plankton abundances during the dry season in the CRE. This study was unique because it combined the operational capacity to regulate Lake Okeechobee inflow through S-79 with the ability to detect ecological responses along the CRE salinity gradient through rapid in situ data acquisition (e.g., flow-through system; Madden and Day, 1992; Lane et al., 2007; Buzzelli et al., in press). This study was an intensive and concerted effort to link low level releases from Lake Okeechobee to CRE water column ecology on synoptic timescales in the WY2013 dry season. The flow-through system allows researchers to obtain surface water data continuously at high speeds and rapidly cover an entire water body. Given this flexible technology, nine research cruises from S-79 to Shell Point in the CRE were conducted during January–May 2013 coincident with releases of fresh water. Patterns of water quality and nekton community composition were interpreted relative to cruise date, distance downstream, and freshwater inflow.

During the WY2013 dry season (January 2013–May 2013), pulse releases from Lake Okeechobee were made to the CRE under the Final Adaptive Protocols for Lake Okeechobee Operations (SFWMD, 2010). Average hourly inflows ranged from 0 to 2,000 cfs during this time except for increases up to 6,000 cfs on February 16, 2013, approximately 4,000 cfs on April 6, 2013, and greater than 3,400 cfs on May 2, 2013. Pulses generally lasted 5 to 7 days with a rapid rise from 0 cfs to the maximum before falling back to minimum levels over a few days. Salinity was nearly constant from 0.2–10 km downstream of S-79 with the average value in the upstream estuary decreasing from January through May. Salinities ranging 15–30 were located approximately 20 km downstream although the 10 isohaline moved downstream with total inflow to approximately 32 km with maximum inflow. Chla concentrations were comparatively low (10–20 µg L⁻¹) and consistent over the first 10 km but were much more variable from 10 to 25 km among the cruise dates. The relationship between inflow and the location of the Chla maximum was hyperbolic as values peaked near 20 km.

The nekton community was divided into early (January 10–April 4) and late (April 18–May 2) dry season assemblages. The late dry season assemblage was distinguished by a lack of winter recruiting species. The March 7, 2013, sampling date occurred after increased freshwater releases and included more freshwater taxa including several exotic, invasive species. Nekton species composition was influenced by temperature, salinity, and dissolved oxygen, but not with freshwater inflow. The differences between groups of stations mostly reflected a transition of dominate nekton from silversides (Menidia spp.) and mosquitofish (Gambusia holbrooki) at upstream stations to higher salinity estuarine residents such as mojarra (e.g., Eucinostomus spp.) in the mid-estuary to numerous marine transient species near the mouth of the CRE.
INTRODUCTION

In accordance with the Northern Everglades and Estuaries Protection Program [NEEPP; Section 373.4595, Florida Statutes (F.S.)], this chapter provides an annual summary of the hydrology, water quality, and aquatic habitat in the St. Lucie and Caloosahatchee River estuaries (SLE and CRE, respectively; Figure 10-1) during Water Year 2013 (WY2013) (May 1, 2012–April 30, 2013). The once abundant fringing wetlands and shallow flats, water column and benthos, submerged aquatic vegetation (SAV), and oyster reefs indicative of South Florida estuaries provide essential habitat for a variety of valuable faunal populations (Tolley et al., 2006; Rozas and Minello, 2006; Rozas et al., 2012). The distribution and status of these valuable ecosystem components are modulated by complex combinations of climate and weather, freshwater inflow, and estuarine circulation (Childers et al., 2006; Phlips et al., 2011; Buzzelli, 2011).

Figure 10-1. Map showing Lake Okeechobee, the St. Lucie Estuary (SLE), and the Caloosahatchee River Estuary (CRE). Outflow from the lake is regulated at structures S-308 (east) and S-77 (west). Freshwater discharge at the estuarine heads is through structure S-80 eastward to the SLE and through S-79 westward to the CRE.
In the case of the SLE and CRE, both coastal watershed runoff and outflows from Lake Okeechobee have profound influence on estuarine physics, water quality, and biotic resources (Buzzelli et al., 2012, 2013a). When summarizing the environmental conditions in these estuaries, it is important to consider that the dynamics of climatic drivers (e.g., rainfall and temperature) vary over timescales ranging from that of atmospheric frontal passages (synoptic scale in days) to longer-term climatic oscillations (El Niño scale of 3–5 years) and decadal patterns. Thus, the wet-dry subtropical seasonality typical of South Florida estuaries should be contrasted annually to both longer-term (greater than 10 years) and shorter-term (1–3 years) patterns.

In 2007, the Florida legislature expanded the existing Lake Okeechobee Protection Act to include river watershed protection programs for the Caloosahatchee and St. Lucie rivers. The legislation required the creation of the Caloosahatchee River Watershed Protection Plan (RWPP; SFWMD et al., 2009a, 2012a) and the St. Lucie RWPP (SFWMD et al., 2009b, 2012b). These plans build on existing approaches and consolidate restoration efforts throughout the entire Northern Everglades system. The first part of this chapter focuses on the Construction Project component of the protection plans and the current physical-chemical (water quality and hydrology) and ecological (oysters and SAV) condition of the two estuaries. This part also serves to meet the annual NEEPP reporting requirements for the river watersheds [Subsection 373.4595(6), F.S.].

The structure and content of the SLE and CRE components of this chapter are identical with summary information on watershed rainfall, freshwater inflow to the estuaries, salinity patterns, patterns of SAV community composition, and status of oyster reef habitat. Monitoring data from both estuaries were summarized by water year. The categorical variable season was defined by splitting the months into dry (November–April) and wet (May–October) classifications for all calculations. Short-term freshwater inflows are in units of cubic feet per second (cfs), where 1 cfs = 1.9835 acre-feet (ac-ft) per day = 2445.1 cubic meters (m³) per day. All spatial references are in acres, where 1 acre = 0.405 hectares. The standardized units and definitions for the entire South Florida Environmental Report (SFER) appear in the document front matter. Salinity is derived from a dimensionless ratio and therefore has no units in reporting (Millero, 2010). Monitoring data were graphed in time series format over the past three water years (WY2011–WY2013) to examine recent intra- and inter-annual patterns. Specific timescales were used to summarize by water year in tabular format (long-term, WY2011, WY2012, and WY2013). Long-term reporting (multi-annual to decadal timescales) depended upon data availability for the variable of interest. PORs were chosen to maintain consistency between the two estuarine systems. Values were summed (rates of rainfall, inflow, and loadings) or averaged (concentrations of salinity, TN, TP, SAV, and oysters) by water year and season in order to compare and contrast among the different timescales.

The second part of the document describes an Adaptive Protocol Release Study (APRS) conducted by the South Florida Water Management District (District or SFWMD) to investigate the effects of low level releases of fresh water to the CRE during the dry season. The regulation schedule for Lake Okeechobee (2008 LORS) has considerable flexibility allowing for releases of up to 450 cfs of water from Lake Okeechobee to the CRE at the Franklin Lock and Dam (S-79). The purpose of these releases is to decrease the probability of higher discharges during the wet season and moderate potential deleterious effects of high salinity in the upper CRE. The Final Adaptive Protocols for Lake Okeechobee Operations document (SFWMD, 2010) provides a decision flowchart to guide when releases are made.
Located in southeastern Florida in Martin and St. Lucie counties, the SLE comprises a major tributary to the Southern Indian River Lagoon (SIRL; Sime, 2005; Ji et al., 2007; Buzzelli et al., 2012; Figure 10-1). Historically, the SLE was a freshwater system exposed to the coastal ocean only through ephemeral passes in the barrier islands. The St. Lucie Inlet was permanently opened in 1892 to provide a connection between the SLE and coastal ocean. The C-44 canal linking Lake Okeechobee to the South Fork of the SLE was completed in 1924. The SLE is now a partially mixed micro-tidal estuary having a semi-diurnal tide with amplitude of 0.38 meters (m). The SLE is geographically divided into four distinct segments: North Fork, South Fork, middle estuary, and lower estuary near the St. Lucie Inlet. Total surface area of the estuary is 29 square kilometers (km$^2$; 2,900 hectares or ha) with an average depth of 2.4 m (Buzzelli et al., 2013). The flushing time of the SLE ranges from 2 to 20 days (Ji et al., 2007).

To accommodate population growth and coastal development, the St. Lucie River Watershed has been highly altered from natural sloughs and wetlands into a system of sub-basins, which make up the eight sub-watersheds of the St. Lucie River Watershed. The SLE receives drainage from a comparatively large area as the ratio between watershed area and SLE surface area is approximately 150:1 (i.e., Tampa Bay has a ratio of 5.5:1). Changes in flow and resultant variations in salinity and water quality are associated with habitat loss, decreased biodiversity, and increased prevalence of marine diseases within the estuary (Sime, 2005; SFWMD et al., 2012a). Connections to and drainage from the watershed and Lake Okeechobee have led to extreme freshwater inflow, phytoplankton blooms, accumulation of flocculent muck-like sediments, severe loss of seagrass habitat, and a dramatic decline in the extent of oyster beds within the SLE (Wilson et al., 2005).

The Caloosahatchee River Watershed is located on the lower west coast of Florida in Lee, Charlotte, Collier, Glades, and Hendry counties (Barnes, 2005; Figure 10-1). The Caloosahatchee River and Estuary have been altered by human activities starting in the 1880s when the river was straightened and deepened losing 76 river bends and 13.2 kilometers (km) of length (Antonini et al., 2002). By 1918 there were three combination lock and spillway structures at Moore Haven, Citrus Center, and Fort Thompson. These structures gave way to newly completed structures at Lake Okeechobee (S-77) and Ortona (S-78) in the 1930s. The Caloosahatchee River spans 70 km from an outflow structure at Lake Okeechobee (S-77) westward to the Franklin Lock and Dam (S-79). A network of secondary and tertiary canals throughout the Caloosahatchee River Watershed (C-43 Basin) supports agriculture and urban development. The mesohaline and polyhaline estuary downstream of S-79 also has been significantly altered (Chamberlain and Doering, 1998). Early descriptions of the CRE characterize it as barely navigable due to extensive shoals and oyster bars near Shell Point (Sackett, 1888). A navigation channel was dredged and a causeway built across the mouth of San Carlos Bay in the 1960s. Historic oyster bars upstream of Shell Point were mined and removed to be used in the construction of roads.

The present C-43 Basin is a series of linked regional sub-watersheds and includes the S-4 Basin adjacent to Lake Okeechobee, East Caloosahatchee Basin, West Caloosahatchee Basin, Tidal Caloosahatchee Basin downstream of S-79, and Cape Coral Coastal Basin to the north of the CRE (SFWMDB et al., 2012b). The Franklin Lock represents the head of the CRE that extends 42 km downstream to Shell Point where it empties into San Carlos Bay. The surface area of the CRE is 56 square kilometers (5,600 hectares) with an average depth of 2.7 m (Buzzelli et al., 2013b). The flushing time ranges from 2 to 30 days (Buzzelli et al., 2013d).
RIVER-WATERSHED CONSTRUCTION PROJECTS

Reducing nutrient loading and high discharges to the SLE and CRE requires action at the regional, sub-regional, and local levels. The Construction Project component includes activities at each of these spatial scales. The focus on water quality and storage is intended to improve hydrology, water quality, and aquatic habitats in both the watershed and estuary. The suite of projects builds upon the Source Control Program (see Chapter 4 of this volume) and includes water quality and quantity projects such as local storm water retrofits, reservoirs, and habitat restoration. A comprehensive summary of all projects was included in the 2012 RWPP Updates (SFWMD et al., 2012a; 2012b).

ST. LUCIE RIVER WATERSHED CONSTRUCTION PROJECT UPDATE

IRL-S C-44 Reservoir/STA Project

The regional project expected to have the greatest benefit for the SLE is the Comprehensive Everglades Restoration Plan (CERP) Indian River Lagoon – South (IRL-S) Project. This is a state-federal partnership to restore the southern portion of the lagoon, the SLE, and the associated watershed. A critical component of the IRL-S Project is the C-44 Reservoir/Stormwater Treatment Area (STA) Project. The objectives of this component are to capture, store, and treat runoff from the C-44 Basin prior to discharge to the SLE. Implementation of this project is expected to reduce damaging freshwater discharges, decrease nutrient loads, and aid in maintaining desirable salinity regimes. This project, located north of the C-44 canal, includes construction of a 3,400-acre reservoir and an adjacent 6,300-acre STA. The District completed the design of the project components with the United States Army Corps of Engineers (USACE) responsible for project construction. The first contract, awarded in July 2011 and expected to be completed in March 2014, includes construction of the project intake canal and access road, the Citrus Boulevard Bridge, and the C-133/C-133N canals. Funding for the initial phase of STA construction was provided to SFWMD by the state legislature through the Save Our Everglades Trust Fund in the 2013 legislative session. Construction is scheduled to begin in 2014.

IRL-S Allapattah Complex – Natural Water Storage and Treatment Area

The Allapattah Complex – Natural Water Storage and Treatment Area is a component of the authorized IRL-S CERP Project and includes approximately 42,348 acres located in the C-23 basin in Martin County. Approximately 21,865 acres have been acquired. This land has been identified for use as alternative storage, rehydration, habitat restoration, and incidental water quality treatment. Approximately 13,319 acres of the Allapattah Complex is currently included under conservation easement and enrolled in the United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) Wetland Reserve Program (WRP), which focuses on habitat restoration and maintaining the area as “open lands.”

From 2003 through 2007 the SFWMD, under a restoration agreement with the USDA-NRCS, constructed water control structures and containment berms, removed and plugged culvert connections, abandoned an old dairy lagoon and filled approximately 17 miles of agricultural drainage ditches on approximately 1,800 acres of the property. Additional hydrologic restoration activities are planned under a current WRP agreement with USDA-NRCS on approximately 12,725 acres of the property. The estimated retention volume of the proposed improvements is 4,743 ac-ft. Conceptual restoration design and hydrologic modeling has been completed.
Permitting and final construction plans are currently under way and it is anticipated that construction will start in 2014.

**Local Water Quality and Restoration Projects**

These projects are local government led initiatives that provide benefits on a local scale individually, but collectively can provide benefits on a sub-regional to regional scale. There are several local water quality and restoration projects identified in the St. Lucie RWPP including storm water improvements and retrofits, wastewater improvement projects (septic to sewer), and habitat restoration projects (e.g., muck sediment removal, oyster habitat creation, and wetland restoration). A complete update of local projects identified in the St. Lucie RWPP can be found in the 2012 St. Lucie RWPP Update (SFWMD et al., 2012a), which can be found in Appendix 10-1 of the *2012 South Florida Environmental Report (SFER) – Volume I*. As part of the St. Lucie River and Estuary Basin Management Action Plan (BMAP), the Florida Department of Environmental Protection (FDEP) produced an inventory of local water quality projects conducted since 2000. These projects have been completed or will be by mid-June 2018 and include storm water improvements, retrofits, and waste water improvement projects (septic to sewer; FDEP, 2013). The BMAP project inventory will continue to grow as annual progress reports and five-year updates are developed. The St. Lucie River and Estuary BMAP Final Order was signed by the secretary of the FDEP on June 11, 2013. Appendix D (BMP Efficiencies and Projects to Achieve the TMDL) of the final BMAP includes a list of adopted projects to reduce TN and TP loading in the first five-year iteration of the BMAP. It is anticipated that this inventory of local restoration projects, along with their associated load reductions, will be adopted in the upcoming 2015 St. Lucie RWPP Update.

**St. Lucie River Watershed Dispersed Water Management Projects**

The Dispersed Water Management (DWM) Program is a multi-faceted approach to working cooperatively with public and private landowners to identify, plan, and implement mechanisms to retain or store water. The objectives are to provide shallow water storage, retention and detention to enhance Lake Okeechobee and estuary health by reducing discharge volumes, reducing nutrient loading to downstream receiving waters and expanding groundwater recharge opportunities. The four main categories of projects under the District’s DWM Program include storage and retention projects on private lands, storage and retention projects on public lands, Northern Everglades Payment for Environmental Services (NE-PES) Projects, and Water Farming Payment for Environmental Services Pilot Projects. Details of the DWM Program and the NE-PES are provided in Chapter 8 of this volume, while some DWM projects in the St. Lucie Watershed are highlighted below.

**Storage and Retention Projects on Public Lands.** Projects on public land benefit Lake Okeechobee and the estuaries by reducing discharge volumes and nutrient loading to downstream receiving waters through modifications to existing water management structures and implementing operational strategies. In many cases, storage, retention and detention is obtained by increasing the discharge control elevation of on-site drainage facilities and/or impounding water in shallow retention and detention areas.

- **Allapattah Parcels.** Allapattah Parcels A & B are discussed above in the section titled *IRL-S Allapattah Complex – Natural Water Storage and Treatment Area*. Allapattah Parcel C is comprised of 6,142 acres of open land and is a component of the Indian River Lagoon Feasibility Study’s recommended plan. The Allapattah Complex was purchased by the SFWMD and Martin County for the purpose of hydrologic restoration. Restoration components consist of filling or plugging agricultural drainage ditches, construction of a perimeter berm, installation of water...
control structures, and eradication of exotic and nuisance plant species. Once completed it is anticipated that up to 1,130 ac-ft of additional on-site retention will occur as a result of these restoration activities. The Allapattah Parcel C final construction work plan is pending approval.

- **Turnpike Dairy and Williamson Ranch.** The Turnpike Dairy and Williamson Ranch are part of the Allapattah Complex and a component of the Indian River Lagoon - South Feasibility Study’s recommended plan (USACE and SFWMD, 2004). The Allapattah Complex was purchased by the SFWMD and Martin County for the purpose of hydrologic restoration. These project lands together total 629 acres and include project features that restore and enhance wetland/upland mosaics and provide benefit to the Indian River Lagoon through water storage in natural wetland systems. The restoration activities are funded by the USDA-NRCS through the WRP with dedicated conservation easements. The estimated retention volume for both sites is 392 ac-ft (387 ac-ft for Williamson Ranch and 5 ac-ft for Turnpike Dairy). Construction activities for Turnpike Dairy and Williamson Ranch were completed in 2013 and the projects are both fully operational.

- **C-23 and C-24 Interim Lands.** The C-23/C-24 Complex is located in St. Lucie County adjacent to State Road 70 and the C-23 and C-24 canals comprising approximately 10,000 acres. This large land complex contains numerous agricultural parcels most of which were originally developed for cattle ranching and citrus production. The SFWMD is currently investigating opportunities to retain additional stormwater runoff within the project lands by better managing existing infrastructure to maximize additional on-site retention. It is estimated that up to 3,000 ac-ft of retention may be achieved by completion of the project. Field investigations have been initiated to prioritize parcels with the greatest potential to retain additional water.

**Storage and Retention Projects on Private Lands.** Projects on private land enhance Lake Okeechobee and estuary health by reducing discharge volumes and nutrient loading to downstream receiving waters through modifications to existing water management structures and implementing operational strategies. In many cases, storage, retention, and detention are obtained though the execution of cooperative agreements that maximize the benefits the project can provide.

- **Harbour Ridge. The Harbour Ridge Yacht and Country Club (HRPOA).** This project is located in St. Lucie County on the north side of the District’s C-23 canal near the S-48 weir structure. The purpose of this project is to reduce discharge to the SLE. The project will pump excess water from the C-23 canal (upstream of S-48) to on-site lakes and wetlands when the canal is discharging to the SLE. The estimated average annual retention volume is 667 ac-ft. The project is currently under construction.

- **Indiantown Citrus Growers Association (ICGA) Phase 1 and 2.** This project is located in Martin County north of the C-44 canal and west of Florida Highway 710. The purpose of the project is to retain excess regional water from the C-44 canal when capacity is available in the ICGA water management system. When excess surface water conditions exist in the C-44 canal, the District contacts the ICGA to request storage of regional water. If capacity is available, the ICGA will pump water from the C-44 Canal into their water management system. It is estimated that the storage available in the ICGA system for regional storage from the C-44 canal can be as much as 3,550 ac-ft. The project is complete and operational.
**Water Farming Payment for Environmental Services Pilot Program.** An innovative approach to delivering environmental services, similar to NE-PES, is the Water Farming Payment for Environmental Services (WF-PES) program. This concept seeks to field test the potential for retaining water on fallow citrus lands. A feasibility analysis was completed in April 2012 by the Indian River Citrus League under a cooperative agreement with the District. The DWM Program WF-PES pilot projects will offer eligible landowners the opportunity to compete for contracts to help determine the cost-effectiveness and benefits associated with retaining water on fallow citrus lands. A WF-PES Pilot Project request for proposal solicitation for the SLE Watershed area (Martin and St. Lucie counties) closed on June 5, 2013, and resulted in five submitted proposals. The proposals have been evaluated and ranked based upon defined evaluation criteria. The SFWMD Governing Board, at their July 11, 2013 meeting, authorized staff to begin negotiating with the respondents in ranked order. Three of the five proposals have been negotiated and agreements have either been executed or are in the process of being executed. The estimated total storage available is 11,285 ac-ft. Upon final approval of the agreements, those projects will move forward with final design, permitting, construction, monitoring, and service documentation.

**CALOOSAHATCHEE RIVER WATERSHED CONSTRUCTION PROJECT UPDATE**

**CERP Caloosahatchee River (C-43) West Basin Storage Reservoir Project**

This project consists of an aboveground reservoir of 170,000 ac-ft capacity located south of the CRE and west of the Ortona Lock (S-78). Excess basin stormwater runoff and regulatory releases from Lake Okeechobee are expected to be captured and stored in the reservoir and released as needed to restore and maintain the estuary. The reservoir is also intended to improve the CRE’s salinity balance by controlling peak flows during the wet season and providing essential flows during the dry season. To date, all needed land has been acquired, preconstruction test cells have been completed and monitored, project design has been completed, and all permits have been obtained. In April 2011, a Record of Decision was issued by the USACE and an approved project implementation report (USACE and SFWMD, 2010) was submitted to the United States Congress for authorization.

In the interim, the District is maximizing water storage and retention opportunities at the site. For example, Tropical Storm Isaac and the above-average rains that followed resulted in freshwater releases from Lake Okeechobee into the Caloosahatchee River. In mid-October 2012 the District implemented an emergency plan to capture water from the river and store it on a portion of the site to reduce freshwater impacts on the downstream estuary. In summer 2013, the District received the regulatory approvals needed to continue implementing this plan in the coming years. The District is also looking for shallow storage at another portion of the same site through its DWM Program’s Berry Groves Water Farming Project. This project involves construction of a shallow water (i.e., 2 feet maximum depth) detention area of up to approximately 2,200 acres on a portion of the site that will also be filled with Caloosahatchee River excess water. If this project is successful, it may be implemented on a larger portion of the site while accommodating the continuation of the emergency storage area. A feasibility report that includes a conceptual design to increase the storage capabilities on this site in advance of the CERP Caloosahatchee River (C-43) West Basin Storage Reservoir will be completed in Fiscal Year (FY) 2014 (October 1, 2013–September 30, 2014).
Spanish Creek/Four Corners Initiative

This is a collaborative initiative between the District and Lee and Hendry counties to develop regional approaches for improving water quality and storage in the CRE Watershed. The goal is to expand upon existing conceptual plans to address conveyance, attenuation, and treatment of stormwater runoff from the Spanish Creek and Jacks Branch (County Line Ditch) watersheds using wetland flow-ways. This initiative has two distinct projects: (1) Spanish Creek Restoration (Lee County) and (2) Jacks Branch (County Line Ditch in Hendry County). Under the Spanish Creek Restoration component, Lee County will create wetland flow-ways that will serve to rehydrate the Daniels Preserve, Bob Janes Preserve, and Spanish Creek. The Bob Janes Preserve is located in Lee County adjacent to state-owned preservation lands. Historically, the preserve has been disturbed by agricultural practices including the use of ditches and canals to quickly drain runoff into the watershed and river. In FY2013 (October 1, 2012–September 29, 2013), the District provided funds to Lee County for the project’s initial design and project construction. Construction is anticipated during the dry season (November 2013–March 2014). Once completed, this project will divert water from the Lighter Canal, restoring and increasing shallow sheet flow and improving site hydrology.

Under the Jacks Branch component, Hendry County will implement improvements to County Line Ditch, which conveys stormwater flows from Jacks Branch Watershed to the Caloosahatchee River. On February 29, 2012, the District executed a cooperative agreement with Hendry County for developing the 100 percent design plans, which are to be completed by May 2014. Project construction will be addressed in the future pending availability of funds.

Mirror Lakes Storm Water Retention Facility Project

This project is part of the Caloosahatchee Basin Storage and Treatment initiative and is also considered a DWM project. The Mirror Lakes Preserve Area, formerly known as Halfway Pond, is a large wetland system at the headwaters of the Estero River Watershed. The channelization of Lehigh Acres reduced the water table in the vicinity of Halfway Pond and directed runoff away from the Estero River and into the Orange River Watershed. The project is divided in three phases and will provide additional surface water storage, restore flow pattern and hydropersiods in Halfway Pond and areas to the south, and induce recharge of surficial waters in the area. The first phase (Phase I), completed in FY2012, is a standalone component of the overall project and it provides 1,000 ac-ft of storage in the C-43 Basin. Phases II and III, will result in additional 500 ac-ft and 2,000 ac-ft of storage, respectively, and convey the surface water made available by Phase I to preserve and restore wellfield areas.

Lake Hicpochee Hydrologic Enhancement Project

Historically, Lake Hicpochee was one of three lakes that were considered the headwaters of the Caloosahatchee River. The channelization of the Caloosahatchee River in the 1800s created an unnatural connection between Lake Hicpochee and Lake Okeechobee. This unnatural connection has bisected Lake Hicpochee into north and south portions resulting in detrimental impacts to hydrology and ecology in the C-43 basin. The objective of the Lake Hicpochee Hydrologic Enhancement Project is to provide shallow water storage within the north half of the lake bed to promote habitat restoration and water quality treatment benefits. FY2013 activities included surveying, geotechnical investigations, and preliminary engineering design. The preliminary engineering design consists of an approximately 7,500-ft long spreader canal and maintenance berm designed to distribute runoff in the form of sheet flow onto the lake bed. Future design phases will rely on a proposed 600-acre flow equalization basin that will be proposed on lands north of the lake bed that are part of the planned Duda land acquisition. Captured excess flows will either be from the C-19 canal or the Caloosahatchee River depending
on the operational plan that is developed for the project. Design will continue through FY2014 and construction is scheduled to begin in FY2015. Restoration of the southern half of Lake Hicpochee is being handled under the DWM Program which is described in more detail in the Caloosahatchee River Estuary Dispersed Water Management Projects section below.

Consistent with the restoration of the northern half of Lake Hicpochee under the Caloosahatchee Basin Storage and Treatment Initiative, the purpose of the Lake Hicpochee South project is to develop appropriate civil works to restore the hydrology of the southern half of Lake Hicpochee. The District in collaboration with the Flaghole Drainage District and the Hendry Hilliard Water Control District, are leveraging prior analysis and studies to develop cost-effective features and modification of existing infrastructure to dissipate concentrated flows coming into the lake and distribute them as sheet flow.

**C-43 Water Quality Treatment and Testing Facility Project**

The District is partnering with Lee County on the development and implementation of the C-43 Water Quality Treatment and Testing Facility Project to investigate and test new strategies for reducing TN in the C-43 canal. A detailed description of the purpose and need of this project was provided in this section of the 2013 SFER – Volume I, Chapter 10. In late 2013, a conceptual design for a testing facility to test and demonstrate wetland technologies that have the potential to effectively remove and/or reduce background TN loading from the facility’s C-43 canal inflow and identify the range of hydrological loading rates per unit area to achieve optimal removal/reduction rates was completed. Full engineering design and permitting of the testing facility is contingent upon funding. The District is also considering opportunities for other cost-effective nutrient removal options at the site. The site, known as Boma, was recently used as a temporary location for testing the Aquifiber technology and contains operational DWM projects.

**Local Water Quality and Restoration Projects**

There are several local water quality and restoration projects identified in the Caloosahatchee RWPP that are similar in type to those described in the SLE Local Water Quality and Restoration Projects section above. A complete update of local projects identified in the Caloosahatchee RWPP can be found in the 2012 Caloosahatchee RWPP update (SFWMD et al., 2012b), which can be found in Appendix 10-2 of the 2012 SFER – Volume I. Many of the local projects are implemented through a cost-sharing approach with state and federal partners. Also, several of the local partnership projects fall under the categories of private and public DWM projects.

The FDEP produced an inventory of local water quality projects conducted since 2000 that have been completed or will be completed by the end of November 2017, which marks the end of the first five-year iteration of the BMAP. This effort identified present and future project-specific load reductions through development of the CRE BMAP (FDEP, 2012). The CRE BMAP Final Order was signed by the secretary of the FDEP on November 28, 2012. The CRE BMAP adopted project inventory list in the first iteration of the BMAP is included in Appendix E: Projects to Achieve the TMDL of the final BMAP. It is anticipated that this inventory of local restoration projects, along with their associated load reductions, will be incorporated into the upcoming 2015 Caloosahatchee RWPP Update.

Much of the future BMAP planning in the CRE watershed will be influenced by the FDEP’s additional TMDL development process. Per stakeholders’ request, the FDEP is currently reevaluating the models used to develop the initial CRE TMDL. After the specific modeling details are vetted through an ongoing public process, a revised TMDL may be proposed if appropriate. Additional TMDLs will also be proposed for many tributaries (freshwater and estuarine) and the major segments of the freshwater main stem of the Caloosahatchee River.
Importantly, some tributaries will not have specific in-stream TMDLs assigned to them but those water bodies will still have an overall watershed load.

**Caloosahatchee River Watershed Dispersed Water Management Projects**

The goals, objectives and categories of DWM are provided above in the *St. Lucie River Estuary Watershed Dispersed Water Management Projects* section and details of the DWM Program are provided in Chapter 8 of this volume. The purpose of this section is to highlight some DWM projects on public lands in the CRE Watershed. In addition, a feasibility analysis is being conducted by the Gulf Citrus Growers Association for the CRE watershed under a cooperative agreement with the District. It is anticipated that WF-PES Pilot projects in this area will be pursued contingent upon future funding. The following DWM projects are within the CRE Watershed.

- **Lake Hicpochee South.** Lake Hicpochee is bisected by the C-43 Canal in Glades County. The purpose of this project is to enhance the hydrology of Lake Hicpochee by redirecting storm water through upland and wetland areas rather than a canal. The District is working in collaboration with the Flaghole Drainage District and Hendry Hilliard Water Control District to refine portions of the existing Lake Hicpochee South Conceptual Basis of Design Report and maximizing the cost-effectiveness of the water retention facilities by integrating project components with existing infrastructure. Funding for design, permitting, and construction of the project needs to be identified.

- **North Six Mile Cypress Slough Preserve.** The North Six Mile Cypress Slough Preserve Hydrologic Restoration is a 1,219-acre Conservation 20/20 preserve located in central Lee County. Preliminary modeling has estimated that the project will provide 1,200–1,400 ac-ft of retention upon completion of the project resulting in improved water quality, reducing discharges to the Caloosahatchee River, reducing flooding in the Orange River Basin, and providing overall hydrologic restoration. The project will enhance existing wetlands and create flow through wetlands to retain water from the Orange River basin and redirect excess water south to Six Mile Cypress Preserve rather than the Caloosahatchee River. This project is currently in the construction phase.

- **Charlotte Harbor Flatwoods Initiative.** This project area is approximately 90 square miles (21,600 acres) and includes the following sub-watersheds: (1) Yucca Pen Creek, (2) Durden Creek, (3) Greenwell Branch, (4) Longview Run, and (5) Gator Slough. Runoff from these systems originates in the northeastern reaches of the Babcock-Webb Wildlife Management Area in Charlotte County within the SFWMD and then passes through the Southwest Florida Water Management District to reach the outfall in Lee County within the SFWMD again. The initiative is a multi-phased regional hydrologic restoration effort coordinated by the SFWMD and Florida Fish and Wildlife Conservation Commission. Multiple local, state, and federal agencies have participated in the effort. Development and topographic changes since the 1950s have blocked, constricted, and concentrated what were formerly sheetflow areas draining in a southeasterly or southerly direction and result in concentrated flows at points of discharge. The overall project purpose is to restore more natural sheetflow patterns and flow rates than currently exist. Projects are being identified to reroute water to historic flow paths. This project is currently in the planning phase.

- **BOMA.** The 2,000-acre BOMA parcel is located in Glades County along the south bank of the Caloosahatchee River, immediately east of the Ortona Lock. Although
this site is currently under lease, portions of the property are fallow and contain the infrastructure necessary to retain water to reduce stormwater discharges to the Caloosahatchee Estuary. The project includes above ground impoundments in the northern and southeastern sections of the parcel that are used to store regional stormwater and divert excess Lake Okeechobee regulatory releases to reduce discharges to the Caloosahatchee Estuary.

- **Barron Water Control District** - The Barron Water Control District (BWCD) is a Special District created under Section 298 of the Florida Statutes. The BWCD is located in Port LaBelle and is comprised of approximately 30,000 acres of agricultural lands within Hendry and Glades counties south of the Caloosahatchee River. The SFWMD and BWCD are collaborative partners for the implementation of water storage within the water management system managed by the BWCD. This project provides approximately 2,000 ac-ft of water storage in BWCD’s system and potentially another 3,000 ac-ft in private landowner systems within the BWCD. The project involved the construction of two weirs in an existing canal to retain more water within the BWCD canal system. Excess water in the Caloosahatchee River due to Lake Okeechobee regulatory releases will be pumped into the BWCD when conditions support additional storage. Storage within the existing ditch system and detention areas will enable reuse by individual growers, thereby promoting water conservation and reducing the volume of discharge to the Caloosahatchee River.

### Alternative Nutrient Reduction Technologies

In addition to the projects discussed above, there have been several alternative nutrient reduction technologies tested in the Northern Everglades. Assessment of new technologies is a key in successfully achieving nutrient reductions goals. Technologies invested to date include hybrid wetland treatment technology, proprietary clay-like materials that bind nitrogen and phosphorus, electro-coagulation technology, and permeable reactive barriers. Details of alternative technologies tested and implementation challenges are provided in Chapter 8 of this volume while information on some testing performed in the river watersheds is provided below.

In the SLE Watershed, the District, in cooperation with Martin County staff, conducted a demonstration study of Phoslock®, a product designed to remove phosphorus from surface waters, at a small lake near Hobe Sound in Martin County. Phoslock® is the commercial name for modified bentonite clay with lanthanum, a rare earth element that acts by the sorption of chemical constituents onto the surface of the mineral particles. The product was invented and developed in Australia by the Commonwealth Scientific & Industrial Research Organization and is effective primarily at sequestering inorganic chemical species. The demonstration study was conducted to evaluate the effectiveness of Phoslock® in realistic field conditions to reduce phosphorus and nitrogen concentrations in surface water and assess the product’s effect on other water quality parameters. Phoslock® removed up to 40 percent of TP and up to 7 percent of TN.

In the Caloosahatchee River Watershed AquaFiber Technologies Corporation (AquaFiber) of Winter Park conducted a pilot study to assess the treatment efficacy of their patented technology (AquaLutions™) to remove TP and TN from surface waters at two sites along the Caloosahatchee River. AquaLutions™ removed up to 96 percent of inflow TP concentrations and up to 55 percent of inflow TN concentrations. There was no targeted monitoring for potential indirect effects of either Phoslock® or AquaLutions™ on water quality conditions.
Knowledge of the environmental conditions that favor biologically productive estuarine habitats can be used to help prescribe freshwater inflow criteria and decision making (Doering et al., 2002; Wolanski et al., 2004; Volety et al., 2009; Adams et al., 2009). This is a concept that is being applied particularly to water management in coastal Texas, Australia, South Africa, and South Florida. All these coastal landscapes are characterized by subtropical climate, accelerated development and freshwater consumption, and valuable estuarine goods (e.g., fishery production) and services (e.g., indirect benefits such as water quality filtration and shoreline stabilization).

The SLE and CRE have different inflow and salinity optima given differences in estuarine geomorphology, volume, flushing, and inflow characteristics (Buzzelli et al., 2013b, 2013d). Oyster habitat provides the biotic indicator of salinity and freshwater discharge in the SLE (Buzzelli et al., 2013a). Oyster physiology, survival, and growth are optimal when salinity fluctuates from 8 to 25 in many estuaries, including the SLE. Systematic analyses of inflows determined that discharge ranging from 350 to 2000 cfs serves to maintain salinity of 8 to 25 throughout much of the SLE (Chamberlain and Doering, 1998; Wilson et al., 2005; Volety et al., 2009; Buzzelli et al., 2013c).

Historically, seagrass meadows and oyster reefs are salient features of the landscape in South Florida estuaries. To evaluate the ecological condition of the SLE, SAV and oysters are routinely monitored. SAV are commonly monitored to gauge the health of estuarine systems (Tomasko et al., 1996; Duarte et al., 2008; Buzzelli et al., 2012) and their environmental requirements can form the basis for water quality goals (Dennison et al., 1993). Oyster beds are a good indicator of estuarine condition as the distribution and abundance of the eastern oyster have ecosystem-scale implications. Oyster beds filter water and suspended solids, couple the water column to the benthos, and provide living aquatic habitat (Peterson et al., 2003; Coen et al., 2007; Buzzelli et al., 2013a).

Different species of SAV have different tolerances for environmental variables including temperature, submarine light penetration, inorganic nutrient availability and salinity (Short et al., 1993; Lirman and Cropper, 2003; Lee et al., 2007; Duarte et al., 2007). While all these variables are important and inter-related, salinity is a useful explanatory tool (Lirman et al., 2008; Buzzelli et al., 2012). In the case of the CRE, the freshwater SAV tape grass (Vallisneria americana) provided the indicator habitat to help prescribe freshwater delivery through S-79 (Doering et al., 2002). Tape grass is very sensitive to both increased salinity and decreased submarine light availability (Bortone and Turpin, 2000; French and Moore, 2003).

To protect valuable resources, critical salinity criteria have been established at Fort Myers as part of the Caloosahatchee River Minimum Flows and Levels (SFWMD, 2000; SFWMD, 2003). Additional salinity data collected at the I-75 Bridge helps to assist implementation of the Lake Okeechobee Regulation Schedule. The Fort Myers location has two salinity criteria: maintaining daily salinity averages of less than 20; and, 30-day salinity averages of less than 10 while the critical salinity criteria at I-75 is less than 5. At the estuary-scale, average monthly inflows of 300–2,800 cfs at S-79 are conducive both to tape grass and favorable for seagrass and oyster habitats in the polyhaline CRE (Chamberlain and Doering, 1998; SFWMD, 2003).
SLE HYDROLOGY, WATER QUALITY AND AQUATIC HABITAT

To better manage freshwater inflows to the SLE, flow and salinity envelopes for the middle estuary were developed based on the requirements of the eastern oyster (Crassostrea virginica; USACE and SFWMD, 2004). Based on relationships between inflows and estuarine salinity, preferred monthly average inflows from the watershed, groundwater, and Lake Okeechobee combined should range from 350 to 2,000 cfs. These flows will maintain salinity in the range of 8–25 at the Roosevelt Bridge.

The FDEP developed a TMDL for the St. Lucie River Watershed. The TMDL technical document was finalized (FDEP, 2008) and the rule was adopted [Chapter 62-304.705, Florida Administrative Code (F.A.C.)] in 2009. The TMDL water quality targets for TP [0.081 milligrams per liter (mg L⁻¹)] and TN (0.72 mgL⁻¹) are applied at the Roosevelt Bridge and upstream to the major water control structures.

Methods

A suite of external drivers and ecological responses are monitored in the St. Lucie River Watershed and Estuary. These variables include rainfall, freshwater discharge, and nutrient loading as external drivers, and patterns of salinity, estuarine nutrient concentrations, oyster habitat status, and SAV community composition in the SIRL as the ecological responses. Salinity gradients provide a conservative property useful to connect freshwater inflow to estuarine flushing time and biological resources (Wilbur, 1992; Jassby et al., 1995; Kimmerer, 2002; Hagy and Murrell, 2007; Pollack et al., 2011).

Next-Generation Radar (NEXRAD) rainfall data from WY1997–WY2013 were obtained through the District’s hydro-meteorological database, DBHYDRO, for the seven distinct NEXRAD units that comprise the St. Lucie River Watershed: Basins 4–6, C-23, C-24, C-44, North Fork, South Coastal, and South Fork (Figure 10-2, left panel). Total rainfall over the whole watershed was calculated using an area-weighted method where the daily rainfall from each sub-basin was scaled by its size relative to the total area of the combined watershed. The derived total daily rainfall was categorized by water year and season to calculate average and total values.

Freshwater discharge is monitored at the major structures of S-80 (C-44 Basin), S-48 (C-23 Basin), and S-49 (C-24 Basin; Figure 10-2). Total daily inflow spanning from WY1996 to WY2013 from these structures were summed and used to evaluate intra- and inter-annual variations in overall inflow and to quantify total inflow of surface water to the SLE each water year. Total daily discharges were categorized by water year and season. Annual TN and TP loads were calculated using summed inflows at the structures and TN and TP concentrations measured from water samples at the structures. To the relative contributions of Lake Okeechobee and the coastal watershed on freshwater inflows and nutrient loads to the SLE, those from Lake Okeechobee using data from S-308 were subtracted from the total flows and loads to the SLE (Figure 10-2).

Surface and bottom salinity observations are recorded every 30 minutes at three stations in the SLE: HR1, Roosevelt Bridge, and A1A Bridge (Figure 10-2, right panel). Data reporting and analyses focused on WY2011–WY2013 at the Roosevelt Bridge. First, daily surface and bottom salinity values were averaged together. Second, the monthly average and standard deviation of salinity were calculated for each station to produce a time series over the past three water years. Third, salinity data were categorized by water year and season to compare and contrast intra- and inter-annual patterns. Fourth, an exponential curve was fit to the relationship between average total monthly discharge and average monthly salinity at the Roosevelt Bridge. The ranges in both values and shapes of the resulting curves were contrasted among WY2011, WY2012, and WY2013. Daily salinity at the US1 Bridge for WY2011–WY2013 was superimposed with time.
series for density and condition of oysters. Daily salinity at the A1A Bridge was superimposed with SAV community composition in the SLE and SIRL.

Water is sampled at mid-depth at 12 stations in the SLE at approximately monthly intervals (Figure 10-2, right panel). To evaluate water quality, three representative stations were chosen (HR1, SE03, SE11). Concentrations of TN, TP, and chlorophyll *a* (*Chla*) from WY1999–WY2013 from each of the stations were included in the analyses (SFWMD, 2011). The long-term median value was calculated along with the interquartile range (difference between the 75th and 25th percentiles) to provide an envelope of historical values. Average monthly concentrations from WY2011–WY2013 were superimposed graphically to contrast patterns among the timescales. To further characterize the status of water quality in the SLE, concentrations were compared to the target TMDL concentrations of 0.72 mg L\(^{-1}\) TN and 0.081 mg L\(^{-1}\) TP and the Impaired Waters Rule (IWR; Chapter 62-303, F.A.C.) value for *Chla* of 11.0 micrograms per liter (\(\mu\)g L\(^{-1}\)).

Oyster monitoring has been ongoing in three segments of the SLE (middle estuary or central, South Fork, and North Fork) since WY2005 (Figure 10-3, left panel). Three basic oyster population metrics were included for interpretation. The first are live oyster densities, which have been estimated at each of these sites since WY2005. Second, the abundance of oyster larvae (e.g., “spat”) as the number of spat shell\(^{-1}\) were determined at each sampling site. Third, the prevalence and intensity of the protozoan pathogen Dermo (*Perkinsus marinus*) at each sampling site were assessed. Seasonal time series for each of these variables were derived for each site from WY2011 to WY2013 for inclusion in this report.

The community composition of submersed macrophyte habitat was monitored at six sites in the SLE and SIRL including Boy Scout Island (BSI), Willoughby Creek (WC) and St. Lucie Inlet Southeast (SLI_SE) monthly, and Ocean Breeze Park (OC_BR_PK), Site 1, and Site 3 bi-monthly. The OC_BR_PK site is situated against the mainland several kilometers north of the St. Lucie Inlet. Two sites (Site 1 and BSI) are located where seagrass habitat is more widespread a few kilometers north of the inlet (Figure 10-3, right panel). While the WC site is in the SLE west of the inlet, Site 3 and SL1_SE are located just south of the inlet. The sizes of seagrass habitats ranged from 1 to 2 acres with average depths of 0.4–0.8 m. At each monthly or bi-monthly sampling, thirty (30) quadrats were deployed randomly throughout each site. Seagrass percent occurrence per quadrat was determined by dividing the number of quadrants occupied by a particular seagrass species by the total possible quadrants (25) then multiplying by 100. To determine the percent occurrence for the entire site, the quadrat percent occurrences (N=30) were averaged by date of field sampling.
Figure 10-2. St. Lucie River Watershed in southeastern Florida (left panel) and SLE boundaries including structures, water quality stations, and locations of continuous salinity monitoring (right panel). The SLE has four distinct segments: North Fork, South Fork, middle estuary, and lower estuary near the mouth of the St. Lucie Inlet. [Note: FDEP = Florida Department of Environmental Protection; Recover – Restoration Coordination and Verification; SFWMD – South Florida Water Management District; WQM – water quality monitoring.]
Figure 10-3. Locations for oyster monitoring locations (left panel), and submerged aquatic vegetation (SAV) (right panel) in the Southern Indian River Lagoon (SIRL) adjacent to the SLE. SAV stations include Boy Scout Island (BSI), Ocean Breeze Park (OC_BR_PK), Site 1 (SITE_1), Site 3 (SITE_3), St. Lucie Inlet Southeast (SLI_SE), and Willoughby Creek (WILL_CR).
Results and Discussion

Daily rainfall to the St. Lucie Estuary watershed ranged from 0 to 3.5 inches per day (0-8.9 centimeters per day) during WY2011–WY2013 and was generally less than 1.0 inches per day except in April 2011, November 2011, September 2012, and March 2013 (Figure 10-4). Total annual rainfall in WY2013 (45.5 inches) was similar to the long-term average (46.8 inches) although it was reduced in the dry season (8.5 versus 11.6) and elevated in the wet season (37.1 versus 35.1; Table 10-1). Much of the wet season contribution was due to Tropical Storm Isaac in late August 2012. Seasonal and total rainfall to the watershed was similar between WY2011 and WY2013. Rainfall was much lower in the dry season of WY2011 largely due to the La Niña climatic phenomena (Childers et al., 2006; Abtew and Trimble, 2010).

![Figure 10-4. Time series of total daily rainfall in inches per day to the St. Lucie River Watershed for Water Years 2010–2012 (WY2010–WY2012) (May 1, 2009–April 30, 2012). 1 inch = 25.4 mm.](image)

Table 10-1. Total rainfall to the St. Lucie Watershed by water year and season. The long-term average (WY1997–WY2013) is provided relative to WY2011, WY2012, and WY2013. The dry season is from November through April, and the wet season is from May through October.

<table>
<thead>
<tr>
<th>Period of Record</th>
<th>Rainfall (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
</tr>
<tr>
<td>WY1997–WY2013 Average</td>
<td>11.6</td>
</tr>
<tr>
<td>WY2011</td>
<td>8.9</td>
</tr>
<tr>
<td>WY2012</td>
<td>9.2</td>
</tr>
<tr>
<td>WY2013</td>
<td>8.5</td>
</tr>
</tbody>
</table>
Freshwater inflows to the SLE during WY2011–WY2013 reflected both fluctuations in hydrologic conditions in the watershed and releases from Lake Okeechobee. Total daily inflows from the three gauged structures to the SLE were generally less than 2,000 cfs with only a few peaks that approached 4,000 cfs in October 2011 and October 2012 with a peak of almost 8,000 cfs following Tropical Storm Isaac in September 2012 (Figure 10-5). In addition to ungauged inputs, total annual freshwater inflow in WY2013 ($0.36 \times 10^6$ ac-ft) was below the long-term average ($0.65 \times 10^6$ ac-ft; Table 10-2). In fact, total inflow was almost half of the long-term average in both WY2011 ($0.31 \times 10^6$ ac-ft) and WY2012 ($0.20 \times 10^6$ ac-ft). Outflow from Lake Okeechobee contributed only 3.2 percent and 13.8 percent of the total inflow in the WY2013 dry and wet seasons, respectively, compared to an average of 19–21 percent from WY1996–WY2013. This outflow was appreciable from May to September 2010 and again from October to November 2012 (Figure 10-5). As Lake Okeechobee discharges declined from November 2010 to September 2012 the relative contribution of SLE watershed fluctuated in the wet seasons of WY2011–WY2013 (28.9, 100, and 86.2 percent) compared to the long-term average (80.3 percent; Table 10-2).

Spatial and temporal fluctuations in salinity are strongly influenced by freshwater inflow (Ji et al., 2007). The inverse nature of salinity and freshwater inflow is evident in Figure 10-5. Salinity was low during the wet season when inflows increase and higher during the dry season when inflows are reduced. Additionally, there can be great inter-annual variations in salinity. For example, highest salinities were observed during the WY2011 dry season and the beginning of WY2012. As mentioned, there was essentially no inflow from Lake Okeechobee through the major water control structures from October 2010 to July 2012 (Figure 10-5).
Table 10-2. Total inflow in million acre-feet per year \((10^6 \text{ ac-ft} \ \text{y}^{-1})\) to the SLE categorized by contribution of Lake Okeechobee relative to the St. Lucie River Watershed \((\text{C23 + C24 + C44 Basins})\) for the long-term average \((\text{WY1996–WY2013})\) relative to WY2011, WY2012, and WY2013. Number in parentheses is percentage of total. [Note: \(10^6\) acre-feet \((\text{ac-ft})\) = 1.2 x \(10^9\) cubic meters.]

<table>
<thead>
<tr>
<th>Inflow ((10^6 \text{ac-ft}))</th>
<th>Lake Okeechobee</th>
<th>SLE Watershed</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Wet</td>
<td>Dry</td>
</tr>
<tr>
<td>WY1996–2013 Average</td>
<td>0.14 (21.1%)</td>
<td>0.13 (19.7%)</td>
<td>0.08 (78.9%)</td>
</tr>
<tr>
<td>WY2011</td>
<td>0.00 (0.0%)</td>
<td>0.22 (71.1%)</td>
<td>0.002 (100%)</td>
</tr>
<tr>
<td>WY2012</td>
<td>0.00 (0.1%)</td>
<td>0.00 (0.0%)</td>
<td>0.03 (99.9%)</td>
</tr>
<tr>
<td>WY2013</td>
<td>0.01 (3.2%)</td>
<td>0.05 (13.8%)</td>
<td>0.02 (96.8%)</td>
</tr>
</tbody>
</table>

Inter-annual variations were evident in the influence of freshwater discharge on salinity. The relationship between average monthly inflow and average monthly salinity at the US 1 Bridge in the SLE in WY2011 was distinct from those in WY2012 and WY2013 (Figure 10-6). The negative exponential curve was steeper in WY2011 indicating that less inflow at the water control structures accounted for faster increases in salinity. By contrast, slopes were similar in WY2012 and WY2013 although greater ranges of average inflows (0–2,250 cfs) and salinities (4–25) occurred in WY2013. Differences between WY2012 and WY2013 were largely due to the increased significance of the SLE watershed in the wet season of WY2012 that accounted for higher flows at a time when Lake Okeechobee outflow was minimal. Maintenance of a salinity of 15 at the US 1 Bridge required an average monthly inflow of less than 500 cfs in WY2011 but 600–700 cfs in WY2012 and WY2013 (Figure 10-6). The relative differences among these curves reflected the varying contribution of groundwater and ungauged inflow from the coastal watershed to estuarine salinity patterns among water years.

![Figure 10-6](image-url). Relationships between average monthly inflows (cfs) and average monthly salinity observed at the US 1 Bridge station in the SLE for WY2011–WY2013 \((2,000 \text{ cfs} = 4.9 \times 10^8 \text{ cubic meters per day})\).
To better manage inflows to the SLE, the salinity tolerances of the eastern oyster were used to target a preferred salinity envelope of 8–25 at the US 1 Bridge. Differences in the frequency of high inflow events accounted for the inter-annual variations in the percentage of days in various salinity ranges. The overall reduced inflow in WY2013 was evident, as salinities lower than 8 occurred for 16.4 percent of the days as compared to the long-term average of 28.0 percent (Table 10-3). The percentage of days in the favorable range of 8–25 in WY2013 was slightly greater than the long-term value (68.5 percent versus 61.2 percent). Over 42 percent of WY2011 had salinity values greater than 25 at the US 1 Bridge as compared to the long-term average of 10.8 percent. WY2012 had the least number of days where salinity was less than 8 (7.1 percent) but the greatest percentage of time in the favorable range (74.3 percent). A majority of the low salinity values in WY2013 occurred during high inflow events in September 2012 (Figure 10-5).

Table 10-3. The percentages of number of days with salinity values at the US 1 Bridge either less than 8 or greater than 25 for WY2011–WY2013 and the long-term average (WY1999–WY2013).

<table>
<thead>
<tr>
<th>Water Years</th>
<th>Days Salinity &lt;8</th>
<th>Days Salinity 8 to 25</th>
<th>Days Salinity &gt;25</th>
</tr>
</thead>
<tbody>
<tr>
<td>WY1999–WY2013</td>
<td>28.0%</td>
<td>61.2%</td>
<td>10.8%</td>
</tr>
<tr>
<td>WY2011</td>
<td>23.0%</td>
<td>34.5%</td>
<td>42.5%</td>
</tr>
<tr>
<td>WY2012</td>
<td>7.1%</td>
<td>74.3%</td>
<td>18.6%</td>
</tr>
<tr>
<td>WY2013</td>
<td>16.4%</td>
<td>68.5%</td>
<td>15.1%</td>
</tr>
</tbody>
</table>
Nutrient loading to the SLE are largely driven by surface flow hydrology (SFWMD, 2009a). Thus, TN and TP loading to the SLE generally followed patterns of freshwater inflow (Table 10-4 and Figure 10-7). TN and TP loads in WY2013 were elevated relative to WY2011–WY2012 but were approximately 50–60 percent less than the long-term average (Table 10-4). Overall, the contribution of Lake Okeechobee to annual TP and TN loadings were much reduced in WY2011 (TP = 34.8 metric tons per year (mt y⁻¹); TN = 357.3 mt y⁻¹) compared to the long-term values (TP = 53.3 mt y⁻¹; TN = 574.4 mt y⁻¹).

Lake Okeechobee did account for greater than 50 percent of total TP and TN loadings to the SLE in WY2011 although this value dropped to 0 percent and approximately 6–14 percent in WY2012 and WY2013, respectively. The SLE watershed accounted for 50.2 percent and 30.6 percent of the TP and TN loading, respectively, in WY2011, but accounted for a much higher percentage of nutrient loading in WY2012 (100 percent TP and 100 percent TN) and WY2013 (93.6 percent TP and 85.6 percent TN). Total nutrient loading in WY2012 during the drought was greatly reduced compared to the long-term averages and WY2011 or WY2013. The SLE watershed contributed relatively more TN and TP to the SLE than Lake Okeechobee in WY2013.

Table 10-4. Total freshwater inflows in 10⁶ acre-feet (ac-ft) y⁻¹ and total nitrogen (TN) and total phosphorus (TP) loads in metric tons (mt) y⁻¹ to the St. Lucie Estuary (SLE). Total loads and the percentages from the SLE watershed and Lake Okeechobee along with the long-term average for WY1996–WY2013, WY2011, WY2012, and WY2013 are provided. 10⁶ ac-ft = 1.2 x 10⁹ m³.

<table>
<thead>
<tr>
<th>Water Year</th>
<th>Total Inflow to SLE (10⁶ ac-ft)</th>
<th>Outflow from Lake Okeechobee (10⁶ac-ft)</th>
<th>SLE watershed (10⁶ac-ft)</th>
<th>Total TP Load (mt)</th>
<th>TP Load from Lake Okeechobee (mt)</th>
<th>TP Load from SLE watershed (mt)</th>
<th>Total TN Load (mt)</th>
<th>TN Load from Lake Okeechobee (mt)</th>
<th>TN Load from SLE watershed (mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WY1996–WY2013</td>
<td>0.65</td>
<td>0.26(40.8%)</td>
<td>0.38(59.2%)</td>
<td>227.2</td>
<td>53.3(23.5%)</td>
<td>173.9(76.5%)</td>
<td>1358.3</td>
<td>574.4(42.3%)</td>
<td>784.0(57.7%)</td>
</tr>
<tr>
<td>WY2011</td>
<td>0.31</td>
<td>0.22(71.1%)</td>
<td>0.09(28.9%)</td>
<td>69.4</td>
<td>34.6(49.8%)</td>
<td>34.9(50.2%)</td>
<td>34.9(50.2%)</td>
<td>357.3(69.4%)</td>
<td>157.5(30.6%)</td>
</tr>
<tr>
<td>WY2012</td>
<td>0.20</td>
<td>0.00(0.0%)</td>
<td>0.2(100.0%)</td>
<td>82.2</td>
<td>0.0(0.0%)</td>
<td>82.2(100.0%)</td>
<td>455.6</td>
<td>0.3(0.1%)</td>
<td>455.3(99.9%)</td>
</tr>
<tr>
<td>WY2013</td>
<td>0.36</td>
<td>0.06(17.0%)</td>
<td>0.38(83.0%)</td>
<td>147.3</td>
<td>9.5(6.4%)</td>
<td>137.9(93.6%)</td>
<td>715.2</td>
<td>103.3(14.4%)</td>
<td>612.0(85.6%)</td>
</tr>
</tbody>
</table>
Figure 10-7. Average annual total nitrogen (TN) (blue; left axis) and total phosphorus (TP) loads (red; right axis) to the SLE from WY1996–WY2013. TN and TP loads in metric tons per year (mt y\(^{-1}\)) are superimposed with total gauged inflow (shaded; far right axis; 10\(^6\) ac-ft per year).

TN concentrations at all stations exhibited a seasonal pattern from WY2011–WY2013 with greater relative concentrations from August to October that reflected greater freshwater inflow during the wet season (Figure 10-8). TN at stations HR1 and SE03 fluctuated from 0.5 to 1.8 mg L\(^{-1}\). Concentrations were lower at SE11 ranging from 0.1–0.75 mg L\(^{-1}\) except during high inflow in September 2012. The overall magnitude and degree of seasonality were suppressed at SE11 compared to the more upstream stations due to the oceanic influence near the St. Lucie Inlet. Dry season concentrations at all three stations were often below the long-term interquartile range with differences most noticeable during WY2011 which was influenced by La Niña. Long-term average (WY1998–WY2010) concentrations of TN exceeded the annually derived TMDL target of 0.72 mg L\(^{-1}\) at HR1 and SE03 (~approximately 1.0 mg L\(^{-1}\)) but not at SE11 (0.62 mg L\(^{-1}\); Table 10-5). Similarly, TN concentrations were in excess of the TMDL target in WY2011–WY2013 at the two upstream stations (0.73–0.88 mg L\(^{-1}\)) but not at SE11 near the St. Lucie inlet.

Table 10-5. Annual and long-term mean concentrations of chlorophyll a (Chla) in micrograms per liter (μg L\(^{-1}\)), TN in milligrams per liter (mg L\(^{-1}\)) and TP (mg L\(^{-1}\)) at three water quality monitoring stations in the SLE.

<table>
<thead>
<tr>
<th></th>
<th>HR1</th>
<th>SE03</th>
<th>SE11</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chla μg L(^{-1})</strong></td>
<td>12.4</td>
<td>9.6</td>
<td>3.7</td>
</tr>
<tr>
<td><strong>TN mg L(^{-1})</strong></td>
<td>1.01</td>
<td>1.03</td>
<td>0.62</td>
</tr>
<tr>
<td><strong>TP mg L(^{-1})</strong></td>
<td>0.22</td>
<td>0.20</td>
<td>0.07</td>
</tr>
<tr>
<td><strong>WY1998–WY2010</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Chla μg L(^{-1})</strong></td>
<td>11.6</td>
<td>6.2</td>
<td>3.9</td>
</tr>
<tr>
<td><strong>TN mg L(^{-1})</strong></td>
<td>0.73</td>
<td>0.75</td>
<td>0.31</td>
</tr>
<tr>
<td><strong>TP mg L(^{-1})</strong></td>
<td>0.23</td>
<td>0.12</td>
<td>0.04</td>
</tr>
<tr>
<td><strong>WY2011</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Chla μg L(^{-1})</strong></td>
<td>12.8</td>
<td>5.3</td>
<td>2.7</td>
</tr>
<tr>
<td><strong>TN mg L(^{-1})</strong></td>
<td>0.88</td>
<td>0.80</td>
<td>0.43</td>
</tr>
<tr>
<td><strong>TP mg L(^{-1})</strong></td>
<td>0.13</td>
<td>0.18</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>WY2012</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Chla μg L(^{-1})</strong></td>
<td>14.1</td>
<td>5.5</td>
<td>2.9</td>
</tr>
<tr>
<td><strong>TN mg L(^{-1})</strong></td>
<td>0.81</td>
<td>0.77</td>
<td>0.26</td>
</tr>
<tr>
<td><strong>TP mg L(^{-1})</strong></td>
<td>0.20</td>
<td>0.16</td>
<td>0.04</td>
</tr>
<tr>
<td><strong>WY2013</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 10-8. Water column concentrations of TN in milligrams per liter (mg/L), TP in mg/L, and chlorophyll a (Chl a) in micrograms per liter (µg/L) at stations HR1, SE03, and SE11 in the SLE. Red dashed lines indicate target concentrations of TN (0.72 mg/L), TP (0.081 mg/L), and Chl a (11.0 µg/L) related to Total Maximum Daily Loads (TMDLs) to the SLE. Note scale for Chl a at station SE11 is only 0–20 µg/L compared to 0–80 µg/L at stations HR1 and SE03.
Similar to TN, TP concentrations exhibited seasonality with greater wet than dry season averages from WY2011 to WY2013 (Figure 10-8). TP concentrations fluctuated from less than 0.1 to 0.4–0.5 mg L\(^{-1}\) at HR1 and SE03. Maximum TP concentrations were observed with increased freshwater inflow in September 2012 at both stations. The overall magnitude and degree of seasonality were suppressed at SE11 compared to the more upstream stations. Dry season TP concentrations generally were less than the long-term medians at all three stations (HR1, SE03, SE11). Long-term average (WY1998–WY2010) concentrations of TP exceeded the TMDL target of 0.081 mg L\(^{-1}\) at HR1 and SE03 (0.20–0.22 mg L\(^{-1}\)) but not at SE11 (0.07 mg L\(^{-1}\); Table 10-5). While TP concentrations in WY2013 at HR1 were similar to the long-term average, concentrations were reduced at SE03 and SE11.

Inter-seasonal variations in water column Chla concentration were not as predictable as those observed for TN and TP (Figure 10-8). Chla is not the only photosynthetic pigment and phytoplankton population densities fluctuate with a variety of physical (transport, sinking), chemical (nutrient supply and turnover), and biological (grazing by zooplankton and larval organisms) factors. The concentration of Chla was generally less than 10 µg L\(^{-1}\) at HR1 and SE03 although there were peaks approaching 80 and 50 µg L\(^{-1}\) at HR1 in September of 2012 and 2013, respectively. It is possible that direct oceanic influence suppressed the overall magnitude and degree of seasonality at SE11. Dry season Chla concentrations in WY2012 and WY2013 were less than the long-term median values. The long-term average (WY1998–WY2010) concentrations (12.4 µg L\(^{-1}\)) exceeded the IWR of 11.0 µg L\(^{-1}\) at HR1 but not at SE03 or SE11 (Table 10-5). Similarly, Chla concentrations were in excess of this target in WY2011-WY2013 at HR1 (11.6–14.1 µg L\(^{-1}\)) but not at SE11 near the St. Lucie inlet.

Salinity values at the US 1 Bridge were generally favorable for oyster habitats (8–25) in the SLE throughout the last three water years (Figure 10-9, panel A). Exceptions were when salinity less than 8 occurred each wet season, particularly during high freshwater inflow following Tropical Storm Isaac in September 2012. This event appeared to suppress live oyster density disproportionately in the North Fork (SL-N) and South Fork (SL-S) relative to the middle of the SLE. Increases and decreases in live oyster density (number per square meter) in the SLE lagged behind corresponding increases or decreases in salinity. Oyster density was 4 to 5 times greater approaching 550–700 m\(^{-2}\) in the central segment of the SLE in the wet seasons of WY2011 and WY2012 and both seasons in WY2013. The number of settled oyster larvae per shell (spat per shell) was variable but generally less than 1.0 spat per shell throughout the POR except in the North Fork of the SLE in the wet season of 2012 where it exceeded 2.0 spat per shell (Figure 10-9, panel B). Extreme freshwater inflow in September 2012 triggered reduced spat abundance at the beginning of the WY2013 dry season. While 20–80 percent of the oysters monitored were infected by the protozoan Dermo from WY2011–WY2013, the average infection intensity ranged from 0.75–2.25 (Figure 10-9, panels C-D). Overall, infection intensity was reduced throughout WY2011 although it increased with reduced inflow in WY2012. Intensity decreased to approximately 1.5 at all three sites in the WY2013 wet season but increased at the central site in the SLE in the following dry season.

Salinity at the A1A Bridge crossing the SIRL ranged from 20 to greater than 30 over the POR (Figure 10-10). Values were greatest in WY2011 peaking in May–June each year. Both shoal grass (Halodule wrightii) and manatee grass (Syringodium filiforme) exhibited seasonality with greatest percent occurrence observed from August to October at the northernmost Ocean Breeze Park site in SIRL from WY2011–WY2013 (Figure 10-10, panel A). However, the percent occurrence for these two species decreased over the period of record from maxima of nearly 100 percent for both in WY2011 to less than 80 percent (manatee grass) and approximately 40 percent (shoal grass) in WY2013. Manatee grass had greater than 80 percent and greater than 90 percent occurrence at Site 1 and BSI, respectively, from WY2011–WY2013 (Figure 10-10, panels B-C).
Figure 10-9. Seasonal averages oyster metrics in the North Fork (black), central estuary (dark grey), and South Fork (white) in the SLE from WY2011–WY2013. (A) live density [number per square meter (# m$^{-2}$)]; (B) larvae [spat per shell (spat shell$^{-1}$)]; (C) Dermo infection (% sampled); (D) Dermo intensity (0.5–5). Daily salinity at the US 1 Bridge is also provided (shaded; right axis).
Figure 10-10. SAV community composition at six stations in the SLE and SIRL. The percent occurrences for each of the observed species (left axis) and the daily salinity at the A1A Bridge (shaded; right axis) are provided.
Shoal grass and Johnson’s grass (*Halophila johnsonii*) had low percent occurrences (less than 20 percent and less than 10 percent, respectively) in WY2011 decreasing over time at BSI. While shoal grass occurred at greater than 90 percent of grid samples south of St. Lucie Inlet (SL 1 Southeast), Johnson’s grass fluctuated widely from 20 to 100 percent at this location (*Figure 10*-10, panel D). The relative coverage of Johnson’s grass was greatest in May–August 2010 and April 2013. The other site south of the Inlet (Site 3) included shoal grass that varied from 80 percent–50 percent from WY2011–WY2013, Johnson’s grass that ranged from 70 percent to approximately 40 percent, and low occurrences of manatee grass and paddle grass (*Halophila decipiens*; *Figure 10*-10, panel E). The percent occurrences of Johnson’s grass and shoal grass inside the Inlet at Willoughby Creek followed increased salinity although both were impacted by the greatly reduced salinity occurring in September–October 2012 (*Figure 10*-10, panel F).

**Significant Findings**

- WY2013 represented an average year for rainfall and freshwater inflow to the SLE. Although both rainfall and inflow were reduced in the dry season, they increased in the wet season. Extreme values during Tropical Storm Isaac in September 2012 influenced these patterns.
- The contribution of Lake Okeechobee declined to 3–13 percent of total inflow compared to the long-term value of ~21 percent. The SLE watershed provided 86-96 percent of the total inflow in WY2013 compared to the long-term average of ~79 percent.
- TN and TP loading to the SLE correlates to freshwater inflow. While TN and TP loads in WY2013 exceeded those of WY2011–WY2012, they were approximately 50–60 percent of the long-term average values.
- Concentrations of TN and TP in WY2013 exceeded the TMDL targets (0.72 mg L\(^{-1}\), 0.081 mg L\(^{-1}\) respectively) and the IWR for Chl\(a\) (11.0 µg L\(^{-1}\)) in the upper SLE, but not in the lower estuary near the St. Lucie Inlet. While concentrations at HR1 in the upper estuary were similar to the long-term averages, those at SE03 and SE11 in the lower estuary were depressed. Inter-seasonal variations in water column Chl\(a\) concentration were not as predictable as those observed for TN and TP.
- The percentage of days with salinity favorable for oysters (8–25) was greater than the long-term average.
- The high freshwater inflow in September 2012 resulting from Tropical Storm Isaac affected benthic ecological resources by suppressing live oyster density in the SLE. The effect was greater in the North Fork and South Fork. This event led to overall reduced spat abundance and the intensity of Dermo infection in WY2013.
- Increasing salinities across the lower SLE and SIRL promoted the salt-tolerant seagrass community from WY2011–WY2012. However, the high freshwater inflow in September 2012 led to reductions in the prevalence of these species, including a large negative impact on seagrass habitat inside the St. Lucie Inlet at Willoughby Creek.
CRE HYDROLOGY, WATER QUALITY AND AQUATIC HABITAT

The FDEP established a TMDL rule for the CRE (Chapter 62-304.800, F.A.C.; FDEP, 2009). The TMDL focuses on the CRE downstream of the S-79 structure, which encompasses three water body identification areas determined to be impaired for nutrients and dissolved oxygen (DO). The final TMDL for the CRE is 4,121 mt y$^{-1}$ of TN, which corresponds to a reduction of 23 percent from current levels.

Historically, seagrass meadows and oyster reefs were salient features of the landscape in South Florida estuaries. To evaluate the ecological condition of the CRE, SAV and oysters are routinely monitored. SAV are commonly monitored to gauge the health of estuarine systems (Tomasko et al., 1996) and their environmental requirements can form the basis for water quality goals (Dennison et al., 1993). Oyster beds are a good indicator of estuarine condition as the distribution and abundance of the eastern oyster have ecosystem-scale implications (Peterson et al., 2003; Coen et al., 2007). Oyster beds filter water and suspended solids, couple the water column to the benthos, and provide living aquatic habitat (Tolley et al., 2006; Volety et al., 2009; Buzzelli et al., 2013a; 2013c).

Methods

A suite of external drivers and ecological responses are monitored in the Caloosahatchee River Watershed and Estuary. These variables include rainfall, freshwater discharge, and nutrient loading as external drivers, and patterns of water column nutrient concentrations, oyster habitat status, and SAV community composition as the ecological responses. Salinity provides a conservative property useful to connect freshwater inflow to estuarine flushing time and biological resource tolerances (Wilber, 1992; Jassby et al., 1995; Kimmerer, 2002; Hagy and Murrell, 2007; Pollack et al., 2011).

NEXRAD Rainfall data from WY1997 through WY2013 were obtained through the District’s DBHYDRO database for 10 distinct NEXRAD units: East Caloosahatchee, West Caloosahatchee, Hicpochee North, Nicodemus Slough South, S-4, Telegraph Swamp, Tidal North, Tidal South, Cape Coral Coastal, and the CRE (SFWMD et al., 2012b; Figure 10-11). Total rainfall estimates relied upon an area-weighted method where the daily rainfall from each basin was scaled by its size relative to the total area of the combined watershed and estuary surface area. Total daily rainfall was derived by summing across all 10 scaled daily unit values and categorized by water year and season to calculate average and total values.

Freshwater discharge is monitored at the major structures along the Caloosahatchee River (C-43 canal): S-77 next to Lake Okeechobee, S-78 near LaBelle, and S-79 at the upstream boundary of the CRE (Figure 10-11). Average daily inflow spanning from WY1996–WY2013 for S-77 and S-79 were used to evaluate intra- and inter-annual variations in overall inflow and to quantify total inflow to the CRE each water year. This included the relative volume contributions from Lake Okeechobee versus contributions from the Caloosahatchee River Watershed upstream of S-79. Total daily discharges and contributions were categorized by water year and season. Daily TN and TP loads were calculated using daily inflows at S-79 and S-77 and TN and TP concentrations determined from water samples at the structure. Daily loads from WY1996 through WY2013 were categorized by water year to evaluate temporal variations at different timescales.
Figure 10-11. Caloosahatchee River Watershed showing the five sub-watershed including the S-4, East Caloosahatchee, West Caloosahatchee, Tidal Caloosahatchee (Telegraph Swamp, Cape Coral, and Tidal South), and Coastal (North Coastal and Nearshore basins). [Note: CO – County; SWFWMD – Southwest Florida Water Management District.]
Surface and bottom salinity observations are recorded every 30 minutes at seven stations in the CRE: S-79, Bridge 31, I-75 Bridge (Val I75), Fort Myers, Cape Coral, Shell Point, and Sanibel Island Bridge (Figure 10-12). Salinity was evaluated at Fort Myers and the I-75 Bridge where critical criteria were derived relative to tape grass habitat requirements (Doering et al., 2002). First, daily surface and bottom salinity values were averaged together. These data were used to calculate moving averages and the percentage of days above or below the critical criteria. Second, the monthly averages were calculated for each station to produce a time series over the past three water years. Third, salinity data were categorized by water year and season to compare and contrast intra- and inter-annual patterns. Fourth, an exponential curve was fit to the relationship between average total monthly discharge and average monthly salinity at Fort Myers. The ranges in both values and shapes of the resulting curves were contrasted among WY2011, WY2012, and WY2013.

Figure 10-12. CRE boundaries including structures, water quality stations, and locations of continuous salinity monitoring. The CRE extends from S-79 approximately 45 kilometers (km) to the Sanibel Island Bridge near the Gulf of Mexico.

Water column properties are determined from sampling at a depth of 0.5 m at 13 stations in the CRE, San Carlos Bay, and Pine Island Sound approximately monthly (Figure 10-12). Four stations (CES01, CES04, CES06, and CES08) were selected to characterize estuarine water quality. Concentrations of TN, TP, and Chla from WY1999 through WY2013 from each of the stations were included in the analyses (SFWMD, 2011). The long-term median value was
calculated along with the interquartile range (difference between the 75th and 25th percentiles) to provide a reference envelope of historical values. Average monthly concentrations from WY2011 through WY2013 were superimposed graphically to contrast patterns among the timescales. Chla concentration was averaged and compared by water year to a value of 11.0 µg L⁻¹ from the IWR (Chapter 62-303, F.A.C.).

Oyster monitoring has been ongoing at multiple sites in the lower CRE since WY2001 (Figure 10-13, top panel). The primary sites for this report are Iona Cove, Kitchell Key, and Bird Island (Volety et al., 2009; SFWMD et al., 2012b). Three basic oyster population metrics were included for interpretation. The first are live oyster densities, which have been estimated at each of these sites since WY2005. Second, the abundance of oyster larvae (e.g., “spat”) as the number of spat per shell was monitored at each sampling site. Third, the prevalence and infection intensity of the protozoan pathogen Dermo (*Perkinsus marinus*) at each sampling site were assessed. Seasonal time series for each of these variables were derived for each site from WY2011–WY2013. Live density counts were discontinued at the Tarpon Bay site in WY2012 (Volety et al., 2009). Daily salinity at Shell Point for the POR was superimposed with the oyster population metrics.

SAV monitoring has been ongoing at multiple sites in the CRE and San Carlos Bay since 1998. There are seven sites (1, 2, 4, 5, 6, 7, and 8; Figure 10-13, bottom panel) ranging in size from 1.0 to 2.0 acres (0.4 to 0.8 hectares). A 1.0-m² quadrat subdivided into 25 equal quadrants was deployed at 30 randomly selected locations within each site. The percent occurrence for each seagrass species within each quadrat is determined by calculating the percentage of quadrants. The average and standard error of percent occurrence for each species is calculated from the 30 locations at each monitoring site for each monitoring event. Sites 1 to 8 were monitored in the same way during 2011, however, starting in April 2012 monitoring at site 1 was modified through the use of a large quadrat (3.0 m x 3.0 m = 9.0 m² = 0.0009 hectares) subdivided into nine 1.0-m² quadrants. The 9.0-m² quadrats were deployed at 20 locations within the upper estuary between the Railroad Bridge and Bird Island. The 20 locations changed with each monitoring period based on data obtained from the previous monitoring. Data obtained from the large quadrats is being used to determine presence or absence of tape grass. Daily salinity at Fort Myers for the POR was superimposed with the SAV community composition at each site.
Figure 10-13. Locations for oyster monitoring locations (top panel), and SAV (bottom panel) in the CRE. Stations for oyster monitoring include Bird Island (BI), Iona Cove (IC), Kitchell Key (KK), and Tarpon Bay (TB).
Results and Discussion

Daily rainfall ranged from 0 to 3.5 inches per day (0–8.9 cm per day) between May 2010 and April 2013 (Figure 10-14). Rainfall amounts were generally less than 1.5 inches per day throughout the POR except for peaks greater than 2.0 inches per day in October–November 2011 and following Tropical Storm Isaac in September 2012. The relatively low total rainfall in WY2011 was due to lower than average wet season rainfall of just 33.7 inches (Table 10-6). While rainfall during the WY2012 wet season was greater than the long-term average (44.6 versus 40.3 inches), the dry season average was reduced (5.9 versus 10.3 inches). The total (50.2 inches) and seasonal (dry = 10.3 and wet = 39.9 inches) rainfall amounts for WY2013 were very close to the long-term averages of 51.0, 10.8, and 40.3 inches, respectively. A similar pattern to the SLE arose as total rainfall in WY2013 was similar to the average from WY1996–WY2013 due to a comparatively drier dry season followed by a wetter wet season through the contribution of Tropical Storm Isaac.

![Graph showing daily rainfall from May 2010 to April 2013.](image)

Figure 10-14. Time series of total daily rainfall [inches per day] to the Caloosahatchee River Watershed for WY2011–WY2013. 1 inch = 25.4 mm

Table 10-6. Total rainfall to the Caloosahatchee River Watershed by water year and season. The long-term average (WY1997–WY2013) is provided relative to WY2011, WY2012, and WY2013. The dry season is November–April and the wet season is May–October. 1 inch = 25.4 mm

<table>
<thead>
<tr>
<th>POR</th>
<th>Rainfall (inches)</th>
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<th></th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Wet</td>
<td>Total</td>
</tr>
<tr>
<td>WY1997–WY2013 Average</td>
<td>10.8</td>
<td>40.3</td>
<td>51.0</td>
</tr>
<tr>
<td>WY2011</td>
<td>10.6</td>
<td>33.7</td>
<td>44.3</td>
</tr>
<tr>
<td>WY2012</td>
<td>5.9</td>
<td>44.6</td>
<td>50.5</td>
</tr>
<tr>
<td>WY2013</td>
<td>10.3</td>
<td>39.9</td>
<td>50.2</td>
</tr>
</tbody>
</table>

10-36
Freshwater discharge at S-79 represents the combined contribution of rainfall driven runoff from the Caloosahatchee River Watershed and releases from Lake Okeechobee (Figure 10-14). During the wet season, water is released from Lake Okeechobee to control water level. During the dry season, water is released to the CRE when available in order to mitigate upstream saltwater intrusion. Inflow was generally less than 1,000 cfs for much of WY2011–WY2013 except for peaks of greater than 8,000 cfs each September of 2011, 2012, and 2013. Total annual inflows in WY2011 and WY2013 (1.1 x 10^6 ac-ft) were nearly identical but less than the long-term average of 1.4 x 10^6 ac-ft (Table 10-7). Freshwater inflow was greatly reduced in WY2012 (0.58 x 10^6 ac-ft). Regulatory discharges from Lake Okeechobee in May 2010 resulted in discharges greater than 4,000 cfs in WY2011. WY2012 was particularly dry with virtually no discharge from Lake Okeechobee throughout the entire wet season. Inflows greater than 4,000 cfs did not occur until September 2011 (WY2012) and late August 2012 (WY2013; Figure 10-14).

**Table 10-7.** Total inflow (10^6 ac-ft per year) to the CRE categorized by contribution of Lake Okeechobee relative to the Caloosahatchee River Watershed for the long-term average (WY1996–WY2013) relative to WY2011, WY2012, and WY2013. The number in parentheses is the percentage of total. 10^6 ac-ft = 1.2 x 10^9 m^3.

<table>
<thead>
<tr>
<th></th>
<th>Lake Okeechobee</th>
<th>Caloosahatchee River Watershed</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Wet</td>
<td>Dry</td>
</tr>
<tr>
<td>WY1996–2013 Average</td>
<td>0.25 (17.4%)</td>
<td>0.28 (19.8%)</td>
<td>0.02 (14.2%)</td>
</tr>
<tr>
<td>WY2011</td>
<td>0.02 (1.9%)</td>
<td>0.44 (38.8%)</td>
<td>0.08 (6.6%)</td>
</tr>
<tr>
<td>WY2012</td>
<td>0.05 (8.0%)</td>
<td>0.00 (0.5%)</td>
<td>0.12 (20.4%)</td>
</tr>
<tr>
<td>WY2013</td>
<td>0.13 (11.8%)</td>
<td>0.21 (19.0%)</td>
<td>0.18 (16.4%)</td>
</tr>
</tbody>
</table>

The contributions of Lake Okeechobee and the C-43 basin to dry season inflows were greatly reduced in WY2011 (1.9 and 6.6 percent) compared to the long-term averages (17.4 and 14.2 percent; Table 10-7). The role of the C-43 basin was exaggerated in the WY2012 wet season given the much reduced freshwater input in WY2012. Dry season inflows in WY2012 were significantly reduced due to the influence of La Niña. Percentages were more similar between the long-term averages and WY2013 although the C-43 basin accounted for a greater relative fraction of total inflows in the wet season (52.8 percent in WY2013).

Salinity at Fort Myers from WY2011–WY2013 ranged from near 0 to 25, exhibiting a seasonal pattern inverse to that of freshwater inflow (Figure 10-14). Average daily salinity was generally low in WY2013 with peak values in May–June 2012, decreased salinity nearing 0 by September 2012, and an increase to 10–12 in the beginning of 2013. Salinity in excess of the critical criteria occurred in the dry season months (November–April) during the latter half of the water year. Compared to WY2012, WY2013 had increased freshwater inflow and lower salinity with no instances of salinity greater than 20 at Fort Myers (Table 10-8). Salinity was greater than 20 approximately 9 percent of the time using long-term data since WY2001. The percentage of time that average daily salinity was greater than 10 (30-day moving average at Fort Myers) was similar between WY2013 and the long-term average (36.7 percent versus 34.7 percent). However, salinity was decreased further upstream as only 29 percent of daily values at the Val I75 location had values greater than 5 compared to a long-term average of 48.0 and 59.7 percent observed in WY2012.
Table 10-8. Exceedances of critical salinity criteria at Fort Myers for WY2011–WY2013. At the Fort Myers station, daily average salinity should not exceed 20 and the 30-day moving average should not exceed 10. At the Val I75 site, the 30-day moving average should not exceed 5. The period of record for the long-term average for the Fort Myers station is WY2001–WY2013 and Val I75 station is WY2006–WY2013.

<table>
<thead>
<tr>
<th>Period of Record</th>
<th>Fort Myers</th>
<th>Val I75</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Days with Daily Salinity &gt; 20</td>
<td>Days with 30-day Moving Average Salinity &gt; 10</td>
</tr>
<tr>
<td>Long-term average</td>
<td>8.9%</td>
<td>34.7%</td>
</tr>
<tr>
<td>WY2011</td>
<td>0.5%</td>
<td>46.3%</td>
</tr>
<tr>
<td>WY2012</td>
<td>17.3%</td>
<td>60.3%</td>
</tr>
<tr>
<td>WY2013</td>
<td>0.0%</td>
<td>36.7%</td>
</tr>
</tbody>
</table>

Estuarine salinity is influenced both by freshwater discharge at S-79 and surface and groundwater inflow from the downstream tidal basin (e.g., the CRE watershed). This influence is evident in the inter-annual variations in the negative exponential relationship between freshwater discharge at S-79 and salinity at Fort Myers (Figure 10-15). WY2011 was characterized by the steep slope of the relationship indicating that a relatively small increase in freshwater inflow at S-79 could lead to a rapid decrease in salinity at Fort Myers. The relationships for WY2012 and WY2013 had similar shapes except that the greatest average monthly inflow was approximately 2,000 cfs with a salinity maximum of 20 in WY2012 compared to values of approximately 5,000 cfs and 14 in WY2013 (Figure 10-16). Inter-annual differences in discharge from the CRE watershed accounted for the variations in these relationships between WY2011 and WY2013. Thus, more inflow from S-79 was required in WY2012 and WY2013 to achieve the target salinity conditions at Fort Myers.

Figure 10-15. Time series of average daily outflow from Lake Okeechobee at S-77 (pink), average daily inflow to the CRE at S-79 (black), and salinity at Fort Myers (blue). Red dashed lines mark the salinity envelope in the CRE from 10 to 20. 1 cfs = 0.029 m³ per second.
Figure 10-16. Relationship between average monthly inflow and average monthly salinity observed at Fort Myers in the CRE from WY2011–WY2013. 1 cfs = 0.029 m³ per second.

Nutrient loading to the CRE is largely driven by surface flow hydrology (SFWMD, 2009b). The loading of TP and TN to the CRE followed total freshwater inflow (Figure 10-17). Total nutrient loading at S-79 is a combination of water and nutrients from Lake Okeechobee and those derived from the C-43 watershed. Overall, the TN:TP ratio of loading was approximately 10:1. Total freshwater inflow and nutrient loads were greatly reduced in WY2012 relative to the long-term averages or WY2011 and WY2012 (Table 10-9). A great fraction of the TP (92.2 percent) and TN (84.6 percent) loading to the CRE in WY2012 were from the C-43 basin. Total TP and TN loadings in WY2013 (230.1 and 2967.2 mt) were similar to the average values from WY1996–WY2013 (234.1 and 2614.8 mt; Table 10-9). In WY2013 the contributions from Lake Okeechobee (TP = 22.2 percent and TN = 30.5 percent) and the C-43 basin (TP = 77.8 percent and TN = 69.5 percent) were less than and greater than the long-term averages, respectively. Loads in WY2013 represented approximately twice those in WY2011 (TP = 162.9 mt; TN = 1869.7 mt) or WY2012 (TP = 111.5 mt; TN = 1010.7 mt (Figure 10-17).

Table 10-9. Total freshwater inflows in 10⁶ acre-feet per year (ac-ft/y⁻¹) and TN and TP loads in mt y⁻¹ to the CRE and the total and contribution of Lake Okeechobee and the C-43 basin to the TN and TP loading to the CRE for the long-term average (WY1996–WY2013), WY2011, WY2012, and WY2013. 10⁶ ac-ft = 1.2 x 10⁹ m³.
Figure 10-17. Average annual TN (blue; left axis) and TP loads (red; right axis) to the CRE from WY1996–WY2013. TN and TP loads superimposed with total gauged inflow (shaded; far right axis).

TN concentrations at stations CES01, CES04, and CES06 did not deviate considerably from the long-term trend between WY2011 and WY2013 except for peaks greater than 2.5 mg L\(^{-1}\) at CES01 in May 2012 and 1.5 mg L\(^{-1}\) at CES06 and CES08 in November 2012 (Figures 10-18 and 10-19). The annual cycle in TN concentrations at CES06 and CES08 in WY2012 lagged the long-term patterns. The temporal pattern was shifted later in the year relative to the long-term at all four stations in WY2013. This shift was most apparent at CES06 and CES08 in the lower CRE and may have resulted from the delay in high inflows greater than 4,000 cfs in WY2012 and WY2013 relative to WY2011.

TP concentrations exhibited seasonal periodicity with increased values in the wet season at all four stations (CES01, CES04, CES06, CES08; Figures 10-18 and 10-19). TP was less than 0.2 mg L\(^{-1}\) from WY2011–WY2013 at CES01, CES04, and CES06 and less than 0.1 mg L\(^{-1}\) at CES08. Values were comparable to the long-term values except for a peak at CES01 in June 2012, reduced concentrations at CES04 in May–June 2011, and the absence of extreme peaks at CES08 in June and September of each water year.

Water column Chl\(a\) concentration was less predictable than either TN or TP (Figures 10-18 and 10-19). Peaks in the monthly averages of approximately 40 and approximately 90 µg L\(^{-1}\) at CES01 in June 2011 and June 2012, respectively, were not evident in 2013. In particular, the phytoplankton bloom in June 2012 was promoted by reduced freshwater inflow coupled with increasing water temperature in April–May 2012. Concentrations generally followed the long-term pattern at CES04 except for an increase to approximately 30 µg L\(^{-1}\) in February 2013. The overall magnitude was much lower than the long-term ranges and medians at CES06 and CES08 except for a peak near 15 µg L\(^{-1}\) at CES06 in September 2012. The concentrations of Chl\(a\) in the entire CRE were less than the IWR of 11.0 µg L\(^{-1}\) in each WY2011–WY2013 averaging 7.9, 9.8, and 8.4 µg L\(^{-1}\), respectively (Table 10-10). There were inter-station differences as the Chl\(a\) concentration was greater upstream (CES01 and CES04) relative to downstream (CES06 and CES08). This is consistent with previous observations (Doering et al., 2006).
Figure 10-18. Water column concentrations of TN, TP, and Chla at stations CES01 and CES04 in the CRE. The long-term (WY1999-WY2010) inter-quartile range (blue shade) and median (black dash) are provided along with monthly values for WY2011–WY2013. Note that the scale for Chla at CES01 ranges from 0–100 µg/L, while the range at CES04 was 0-50 µg/L.
Figure 10-19. Water column concentrations of TN, TP, and Chlα at stations CES06 and CES08 in the CRE. The long-term (WY1999-WY2010) inter-quartile range (blue shade) and median (black dash) are provided along with monthly values for WY2011–WY2013. Note that the scale for Chlα at CES06 ranges from 0–50 µg L⁻¹ while the range at CES08 was 0-25 µg L⁻¹.
Minimum salinity conditions at Shell Point in the lower CRE were generally favorable for oyster habitat (greater than 15; Figure 10-20). Live oyster densities were greater at the Bird Island (approximately 1,500–3,000 oysters per m²) site compared to Kitchell Key or Iona Cove (approximately 1,000 oysters per m²). The exception was a peak of 2,500 oysters per m² at Iona Cove in the wet season of WY2013 (Figure 10-20, panel A). Spat fall levels were greatest in the wet season of WY2011 at Bird Island and Iona Cove (25–40 spat per shell) but decreased to very low levels the following dry season with values of less than 10 spat per shell throughout the rest of the POR (Figure 10-20, panel B). Spat amounts were particularly reduced at the Kitchell Key site in the lower CRE. There was an overall upward trend in the percentage of oysters infected with the protozoan disease, Dermo, from WY2011 to WY2013 (Figure 10-20, panel C). Approximately 50–80 percent of oysters that were sampled were infected from the 2011 wet season to the 2013 wet season. The maximum increased to 90–100 percent in the WY2012 dry season and into the WY2013 wet season. Similar to live density and spat fall, the Bird Island and Iona Cove sites had greater numbers than the Kitchell Key site. However, unlike the greater values for the first two indicators at Bird Island and Iona Cove, in the case of Kitchell Key a reduction in the percentage of infected oysters is more desirable. While a majority of the oysters were infected with Dermo, the overall infection level was comparatively low ranging from 1.0–2.0 throughout the POR (Figure 10-20, panel D). The exception was at Iona Cove in the dry season of WY2012 when relative infection exceeded 2.5. Patterns of infection were consistent with the conventional knowledge of the CRE where infection intensity is reduced because the marine parasite is suppressed by low salinity in the wet season and low temperature in the dry season (LaPeyre et al., 2003).

SAV community composition in the CRE varies along longitudinal gradients in salinity and light. These gradients vary seasonally depending upon freshwater inflow and the loading of particulate and dissolved materials. Upstream Sites 1 and 2 featured a combination of tape grass and widgeon grass (Ruppia maritima) until March 2011 (Figure 10-21). Both species declined to near zero at Site 1 by June–July 2011 after extended drought conditions and accompanying high salinity. Tape grass was present at Site 2 but at decreasing levels throughout WY2011 while widgeon grass peaked at 40 percent and approximately 20 percent occurrence in May 2011 and August 2012, respectively. Both species declined to near zero with increased salinity during the dry season of WY2011 when total freshwater inflow was negligible. There were small amounts of shoal grass at Site 2 over the three water years. Widgeon grass increased in percent occurrence with dry season increases in salinity at Site 4. Both tape grass and shoal grass exhibited similar patterns to those observed at Site 2 with low percent occurrences. Shoal grass was the dominant species at Sites 5 and 6 fluctuating from 60–100 percent and 10–70 percent at the two sites, respectively. Sites 7 and 8 in San Carlos Bay included both shoal grass and turtle grass (Thalassia testudinum; Figure 10-21). Turtle grass, a dominant marine SAV species, exhibited increasing occurrence and dominance until August–September 2012 when its percentage decreased to 80 percent (Site 7) and 50 percent (Site 8).

<table>
<thead>
<tr>
<th>Average Water Year</th>
<th>CES01</th>
<th>CES04</th>
<th>CES06</th>
<th>CES08</th>
</tr>
</thead>
<tbody>
<tr>
<td>WY2011</td>
<td>13.5</td>
<td>9.0</td>
<td>6.8</td>
<td>2.4</td>
</tr>
<tr>
<td>WY2012</td>
<td>22.6</td>
<td>7.5</td>
<td>4.9</td>
<td>4.0</td>
</tr>
<tr>
<td>WY2013</td>
<td>10.2</td>
<td>16.3</td>
<td>5.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Table 10-10. Average water column Chla concentrations from stations CES04, CES06, and CES08 on the CRE from WY2011–WY2013. Critical concentration is 11 µg L⁻¹.
Figure 10-20. Seasonal averages oyster metrics at Bird Island (BI; black), Iona Cove (IC; dark grey), and Kitchell Key (KK; white) in the SLE from WY2011–WY2013. (A) live density [number per square meter (# m⁻²)]; (B) larvae [spat per shell (spat shell⁻¹)]; (C) Dermo infection (% sampled); (D) Dermo intensity (0.5–5). Daily salinity at the Shell Point (SP) is also provided (shaded; right axis).
Figure 10-21. SAV community composition at six stations in the CRE. The percent occurrences for each of the observed species (left axis) and the daily salinity at Fort Myers (shaded; right axis) are provided.
Significant Findings

- Total rainfall in WY2013 was similar to the long-term average. Less rainfall in the dry season and more in the wet season summed to approximate the long-term value.
- The respective contributions of Lake Okeechobee and the CRE watershed upstream of S-79 to total freshwater inflow were within range of the long-term averages. As with rainfall, reduced inflow in the dry season was offset by increased inflow in the wet season. Freshwater inputs associated with Tropical Storm Isaac in September 2012 were an important component.
- Average daily salinity was greater than 10 at Fort Myers approximately 37 percent of the days in WY2013, which was similar to the long-term average. Only 29 percent of daily values at the Val I75 location had values greater than 5 compared to a long-term average of 48.0 and 59.7 percent observed in WY2012
- Average daily salinity was generally low in WY2013, with peak values in May–June 2012, decreased salinity nearing 0 by September 2012, and an increase to 10–12 in the beginning of 2013. Lake Okeechobee regulatory releases in the WY2013 dry season suppressed patterns of upstream saltwater intrusion observed the previous two water years.
- The CRE watershed downstream of S-79 was comparatively dehydrated in WY2013 as more inflow at the head of the estuary was required to maintain target salinities at Fort Myers.
- While total TP and TN loads in WY2013 were similar to the long-term values (WY1996–WY2013), they were almost twice those observed in WY2011 and WY2012.
- TN and TP concentrations in the estuary were similar to the long-term averages. Exceptions occurred when TN increased in the upper CRE in May–June 2012 and in the lower CRE in October–November 2012. Increased values early in 2012 resulted from a phytoplankton bloom in April 2012 while the downstream increases later in 2012 were associated with the tropical storm-induced inflow in September 2012.
- WY2013 concentrations of Chla in the entire CRE (8.4 µg L⁻¹) were less than the critical value of 11.0 µg L⁻¹.
- Salinity conditions at Shell Point in the lower CRE were generally favorable for oyster habitat. Live densities were greater than 1000 oysters per m² at all sampling locations. Larval abundance measured as the number of spat per shell decreased throughout WY2012–WY2013. While a large percentage (80–90 percent) of the oysters sampled were positive for Dermo infection in WY2012–WY2013, overall infection intensity was comparatively low.
- The effects of drought and increasing salinities throughout WY2011–WY2012 accounted for the decline of freshwater SAV (tape grass and widgeon grass) in the upper CRE and increased prevalence of salt-tolerant SAV species in the lower CRE. However, increased freshwater inflow in the wet season of WY2013, particularly in September 2012, led to decreased percentages of shoal grass and turtle grass in the lower CRE.
ADAPTIVE PROTOCOL RESEARCH STUDY

Gradients of salinity, nutrient supply, and submarine light penetration regulate the composition and magnitude of biological production in estuaries (Buzzelli et al., 2013b). The conventional wisdom dictates that freshwater inflow brings the required materials and nutrients to stimulate phytoplankton in the upper estuary where and when there is adequate submarine light. Phytoplankton production can sink to the benthos, become part of aquatic food webs, or be available for downstream transport. Low discharge and long flushing times can result in an over-accumulation of phytoplankton-derived organic matter (phyto-detritus; Dettmann, 2001; Sheldon and Alber, 2006; Buzzelli, 2011). Because the phyto-detritus is highly labile and easily remineralized in the water column and sediments, overproduction can stimulate algal blooms (Philips et al., 2011). By contrast, rapid flushing pushes phytoplankton downstream too quickly to permit sinking or biological consumption (Doering et al., 2006; Lucas et al., 2009). Between these extremes exists an optimal range of inflows to promote phytoplankton production, zooplankton growth and consumption, and trophic transfer to larval and juvenile fishes (Kimmerer, 2002; Lucas et al., 2009). Thus, freshwater inflow has a great influence over the early life history and community composition of estuarine fish assemblages in the upper and lower reaches of the estuary (Whitfield, 1994; Livingston et al., 1997; Gillson, 2011).

There is little information on the effects of low level releases on either the salinity distribution or ecology of the CRE. Therefore, quantifying how to optimize releases for environmental benefits provided the impetus for the APRS. This study presented a unique opportunity to evaluate the potential effects of different short-term inflow strategies on water quality and plankton abundances during the dry season. This study was unique because it combined the operational capacity to regulate Lake Okeechobee inflow through S-79 with ecological responses along the CRE salinity gradient and rapid in situ data acquisition (e.g., flow-through system; Madden and Day, 1992; Lane et al., 2007; Buzzelli et al., in press).

Salinity distributions can vary on both synoptic (3–5 days) and seasonal (dry versus wet) scales. While most of this chapter assessed patterns at the seasonal and water year scales, the APRS focused on the synoptic timescale to assess potential effects of short-term pulses of Lake Okeechobee derived fresh water on water column ecological attributes along the length of the CRE. Nine individual intensive research cruises occurred from January to May 2013. The cruises coincided with controlled freshwater releases and utilized a combination of continuous flow-through technology and a series of vertical sampling stations. Cruises spanned the entire length of the CRE from S-79 to the San Carlos Bay, a distance of approximately 45 km (Figure 10-22). There were nine mid-channel stations along this distance for vertical profiling of the water column using a multi-probe water quality sampling device. These mid-channel stations were adjacent to shoreline sites where sampling for juvenile fishes occurred in the lateral shoals. Results of the 2013 APRS were assessed for overall longitudinal patterns of salinity, turbidity, and Chl a along with the structure and diversity of the juvenile fish populations in the shoal environments.
Figure 10-22. Adaptive Protocol Release Study Map showing transects spanned from S-79 to near the Sanibel Island Bridge. The distances (km) downstream of S-79 are shown in white circles. Mid-channel locations for vertical profiling are shown in yellow boxes.

Methods

Operations

During the WY2013 dry season (January–May 2013), pulse releases from Lake Okeechobee were made to the CRE under the Final Adaptive Protocols for Lake Okeechobee Operations (SFWMD, 2010). Average hourly inflows ranged from 0 to 2,000 cfs during this time except for increases up to 6,000 cfs on February 16, 2013, approximately 4,000 cfs on April 6, 2013, and greater than 3,400 cfs on May 2, 2013 (Figure 10-23). Pulses generally lasted 5 to 7 days with a rapid rise from 0 cfs to the maximum before falling back to minimum levels over a few days. Freshwater discharge to the CRE exhibited a periodic or oscillatory pattern throughout the APRS in 2013.
Figure 10-23. Daily freshwater inflow at S-79 from January 1–May 3, 2013. There were nine flow-through cruises during this time (cruise dates in red).

[Note: 2,000 cfs = 4.9 x 10^6 cubic meters per day.]

**Flow-through System**

The flow-through system offers a novel method of acquiring in situ surface water data while the research vessel is under way permitting researchers to rapidly sample vast areas of an estuary (Madden and Day, 1992; Lane et al., 2007; Buzzelli et al., in press). The system consists of an intake ram attached to the stern, a flow meter, a Trimble Global Position System (GPS), a YSI 6600 multi-probe instrument, a bathymetric profiler, and a laptop computer with Streamline GEO software (Figure 10-24). The YSI 6600 was set up to record temperature, salinity, pH, turbidity, DO, and in situ Chla. The intake ram was at 0.5 m below the water surface with an in-line pump to ensure water flow through the system. The GPS and YSI recorded data every 5 seconds. Streamline Geo software permitted integration of the GPS and surface water data into an ArcGIS shape file useful both to display surface water properties in real time and in the post-processing of spatial data. Approximately 7–8 hours were required to travel from S-79 to San Carlos Bay at an average speed of 15.2 km per hour resulting in an average distance of 15–26 m (0.015–0.026 km) between surface water recordings. Optical data (Chla, turbidity, dissolved oxygen) data from the middle and lower estuary was unusable on January 10, 2013, due to particle entrapment within the flow-through system. Temperature and salinity data from this day was unaffected. The cruise on April 4, 2013, was truncated due to severe weather.
Figure 10-24. (A) Schematic of flow-through system for in situ monitoring of surface water quality. A shipboard battery-pump system brings water through an aft-mounted intake to the boat deck where it passes across a flow meter and onto an YSI multi-probe unit. The entire system is connected to a Global Positioning System (GPS) and onboard lap top computer. (B) Pictures of the YSI multi-probe, battery, flow meter, GPS antenna, water delivery tubing, and the aft-mounted intake.
**Vertical Profiling**

On each of the nine cruises the research vessel stopped at up to nine mid-channel stations along the mid-estuary axis to conduct vertical profiling of temperature, salinity, pH, DO, turbidity, Chl a with the YSI 6600 multi-probe instrument (**Figure 10-22**). Recordings using the multi-probe instrument occurred at one meter intervals between the surface and bottom allowing for instrument stabilization between successive recordings. Thus, while one meter intervals were targeted, data were collected throughout the entire water column. Post-processing of the data revealed that this approach resulted in greater than 300 measurements at each station at a vertical spacing of approximately 0.15 m. There were data acquisition limitations on occasion. Only the most upstream stations CRE 1, 3, and 5 were sampled on January 10, 2013. This date was omitted from analyses of vertical water column structure. CRE 9 was missed on March 7, 2013, as were CRE 15 and 16 on April 4, 2013. Finally, vertical measurements occurred at 0.5-m intervals and not as a continuous series on May 2, 2013 due to problems with inclement weather.

**Fauna Sampling**

Nekton (water column fauna) was collected at each of the nine shoreline stations adjacent to the mid-channel stations (**Figure 10-22**). The selected locations represented the dominant shoreline type between S-79 and the Sanibel Bridge ranging among vegetated, shoal, or altered (i.e., sea wall or bulkhead) types. If dominant types differed on opposing shorelines of the CRE, a random number generator was used to select which shoreline (and thus shoreline type) was sampled. Collections were made using two replicate hauls of a 6.1-m, 3.2-millimeter (mm) mesh, center bag seine. The seine was deployed into the current and pulled parallel to shore, with the inner wing as close to the shoreline as possible, over a distance of 10 m while maintaining a 5-m separation of the wings. This approach resulted in a 50-m² area sampled twice at each station. After deployment, temperature, salinity, dissolved oxygen, and pH were measured with a YSI multi-probe instrument.

All macrofauna collected were placed into 5 gallon buckets, sorted, identified to the lowest practical taxonomic level, and counted. A maximum of 20 individuals of each fish species and select decapod crustaceans [blue crabs (Callinectes spp.) and pink shrimp (Farfantepanaeus duorarum)] were measured to the nearest mm. Size was recorded as standard length (SL) for most fish, disk width (DW) for rays, carapace length (CL) for shrimp, and carapace width (CW) for crabs. Due to hybridization or complicated identification, several species complexes were not mojarra (less than 40 mm SL), and Strongylura (needlefish, less than 100 mm SL).

**Data Analyses**

Descriptive statistics derived from the flow-through variables of temperature, salinity, turbidity, in situ Chla, and DO included the total sample size, data range, average ± standard deviation, and the location of the maximum value in kilometers downstream of S-79 for each of the nine cruise dates. Three variables of importance were salinity, turbidity, and Chla. In situ surface water observations for these three variables obtained using the flow-through system were averaged at 100-m intervals and analyzed by distance from S-79. The vertical salinity profiles among the nine mid-channel stations were interpolated in two-dimensions (distance and depth) using a kriging technique to examine variations in stratification and isohaline position among eight cruises (January 24, February 5 and 21, March 7 and 21, April 4 and 18, and May 2). Potential relationships between inflow and hydrologic and ecological attributes of the CRE were assessed through an integrative approach. Since the cruises occurred approximately every 14 days, the downstream locations where salinity was 10 (10 isohaline) and the maximum concentration of Chla on each date were plotted versus freshwater inflow at S-79 the previous 14 days. While this summary focused on WY2013, this analysis incorporated cruise data from WY2012 (January–April 2012) to increase the total sample size. This approach combined results
from all 16 cruise dates in early 2012 (n = 7) and early 2013 (n = 9) in order to quantify relationships between inflow and estuarine attributes.

Differences in fauna community structure were analyzed using non-parametric multivariate statistics. This allowed for the identification of differences in the assemblages among groups of samples and explanatory variables through construction of similarity matrices, application of group-averaged hierarchal cluster analysis and non-metric multidimensional scaling. This approach helped to identify station groupings, calculation of similarity percentages to identify species contributing most to the overall dissimilarity between defined groups, and correlating the observed pattern of species assemblages to environmental characteristics.

Spatial differences in assemblage structure were identified by constructing species by station matrices from fourth root transformed mean densities of the species at each of the nine stations within each seasonal period. Group-averaged hierarchal cluster analysis and multi-dimensional scaling were performed on the matrices to identify ecologically significant groupings. Species richness and the Shannon-Wiener diversity index ($H'$) were calculated for each station on each sample date. Species richness was calculated as the average number of species collected from the two replicate seine samples. The Shannon-Wiener diversity index was calculated as follows:

$$H' = - \sum_{i=1}^{R} p_i \ln p_i$$

**Results and Discussion**

Average salinity was greatest on January 24 and least on February 21 and March 7 (Table 10-11). Salinity decreased from January 24 to April 4 before increasing to 10.6 on April 18. While salinity was nearly constant from 2–10 km downstream of S-79 for each cruise, the average value in the upstream estuary decreased over time (Figure 10-25, panel A). Salinity increased nearly linearly between 10 and 40 km for each cruise date before rapidly increasing near the oceanic end. Fluctuations in salinity were more apparent on March 21 and April 18 (Figure 10-25, panel A). The upper estuary (less than 15 km downstream of S-79) was comparatively saltier on January 24 and February 5 compared to the later cruise dates (Figure 10-26, panels A-B). However, there was little vertical stratification in this part of the estuary on these first two dates compared to the others. Reduced inflow and increased salinity on the last two cruise dates (April 18 and May 2) in the upper CRE were evident in the interpolated profile data (Figure 10-26, panels G-H). Salinity patterns with values ranging 10–20 starting approximately 20 km downstream were consistent from February 21 to April 4 (Figure 10-26, panels C-F). Results combined from all cruises in 2012 and 2013 dry seasons revealed that the position of the 10 isohaline increased to a limit of approximately 32 km when average S-79 inflow the previous 14 days was maximized (Figure 10-27). The hyperbolic shape of this relationship suggests that dry season freshwater inflow does not serve to freshen the entire CRE as salty water is present in the lower estuary.
Table 10-11. Statistics for surface water temperature [T; in degrees Celsius (°C)], salinity, turbidity [in nephelometric turbidity units (NTU)], in situ Chla [in micrograms per liter (μg L⁻¹)], and dissolved oxygen [DO; in milligrams per liter (mg L⁻¹)] determined using flow-through sampling of the CRE from January to May 2013. Included are the total number of surface water recordings (N), the range in values, the average (Avg) and standard deviation (SD), and the location of the maximum value in kilometers (km) downstream of S-79 (Xₜ₉₇₉). [Note: * Cruise on April 4 was truncated due to severe weather.]

<table>
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<tr>
<th>Date</th>
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<th>Avg ± SD</th>
<th>Xₜ₉₇₉ (km)</th>
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Figure 10-25. CRE property versus distance downstream of S-79 (km) plots from eight flow-through cruises occurring from January to May 2013. (A) salinity; (B) in situ Chl a [micrograms per liter (µg L⁻¹)]; (C) turbidity [nephelometric turbidity units (NTU)].
Figure 10-26. Distance versus depth contour plots of salinity for each cruise date (A-H). Location of vertical profiling stations shown as black circles. See the Methods section for description of contour plots using the vertical profile data. Salinity ranged from 0–2 (light blue) to greater than or equal to 30 (red).
Figure 10-27. Plots of the downstream location (km) of the S=10 isohaline (top panel) and the Chla maximum concentration (bottom panel) in the surface water versus the average inflow from S-79 over the 14 day period prior to each flow-through cruise date. A total of 16 cruises were included (7 in 2012; 9 in 2013). 1 cfs = 0.029 m$^3$ per second.
Patterns of Chla and turbidity varied along the length of the CRE among eight of the cruises (Figure 10-25, panels B-C). Similar to salinity, Chla concentrations were reduced (10–20 µg L⁻¹) and consistent within the first 10,000 m of S-79. There was much more variability in Chla between 10 and 25 km among the cruise dates. Values ranged from 10 to 50 µg L⁻¹ within each cruise in this region of the CRE but declined to less than 10 µg L⁻¹ further downstream (greater than 30 km downstream of S-79). The greatest range of Chla concentration was observed on February 5 and April 4, 2013 (Table 10-11). The maximum concentration was located the furthest downstream at 20.9 km on April 4 and May 2. Although the total freshwater inflow was greatest the two weeks prior to the February 21 cruise date, the Chla maximum concentration was 18.1 km downstream (Table 10-11 and Figure 10-27). The hyperbolic shape of the relationship between 2 week total inflow and the location of the Chla maximum was similar to that for the salinity 10 isohaline. However, the position of the Chla maximum was less predictable than the conservative property of salinity isohalines. As with Chla, turbidity values exhibited the greatest range and variability from 10 to 25 km downstream of S-79 (Figure 10-25, panel C). Turbidity was greatest in this region of the CRE for all of the cruise dates except for April 18 when the maximum value was located at 43.1 km (Table 10-11). Surface water turbidity was the most variable on March 7 and 21, and April 4 when values ranged from 3.0 to 13.2.

The nekton assemblage changed seasonally over the period sampled with early (January 10–April 4) and late (April 18–May 2) dry season assemblages apparent at a similarity level of 55 percent (Figure 10-28, panel A; stress = 0.12). Average daily inflows of 650 versus 1,000 cfs did not appear to differentiate results among the cruise dates (p = 0.278). However, the March 7 sampling event was somewhat distant from the other members of the early dry season group in multidimensional scaling analysis, potentially indicating a secondary difference. This sampling occurred after 3 weeks of 1,000 cfs releases and was the only event that contained exotic, invasive fishes [cichlids (Cichlasoma urenphlthalmus); Hemichromis letourneuxi]. Additionally, freshwater species such as saillfin molly (Poecilia latipinna) and the coastal shiner (Notropis petersoni) were present only during this event, while densities of grass shrimp (Palaeomonetes pugio) and mosquitofish (Gambusia holbrook) increased by an order of magnitude at upstream stations.

There were spatial differences in species assemblages within both the early and late dry seasons. The early and late dry season assemblages were distinguished from one another by a lack of winter recruiting species like blue crab combined with an influx of spring recruits of pinfish (Lagodon rhomboids) and pig fish (Orthopristis chrysoptera) later in the dry season (Figure 10-28, panels B-C). Correlation analyses between patterns of biotic and abiotic similarity among sample dates indicated that fish assemblages changed with temperature, salinity, and DO, but not with freshwater inflow (data not shown).

During the early dry season, upstream stations 1 through 9 grouped together, mid-estuary stations 11 through 13 comprised a second group, and the two downstream stations (15 and 16) represented a third group at the 20 percent similarity level (Figure 10-28, panel B; stress = 0.19). The differences between groups of stations reflected a transition of dominate nekton from silversides and mosquitofish at upstream stations to higher salinity estuarine residents (e.g., mojarra) in the mid-estuary to numerous marine transient species near the mouth of the CRE. During the late dry season, the upstream stations (1 through 7) and the downstream stations (15 and 16) were independent groups using a 20 percent similarity level (Figure 10-28, panel C; stress = 0.06). Stations 9 and 13 were somewhat different than all others, while no species were collected at station 11 during the late dry season. The differences among groups again reflected a transition from silversides upstream to marine transients including pinfish and pigfish downstream.
**Figure 10-28.** Multidimensional scaling ordination plots derived from sampling of nekton in lateral shoal habitats on nine flow-through cruise dates from January to May 2013. (A) Mean species density by sample date. (B) Mean species density by station within the identified early dry season. (C) Mean species density by station within the identified late dry season.
Species richness and species diversity (H‘) varied somewhat spatially but showed no significant pattern of seasonality (Figure 10-28, panel A; Kruskal-Wallis One-way Analysis of Variance; p = 0.364 and p = 0.582). Across all dates, species richness was significantly higher at station 1 and 3 than at stations 11 and 13 (Kruskal-Wallis one-way analysis of variance; p < 0.001), while richness was lower at station 13 than at station 15 [Kruskal-Wallis one-way analysis of variance (ANOVA); p < 0.001]. Generally, there was a species richness minimum at station 13 as compared to all other stations across all dates. Species diversity followed a similar trend with significantly higher diversity at station 1 than at station 13 (Figure 10-29, panel B; Kruskal-Wallis one-way ANOVA; p < 0.001). However, species diversity was also significantly higher at station 7 than at station 13 (Kruskal-Wallis one-way ANOVA; p < 0.001).

**Figure 10-29.** Average species richness (A) and species diversity (H‘; B) of nekton assemblages at each sampling location for each flow-through cruise date. [See Figure 10-22 for downstream locations of stations.]
Significant Findings

- The APRS presented a unique opportunity to evaluate the effects of short-term inflow strategies on water quality and plankton abundances during the dry season. This study focused on the synoptic timescale to assess effects of short-term pulses of Lake Okeechobee derived fresh water on water column ecological attributes along the length of the CRE.

- Salinity was nearly constant from 0.2–10 km downstream of S-79 with the average value in the upstream estuary decreasing from January to May. In general, salinities ranging from 10 to 20 were located approximately 20 km downstream although the position of the 10 isohaline migrated downstream with freshwater inflow.

- Chla concentrations were comparatively low (10–20 µg L\(^{-1}\)) and consistent over the first 10 km but were greater and more variable from 10 to 25 km among the cruise dates. The relationship between 14 day average inflow and the location of the Chla maximum was hyperbolic as maximum values reached 20 km downstream when inflow was greatest.

- The nekton community split into early (January 10–April 4) and late (April 18–May 2) dry season assemblages. The late season assemblage was distinguished by a lack of winter recruiting species combined with an influx of spring recruits. The March 7, 2013 sampling date occurred after increased freshwater releases, which introduced freshwater taxa including several exotic species.

- Nekton species composition was influenced by temperature, salinity, and DO, but not necessarily freshwater inflow.

- The spatial differences in nekton assemblages varied from silversides and mosquitofish at upstream stations to higher salinity estuarine residents in the mid-estuary to numerous marine transient species near the mouth of the CRE.

- While this assessment of juvenile fishes in lateral shoal environments was useful, future efforts will focus on larval planktonic forms that are likely to be more dependent on food web resources along the mid-channel of the CRE.

LITERATURE CITED


SFWMD, FDEP and FDACS. 2012a Appendix 10-1: St. Lucie River Watershed Protection Plan 2012 Update. 2012 South Florida Environmental Report – Volume 1, South Florida Water Management District, West Palm Beach, FL; Florida Department of Environmental Protection, Tallahassee, FL; and Florida Department of Agriculture and Consumer Services, Tallahassee, FL. Available online at www.sfwmd.gov/SFER.

SFWMD, FDEP and FDACS. 2012b. Appendix 10-2: Caloosahatchee River Watershed Protection Plan 2012 Update. 2012 South Florida Environmental Report – Volume 1, South Florida Water Management District, West Palm Beach, FL; Florida Department of Environmental Protection, Tallahassee, FL; and Florida Department of Agriculture and Consumer Services, Tallahassee, FL. Available online at www.sfwmd.gov/SFER.


