Chapter 2: South Florida Hydrology and Water Management

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SUMMARY

Given hydrology's significance to the entire South Florida ecosystem and all aspects of regional water management, this chapter presents hydrologic data and analysis for Water Year 2016 (WY2016) (May 1, 2015–April 30, 2016). Similar information from previous water years is available in Chapter 2 of past *South Florida Environmental Reports* (SFERs) – *Volume I*. This year's chapter includes a brief overview of the regional water management system, hydrologic impact of WY2016 tropical systems, a major rainfall event in December 2015, the 2015-2016 strong El Niño impact on South Florida hydrology in comparison to the 1997-1998 strong El Niño, and WY2016 hydrology of several subregions and major hydrologic units within South Florida Water Management District (SFWMD or District) boundaries. Appendices 2-1 through 2-7 of this volume provide supplementary information for this chapter. The broad influences of water year hydrology on various aspects of the regionwide system are covered in most other Volume I chapters. The El Niño-Southern Oscillation (ENSO) climatic phenomenon is linked to South Florida hydrology. El Niño events result in increased rainfall in the dry season and La Niña events are associated with drought. Warming sea surface temperature (SST) of the tropical Pacific west of Peru that was observed in 2015 continued into 2016 resulting in a strong El Niño event comparable to the 1997–1998 event and resulted in a wet dry season.

WY2016 District areal average rainfall was 55.35 inches which is 2.6 inches above the historical average. As a result of the 2015-2016 strong El Niño, the dry season was wet and most rain areas had above average rainfall for the water year, except the East Everglades Agricultural Area (EAA), Palm Beach, Broward, and Everglades National Park (ENP). Rainfall deviations from historical average were Southwest Coast (+11.5 inches), Lower Kissimmee (+8.32 inches), East Caloosahatchee (+5.75 inches), Water Conservation Area (WCA) 1 and WCA-2 (+3.6 inches), WCA-3 (+3.55 inches), Lake Okeechobee (+3.38 inches), Big Cypress Basin (+3.32 inches), Miami-Dade (+3.13 inches), Martin/St. Lucie (+2,64 inches), Upper Kissimmee (+2.1 inches), West EAA (-0.61) inches, Broward (-2.93 inches), ENP (-3.53 inches), Palm Beach (-6.91 inches), and East EAA (-7.2 inches).

As a result of the 2015-2016 strong El Niño, the dry season months of November 2015 to February 2016 were very wet. January rainfall in most areas of the District and ENP was the wettest in 100 years. As a result, WCA-3A water level rose to record level of 11.50 feet (ft) National Geodetic Vertical Datum of 1929 (NGVD29) in mid-February 2016. On February 11, 2016, the Florida Department of Environmental Protection (FDEP) issued an emergency final order to SFWMD and the United States Army Corps of Engineers (USACE) to lower water levels deviating from existing water management practice. The order was accomplished in 90 days resulting in lowered water levels in WCA-3A.

[1] **Acknowledgments:** The authors acknowledge Andrew Neidrauer's contribution in providing Lake Okeechobee water levels, regulation schedule, and the water management decisions figure.

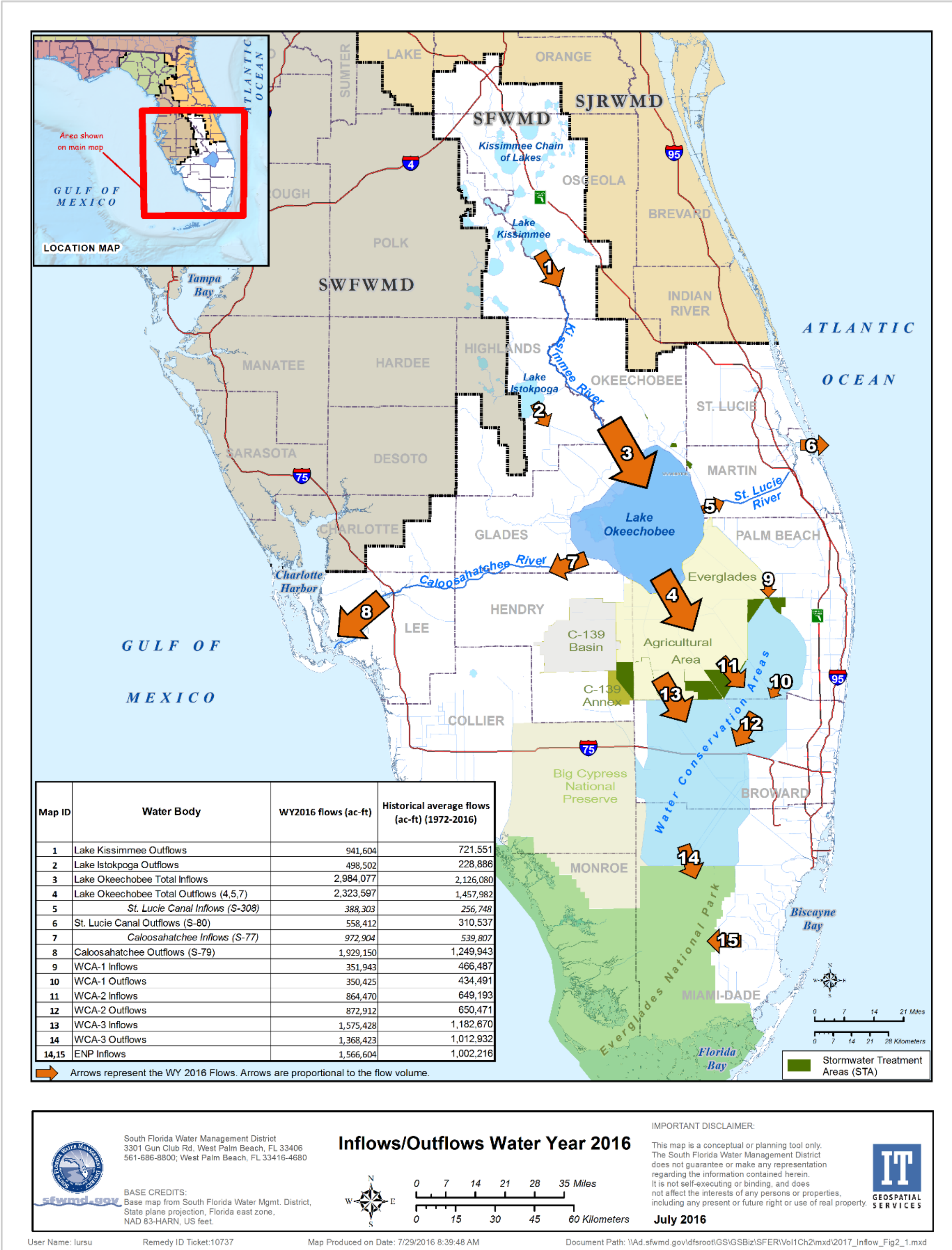
Lake Okeechobee—the main storage of the regional water management system—was at a stage of 13.84 ft NGVD29 on May 1, 2015. The lake stage reached the minimum of 11.98 ft NGVD29 on July 16, 2015, and started rising to the water year maximum stage of 16.40 ft NGVD29 by February 7, 2016, due to the wet dry season in the watershed. The lake stage reached 14.21 ft NGVD29 by the end of WY2016. The 2015-2016 El Niño influenced wet dry season is a factor in high lake stage at the end of April. During WY2016, there was no concern of water supply from Lake Okeechobee. In WY2016, the average stage in lakes and WCAs were higher than the historical average except Lake Kissimmee average stage.

Table 2-1 compares WY2016 flows to the last water year's flows and historical average flows. **Figure 2-1** presents WY2016 surface water flows for major hydrologic components in the regional system, along with historical average flows shown for comparison. Inflows and outflows in WY2016 were well above the historical average and that of WY2015.

Table 2-1. Summary of flows in acre-feet (ac-ft) for WY2016, the percent of historical average they represent, and their comparison to WY2015 flows. (Note: Structures used to calculate inflows and outflows into the major hydrological units are presented in Appendix 2-6 of this volume.)

Location	WY2016 Total Flow (ac-ft)	Percent of Historical Average	WY2015 Flow (ac-ft)
Northern Everglades			
Lake Kissimmee Outflows	941,604	130	1,170,556
Lake Istokpoga Outflows	498,502	218	446,215
Lake Okeechobee Inflows	2,984,077	140	2,831,832
Lake Okeechobee Outflows	2,323,597	159	1,933,353
Flows into St. Lucie Canal from Lake Okeechobee	388,303	151	129,227
Flows into St. Lucie Estuary through St. Lucie Canal	558,412	180	188,236
Lake Okeechobee Releases to St. Lucie Estuary [a]	369,844		80,250
C-44 basin runoff into St. Lucie Estuary [a]	188,568		107,986
Flows into Caloosahatchee Canal from Lake Okeechobee	972,904	180	575,971
Flows into Caloosahatchee Estuary through Caloosahatchee Canal	1,929,150	154	1,234,173
Lake Okeechobee Releases to Caloosahatchee Estuary [a]	849,042		486,598
Basin runoff into Caloosahatchee Estuary [a]	1,080,108		747,575
Southern Everglades			
WCA-1 Inflows	351,943	75	245,360
WCA-1 Outflows	350,425	81	198,051
WCA-2 Inflows	864,470	133	823,997
WCA-2 Outflows	872,912	134	810,056
WCA-3 Inflows	1,575,428	133	1,312,417
WCA-3 Outflows	1,368,423	135	779,167
ENP Inflows	1,566,604	156	1,015,301

a. Calculated.



Map ID	Water Body	WY2016 flows (ac-ft)	Historical average flows (ac-ft) (1972-2016)
1	Lake Kissimmee Outflows	941,604	721,551
2	Lake Istokpoga Outflows	498,502	228,886
3	Lake Okeechobee Total Inflows	2,984,077	2,126,080
4	Lake Okeechobee Total Outflows (4,5,7)	2,323,597	1,457,982
5	*St. Lucie Canal Inflows (S-308)*	*388,303*	*256,748*
6	St. Lucie Canal Outflows (S-80)	558,412	310,537
7	*Caloosahatchee Inflows (S-77)*	*972,904*	*539,807*
8	Caloosahatchee Outflows (S-79)	1,929,150	1,249,943
9	WCA-1 Inflows	351,943	466,487
10	WCA-1 Outflows	350,425	434,491
11	WCA-2 Inflows	864,470	649,193
12	WCA-2 Outflows	872,912	650,471
13	WCA-3 Inflows	1,575,428	1,182,670
14	WCA-3 Outflows	1,368,423	1,012,932
14,15	ENP Inflows	1,566,604	1,002,216

Figure 2-1. WY2016 and historical average inflow and outflow in acre-feet (ac-ft) into major hydrologic units of the regional water management system. (Note: The three arrows depicted from Lake Okeechobee represent lake outflows in inset.)

INTRODUCTION

THE SOUTH FLORIDA WATER MANAGEMENT SYSTEM: A REGIONAL OVERVIEW

The ecological and physical characteristics of South Florida have been shaped by years of hydrologic variation—ranging from extreme drought to flood—sometimes within a relatively short time period. The regional hydrology is driven by rainfall, rainfall-generated runoff, groundwater recharge and discharge, and evapotranspiration. Surface water runoff is the source for direct and indirect recharge of groundwater, lake and impoundment storage, and replenishments of wetlands. Excess surface water is discharged to the peninsula's coasts. Most of the municipal water supply is from groundwater that is sensitive to surface recharge through direct rainfall, runoff, or canal recharge. The general hydraulic gradient is north-to-south, where excess surface water flows from the Upper Kissimmee Basin in the north to the Everglades in the south, with water supply and coastal discharges to the east and west. The current hydraulic and hydrologic system includes lakes, impoundments, wetlands, canals, and water control structures managed under water management schedules and operational rules.

The development of South Florida requires a complex water management system to manage floods, droughts, and hurricane impacts. Excess water is stored in lakes, detention ponds, wetlands, impoundments, and aquifers, or is discharged to the coast to estuaries and the ocean. Information regarding the operation of the South Florida water management system is summarized in Abtew et al. (2011). As a major component of this system, Lake Okeechobee's storage capacity is over 3.54 million acre-feet (ac-ft) at an average lake level of 14.02 ft NGVD29—the largest of any hydrologic feature in South Florida. The lake is critical for flood control during wet seasons and water supply during dry seasons. Lake outflows are received by the EAA, St. Lucie River and Estuary, Caloosahatchee River and Estuary, Lake Worth Lagoon, and Everglades Stormwater Treatment Areas (STAs). The STAs discharge into the Everglades Protection Area. In drought conditions, some water from the lake is directly sent south for water supply to reduce transmission losses. Further details of these subregional flows are presented in the *Water Levels and Flows* section of this chapter.

Over an 18,000-square mile area, the District manages the region's water resources for flood control, water supply, water quality, and natural systems' needs under water management schedules based on specific criteria. The major hydrologic components are the Upper Kissimmee Chain of Lakes, Lake Istokpoga, Lake Okeechobee, EAA, Caloosahatchee and St. Lucie River basins, Upper East Coast (UEC), Lower East Coast (LEC), WCAs, Lower West Coast (LWC), and ENP. The Kissimmee Chain of Lakes (Lake Myrtle, Alligator Lake, Lake Mary Jane, Lake Gentry, Lake East Tohopekaliga, Lake Tohopekaliga, and Lake Kissimmee) is a principal source of inflow to Lake Okeechobee. Various groundwater aquifers are part of the water resources, with most of their water levels responding relatively quickly to changes in rainfall and surface water conditions.

Generally, the region is wet with an average annual rainfall of 53 inches. For water management purposes, the District has divided the region into 14 rainfall areas plus ENP (**Figure 2-2**). Rainfall for each area is reported daily, and multiple and overlapping gauges are used to compute average rainfall over each area. Real-time rainfall observations over the rainfall areas aid real-time water management decisions. Due to the relatively low gradient of regional topography, pumping is necessary to move water in the system. Across the region, the average pumping volume for Fiscal Years (October 1–September 30) 1995-1996 through 2014-2015 was 2.9 million ac-ft (**Table 2-2**). Fiscal Year 2014-2015 pumping was 3,023,409 ac-ft. In many cases, the same water is pumped in and out, as is the case with most of the Everglades STAs. The number of pump stations has increased from 20 to over 70 since 1996, with additional temporary pumps that vary in number from time to time. Some pumps are installed but not yet certified or registered and fully operational.

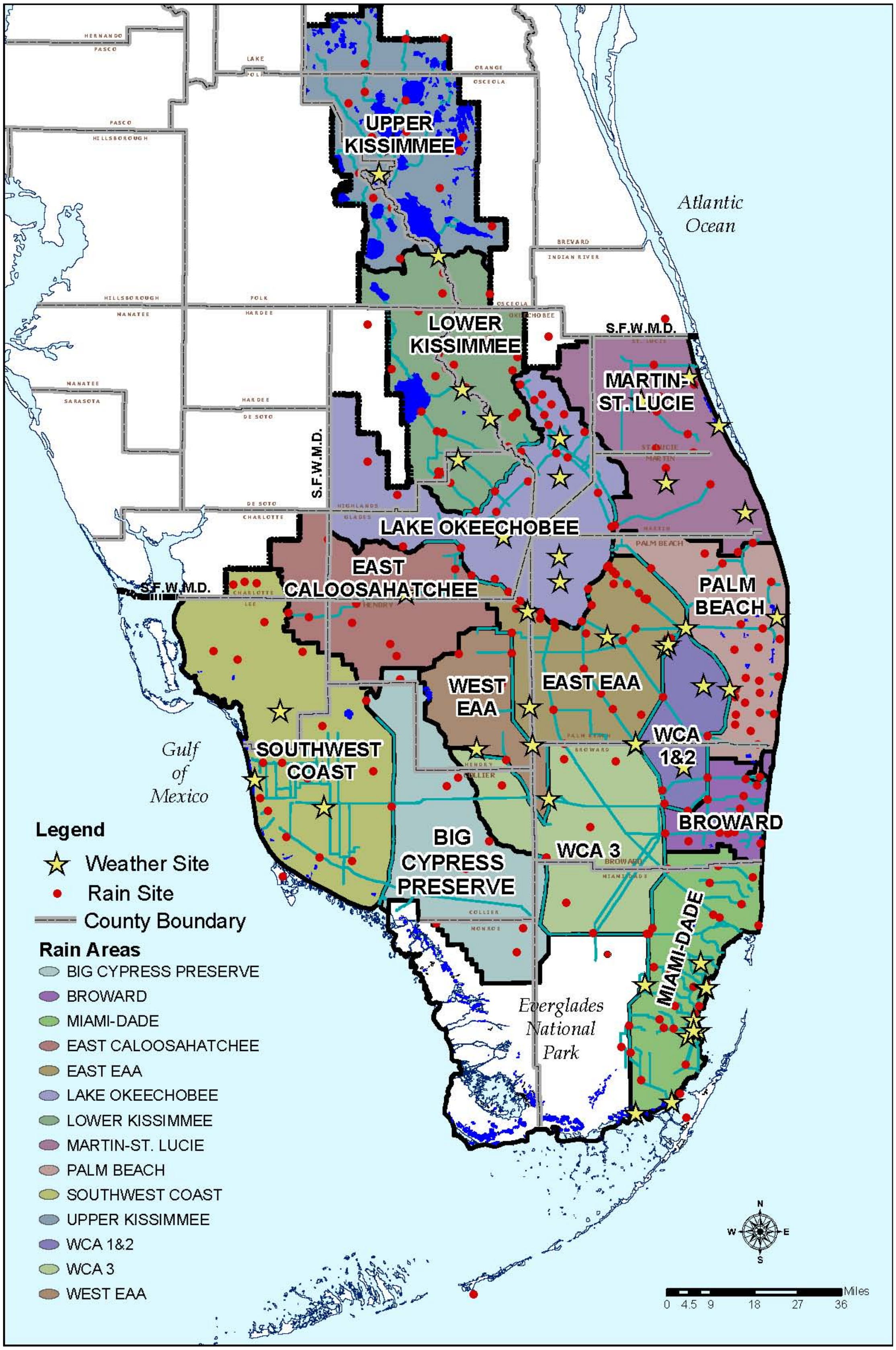


Figure 2-2. SFWMD rainfall areas.

Table 2-2. SFWMD water pumping volumes for Fiscal Year 1995-1996 through Fiscal Year 2014-2015.

Fiscal Year	Volume of Water Pumped (ac-ft)
1995-1996	2,480,000
1996-1997	1,840,000
1997-1998	2,020,000
1998-1999	2,090,000
1999-2000	2,517,000
2000-2001	2,131,000
2001-2002	3,131,000
2002-2003	3,339,000
2003-2004	3,404,000
2004-2005	3,938,000
2005-2006	3,583,000
2006-2007	1,281,000
2007-2008	3,767,700
2008-2009	3,660,000
2009-2010	3,031,622
2010-2011	1,584,057
2011-2012	3,254,308
2012-2013	4,419,510
2013-2014	3,445,573
2014-2015	3,023,409
Average	**2,897,009**

STORAGE OF LAKES AND IMPOUNDMENTS

Storage is required for both flood control and water supply in the regional water management system. The amount of storage volume available varies significantly from year to year due to large variations in rainfall and runoff both temporally and spatially. The impact of variation in rainfall amount and timing is reduced by managing available storage. Regulation schedules provide guidance for water level and storage management of lakes and impoundments. The regulation schedule for each water body is covered in the following sections where WY2016 water levels are discussed. Temporary modifications from normal regulation schedules for WY2016, if any, are also presented. Regulation schedule deviations include environmental needs, such as those of the Everglade snail kite (*Rostrhamus sociabilis plumbeus*), and construction and maintenance activities.

The combined average storage of the major lakes and impoundments is over 5.2 million ac-ft; Lake Okeechobee provides about 68 percent of this storage volume. During wet conditions and high flow periods, storage between the actual stage and maximum regulatory stage is limited and water has to be released. The successful operation of the system depends on timely water management decisions and the constant movement of water. Excess water is mainly discharged to the Gulf of Mexico, St. Lucie Estuary, Atlantic Ocean, and Florida Bay. Stage-storage relationships of lakes and impoundments are critical information for managing water levels and storage and computing average hydraulic residence time. Appendix 2-2 in the 2007 SFER – Volume I (Abtew et al. 2007a) presents the compiled charts for stage-storage for the major lakes and impoundments and stage-area relationships where data are available.

SELECTED HYDROLOGIC COMPONENTS

During WY2016, most of the District regions received above average rainfall. Conceptual descriptions of these areas are summarized in this section, while specific hydrology and structure flow information for each is presented in the *Water Management in Water Year 2016* section of this chapter.

Upper and Lower Kissimmee Basins

The Upper Kissimmee Basin comprises the Kissimmee Chain of Lakes with a drainage area of 1,596 square miles (Guardo 1992). Historically, the Kissimmee Chain of Lakes is hydraulically connected to the Kissimmee River; during the wet season, the lakes overflow into surrounding marshes and then into the river (Williams et al. 2007). Water from the Upper Kissimmee Basin is discharged into the Lower Kissimmee Basin as the outflow of Lake Kissimmee. The Lower Kissimmee Basin has a drainage area of 727 square miles (Abtew 1992). Flows are through the restored segments of the Kissimmee River and C-38 canal. Along the reaches of the river, there are four water control structures (S-65A, S-65C, S-65D, and S-65E) that regulate the river stage. At the terminal of the Kissimmee River, discharge from the S-65E structure flows into Lake Okeechobee as the main source of inflows to the lake. Overall, the Kissimmee Basin is an integrated system consisting of several lakes with interconnecting canals and flow control structures (see also Chapter 9 of this volume).

Lake Okeechobee

Lake Okeechobee is the largest lake in the southeastern United States. It is relatively shallow with an average depth of 8.9 ft and surface area of 436,300 acres at the average water surface elevation of 14.02 ft NGVD29. Water levels are regulated through numerous water control structures operated according to a seasonally varying regulation schedule. The lake serves multiple functions for flood control, water supply, recreation, and environmental restoration efforts. Chapter 8B of this volume discusses the status of Lake Okeechobee.

Everglades Agricultural Area

The EAA is an agricultural irrigation and drainage basin where, generally, ground elevation is lower than the surrounding area. During excess rainfall, runoff has to be pumped out of the area; during dry times, irrigation water supply is needed. Irrigation water supply during dry seasons comes mainly from Lake Okeechobee, with the WCAs as secondary sources. On average, about 900,000 ac-ft of water is discharged from and through the EAA to the south and southeast, historically, mostly discharging into the Everglades Protection Area (EPA) (Abtew and Khanal 1994, Abtew and Obeysekera 1996). Four primary canals (Hillsboro, North New River, Miami, and West Palm Beach) and three connecting canals (Bolles, Cross, and Ocean) facilitate runoff removal and irrigation water supply. Currently, runoff and drainage from the EAA is discharged to the Everglades STAs for treatment and released to the EPA. Additional information on the EAA and Everglades STAs is presented in Chapters 4 and 5B of this volume, respectively.

Upper East Coast

The main canal in the UEC is the St. Lucie River (C-44 canal). It runs from Lake Okeechobee to the St. Lucie Estuary. Inflows to the St. Lucie River are runoff from the basin and releases from Lake Okeechobee by operation of the S-308 structure according to regulation procedures described by USACE (2008). Downstream of S-308 is a gated spillway, S-80, that also receives inflows from the local watershed to the west and discharges to the estuary. The C-23 canal discharges into the North Fork of the St. Lucie River at structure S-48. The C-24 canal discharges into the same fork at the S-49 structure. The C-25 canal discharges into the southern part of the Indian River Lagoon at structure S-50.

Lower East Coast

The LEC includes urban areas in Palm Beach, Broward, and Miami-Dade counties. The purposes of the major canals in the LEC are flood control, prevention of overdrainage in the area, water supply, prevention of saltwater intrusion into groundwater, and conveyance of runoff to ENP when available. The system is also intended to improve water supply and distribution to ENP. It was designed to supply water during a 10-year drought and deliver minimum water needs to Taylor Slough and the C-2, C-4, C-1, C-102, C-103, and C-113 basins. The stages in canals are usually allowed to recede before supplemental water is introduced. Flow releases during major flood events are made according to established guidelines (USACE 1995). Lake Okeechobee is connected to the LEC through the major canals. During dry periods, flows from the WCAs and Lake Okeechobee are released to raise canal and groundwater levels. During wet periods, the canal network is used to move runoff to the ocean as quickly as possible.

Lower West Coast

The main canal in the LWC is the Caloosahatchee River (C-43 canal). It runs from Lake Okeechobee to the Caloosahatchee Estuary. Inflows to the Caloosahatchee River are runoff from the basin and releases from Lake Okeechobee by operation of the S-77 structure according to regulation procedures described by USACE (2008). Downstream of S-77 is a gated spillway, S-78, that also receives inflows from the local watershed. The outflow from the Caloosahatchee River (downstream of S-78) is discharged into the estuary via S-79, a gated spillway and lock operated by USACE. The operations of S-79 include managing stormwater runoff from the Caloosahatchee Watershed. The LWC includes large areas outside the drainage basin of the Caloosahatchee River.

WATER YEAR 2016 EXTREME HYDROLOGIC EVENTS

DECEMBER 2015 HEAVY RAINFALL EVENTS ON SOUTH MIAMI-DADE

December 3 to 6, 2015, south Miami-Dade experienced heavy rainfall causing flooding of farms (**Table 2-3** and **Figure 2-3**). The flooding caused crop loss for vegetable farmers of the area. The Miami Herald on December 14, 2015, citing the county agricultural manager, estimated crop losses between 40 and 100 percent. The paper also reported on December 15, 2015, that federal assistance was asked from the United States Department of Agriculture to declare flooded farm lands a disaster to get relief in the form of loans. Rainfall for the month of December 2015, measured at monitoring sites near the S-177, S-180, and S-20G structures (S177, S180, and S20G monitoring sites, respectively) and areal rainfall average for Miami-Dade rain area, were rare events as shown by the return period in **Table 2-4**.

Table 2-3. Early December 2015 high rainfall event in the Miami-Dade rain area.

Recording Date [a]	Rainfall (inches)			
	Miami-Dade Rain Area	S177	S18C	S20G
December 3, 2015	0.75	0.55	0.99	0.45
December 4, 2015	3.50	3.19	4.53	4.36
December 5, 2015	0.81	0.52	0.63	1.29
December 6, 2015	3.48	4.64	5.18	6.56
Total	**8.54**	**8.9**	**11.33**	**12.66**

a. Rainfall observation from 7:00 a.m. previous day to 6:59 a.m. recording day.

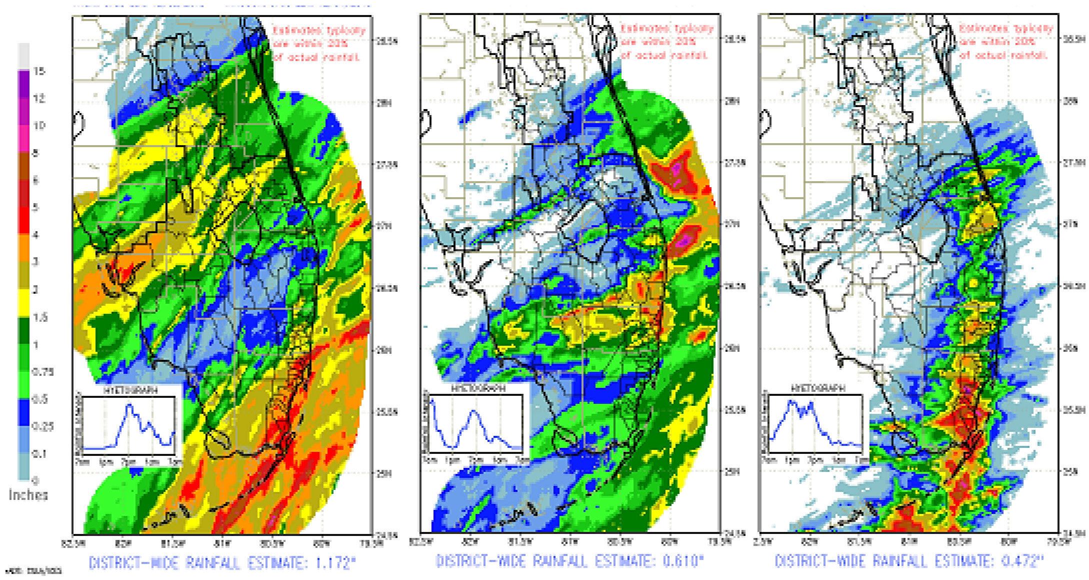


Figure 2-3. December 3, 4, and 5, 2015, high rainfall over southeastern Florida.

Table 2-4. December 2015 rainfall in the Miami-Dade rain area in comparison to historical data.

Month	Rainfall (inches)			
	Miami-Dade Rain Area	S177	S18C	S20G
December 2015	10.89	10.77	13.1	15.57
Estimated Return Period	> 100 year	> 100 year	> 100 year	> 100 year
Historical Average	1.75	1.93	2.34	2.48

There was another high rainfall event in the middle of September 2015 that was reported by the Palm Beach Post (September 18, 2015). Although, the rains came during a drought period, some flooding was reported in Broward County and Vero Beach. Part of the rain is from remnants of Tropical Storm Grace. From September 16 to 19, a site in St. Lucie (SVWX) received 11.2 inches and the Martin/St Lucie rain area received 4.68 inches of areal rainfall. Palm Beach rain area received 3.5 inches with Palm Beach International Airport receiving 4.5 inches. Broward rain area received 3.9 inches while a site in Broward (PMP) received 5.85 inches of rainfall. There was some localized flooding reported in Broward County.

HIGH WATER CONDITIONS AND EMERGENCY OPERATIONS

In December 2015 and January 2016, normally the dry season, South Florida experienced an extremely unusual amount of rainfall from El Niño conditions. In fact, January 2016 was the wettest in 100 years for most of South Florida. Rainfall over WCA-3A in January 2016 was 9.5 inches. This extraordinary natural phenomena resulted in WCA-3A extreme water level rise and caused severe impacts to natural resources. The rapid rise, especially since it occurred during a time of year when water levels are historically low, inundated tree islands and other wildlife habitat. Flooding eliminates nesting opportunities that can inhibit recovery of imperiled bird species. Sustained flooding seriously impacts and reduces population levels of white-tailed deer, nesting birds, and wading birds.

Immediate action beyond what was allowed under existing regulatory criteria was necessary to move significant volumes of water out of WCA-3A. On February 11, 2016, FDEP issued an emergency final order authorizing SFWMD and USACE to lower water levels by moving water out of WCA-3A to ENP through Shark River Slough.

Water levels in WCA-3A crested at elevation 11.50 ft NGVD29 in mid-February and returned to below the highest zone (Zone A) of the regulation schedule by May 9, 2016, after the emergency operations. Over 700,000 ac-ft of water was discharged from WCA-3A during the 90-day emergency operations period, February 12–May 11, 2016. ENP received approximately one-half million ac-ft of water during the emergency operations period. Approximately 60 percent went to Western Shark River Slough and 40 percent went to Northeast Shark River Slough.

SFWMD field station staff and crews and contractors constructed numerous temporary features to move more water and to mitigate the effects of higher water levels to wildlife, businesses, and communities. Construction activities included deployment of temporary pumps next to S-355B, rehabilitation of six earthen plugs in the L-28 borrow canal, installation of ramps and walkways with safety handrails and creation of dry land refuge for alligators and crocodiles for airboat vendors along Tamiami Trail, installation of temporary pumps in the C-358 seepage collection canal south of the Las Palmas community, construction of C-358 berm improvements and Richmond Drive ditch plugs to inhibit surface water flows to the C-358 canal, excavation of a temporary open connection between the C-358 and C-57 canals, installation of gated culverts with risers at the south end of the 8.5-Square Mile Area detention area, and securing authorization to degrade a portion of the S-327 weir in the S-332D detention area.

SFWMD maintained close coordination with USACE, FDEP, and other interested stakeholders in order to address in a timely manner any potential water quality, flood protection, or environmental resource issues. Interested stakeholders included the United States Department of Interior, Florida Department of Agriculture and Consumer Services, FWC, and Miccosukee Tribe of Indians of Florida.

SFWMD and USACE implemented emergency operations in a manner that minimized harmful impacts, including flooding and degradation of water quality, to the environment, the public, adjacent properties, and downstream receiving waters. SFWMD and USACE ensured that adverse off-site water resource related impacts did not occur and fully monitored conditions related to the activities authorized by the order. SFWMD and USACE implemented emergency operations that maximized beneficial impacts to the environment to the greatest extent practicable consistent with the hydrological and biological restoration goals of the Everglades.

SFWMD submitted $1.314 million of field operations expenses for the S-355B temporary pumps, Las Palmas community mitigation, and L-28 canal plug rehabilitation conducted during the emergency operations period to FDEP for reimbursement. Funds were made available by FDEP through a release of funds from the Land Acquisition Trust Fund for the Grants and Aids to Water Management Districts Wetlands Protection special category.

For more information see Appendix 2-1: Emergency Operations After Action Report, High Water Conditions in the South Florida Region, February 12–May 11, 2016.

WATER YEAR 2016 HURRICANE SEASON

WY2016 (2015 hurricane season) Atlantic, Gulf of Mexico, and Caribbean tropical activities stayed below normal with 11 named storms, as predicted. Four hurricanes developed (Danny, Fred, Joaquin, and Kate) with Danny and Joaquin becoming major hurricanes (**Figure 2-4**) (http://www.noaanews.noaa.gov/stories2015/120115-below-normal-atlantic-hurricane-season-ends-active-eastern-and-central-pacific-seasons-shatter-records.html).

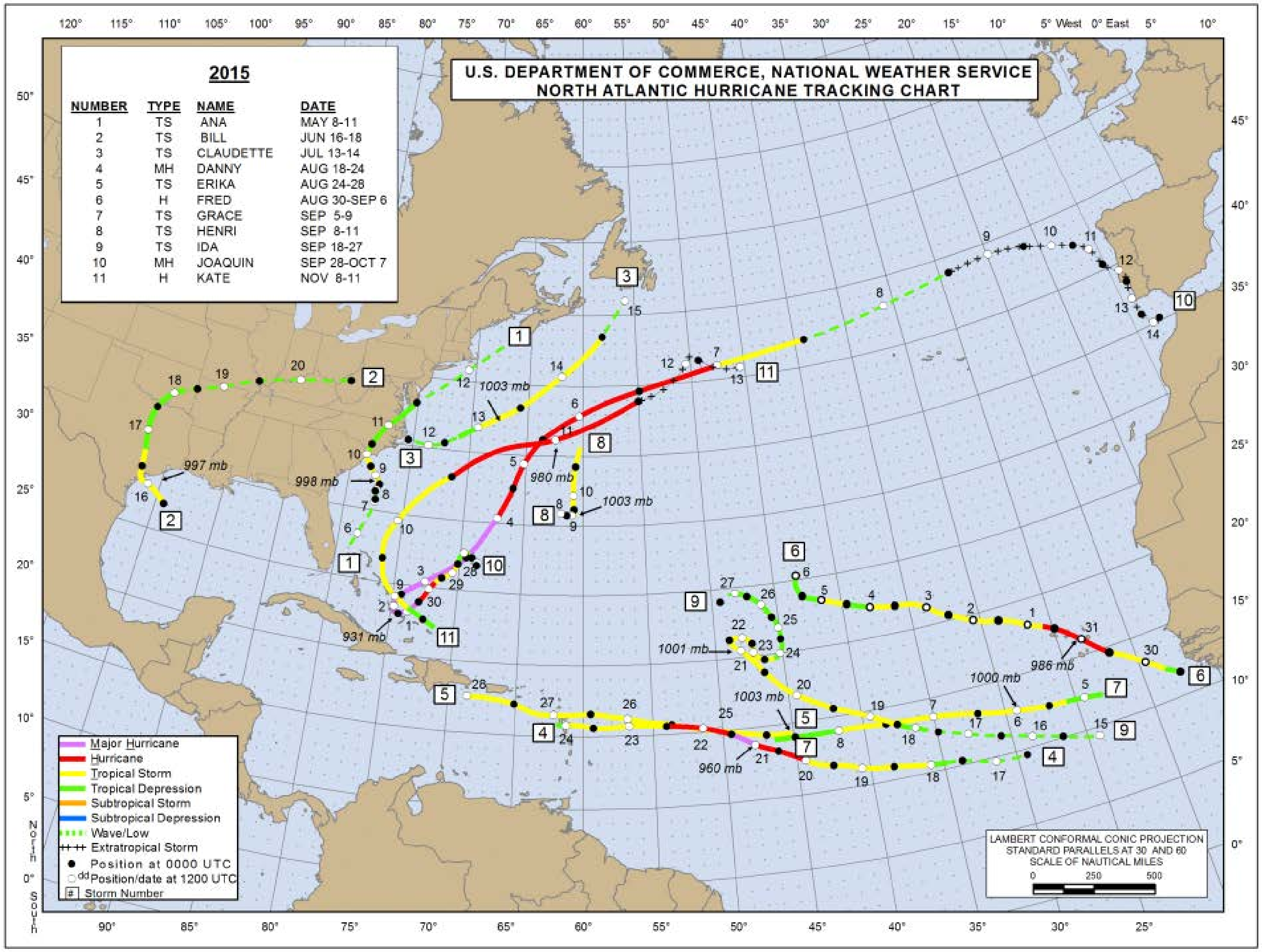


Figure 2-4. 2015 tropical systems tracks and durations (http://www.nhc.noaa.gov/data/tcr/index.php?season=2015&basin=atl). (Note: UTC – Coordinated Universal Time.)

The August 6, 2015, the National Oceanic and Atmospheric Administration (NOAA) hurricane season outlook showed prediction of 6 to 10 named storms, 1 to 4 hurricanes with 0 to 1 major hurricanes, with a 90 percent probability of below normal season. The reduced number of forecasted and actual observed storms was due to the development of El Niño weather pattern, which causes wind shear that reduces the intensity and number of storms in the Atlantic. According to NOAA, El Niño atmospheric conditions such as strong vertical wind shear, increased atmospheric stability, stronger sinking motion, and drier air across the Atlantic helped reduce the number of storms.

None of the storms made landfall on Florida, Hurricane Danny and Tropical Storms Erika and Grace had some rainfall contribution to South Florida. Hurricane Danny was a short-lived major hurricane in the Atlantic from August 18 to 24, 2015. Danny's intensity decreased moving through the central and southern Leeward Islands. Danny degenerated into an open wave in the Caribbean Sea. The remnants of Danny moved west making rainfall contribution to South Florida on August 26, 2015 (**Figure 2-5**). Tropical Storm Erika dissipate over Cuba but the remnant contributed significant rainfall to South Florida (**Figure 2-6**). Erika was predicted as threatening South Florida and emergency activities occurred (Sun Sentinel, September 1, 2015). Palm Beach County got as much as 1.65 inches of rainfall. Tropical Storm Grace fizzled out in the Atlantic 825 miles east of the Lesser Antilles (September 5–9, 2015). But its remnants moved to the west and the District received lots of rainfall (Palm Beach Post, September 17, 2015). Most of the rainfall was on September 16 and 17, 2015 (**Figure 2-7**).

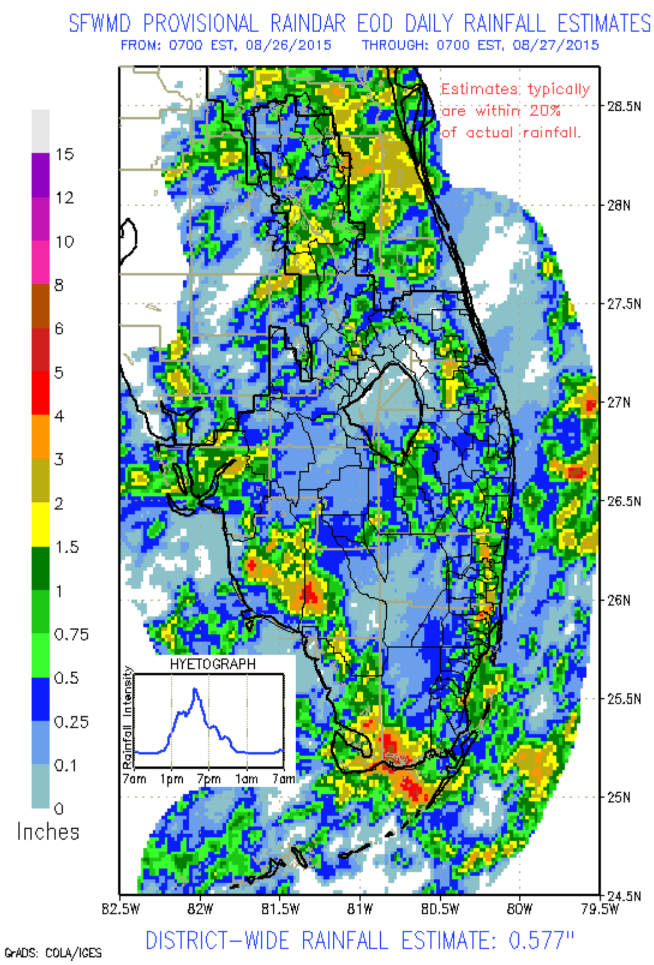


Figure 2-5. Tropical rainfall from remnant of Hurricane Danny, August 26–27, 2015.

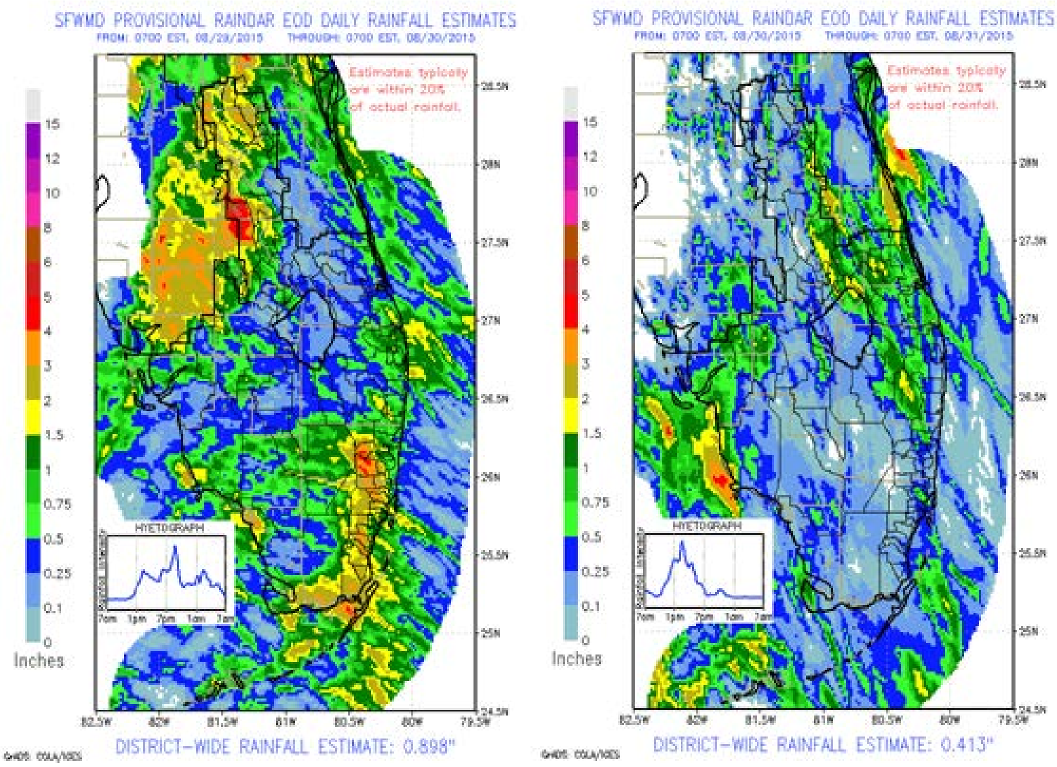


Figure 2-6. Tropical system related rainfall from Tropical System Erika, August 29–30, 2015.

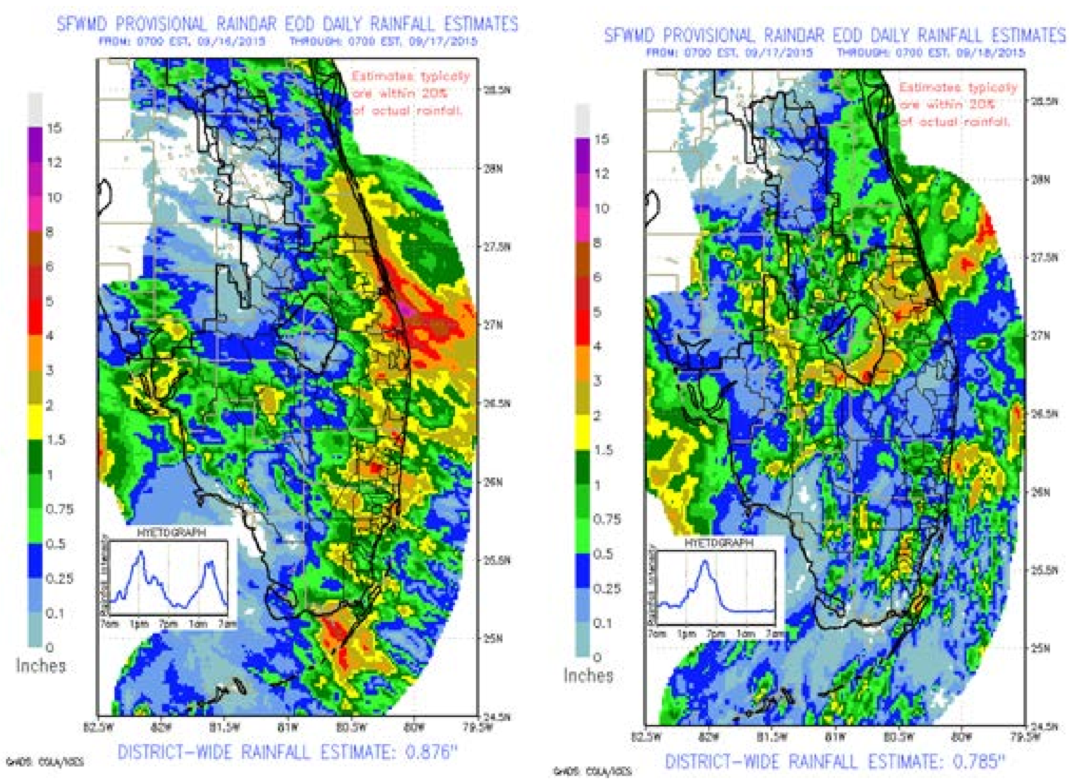


Figure 2-7. Tropical system related rainfall from Tropical System Grace, September 16–17, 2015.

2015-2016 EL NIÑO SOUTHERN OSCILLATION

El Niño is an ocean-atmosphere phenomenon where the cooler equatorial eastern Pacific warms up once every 2 to 7 years. The increase in temperature at the equatorial eastern Pacific is attributed to the weakening of the easterly trade winds that result in warm water from the western Pacific moving to the east. Strong easterly trade winds bring cooler water to the surface and create a La Niña event. During El Niño years, the South Florida dry season gets wetter and during La Niña, the dry season gets drier (Abtew and Trimble 2010).

The Pacific SST warming condition that started in August 2014 continued in 2015. The warming continued through 2015 indicating a strong El Niño comparable to the 1997-1998 El Niño. Positive SST anomalies were observed across tropical Pacific west of Peru. **Figure 2-8** depicts a cumulative SST tracking index where positive values indicate the presence of El Niño and negative values indicate La Niña; values closer to zero indicate a neutral condition (Abtew et al. 2009, Abtew and Trimble 2010). Strong El Niño is indicated by above 5 degrees Celsius (°C) cumulative SST and strong La Niña is indicated by cumulative SST of less than -5 °C. El Niño conditions create wind shear that weakens Atlantic tropical systems and also influence the path of tropical storms to curve to the north and east away from the land mass of the eastern United States. As a result of the El Niño condition in 2015, the number of tropical storms was lower than the median 12 named storms as forecasted (Klotzbach and Gray 2015). The hydrology of South Florida during an El Niño year is characterized by high rainfall during the following dry season and low rainfall during La Niña. La Niña conditions create favorable conditions for Atlantic tropical storms. The 2016 ENSO development parallels 1998, which also followed a strong El Niño year (**Figure 2-8**).

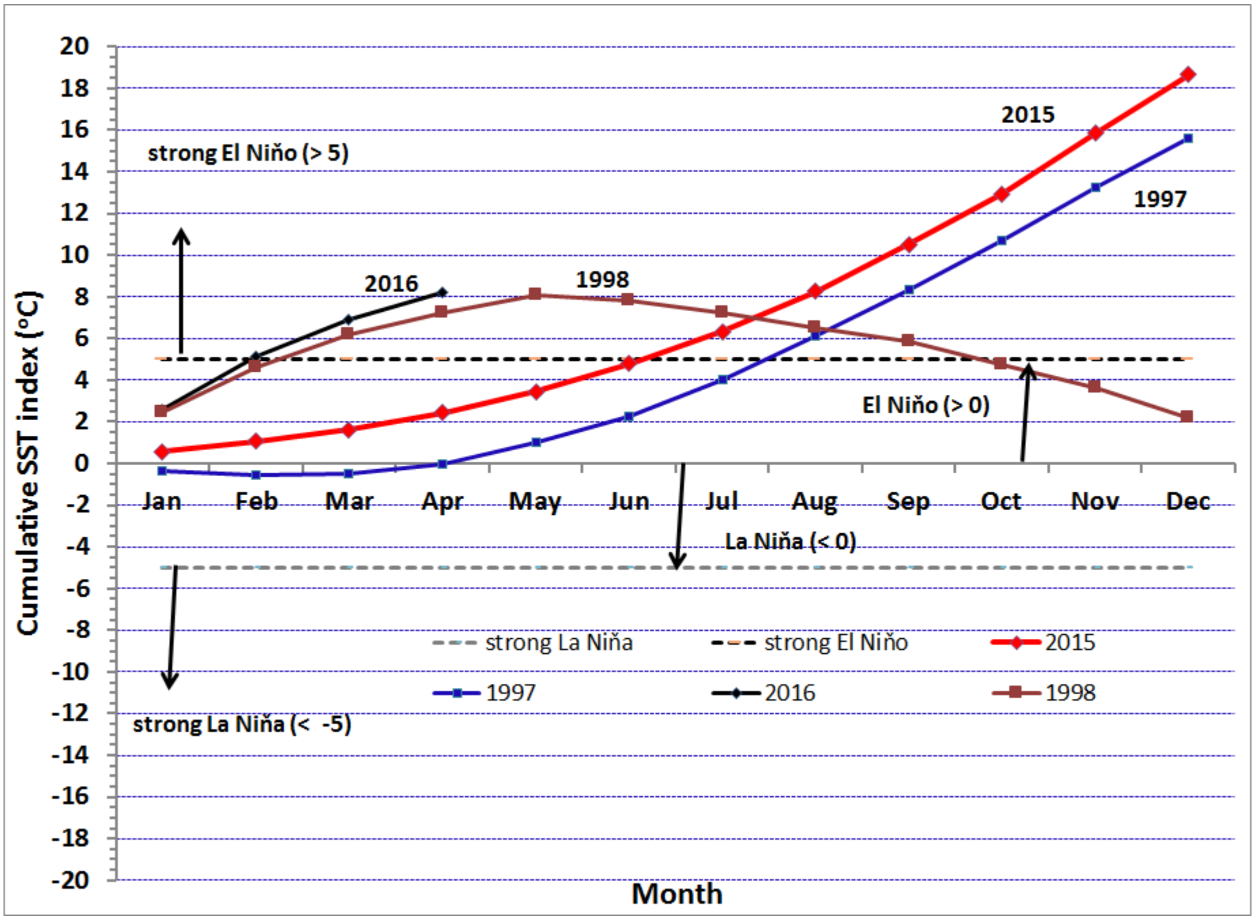


Figure 2-8. 2015 cumulative SST index showing a strong El Niño comparable to 1997 and beginning of 2016 comparable to 1998 ENSO developments.

COMPARISON OF THE 2015-2016 AND 1997-1998 EL NIÑO EVENTS

In recent years, 1997-1998 and 2015-2016 were strong El Niño years. As shown in **Figure 2-8**, looking back, there was indication of a strong El Niño by July 1997 and June 2015 of the respective El Niño year. South Florida dry season rainfall has a connection to ENSO events with El Niño years having higher than average dry season rainfall, although the dry season is from November through May but the El Niño effect is mostly from November through March of following year. As a result of the strong El Niño weather pattern, the dry season was wet in both El Niño years. The five month (November through March) rainfall was two to three times of the historical average (**Table 2-5**). One difference between the two strong El Niño years is that the 1997–1998 period had higher rainfall upstream of Lake Okeechobee resulting in high inflows to the lake. The 2015–2016 period had higher rainfall on the WCAs and areas that are connected to WCAs by drainage. The dry season months of November 2015 to February 2016 were very wet. January rainfall in most areas of the District and ENP was the wettest in 100 years. As a result, WCA-3A water level rose to record level for the time, 11.50 ft NGVD29, in mid-February 2016 as discussed previously in the *High Water Conditions and Emergency Operations* subsection of the *Water Year 2016 Extreme Hydrologic Events* section. On February 11, 2016, FDEP issued an emergency final order to SFWMD and USACE to lower water levels deviating from existing water management practices. The order was accomplished in 90 days resulting in lowered water level in WCA-3A. For more information see Appendix 2-1 of this volume.

Table 2-5. Comparison of the 1997-1998 and 2015-2016 strong El Niño dry season rainfall and historical average for each rain area (November to March).

Rain Area	Rainfall (inches)		
	November 1997–March 1998	November 2015–March 2016	Historical Average
Upper Kissimmee	35.26	17.22	12.26
Lower Kissimmee	30.51	19.74	10.25
Lake Okeechobee	23.19	19.79	9.89
East EAA	19.28	19.86	10.53
West EAA	20.89	20.85	11.71
Martin/St. Lucie	22.05	24.1	13.19
Palm Beach	25.44	25.76	15.37
WCA-1 & WCA-2	21.24	26.08	12.04
WCA-3	21.24	22.37	12.04
Broward	21.73	26.95	12.2
Miami-Dade	22.33	26.29	10.91
East Caloosahatchee	26.36	19.62	9.5
Southwest	23.69	20.28	9.51
Big Cypress Basin	23.69	18.87	9.51

WATER YEAR 2016 HYDROLOGY

RAINFALL AND EVAPOTRANSPIRATION

Following the two below average rainfall years of WY2011 and WY2012, hydrologic conditions of South Florida improved with average rainfall in WY2013, wetter than average in WY2014, and close to average in WY2015. District areal average rainfall of 55.35 inches in WY2016 is 2.6 inches above the historical average making it a wetter than average year. Most of the District regions were wetter than average: Upper Kissimmee (+2.1 inches), Lower Kissimmee (+8.32 inches), Lake Okeechobee (+3.38 inches), East EAA (-7.2 inches), West EAA (-0.61 inches), WCA-1 and WCA-2 (+3.6 inches), WCA-3 (+3.55 inches), Martin/St, Lucie (+2.64 inches), Palm Beach (-6.91 inches), Broward (-2.93 inches), Miami-Dade (+3.13 inches), East Caloosahatchee (+5.75 inches), Big Cypress Basin (+3.3 inches), Southwest Coast (+11.5 inches), and ENP (-3.53 inches).

Table 2-6 depicts monthly rainfall for each rainfall area for WY2016. **Table 2-7** presents dry and wet return periods of monthly rainfall in each rainfall area during WY2016, showing each month's state in each area. As shown in **Table 2-7**, most months were wetter than average rainfall. December 2015 was a wet month and January 2016 was very wet throughout the District with most as rare as 100-year frequency of occurrence. WY2016 tropical storm activity was low; there was relatively small contribution of tropical systems-related rainfall in July, August, and September 2015. District rainfall areas daily rainfall data was acquired from the District's Operations rain gauge network available online at https://my.sfwmd.gov/sfwmd/common/images/weather/site_frm.html. ENP rainfall was acquired from the 24 ENP rain gauge network for which data is available in the District's corporate environmental database, DBHYDRO (www.sfwmd.gov/dbhydro).

Regionally, the balance between rainfall and evapotranspiration maintains the hydrologic system in either a wet or dry condition. ETp is potential evapotranspiration or actual evaporation for lakes, wetlands, and any feature that is wet year round. In South Florida, most of the variation in evapotranspiration is explained by solar radiation (Abtew 1996, Abtew and Melesse 2013). Regional estimates of average ETp from open water and wetlands that do not dry out range from 48 inches in the District's northern section to 54 inches in the Southern Everglades (Abtew et al. 2003, Abtew 2005). Available ETp data from the closest site to a rainfall area was used to estimate ETp for the area. **Table 2-8** shows monthly ETp for each rainfall area, ENP, and District average. **Table 2-9** summarizes WY2015, WY2016, and historical average annual rainfall; WY2016 ETp; and WY2016 rainfall anomalies. Appendix 2-2 of this volume compares WY2015 and WY2016 monthly rainfall, historical average rainfall, and WY2016 ETp for each rainfall area.

Table 2-6. WY2016 monthly rainfall (inches) for each rainfall area. (Note: Data from each rainfall area is from the District's Operations rainfall database, which accumulates daily rainfall data from 7:00 a.m. of the previous day through 6:59 a.m. of the data registration day, both in Eastern Standard Time; ENP rainfall is the average of 24 stations located in ENP.)

Year	Month	Upper Kissimmee	Lower Kissimmee	Lake Okeechobee	East EAA	West EAA	WCA-1 & WCA-2	WCA-3	Martin/St Lucie	Palm Beach	Broward	Miami-Dade	East Caloosahatchee	Big Cypress Basin	Southwest Coast	District Average	ENP
2015	May	0.98	1.58	1.56	1.14	2.06	1.92	1.60	1.61	1.57	1.90	1.57	2.31	2.82	4.08	1.98	1.26
2015	June	8.39	6.51	5.75	3.75	5.72	3.42	4.75	4.80	4.41	2.13	3.69	8.78	8.22	7.62	6.09	5.64
2015	July	5.95	7.07	6.02	5.00	4.84	5.84	5.76	6.80	5.50	3.80	5.31	7.99	5.91	10.28	6.54	6.44
2015	August	11.07	8.03	7.17	7.84	10.40	8.90	7.20	7.20	7.21	6.84	7.18	8.96	8.56	9.80	8.41	6.78
2015	September	5.19	6.43	6.37	6.83	8.42	6.76	9.60	8.87	7.49	9.66	10.43	6.64	10.31	10.02	8.01	8.07
2015	October	1.15	2.15	1.82	1.01	1.17	2.37	2.41	1.66	1.66	3.52	4.57	1.10	1.41	2.37	1.94	2.63
2015	November	2.22	3.54	2.83	2.57	2.65	3.40	3.99	4.12	3.09	5.32	5.12	2.70	3.24	2.96	3.29	3.34
2015	December	1.35	2.63	2.95	2.82	2.78	6.19	4.27	4.31	6.52	7.11	10.89	2.67	2.64	2.76	3.75	6.71
2016	January	6.56	8.24	8.83	9.67	11.12	10.64	9.54	9.09	9.09	7.79	6.38	10.23	9.60	11.54	9.18	5.99
2016	February	2.21	2.67	2.80	2.79	2.63	3.07	2.75	2.84	2.83	3.45	2.45	2.58	2.18	2.21	2.58	2.03
2016	March	4.88	2.66	2.38	2.01	1.67	2.78	1.82	3.74	4.23	3.28	1.45	1.44	1.21	0.81	2.39	1.01
2016	April	2.24	1.26	0.87	0.85	0.88	0.27	1.10	1.74	1.03	0.40	1.20	1.03	1.34	1.17	1.19	1.14
	Total	**52.19**	**52.77**	**49.35**	**46.28**	**54.34**	**55.56**	**54.79**	**56.78**	**54.63**	**55.20**	**60.24**	**56.43**	**57.44**	**65.62**	**55.35**	**51.05**

Table 2-7. WY2016 monthly rainfall dry and wet return periods for each rainfall area (derived from Ali and Abtew 1999). (Note: yr – year.)

Year	Month	Upper Kissimmee	Lower Kissimmee	Lake Okeechobee	East Everglades Agricultural Area	West Everglades Agricultural Area	Water Conservation Areas 1,2	Water Conservation Area 3	Martin/St Lucie	Palm Beach	Broward	Miami-Dade	East Caloosahatchee	Big Cypress Preserve	Southwest Coast
2015	May	≈20-yr dry	< 10-yr dry	<10-yr dry	> 5-yr dry	<5-yr dry	≈10-yr dry	> 10-yr dry	> 10-yr dry	<20-yr dry	<10-yr dry	> 10-yr dry	<5-yr dry	<5-yr dry	average
2015	Jun	< 5-yr wet	<average	< 5-yr wet	> 5-yr dry	5-yr dry	> 10-yr dry	5-yr dry	<5-yr dry	5-yr dry	<50-yr dry	<10-yr dry	>average	<average	<5-yr dry
2015	Jul	<5-yr dry	>average	average	<10-yr dry	≈ 10-yr dry	<5-yr dry	<5-yr dry	>average	<5-yr dry	<10-yr dry	<5-yr dry	< 5-yr wet	> 5-yr dry	< 5-yr wet
2015	Aug	< 20-yr wet	> 5-yr wet	< 5-yr wet	> 5-yr wet	<5-yr dry	> 5-yr wet	< 5-yr wet	< 5-yr wet	< 5-yr wet	<5-yr dry	>average	< 5-yr wet	>average	< 5-yr wet
2015	Sep	<average	< 5-yr wet	≈average	< 5-yr wet	5-yr wet	>average	< 10-yr wet	< 5-yr wet	<5-yr dry	<5-yr dry	< 5-yr wet	<5-yr dry	≈ 5-yr wet	< 5-yr wet
2015	Oct	5-yr dry	<5-yr dry	<5-yr dry	< 10-yr dry	<5-yr dry	<5-yr dry	<5-yr dry	> 10-yr dry	50-yr dry	<5-yr dry	<5-yr dry	<10-yr dry	5-yr dry	<5-yr dry
2015	Nov	average	≈ 10-yr wet	> 5-yr wet	≈ 5-yr wet	< 5-yr wet	< 5-yr wet	< 5-yr wet	< 5-yr wet	<average	≈ 10-yr wet	≈ 10-yr wet	>average	≈ 10-yr wet	<10-yr wet
2015	Dec	<5-yr dry	< 10-yr wet	< 10-yr wet	≈ 5-yr wet	< 5-yr wet	>20-yr wet	< 10-yr wet	≈ 10-yr wet	< 20-yr wet	>20-yr wet	>100-yr we	< 10-yr wet	> 5-yr wet	> 5-yr wet
2016	Jan	>20-yr wet	>100-yr we	100-yr wet	>100-yr we	>100-yr wet	>100-yr wet	100-yr wet	>100-yr wet	≈ 50-yr wet	>50-yr wet	>20-yr wet	>100-yr we	100-yr wet	>100-yr we
2016	Feb	<average	>average	< 5-yr wet	≈ 5-yr wet	>average	< 5-yr wet	< 5-yr wet	>average	>average	5-yr wet	>average	<5-yr wet	average	average
2016	Mar	5-yr wet	≈average	<average	<5-yr dry	<5-yr dry	>average	<average	< 5-yr wet	< 5-yr wet	< 5-yr wet	<5-yr dry	<5-yr dry	<5-yr dry	<5-yr dry
2016	Apr	<average	<5-yr dry	5-yr dry	> 5-yr dry	> 5-yr dry	> 10-yr dry	<5-yr dry	<5-yr dry	≈5-yr dry	10-yr dry	<5-yr dry	<5-yr dry	<5-yr dry	<5-yr dry
dry months		7	4	4	6	6	5	6	4	6	7	6	5	6	4
extreme dry										1					
wet months		4	7	7	5	5	5	5	7	4	3	4	6	5	7
extreme wet		1	1	1	1	1	2	1	1	1	2	2	1	1	1
≈ average															
dry = < average															
extreme dry>= 20 yr dry															
wet = > average															
extreme wet >= 20-yr															

Table 2-8. WY2016 monthly ETp for each rainfall area (inches).

Year	Month	Upper Kissimmee	Lower Kissimmee	Lake Okeechobee	East EAA	West EAA	WCA-1 & WCA-2	WCA-3	Martin/St Lucie	Palm Beach	Broward	Miami-Dade	East Caloosahatchee	Big Cypress Basin	Southwest Coast	District	ENP
2015	May	6.37	6.42	6.64	6.34	5.84	6.21	5.89	6.38	6.34	5.89	5.89	6.78	5.89	5.68	6.18	5.89
2015	June	5.44	5.74	5.52	5.83	5.28	5.42	4.73	5.96	5.83	4.73	4.73	5.79	4.73	5.10	5.34	4.73
2015	July	5.22	5.42	5.09	5.39	5.06	5.11	5.12	5.09	5.39	5.12	5.12	5.29	5.12	4.76	5.17	5.12
2015	August	4.75	5.20	5.31	5.22	5.26	4.71	4.69	5.00	5.22	4.69	4.69	5.11	4.69	4.71	4.95	4.69
2015	September	4.18	4.39	4.46	4.29	4.30	4.18	3.59	4.11	4.29	3.59	3.59	4.22	3.59	3.86	4.04	3.59
2015	October	3.93	4.16	4.33	4.09	3.78	4.02	3.91	3.99	4.09	3.91	3.91	4.10	3.91	4.11	4.02	3.91
2015	November	3.12	3.25	3.66	3.30	3.54	3.31	3.42	3.14	3.30	3.42	3.42	3.37	3.42	3.35	3.36	3.42
2015	December	2.57	2.85	3.04	2.72	2.83	2.68	2.65	2.77	2.72	2.65	2.65	2.79	2.65	2.87	2.75	2.65
2016	January	2.77	2.62	2.75	2.73	3.39	2.55	2.69	2.84	2.73	2.69	2.69	2.81	2.69	2.72	2.76	2.69
2016	February	3.89	3.69	4.10	3.99	3.76	3.57	4.10	4.14	3.99	4.10	4.10	4.10	4.10	3.94	3.97	4.10
2016	March	4.54	4.44	4.84	4.53	4.69	4.17	4.40	4.80	4.53	4.40	4.40	4.82	4.40	4.81	4.56	4.40
2016	April	5.43	5.44	6.22	5.58	5.53	5.26	5.38	5.91	5.58	5.38	5.38	5.81	5.38	5.67	5.57	5.38
	Total	**52.22**	**53.63**	**55.95**	**54.01**	**53.26**	**51.20**	**50.57**	**54.12**	**54.01**	**50.57**	**50.57**	**55.00**	**50.57**	**51.57**	**52.66**	**50.57**

Table 2-9. WY2016, WY2015, and historical average annual rainfall; WY2016 ETp; and WY2016 rainfall deviation from historical average (inches) for each rainfall area.

Rainfall Area	WY2016 Rainfall	WY2015 Rainfall	Historical Average Rainfall	WY2016 ETp	WY2016 Rainfall Deviation
Upper Kissimmee	52.19	56.8	50.09	52.22	2.1
Lower Kissimmee	52.77	57.44	44.45	53.63	8.32
Lake Okeechobee	49.35	47.95	45.97	55.95	3.38
East EAA	46.28	44.64	53.48	54.01	-7.2
West EAA	54.34	50.06	54.95	53.26	-0.61
WCA-1 & WCA-2	55.56	48.43	51.96	51.20	3.6
WCA-3	54.79	45.56	51.24	50.57	3.55
Martin/St. Lucie	56.78	54.22	54.14	54.12	2.64
Palm Beach	54.63	54.27	61.54	54.01	-6.91
Broward	55.2	55.09	58.13	50.57	-2.93
Miami-Dade	60.24	54.83	57.11	50.57	3.13
East Caloosahatchee	56.43	45.54	50.68	55.00	5.75
Big Cypress Basin	57.44	50.14	54.12	50.57	3.32
Southwest Coast	65.62	50.82	54.12	51.57	11.5
ENP	51.05	44.68	54.58 [a]	50.57	-3.53
SFWMD Spatial Average	**55.35**	**51.09**	**52.75**	**52.66**	**2.6**

a. Calendar Years 1941–2015 (January 1, 1941–December 31, 2015).

WILDFIRES

One of drought's impacts on the South Florida environment is creating conditions that promote and spread wildfires. The size and number of wildfires are generally correlated to dry conditions. Generally, drought years have above average total number of acres burned and number of acres burned per fire. For instance, the area burned by wildfire in WY1989, WY1990, WY2001, and WY2007 drought years was high. **Figure 2-9** depicts the number of acres burned per water year in the SFWMD area from wildfires that were 10 acres or larger from WY1982 to WY2016. Mostly, major droughts correspond to larger areas burned by wildfire. The number of acres burned in WY2016 was 49,853 acres, a reflection of the wetter conditions. The average area burned in a year was 103,985 acres.

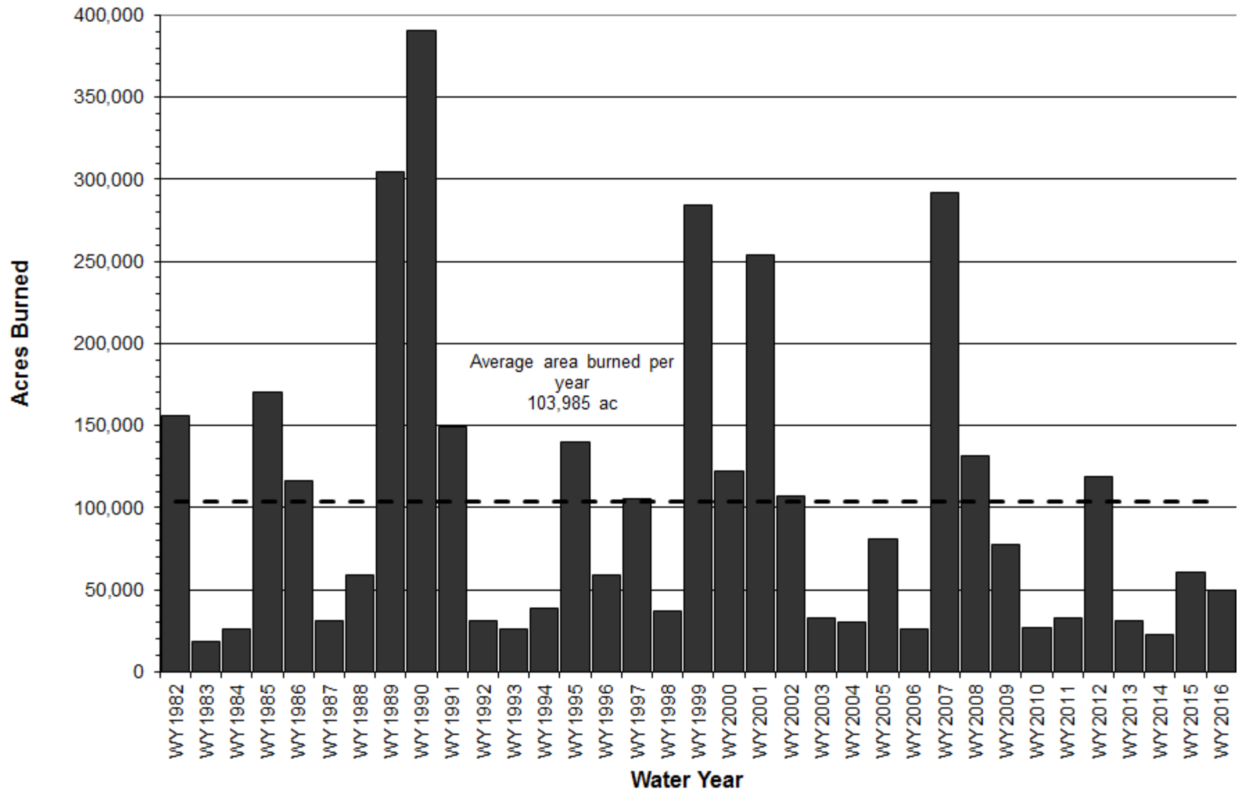


Figure 2-9. Number of acres (ac) burned per water year in the SFWMD area from wildfires that were 10 acres or larger (WY1982–WY2016).

GROUNDWATER

The District is divided into four major water resource planning regions: UEC, LEC, LWC, and Upper Kissimmee Basin (see Appendix 2-3, Figure 1). Each has aquifers that provide water for agricultural, commercial, industrial, and domestic use. The LEC principal groundwater source is the surficial Biscayne aquifer. The UEC principal source of groundwater is the surficial aquifer. The LWC relies on three aquifer systems for water supply: the surficial aquifer system, the intermediate aquifer system, and the Floridan aquifer system. The Lower Tamiami aquifer is part of the surficial aquifer system. The sandstone and the mid-Hawthorne aquifers are part of the intermediate aquifer system (SFWMD 2006). The Kissimmee Basin is served by a surficial or shallow aquifer and a deep aquifer, the Floridan aquifer system.

In general, WY2016 groundwater levels reflect regional rainfall conditions showing increasing and no concern for water supply. Representative groundwater level fluctuation observations from the United States Geological Survey are shown in Appendix 2-3 for the stations shown in Figure 1 of the same appendix.

WATER MANAGEMENT IN WATER YEAR 2016

OVERVIEW

District-wide water management operations depend largely on the spatial and temporal distribution of rainfall across the South Florida region and antecedent conditions. Although water management of SFWMD facilities is performed according to prescribed operation plans, there are various constraints that are considered while developing and implementing shorter-term operating strategies. Flood control operations are conducted in the wet season and tropical storm events occur in this season. Inflow and outflow operations were regularly conducted to bring water levels of the major water bodies closer to the respective regulation schedules. The water management system was operated both in flood control and water supply mode based on weather and antecedent conditions. Most of the months in most rain areas were wet. December 2015 and January 2016 were very wet requiring emergency water management actions. The Lower Kissimmee, East Caloosahatchee, and the Southwest rain areas were very wet. East EAA, Palm Beach, Broward, and ENP rain areas were drier than average (**Table 2-9**).

Water management is performed by using previously established regulation schedules that integrate different purposes. Regulation schedules are rule curves designed to manage the regional storage. In order to broadly satisfy flood control and water supply needs on a long-term basis, daily water level regulation schedules for each of the regional water bodies were developed by USACE and SFWMD in cooperation with other agencies and stakeholders. The regulation schedules for the regional lakes and WCAs are published in detail in the 2007 SFER – Volume I, Appendix 2-6 (Abtew et al. 2007b). At times, deviations from the regular regulation schedules are made for a specific lake or WCA to manage water under particular infrastructural, environmental, or weather-related conditions. In WY2016, on February 11, 2016, FDEP issued an emergency final order authorizing SFWMD and USACE to take immediate action to deviate from permitted water management practices to move significant volumes of flood water out of WCA-3A to ENP through Shark River Slough. The reason was extreme rainfall events in December 2015 and January 2016, associated with the 2015-2016 El Niño, that resulted in WCA-3A water level rising dramatically with severe impacts to natural resources. Immediate drawdown was necessary and undertaken as described earlier in this chapter and in Appendix 2-1.

Initiated in May 2008, the current regulation schedule for Lake Okeechobee, known as LORS2008 (USACE 2008), incorporates current and future (outlook) climatic information in the decision making process. The regulation schedule has three main bands (**Figure 2-10**): High Lake Management Band, Operational Band, and Water Shortage Management Band. The Operational Band is further divided into High, Intermediate, Low, Base Flow, and Beneficial subbands or use categories. In the High Lake Management Band, large flood control releases may be required and outlet canals may be maintained above their optimum water management elevations. In the Operational Band, substantial flood control releases may be implemented and outlet canals should be maintained within their optimum water management elevations. In the Water Shortage Management Band, outlet canals may be maintained below optimum water management elevations and water supply releases from the lake are restricted according to the severity of prolonged dry climate conditions. More information on LORS2008 is also presented in the *Lake Okeechobee* subsection of this section.

Water supply releases are made for various beneficial uses that include water supply for municipal and industrial use, irrigation for agriculture, deliveries to ENP, salinity control, estuarine management, and other environmental releases. Releases are made to the St. Lucie Canal and Caloosahatchee River to maintain navigation depths if sufficient water is available in Lake Okeechobee. The outflows from Lake Okeechobee are received by the St. Lucie Canal, Caloosahatchee River, EAA, Lower East Coast, and the WCAs through the Everglades STAs. **Figure 2-10** depicts Lake Okeechobee daily water level, regulation schedule, and water management decisions. Based on the lake water level and other relevant factors, various water management decisions are depicted on the figure. Release from the lake through S-308 into the

St. Lucie Canal, which discharges into the St. Lucie Estuary through S-80; releases from the lake through S-77 and into the Caloosahatchee River, which discharges into the Caloosahatchee Estuary through S-79; and regulatory releases to WCAs are also shown on the figure. Further details of these subregion flows are provided in the *Water Levels and Flows* subsection of this section and Appendices 2-6 and 2-7 of this volume.

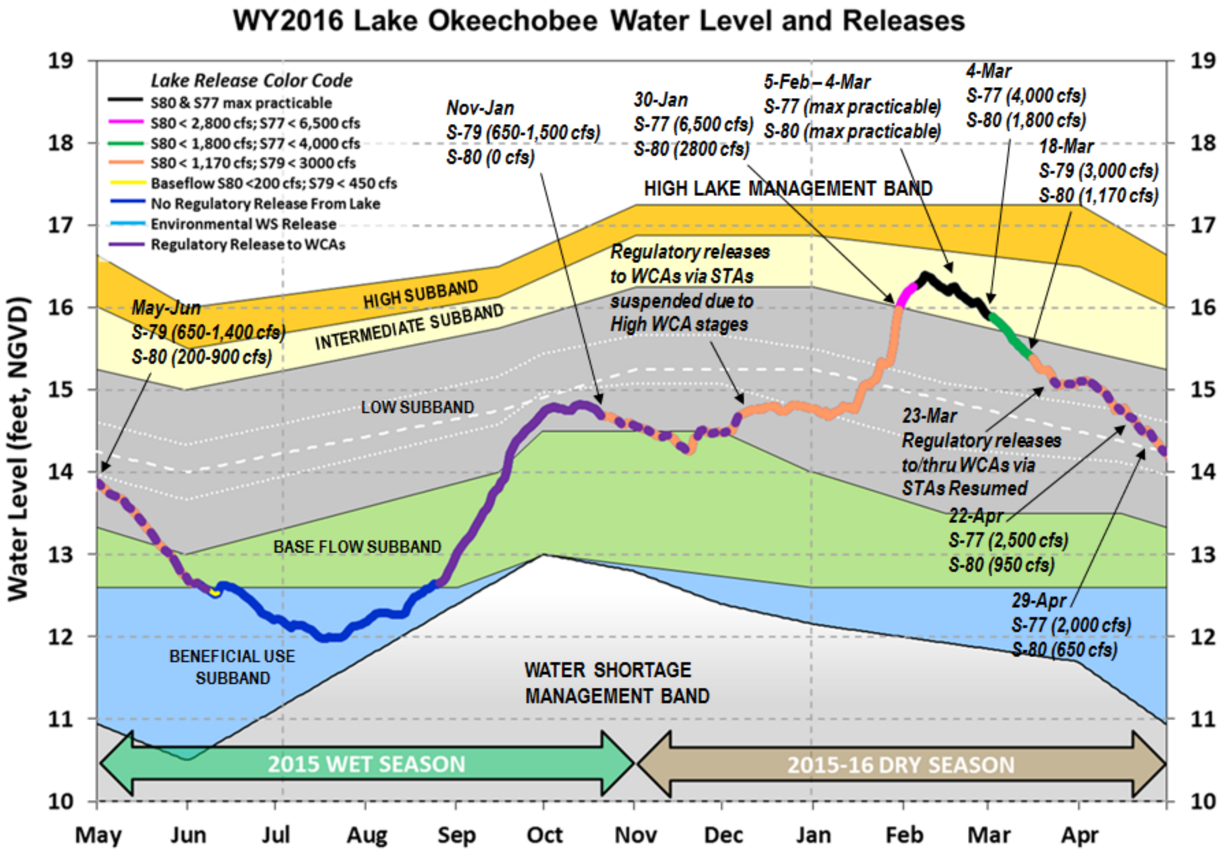


Figure 2-10. Daily Lake Okeechobee water levels, regulation schedule, and water management decisions in WY2016. (Note: Apr – April; cfs – cubic feet per second; Feb – February; ft, Jan – January; Jun – June; Mar – March; max – maximum; NGVD – feet National Geodetic Vertical Datum of 1929; Nov – November; and WS – water supply.)

During WY2016, water managers, scientists, and engineers from the District, USACE, and other federal and state agencies met weekly to discuss the state of the regional system and possible operational scenarios. Reports on the ecological and hydrological status of various areas (e.g., Kissimmee Basin, Lake Okeechobee, St. Lucie and Caloosahatchee estuaries, Everglades STAs, Everglades, water supply, and groundwater conditions) were presented. How well the objectives of the Central and Southern Florida Flood Control Project (water supply, flood control, and protection of fish and wildlife) were met were also discussed. The meeting starts with the previous week's weather report and coming week's rainfall predictions, followed by climate forecast. The previous week's Lake Okeechobee operations and the rest of the water management system were reported in each meeting. Operational recommendations were given to District managers for approval and then submitted to USACE in a *Weekly Environmental Conditions for Systems Operations* memoranda.

In WY2016, there were no major tropical system events and amount of tropical system-related rainfall was modest. There were non-tropical high rainfall events in December 2015 and January 2016. Lake

Okeechobee was at 13.84 ft NGVD29 on May 1, 2015, at the start of WY2016. The lake level rose to a maximum of 16.40 ft NGVD29 by February 7, 2016, from runoff generated by rainfall of preceding months. Since the dry season was wet in the lake watershed as a result of the 2015-2016 El Niño, 51 percent of the lake inflows were in the dry season months of November 2015 through April 2016 (see Appendix 2-6, Table 2). Dry season operations of the water management system is reported in detail in the *Review of South Florida Water Management System Operations and Hydrology for the 2015-2016 Dry Season (November 2015 through May 2016* (SFWMD 2016).

WATER LEVELS AND FLOWS

For parts of the WY2016 wet and dry seasons, most water control structures were operated for water supply during dry conditions and flood control during the wet season and other high rainfall events. Period of record daily mean water levels (stage) graphs for the lakes, impoundments, and ENP are shown in Appendix 2-4. All water levels are expressed in ft NGVD29 in these and related publications. **Table 2-10** depicts WY2016, WY2015, and historical mean, maximum, and minimum stages. WY2016 average water levels were higher than historical averages. The average Lake Okeechobee water level was 0.26 ft lower than WY2015 but 0.10 ft higher than the historical average. Comparison of monthly historical averages, WY2015, and WY2016 water levels are shown in Appendix 2-5. Water levels are also a measure of the amount of stored water. Relationships of water levels (stage) and storage for lakes and impoundments are presented in the 2007 SFER – Volume I, Appendix 2-2 (Abtew et al. 2007a).

WY2016 surface water flow statistics were also compared to WY2015 and historical flow records. WY2016 flows were higher than historical mean flows for all cases except WCA-1 inflows and outflows. In comparison to WY2015 flows, WY2016 flows were higher except for Lake Kissimmee outflows. **Table 2-11** depicts WY2016, WY2015, and historical flow statistics for major impoundments and canals. Monthly flows by structure are shown in Appendix 2-6. Comparison of historical, WY2015, and WY2016 monthly flows are shown in Appendix 2-7. Maps showing water control structures, canals, water bodies, and hydrologic units are available in previous SFERs.

Table 2-10. WY2016, WY2015, and historical stage statistics for regional major lakes and impoundments.

Lake or Impoundment	Beginning of Record [a]	Stage (ft NGVD29)				
		Historical Mean	WY2016 Mean	WY2015 Mean	Historical Maximum	Historical Minimum
Alligator Lake	1993	62.63	63.10	61.86	58.13	64.33
Lake Myrtle	1993	60.86	60.97	61.06	58.45	65.22
Lake Mary Jane	1993	60.09	60.12	60.32	57.19	62.16
Lake Gentry	1993	60.72	60.90	60.97	58.31	61.97
East Lake Tohopekaliga	1993	56.63	56.70	56.70	54.41	59.12
Lake Tohopekaliga	1993	53.73	53.87	53.80	48.37	56.63
Lake Kissimmee	1929	50.39	50.33	50.94	42.87	56.64
Lake Istokpoga	1993	38.79	38.92	38.98	35.84	39.78
Lake Okeechobee	1931	14.02	14.12	14.38	8.82	18.77
WCA-1	1953	15.69	16.29	16.49	10.00	18.16
WCA-2A	1961	12.51	12.38	12.30	9.33	15.64
WCA-3A	1962	9.60	9.93	9.74	4.78	12.79
ENP, Slough	1952	6.02	6.42	6.28	2.01	8.08
ENP, Wet Prairie	1953	2.18	2.78	2.51	-2.69	7.10

a. Calendar years (January 1–December 31).

Table 2-11. WY2016, WY2015, and historical flow statistics for major impoundments, lakes, and canals.

Lake, Impoundment, Canal	Beginning of Record [a]	Historical Mean Flow (ac-ft)	WY2016 Flow (ac-ft)	Percent of Historical Mean	WY2015 Flow (ac-ft)	Historical Maximum Flow (ac-ft)	Historical Minimum Flow (ac-ft)
Lake Kissimmee Outflow	1972	721,551	941,604	130%	1,170,556	2,175,297	16,195
Lake Istokpoga Outflow	1972	228,886	498,502	218%	446,215	637,881	26,559
Lake Okeechobee Inflow	1972	2,126,080	2,984,077	140%	2,831,832	4,905,838	377,671
Lake Okeechobee Outflow	1972	1,457,982	2,323,597	159%	1,933,353	3,978,904	176,568
St. Lucie (C-44 Canal) Inflow at S-308	1972	256,748	388,303	151%	129,227	1,117,159	4,061
St. Lucie (C-44 Canal) Outflow at S-80	1972	310,537	558,412	180%	188,236	1,192,782	0
Caloosahatchee River (C-43 Canal) Inflow at S-77	1972	539,807	972,904	180%	575,971	2,175,765	42,301
Caloosahatchee River (C-43 Canal) Outflow at S-79	1972	1,249,943	1,929,150	154%	1,234,148	3,615,526	86,895
WCA-1 Inflow	1972	466,487	351,943	75%	245,360	1,307,517	152,641
WCA-1 Outflow	1972	434,491	350,425	81%	198,051	1,433,399	14,812
WCA-2 Inflow	1972	649,193	864,470	133%	823,996	1,754,710	113,225
WCA-2 Outflow	1972	650,471	872,912	134%	810,057	1,729,168	93,564
WCA-3A Inflow	1972	1,182,670	1,575,428	133%	1,312,417	2,177,198	393,233
WCA-3A Outflow	1972	1,012,932	1,368,423	135%	779,167	2,581,129	245,951
ENP Inflow	1972	1,002,216	1,566,604	156%	1,015,301	2,838,481	165,372
Upper East Coast C-23 Canal Outflow at S-48	1995	120,138	106,701	89%	104,992	297,214	33,644
Upper East Coast C-24 Canal Outflow at S-49	1972	133,633	176,615	132%	104,548	274,827	10,591
Upper East Coast C-25 Canal Outflow at S-50	1972	136,782	189,671	139%	120,838	249,159	21,154

a. Calendar years (January 1–December 31).

Kissimmee Chain of Lakes

The Upper Kissimmee Basin is an integrated system of several lakes with interconnecting canals and flow control structures (Abtew et al. 2011). The major lakes are shallow with depths from 6 to 13 ft (Guardo 1992). The Upper Kissimmee Basin structures are operated according to regulation schedules. The details of the water control plan for the Kissimmee River are presented in the *Master Water Control Manual for Kissimmee River – Lake Istokpoga* (USACE 1994). Average stage for WY2016, WY2015, and historical observation statistics for the Kissimmee Chain of Lakes are shown in **Table 2-10**. Stages were higher than historical average. Historical daily water levels are shown in Appendix 2-4. Monthly historical average, WY2016, and WY2015 water levels for the lakes are shown in Appendix 2-5. In WY2016, the Upper Kissimmee Basin produced above average flow volume (941,604 ac-ft), 130 percent of the historical average, as a result of a wet dry season in the watershed. Monthly inflows and outflows by structure are shown in Appendix 2-6. Appendix 2-7 depicts monthly historical average, WY2016, and WY2015 flows for each water body or canal.

The Upper Kissimmee Basin received above average rainfall (+2.1 inches) resulting in above average discharge out of Lake Kissimmee (941,604 ac-ft, 130 percent of the historical average). There was discharge from Lake Kissimmee to the Kissimmee River throughout the water year except for four days in June 2015. **Table 2-11** depicts WY2016, WY2015, and historical flow statistics for major impoundments. WY2016 monthly flows are shown in Appendix 2-6, Table 1. Monthly historical average, WY2015, and WY2016 flows are presented in Appendix 2-7, Figure 1.

Alligator Lake

The outflows from Lakes Alligator, Center, Coon, Trout, Lizzie, and Brick are controlled by two structures: S-58 and S-60. S-58 is located in the C-32 canal that connects Lakes Trout and Joel, and S-60 is located in C-33 canal between Alligator Lake and Lake Gentry. Culvert S-58 maintains stages in Alligator Lake upstream from the structure, while the S-60 spillway is operated to main the optimum lakewide stage. These lakes are regulated between elevations 61.5 and 64.0 ft NGVD29 on a seasonally varying schedule. Daily water level observations for Alligator Lake over the last 23 years show that the most significant change in water levels occurred during the 2000-2001 drought, with water levels showing a big drop (Appendix 2-4, Figure 1). **Figure 2-11**, panel a, shows the WY2016 daily average stage at the headwater of S-60, daily rainfall, and flood regulation schedule for Alligator Lake. Generally water levels were lower than the regulation schedule in the middle of the water year. WY2016 average stage (63.10 ft NGVD29) was higher than WY2015 and the historical average (**Table 2-10**). Monthly historical average, WY2016, and WY2015 water levels for the lake are shown in Appendix 2-5, Figure 1.

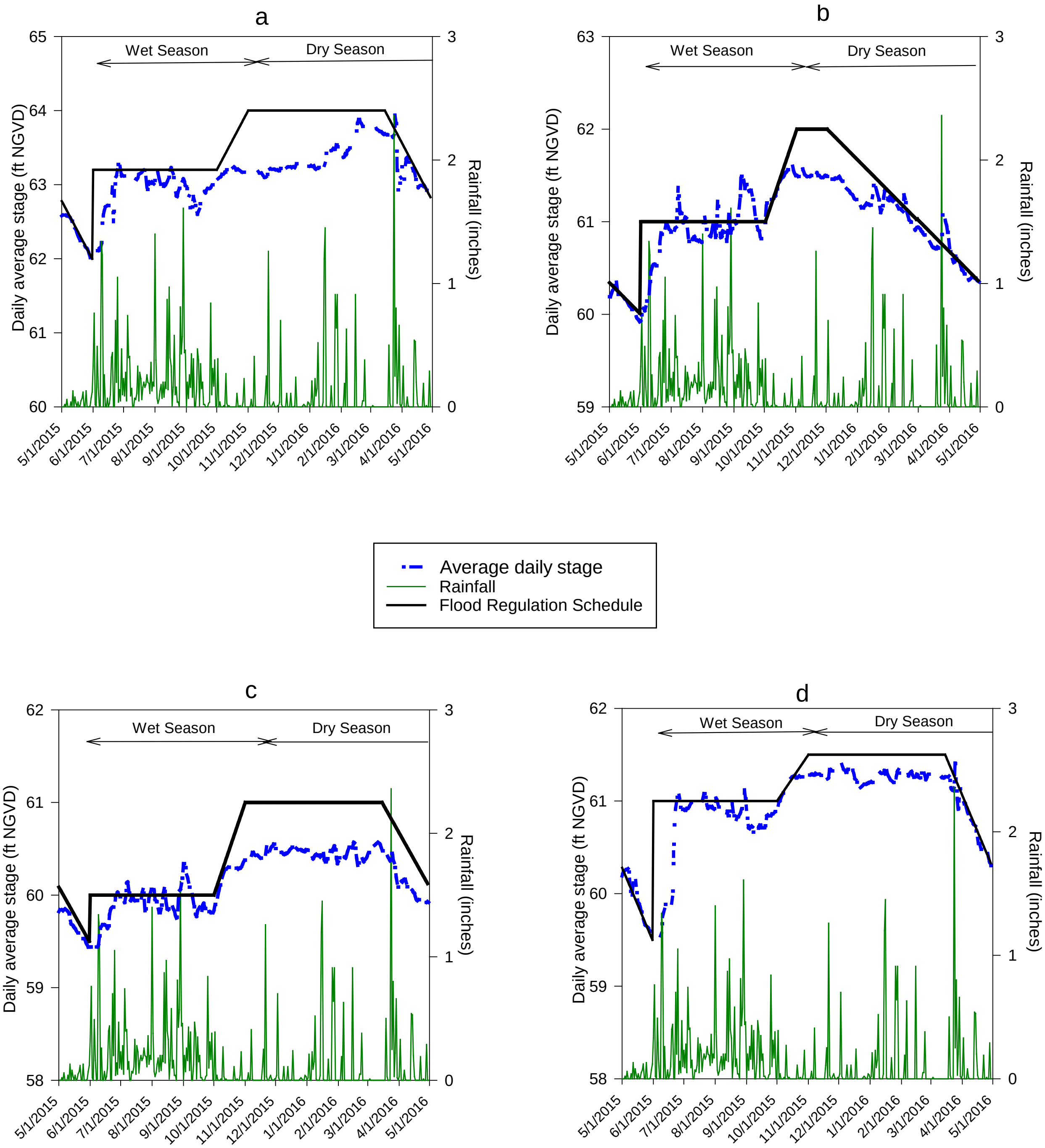


Figure 2-11. Average daily water levels (stage), regulation schedule, and rainfall for (a) Alligator Lake, (b) Lake Myrtle, (c) Lake Mary Jane, and (d) Lake Gentry.

Lakes Joel, Myrtle, and Preston

Lakes Joel, Myrtle, and Preston are regulated by structure S-57. The S-57 culvert is located in the C-30 canal that connects Lakes Myrtle and Mary Jane. The lakes are regulated between 59.5 and 62.0 ft NGVD29 on a seasonally varying schedule. **Figure 2-11**, panel b, shows the WY2016 daily average stage at the headwater of S-57, daily rainfall, and regulation schedule for Lake Myrtle. Generally water levels were at the regulation schedule except at the beginning of the dry season. Daily water level observations for Lake Myrtle over the last 23 years show that the most significant drop in water level occurred in the 2000-2001 and 2010-2011 drought years (Appendix 2-4, Figure 2). WY2016 average stage for Lake Myrtle (60.97 ft NGVD29) was lower than WY2015 and higher than the historical average (**Table 2-10**). Monthly historical average, WY2016, and WY2015 water levels for the lake are shown in Appendix 2-5, Figure 2.

Lakes Hart and Mary Jane

Lakes Hart and Mary Jane are regulated by structure S-62. The S-62 spillway is located in the C-29 canal that discharges into Lake Ajay. The lakes are regulated between elevations of 59.5 and 61.0 ft NGVD29 according to a seasonally varying schedule. **Figure 2-11**, panel c, shows the WY2016 daily average stage at the headwater of S-62, daily rainfall, and flood regulation schedule for Lake Mary Jane. The stages mostly were below the regulation schedule. Flow releases were made based on water supply needs and flood control. Daily water level observations for Lake Mary Jane over the last 23 years show that the most significant drop in water level occurred in May 2001 during a severe drought year (Appendix 2-4, Figure 3). WY2016 average stage for Lake Mary Jane (60.12 ft NGVD29) was lower than WY2015 and a bit higher than the historical average (**Table 2-10**). Monthly historical average, WY2016, and WY2015 water levels for the lake are shown in Appendix 2-5, Figure 3.

Lake Gentry

Lake Gentry is regulated by the S-63 structure, located in the C-34 canal at the south end of the lake. The stages downstream of S-63 are further lowered by S-63A before the canal discharges into Lake Cypress. The lake is regulated between elevations of 59.0 and 61.5 ft NGVD29 according to a seasonally varying schedule. **Figure 2-11**, panel d, shows the WY2016 daily average stage at the headwater of the S-63 spillway, daily rainfall, and flood regulation schedule for Lake Gentry. Water levels were generally close to the regulation schedule. Daily water level observations for Lake Gentry over the last 23 years show the most significant drop in water level occurred in May 2001 during a severe drought year (Appendix 2-4, Figure 4). WY2016 average stage for Lake Gentry (60.90 ft NGVD29) was lower than WY2015 and higher than the historical average (**Table 2-10**). Monthly historical average, WY2016, and WY2015 water levels for the lake are shown in Appendix 2-5, Figure 4.

East Lake Tohopekaliga

East Lake Tohopekaliga and Lake Ajay are regulated by structure S-59, located in the C-31 canal between East Lake Tohopekaliga and Lake Tohopekaliga. The lakes are maintained between elevations 54.5 and 58.0 ft NGVD29 on a seasonally varying schedule. A weir structure was built downstream of the S-59 spillway to control the tailwater elevation at S-59. The weir crest is at an elevation of 51.0 ft NGVD29. The weir is often submerged and therefore, the tailwater influences the headwater of S-59. **Figure 2-12**, panel a, shows the WY2016 daily average stage at the headwater of S-59, daily rainfall, regulation schedule, and ecological regulation schedule for East Lake Tohopekaliga. The stages mostly were below the regulation schedule but briefly peaked above the schedule in September 2015. Flow releases were based on water supply needs, flood control, and maintaining the regulation schedule whenever possible. Daily water level observations for East Lake Tohopekaliga in the last 23 years are shown in Appendix 2-4, Figure 5. WY2016 average stage for Lake East Tohopekaliga (56.70 ft NGVD29) was the same as WY2015 and higher than the historical average (**Table 2-10**). Monthly historical average, WY2016, and WY2015 water levels for the lake are shown in Appendix 2-5, Figure 5.

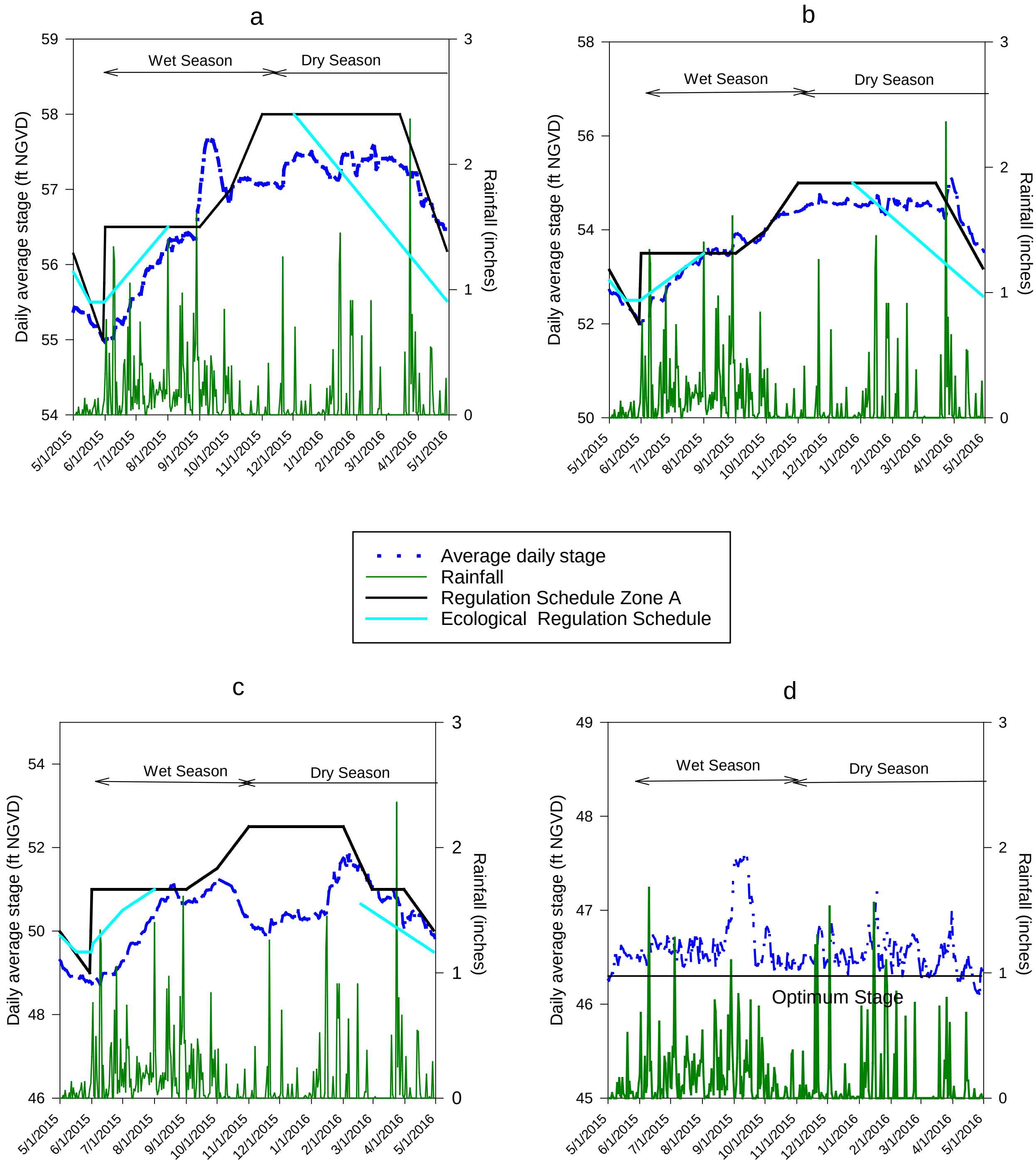


Figure 2-12. Average daily water levels (stage), regular regulation schedule, temporary modifications, and rainfall for (a) East Lake Tohopekaliga, (b) Lake Tohopekaliga, (c) Lake Kissimmee, and (d) Pool A.

Lake Tohopekaliga

Lake Tohopekaliga is regulated by structure S-61, located in the C-35 canal at the south shore of the lake. The lake is regulated between the elevations of 51.5 and 55.0 ft NGVD29 on a seasonally varying schedule. The S-61 structure is used to maintain the optimum stage in Lake Tohopekaliga. **Figure 2-12**, panel b, shows the WY2016 daily average stage at the headwater of S-61, daily rainfall, regulation schedule, and ecological regulation schedule for Lake Tohopekaliga. The stages followed the regulation schedule. Daily water level observations for Lake Tohopekaliga over the last 23 years show the most significant drop in water level occurred in June 2004 during the lake drawdown (Appendix 2-4, Figure 6). WY2016 average stage for Lake Tohopekaliga (53.87 ft NGVD29) was higher than WY2015 and the historical average (**Table 2-10**). Monthly historical average, WY2016, and WY2015 water levels for the lake are shown in Appendix 2-5, Figure 6.

Lakes Kissimmee, Hatchineha, and Cypress

Lakes Kissimmee, Hatchineha, and Cypress are regulated by the S-65 spillway and lock structure located at the outlet of Lake Kissimmee and the head of the Kissimmee River (C-38 canal). Lake Kissimmee covers approximately 35,000 acres and is regulated between 48.5 and 52.5 ft NGVD29 on a seasonally varying schedule. **Figure 2-12**, panel c, shows the daily average stage at the headwater of S-65, daily rainfall, regulation schedule, and ecological regulation schedule for Lake Kissimmee during WY2016. The stages followed the ecological regulation schedule but mostly were below the regulation schedule. Releases were made based on downstream water needs and flood control. Appendix 2-4, Figure 7 shows daily water level (1929–2016). WY2016 average stage for Lake Kissimmee (50.33 ft NGVD29) was lower than WY2015 and the historical average (**Table 2-10**). Monthly historical average, WY2016, and WY2015 water levels for the lake are shown in Appendix 2-5, Figure 7.

Lower Kissimmee System

The Lower Kissimmee System consists of the Kissimmee River (C-38 canal) and four structures (S-65A, S-65C, S-65D, and S-65E) that form four pools (A, C, D, and E). These structures are operated according to optimum stages. Optimum stages for S-65A, S-65C, S-65D, and S-65E are 46.3, 34.4, 26.8, and 21.0 ft NGVD29, respectively (Abtew et al. 2011). WY2016 conditions in the Kissimmee River system are covered in detail in Chapter 9 of this volume.

Pool A

Stages in Pool A are controlled by the S-65A gated spillway and lock, and the pool is downstream of the S-65 structure. In addition to S-65A, a culvert structure is located through the east tieback levee at the natural channel of the Kissimmee River. During water supply periods, minimum releases are made to satisfy water demands and maintain navigation downstream. The culvert also provides water to the oxbows of the natural river channel. **Figure 2-12**, panel d, shows the daily average stage at the headwater of S-65A, daily rainfall, and optimum stage for Pool A during WY2016. Stages remained higher than the optimum stage of 46.3 ft NGVD29 for the water year reflecting the wet conditions in the watershed.

Pool C

Stages in Pool C are controlled by the S-65C gated spillway and lock, which is downstream of the S-65A structure. In addition to S-65C, there is a culvert structure that is located through the east tieback levee at the natural channel of the Kissimmee River. During WY2016, minimum and maximum headwater stages at S-65C were 33.14 and 35.53 ft NGVD29, respectively, with mean stage of 34.36 ft NGVD29.

Pool D

Stages in Pool D are controlled by the S-65D gated spillway and lock downstream of S-65C. During WY2016, headwater stages at S-65D ranged from 26.66 to 27.59 ft NGVD29 with mean stage of 26.66 ft NGVD29.

Pool E

Stages in Pool E are controlled by the S-65E gated spillway and lock, which is downstream of S-65D. During WY2015, minimum and maximum headwater stages at S-65E were 20.83 and 21.15 ft NGVD29, respectively with mean stage of 21 ft NGVD29.

Lake Istokpoga

Lake Istokpoga has a surface area of approximately 27,700 acres. Stages in Lake Istokpoga are maintained in accordance with a regulation schedule that varies seasonally. The S-68 spillway, located at the south end of the lake, regulates the lake stage and discharges water to the C-41A canal (the Slough Canal). The C-41 canal (Harney Pond Canal), C-40 canal (Indian Prairie Canal), and C-39A canal (State Road 70 Canal) provide secondary conveyance capacity for the regulation of floods in the Lake Istokpoga Water Management Basin. The C-40 and C-41 canals flow into Lake Okeechobee, whereas the C-41A canal flows into the Kissimmee River, which flows into Lake Okeechobee. Details of Lake Istokpoga water control plan are available in the *Master Water Control Manual for Kissimmee River – Lake Istokpoga Basin* (USACE 1994).

Figure 2-13, panel a, shows the daily average stage at the headwater of S-68, daily rainfall, and regulation schedules for Lake Istokpoga during WY2016. Appendix 2-4, Figure 8, shows daily water levels from 1993 to 2016. Stages were close to the regulation schedule. WY2016 average stage for Lake Istokpoga (38.92 ft NGVD29) was lower than WY2015 and higher than the historical average (**Table 2-10**). Minimum releases, based on water supply needs, were made during drier periods and flood control releases during wet periods. WY2016 flows (498,502 ac-ft) were twice as much as the historical average and higher than WY2015. **Table 2-11** depicts WY2016, WY2015, and historical flow statistics for major impoundments. Monthly historical average, WY2015, and WY2016 water levels are shown in Appendix 2-5, Figure 8. WY2016 monthly flows are shown in Appendix 2-6, Table 1. Monthly historical average, WY2015, and WY2016 flows are presented in Appendix 2-7, Figure 2.

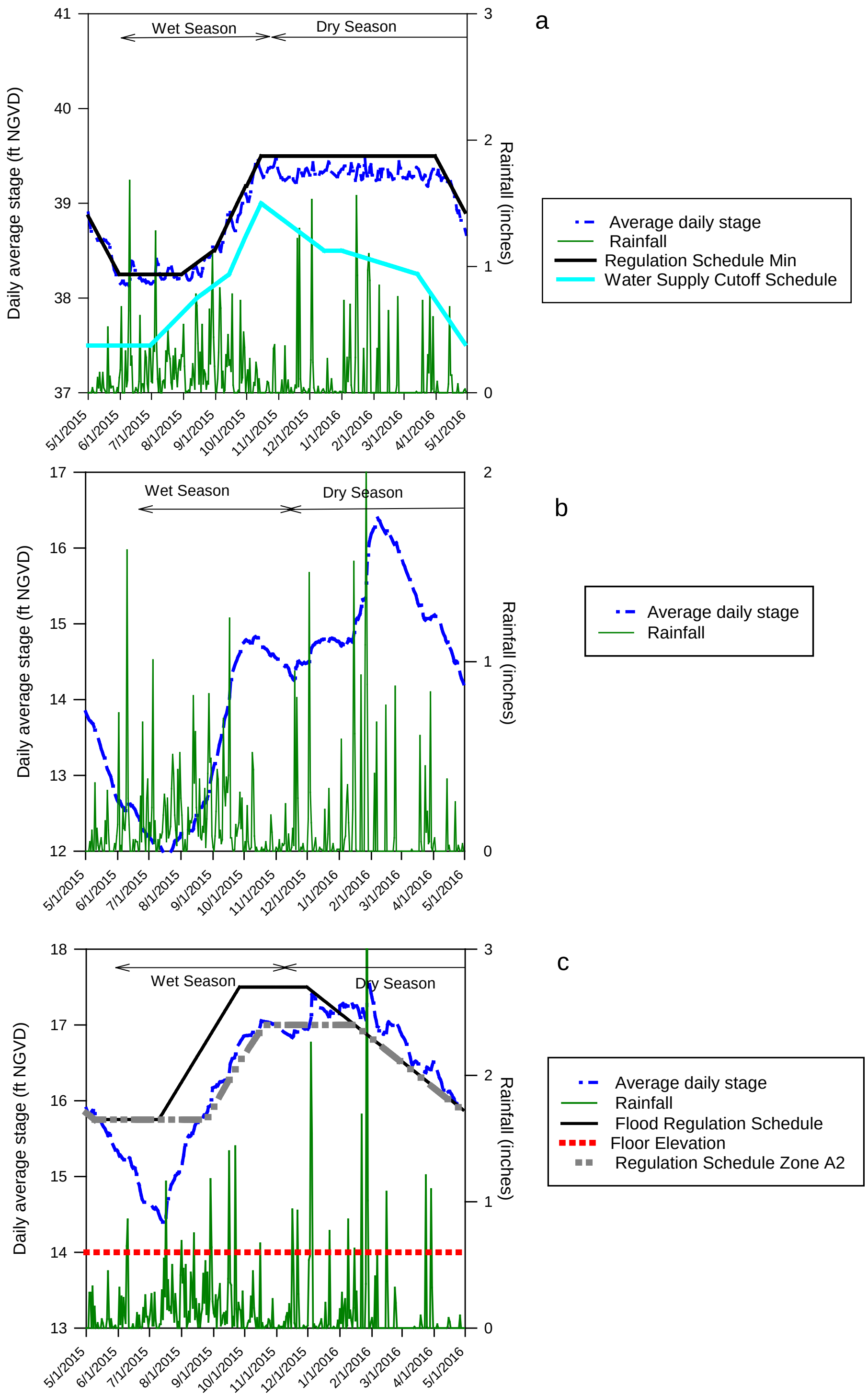


Figure 2-13. Average daily water levels (stage), regulation schedule, and rainfall for (a) Lake Istokpoga, (b) Lake Okeechobee, and (c) WCA-1.

Lake Okeechobee

Lake Okeechobee's water level is regulated to provide (1) flood control; (2) navigation; (3) water supply for agricultural irrigation, municipalities and industry, the EPA, and the Everglades STAs; (4) regional groundwater control; (5) salinity control; (6) enhancement of fish and wildlife; and (7) recreation (Abtew et al. 2011). The regulation schedule accounts for varying and often conflicting purposes. The lake was regulated under a different regulation schedule in previous water years (Abtew et al. 2007b). An updated regulation schedule was adopted on April 28, 2008, for Lake Okeechobee, which was implemented on May 1, 2008 (USACE 2008). Details of the current regulation schedule are discussed below and shown in **Figure 2-14**.

Lake Okeechobee has an approximate surface area of 436,300 acres at the historical average stage of 14.02 ft NGVD29 (1931–2015). At the beginning of WY2016, the lake stage was 13.84 ft NGVD29 and the average stage was 14.12 ft NGVD29 for the water year, 0.1 ft higher than the historical average (**Table 2-10**). Stage at the end of the water year was 14.21 ft NGVD29. **Figure 2-13**, panel b, shows the daily average stage and daily rainfall for Lake Okeechobee during WY2016. **Figure 2-10** shows lake regulation schedule, daily water level, and water management decisions. Water levels fluctuated between the Beneficial Use Subband and the Intermediate Subband. Appendix 2-4, Figure 9, shows daily water levels for Lake Okeechobee for the period of record, 1931–2016. WY2016 average stage for Lake Okeechobee (14.12 ft NGVD29) was lower than WY2015 but higher than the historical average (**Table 2-10**). Monthly historical average, WY2015, and WY2016 water levels are shown in Appendix 2-5, Figure 9. **Table 2-10** depicts WY2016, WY2015, and historical mean, maximum, and minimum stages.

WY2016 inflow into Lake Okeechobee (2,984,077 ac-ft) were high, 140 percent of the historical average inflow (2,126,080 ac-ft). WY2016 outflow of 2,323,597 ac-ft was 159 percent of historical annual outflow (1,457,982 ac-ft) since 1972. During the dry season (November 2015 to April 2016), surface water inflows into the lake was 1,521,697 ac-ft, 51 percent for the water year. At the same time, 1,540,650 ac-ft was discharged from the lake to control the rise in stage reflecting the relatively wet dry season in the watershed. **Table 2-11** depicts WY2016, WY2015, and historical flow statistics for major impoundments. WY2016 monthly inflows and outflows are shown in Appendix 2-6, Tables 2 and 3, respectively. Monthly historical average, WY2015, and WY2016 inflows and outflows are shown in Appendix 2-7, Figures 3 and 4, respectively. Culvert 5A structure is being rebuilt.

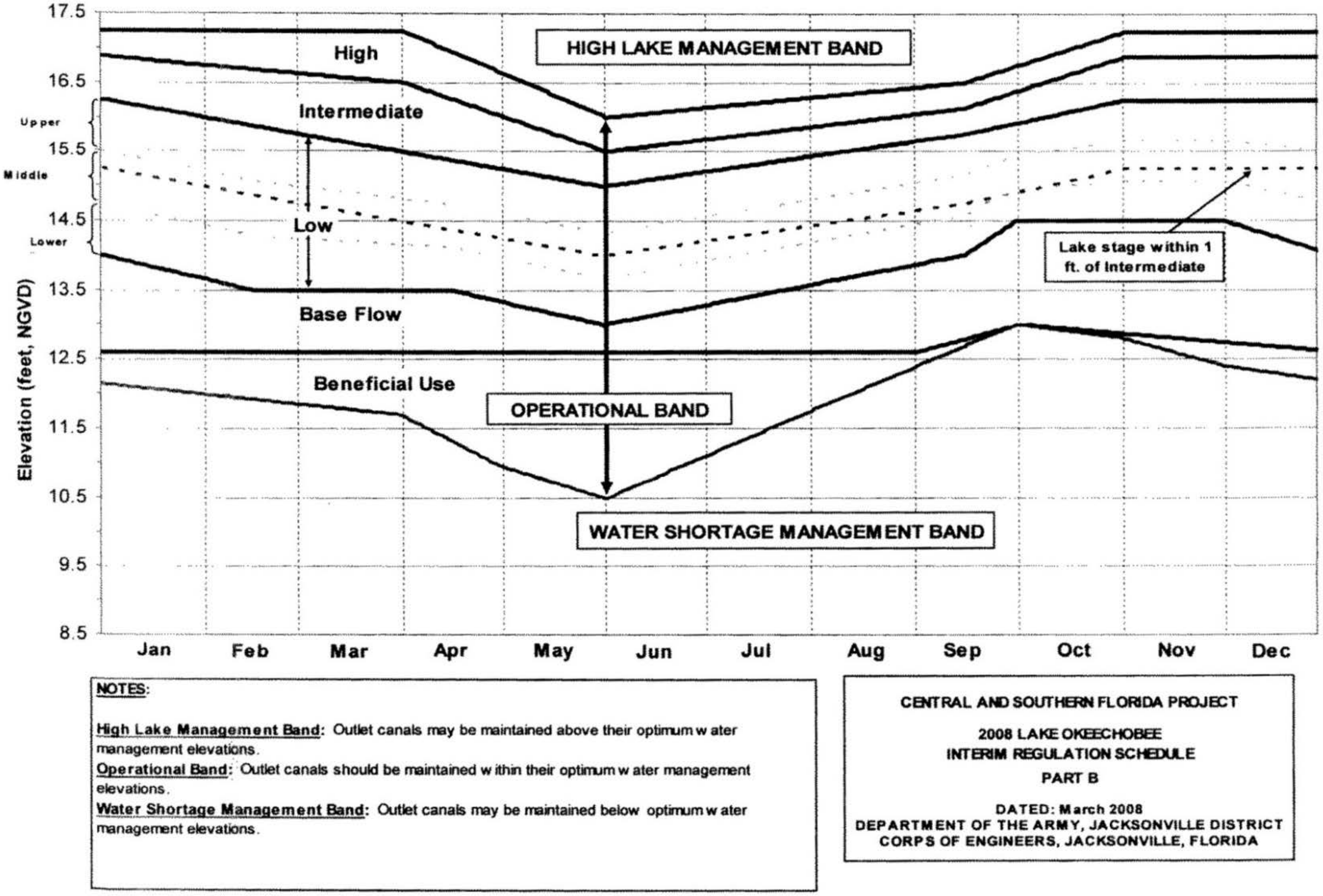


Figure 2-14. Lake Okeechobee's current regulation schedule (LORS2008).

As previously noted in the *Overview* subsection of this section, the current regulation schedule for Lake Okeechobee is divided into three major bands: High Lake Management Band, Operational Band, and Water Shortage Management Band (**Figure 2-14**). The regulation schedule was developed by USACE based on several key considerations including the lake's ecology and environmental needs, Caloosahatchee and St. Lucie estuaries' environmental needs, Everglades environmental needs, water supply, flood control, structural integrity of the Herbert Hoover Dike, and potential danger from hurricanes. While this regulation schedule attempts to balance the multipurpose needs of flood control, water supply, navigation, enhancement of fish and wildlife resources, and recreation, the dominant objective is public health and safety related to dike structural integrity. Notably, LORS2008 has expanded operational flexibility throughout the year and allows Lake Okeechobee to be managed at lower levels than the previous regulation schedule. It is implemented through a decision tree that considers lake water level, WCA water levels, tributary hydrologic conditions, multi-season climatic and hydrologic outlook, and downstream estuary conditions. The decision tree for establishing allowable lake releases to the WCAs and to tide (estuaries) can be found in Abtew et al. (2011).

Upper East Coast and St. Lucie Canal and Estuary

Inflows to the St. Lucie Canal are received from Lake Okeechobee by operation of S-308, a gated spillway, the Port Mayaca lock, and runoff from the basin (Abtew et al. 2011). The optimum water control elevations for the St. Lucie Canal vary between 14.0 and 14.5 ft NGVD29. When the lake stage is below 14.5 ft NGVD29 and the S-308 structure is open, runoff from the C-44 (St. Lucie Canal) basin flows back to the lake with the C-44 canal stage relatively higher. The outflow from the St. Lucie Canal that is not used in the basin for water supply or canal stage maintenance is discharged into the estuary via the S-80 structure. Runoff from the basin (C-44) is discharged to the estuary through S-80. WY2016 flows from Lake Okeechobee to the St. Lucie Canal were 388,303 ac-ft while inflow into the St. Lucie Estuary through S-80 was 558,412 ac-ft. Lake Okeechobee discharge through S-308 in to the St. Lucie Canal that is not used for water supply and is discharged to the estuary was estimated at 369,844 ac-ft. The estimated basin runoff discharged to the estuary was 188,568 ac-ft (**Tables 2-1** and **2-11**). As salinity is an important measure of estuary viability, volume and timing of freshwater flow at S-80 is a key feature of water management activities.

The C-23 canal discharges into the North Fork of the St. Lucie River at structure S-48. The C-24 canal discharges into the same fork at S-49. The C-25 canal discharges into the southern part of the Indian River Lagoon at structure S-50. Structure S-80 discharges water from the St. Lucie Canal into the South Fork of the St. Lucie River. Rainfall in the Martin/St. Lucie rainfall area was above average (+2.64 inches) for WY2016. Outflows from the C-23 canal (S-48), C-25 canal (S-50), and St. Lucie Canal (S-80) were higher than WY2015 (**Table 2-11**). WY2016 monthly flows for S-48, S-49, S-50, and S-80 are shown in Appendix 2-6, Table 4. Monthly historical average, WY2015, and WY2016 flows are shown in Appendix 2-7, Figures 5 through 8. Water management decision regulating releases through S-80 into the St. Lucie River is shown in **Figure 2-10**.

Lower West Coast

Inflows to the Caloosahatchee River (C-43 canal) are runoff from the basin watershed and releases from Lake Okeechobee by operation of S-77, a gated spillway and lock structure (Abtew et al. 2011). Structure S-77 operations use regulation procedures are described in USACE (2008). Environmental water supply releases from the lake to the Caloosahatchee River occurred at various times (**Figure 2-10**). WY2016 flows from Lake Okeechobee to the Caloosahatchee River were 972,904 ac-ft, which is 180 percent of the historical and 169 percent of WY2015 flows. WY2016 monthly Lake Okeechobee flows through S-77 are shown in Appendix 2-6, Table 5.

Downstream of S-77, S-78 is a gated spillway that also receives runoff from the East Caloosahatchee Watershed, its local watershed. The optimum water control elevation for this portion of the Caloosahatchee

Canal (upstream of S-78 and downstream of S-77) is between 10.6 and 11.5 ft NGVD29. The outflow from the Caloosahatchee Canal (downstream of S-78) is discharged into the estuary via S-79, a gated spillway and lock operated by USACE. The operations of S-79 include runoff from the West Caloosahatchee and Tidal Caloosahatchee watersheds. The optimum water control elevations near S-79 range between 2.8 and 3.2 ft NGVD29. Because salinity is an important measure of estuary viability, the volume and timing of freshwater flow at S-79 is an important feature of water management activities. Water management decision regulating releases through S-79 into the Caloosahatchee Estuary is shown in **Figure 2-10**. WY2016 discharge through S-79 to the coast, 1,929,150 ac-ft, is 154 percent of the historical average (1972–2016) and 156 percent of WY2015. Lake Okeechobee inflow into the Caloosahatchee Canal that is not used for water supply in the basins or canal stage maintenance is discharged into the estuary via the S-79 structure passing through S-78 along the route. Runoff from the basin (West Caloosahatchee and Tidal Caloosahatchee) is also discharged to the estuary. Lake Okeechobee discharge through S-77 that passed through S-78, not used for water supply, but discharged to the estuary, was estimated at 849,042 ac-ft. The estimated basin runoff discharged to the estuary was 1,080,108 ac-ft (**Tables 2-1** and **Table 2-11**). WY2016 monthly flows for S-77 and S-79 are shown in Appendix 2-6, Table 5. Monthly historical average, WY2015, and WY2016 outflows at S-79 are shown in Appendix 2-7, Figure 9. **Table 2-11** depicts WY2016, WY2015, and historical flow statistics.

Everglades Agricultural Area

Four major canals pass through the EAA: West Palm Beach, Hillsboro, North New River, and Miami. Flows from Lake Okeechobee and runoff from the EAA are discharged via these four canals to relieve flooding for the local drainage area and into the Everglades STAs for water quality improvement. Discharges to the east coast occur through the West Palm Beach Canal. At times, when conditions do not allow for the STAs to treat all runoff water, diversion to the WCAs could occur. The inflows from Lake Okeechobee to these canals are from structures S-351, S-352, and S-354. These structures are gated spillways with a maximum tailwater elevation not to exceed 12 ft NGVD29 for Lake Okeechobee operation. The optimum tailwater control elevations for S-351 and S-354 range between 11.5 and 12.0 ft NGVD29. During WY2016, daily average tailwater elevations at S-351 ranged from 9.34 to 12.68 ft NGVD29, at S-354 ranged from 9.25 to 11.88 ft NGVD29, and at S-352 ranged from 9.19 to 13.23 ft NGVD29. The outflows from the four canals to the STAs are discharged through pump structures S-5A, S-319, S-6, G-370, G-372, and G-434. Outflows from STAs are inflows into WCAs. During the dry season and drier-than-normal wet seasons, water supply for agricultural irrigation is provided by these four primary canals, mainly through gravity release from Lake Okeechobee. During droughts, when Lake Okeechobee levels are low, forward pumping is required to withdraw water from the lake. At times, water is also supplied to the EAA from the WCAs. Farmers utilize a set of secondary and tertiary farm canals to distribute water from several gated culverts and pumps to their respective fields. During extreme flooding potential or conditions in the EAA, water is pumped into the lake following guidelines. In WY2016, 19,444 ac-ft was pumped through the S-2 pump station and 13,145 ac-ft through the S-3 pump station into the lake from the EAA, mostly during the extreme January 2016 wet conditions to control flooding (Appendix 2-6, Table 2).

Everglades Protection Area

Water Conservation Area 1

The primary objectives of the WCAs are to provide (1) flood control; (2) water supply for agricultural irrigation, municipalities, industry, and ENP; (3) regional groundwater control and prevention of saltwater intrusion, (4) enhancement of fish and wildlife; and (5) recreation. A secondary objective is the maintenance of marsh vegetation in the WCAs, which is expected to provide a dampening effect on hurricane-induced wind tides (Abtew et al. 2011). WCA-1 covers approximately 141,440 acres with a daily average water level of 15.69 ft NGVD29 (1960–2016). WCA-1 is regulated mainly by outflow structures

S-10A, S-10C, S-10D, and S-39; the regulation schedule for WCA-1 is provided by the *Master Water Control Manual – Water Conservation Areas, Everglades National Park, and ENP-South Dade Conveyance System* (USACE 1996). The main inflow structures are the G-251, G-310, and S-362 pump stations. Water supply releases are made through the G-94A, G-94C, G-300, G-301, and S-39 structures. S-39 is also used to discharge excess water to the coast through the Hillsboro Canal. The regulation schedule varies from high stages in the late fall and winter to low stages at the beginning of the wet season (Abtew et al. 2007b). The seasonal range allows runoff storage during the wet season and water supply during the dry season and fulfills ecological needs. Water levels in WCA-1 started at 15.90 ft NGVD29 on May 1, 2015, and ended the year at 15.85 ft NGVD29. Water level rose to a maximum of 17.58 ft NGVD29 in January 2016 during an extreme high rainfall month and declined the rest of the water year with few reversals due to high rainfall events. The mean water year stage was 16.29 ft NGVD29, 0.2 ft lower than WY2015 and 0.6 ft higher than the historical average. Four gauges (1-8C, 1-7, 1-8T, and 1-9) are used for stage monitoring. Daily water levels were compiled from the four gauges based on their regulation schedule uses. Site 1-8C was used from January 1 to June 30, while the remaining sites (1-7, 1-8T, and 1-9) were used to calculate the average water level for the year, but only if the average was lower than that of site 1-8C. **Figure 2-13**, panel c, depicts the WY2016 daily average water level, daily rainfall, and regulation schedule for WCA-1. Daily average historical water levels are shown in Appendix 2-4, Figure 10, for the period of record (1960–2016). Monthly historical average, WY2015, and WY2016 water levels are shown in Appendix 2-5, Figure 10. **Table 2-10** depicts WY2016, WY2015, and historical mean, maximum, and minimum stages.

The main inflows into WCA-1 are from STA-1 West (STA-1W) through the G-251 and G-310 pump stations and from STA-1 East (STA-1E) via pump station S-362. There are three diversion structures that can flow in both directions (G-300, G-301, and G-338). The main outflow from WCA-1 is to WCA-2 through the S-10 structures and S-39 to the east urban areas and to the coast. The two diversion structures (G-300 and G-301) may also be used to discharge water from WCA-1 to the north to the L-8 and C-51 canals via the STA-1 inflow basin under extreme events. S-39 discharges to the east via the Hillsboro Canal. The G-94A and G-94C structures are used to make water supply releases to the east urban area.

Historical flows through each structure have varying lengths of period of record because new structures come online, or because existing structures may no longer contribute to the inflow and outflows. The structures related to the Everglades STAs are relatively recent additions. WCA-1 is regulated between 14.00 and 17.50 ft NGVD29. WY2016 inflows into WCA-1 (351,943 ac-ft) were 75 percent of the historical average. In WY2016, 63 percent of the inflow was from STA-1E through pump station S-362, and 47 percent was from STA-1W through pump stations G-251 and G-310. No backflows occurred through the G-94s or S-10s. No inflow occurred through G-338. There was no flood diversion inflow through G-300 and G-301. Monthly historical average, WY2015, and WY2016 inflows are shown in Appendix 2-7, Figure 10.

WY2016 outflows from WCA-1 (350,425 ac-ft), were 81 percent of the historical average, for the analysis period from 1972 to 2016. Outflows from WCA-1 were mainly into WCA-2A through the S-10 structures (59 percent), to the east through the S-39 structure and the Hillsboro Canal (35 percent), and no backflow through the G-300 and G-301 structures for water supply into the L-8 or C-51 canals. Water was syphoned back into STA-1W from WCA-1 through the G-310 pump structure for the purpose of hydrating STA-1W cells (2,703 ac-ft). Capacity to provide water to the affected cells through the normal northern path was limited. Flow to the east through G-94A was 5 percent. **Table 2-11** depicts WY2016, WY2015, and historical flow statistics. WY2016 monthly outflows are shown in Appendix 2-6, Table 7. Monthly historical average, WY2015, and WY2016 outflows are shown in Appendix 2-7, Figure 11.

Water Conservation Area 2

WCA-2 is located south of WCA-1. An interior levee across the southern portion of the area subdivides it into WCA-2A and WCA-2B, reducing water losses due to seepage into the extremely pervious aquifer that underlies WCA-2B and precludes the need to raise existing levees to the grade necessary to provide protection against wind tides and wave run-up. Combined, WCA-2A and WCA-2B have a total area of 133,400 acres, with 80 percent of the area in WCA-2A. The regulation schedule for WCA-2A is provided by the *Master Water Control Manual – Water Conservation Areas, Everglades National Park, and ENP-South Dade Conveyance System* (USACE 1996). A regulation schedule is not used for WCA-2B because of high seepage rates. Releases to WCA-2B from S-144, S-145, and S-146 are terminated when the indicator stage gauge 99 in WCA-2B exceeds 11.0 ft NGVD29. Discharges from WCA-2B are made from spillway structure S-141 to the North New River Canal when the pool elevation in WCA-2B exceeds 11.0 ft NGVD29. For WY2016, the water level in WCA-2A started at 11.79 ft NGVD29 and reached a maximum of 14.4 ft NGVD29 in February 2016 and ended at 11.6 ft NGVD29 by the end of the water year. Water level stayed above the regulation schedule throughout the water year. The average stage was 12.38 ft NGVD29. Appendix 2-4, Figure 11, shows the daily water level for the period 1961–2015. **Figure 2-15**, panel a, depicts WY2016 daily average water level, daily rainfall, and regulation schedule for WCA-2A. **Table 2-10** depicts WY2016, WY2015, and historical mean, maximum, and minimum stages. Monthly historical average, WY2015, and WY2016 water levels are shown in Appendix 2-5, Figure 11.

WY2016 inflows into WCA-2 (864,470 ac-ft) were 133 percent of the historical average and about the same as inflows in WY2015. The major inflows to WCA-2A were STA-2 discharges through pump station G-335 and G-436 (53 percent), STA-3/4 discharges through the S-7 pump station (23 percent), outflow from WCA-1 through the S-10 structures (24 percent), and no flows through S-142 and G-339.

WY2016 outflows from WCA-2 (872,912 ac-ft) were 134 percent of the historical average and 108 percent of WY2015 outflows. Outflows from WCA-2 were primarily into WCA-3A through structures S-11A, S-11B, and S-11C (81 percent) and discharge to canals 13 and 14 through structure S-38 (17 percent) and S-34 (2 percent). This water year, no water backflowed into the EAA from WCA-2. No outflow occurred through structures S-34 and G-339. A small discharge to WCA-3A occurred through S-142. WY2016 monthly inflows and outflows are shown in Appendix 2-6, Tables 8 and 9, respectively. Monthly historical average, WY2015, and WY2016 inflows and outflows are shown in Appendix 2-7, Figures 12 and 13, respectively. **Table 2-11** depicts WY2016, WY2015, and historical flow statistics.

Water Conservation Area 3

WCA-3 is located south and southwest of WCA-2A. Two interior levees across the southeastern portion of the area subdivide it into WCA-3A and WCA-3B. These levees reduce water losses due to seepage into the extremely pervious aquifer that underlies WCA-3B. WCA-3A and WCA-3B combined have a total area of 585,560 acres, with 83 percent of the area in WCA-3A. The regulation schedule for WCA-3A is provided in the *Master Water Control Manual – Water Conservation Areas, Everglades National Park, and ENP-South Dade Conveyance System* (USACE 1996). A regulation schedule is not used for WCA-3B because of high seepage rates. Indicator gauge 3B-2 is used for WCA-3B. Flow releases into WCA-3B are from the S-142 and S-151 structures, while releases from WCA-3B are through S-31 or S-337. S-151 permits releases of water from WCA-3A to supply water needs to south Miami-Dade County and along the Miami (C-6), C-7, and C-8 canals during the dry season. Discharges from WCA-3B are rarely made from culvert L-29-1 for water supply purposes.

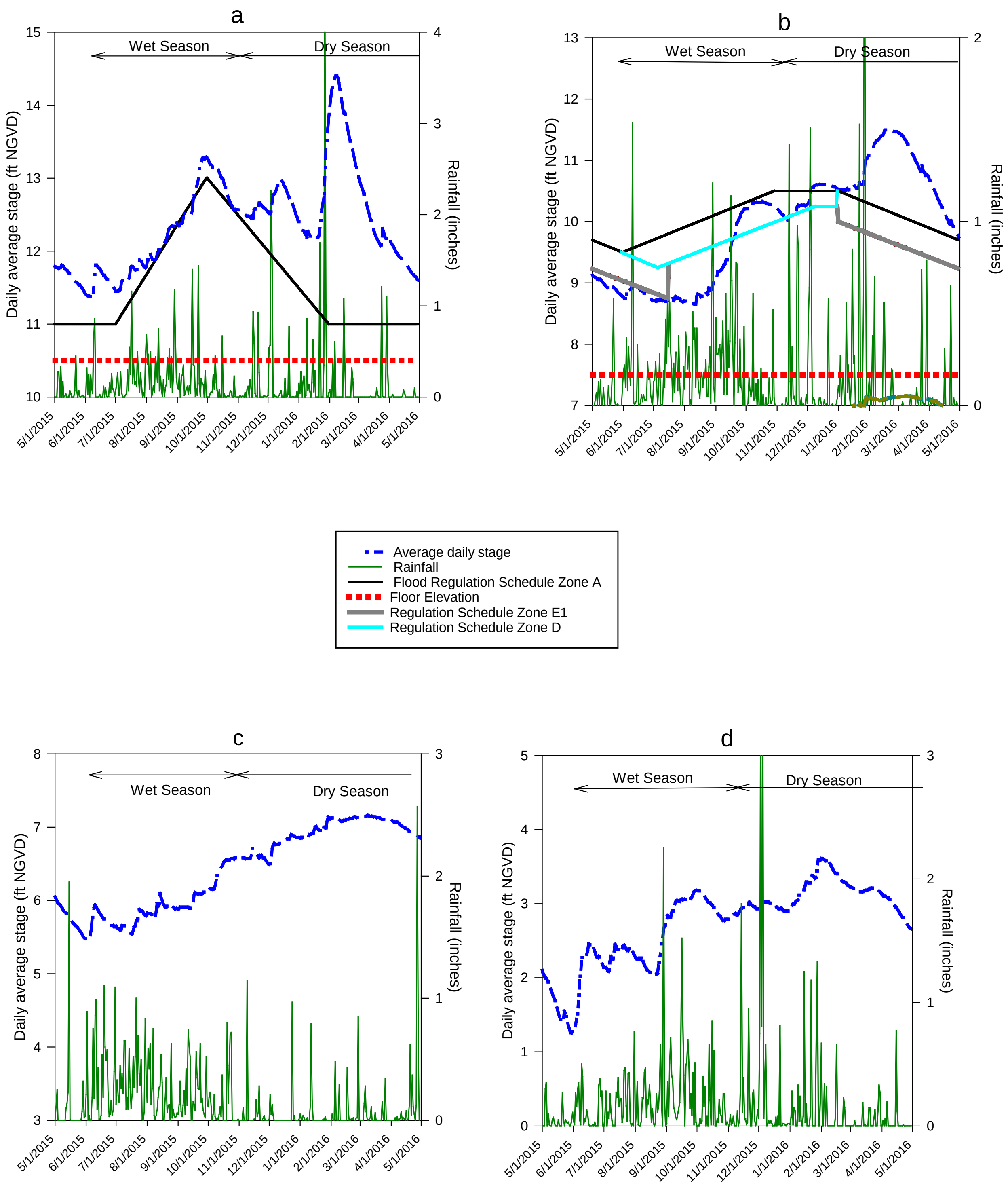


Figure 2-15. Average daily water levels (stage), regulation schedule, temporary deviation, and rainfall for (a) WCA-2A, (b) WCA-3A, (c) ENP gauge P-33, and (d) ENP gauge P-34.

Figure 2-15, panel b, depicts the WY2016 daily average water level, daily rainfall, and regulation schedule for WCA-3A. The previous regulation schedule, which was known as the Interim Operational Plan for the Protection of the Cape Sable Seaside Sparrow, was replaced by a new regulation schedule known as the Everglades Restoration Transition Plan as of October 19, 2012. Water levels in WCA-3 were above the flood regulation schedule in WY2016 and receded as a result of the emergency final order operations (Appendix 2-1). The average stage was 9.93 ft NGVD29 with a maximum of 11.5 ft NGVD29 and minimum of 8.65 ft NGVD29 The average water level was higher than WY2015 levels. Appendix 2-4, Figure 12, shows the daily water level for the period 1962–2016. Monthly historical average, WY2015, and WY2016 water levels are shown in Appendix 2-5, Figure 12. **Table 2-10** depicts WY2016, WY2015, and historical mean, maximum, and minimum stages.

WY2016 inflows into WCA-3A (1,575,428 ac-ft) were 133 percent of historical average. The major inflows to WCA-3A in WY2016 were through S-11A, S-11B, and S-11C (45 percent) from WCA-2, and from STA-3/4 through structures S-8 (15 percent). Flows through S-150 were 4 percent. Inflows through the northwest gap opening were estimated at 9 percent with STA-5/6 contributions through the gap estimated at 5 percent. L-4 borrow canal gap or opening into the L-3 extension canal that is currently not gauged has a bottom width of 150 ft at an elevation of 3 ft NGVD29 (SFWMD 2002). Water released from the Miami Canal through the G-404 pumps into the L-4 canal but not released to the west through G-409 is estimated as inflow to WCA-3A through the gap. Also, outflows from STA-5/6 are considered inflows into WCA-3A through the gap as reported in Chapter 3A of this volume. Inflows from the east through structures S-9 and S-9A accounted for 11 percent of the total inflow. The S-140 and S-190 structures to the northwest contributed 10 and 6 percent of the inflow to WCA-3A, respectively.

WY2016 outflows from WCA-3A (1,368,423 ac-ft) were 135 percent of the historical average. Outflows from WCA-3A into ENP were through structures S-12A, S-12B, S-12C, and S-12D (51 percent); S-151 (13 percent); S-333 (21 percent) with potential flow to ENP to the south or flow east through S-334; S-344 and S-343 (2 percent); S-31 (4 percent); S-337 (8 percent); and S-30 (2 percent). There was minor flow through S-142. There was minor backflow through S-8 but not S-150. WY2016 monthly inflows and outflows are shown in Appendix 2-6, Tables 10 and 11, respectively. Monthly historical average, WY2015, and WY2016 inflows and outflows are shown in Appendix 2-7, Figures 14 and 15, respectively. **Table 2-11** depicts WY2016, WY2015, and historical flow statistics.

Everglades National Park

ENP is located south of WCA-3A and WCA-3B. Criterion for water delivery into ENP is the new Everglades Restoration Transition Plan regulation schedule, which replaced the Interim Operational Plan for the Protection of the Cape Sable Seaside Sparrow as of October 19, 2012. Water levels in WCA-3 were above the flood regulation schedule in 2016 and discharge into ENP was increased as a result of the emergency final order operations (Appendix 2-1). Water level monitoring at sites P-33 and P-34 has been used in previous reports as representative of slough and wet prairie, respectively (Sklar et al. 2003). Station elevations for P-33 and P-34 are 5.06 and 2.09 ft NGVD29, respectively (Sklar et al. 2000). Historical water level data for sites P-33 (1952–2016) and P-34 (1953–2016) were obtained from DBHYDRO. WY2016 water level at both sites were higher than WY2015 and historical averages. WY2016 average water level at P-33 was 6.42 ft NGVD29 and at P-34 was 2.78 ft NGVD29. **Figure 2-15**, panels c and d, depict the daily average water level and rainfall at P-33 and P-34, respectively, for WY2016. WY2016 daily and historical average water levels for P-33 and P-34 are shown in Appendix 2-4, Figures 13 and 14, respectively. Monthly historical average, WY2015, and WY2016 water levels for P-33 and P-34 are shown in Appendix 2-5, Figures 13 and 14, respectively. **Table 2-10** depicts WY2016, WY2015, and historical mean, maximum, and minimum stages.

WY2016 inflow into ENP (1,566,604 ac-ft) was 156 percent of the historical average and 154 percent of WY2015 inflows. Inflow into ENP is mainly through structures S-12A, S-12B, S-12C, S-12D, S-18C, S-332B, S-332C, S-332D, S-333, S-199, and S-200. The major inflow (45 percent) was through the S-12 structures. The other structures contributed the following percentages of inflow: S-332B, 7 percent; S-332C, 8 percent; S-332D, 7 percent; S-18C, 6 percent; S-333, 16 percent; S-200, 4 percent; S-199, 4 percent; S-355B, 1 percent; and S356, 1 percent. WY2016 monthly inflows are shown in Appendix 2-6, Table 12. Monthly historical average, WY2015, and WY2016 inflows are shown in Appendix 2-7, Figure 16. **Table 2-11** depicts WY2016, WY2015, and historical flow statistics.

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