Chapter 8C: St. Lucie and Caloosahatchee River Watershed Research and Water Quality Monitoring Results and Activities

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SUMMARY

The Northern Everglades and Estuaries Protection Program (NEEPP; Section 373.4595, Florida Statutes [F.S.]) requires the establishment of a River Watershed Research and Water Quality Monitoring Program (RWQMP), as a major component of river watershed protection plans (RWPPs), for both the St. Lucie River and Caloosahatchee River watersheds. The original RWPPs were completed and submitted to the Florida legislature in March 2009 with significant stakeholder input (SFWMD et al. 2009a, 2009b). Prior to 2016, NEEPP required annual progress reports and three-year evaluations of the RWPPs. In addition to annual NEEPP reporting, three-year updates were previously completed in March 2012 (Bertolotti and Balci 2012, Balci and Bertolotti 2012) and March 2015 (Buzzelli et al. 2015), while the last annual progress report was published in March 2016 (Zheng et al. 2016). During the 2016 legislative session, the Florida legislature amended NEEPP to strengthen provisions for implementing the basin management action plans (BMAPs) for the respective Northern Everglades basins and to further clarify the roles and responsibilities, coordination, implementation, and reporting efforts among the three coordinating agencies.

This chapter of the *2017 South Florida Environmental Report (SFER) – Volume I* fulfills the Water Year 2016 (WY2016) (May 1, 2015–April 30, 2016) annual reporting requirements of NEEPP focusing on the latest scientific results from the research and water quality monitoring program (Note: See footnote below for units of measurement reporting in this chapter[2]). Specifically, this chapter, in conjunction with

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[2] For monitoring data, the categorical variable season is defined according to dry (November–April) and wet (May–October) groupings for calculations. The units of measurement in this chapter are reported dually in both United States Customary and International System of Units (SI) units, including acres (ac)/hectares (ha) for area, feet (ft)/meters (m) for depth, and inches /centimeters (cm) for rainfall. Short-term freshwater inflows are in units of cubic feet per second (cfs), annual inflows are in units of acre-feet per year (ac-ft/yr), and annual loads are shown as metric tons per year (mt/yr). Salinity is derived from a dimensionless ratio and therefore has no units in reporting (Millero 2010). Similar to previous RWPP updates, data are reported consistently for each estuary over the past three water years (WY2014–WY2016) to show recent intra- and interannual patterns; longer-term reporting (multiannual period-of-record timescales) is also included based upon data availability for the given variable. Values are summed (rates of rainfall, inflow, and loadings) or averaged (concentrations of salinity, total nitrogen [TN], total phosphorus [TP], chlorophyll *a* [Chla], submerged aquatic vegetation [SAV], and oysters) by water year and season in order to compare and contrast among the various timescales. TN and TP concentrations are both reported in milligrams per liter (mg/L), and Chla is shown in micrograms per liter (µg/L). Note that

Chapter 8A (NEEPP Annual Progress Report) and Chapter 8B (Lake Okeechobee Watershed Research and Water Quality Monitoring Results and Activities), fulfills the specific reporting requirements outlined in NEEPP for the annual progress report. To better address the conditions of hydrology, water quality, and ecology in WY2016, data summaries for the river estuaries are provided in this chapter for WY2016 along with comparisons to the two previous water years (WY2014 and WY2015) as well as the long-term periods of record (POR), respectively. To supplement data summarized in this chapter, WY2016 data for total phosphorus (TP) and total nitrogen (TN) average concentrations for the East and West Caloosahatchee basins of the Caloosahatchee River Watershed, and the C-23, C-24, and C-44 basins of the St. Lucie River Watershed are also presented in Appendix 8C-1 of this volume.

ST. LUCIE ESTUARY

During WY2016, El Niño conditions caused significantly higher than normal rainfall during the dry season in the St. Lucie Watershed (SFWMD 2016). This resulted in unusual patterns of hydrology, water quality, and ecology in St. Lucie Estuary (SLE) since rainfall is one of the most important external drivers of the physics, chemistry, and ecology to the estuary.

In WY2016, total rainfall to the St. Lucie River Watershed was 54.17 inches (137.6 centimeters [cm]), with 54.5 percent (29.5 inches or 74.9 cm) falling in the wet season and 45.5 percent (24.67 inches or 62.7 cm) in the dry season. Dry season rainfall was much higher than recent dry seasons in WY2014 (15.8 inches or 40.1 cm), and WY2015 (14.41 inches 36.6 cm), and the long-term average (WY1997–WY2016; 12.78 inches or 32.5 cm). This year's wetter than normal dry season resulted from El Niño conditions. Annual rainfall in WY2016 was comparable to WY2014 (53.43 inches or 135.7 cm), while slightly higher than WY2015 (49.85 inches 126.6 cm) and the long-term average (47.97 inches or 121.8 cm). Spatially, the greatest rainfall in WY2016 occurred in the Ten Mile Creek Subbasin (58.38 inches or 148.3 cm) and the least in the C-23 Basin (51.89 inches or 131.8 cm).

The total inflow to the SLE was 1.219 million acre-feet (ac-ft) in WY2016, which was slightly lower than WY2014 (1.305 million ac-ft) and significantly greater than both WY2015 (0.751 million ac-ft) and the long-term average (0.988 million ac-ft). A majority of the total inflow (~69 percent) occurred in the dry season contrasting with the normal pattern observed during WY2014 and WY2015 in which most of the inflow occurred in the wet season. The St. Lucie River Watershed dominated inflow, contributing 69.6 percent of the total estuary inflow. Lake Okeechobee contributed 30.4 percent inflow (0.370 million ac-ft), of which 91 percent atypically occurred in the dry season.

Salinity is inversely related to freshwater inflow in the estuary. The seven-day moving average water column salinity at the US1 Bridge was within the salinity envelope of 10 to 26 (reflecting a good salinity range for adult oyster growth) for 58.3 percent of the time (measured days) in WY2016. This was lower than the previous two water years (63.8 percent for WY2014 and 76.7 percent for WY2015) and the long-term average (63.9 percent).

In WY2016, TN and TP loadings to the SLE were 1990.7 metric tons (mt) and 333.2 mt, respectively. The St. Lucie River Watershed contributed 64.0 percent of the TN load and 74.9 percent of TP load while Lake Okeechobee contributed 36.0 percent of the TN load and 25.1 percent of the TP load. The TN and TP loadings during WY2016 were, in general, slightly lower than those in WY2014, but significantly higher than WY2015 and slightly higher than the long-term average. Around 72 percent of TN and 68 percent of TP loads to SLE were delivered in the dry season. Nearly all the TN (93 percent) and TP (94 percent) loads from Lake Okeechobee were also delivered during the dry season.

all Chla concentration data reported represent corrected Chla values. SAV communities are shown biomass index (no units), while oyster densities are reported as number of individuals per square meter (m^2) and oyster larval recruitment is average spat per shell per month (spat/shell/month). Also, refer to the Conversion of Units of Measurement document provided with the 2017 SFER.

Chla concentrations repeated the same seasonal patterns observed in previous years and over the long-term; it was higher in the wet and lower in dry season. Spatially, both wet season and annual average Chla concentrations decreased as proximity to the ocean increased. However, during the dry season in WY2016, Chla concentration in the lower estuary close to the St. Lucie Inlet (at SE11) was greater than that in the Middle Estuary (at SE03).

WY2016 TN and TP concentrations decreased from upstream to downstream—North Fork (HR1) > Middle Estuary (SE03) > Lower Estuary closer to the ocean at the St. Lucie Inlet (SE11)—showing a typical spatial pattern, except for TN concentrations in the dry season in which Middle Estuary levels at SE03 were higher than in the North Fork at HR1 likely due to regulatory releases from Lake Okeechobee.

The seagrass biomass index fluctuated with salinity at Willoughby Creek within the lower SLE during the POR from WY2008 to WY2016. Seagrass species at this site are adapted to variable salinities and typically recovered faster from freshwater impacts than manatee grass (*Syringodium filiforme*) at Boy Scout Island. The near elimination of manatee grass had resulted in an extremely low seagrass biomass index at Boy Scout Island. Low and variable salinities due to high freshwater inflows as well as physical forces from storms were likely causes of the decline.

The live oyster density counts during the WY2007–WY2016 POR ranged from 8.8 (October 2008) to 1123 oysters per square meter (oysters/m^2) (September 2016). Notably, the highest spat count (4.5 spat/shell/month) was observed in May 2015 over the past 10 water years. Larval (spat) supply continued to support natural recovery of oyster population within the SLE even with extremely low salinities at times.

CALOOSAHATCHEE RIVER ESTUARY

Similar to the St. Lucie River Watershed, in WY2016 the seasonal pattern of rainfall observed over the Caloosahatchee River Watershed was unique, with remarkably high rainfall in the dry season causing unusual patterns in hydrology, water quality, and ecology compared with other recent water years.

In WY2016, the total rainfall to the Caloosahatchee River Watershed was 60.19 inches (152.9 cm), which was 22 percent higher than the long-term average (WY1997–WY2016; 49.41 inches or 125.5 cm), 29 percent higher than WY2015 (46.67 inches or 118.5 cm), and slightly higher (3 percent) than WY2014 (58.35 inches or 148.2 cm). The rainfall in the dry season of WY2016 was 21.13 inches (53.7 cm, 35.1 percent of annual rainfall), which was noticeably higher than the long-term average dry season rainfall (11.36 inches or 28.9 cm) and that occurring during the dry seasons of WY2014 (11.34 inches or 28.8 cm) and WY2015 (12.07 inches or 30.7 cm).

During WY2016, a total inflow of 2.377 million ac-ft was discharged into the Caloosahatchee River Estuary (CRE), with 35.7 percent from Lake Okeechobee, 40.3 percent from the C-43 Basin, and 24.0 percent from the Tidal Basin. The inflow from the lake was 0.850 million ac-ft in WY2016, notably less than in WY2014 (1.146 million ac-ft) but significantly greater than both in WY2015 (0.487 million ac-ft) and the long-term average (0.576 million ac-ft). The majority of inflow from Lake Okeechobee (87.3 percent) was released in the dry season, contrasting with the more typical patterns (wet season > dry season) observed in WY2014 and WY2015.

Similar to the SLE, salinity typically displays an inverse relationship to freshwater inflow in the CRE. Salinities at the Ft. Myers station were favorable for the estuary, as both the daily average salinity goal (< 20) and the 30-day average goal (< 10) were not exceeded this current water year.

Chla concentrations in the middle estuary at site CES06 were higher than both the upper estuary site CES04 and lower estuary site CES08 during the wet seasons of WY2016 and WY2014 and during the dry season of WY2016. Significant amounts of flow were released through the S-79 structure in those three seasons. This was evidence that increased flow at S-79 pushes the location of the maximum Chla concentration downstream.

The variation of TN and TP loading was driven by fluctuations in freshwater inflow. In WY2016, the TN load to the CRE was 3566.5 mt and the TP load was 301.7 mt, both less than WY2014 (TN, 5087.4 mt and TP, 418.5 mt) and greater than in WY2015 (TN, 2078.9 mt and TP, 215.5 mt) and the long-term average (TN, 2939.4 mt and TP, 279.0 mt). Lake Okeechobee contributed most of this annual TN load (44.6 percent) while the C-43 Basin contributed most of this annual TP load (46.4 percent). More than half of the total nutrient loading in WY2016, 60.6 percent of TN and 52.9 percent of TP, unusually occurred in the dry season. Nutrient loads from Lake Okeechobee followed the same seasonal pattern, with 67.7 percent of TN and 59.2 percent of TP delivered in the dry season.

In general, higher TN and TP concentrations occur in the upper estuary (CES04), with progressively lower concentrations downstream at CES06 (middle estuary) and CES08 (nearest the ocean). This spatial variation pattern was repeated in WY2016. Nutrient concentrations were generally greater in the wet than the dry season. TP concentrations exhibited this seasonal pattern at all three stations in WY2016. TN showed this pattern only at CES08, whereas TN concentrations observed at CES04 and CES06 during the dry season were higher than in the wet season.

The biomass of seagrasses showed a seasonal fluctuation with higher values in the wet season and lower values in the dry season in WY2016. The biomass index at site 2 (tape grass, *Vallisneria americana*) appeared inversely related to salinity whereas, at sites 4 (widgeon grass, *Ruppia maritima*), 5 (shoal grass, *Halodule wrightii*), and 7 (turtle grass, *Thalassia testudinum*, and shoal grass), the biomass index was relatively proportional to salinity level.

Oyster densities continued to remain high at the Bird Island site and rebound at Iona Cove from no oysters counted in WY2014 to 1,934 counted in WY2016. Overall, the larval settlement rate continued to be greater in the wet season.

INTRODUCTION

The St. Lucie and Caloosahatchee River watersheds and estuaries are located on the southern peninsula of Florida. Together with the Lake Okeechobee Watershed, they comprise a major overall region known as the Northern Everglades (**Figure 8C-1**). The St. Lucie River Watershed lies to the east of Lake Okeechobee and the Caloosahatchee River Watershed to the west. Overall, the Northern Everglades is a highly modified system as it is part of the larger overall Central and South Florida Flood Control Project (USACE and SFWMD 1999). Importantly, the western part of the St. Lucie River Watershed (C-44/S-153) and the eastern portion of the Caloosahatchee River Watershed (C-43 East) have the ability to drain either into Lake Okeechobee or into their respective estuaries.

In 2007, NEEPP was authorized under Section 373.4595, F.S., in response to legislative findings that the Lake Okeechobee, Caloosahatchee River, and St. Lucie River watersheds are critical water resources that have been and continue to be adversely affected from changes to hydrology and water quality. The NEEPP legislation specifically called for the development of the three northern watershed protection plans: Lake Okeechobee, St. Lucie River, and Caloosahatchee River. In 2009, the St. Lucie River Watershed Protection Plan (SLRWPP; SFWMD et al. 2009b) and the Caloosahatchee River Watershed Protection Plan (CRWPP; SFWMD et al. 2009a) were developed by the South Florida Water Management District (SFWMD or District), Florida Department of Environmental Protection (FDEP), and Florida Department of Agriculture and Consumer Services, collectively known as the coordinating agencies, with extensive stakeholder input. These plans aim to minimize the undesirable flows and improve the quality of water delivered to the St. Lucie and Caloosahatchee river estuaries through implementation of the respective River Watershed Construction Projects and RWQMPs (Paragraphs 373.4595(4)(a) and (c), F.S. respectively). Key to these projects and programs are the FDEP BMAPs, which are the blueprint to meet FDEP's total maximum daily loads (TMDLs) and are the overarching water quality restoration plans for the Northern Everglades.

In addition to annual NEEPP reporting, three-year updates were previously submitted in 2012 and 2015 for both estuaries as part of the annual SFER – Volume I (Bertolotti and Balci 2012, Balci and Bertolotti 2012, Buzzelli et al. 2015) in accordance with NEEPP requirements at that time. The previous (WY2015) RWQMP annual progress report is provided in the 2016 SFER – Volume I, Chapter 10 (Zheng et al. 2016). In accordance with NEEPP (which was amended in 2016), this chapter fulfills the RWQMP annual progress report for the WY2016 reporting period. In conjunction with Chapter 8A (NEEPP Annual Progress Report) and Chapter 8B (Lake Okeechobee Watershed Research and Water Quality Monitoring Results and Activities), this chapter fulfills the specific reporting requirements outlined in NEEPP for the annual progress report.

This report starts with a description of the estuaries and the river watersheds to set the stage for the rest of the chapter. This is followed by a summary of the conditions of the hydrology (rainfall and flow), water quality (salinity, phosphorus, and nitrogen), and aquatic habitat (oysters and submerged aquatic vegetation [SAV]) based on results of the RWQMPs. Following the summary for each estuary, significant findings during the WY2016 reporting period are highlighted. In addition, the St. Lucie and Caloosahatchee River watershed water quality monitoring results for TP and TN by basin are presented in Appendix 8C-1 of this volume as supplemental information.

ESTUARINE HABITATS AS INDICATORS OF INFLOW

Freshwater inflow and nutrient loading from the upstream watershed are the major external drivers of abiotic and biotic conditions in an estuary (Alber 2002). Knowledge of the causative mechanisms underlying the relationships between inflow patterns and estuarine condition plays a crucial scientific role in establishing freshwater inflow standards for better decision making and management of estuarine resources (Alber 2002, Doering et al. 2002, Wolanski et al. 2004, Adams et al. 2009, Volety et al. 2009). This concept is being applied particularly to water management in coastal Texas, Australia, South Africa, and South Florida.

Estuarine habitats, such as seagrass meadows or oyster reefs are widely used as indicators to evaluate effects of freshwater inflows (Alber 2002, Flannery et al. 2002, Mattson 2002, Montagna et al. 2002). To evaluate the ecological conditions of the SLE and CRE, SAV and oysters are routinely monitored. SAV is 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). 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, Duarte et al. 2007, Lee et al. 2007). While all these variables are important and interrelated, 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 provides a good indicator of the 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).

Oyster beds also are a good indicator of estuarine condition because 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. 2012).

To protect valuable resources, critical salinity criteria have been established at Ft. Myers as part of the Caloosahatchee River Minimum Flows and Levels (MFL) Rule (SFWMD 2000, 2003). Additional salinity data collected at the I-75 Bridge supports implementation of the current Lake Okeechobee regulation schedule, LORS2008 (SFWMD 2010). The Ft. Myers location has two salinity criteria: (1) maintaining daily salinity averages of less than 20, and (2) 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 to 2,800 cubic

feet per second (cfs) at the S-79 structure are conducive to tape grass and favorable for seagrass and oyster habitats in the polyhaline CRE (Chamberlain and Doering 1998, Doering et al. 2002, SFWMD 2003, Volety et al. 2009).

In contrast to the CRE, the SLE has different inflow and salinity targets given the differences in estuarine geomorphology, volume, flushing, and inflow characteristics (Buzzelli et al. 2013b). Oyster habitat provides the biotic indicator of salinity and freshwater discharge in the SLE (USACE and SFWMD 2004, Buzzelli et al. 2012, 2013c). To maintain a good salinity range for adult oyster growth and reproduction in the SLE, a salinity envelope of 10 to 26 was established based on 7-day moving average of water column salinity observed at the US1 Bridge. This salinity envelope was initially established in the *Central and Southern Florida Project Indian River Lagoon – South Final Integrated Project Implementation Report and Environmental Impact Statement* (USACE and SFWMD 2004) and then revised by Alleman (2012). Systematic analyses of inflows determined that discharge ranging from approximately 350 to 2,000 cfs can help to maintain a salinity range favorable for oysters in the SLE (USACE and SFWMD 2004, Wilson et al. 2005).

ST. LUCIE RIVER ESTUARY AND WATERSHED CONDITIONS

BACKGROUND

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; see Figure 8A-1 in Chapter 8A of this volume). 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 the 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 an amplitude of 1.25 feet (ft; 0.38 meters [m]). The SLE is geographically divided into four distinct segments: North Fork, South Fork, Middle Estuary, and Lower Estuary, which is near the St. Lucie Inlet. Total surface area of the estuary is 29 square kilometers (km^2; 2,900 hectares [ha]) with an average depth of 7.87 ft (2.4 m) (Buzzelli et al. 2013a). 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 subbasins, which make up the eight basins 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, Bertolotti and Balci 2012). 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).

Figure 8C-1 shows the nine basins comprising the St. Lucie River Watershed. Of those basins, eight drain directly into the St. Lucie River or Estuary (C-24, C-23, C-44/S-153, Ten Mile Creek, North Fork, Basin 4/5/6, and South Fork basins, and a portion of the South Coastal Basin; see SFWMD et al. 2009a for further descriptions). The Basin 1 and C-25 basins mostly drain to the SIRL and therefore are not the focus of the RWPP analysis. Occasional inter-basin transfer between the C-25 and C-24 basins occurs at the SFWMD structure G-81, mostly from C-25 to C-24, which is captured in the C-24 flows and loads.

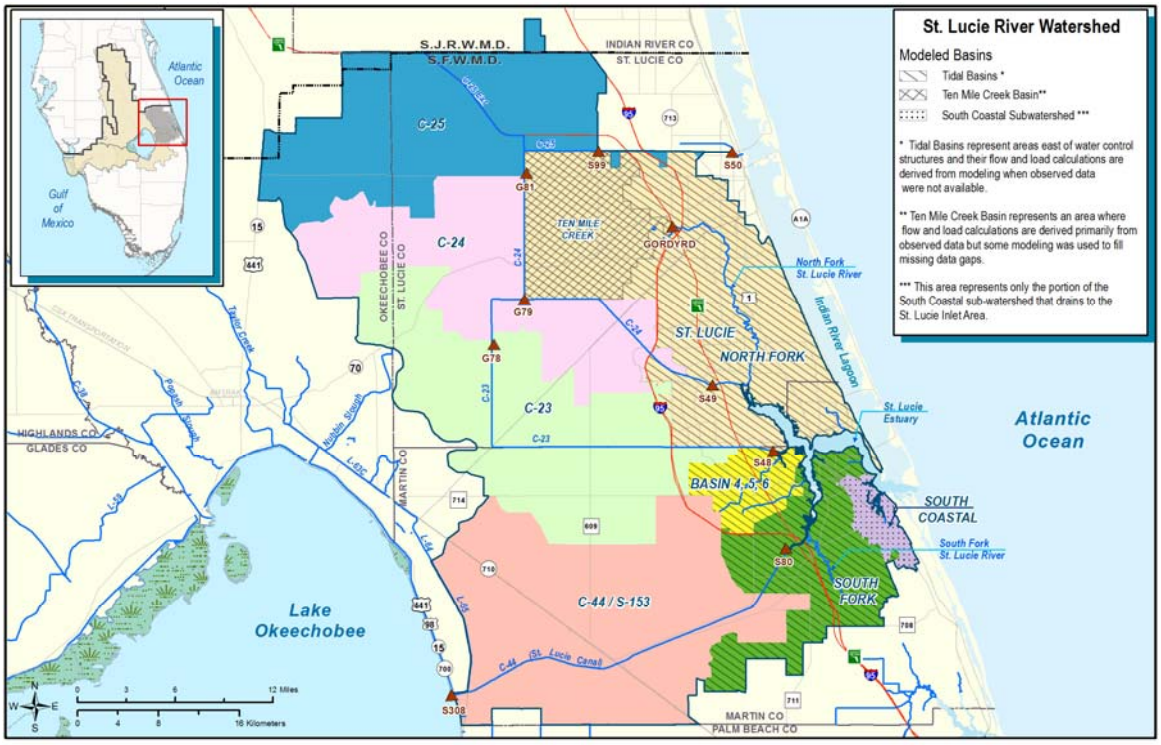

Figure 8C-1. The St. Lucie Watershed with its subwatersheds and major water control structures. Modeled basins areas are also depicted.

To the southeast of G-81 (**Figure 8C-1**), the Gordy Road structure is the division between the Ten Mile Creek Basin and the tidal North Fork of the SLE. Further south, the SFWMD structure S-49 separates the freshwater C-24 Basin from tidal waters, and the S-48 structure is the dividing line for the freshwater C-23 Basin. Finally, the United States Army Corps of Engineers (USACE) structure S-80 represents the confluence of the freshwater C-44/S-153 Basin and estuarine waters. In addition, waters discharged from Lake Okeechobee also may pass through S-80. Cumulatively, the Tidal Basin of the St. Lucie Watershed (**Figure 8C-1**) located to the east of all these structures (including Basin 4, 5, and 6) represents approximately 30 percent of the SLE's watershed.

Runoff from the coastal watershed and outflows from Lake Okeechobee have a profound influence on estuarine physics, water quality, and biotic resources in SLE (Buzzelli et al. 2012, 2013b, 2013c, 2013d, 2014). When summarizing environmental conditions in the 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 to 5 years) and decadal patterns. Therefore, the wet-dry subtropical seasonality typical of South Florida estuaries should be contrasted annually to both longer-term (> 10 years) and shorter-term (1 to 3 years) patterns.

HYDROLOGY, WATER QUALITY, AND AQUATIC HABITAT

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 loads as external drivers, and patterns of salinity, estuarine nutrient concentrations, oyster habitat status, and SAV community composition as the estuarine ecological responses. Salinity gradients are a conservative property of the water body and therefore are useful to connect the sources of freshwater inflow, circulation, and biological indicators (Wilber 1992, Jassby et al. 1995, Hagy and Murrell 2007, Pollack et al. 2011).

Daily Next Generation Radar (NEXRAD) rainfall data from WY1997 to WY2016 for each subbasin of the St. Lucie River Watershed were downloaded from the District's corporate environmental database, DBHYDRO, on the District's website at http://my.sfwmd.gov/nexrad2/. The amount of rainfall across the watershed was computed using an area-weighted method.

Table 8C-1 describes the major contributing areas (Tiers 1 and 2) of the St. Lucie River Watershed and the methodology associated with the reported flows and loads. Freshwater discharge is monitored in the St. Lucie River Watershed at the major structures: S-80 (C-44/S-153 Basin), S-48 (C-23 Basin), S-49 (C-24 Basin), and Gordy Road Structure (GRS; Ten Mile Creek Basin) (**Figure 8C-1**). The drainage area downstream of these major structures comprises the SLE Tidal Basin, which includes several subbasins: North Fork, South Fork, Basin 4/5/6, and South Coastal. The Tidal Basin flow was simulated using the SLE Tidal Basin Lin-Res Model calibrated to the SLE Watershed Hydrology Model (WaSH Model) and data collected in the nearby basins. Measured flow at GRS from WY1997 through WY1999 was identified as incomplete and simulated flows were used. Total daily inflows during WY1997–WY2016 from all these basins and Lake Okeechobee (through the C-44 canal via S-308 and S-80) were summed and used to quantify total inflow to the SLE each water year, evaluate intra- and interannual variations in inflow, and estimate the contributions of each source to total inflow. Total daily discharges were categorized by water year and season. The concentrations of TN and TP are monitored at S-80, S48, S-49, S-308, and GRS. Concentrations from WY1997 through WY1999 at GRS were simulated for use in TN and TP loading estimates. The daily loads of TN and TP were calculated as the product of the total daily flow and the estimated daily nutrient concentration. For phosphorous, the daily concentrations are estimated based on the auto-sampler results first or, if these are missing, they are based on grab samples taken on the days with freshwater inflow. Nitrogen values tend to vary over time even in an enclosed container; therefore, the daily nitrogen concentrations are estimated only based on grab samples on the days with flow. Nutrient concentrations of the days between sampling events are estimated through linear interpolation. While TP concentrations are directly measured during sampling events, TN is calculated as the sum of the measured concentrations of total Kjeldahl nitrogen and nitrite + nitrate.

Table 8C-1. Major contributing areas of the St. Lucie River Watershed.

Tier 1 Contributing Areas	Tier 2 Contributing Areas	Flows and Loads
Tidal Basin	North Fork	Modeled
	Basin 4,5,6	Modeled
	South Fork	Modeled
St. Lucie Basin	C-44/S-153	Measured
	C-23	Measured
	C-24	Measured
	Ten Mile Creek	Measured and Modeled
Lake Okeechobee	S-80 and S-308	Calculated

The relative contributions of Lake Okeechobee and the St. Lucie Basin (comprised of gauged basins including C-44, C-23, C-24, and Ten Mile Creek) to freshwater inflows and nutrient loads to the SLE were calculated using the measured outflow and nutrient concentrations at S-308 (from Lake Okeechobee), S-80 (C-44/S-153), S48 (C-23), S-49 (C-24), and GRS. The Tidal Basin TN and TP loads downstream of the water management structures were calculated using simulated flow data along with observed concentrations of TN and TP, when available. Simulated TN and TP concentrations were used when measured data were not available. The monthly masses of TN and TP were summed for each water year as annual loads and divided by the total annual inflow volume to derive a flow-weighted mean (FWM) concentration. Because the determination of FWM concentrations was derived using point-source measurements of concentration and flow over finite time intervals at the structures, this calculation was not extended to the modeled estimates of concentration and inflow across the entire Tidal Basin.

Surface and bottom salinity observations were recorded every 30 minutes at three stations in the SLE: HR1, US1 at the Roosevelt Bridge, and the A1A Bridge that crosses the SLE (**Figure 8C-2**). Data reporting and analyses focused on WY2016 at US1 and comparison with previous two water years and long-term average were made. Daily surface and bottom salinity recordings were averaged to produce a time series over the long-term POR (WY1999–WY2016). The percentages of days for different salinity criteria were calculated over the POR as well as WY2014, WY2015, and WY2016. The time series for average daily salinities at US1 were superimposed with the oyster habitat attributes. The daily minimum salinity at each SAV monitoring site predicted from the A1A Bridge or on-site sondes were superimposed with SAV community composition.

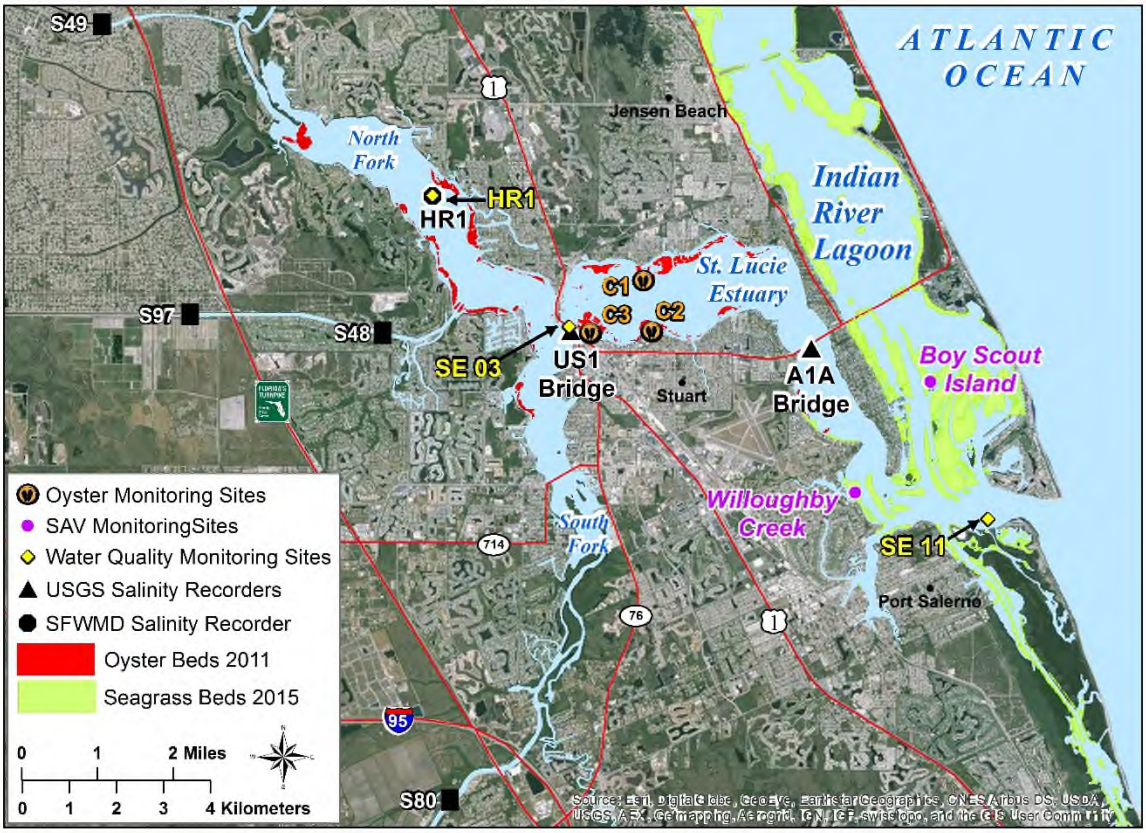

Figure 8C-2. Monitoring locations of salinity, water quality, and living aquatic habitat (oysters and SAV) for the SLE. Map also depicts distribution of SAV habitat in the St. Lucie Inlet and SIRL.

Water was sampled at mid-depth at 12 stations in the SLE at approximately monthly intervals. To evaluate water quality, three representative stations were chosen in the North Fork (HR1), the Middle Estuary (SE03), and near the St. Lucie Inlet (SE11) (**Figure 8C-2**). Concentrations of TN, TP, and Chla[3] during WY1997–WY2016 from each of the stations were included in the analyses.

Seagrass was monitored at Willoughby Creek in the SLE and Boy Scout Island in the SIRL (**Figure 8C-2**). The Willoughby Creek and Boy Scout Island study sites are each about 2 acres in size. Within each site, 30 randomly distributed points are generated for each monitoring event. Each point is navigated to using submeter accuracy global positioning system (GPS) and is monitored using a 1 meter square (m^2) quadrat subdivided into 25 equal quadrants. Presence/absence of seagrass within each quadrant of each quadrat is determined. Additionally, canopy height (cm) for the dominant species is determined per quadrat. Using these measures, a seagrass biomass index (BI, range: 0 to 10) is calculated for each site for each monitoring event (the index is calculated for each quadrat and averaged for the site per date, sample size [n] = 30) as follows:

$$BI_{seagrass} = \left[\frac{seagrass\ count\ per\ quadrat}{maximum\ possible\ count} \times \frac{seagrass\ canopy\ height\ per\ quadrat}{maximum\ mean\ canopy\ height\ per\ site}\right].$$

Oyster monitoring has been ongoing in three segments of the SLE (Middle Estuary, South Fork, and North Fork) since WY2007 (**Figure 8C-2**). Four basic oyster population metrics were included for interpretation. The first is live oyster densities, which are determined seasonally. Second, the settlement rate for oyster larvae (e.g., spat) shells that settle from the water column as the number of spat per shell per month (spat/shell/month) were determined every 1 to 2 months at each sampling site. Finally, the prevalence and intensity of the protozoan pathogen Dermo at each sampling site were assessed at monthly intervals. Seasonal time series for each of these variables were derived for each site from WY2007 through WY2016 for inclusion in this report. The aforementioned data obtained in WY2016 were compared with the long-term average and two previous water years (WY2014 and WY2015) to characterize hydrological and ecological conditions of SLE, respectively.

Results and Discussion

Rainfall

The daily rainfall over the past three water years (WY2014–WY2016) is presented in **Figure 8C-3**. In WY2016, total rainfall to the St. Lucie River Watershed was 54.17 inches (137.6 cm), which was comparable to WY2014 (53.43 inches or 135.7 cm), and higher than WY2015 (49.85 inches or 126.6 cm) and the long-term average (WY1997–WY2016; 47.97 inches or 121.8 cm) covering the period from WY1997 through WY2016 (**Figure 8C-4**). Due to El Niño conditions (SFWMD 2016), the dry season of WY2016 was unusually wet with 24.67 inches (62.7 cm) of rainfall (45.5 percent of annual rainfall). This amount of rainfall was much higher than in the dry seasons of WY2014 (15.8 inches or 40.1 cm) and WY2015 (14.41 inches or 36.6 cm), and greater than the long-term average (12.78 inches or 32.5 cm) (**Figure 8C-4**).

The highest daily rainfall in WY2016 was observed during the wet season (3.08 inches or 7.8 cm on September 17, 2015) and the second highest daily rainfall occurred unusually in the dry season (2.93 inches or 7.4 cm on January 27, 2016) (**Figure 8C-3**). Spatially, the greatest rainfall in WY2016 occurred in the Ten Mile Creek subbasin (58.38 inches or 148.3 cm) and the least was in the C-23 Basin (51.89 inches or 131.8 cm) (**Figure 8C-5**). Generally, the Tidal and Ten Mile Creek basins have slightly higher rainfall than the in-land subbasins (C-23, C-24, and C-44/S-153) (**Figure 8C-5**). Annual rainfall varied within a similar range for all subbasins.

[3] Note that all Chla concentration data reported for the SLE in this report represent corrected Chla values.

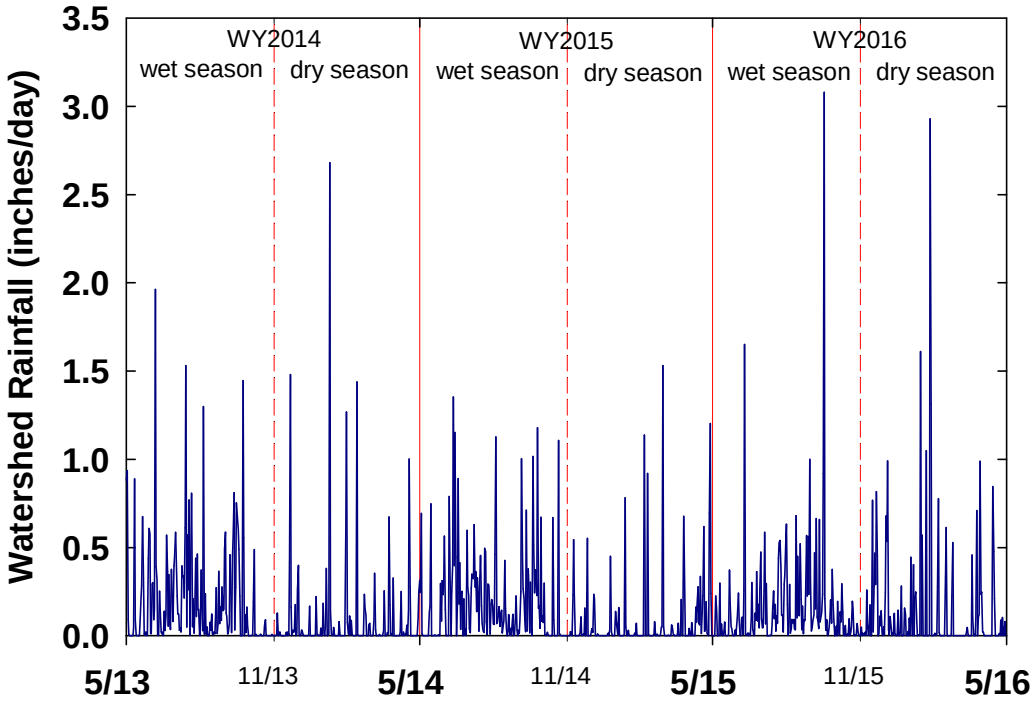

Figure 8C-3. Time series of total daily rainfall to the St. Lucie River Watershed from WY2014 through WY2016.

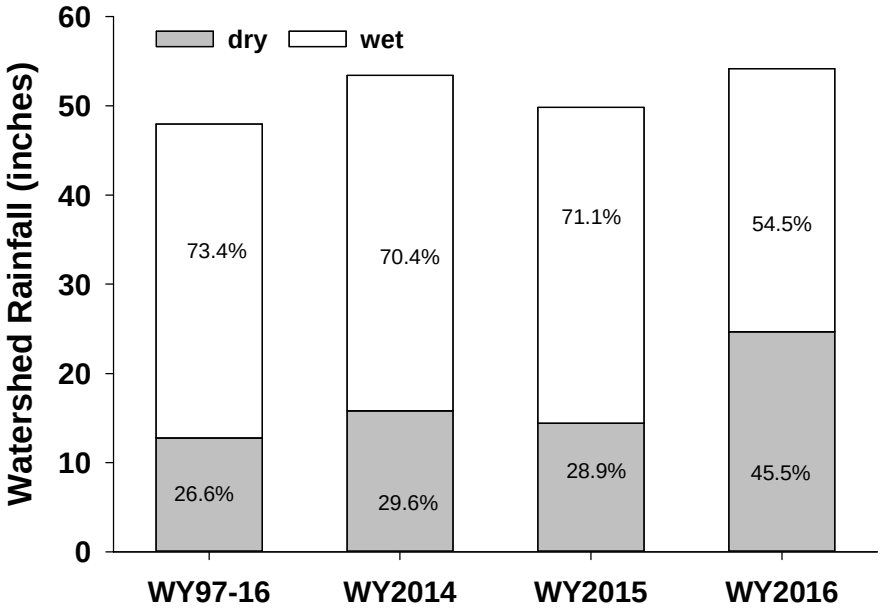

Figure 8C-4. Total rainfall to the St. Lucie River Watershed by water year and season, including the long-term average (WY1997–WY2016), WY2014, WY2015, and WY2016.

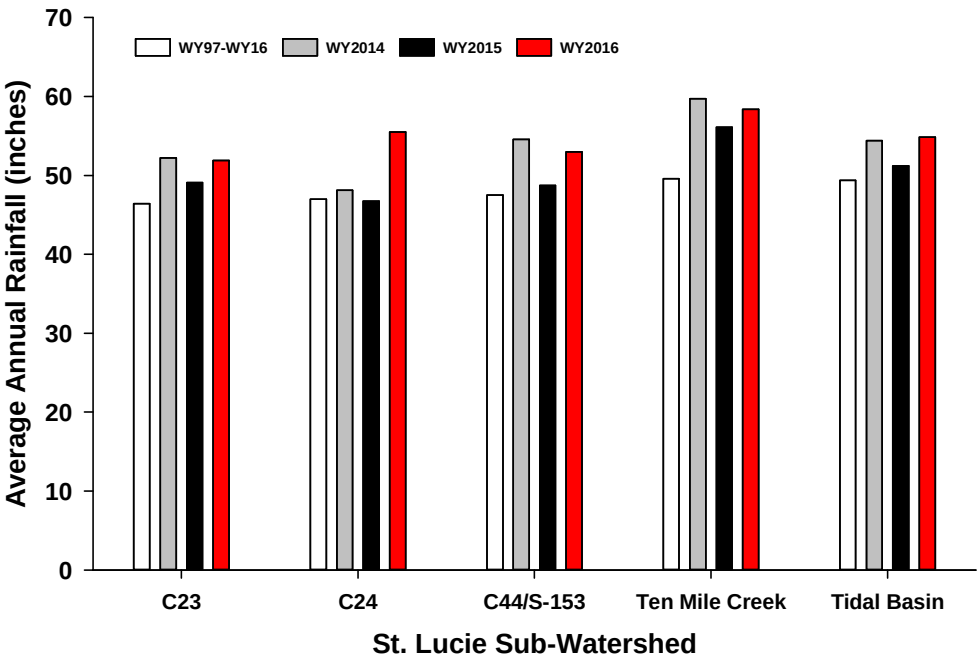

Figure 8C-5. Average annual rainfall to the St. Lucie subbasins, including the long-term average (WY1997–WY2015), WY2013, WY2014, and WY2015.

Inflow

The SLE receives freshwater inflow from the local ungauged Tidal Basin (Basins 4,5,6; South Fork; and North Fork), the gauged St. Lucie Basin (C-44/S-153, C-23, C-24, and Ten Mile Creek), and Lake Okeechobee. During the wet season, water may be released from Lake Okeechobee to control water levels and offer flood protection across the South Florida landscape. In the dry season, water may be released to the SLE in order to promote favorable estuarine conditions in the estuary.

The total daily inflow and flow from Lake Okeechobee from WY2014 through WY2016 to the SLE and the daily rainfall are presented in **Figure 8C-6**. In WY2016, a majority of the total inflow (~69 percent) occurred in the dry season contrasting with the normal pattern of most of the inflow in the wet season. Inflow mirrored the rainfall pattern, i.e., high rainfall observed in the dry season (**Figure 8C-4**) and high inflows from the watershed. The wetter than normal dry season throughout South Florida necessitated releases from Lake Okeechobee further increasing flows to the SLE during the dry season (**Figure 8C-6**). Generally, inflow positively responded to rainfall, as shown in **Figure 8C-6**.

The total inflow to the SLE was 1.219 million ac-ft in WY2016, which was slightly lower than WY2014 (1.305 million ac-ft) and significantly greater than WY2015 (0.751 million ac-ft) and the long-term average (0.988 million ac-ft) (**Table 8C-2** and **Figure 8C-7**, panel a). Notably, of the total inflow in WY2016, 69.6 percent (0.849 million ac-ft) was from the St. Lucie River Watershed (St. Lucie Basin and Tidal Basin) and 30.4 percent (0.370 million ac-ft) from Lake Okeechobee, indicating that watershed flow was dominant as in the two previous water years and over the long-term. About 91 percent of the flow from Lake Okeechobee and 59 percent of inflow from the St. Lucie River Watershed occurred in the dry season due to higher than normal rainfall during WY2016, which was an atypical pattern.

The contribution from Lake Okeechobee in WY2016 (30.4 percent) was slightly lower than WY2014 (32.1 percent) but considerably higher than WY2015 (10.7 percent) and the long-term average (24.7 percent) (**Table 8C-2** and **Figure 8C-7**, panel a). The daily total inflow to the SLE was within the target flow range of 350–2,000 cfs (**Figure 8C-6**) for a total of 148 days (~40 percent days of the water year) in WY2016.

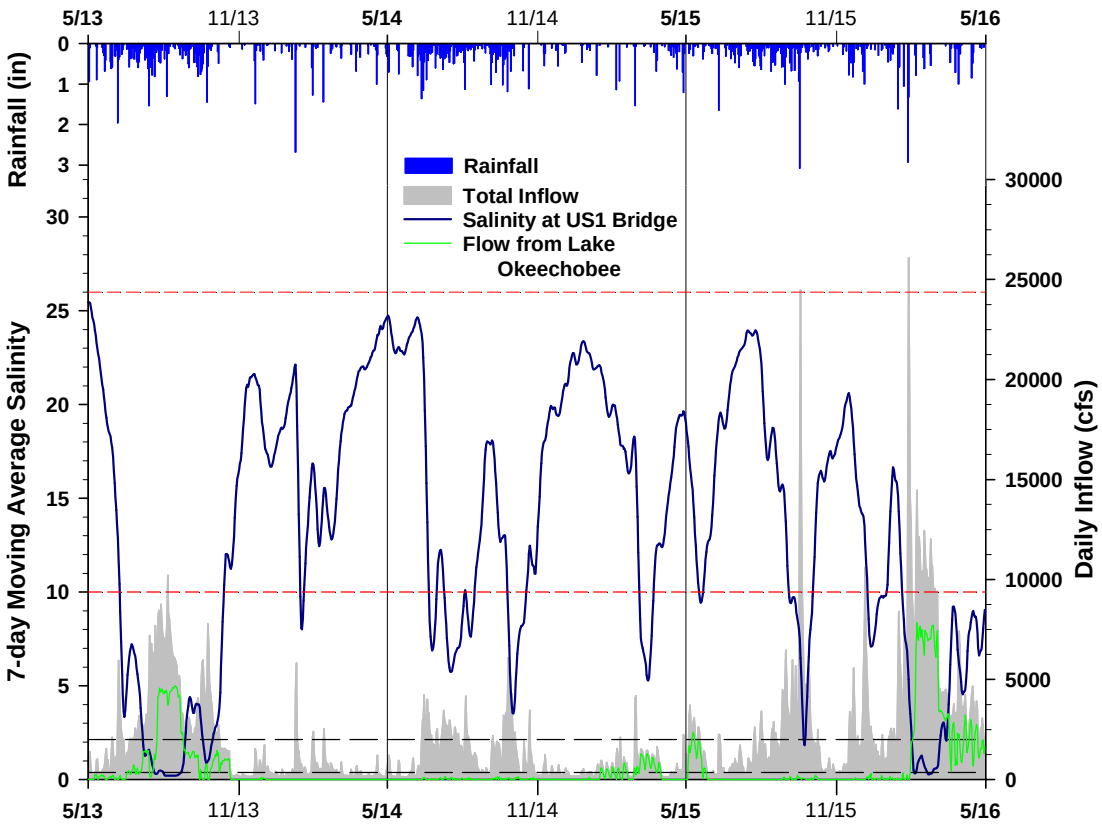

Figure 8C-6. Time series of total freshwater inflow (grey) and flow from Lake Okeechobee (green) (cfs) to the SLE and 7-day moving average salinity at US1 Roosevelt Bridge (dark blue) in the SLE from WY2014 through WY2016. The red dashed lines denote target salinities of 10 to 26. The black dashed lines represent freshwater inflow targets of 350 to 2,000 cfs. The upper panel shows rainfall data in inches (in) in the SLE (blue bar).

Table 8C-2. Summary of flow, TN, and TP from Lake Okeechobee, gauged St. Lucie Basin (C-23, C-24, C-44, and Ten Mile Creek), and Tidal Basin (ungauged) to SLE for the long-term average (WY1997–WY2016), WY2014, WY2015, and WY2016.

		WY97-16	WY14	WY15	WY16
FLOW	Total	0.988	1.305	0.751	1.219
(10^6 ac-ft)	Lake Okeechobee	0.244(24.7%)	0.419(32.1%)	0.080(10.7%)	0.370(30.4%)
	St. Lucie Basin	0.491(49.7%)	0.619(47.4%)	0.402(53.5%)	0.586(48.1%)
	Tidal Basin	0.253(25.6%)	0.268(20.5%)	0.269(35.8%)	0.263(21.5%)
TN	Total	1731.6	2153.7	1049.2	1990.7
(mt)	Lake Okeechobee	530.6(30.6%)	660.2(30.7%)	124.7(11.9%)	717.2(36.0%)
	St. Lucie Basin	902.1(52.1%)	1175.0(54.6%)	659.1(62.8%)	969.7(48.7%)
	Tidal Basin	298.9(17.3%)	318.5(14.8%)	265.4(25.3%)	303.7(15.3%)
TP	Total	320.0	375.0	199.1	333.2
(mt)	Lake Okeechobee	54.7(17.1%)	70.9(18.9%)	13.3(6.7%)	83.6(25.1%)
	St. Lucie Basin	219.7(68.7%)	266.2(71.0%)	155.2(77.9%)	219.0(65.7%)
	Tidal Basin	45.5(14.2%)	37.9(10.1%)	30.6(15.4%)	30.6(9.2%)

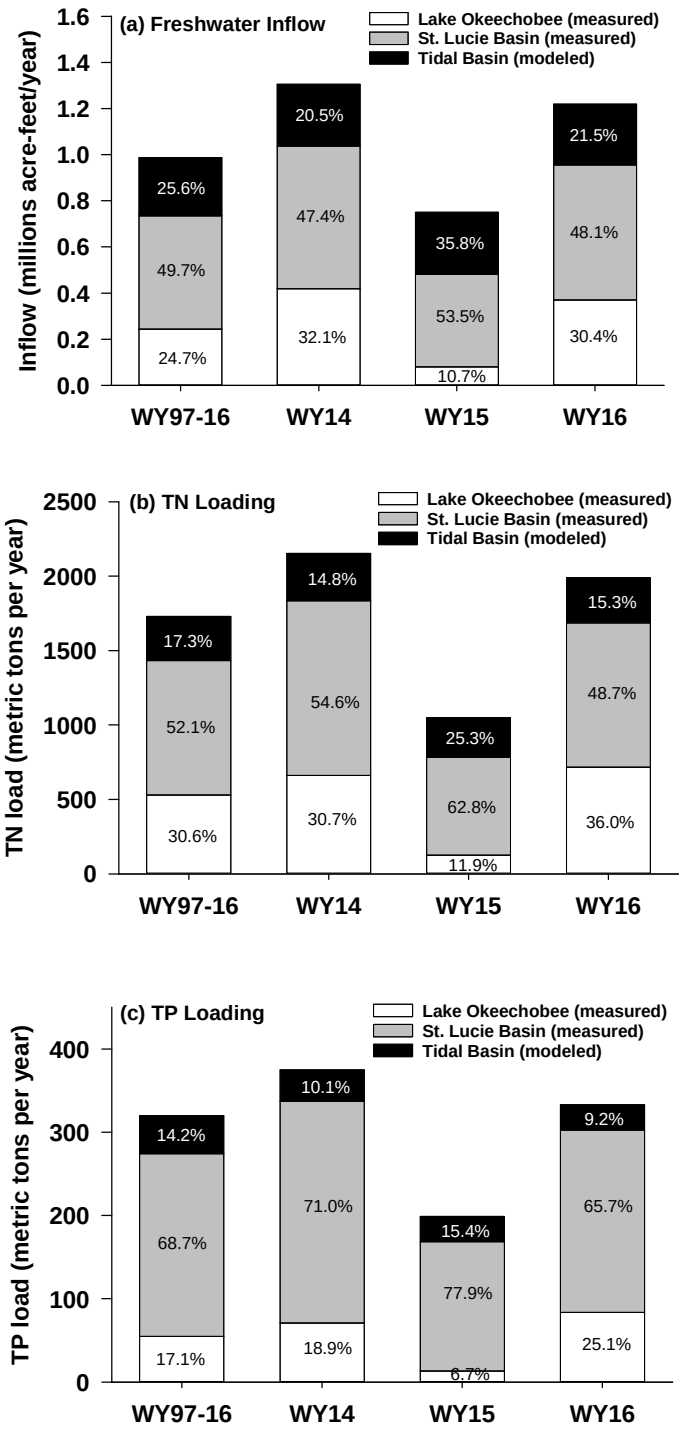

Figure 8C-7. Stacked bar chart for the (a) total freshwater inflow, (b) TN loading, and (C) TP loading attributable to Lake Okeechobee, the St. Lucie Basin, and the Tidal Basin. It includes the long-term average from WY1997 to WY2016, WY2014, WY2015, and WY2016. Tidal basin inflow was estimated using a linear reservoir modeling approach.

Salinity

The seven-day moving average salinity at the US1 Bridge was calculated for the long-term POR from WY1999 through WY2016. Results for the previous three water years are presented in **Figure 8C-6**. The percentage of time (measured in days) that the 7-day moving average salinity was within the preferred envelope of 10 to 26 is shown in **Table 8C-3**. In WY2016, the seven-day moving average salinity at the US1 Bridge ranged from 0.27 (February 21, 2016) to 24.0 (July 25, 2015) (**Figure 8C-6**) and was within the preferred envelope for 58.3 percent of the time (measured in days). This percentage was lower than the previous two water years (63.8 percent for WY2014 and 76.7 percent for WY2015) and the long-term average (63.9 percent) (**Table 8C-3**). As in WY2014 and WY2015, the upper limit of the salinity envelope (26) was not exceeded in WY2016. In contrast, salinity was below the lower envelope limit (10) for 42.7 percent of the time (measured in days), higher than both WY2014 and WY2015. It is apparent that salinity patterns are inversely related to freshwater inflow in the estuaries as shown in **Figure 8C-6**.

Table 8C-3. The percentage of 7-day moving average salinity at the US1 Roosevelt Bridge either less than 10, between 10 ~ 26 (preferred envelope), or greater than 26 for the past three water years (WY2014–WY2016) and the long-term average (WY1999–WY2016), respectively.

	7-day moving average salinity at US1 Bridge		
Water Year	Days with salinity<10	Days with salinity 10 - 26	Days with salinity>26
WY1999-WY2016	29.9%	63.9%	6.2%
WY2014	36.2%	63.8%	0.0%
WY2015	23.3%	76.7%	0.0%
WY2016	41.7%	58.3%	0.0%

Nutrient Loads and Inflow Concentrations

TN and TP loads to SLE from Lake Okeechobee, gauged St. Lucie Basins (C-23, C-24, C44/S-153, and Ten Mile Creek), and Tidal Basin (ungauged St. Lucie Basins, including South Fork, Basin 4/5/6, North Fork) are presented in **Table 8C-2** for the past three water years along with the long-term average (WY1997–WY2016). There is considerable correspondence between interannual fluctuations in total inflow and TN and TP loads suggesting that the loads are hydraulically driven (**Figure 8C-8**).

In WY2016, the total TN and TP loadings to SLE were 1,990.7 and 333.2 mt, respectively. St. Lucie River Watershed (St. Lucie Basin and Tidal Basin) contributed 64.0 percent of the TN load and 74.9 percent of TP load while Lake Okeechobee contributed 36.0 percent of the TN load and 25.1 percent of the TP load (**Table 8C-2**). The TN and TP loadings in WY2016 were slightly lower than those in WY2014, but significantly higher than WY2015 and slightly higher than the long-term average (WY1997–WY2016) (**Table 8C-2** and **Figure 8C-7**, panels b and c). During the past three water years and over the long-term POR, the St. Lucie Basin contributed the highest percentage TN and TP loads to SLE (**Figure 8C-7**, panels b and c, respectively). This suggests that the St. Lucie Basin may have more influence than Lake Okeechobee on nutrient cycling and eutrophication in the SLE. In WY2016, unusually, most of the nutrient load, with 72 percent of TN and 68 percent of TP, to SLE was delivered in the dry season. Of note, a similar seasonal pattern was observed for nutrient loads from Lake Okeechobee: 93 percent of TN and 94 percent of TP loads were delivered during the dry season.

For the long-term average (WY1997-WY2016), the mass ratio for TN:TP loading from Lake Okeechobee was 9.7:1 while the TN:TP ratio for the nutrient load from the St. Lucie River Watershed was much lower (4.5:1). This difference may indicate that water introduced from the St. Lucie Watershed was relatively enriched with TP compared to that from Lake Okeechobee.

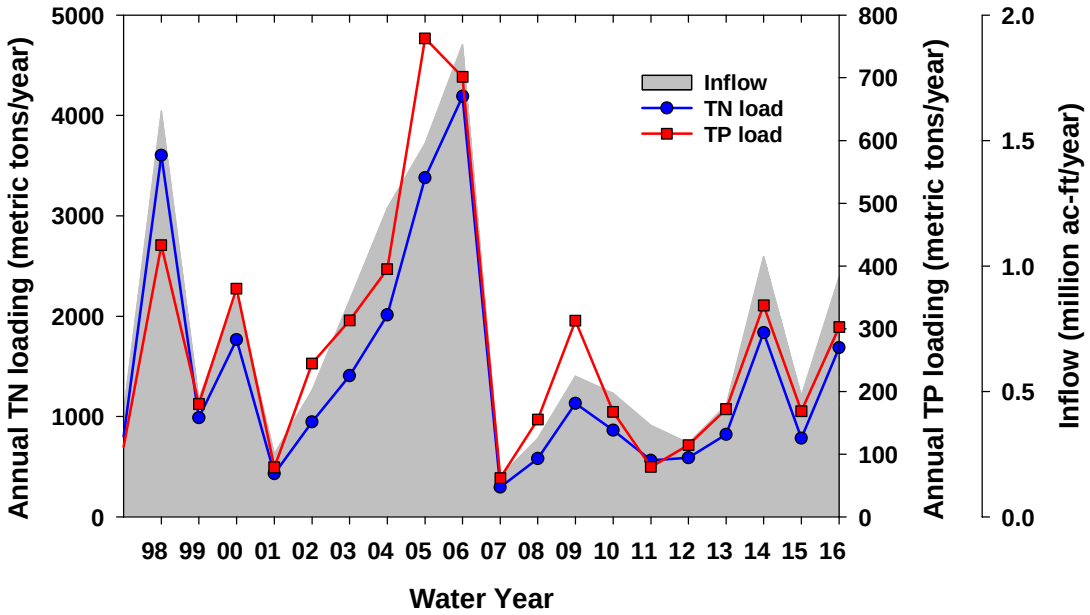

Figure 8C-8. Time series of annual freshwater inflow (shaded area), TN (blue), and TP (red) loading from the sum of C-44, S-48 (C-23 subwatershed), S-49 (C-24 subwatershed), and Lake Okeechobee to the SLE from WY1997 through WY2016.

To evaluate the quality of water flowing to the estuary, annual FWM TN and TP concentrations were calculated from WY1997 through WY2016 for the gauged St. Lucie Basin (comprising C-44/S-153,C-23, C-24, and Ten Mile Creek) and Lake Okeechobee (**Figure 8C-9**). The absence of a freshwater contribution (zero flow) from the Lake Okeechobee in WY2008 and WY2012 and from C-44/S-153 in WY2008 account for missing data from the figure.

WY2016 FWM TN concentrations in the flow from Lake Okeechobee and Ten Mile Creek were higher than WY2015, while these concentrations from C-44/S-153, C-23, and C-24 were comparable to WY2015. TN concentrations from the five sources in WY2016 varied from 1.06 milligram per liter (mg/L; Ten Mile Creek) up to 1.57 mg/L (Lake Okeechobee) and were within the historical (WY1997–WY2016) range of 0.71–2.61 mg/L (**Figure 8C-9**, panel a). Ten Mile Creek had the lowest FWM TN concentration among the five sources during the last three water years and Lake Okeechobee had the highest.

The flow from Lake Okeechobee and Ten Mile Creek had a higher FWM TP concentration in WY2016 than WY2015 while the concentrations for C-44/S-153, C-23, and C-24 were lower in WY2016 than WY2015. Overall, FWM TP concentrations in WY2016 varied from 0.18 mg/L (Lake Okeechobee) to 0.41 mg/L (C-23 Basin) depending on the source (**Figure 8C-9**, panel b) and were within the historical (WY1997–WY2016) range of 0.05–0.66 mg/L. During the past three water years, Lake Okeechobee had the lowest FWM TP concentration and the C-23 Basin had highest among the five sources. This may help explain why the TN:TP ratio of the nutrient load from the lake was relatively higher than that of the load from the basin (see above).

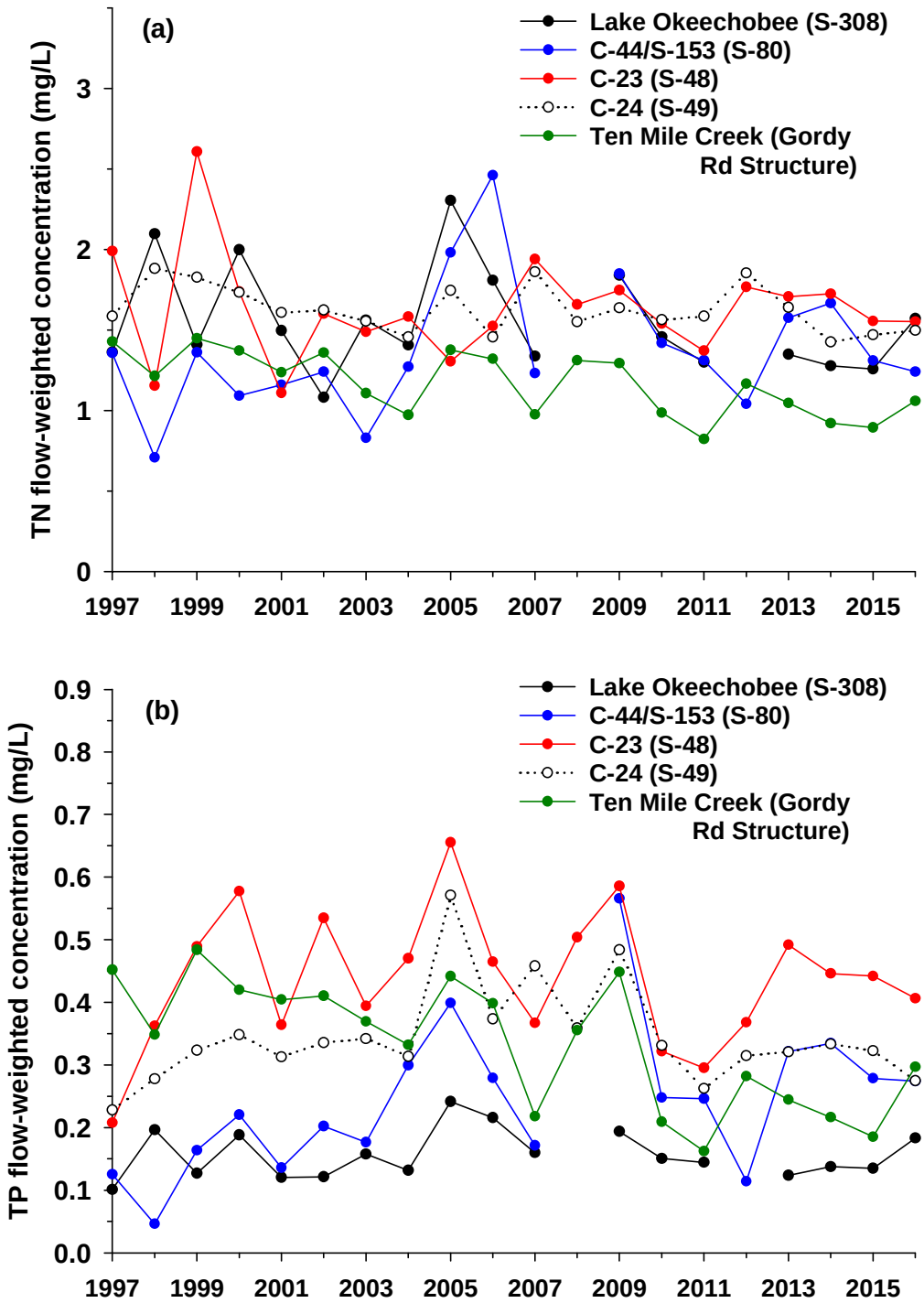

Figure 8C-9. Time series of FWM concentrations of (a) TN (a) and (b) TP from S-308 (solid black), S-80 (blue), S-48 (red), S-49 (open dash), and GRS (green) from WY1997 through WY2016. No data signifies no flow contribution to the SLE from the specific source of the year.

In-Estuary Water Quality

Chla, TN, and TP were selected as parameters to characterize water quality conditions in SLE. To evaluate water quality status, the measured Chla, TN, and TP concentrations from WY1997 through WY2016 at three stations (HR1, SE03, and SE11) were plotted in **Figure 8C-10**. The long-term averages (and standard deviations) over the entire POR (WY1997–WY2016) and average values for the most recent three water years (WY2014, WY2015, and WY2016) were calculated and presented in **Table 8C-4**. These include dry season, wet season, and annual averages.

The sum of flows at S-80 (flow from C-44/S-153 Basin and Lake Okeechobee), S-48 (flow from C-23 Basin) and S-49 (flow from C-24 Basin) are also included in **Figure 8C-10**. The relationships between freshwater inflow and Chla are generally hard to distinguish in the SLE (Buzzelli 2011; **Figure 8C-10**, panels a through c). In small subtropical estuaries like the SLE, other physical (transport and sinking), chemical (nutrient supply and turnover), and biological (grazing by zooplankton and larval organisms) factors cause fluctuations in phytoplankton growth and biomass (Lucas et al. 2009, Philips et al. 2011). There were significant intra- and interannual variations in water column Chla concentrations among the three monitoring locations over the long-term POR from WY1997 through WY2016 (**Figure 8C-10**, panels a through c). At the three sites, Chla concentrations were higher in wet season than dry season with the exception of WY2015 at HR1 and SE11 (**Table 8C-4**).

Spatially, Chla concentrations decreased as proximity to the ocean increased (i.e., $C_{\text{Chla at HR1}} > C_{\text{Chla at SE03}} > C_{\text{Chla at SE11}}$) (**Figure 8C-10**, panels a through c and **Table 8C-4**). In WY2016, Chla concentrations followed the same spatial pattern in the wet season average and total annual average but not the dry season average. Instead, the Chla concentration at SE11 was greater than that at SE03 in the dry season.

In many estuaries, the freshwater from the land has higher concentrations of nutrients than water from the ocean. The mixing of these two sources in the estuary generally results in a spatial gradient typically with higher concentrations near land sources and lower concentrations near the ocean. Generally, all three water quality indicators exhibit a spatial concentration gradient with the North Fork (HR1) most landward > Middle Estuary (SE03) > Lower Estuary (SE11, nearest the ocean). With few exceptions this pattern holds for dry season, wet season, and annual average concentrations. Notably, the TN concentration in the WY2016 dry season at SE03 was higher than at HR1, which is further upstream. This may have been caused by the unusually higher releases from Lake Okeechobee during the WY2016 dry season. The water from the lake flowing through the South Fork into the Middle Estuary had the highest TN concentration of the five inflow sources, **Figure 8C-9**, panel a). Another exception is relatively similar TP levels for HR1 and SE03 in dry season.

In general, the typical temporal pattern with higher TN and TP concentrations in the wet season than dry season was observed at the three stations. TN at SE03 in WY2016 was an exception, with the dry season concentration being higher than in the wet season. This was also probably caused by the high flow released from Lake Okeechobee in the dry season of this water year. This reversed temporal pattern was also found in TN at SE11 for WY2015.

Both TN and TP concentrations in the WY2016 dry season were higher than WY2014 and WY2015 at all three stations. This may be attributed to the relatively high inflow from St. Lucie local basins and the lake resulting from the higher than normal rainfall experienced during the dry season. The TN and TP concentrations in the wet season and total year average at the three sites in WY2016 were either comparable to or between those in WY2014 and WY2015.

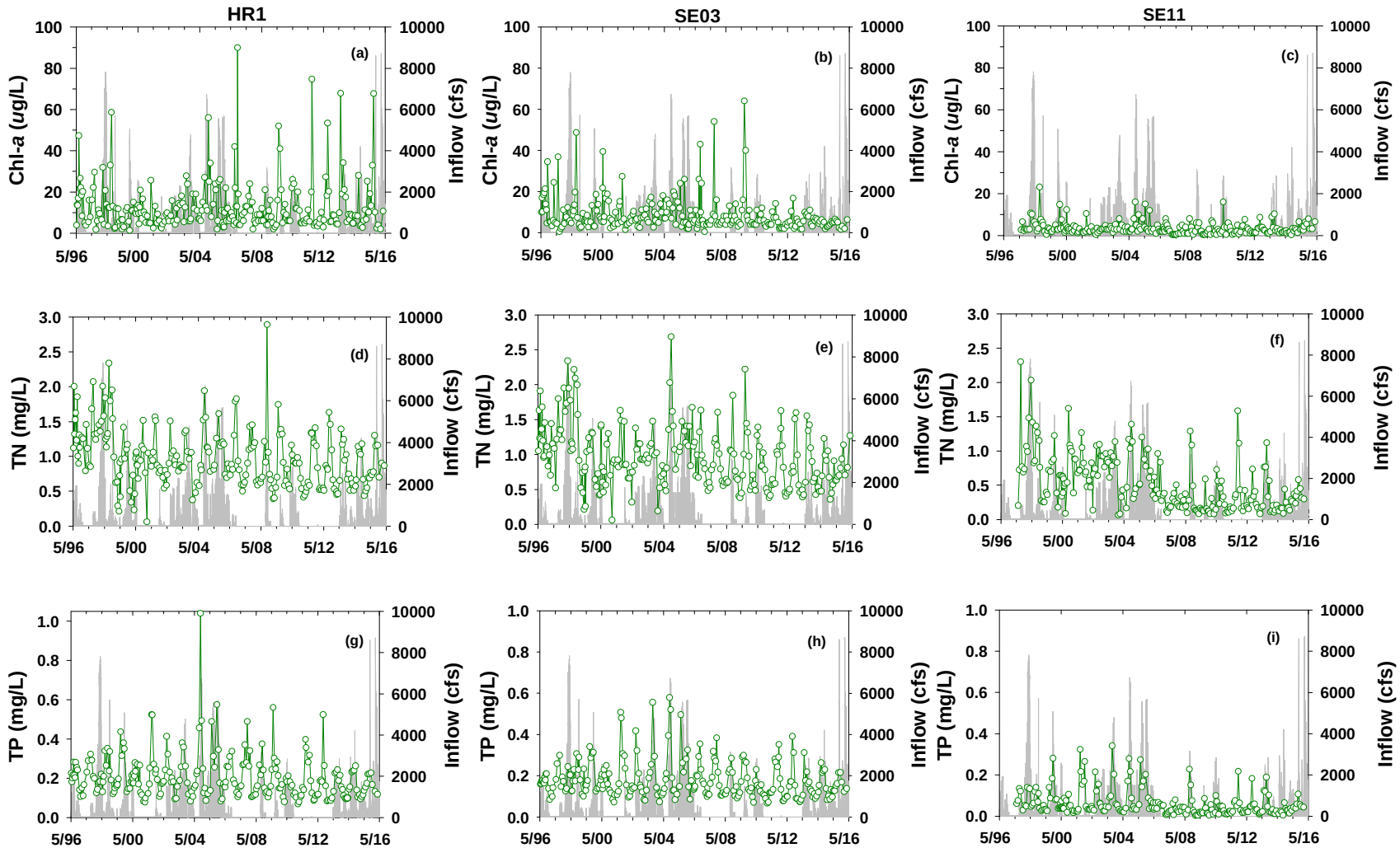

Figure 8C-10. Time series of chlorophyll *a* (Chl-*a*; in micrograms per liter [µg/L]), TN, and TP (green line with open circle) at stations HR1, SE03, and SE11 in the SLE, and flow (grey line) from WY1997 through WY2016.

Table 8C-4. Summary of water column concentrations of chlorophyll a (Chl-*a*; micrograms per liter [µg/L]), TN (mg/L), and TP (mg/L) at three stations (HR1, SE03, and SE11) in the SLE. The table includes dry season, wet season, and total averages and standard deviations (average ± standard deviations) from WY1997 through WY2016 and average values for WY2014, WY2015, and WY2016.

HR1	Chl-*a*			TN			TP		
	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total
Avg±SD	9.4±7.4	16.1±14.9	12.9±12.3	0.85±0.33	1.20±0.39	1.03±0.40	0.14±0.05	0.26±0.12	0.20±0.11
WY14	7.28	28.24	17.76	0.62	1.07	0.85	0.12	0.21	0.16
WY15	10.37	10.15	10.26	0.59	0.94	0.77	0.11	0.21	0.16
WY16	**5.58**	**24.28**	**18.05**	**0.82**	**0.98**	**0.93**	**0.14**	**0.19**	**0.17**

SE03	Chl-*a*			TN			TP		
	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total
Avg±SD	6.3±4.0	11.2±10.4	8.8±8.4	0.78±0.39	1.12±0.41	0.97±0.44	0.13±0.04	0.23±0.10	0.18±0.09
WY14	5.60	8.75	7.18	0.57	1.15	0.86	0.11	0.19	0.15
WY15	4.02	4.47	4.24	0.60	0.89	0.74	0.11	0.20	0.15
WY16	**3.81**	**5.28**	**4.84**	**0.93**	**0.82**	**0.85**	**0.14**	**0.17**	**0.16**

SE11	Chl-*a*			TN			TP		
	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total
Avg±SD	2.9±2.4	4.1±3.5	3.5±3.1	0.41±0.35	0.70±0.37	0.63±0.38	0.04±0.03	0.09±0.07	0.06±0.06
WY14	1.76	5.10	3.43	0.15	0.62	0.39	0.02	0.10	0.06
WY15	3.16	1.68	2.42	0.21	0.19	0.20	0.03	0.03	0.03
WY16	**4.33**	**4.95**	**4.74**	**0.31**	**0.40**	**0.38**	**0.05**	**0.06**	**0.06**

Ecological Indicator Results

Seagrasses are influenced by the availability of submarine light and nutrients, seasonal shifts in water temperature and plant physiology, grazing by macro- and mega-fauna, and salinity (Duarte et al. 2007, Lee et al. 2007, Lirman et al. 2008, Buzzelli et al. 2012). The Willoughby Creek site is located in the most upstream persistent seagrass bed in the St. Lucie River, and is influenced by both SLE freshwater discharges and salt water from the Atlantic Ocean entering through the St. Lucie Inlet. Two seagrass species are resilient enough to occur in this variable salinity environment: shoal grass and Johnson's seagrass (*Halophila johnsonii*). The biomass index fluctuated with salinity at Willoughby Creek within the lower SLE from WY2008 through WY2016 (**Figure 8C-11**, panel a).

At Boy Scout Island in the SIRL salinity tends to be higher and more stable than at Willoughby Creek (**Figure 8C–11**). Manatee grass is the historically dominant species at this site and is more sensitive to low salinity and salinity variation than the seagrass species at Willoughby Creek. Both the distribution and density of manatee grass typically decrease following extreme freshwater events (Buzzelli et al. 2012). Manatee grass was largely eliminated from this site due to low salinities and physical forces of Hurricanes Frances, Jeanne, and Wilma in WY2005 and WY2006. As manatee grass recovered, the biomass index increased, peaking in WY2012. However, low salinity and physical forces associated with Tropical Storm Isaac and Hurricane Sandy in August and October WY2013, respectively, once again impacted the manatee grass community at Boy Scout Island as indicated by the biomass index decline. The WY2014 wet season further exacerbated the impacts leaving very little manatee grass at the site. Low salinities associated with Lake Okeechobee and watershed discharges in WY2016 continued to impact the remaining manatee grass at the site resulting in extremely low biomass index values for this location. Once manatee grass is eliminated (or nearly eliminated) from a site, it can take a relatively long time to recover (5+ years based on past observations by SFWMD).

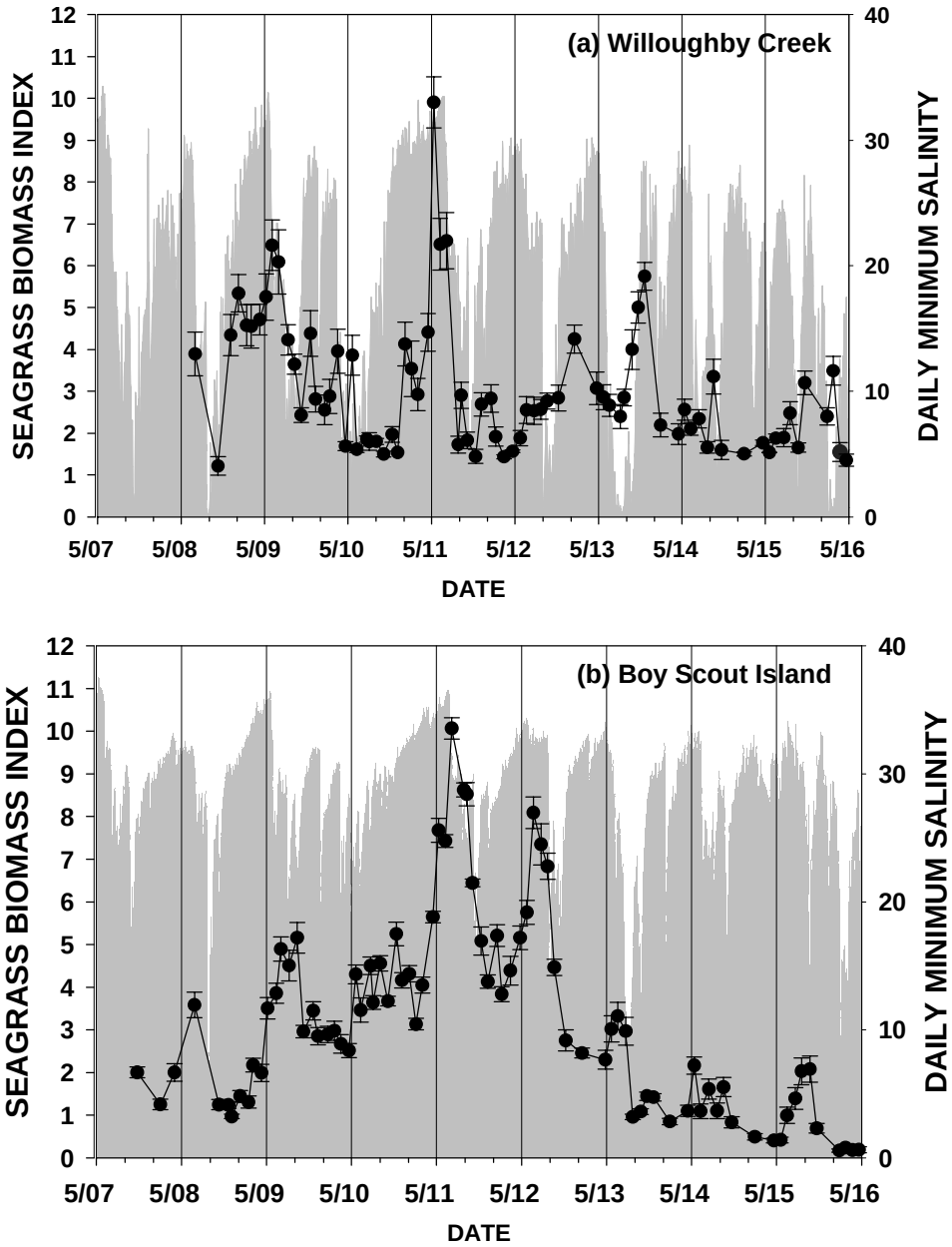

Figure 8C-11. Time series of seagrass biomass index for the SAV communities at (a) Willoughby Creek and (b) Boy Scout Island from WY2008 through WY2016. Includes daily minimum salinity at each site predicted from A1A bridge data or on-site salinity sondes. Vertical grid lines delineate water years.

The survival of oysters is affected by the interaction of salinity and temperature (Shumway 1996, Parker 2015). Water quality has a large influence on oyster health and survivorship; rapid changes in salinity, high temperatures, low dissolved oxygen concentrations, and siltation can all be stressors to oyster populations (Parker et al. 2015). Salinities at the US1 Bridge recorder have ranged from 21.7 to 12.3 over the last 10 water years (WY2007–WY2016). More current (WY2016) salinities at this location have been below 20 since mid-November 2015, with a yearly salinity mean at 12.3—the 10-year lowest yearly mean salinity due to high freshwater inflow during the dry season.

Data were collected for live oyster density, larval recruitment, and prevalence and intensity of the protozoan pathogen Dermo from three sites in the Middle Estuary (**Figure 8C-2**) from WY2007 to WY2016. The biannual live oyster density counts varied throughout the past 10 water years. The time series of averages over the three sites in Middle Estuary are shown in **Figure 8C-12**. The lowest density was 8.8 oysters/m^2 occurring in December 2008, and the highest densities at 1,123 oysters/m^2 were recorded in September 2014. Live oyster density in the Middle Estuary shows a wide range of counts between dry and wet seasons from WY2007 through WY2016 (**Figure 8C-12**, panel a). Average densities in WY2016 were 450 oysters/m^2, just above the 10-year mean (431 oysters/m^2).

The average monthly oyster larval (spat) recruitment counts (WY2007–2016) ranges from 0 to 4.5 spat/shell/month (**Figure 8C-12**, panel b). The 10-year average of spat recruitment is 0.2 spat/shell/month for dry seasons and 0.8 spat/shell/month for wet seasons. WY2016 had the highest yearly average (1.0 spat/shell/month) recruitment counts and WY2011 had the lowest (0.1 spat/shell/month) yearly average. These larval recruitment numbers, although at times very low, continue to be enough to support natural repopulating of the oyster beds even after extreme oyster mortality events (e.g., 2008 and 2013). Notably, May 2015 recorded the highest recruitment counts (4.5 spat/shell) for the last 10 years. Even though the SLE was subjected to large variations in salinity during 2015, the year was fairly harmless in that there were no extreme rainfall events or prolonged freshwater releases. Salinities stayed fairly moderate throughout the year with severe decreases occurring in March and September when freshwater inflows increased. Also, the 2015 live and dead oyster counts conducted in the spring and fall showed a low ratio of dead oysters to the total number of live and dead oysters reflecting the stability of the oyster populations in 2015 with more oysters available to spawn. Thus, 2015 were among the highest recorded for recruitment (spat) back to 2006.

Disease typically increases as temperature and salinity increases. The disease prevalence measurement (0–100 percent) or the percentage of oysters in the SLE infected with the marine protozoan disease Dermo in WY2016 ranged from 0 to 60 percent, with the yearly average at 34 percent. Overall, the 10-year average (WY2007–WY2016) of the oysters detected with Dermo average 25 percent, with the highest percent in WY2012 at 72 percent, followed by WY2013 at 58 percent (**Figure 8C-12**, panel c). The average intensity (1 to 5) of the Dermo infection or amount of infection within individual oysters has stayed fairly low (< 1.7) over the most recent 10 monitoring water years (WY2007–WY2016), with the average Dermo intensity quite low at 0.239. WY2016 (~0.244) showed an average year for Dermo intensity (**Figure 8C-12**, panel d).

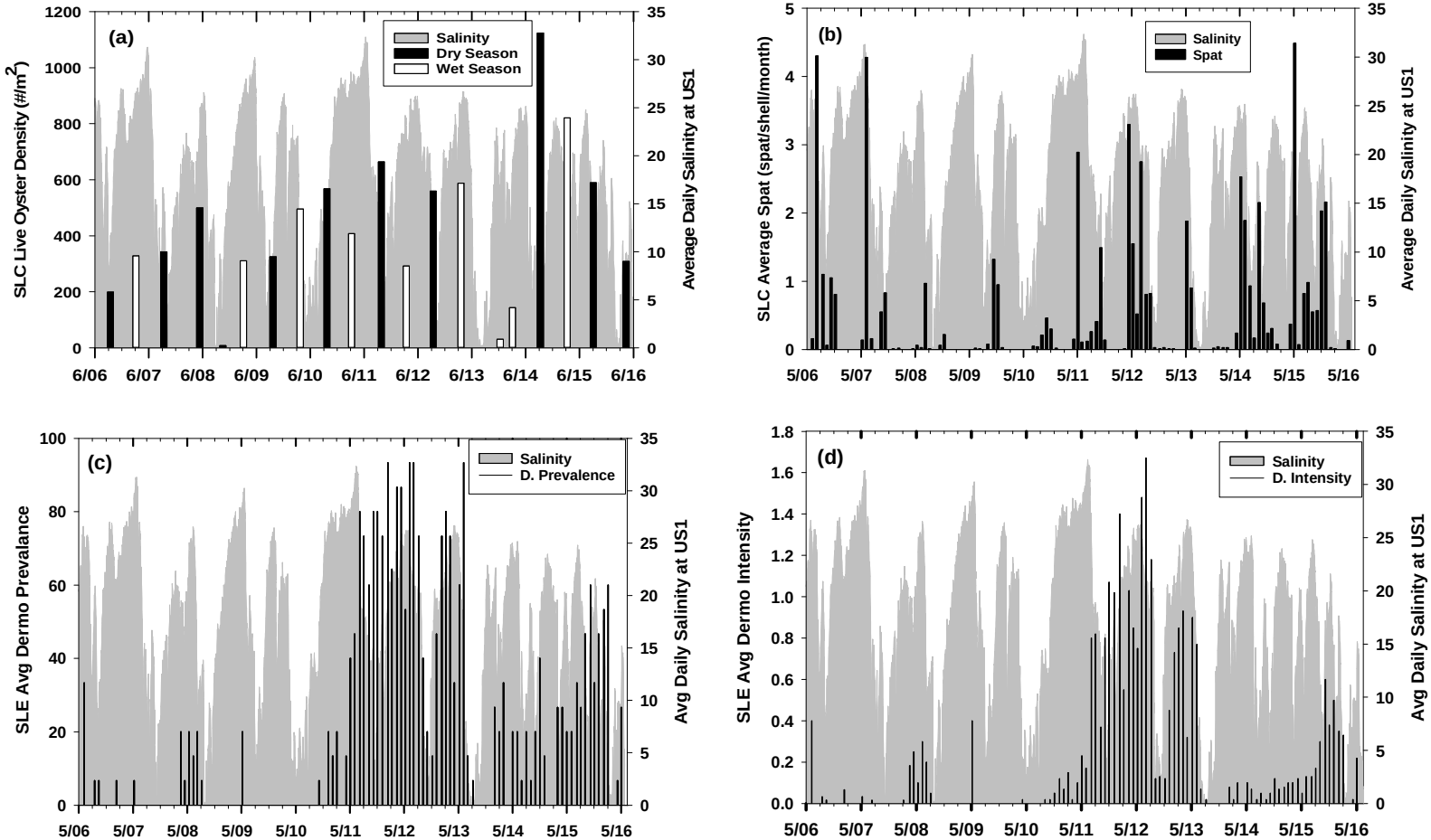

Figure 8C-12*. Time series for average (a) live oyster density, (b) larval (spat) recruitment, and (c) prevalence and (d) intensity of the oyster-specific pathogen, Dermo, from WY2007 through WY2016 in SLE Middle Estuary, with the average salinity at the US1 Bridge in the SLE included in each time series. (Note: The data for the SLE oysters was provided by the following contractor: Melanie L. Parker, PhD, Molluscan Fisheries Research Group, Florida Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission, St. Petersburg, Florida. Avg – Average.)

SIGNIFICANT FINDINGS FOR WY2016 IN THE ST. LUCIE ESTUARY

- In WY2016, total rainfall to the St. Lucie River Watershed was 54.17 inches (137.6 cm), with 54.5 percent (29.5 inches or 74.9 cm) falling in the wet season and 45.5 percent (24.67 inches or 62.7 cm) in the dry season. Dry season rainfall was much higher than recent dry seasons in WY2014 (15.8 inches or 40.1 cm), and WY2015 (14.41 inches 36.6 cm), and the long-term average (12.78 inches or 32.5 cm, WY1997-WY2016). Annual rainfall in WY2016 was comparable to WY2014 (53.43 inches or 135.7 cm), while slightly higher than WY2015 (49.85 inches 126.6 cm) and the long-term average (47.97 inches or 121.8 cm).
- The total inflow to the SLE was 1.219 million ac-ft in WY2016, slightly lower than WY2014 (1.305 million ac-ft) and significantly greater than both WY2015 (0.751 million ac-ft) and the long-term average (WY1997–WY2016; 0.988 million ac-ft). A majority of the total inflow (~69 percent) occurred in dry season contrasting with the normal pattern observed during WY2014 and WY2015 in which most of the inflow occurred in the wet season. The St. Lucie River Watershed dominated inflow, contributing 69.6 percent of the total estuary inflow. Lake Okeechobee contributed 30.4 percent inflow (0.370 million ac-ft), of which 91 percent atypically occurred in the dry season.
- The seven-day moving average water column salinity at the US1 Bridge was within the salinity envelope of 10 to 26 (reflecting a good salinity range for adult oyster growth) for 58.3 percent of the time (measured days) in WY2016. This was lower than the previous two water years (63.8 percent for WY2014 and 76.7 percent for WY2015) and long-term average (63.9 percent).
- In WY2016, total nitrogen (TN) and total phosphorus (TP) loadings to the SLE were 1,990.7 and 333.2 mt, respectively. The St. Lucie River Watershed contributed 64.0 percent of the TN load and 74.9 percent of TP load while Lake Okeechobee contributed 36.0 percent of the TN load and 25.1 percent of the TP load. The TN and TP loadings during WY2016 were slightly lower than those in WY2014, but significantly higher than WY2015 and slightly higher than the long-term average. Around 72 percent of TN and 68 percent of TP loads to SLE were delivered in the dry season. Nearly all the TN (93 percent) and TP (94 percent) loads from Lake Okeechobee were also delivered during the dry season.
- Chla concentrations repeated the same seasonal patterns observed in previous years and over the long-term, which were higher in the wet season and lower in the dry season. Spatially, both wet season and annual average Chla concentrations decreased as proximity to the ocean increased. However, during the WY2016 dry season, the Chla concentration in the lower estuary close to the St. Lucie Inlet was greater than that in the Middle Estuary.
- WY2016 TN and TP concentrations decreased from upstream to downstream showing a typical spatial pattern, except for TN concentrations in the dry season in which Middle Estuary levels were higher than in the North Fork most likely due to regulatory releases from Lake Okeechobee.
- Seagrass species at Willoughby Creek, which is within the lower SLE, are adapted to variable salinities and typically recovered faster from freshwater impacts than manatee grass at Boy Scout Island. The near elimination of manatee grass had resulted in an extremely low seagrass biomass index at Boy Scout Island. Low and variable salinities due to high freshwater inflows as well as physical forces from storms were likely causes of the decline.

- The live oyster density counts during the WY2007–WY2016 POR ranged from 8.8 (October 2008) to 1,123 oysters/m^2 (September 2016). Notably, the highest spat count (4.5 spat/shell/month) was observed in May 2015 over the past 10 water years. Larval (spat) supply continued to support natural recovery of oyster population within the SLE even with extremely low salinities at times.

CALOOSAHATCHEE RIVER ESTUARY AND WATERSHED CONDITION

BACKGROUND

The Caloosahatchee River Watershed is located on the lower west coast of Florida in Lee, Charlotte, Collier, Glades, and Hendry counties (Barnes 2005; **Figure 8A-1**). The CRE have been altered by human activities starting in the 1880s when the river was straightened and deepened resulting in the loss of 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 more recent 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 Caloosahatchee River Watershed is a series of linked regional subwatersheds and includes the S-4 Basin adjacent to Lake Okeechobee, East Caloosahatchee Basin, West Caloosahatchee Basin, Tidal Basin located downstream of S-79, and Cape Coral Coastal Basin to the north of the CRE (Balci and Bertolotti 2012). 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 km^2 (5,600 hectares [ha]) with an average depth of 8.86 ft (2.7 m) (Buzzelli et al. 2013a). The flushing time ranges from 2 to 30 days (Buzzelli et al. 2013b).

Figure 8C-13 shows the five basins comprising the Caloosahatchee River Watershed, as reported in the 2012 CRWPP update (Balci and Bertolotti 2012). The CRWPP study area includes the areas that drain to the mouth of the Caloosahatchee River and the associated offshore estuarine area. The Caloosahatchee River Watershed is a linearly aligned system, unlike the St. Lucie Watershed. Starting with its eastern point at the USACE structure S-77 adjacent to Lake Okeechobee, water generally flows east to west to the USACE structure S-78, which represents a major division in the freshwater portion. Moving west, flow is also modified by the S-79 that represents the confluence with the estuarine waters. The Tidal Basin of the Caloosahatchee River Watershed represents approximately 30 percent of the watershed. Numerous tributaries exist throughout both the freshwater and estuarine portions of the watershed and can influence overall hydrology of the river dependence on rainfall and regional hydrological conditions.

Similar to the SLE, runoff from the coastal watershed and outflows from Lake Okeechobee have a profound influence on estuarine physics, water quality, and biotic resources in CRE (Buzzelli et al. 2012, 2013b, 2013c, 2013d, 2014). When summarizing environmental conditions in the 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 to 5 years) and decadal patterns. Therefore, the wet-dry subtropical

seasonality typical of South Florida estuaries should be contrasted annually to both longer-term (> 10 years) and shorter-term (1 to 3 years) patterns.

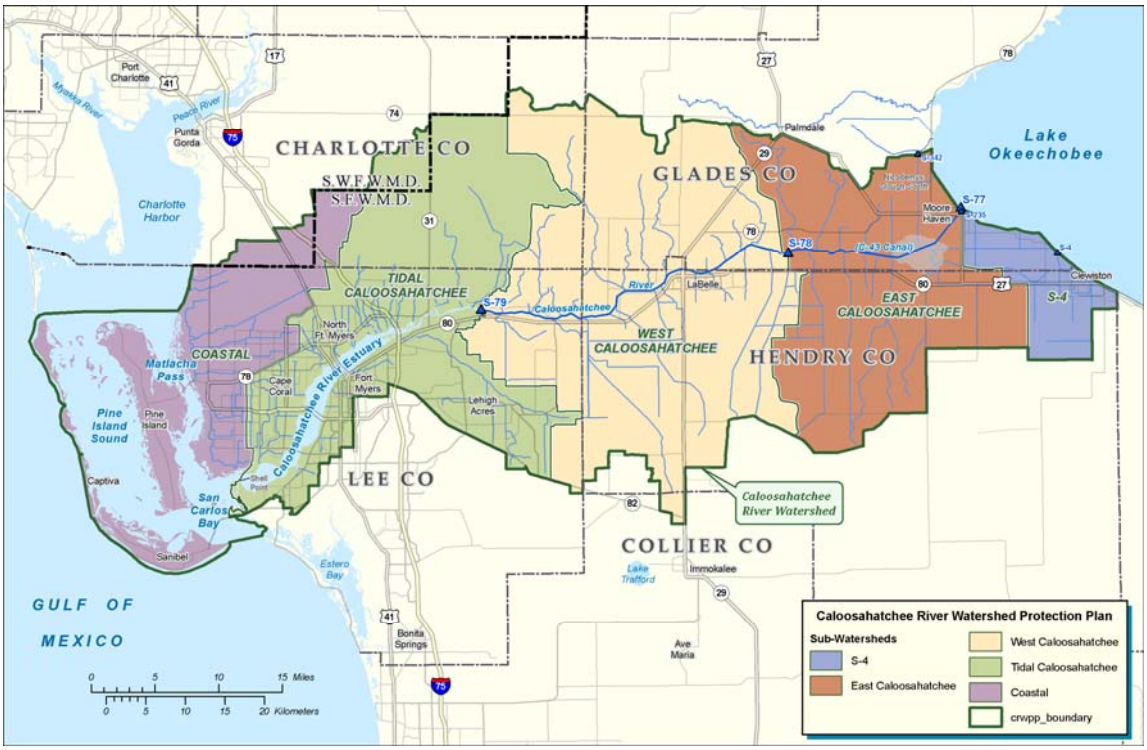

Figure 8C-13. The Caloosahatchee River Watershed with its subwatersheds and major water control structures.

HYDROLOGY, WATER QUALITY, AND AQUATIC HABITAT

Methods

A suite of external drivers and ecological responses are routinely monitored in the Caloosahatchee River Watershed. 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).

Daily NEXRAD rainfall data from WY1997 to WY2016 for each subbasin of the Caloosahatchee River Watershed were downloaded from the DBHYDRO database on the District's website at http://my.sfwmd.gov/nexrad2/. The amount of rainfall across the watershed was computed using an area-weighted method.

Table 8C-5 describes the major contributing areas (Tiers 1 and 2) of the Caloosahatchee River Watershed and the methodology associated with the reported flows and loads (see **Figure 8C-13** for locations of the contributing areas). 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 8C-13**). For the purposes of this report, the East Caloosahatchee Basin and the S-4 Basin are reported together. Average daily inflows from WY1997 through WY2016 for S-79, S-78, S-77, and the Tidal Basin were used to evaluate intra- and interannual variations in inflow,

quantify total inflow to the CRE, and estimate the contributions of the subbasins to total inflow. This included the relative volume contributions from Lake Okeechobee, the C-43 Basin, and the Tidal Basin. Total daily discharges and contributions were categorized by water year and season. Daily TN and TP loads were calculated using measured daily inflows at S-79 and S-77, and TN and TP concentrations were determined from water samples at the structure. The contribution of the Tidal Basin to freshwater inflow and nutrient loads was estimated using a linear reservoir modeling approach. Flows and loads from the Coastal Subbasin were not estimated as they do not discharge into the CRE. The estimated daily loads from WY1997 through WY2016 were categorized by water year to evaluate temporal variations at different timescales. The monthly masses of TN and TP were summed for each water year and divided by the total volume of inflow that occurred each water year to drive annual FWM concentrations. Because the determination of FWM concentrations were derived using point source measurements of concentration and flow over finite time intervals at the structures, this calculation was not extended to the modeled estimates of concentration and inflow across the entire Tidal Basin.

Table 8C-5. Major contributing areas of the Caloosahatchee River Watershed.

Tier 1 Contributing Areas	Tier 2 Contributing Area	Flows and Loads
C-43 Basin	East Caloosahatchee/S-4	Measured
	West Caloosahatchee	Measured
Tidal Basin	Tidal Basin	Modeled
Lake Okeechobee	Lake Okeechobee via S-77 and S-79	Measured

The concentrations of TN and TP in the tributaries of the CRE were monitored at 16 stations in the Tidal Basin by Lee County and the City of Cape Coral from WY2000 through WY2016. These data were requested from the Lee County Department of Natural Resources (http://www.leegov.com/naturalresources) and City of Cape Coral. The monitoring data from the 16 stations along with the estimated freshwater inflows from the Tidal Basin were used to derive monthly time series of TN and TP loading to the CRE. These data were used to compute nutrient loads from the Tidal Basin.

Surface and bottom salinity observations were recorded every 30 minutes at six stations in the CRE: S-79, Bridge 31, Ft. Myers, Cape Coral, Shell Point, and Sanibel Island Bridge (**Figure 8C-14**). The station at I-75 (ValI75) was temporarily removed due to bridge construction and, therefore, measurements for WY2016 were not collected. Daily surface and bottom salinity values were averaged together to visualize temporal variations. Additionally, critical criteria for surface salinities at Ft. Myers and the I-75 Bridge were derived relative to tape grass habitat requirements (Doering et al. 2002). These data were used to calculate moving averages and the percentage of days above or below the specified critical criteria.

Water column properties were determined from sampling at a depth of 0.5 m at 10 stations in the CRE, San Carlos Bay, and Pine Island Sound at approximately monthly intervals (**Figure 8C-14**). Three stations (CES04, CES06, and CES08) with the most complete records were selected to characterize estuarine water quality. Concentrations of TN, TP, and Chla[1] from WY2000 through WY2016 were assessed for this report.

Seagrass was monitored 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 8C-14**) ranging in size from 1.0 to 2.0 acres (0.4 to 0.8 ha). The study sites run from the oligohaline zone of the upper portion of the river down to the euryhaline areas in San Carlos Bay. Within each site, 30 randomly distributed points are generated for each monitoring event. Each

[1] Note that all Chla concentration data reported for the CRE in this report represent corrected Chla values.

point is navigated to using submeter accuracy GPS and is monitored using a 1-m^2 quadrat subdivided into 25 equal quadrants. Presence/absence of seagrass within each quadrant of each quadrat is determined. Additionally, canopy height (cm) for the dominant species is determined per quadrat. Using these measures, a seagrass biomass index (BI, range: 0 to 10) is calculated for each site for each monitoring event (the index is calculated for each quadrat and averaged for the site per date, n = 30) as the following:

$$BI_{seagrass} = \left[\frac{seagrass\ count\ per\ quadrat}{maximum\ possible\ count} \times \frac{seagrass\ canopy\ height\ per\ quadrat}{maximum\ mean\ canopy\ height\ per\ site}\right] \times 10$$

Sites 2, 4, 5, and 7 were selected for this report because they span the salinity gradient in the CRE and have the most complete data records. Daily salinity at Ft. Myers, Shell Point, and Sanibel were superimposed with the SAV community composition at corresponding site from WY2010 through WY2016.

Oyster monitoring has been ongoing at multiple sites in the lower CRE since WY2001 (**Figure 8C-14**). The primary site for this report is Bird Island near Shell Point (Volety et al. 2009, Balci and Bertolotti 2012). The Bird Island site was selected for its central location in the lower CRE and data set completeness. Four basic oyster population metrics were included for interpretation. Live oyster densities have been estimated at each of these sites seasonally since WY2005. Oyster larval (spat) abundances were monitored at each sampling site every 1 to 2 months. The prevalence and infection intensity of the protozoan pathogen Dermo at each sampling site were assessed at monthly intervals. Seasonal time series for each of these variables were derived for each site from WY2007 through WY2016. Average daily salinity in the lower CRE for the POR was superimposed with the oyster population metrics.

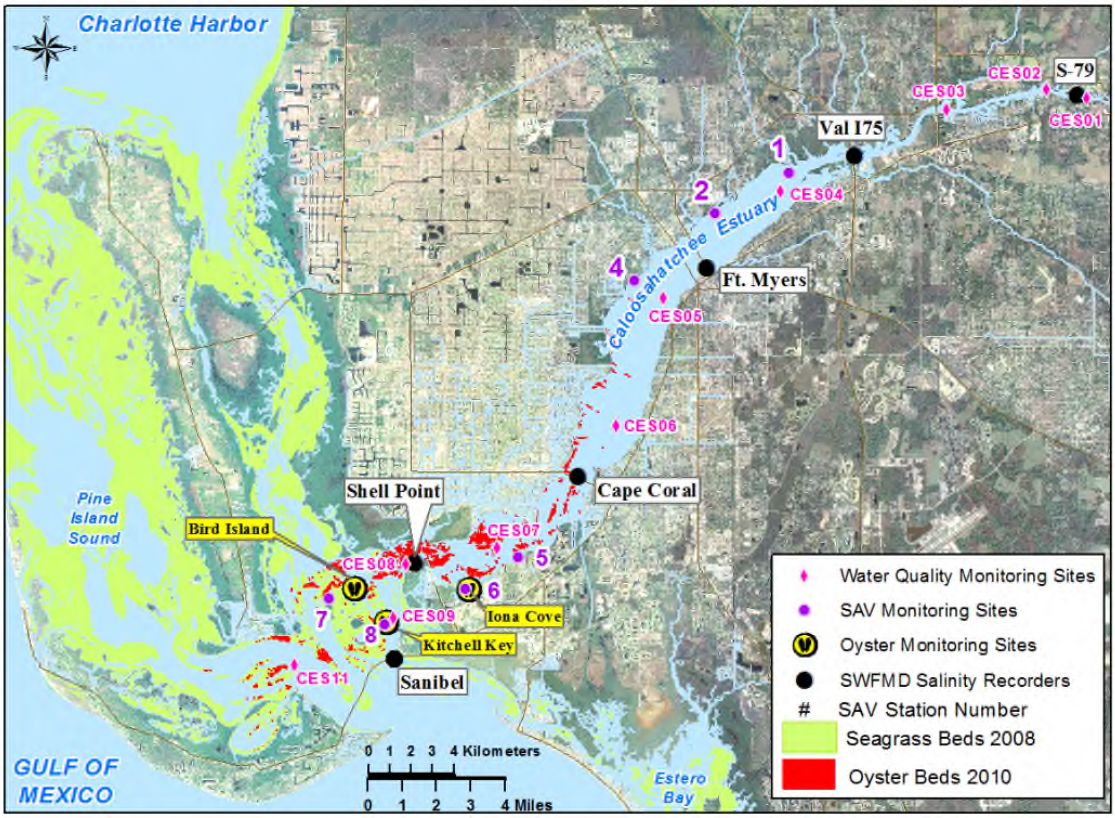

Figure 8C-14. Monitoring locations of salinity, water quality, and living aquatic habitat (oysters and SAV) for the CRE; includes depiction of the distribution of SAV habitat in the lower CRE, Matchalas Pass, and Pine Island Sound.

WY2016 data were compared to the long-term average and two previous water years (WY2014 and WY2015) to characterize the hydrological and ecological conditions of CRE.

Results and Discussion

Rainfall

The daily rainfall over the past three water years (WY2014–WY2016) is presented in **Figure 8C-15**. The annual rainfall and wet and dry season percentages for the long-term average and the past three water years are presented in **Figure 8C-16**. In WY2016, the total rainfall to the Caloosahatchee River Watershed was 60.19 inches (152.9 cm), with 64.9 percent in the wet season and 35.1 percent in the dry season. This amount of WY2016 rainfall was 22 percent higher than the long-term average (WY1997–WY2016; 49.41 inches or 125.5 cm), 29 percent higher than WY2015 (46.67 inches or 118.5 cm), and slightly higher (3 percent) than WY2014 (58.35 inches or 148.2 cm). The rainfall during the dry season of WY2016 was 21.13 inches (53.7 cm), which was noticeably higher than the long-term average (11.36 inches or 28.9 cm) dry season rainfall and that occurring in recent dry seasons of WY2014 (11.34 inches or 28.8 cm) and WY2015 (12.07 inches or 30.7 cm) (**Figure 8C-16**). The relatively high dry season rainfall in WY2016 is a reflection of El Niño conditions. Interestingly, the highest daily rainfall (2.83 inches or 7.2 cm, January 26, 2016), the second highest (2.28 inches or 5.8 cm, January 17, 2016), and the third highest (2.08 inches or 5.3 cm, December 2, 2016) all occurred during the WY2016 dry season (**Figure 8C-15**).

Spatially, in WY2016, the greatest rainfall was observed in the Tidal Caloosahatchee Basin (72.07 inches or 183.1 cm) and the least was in the S-4 Basin (46.10 inches or 117.1 cm) (**Figure 8C-17**). Generally, the Coastal Basin and Tidal Caloosahatchee Basin have higher rainfall than basins further inland (West Caloosahatchee, East Caloosahatchee, and S-4 basins). This year's spatial pattern was similar to WY2014 and the long-term average POR (WY1997–WY2016).

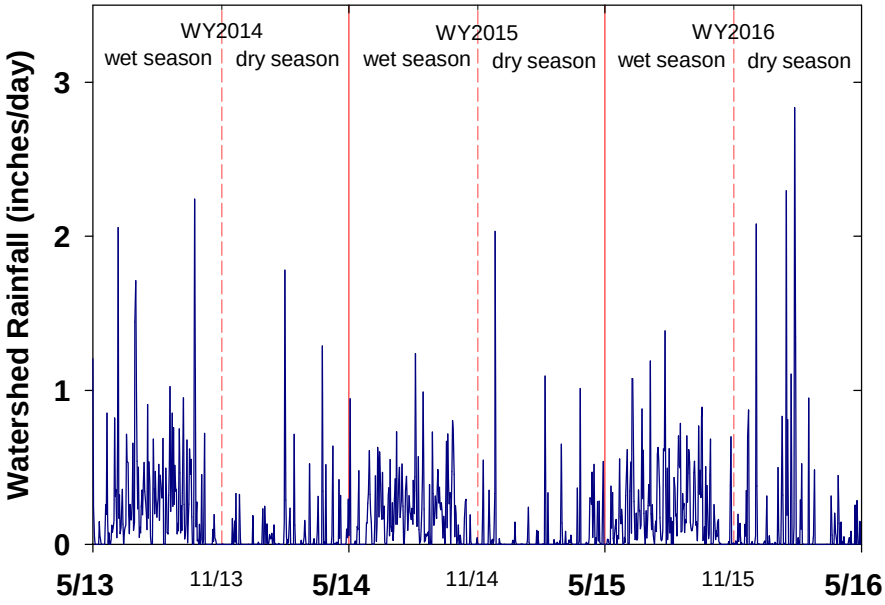

Figure 8C-15. Time series of total daily rainfall to the Caloosahatchee River Watershed WY2014–WY2016.

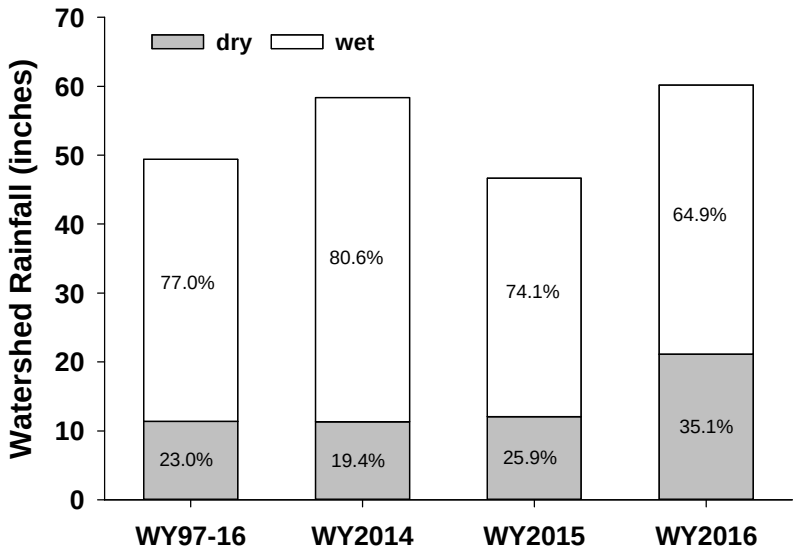

Figure 8C-16. Total rainfall to the Caloosahatchee River Watershed by water year and season, including the long-term average (WY1997–WY2016), WY2014, WY2015, and WY2016.

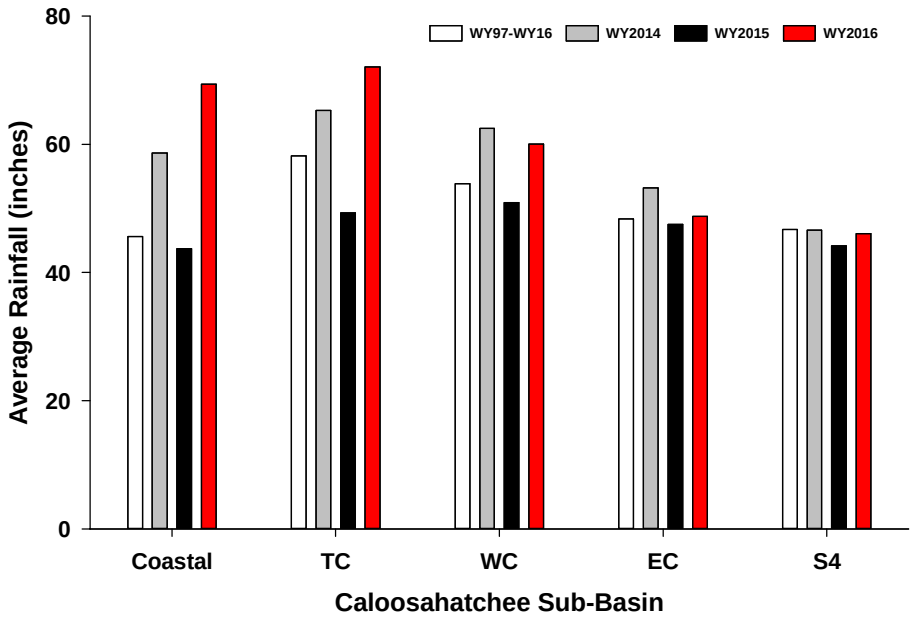

Figure 8C-17. Average annual rainfall to the Caloosahatchee subwatersheds, including the long-term average (WY1997–WY2015), WY2013, WY2014, and WY2015. Subbasins are Coastal, Tidal Caloosahatchee (TC), West Caloosahatchee (WC), East Caloosahatchee (EC), and S-4 (S4) (see **Figure 8C-13** for subwatershed locations).

Inflow

The total freshwater inflow to CRE includes the freshwater discharge at S-79 and the runoff from the Tidal Basin (downstream of S-79). The inflow through S-79 represents the combined contribution of rainfall-driven runoff from the East Caloosahatchee Basin (including S-4 Basin) and West Caloosahatchee Basin, as well as releases from Lake Okeechobee (**Figure 8C-13**). Runoff from S-4 flows into the C-43 canal through S-235 (culverts) just downstream of S-77. In the dry season, water is released to the CRE when available in order to help mitigate saltwater intrusion and maintain a preferred salinity level in the estuary when water is available under the Lake Okeechobee regulation schedule. For flood control and regulation of the lake water stage, water may be released from the lake during the wet season and even during the dry season when high rainfall occurs (e.g., atypical conditions that occurred during the dry season in WY2016).

In WY2016, a total inflow of 2.377 million ac-ft was discharged into the CRE, with 35.7 percent from Lake Okeechobee, 40.3 percent from the C-43 Basin, and 24.0 percent from the Tidal Basin (**Table 8C-6** and **Figure 8C-18**, panel a). This amount of freshwater inflow was less than in WY2014 (3.023 million ac-ft) but greater than in WY2015 (1.434 million ac-ft) and the long-term average (WY1997–WY2015, 1.801 million ac-ft).

Inflow at S-79 positively responded to rainfall (**Figure 8C-19**). The inflow from the lake was 0.850 million ac-ft in WY2016, less than in WY2014 (1.146 million ac-ft) and greater than in WY2015 (0.487 million ac-ft) and long-term average (0.576 million ac-ft). In contrast to more typical water year conditions, over half (59 percent) of the total flow to the CRE was delivered in the dry season during WY2016. The majority of inflow from Lake Okeechobee (87.3 percent) was also released in the dry season (**Figure 8C-19**) in response to high rainfall (**Figure 8C-16**). As a result, the flow in the dry season at S-79 was higher (67.6 percent) than the wet season (32.4 percent). The inflow from the Tidal Basin was (0.570 million ac-ft) in WY2016. Like rainfall, this value was greater than the previous two water years (WY2014 and WY2015) and the long-term average (WY1997–WY2016).

Table 8C-6. Summary of flow, TN, and TP from Lake Okeechobee, the C-43 Basin, and the Tidal Basin to CRE for the long-term average (WY1997–WY2016), WY2014, WY2015, and WY2016.

		WY97-16	WY14	WY15	WY16
FLOW	Total	1.801	3.023	1.434	2.377
(10^6 ac-ft)	Lake Okeechobee	0.576(32.0%)	1.146(37.9%)	0.487(33.9%)	0.850(35.7%)
	C-43 Basin	0.852(47.3%)	1.377(45.6%)	0.748(52.1%)	0.957(40.3%)
	Tidal Basin	0.373(20.7%)	0.500(16.5%)	0.200(13.9%)	0.570(24.0%)
TN	Total	2939.4	5087.4	2078.9	3566.5
(mt)	Lake Okeechobee	1016.0(34.6%)	1879.5(36.9%)	725.2(34.9%)	1589.5(44.6%)
	C-43 Basin	1494.0(50.8%)	2365.9(46.5%)	1171.2(56.3%)	1349.7(37.8%)
	Tidal Basin	429.4(14.6%)	842.0(16.6%)	182.5(8.8%)	627.3(17.6%)
TP	Total	279.0	418.5	215.5	301.7
(mt)	Lake Okeechobee	65.9(23.6%)	108.0(25.8%)	47.7(22.1%)	105.9(35.1%)
	C-43 Basin	166.7(59.8%)	268.8(64.2%)	144.9(67.2%)	140.0(46.4%)
	Tidal Basin	46.4(16.6%)	41.8(10.0%)	22.9(10.7%)	55.8(18.5%)

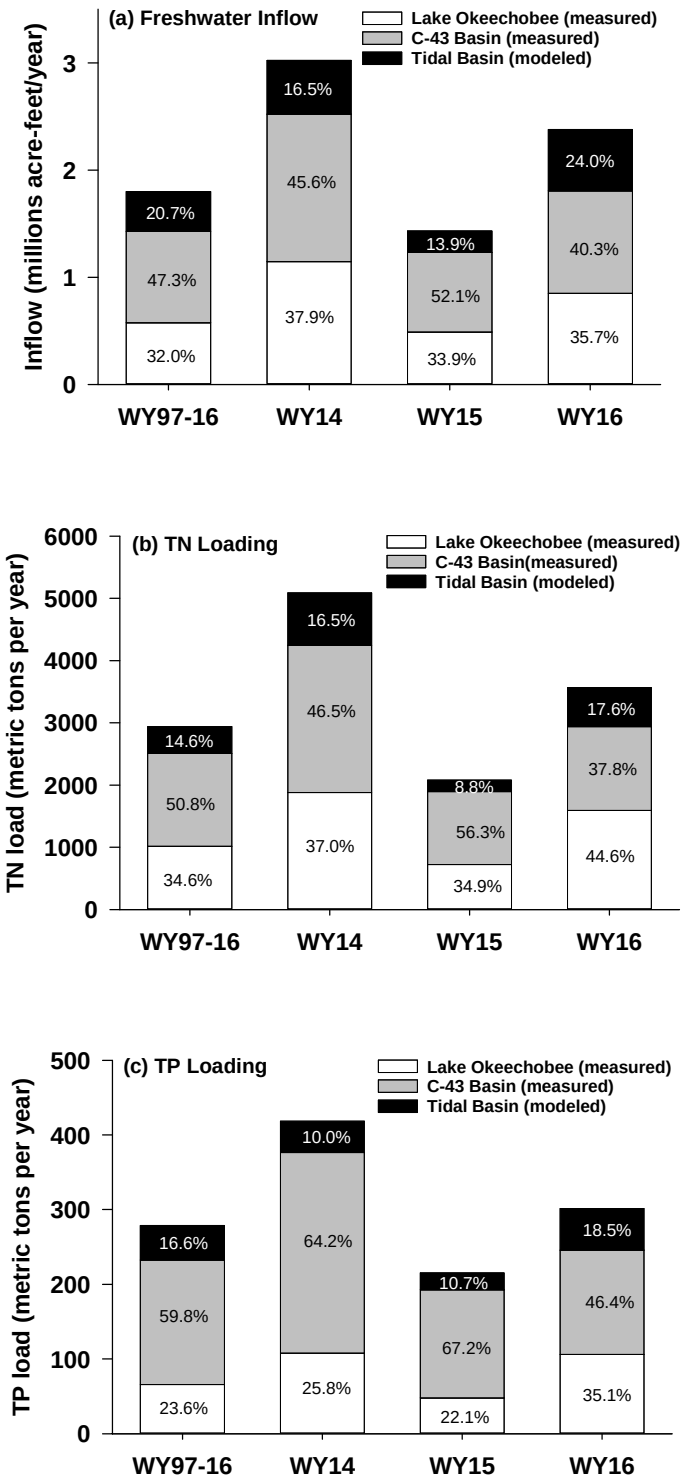

Figure 8C-18. Stacked bar chart for the (a) total freshwater inflow, (b) TN loading, and (c) TP loading attributable to Lake Okeechobee (white), the C-43 Basin (grey), and the Tidal Basin (black). This includes the long-term average from WY1997–WY2016, WY2014, WY2015, and WY2016. The Tidal Basin inflow was estimated using a linear reservoir approach.

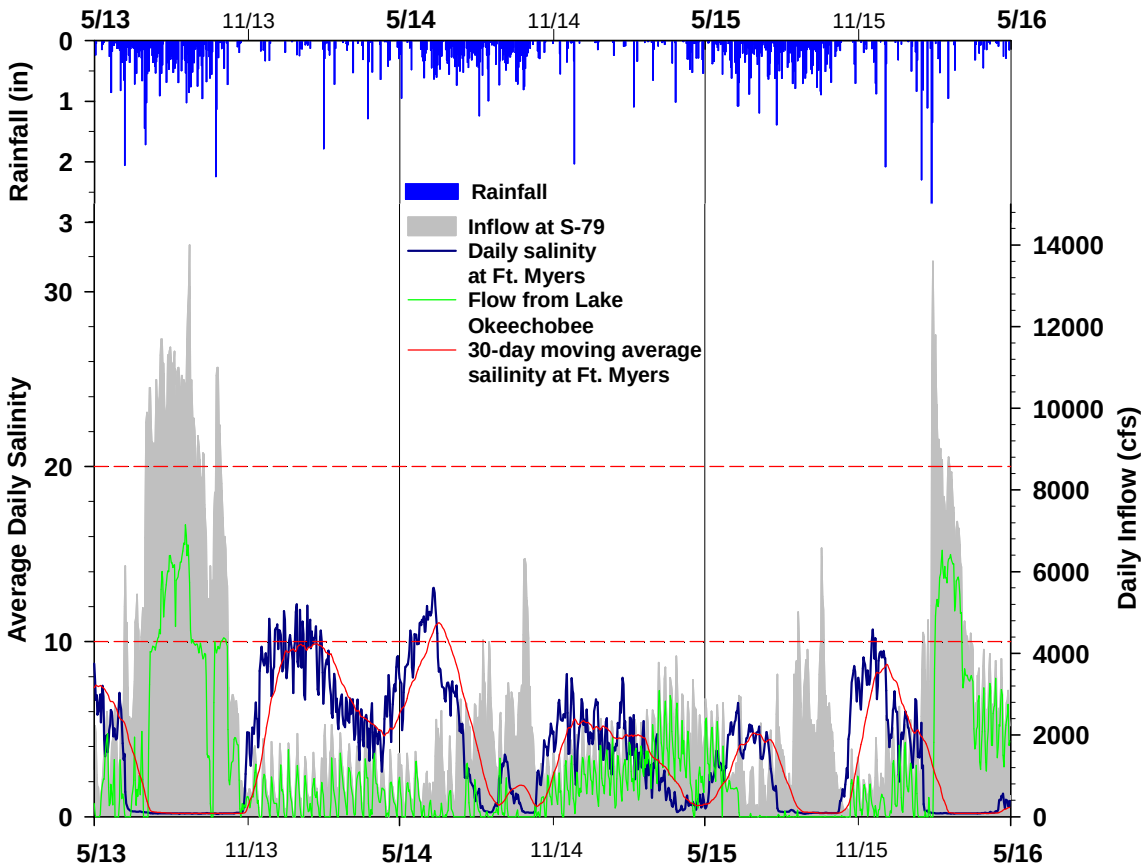

Figure 8C-19. Time series of total freshwater inflow at S-79 and surface salinity (Ft. Myers) in the CRE for WY2014–WY2016. Freshwater inflow at S-79 is the combination of the C-43 Basin and releases from Lake Okeechobee. Red dashed lines denote target salinities of 10 and 20 (see **Table 8C-7**).

Salinity

The 30-day average criterion of 10 at Ft. Myers was not exceeded during WY2016 at Ft. Myers (**Figure 8C-19** and **Table 8C-7**). This was better than the long-term average (28.0 percent, WY1994–WY2016) and previous two water years (6.3 percent for WY2015 and 25.2 percent for WY2014). This improvement in salinity level was attributed to high freshwater inflow from Lake Okeechobee and the Caloosahatchee River Watershed in the WY2016 dry season resulting from unusual high rainfall. Salinity conditions improved during WY2016; daily salinity at Ft. Myers ranged from 0.17 (observed on August 22, 2015) to 10.70 (observed on November 18, 2015), exhibiting a pattern inverse to that of freshwater inflow (**Figure 8C-19**). As in the two previous water years (WY2014 and WY2015), the daily salinity criterion of 20 was not exceeded in WY2016. (**Table 8C-19**).

Table 8C-7. Exceedances of critical salinity criteria at Ft. Myers for WY2014–WY2016 and the long-term average (WY1994–WY2016). At the Ft. Myers station, the daily average salinity goal is to not exceed 20 and the 30-day moving average goal is to not exceed 10. At the Val I75 site, the 30-day moving average is to not exceed 5. The POR for the long-term average for the Ft. Myers station is WY1994–WY2016 and the Val I75 station is WY2007–WY2015.

	Fort Myers		VALI75
Water Year	Days with salinity>20	Days with 30-day moving average salinity>10	Days with 30-day moving average salinity>5
WY1994-WY2016	5.8%	28.0%	35.9%
WY2014	0.0%	25.2%	0.0%
WY2015	0.0%	6.3%	0.0% [1]
WY2016	0.0%	0.0%	No Data [1]

[1] The data at VALI75 is available up to October 15, 2014. No data were collected for WY2016 and part of WY2015 because the station was temporarily removed for construction of I-75 Bridge and expected to resume after the construction.

Nutrient Loads and Inflow Concentrations

TN and TP loads to the CRE from Lake Okeechobee (measured), the C-43 Basin (measured), and the Tidal Basin (modeled), are presented in **Figure 8C-18**, panels b and c, respectively, and **Table 8C-6**. The measured annual TP and TN loadings to the CRE from S-79 are shown in **Figures 8C-20** for the long-term POR (WY1997–WY2016). TN and TP loads followed total freshwater inflow from WY1997 through WY2016, indicating that annual loads varied with the fluctuation of discharge.

In WY2016, the TN load to the CRE was 3566.5 mt and the TP load was 301.7 mt, both lower than WY2014 (TN, 5087.4 mt and TP, 418.5 mt) but higher than the long-term average (TN, 2939.4 mt and TP, 279.0 mt) and WY2015 (TN, 2078.9 mt and TP, 215.5 mt) (**Table 8C-6** and **Figure 8C-18**, panels b and c, respectively). Over the long-term, the C-43 Basin contributes most of the TN (50.8 percent) and TP load (59.8 percent) to the estuary followed by Lake Okeechobee (TN, 34.6 percent and TP, 23.6 percent); the Tidal Basin contributes the least (TN, 14.6 percent and TP, 16.6 percent). During WY2016, Lake Okeechobee contributed most of the TN load (44.6 percent), followed by the C-43 Basin (37.8 percent) and the Tidal Basin (17.6 percent). Regarding the TP load in WY2016, the relative distribution among sources was consistent with the long-term average and two previous water years. During WY2016, the C-43 Basin contributed the most (46.4 percent), followed by Lake Okeechobee (35.1 percent) and the Tidal Basin (18.5 percent (**Table 8C-6** and **Figure 8C-18**, panel c).

More than half of the total nutrient loads in WY2016, 60.6 percent of TN, and 52.9 percent of TP, were delivered in dry season. Nutrient loads from Lake Okeechobee followed the same atypical seasonal pattern, 67.7 percent of TN and 59.2 percent of TP occurred in dry season due to the high release from the lake resulting from high rainfall.

The TN:TP ratio of loading was approximately 11.8:1 in WY2016, slightly higher than the long-term average (10.5:1).

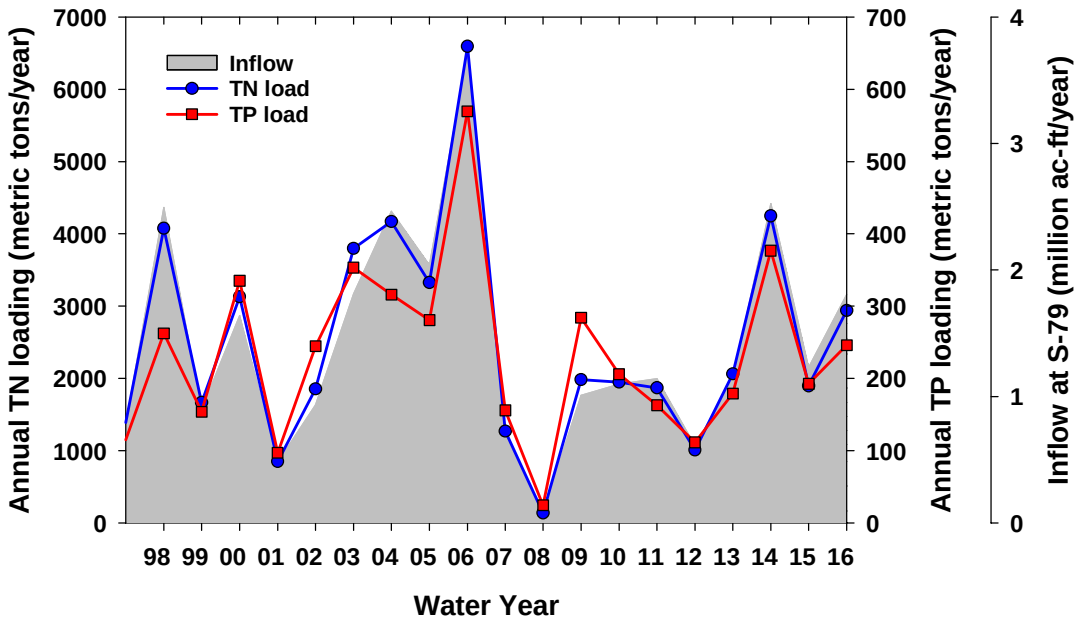

Figure 8C-20. Time series of average annual freshwater inflow (shaded area), TN (blue), and TP (red) loading from S-79 to the CRE from WY1997 through WY2016.

FWM TN and TP concentrations were calculated for the flow from Lake Okeechobee, and the East and West Caloosahatchee basins from WY1997 through WY2016 (**Figure 8C-21**, panels a and b, respectively). The annual FWM TN concentrations in WY2016 were 1.576 mg/L for Lake Okeechobee and 1.752 mg/L from the East Caloosahatchee Basin, both greater than the previous two water years (WY2014 and WY2015). The WY2016 FWM TN concentration of 1.325 mg/L for the West Caloosahatchee Basin was comparable to WY2014 and WY2015 (**Figure 8C-21**, panel a).

The annual FWM TP concentration for Lake Okeechobee in WY2016 (0.108 mg/L) was higher than the previous two water years, respectively. The WY2016 FWM TP concentrations from the East and West Caloosahatchee basins were 0.133 mg/L and 0.123 mg/L respectively, both within the historical (WY1997–WY2016) range (0.091–0.304 mg/L for East Caloosahatchee Basin and 0.105–0.243 mg/L for West Caloosahatchee Basin) (**Figure 8C-21**, panel b).

During WY2016, the lowest FWM TN concentration was in the flow from West Caloosahatchee Basin (**Figure 8B-21**, panel a), while the lowest FWM TP concentration was in the flow from Lake Okeechobee (**Figure 8B-21**, panel b). Both the highest FWM TN and TP concentrations were in the flow from East Caloosahatchee Basin.

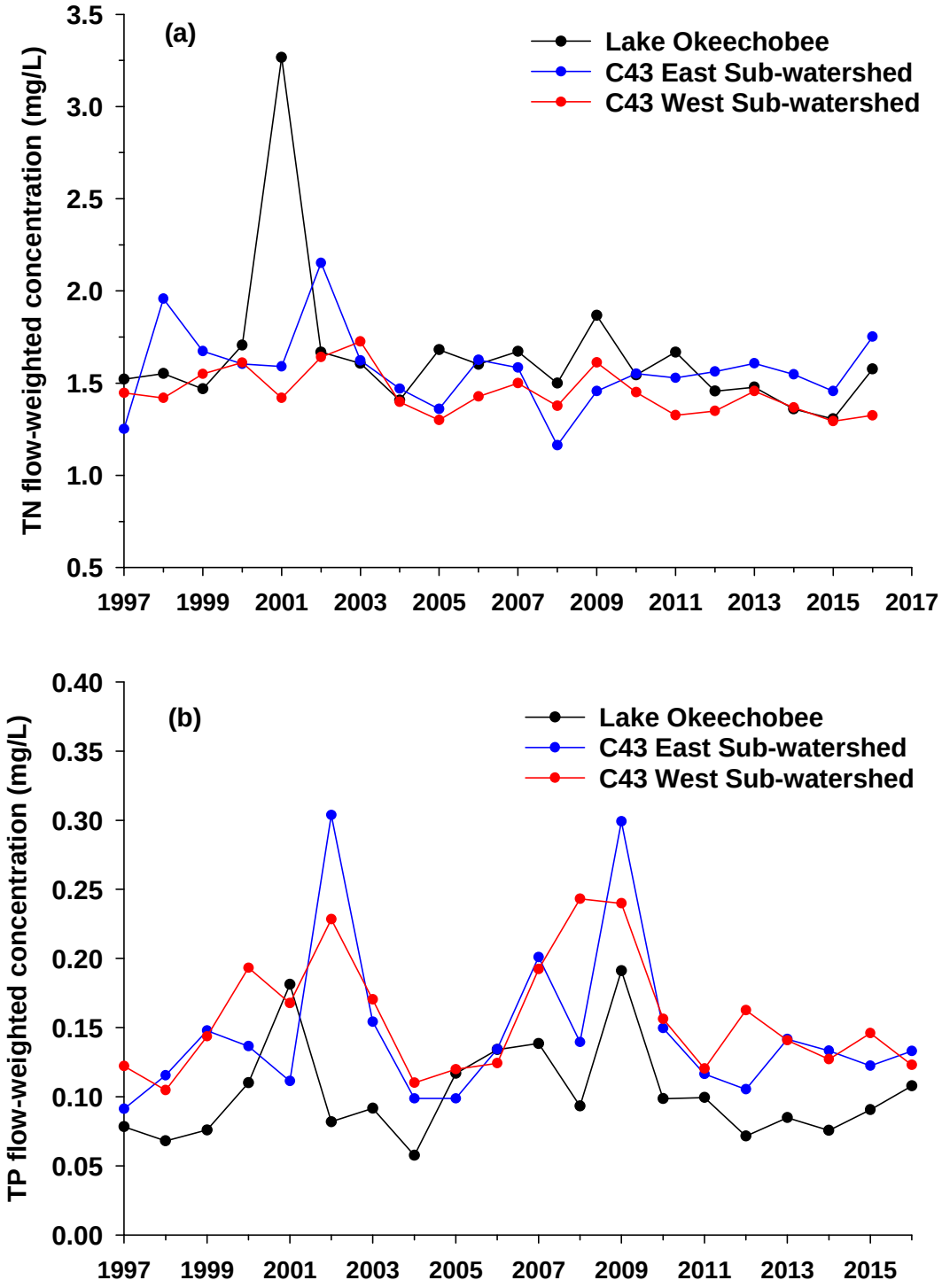

Figure 8C-21. Time series of FWM concentrations of (a) TN and (b) TP from Lake Okeechobee (solid black), and the Caloosahatchee East (blue) and West (red) subwatersheds (WY1997–WY2016).

In-Estuary Water Quality Results

To address water quality conditions in the CRE, Chla, TN, and TP concentrations in the water column at three sites (CES04, CES06, and CES08, **Figure 8C-14**) were used to calculate annual averages (and standard deviations) over the long-term POR (WY2000–WY2016), and average values for the most recent three water years (WY2014, WY2015, and WY2016) (**Table 8C-8**). For the selected water quality monitoring sites, CES04 is located in the upper estuary, and CES06 and CES8 represent the middle and lower estuaries, respectively.

Table 8C-8. Summary of water column concentrations chlorophyll *a* (Chl-*a*; µg/L), TN (mg/L), and TP (mg/L) at three stations (CES04, CES06, and CES08) in the CRE; includes dry season, wet season, and total averages and standard deviations (average ± standard deviations) from WY2000 through WY2016 and average values for WY2014, WY2015, and WY2016.

CES04	Chl-*a*			TN			TP		
	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total
Avg±SD	8.8±7.8	11.6±17.8	10.2±13.8	1.13±0.48	1.25±0.38	1.19±0.43	0.11±0.05	0.15±0.10	0.13±0.08
WY14	10.72	7.44	9.08	1.18	1.30	1.24	0.12	0.12	0.12
WY15	3.77	6.40	5.08	1.15	1.15	1.15	0.09	0.15	0.12
WY16	**2.97**	**4.95**	**4.20**	**1.16**	**1.07**	**1.10**	**0.09**	**0.12**	**0.11**

CES06	Chl-*a*			TN			TP		
	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total
Avg±SD	7.1±7.5	11.6±14.5	9.4±11.8	0.76±0.31	1.08±0.39	0.92±0.38	0.08±0.04	0.12±0.06	0.10±0.06
WY14	6.11	7.90	7.00	0.82	1.16	0.99	0.08	0.11	0.09
WY15	4.13	7.21	5.67	0.90	0.92	0.91	0.08	0.12	0.10
WY16	**7.74**	**5.14**	**6.12**	**0.98**	**0.94**	**0.96**	**0.08**	**0.11**	**0.10**

CES08	Chl-*a*			TN			TP		
	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total
Avg±SD	2.5±2.2	4.4±3.7	3.4±3.1	0.43±0.22	0.59±0.35	0.51±0.30	0.06±0.03	0.09±0.08	0.07±0.06
WY14	1.86	5.70	3.78	0.50	0.88	0.69	0.05	0.08	0.07
WY15	1.73	2.64	2.19	0.63	0.57	0.60	0.06	0.06	0.06
WY16	**3.00**	**2.68**	**2.80**	**0.73**	**0.75**	**0.74**	**0.06**	**0.08**	**0.07**

Over the long-term, annual average Chla concentrations exhibited a spatial gradient, being highest in the upper estuary (CES04) and lowest at CES08, with CES06 being intermediate (**Table 8C-8** and **Figure 8C-22**). Long-term average Chla concentrations also generally tend to be higher in the wet season than in the dry season. However, there are exceptions and, in particular, water year concentrations may not conform to these patterns (**Table 8C-8** and **Figure 8C-22**). In WY2016, annual average, wet season average and dry season average Chla were all highest at CES06. This may reflect the above average discharges (> long-term average) at S-79 that occurred during this water year. As discharge increases, water in the upper estuary typically becomes darker (i.e., higher concentration of color, Chen et al. 2015) and the position of maximum Chla concentrations moves downstream (Doering et al. 2006). Both these effects, less light availability in the upper estuary and translation of the Chla maximum downstream, may account for lower than expected Chla in the upper estuary.

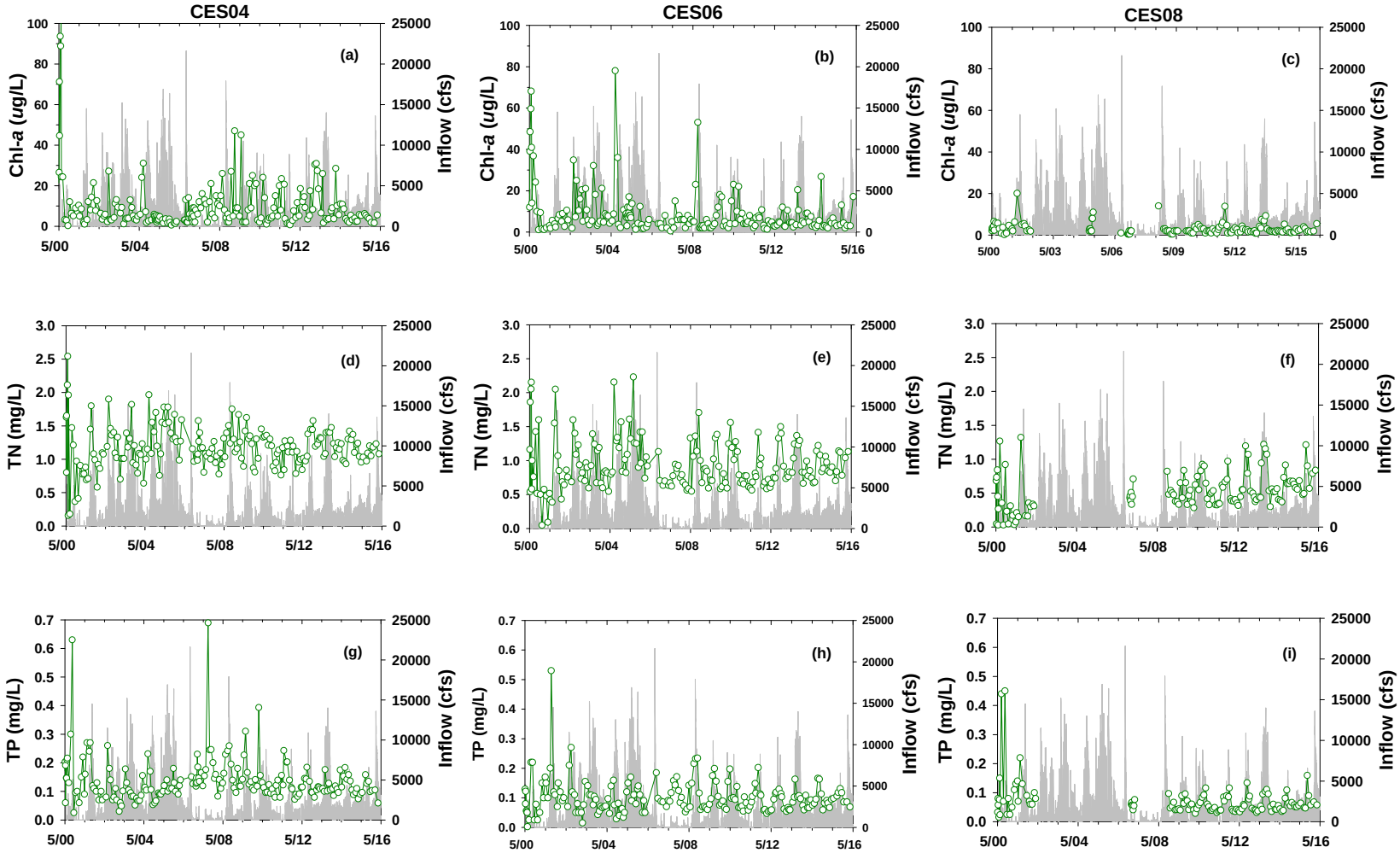

Figure 8C-22. Time series of chlorophyll *a* (Chl-*a*), TN, and TP (green line with open circle) at stations CES04, CES06, and CES08 in the CRE, and flow at S-79 (grey line) from WY2000 through WY2016.

The TN and TP concentrations at all three sites appeared generally proportional to the inflow from S-79 (**Figure 8C-22**, panels d through f for TN variation versus flow, and panels g through i for TP variation versus flow). Mixing of fresh water from the upstream watershed and Tidal Basin with ocean water in the CRE typically results in higher TN and TP concentrations in the upper estuary (CES04) and lower TN and TP concentrations in the lower estuary (CES08), with intermediate concentrations in the middle estuary (CES06) (**Table 8C-8**). This spatial pattern was also repeated in WY2016.

Over the long-term, TN and TP concentrations were slightly higher at all three stations during the wet season than during the dry season, except for WY2016 dry season TN concentrations at CES04 and CES06, which were slightly higher than in the wet season (**Table 8C-8**). This was perhaps due to the relatively high dry season discharges associated with El Niño.

Ecological Indicator Results

Four seagrass monitoring stations (sites 2, 4, 5, and 7) (**Figure 8C-14**) were selected for evaluation of SAV trends and conditions within the CRE. The biomass index was calculated for seagrass data from WY2010 through WY2016 (**Figure 8C-23**). The distribution and abundance of different SAV populations are influenced by the availability of submarine light and nutrients, seasonal shifts in water temperature and plant physiology, grazing by macro- and mega-fauna, and salinity (Duarte et al. 2007, Lee et al. 2007, Lirman et al. 2008, Buzzelli et al. 2012). Site 2 is located in the upper estuary just northeast of Ft. Myers and is heavily influenced by runoff mainly from four rivers (Telegraph Creek, Orange River, Trout Creek, and Doughtrey Creek) and freshwater discharges from S-79. Salinities at the Ft. Myers Bridge have remained less than 10 (excluding a four-week period from mid-May to mid-June 2014 and 3 days in November 2015) since February 2014. Tape grass, which requires salinity < 10 for a sustainable population (French and Moore 2003) notably began to reappear in April 2015. In previous years, widgeon grass was the most abundant species at Site 2. By September 2015, species dominance had shifted to tape grass. Continued low salinities at Site 2 have resulted in a seasonal signal in the biomass index with higher biomass in the spring and summer growing season and lower biomasses in the winter (**Figure 8C-23**, panel a). Widgeon grass remained the dominant species at Site 4. Over the POR (WY2010–WY2016) at Site 4, the biomass index of widgeon grass appeared increase during periods of higher salinity and decline during periods of lower salinity. This pattern was repeated during WY2016 (**Figure 8C-23**, panel b). A similar trend with shoal grass was apparent at Site 5 (**Figure 8C-23**, panel c). The more halophilic species, shoal grass and turtle grass, were present at downstream Site 5 and Site 7. At Site 7, species dominance appeared to be related to salinity, with the presence of turtle grass typically being associated with higher salinity levels. The biomass index at Site 7 also tended to be proportional to salinity (**Figure 8C-23**, panel d). At all four sites, the biomass showed a seasonal fluctuation, being high in the summer wet season and low in the winter dry season in WY2016.

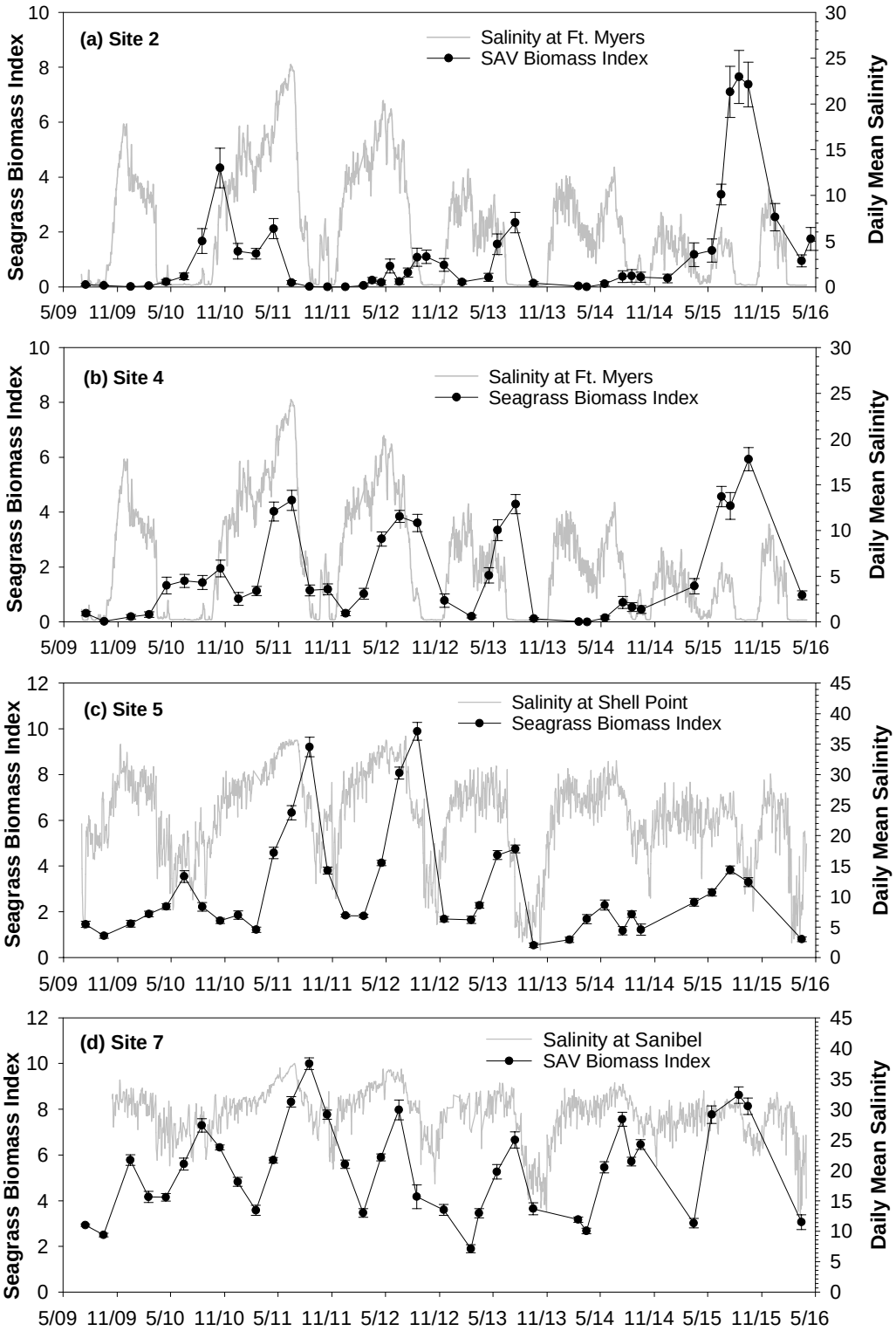

Figure 8C-23. Time series of seagrass biomass index for the SAV communities at (a) Site 2, (b) Site 4, (c) Site 5, and (d) Site 7 in the CRE from WY2010 through WY2016; includes the average daily salinity (grey area).

The distribution, density, and status of oyster habitat in the CRE varies greatly in time and space depending upon salinity, substrate availability, predation, and disease (Barnes et al. 2007, Volety et al. 2009, Buzzelli et al. 2013d, Parker et al. 2013). Temperature and salinity are two of the most important physical parameters that impact oyster populations (Shumway 1996, Parker 2015). Juvenile and younger stages of oysters are more susceptible to stressors such as salinity, temperature, food quality and quantity, predators, and dissolved oxygen (Shumway 1996, Volety et al. 2010, 2014). Higher salinities typically attract more predators and disease; thus, oysters at high salinities are more susceptible to predation and mortality (White and Wilson 1996). Ten-year salinities at Shell Point ranged from 2.3 to 37.6, with an average of 25.1 (**Figure 8C-24**). At this location, the salinity for WY2016 ranged from 3.1 to 30.3, with a yearly average of 20.4.

During the WY2007–WY2016 period, oyster densities at the Bird Island site in the lower CRE ranged from 436 oysters/m^2 in WY2008 up to 3,070 oysters/m^2 in WY2013 with an average of 1,744 oysters/m^2. In WY2016, the average of biannual oyster density at Bird Island was 1,789 oysters/m^2 with low of 1,643 oysters/m^2 and high of 1,934 oysters/m^2 (**Figure 8C-24**, panel a). The high densities of oysters found at this site demonstrated that the estuarine salinities continue to be favorable for larval recruitment and survival (Volety and Haynes 2015) with a mean salinity at 25 (± 10.3). In contrast, the Iona Cove site further upstream had densities ranging from none observed in WY2014 to 2,449 oysters/m^2 counted in WY2013. Since the WY2014 die off, oyster densities have returned steadily, with the current water year count ending with 1,552 oyster/m^2 slightly below the 10-year mean (**Figure 8C-25**). Salinities dropped below 16 both in fall 2012 and again for an extended period in fall 2013. These drops in salinity twice within a years' time may very well have caused serious stress on the adult oyster population at the Iona Cove site causing the die off in WY2014. Salinities improved after winter 2013 and have stayed > 16 through spring 2016 thus allowing oysters to thrive and steadily increase in densities.

Larval (spat) recruitment at Bird Island ranged from 0 to 148 spat/shell/month (**Figure 8C-24**, panel b), with a 10-year average of 10 spat/shell/month and the highest monthly recruitment occurring in June 2010. Overall, the larval recruitment rate was significantly greater in the wet season, with a mean of 17.1 spat/shell/month and the dry season averaging 2.6 spat/shell/month over the POR (WY2007–WY2016). This trend across seasons was also observed in WY2016. Larval recruitment generally varied from water year to water year, with WY2008 having the lowest average yearly recruitment rate (1.1 spat/shell/month) and WY2011 having the highest yearly average recruitment rate (21.1 spat/shell/month) at the Bird Island site. WY2016 yearly average (10.2 spat/shell/month) fell close to the 10-year average.

At the Bird Island oyster site, prevalence or the percentage of oysters infected with the marine protozoan Dermo over the 10-year period (WY2007–WY2016) ranged from 20 to 100 percent (**Figure 8C-24**, panel c) with an average of 77 percent. While the yearly means of Dermo prevalence have been relatively high (ranging from 64 to 92 percent), the intensity or amount of infection in each oyster with Dermo has been generally minimal with a 10-year annual average of 1.3 (**Figure 8C-24**, panel d). In WY2016, Dermo prevalence (89 percent) was above the 10-year average, with an intensity (1.0) below the 10-year average.

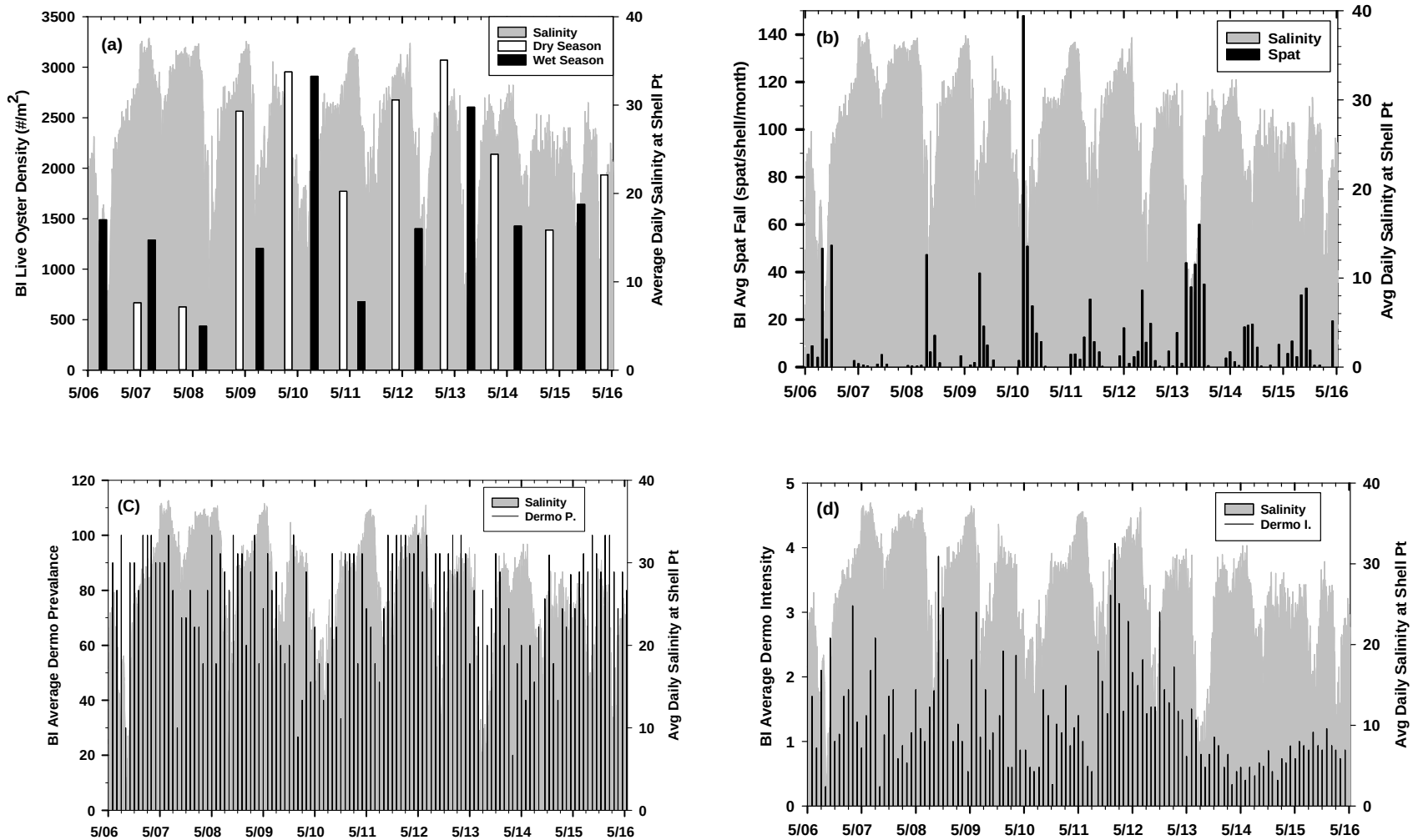

Figure 8C-24. Time series for (a) average live oyster density, (b) larval (spat) recruitment, and the (c) prevalence and (d) intensity of the oyster-specific pathogen, Dermo, from WY2007 through WY2016 at Bird Island (BI). The average salinity in the lower CRE is included in each time series. (Note: The data for the SLE oysters was provided by the following contractor: Aswani Volety, PhD, Florida Gulf Coast University, Ft. Myers, FL)

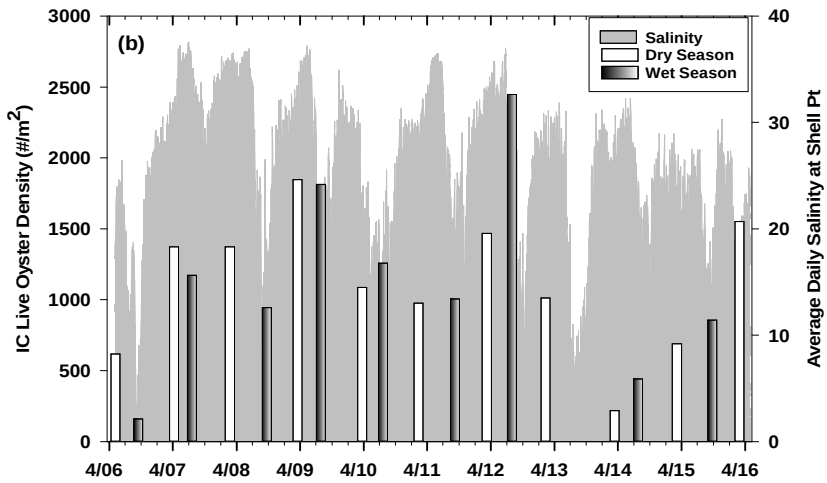

Figure 8C-25. Time series for average live oyster density from WY2007 to WY2016 at Iona Cove (IC). The average salinity in the lower CRE is included in the time series. (Note: The data for the SLE oysters was provided by the following contractor: (Note: The data for the SLE oysters was provided by the following contractor: Aswani Volety, PhD, Florida Gulf Coast University, Ft. Myers, FL)

SIGNIFICANT FINDINGS FOR WY2016 IN THE CALOOSAHATCHEE RIVER ESTUARY

- In WY2016, the total rainfall to the Caloosahatchee River Watershed was 60.19 inches (152.9 cm), which was 22 percent higher than the long-term average (WY1997–WY2016; 49.41 inches or 125.5 cm), 29 percent higher than WY2015 (46.67 inches or 118.5 cm), and slightly higher (3 percent) than WY2014 (58.35 inches or 148.2 cm). The rainfall in the WY2016 dry season was 21.13 inches (53.7 cm, 35.1 percent of annual rainfall), which was noticeably higher than the long-term average dry season rainfall and that occurring during the WY2014 and WY2015 dry seasons.
- During WY2016, a total inflow of 2.377 million ac-ft was discharged into CRE, with 35.7 percent from Lake Okeechobee, 40.3 percent from the C-43 Basin, and 24.0 percent from the Tidal Basin. The inflow from the lake was 0.850 million ac-ft in WY2016, notably less than in WY2014 (1.146 million ac-ft) but significantly greater than both in WY2015 (0.487 million ac-ft) and the long-term average (WY1997–WY2016, 0.576 million ac-ft). The majority of inflow from Lake Okeechobee (87.3 percent) was released in the dry season.
- Salinities at the Ft. Myers station were favorable for the estuary, as both the daily average salinity goal (< 20) and the 30-day average goal (< 10) were not exceeded this current water year.
- Chla concentrations in the middle estuary at site CES06 were higher than both the upper estuary site CES04 and lower estuary site CES08 during the WY2016 and WY2014 wet seasons and the WY2016 dry season. Significant amounts of flow were released through S-79 in those three seasons. This was evidence that increased flow at S-79 pushes the location of the maximum Chla concentration downstream.

- In WY2016, the TN load to the CRE was 3,566.5 mt and the TP load was 301.7 mt, both less than WY2014 (TN, 5087.4 mt and TP, 418.5 mt) and greater than in WY2015 (TN, 2078.9 mt and TP, 215.5 mt) and the long-term average (WY1997–WY2015; TN, 2939.4 mt and TP, 279.0 mt). Lake Okeechobee contributed most of this annual TN load (44.6 percent) while the C-43 Basin contributed most of this annual TP load (46.4 percent). More than half of the total nutrient loading in WY2016, 60.6 percent of TN and 52.9 percent of TP, unusually occurred in the dry season. Nutrient loads from Lake Okeechobee followed the same seasonal pattern, with 67.7 percent of TN and 59.2 percent of TP delivered in the dry season.
- In general, higher TN and TP concentrations occur in the upper estuary (CES04), with progressively lower concentrations downstream at CES06 (middle estuary) and CES08 (nearest the ocean). This spatial variation pattern was repeated in WY2016. Nutrient concentrations were generally greater in the wet than dry season. TP concentrations exhibited this seasonal pattern at all three stations in WY2016. TN showed this pattern only at CES08, whereas TN concentrations observed at CES04 and CES06 during the dry season were higher than in the wet season.
- The biomass of seagrasses showed a seasonal fluctuation with higher values in the wet season and lower values in the dry season in WY2016. The biomass index at Site 2 (tape grass) appeared inversely related to salinity whereas, at Sites 4 (widgeon grass), 5 (shoal grass), and 7 (turtle grass and shoal grass), the biomass index was relatively proportional to salinity level.
- Oyster densities continued to remain high at the Bird Island site and rebound at the Iona Cove site from no oysters counted in WY2014 to 1,934 counted in WY2016. Overall, the larval settlement rate continued to be greater in the wet season.

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