Chapter 2: Hydrology of the South Florida Environment

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SUMMARY

Given hydrology's significance to the entire South Florida ecosystem, this chapter updates hydrologic data and analysis for Water Year 2010 (WY2010) (May 1, 2009–April 30, 2010). A water year covers the 12 months from May of the previous year to the end of April of the reporting year. WY2009 hydrology is available in Chapter 2 of the *2010 South Florida Environmental Report* (SFER) – *Volume I.* This chapter includes a brief overview of the South Florida regional water management system, the hydrologic impact of the 2009–2010 El Niño event, and WY2010 hydrology.

In multi-objective water management systems, challenges are created by hydrologic variation. Too much or too little water creates flooding, water shortage, and ecological impacts. Although South Florida is a wet region, serious droughts do happen, and there is potential for periodic water shortages. Tropical systems make significant contributions to the hydrology of South Florida. Historically, drought streaks have been broken by deluges from tropical systems (tropical depressions, tropical storms, and hurricanes). The El Niño-Southern Oscillation climatic phenomenon is linked to South Florida hydrology. During El Niño years, the region gets above-average rainfall and above-average surface water flows during the dry season. In La Niña years, conversely, droughts prevail. Impacts from hydrologic variation can be mitigated with storage and conveyance capacity increases.

The hydrology of South Florida for WY2010 reflects the impact of an El Niño event on dry season hydrology. Meteorologically, the water year's rainfall was wet with above-average rainfall in all of the South Florida Water Management District's (SFWMD or District) rainfall areas. WY2010 rainfall over the District area was 61.43 inches, which is 116 percent of the historical average. Because of El Niño, the dry season (November–May) was wetter than normal. May and December 2009 and February, March and April 2010, were wet. May 2009, for example, had two times the average rainfall. The summer months had average rainfall, but October and November were drier than normal. The Upper Kissimmee rainfall area was the wettest with 19.93 inches above-average rainfall, followed by Broward (+16.57 inches), West Everglades Agricultural Area (+15.39 inches), Water Conservation Areas 1 and 2 (13.67 inches), East Caloosahatchee (+10.93 inches), Southwest Coast (+9.57 inches), Water Conservation Area 3 (+9.23 inches), Lower Kissimmee (+8.51 inches), Miami-Dade (+7.98 inches), Big Cypress Basin (+7.93 inches), East Everglades Agricultural Area (+7.78 inches), Everglades National Park (+5.23 inches), Palm Beach (+4.85 inches), Lake Okeechobee (+4.3 inches), and Martin/St. Lucie (+2.04 inches). The spatial average District WY2010 rainfall positive anomaly of 8.68 inches broke the drought streak of the past three water years: the WY2009 rainfall deficit of 7.51 inches, the WY2008 deficit of 3.8 inches, and the WY2007 deficit of 12 inches.

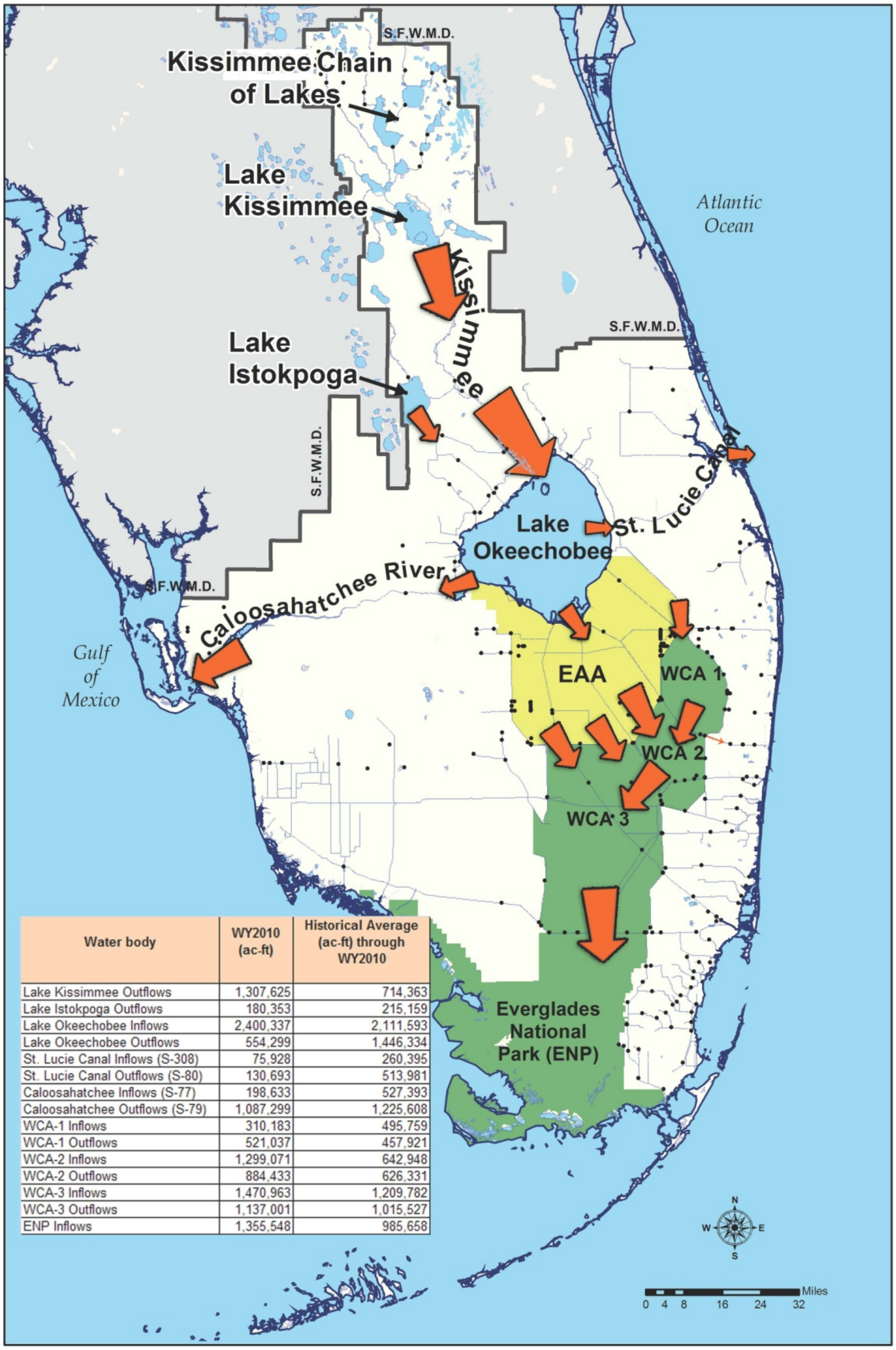
At the beginning of WY2010, the main storage of the system, Lake Okeechobee, continued to show record low water and storage levels from the three-year drought. Gravity discharge from the

lake was restricted for a while in May 2009 due to low water levels (stage) and forward pumping was used briefly. The water year started with Lake Okeechobee stage at 11.09 feet National Geodetic Vertical Datum 1929 (ft NGVD) and receded to the water year low level of 10.55 ft NGVD on May 18, 2009. Wet conditions in the second half of May 2009, and the following wet season (June–October), reversed the decline in stage rising to a maximum of 14.56 ft NGVD on September 25, 2009. The lake's stage declined in October and November 2009 due to dry conditions. Mainly, El Niño-related rainfall from December 2009 through April 2010 maintained higher lake levels than normal for the dry months (see the *El Niño Impact on South Florida Dry Season Hydrology* section of this chapter). Rainfall from El Niño-related fronts was as high as 14.25 inches in one day in North Miami Beach at the S29 rainfall station. Runoff from El Niño-related fronts and other rains in summer 2009 raised Lake Okeechobee's water level and replenished surface and subsurface storage ending drought conditions that persisted from WY2006–WY2009.

In summary, WY2010's hydrology was wet. Rainfall for most months of the dry season and the water year was above average throughout the District. Rainfall and runoff from the wet months' rains replenished subsurface storage, Lake Okeechobee, and the Water Conservation Areas' surface storage and kept water demand low. **Figure 2-1** presents WY2010 surface water flows for major hydrologic components in the regional system with historical average flows shown for comparison; **Table 2-1** shows WY2010 flows comparative to the last water year's flows and historical average flows.

Hydrology is linked to all aspects of water management at the District. Influences of the water year hydrology on various aspects of the system can be found in other chapters of this volume as follows:

- Chapter 3A Status of Water Quality in the Everglades Protection Area
- Chapter 3B Mercury and Sulfur Monitoring, Research And Assessment in South Florida
- Chapter 4 Nutrient Source Controls for the South Florida Environment
- Chapter 5 Performance and Optimization of the Everglades Stormwater Treatment Areas
- Chapter 6 Ecology of the Everglades Protection Area
- Chapter 10 Lake Okeechobee Protection Program – State of the Lake and Watershed
- Chapter 11 Kissimmee Basin
- Chapter 12 Coastal Ecosystems



Water body	WY2010 (ac-ft)	Historical Average (ac-ft) through WY2010
Lake Kissimmee Outflows	1,307,625	714,363
Lake Istokpoga Outflows	180,353	215,159
Lake Okeechobee Inflows	2,400,337	2,111,593
Lake Okeechobee Outflows	554,299	1,446,334
St. Lucie Canal Inflows (S-308)	75,928	260,395
St. Lucie Canal Outflows (S-80)	130,693	513,981
Caloosahatchee Inflows (S-77)	198,633	527,393
Caloosahatchee Outflows (S-79)	1,087,299	1,225,608
WCA-1 Inflows	310,183	495,759
WCA-1 Outflows	521,037	457,921
WCA-2 Inflows	1,299,071	642,948
WCA-2 Outflows	884,433	626,331
WCA-3 Inflows	1,470,963	1,209,782
WCA-3 Outflows	1,137,001	1,015,527
ENP Inflows	1,355,548	985,658

Figure 2-1. Water Year 2010 (WY2010) (May 1, 2009–April 30, 2010) and historical average inflow and outflow into major hydrologic units of the regional water management system.

Table 2-1. Summary of flows for WY2010, the percent of historical average they represent, and their comparison to WY2009.

Location	WY2010 total flow (ac-ft*)	Percent of historical average	WY2009 total flow (ac-ft)
Northern Everglades			
Lake Okeechobee's Inflow	2,400,337	114	2,090,775
Lake Okeechobee's Outflow	554,299	38	1,141,084
Lake Kissimmee's Outflow	1,307,625	183	494,638
Lake Istokpoga's Outflow	180,353	84	289,437
Flows into the St. Lucie Canal from Lake Okeechobee	75,928	29	172,602
Flows into the St. Estuary through the St. Lucie Canal	130,693	26	164506
Flows into the Caloosahatchee Canal from Lake Okeechobee	198,633	34	375,722
Flows into the Caloosahatchee Estuary through the Caloosahatchee Canal	1,087,299	89	1,016,333
Southern Everglades			
Water Conservation Area 1 Inflow	310,183	65	336,293
Water Conservation Area 1 Outflow	521,037	114	334,724
Water Conservation Area 2 Inflow	1,299,071	202	905,864
Water Conservation Area 2 Outflow	884,433	141	737,421
Water Conservation Area 3 Inflow	1,470,963	122	1,212,107
Water Conservation Area 3 Outflow	1,137,001	94	1,556,182
Everglades National Park Inflow	1,355,548	138	1,392,932

*1 acre-foot = 0.1233 hectare-meter

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. South Florida's hydrology is driven by the continuous balance of rainfall and evapotranspiration reflected in surface water runoff, surface and subsurface storage, flows through the topographic low-relief features, floods, dryouts, and wildfires. Generally, the region is wet with an average annual rainfall of 53 inches. 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 to the west. The current hydraulic and hydrologic system is composed of lakes, impoundments, wetlands, canals, and water control structures that are managed under water management schedules and operational decisions.

Because there is significant overlap between this overview of the hydrology of the South Florida environment and day-to-day water management and Everglades restoration efforts, detailed updates for the major hydrologic components of the South Florida Water Management District's (SFWMD or District) system appear in other chapters of this volume. For example, Table 1-1 in Chapter 1 describes the major features of the South Florida environment in terms of surface area and general role in South Florida's hydrology, while a detailed analysis of the coastal areas of South Florida, including current conditions, is available in Chapter 12 of this volume.

The development of South Florida has required a complex water management system to manage flooding, occasional drought, and hurricane impacts. Excess water is stored in lakes, detention ponds, wetlands, impoundments, and aquifers, or is discharged to the coast through estuaries. Hydrologic extremes are exemplified by flooding and excess water during wet years and wildfires and water shortage during drought years.

Lake Okeechobee is a major component of the South Florida hydrologic system. Its storage capacity of over 3.75 million acre-feet (ac-ft) at a lake level of 14.5 feet National Geodetic Vertical Datum 1929 (ft NGVD) is 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. The outflows from Lake Okeechobee are received by the St. Lucie River and Estuary, Caloosahatchee River and Estuary, Everglades Agricultural Area (EAA), and sometimes the Stormwater Treatment Areas. The details of these sub-regional flows are provided in the *Water Levels and Flows* section of this chapter. While Lake Okeechobee and its related watersheds are outlined in this chapter, a detailed discussion of the lake is presented in Chapter 10 of this volume.

The SFWMD area extends from Orlando in the north to the Florida Keys in the south (**Figure 2-1**). It covers an area of 18,000 square miles (sq mi) and extends across 16 counties. 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 these criteria.

The major hydrologic components of the SFWMD are the Kissimmee Chain of Lakes, Lake Istokpoga, Lake Okeechobee, the EAA, the Caloosahatchee and St. Lucie River basins, the Lower East Coast, the Water Conservation Areas, the Lower West Coast, and Everglades National Park (ENP or Park). The Kissimmee Chain of Lakes (Lake Myrtle, Alligator Lake, Lake Mary Jane, Lake Gentry, Lake East Tohopekaliga, Lake Tohopekaliga, and Lake Kissimmee) are 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 surface water conditions.

South Florida experiences hydrologic variation that ranges from extreme drought to flood. The hydrology of the area 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.

Water Management

Water management is accomplished by the operation of hundreds of water control structures across the District. It is complicated by many factors including surface water-groundwater interaction, rainfall-runoff relationships, topography, multiple competing objectives, errors in measurements, and/or estimates of hydrologic components (e.g., flow, rainfall, evapotranspiration, storage and seepage), and the uncertainty of forecasting meteorological events. In addition, there are significant spatial and temporal variations of the hydrologic components across the District.

Water management meets various purposes by using established regulation schedules that integrate different objectives. Regulation schedules are rule curves of time-dependent water levels designed to manage the regional storage for flood control, water supply, and ecology. In order to broadly satisfy flood control and water supply needs on a long-term basis, day-of-the-year water level regulation schedules for each of the water bodies were developed by the District and U. S. Army Corps of Engineers (USACE) in cooperation with other agencies and stakeholders.

Every Tuesday morning, on a weekly basis, a group of water managers, scientists, and engineers from the District, USACE, and other federal and state agencies meet via telephone and face-to-face to discuss the state of the system and possible operational scenarios. The focus is on making recommendations that consider the environmental impacts of operational decisions. Weather reports that include the past week's rainfall amounts and the coming week's rainfall forecast are presented at the meeting. In addition, the longer-term climatic outlook for rainfall produced by the National Oceanic and Atmospheric Administration (NOAA) Climatic Prediction Center (CPC) is reviewed. Reports on the ecological and hydrological status of different areas of the system, such as the Kissimmee Basin, Lake Okeechobee, Stormwater Treatment Areas, the estuaries, the Everglades, groundwater, and water supply, are presented. The information presented during this meeting is recorded in a memorandum entitled "Weekly Environmental Conditions for Systems Operations." System status and water management recommendations for the week are prepared by the District. Then, a set of recommendations is provided to the U.S. Army Corps of Engineers (USACE) and used to guide decisions on regulatory discharges from major impoundments such as Lake Okeechobee.

Purpose of Water Management

The District manages water resources for multiple purposes such as (1) flood control, (2) water supply for municipal, industrial, recreational and agricultural uses, (3) groundwater recharge for well fields, (4) prevention of saltwater intrusion, (5) water supply for environmental needs, (6) protection of fish and wildlife resources, and (7) navigation and water quality improvements. These purposes are grouped into two major objectives of water management: flood control and water supply. During the annual wet season (June–October), the primary purpose of water management is flood control. During the dry season (November–May), the water management system is operated primarily to satisfy various water supply needs that include environmental deliveries, irrigation requirements, urban demands, and prevention of saltwater intrusion into groundwater.

Multi-purpose water resources objectives are met by using established regulation schedules that integrate these different objectives. Regulation schedules are developed and published in water control plans to manage the regional storage to satisfy flood control and water supply needs on a long-term basis using historical data for each water body.

Water control structures and water bodies are managed in accordance with operating criteria and regulation schedules described in water control plans. For lakes and reservoirs, regulation schedules are designed to balance competing objectives including water supply, flood control, navigation, and environmental needs. An unintended consequence of managing for better performance of one objective often leads to poorer performance in a competing objective. For example, higher regulation schedules benefit water supply but may harm the ecology of a lake. Lower lake schedules may produce stages more desirable for lake ecology and flood protection, but simultaneously reduce water supply potential. A regulation schedule also typically triggers flood control releases so as to protect the design integrity of the water management structures and levees and preserve native flora and fauna.

Use of Regulation Schedules for Water Management

The amount of storage volume available for water management varies significantly year to year due to large variations in rainfall. This variation causes large gaps between available water volumes generated from rainfall runoff and water demands. For any given year, up to 30–40 percent of the Standard Project Flood (SPF) is met for flood control while most of the water supply needs of the District are met. In order to broadly satisfy flood control and water supply needs on a long-term basis, monthly water level regulation schedules for each of the water bodies were developed by the District and the USACE in cooperation with other agencies and stakeholders.

The SPF is defined as the runoff flow generated from the Standard Project Storm (SPS) within the watershed. SPS is considered as one of several design storms over the watershed. A design storm is the most serve storm for which the canals and water control structures will accommodate that storm's runoff without an unacceptable level of flooding occurring in the watershed. A severe storm is described by the frequency with which it may occur. For example, on a long-term average basis, a storm with a rainfall intensity that has a four percent chance of being equaled or exceeded in any given year is known as 1 in 25 years storm. The USACE specifies an SPS that has rainfall amounts of 125 percent of the 1 in 100 years storm for estimating SPF. For calculations and modeling, design storms are assumed to occur most often during the wet season in South Florida when water tables are high and soils are wet. The runoff from the SPS is designated as SPF. The capacity of a canal and related structures may be given as percent of the SPF, for example 30 percent of SPF.

These regulation schedules account for physical capacities of lakes and impoundments and upstream and downstream conditions of canals and water control structures. Appropriate and relevant constraints, such as ecological conditions, salinity intrusion, water quality and others, are also incorporated in the regulation schedule. These regulation schedules are revised when necessary to better balance system objectives. Regulation schedules for lakes and impoundments were presented in Abtew et al. (2007).

Temporary deviations from the normal regulation schedules are granted on occasions. This is to accommodate changing weather, hydrologic and ecological conditions, structure malfunction, maintenance, and or emergency conditions for a short time interval that has a start and end date. The deviations are typically requested by District managers and or the USACE's district engineer.

Elements of Water Management

The District is the local sponsor for the Central and Southern Florida (C&SF) Project designed and built by the USACE and is in charge of the daily maintenance and operation of the majority of the system. However, the USACE maintains flood control and navigation operating authority for the primary waterway structures. **Table 2-2** shows a list of major water control structures that are operated by the USACE.

Table 2-2. Water control structures operated by the U.S. Army Corps of Engineers.

Basin or Area	Water Control Structures
Lake Okeechobee	CULV1, CULV1A, CULV2, CULV3, CULV4A, CULV5, CULV5A
	CULV6, CULV7, CULV8, CULV9, CULV10, CULV10A, CULV11
	CULV12, CULV12A, CULV13, CULV14, CULV16
	S351, S352, S354 (only during a hurricane)
	S310 Lock (only during a hurricane)
	S77, S78, S79 (Caloosahatchee River)
	S308, S308B, S308C, S80 (St. Lucie Canal)
Water Conservation Areas	S10A, S10C, S10D (From WCA-1 to WCA-2A)
	S11A, S11B, S11C (From WCA-2A to WCA-3A)
	S12A, S12B, S12C, S12D (From WCA-3A to ENP)
	S356
Lower East Coast	S332C

The District has divided the region into 14 rainfall areas plus Everglades National Park (ENP or Park) for water management purposes; rainfall for each rainfall area is reported daily (**Figure 2-2**). Multiple and overlapping gauges are used to compute average rainfall over each rainfall area. Real-time rainfall observations over the rainfall areas aid real-time water management decisions.

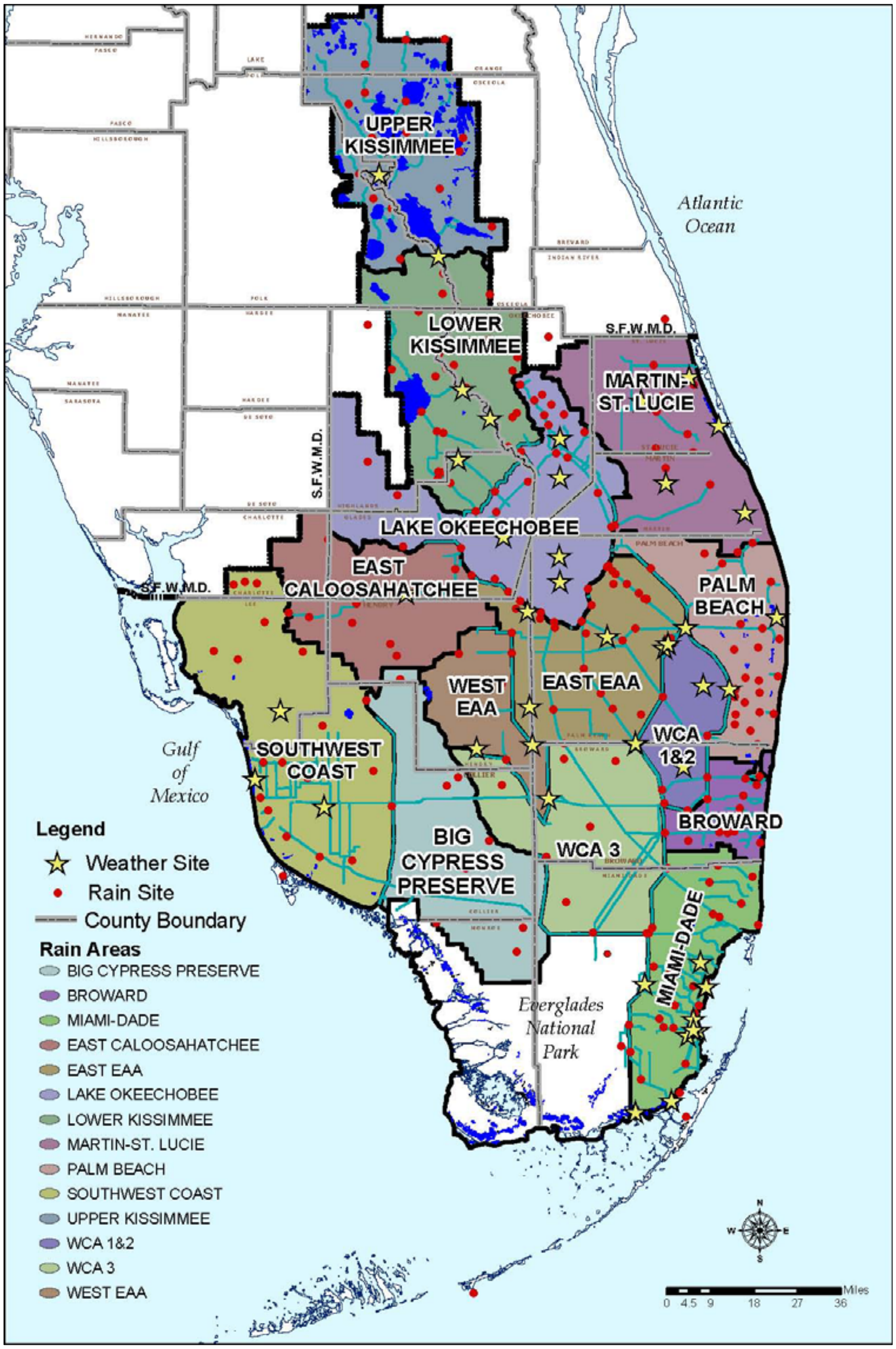


Figure 2-2. The South Florida Water Management District's rainfall areas.

Operation of Water Control Structures

The operation of structures is performed on a continuous basis by using current water level and weather conditions and following a set of previously established operating rules as guidelines. The operational rules of structures are available in water control manuals. Water managers pay close attention to the safety of people and property as a result of operations, specifically during extreme storm events. This requires knowing and understanding the physical capacity and capability of water control structures, levees, and canals.

Operations of the water control structures include adjustment of gate openings for gated spillways and gated culverts and the starting and stopping of pumps. Gated structure operations are classified into three groups. The first consists of Derived Data Set Point sites, which are computer controlled and operated from the Operations Control Center (OCC). The second consists of automatic sites, which are operated by computers or mechanical devices at the structure site not controlled from the OCC. The third group consists of manually operated gated structures.

District staff is dispatched by the OCC operator from the appropriate field station to open or close the manually operated gated structures. Pumps are controlled by the operators located at the respective pump stations, while some of the unmanned pump stations are operated by dispatches from field stations. Although these stations are typically operated during regular work hours, some must be operated after hours during most of the wet season and during extreme weather events.

Tools Used for Operations and Water Management

Currently, there are two tools used in OCC operations. The first tool is a computer-based SCADA (Supervisory Control and Data Acquisition) system also known as Telvent. This system provides real-time data acquired from field sensors. The system graphically displays the real-time data for a group of structures. The data include upstream and downstream stages, gate openings, and pump speed. Structures are grouped by the Field Operations Centers or operational sub-region.

The second tool, Auxiliary Operator Display, displays the real-time data for a specific structure or site on computer monitors. This display provides fairly detailed information about the structure, including upstream and downstream stages, gate openings, pump speed, flow, alarm setting, power availability, etc.

Use of Data and Decision Making for Operations

There are many pieces of data and information that are used in decision making for operations. The most important data for operations are real-time stage and gate opening or pump operation data from the water body in consideration. A water control manual or operating plan provides operations criteria for each water control structure. While it is necessary to follow the operations criteria, water managers are required to make decisions using sound engineering judgment when physical conditions dictate and make temporary deviations from these criteria as necessary. At the District, water management decisions for operations are made in two primary modes – flood control and water supply. In both modes, daily and/or hourly rainfall amounts that vary from one geographic area to another are critical in decision making for operations. In addition, groundwater flow to and from the water bodies plays a significant role in maintaining a specific gate opening or pump operation. Water managers have learned from experience how much influence groundwater flow has on the stage of a lake or a canal and, in turn, on gate or pump operations.

Management and Operations of Lake Okeechobee Water Levels

The regulation of lake water levels is performed by the USACE in consultation with the District. Flood control releases from Lake Okeechobee are made to the west through the Caloosahatchee River, to the east through the St. Lucie River, and southward to the Everglades.

Since the early part of 1900 and until the middle of 2000, the lake was operated using a variety of calendar-based regulation schedules. During the 1990s, the District and the USACE conducted a study to develop and implement a more robust regulation schedule. The Water Supply and Environment Lake Okeechobee regulation schedule, instituted in July 2000, had several major constraints which made it complex. The schedule included tributary hydrologic conditions and climate forecasts into operational guidelines for use with the Operational Guideline Decision Tree.

A new regulation schedule for Lake Okeechobee operations was implemented in May 2008, the beginning of Water Year 2009 (WY2009) (May 1, 2008–April 30, 2009). The new regulation schedule (Lake Okeechobee Regulation Schedule 2008) has three main bands: (1) High Lake Management Band, (2) Operational Band, and (3) Water Shortage Management Band. The Operational Band is divided into high, intermediate, low, base flow, and beneficial use categories. In the High Lake Management Band, outlet canals may be maintained above their optimum water management elevations. In the Operational Band, 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. Details are available in USACE (2008) and the *Lake Okeechobee Regulation Schedule 2008* section of this chapter.

The normal Lake Okeechobee operation level is below 15.5 ft NGVD. Levee inspections at intervals of seven to 30 days are initiated when water levels are between 15.5 and 16.49 ft NGVD. When water levels are 16.5–17.49 ft NGVD, levee inspections are conducted at intervals from one to seven days depending upon location. The levees are inspected daily when levels are above 17.5 ft NGVD.

Although flood control releases are made under the USACE's authority, water supply deliveries from Lake Okeechobee for agriculture, domestic use, or environmental needs are made under the District's water supply authority. Supply-side management provides guidelines for apportioning lake releases among different water users and release points when extreme drought conditions persist and water use restrictions are imposed by the District.

Hydraulics and Operations

The Upper and Lower Kissimmee basins drain into Lake Okeechobee through the Kissimmee River (C-38 canal). Lake Istokpoga and the Lake Istokpoga water management basin drain into Lake Okeechobee through three major canals (C-40, C-41, and C-41A). Lake Okeechobee discharge and local runoff flows into the Caloosahatchee Estuary and the Gulf of Mexico to the west through the Caloosahatchee River (C-43 canal) and to the St. Lucie Estuary and Atlantic Ocean to the east through the St. Lucie River (C-44 canal). Water supply and Lake Okeechobee regulatory releases are made to the south, to the Everglades Agricultural Area (EAA), the Everglades Protection Area (EPA), and the Lower East Coast. Major canals connecting Lake Okeechobee, the EAA, Water Conservation Areas (WCAs), and the Lower East Coast are the Miami Canal, North New River Canal, Hillsboro Canal, and the West Palm Beach (C-51) Canal (see the *Selected Hydrologic Components* section of this chapter for more detail on hydraulic structures).

Drainage from the EAA and a portion of the outflows from Lake Okeechobee are discharged to the south mainly through the Everglades Stormwater Treatment Areas (STAs), which are constructed wetlands with a treatment area of about 45,000 acres designed to remove phosphorus from EAA outflows. The STAs then discharge to the WCAs to the south and these WCAs discharge to the ENP and the east coast.

The regional drainage system consists of three layers: primary, secondary, and tertiary. The primary system is managed by the District and is comprised of vast surface water storage areas such as lakes, impoundments, and wetlands. This layer consists of 1,875 miles of canals and more than 400 water control structures. The secondary system is also made up of canals and water control structures and is operated by local drainage districts. The tertiary system is mainly composed of residential and business area retention ponds, drainage canals, and water control structures and is maintained privately by entities like homeowner associations. In general, the tertiary (residential/business) system drains into the secondary system (drainage district or municipal), which then discharge to the primary system (the SFWMD).

Generally, South Florida has low topographic relief, meaning that the differences in ground surface elevation from site to site are relatively small. From Lake Tohopekaliga in the Upper Kissimmee Basin to Florida Bay in the south, the elevation drop is a gradual 54 ft over 250 miles. Most of the drop occurs in the basin north of Lake Okeechobee (the elevation drop from Lake Tohopekaliga to Lake Okeechobee is 44 ft in about 81 miles). On average, the water level drop from Lake Okeechobee to the Caloosahatchee Estuary (71 miles to the west) and to the St. Lucie Estuary (35 miles to the east) is 14.1 ft. This low-relief topography dominates the water control system in South Florida.

Major lakes and impoundments in the system are interconnected by the conveyance system of canals with flows and water levels regulated by water control structures. The District has an extensive hydrometeorological and hydraulics monitoring network that enhances real-time water management decision making. Water at lower elevations is moved by pumping as needed. The District pumps large volumes of water every year in order to control flooding and supply water. As depicted in **Table 2-3**, the annual average volume of water pumped from Fiscal Year (October 1–September 30) 1996 through 2009 was 2,799,000 ac-ft.

Table 2-3. District water pumping volumes for Fiscal Years 1996–2009 (October 1, 1995–September 30, 2009).

Fiscal Year	Volume of water pumped (ac-ft)
1996	2,480,000
1997	1,840,000
1998	2,020,000
1999	2,090,000
2000	2,517,000
2001	2,131,000
2002	3,131,000
2003	3,339,000
2004	3,404,000
2005	3,938,000
2006	3,583,000
2007	1,281,000
2008	3,767,700
2009	3,660,000

STORAGE OF LAKES AND IMPOUNDMENTS

Storage is a requirement for both flood control and water supply in the South Florida water management system. The amount of storage volume available varies significantly year to year due to large variations in rainfall 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/storage management of lakes and impoundments. The regulation schedule for each water body is presented in the following sections where WY2010 water levels are discussed. Temporary deviations from the normal regulation schedules for WY2010 are also presented.

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 the 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, the St. Lucie Estuary, the Atlantic Ocean, and Florida Bay.

Table 2-4 depicts average stage, surface area and storage for each major water body; storage at end of WY2009; storage at the end of WY2010 and change in storage between WY2009 and WY2010. The significance of the storage of Lake Okeechobee is clearly shown since 68 percent of the total storage gain in the system is attributed to it. Stage-storage relationships of lakes and impoundments are critical information for managing water levels, storage, and to compute average hydraulic residence time. Appendix 2-2 in *2007 South Florida Environmental Report* (SFER) – *Volume I*, presents the compiled charts for stage-storage for the major lakes and impoundments and stage-area relationships where data are available.

Table 2-4. Average stage, surface area, storage (at average water level), end of WY2010 storage, and change in storage for major lakes and impoundments.

Lake/Impoundment	Average Stage (ft NGVD)	Average Surface Area (ac)	Average Storage (ac-ft)	WY2009 Ending Storage (ac-ft)	WY2010 Ending Storage (ac-ft)	Change in Storage (ac-ft)
Lake Alligator	62.53	3,953	47,821	47,194	54,630	7,436
Lake Myrtle	60.88	1,476	8,380	7,400	7,879	479
Lake Mary Jane	60.07	3,435	22,045	21,905	20,510	-1,395
Lake Gentry	60.66	1,666	15,452	14,106	15,108	1,002
Lake Tohopekaliga	53.72	20,280	121,040	112,070	125,915	13,845
Lake East Tohopekaliga	56.65	12,773	108,975	101,170	108,055	6,885
Lake Kissimmee	50.38	35,140	332,088	292,736	309,481	16,745
Lake Istokpoga	38.76	27,700	165,622	144,210	161,956	17,746
Lake Okeechobee	14.05	436,660	3,549,650	2,415,840	4,037,850	1,622,010
Water Conservation Area 1	15.63	141,440	121,520	41,100	206,880	165,780
Water Conservation Area 2A	12.53	105,408	151,180	16,156	46,460	30,304
Water Conservation Area 3A	9.56	491,072	586,880	246,200	844,000	597,800

SELECTED HYDROLOGIC COMPONENTS

During WY2010, all regions of the District received above-average rainfall. The increase in rainfall in the dry season is attributed to the El Niño weather pattern. The impact of the El Niño weather phenomenon is presented in a later section in this chapter. Brief conceptual descriptions of these areas are given here, while the specific hydrology and structure flow information for each is presented in the *Water Year 2010 Hydrology* 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 (sq mi) (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. 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. Discharge from the S-65E structure flows into Lake Okeechobee. The stage of the river is regulated through the operation of the water control structures. Overall, the Kissimmee Basin is an integrated system consisting of several lakes with interconnecting canals and flow control structures (**Figure 2-3**; see also Chapter 11 of this volume).

Lake Okeechobee

Lake Okeechobee (**Figure 2-4**) is the largest lake in the southeastern United States (26^{o} 58’N, 80^{o} 50’W). It is a relatively shallow lake with an average depth of 8.9 ft. Water levels are regulated through numerous water control structures. The lake performs multiple functions for flood control, water supply, recreation, and environmental restoration efforts. Lake water levels and releases are regulated based on a seasonally varying regulation schedule. Chapter 10 of this volume discusses the status of Lake Okeechobee.

Everglades Agricultural Area

The Everglades Agricultural Area is an agricultural irrigation and drainage basin where, generally, ground elevation is lower than the surrounding area. The major commercially grown crops are sugarcane, vegetables, sod, and rice. 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 the 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 EPA (Abtew and Khanal, 1994; Abtew and Obeysekera, 1996). Four primary canals (Hillsboro Canal, North New River Canal, Miami Canal, and West Palm Beach Canal), and three connecting canals (Bolles Canal, Cross Canal, and Ocean Canal) facilitate runoff removal and irrigation water supply. But currently runoff/drainage from the EAA is discharged to the Stormwater Treatment Areas for treatment and released to the EPA. Additional information on the EAA is presented in Chapter 4 of this volume. Information on the Stormwater Treatment Areas is presented in Chapter 5.

Lower East Coast

The Lower East Coast (LEC) includes the South Dade Conveyance System (**Figure 2-5**). The purposes of the LEC are flood control, the prevention of over-drainage in the area, saltwater intrusion into groundwater, and facilities to convey runoff to the ENP when available. The system is also to improve water supply and distribution to the 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 Miami Canal. 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 remove runoff to the ocean as quickly as possible.

Lower West Coast

The main canal in the Lower West Coast 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 in USACE (2008). Downstream of S-77 is a gated spillway, S-78, that also receives inflows from its local watershed to the east. **Figure 2-6** shows the Lower West Coast and main hydrologic features. 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 the USACE. S-79 is the last structure on the Caloosahatchee River that controls discharges into its estuary. The operations of S-79 include managing stormwater runoff from west Caloosahatchee and tidal (east) Caloosahatchee watersheds.

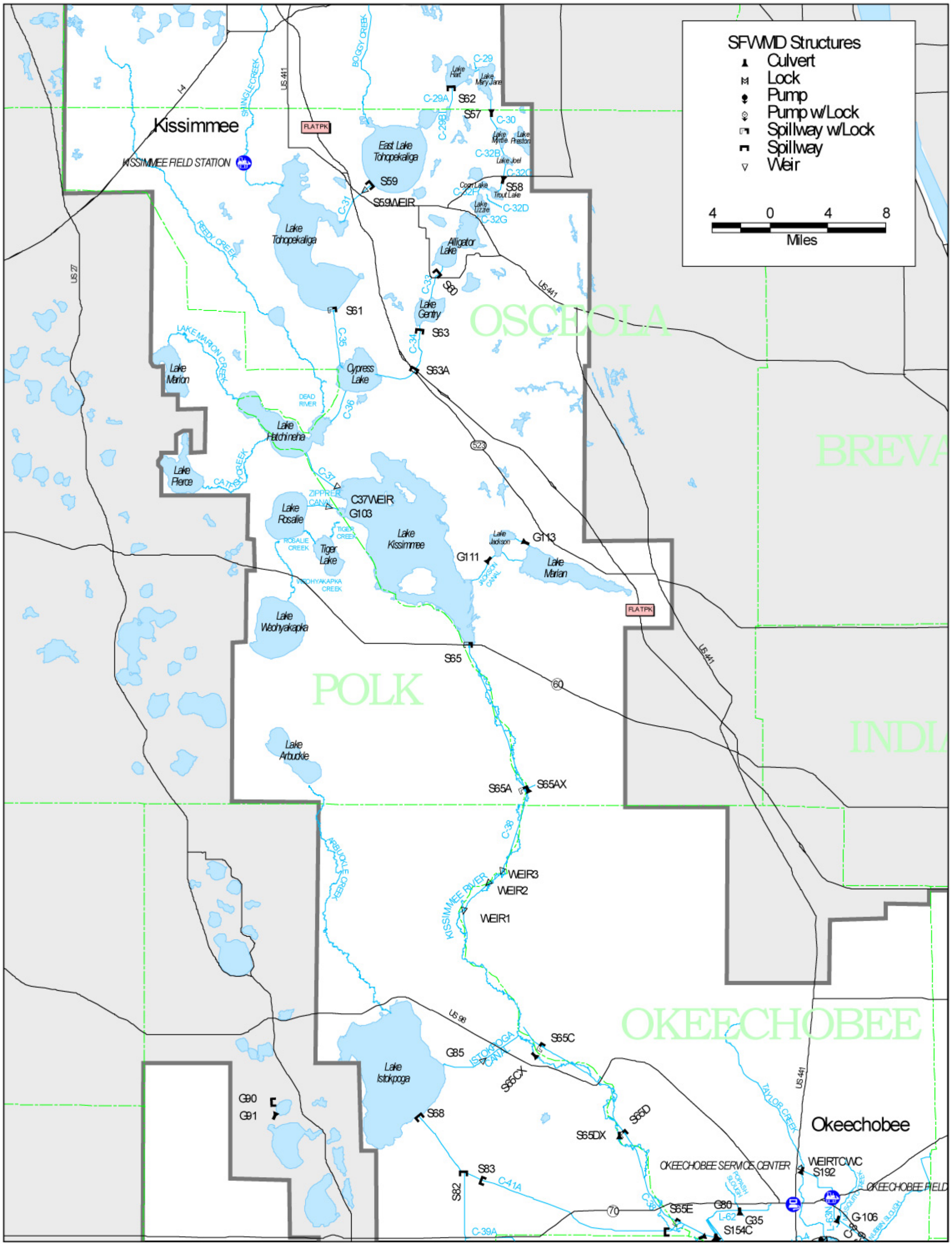


Figure 2-3. Upper and Lower Kissimmee basins, including the Kissimmee Chain of Lakes and Lake Istokpoga.

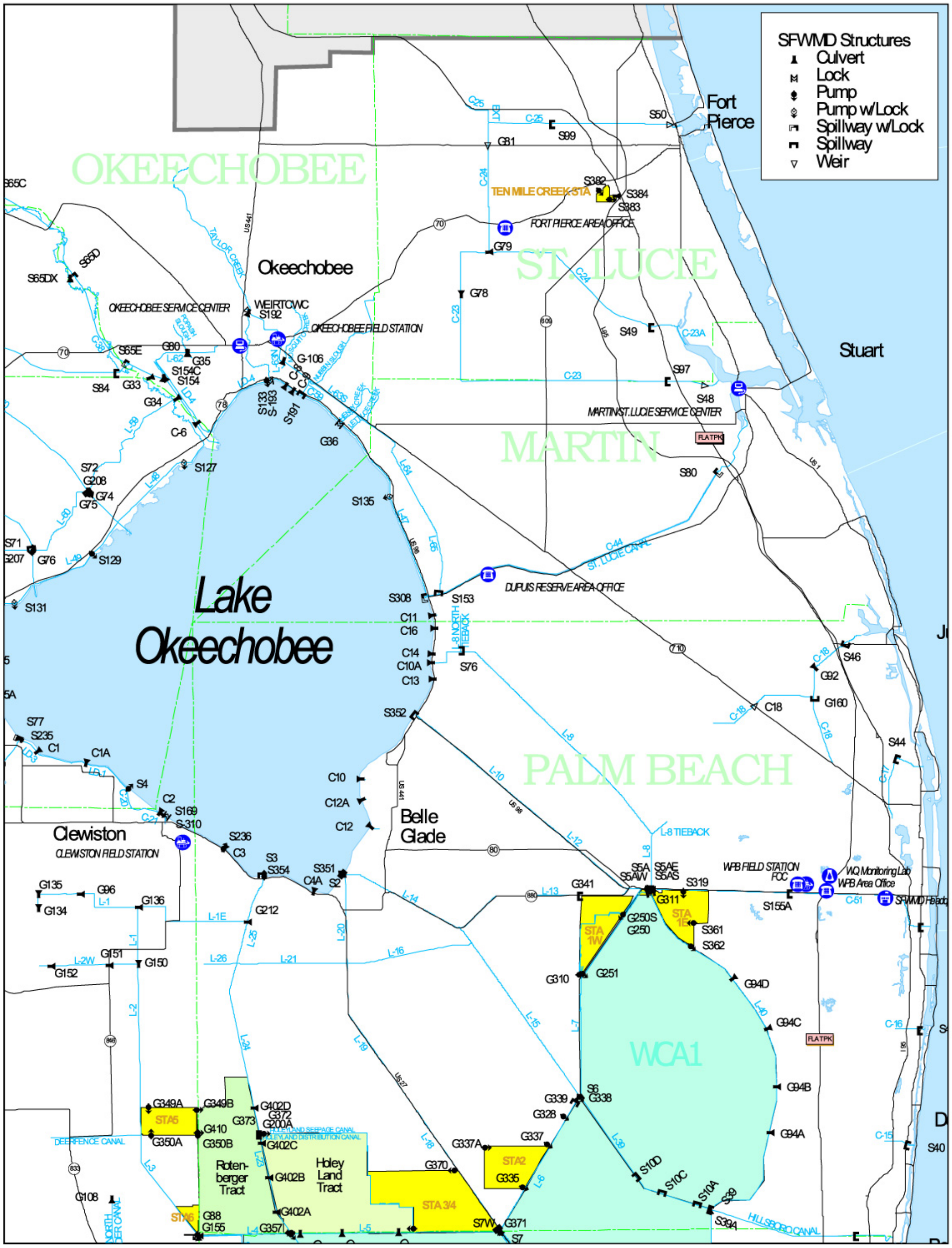


Figure 2-4. The Lake Okeechobee, Upper East Coast, and St. Lucie Canal and Estuary system.

Figure 2-5. Everglades National Park and the Lower East Coast.

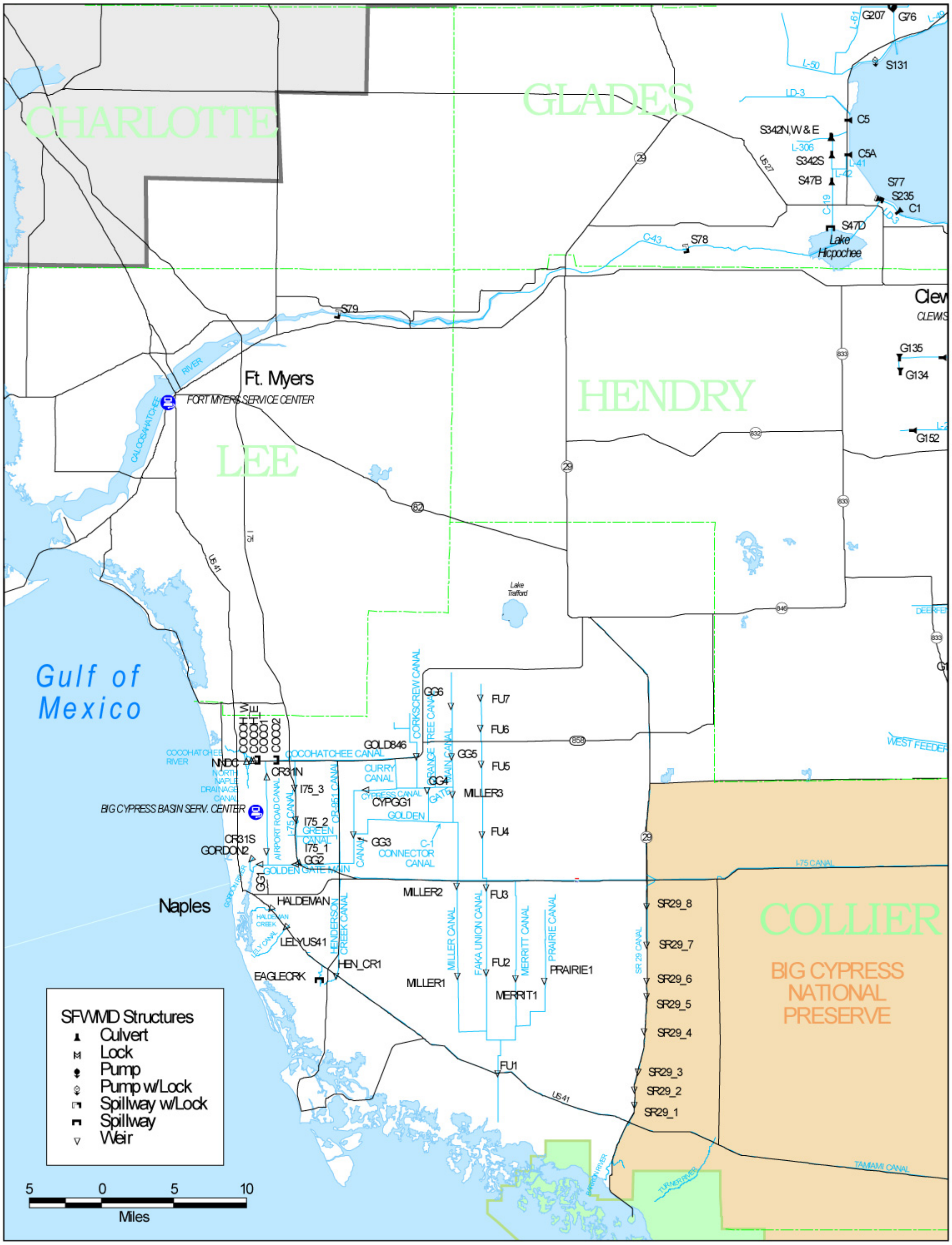


Figure 2-6. The Lower West Coast.

EL NIÑO'S IMPACT ON DRY SEASON HYDROLOGY IN SOUTH FLORIDA

INTRODUCTION

El Niño-Southern Oscillation (ENSO) is an ocean-atmosphere phenomenon where the cooler equatorial eastern Pacific Ocean warms up once every two to seven years. The increase in equatorial eastern Pacific sea surface temperature (SST) is attributed to the weakening of the easterly trade winds that result in warm water from the western Pacific moving to the east. An average of ±0.5 ^{o}C deviation from average SST for three consecutive months indicates an ENSO event (NOAA, 2009). The Southern Oscillation (SO) is the variation in air pressure between the western and eastern tropical Pacific. The Southern Oscillation Index (SOI) is a measure of the air pressure difference between Tahiti in the east and Darwin, Australia, to the west as compared to the historical average of the differences. Negative differences indicate El Niño (positive SST) conditions as lower pressure in the eastern Pacific is associated with warmer water and weakened easterly trade winds. Positive SOI corresponds to La Niña (negative SST). Either cumulative SST or SOI can be used for tracking ENSO events as the two indices are negatively correlated (Abtew et al., 2009). An ENSO strength tracking method has been developed to determine the type and strength of the event and earn months of lead time for water management decisison making (Abtew et al., 2009; Abtew and Trimble, 2010). Based on this method, strong El Niño and La Niña years since 1877 are shown in **Table 2-5**. The 2009 El Niño was similar in strength to the 1963 event. The ENSO strength classification from cumulative SST and SOI presented here agrees with other consensus classifications (Null, 2009).

Table 2-5. Strong El Niño-Southern Oscillation (ENSO) years ordered by column from the strongest event (Abtew and Trimble, 2010).

Strong El Niño Years				Strong La Niña Years			
1877	1940	1969	1958	1890	1971	1886	1945
1987	1902	1878	1885	1893	1916	1875	1933
1997	1930	1926	1994	1955	1910	1984	1887
1941	1992	1977	2004	1999	1894	2008	1954
1982	1919	1914	1963, 2009	1874	1909	1872	2007
1905	1965	1957	1915	1950	2000	1985	1898
1888	1991	1931	1953	1975	1956	1873	1964
1972	2002	1983		1988	1892	1879	
1900	1896	1993		1974	1989	1973	

RELATION OF EL NIÑO–SOUTHERN OSCILLATION INDICES TO LAKE OKEECHOBEE WATERSHED HYDROLOGY

The prediction of hydrometeorology using global climate indices has become a necessity for water resources management; in the future, water supply per capita is predicted to decline, making the impact of the variability of water greater. Accurate forecasting of temporal and spatial variation of precipitation and runoff is critical for water resource planning and management to mitigate the effects of droughts and floods. Analysis of ENSO correlation with rainfall and surface water flows in a watershed provides statistically based, conclusive results. Especially when using surface water flows that are not controlled, analysis can provide the true relationships of ENSO indices to the hydrology of a region. For the Lake Okeechobee Watershed, analysis of the ENSO and watershed hydrology relationship was performed by comparing Upper Kissimmee Basin dry season (November–May) rainfall deviations from the average, Lake Okeechobee dry season surface water inflow deviations, and Arbuckle Creek and Josephine Creek dry season surface water inflow deviations to the cumulative SST index at Nino 3.4 (a region in the equatorial Pacific west of Peru). Arbuckle Creek and Josephine Creek form part of the Lower Kissimmee Basin and flow into Lake Istokpoga. Their watersheds are the least managed of those with available data, making them ideal for analysis.

The statistical analysis used to determine the relationship of ENSO events to rainfall deviations is event correspondence analysis, which differs from correlation analysis (Abtew et al., 2009; Abtew et al., 2010). Event correspondence analysis does not consider the magnitude of change while correlation is sensitive to it. This kind of statistical analysis was performed to investigate the correspondence of SST anomalies to Upper Kissimmee Basin rainfall and downstream flow anomalies in the Lake Okeechobee Watershed and Lower Kissimmee Basin. A test of significance of a binomial proportion was applied to show that the events are not random with an assumed probability of 0.5. The null hypothesis was the correspondence of ENSO events to rainfall or flow deviations (above average with El Niño and below average with La Niña) is a random event and a Chi square (χ^2) test of goodness of fit was performed.

Comparison of the annual rainfall deviations relationship to strong ENSO events demonstrates that the strength of ENSO is a factor in the relationship of ENSO events and watershed hydrology. Since the impact of El Niño rainfall is in the dry season, Upper Kissimmee Basin dry season rainfall deviations correspond with ENSO events better than annual rainfall deviations (see the *Upper Kissimmee Dry Season Rainfall Deviations and ENSO Relationships* section of this chapter). Dry season rainfall anomalies correspond to ENSO events with strong ENSO events capturing the majority of the extreme deviations (Abtew and Trimble, 2010).

Although inflows to Lake Okeechobee are regulated through the operation of upstream lakes and canals, analysis shows that, in general, surface water flow relationships to ENSO events reflect a relationship between basin rainfall and ENSO events. Quality checked Lake Okeechobee inflow data were available (1972–2008) for ENSO relationship analysis. Correspondence of annual inflow deviations from the average to ENSO events is not strong; but dry season flows show a distinct correspondence with strong ENSO events (Abtew and Trimble, 2010). Lake Okeechobee stage fluctuations through the years have noticeable marks of the effect of ENSO events (**Figure 2-7**).

Arbuckle and Josephine Creeks are hydrologically connected to the Lower Kissimmee Basin in the District's Kissimmee Basin Planning Area. Arbuckle Creek flows into Lake Istokpoga from the north, and both annual and dry season flows display statistically significant correspondence to ENSO events. The mean annual flow for Arbuckle Creek was 221,283 ac-ft with a standard deviation of 128,663 ac-ft. Josephine Creek flows into Lake Istokpoga from the northwest. Both annual and dry season flow display statistically significant correspondence to ENSO events. The mean annual flow for Josephine Creek (1947–2006) was 50,838 ac-ft with a standard deviation of 40,194 ac-ft (Abtew and Trimble, 2010). **Table 2-6** depicts Arbuckle Creek dry season flow deviations from the historical average and strong ENSO events with increasing flows during El Niño years and decreasing flows during La Niña years.

Table 2-6. Arbuckle Creek dry season flow deviations and strong ENSO events.

El Niño Year	Change in dry season flow (ac-ft)	La Niña Year	Change in dry season flow (ac-ft)
1940	36,882	1945	-12,206
1941	58,588	1954	-20,041
1953	108,748	1955	-64,711
1957	79,682	1964	-26,015
1958	18,352	1971	-27,899
1965	55,166	1973	-47,562
1969	92,258	1974	-51,690
1972	3,988	1975	-33,861
1982	99,579	1984	-56,520
1983	3,597	1985	-32,118
1987	52,217	1988	-41,789
1994	25,146	1989	-27,792
1997	360,879	1999	-23,492
2002	42,609	2000	-67,059
2004	14,943	2007	-62,655
		2008	-55,561

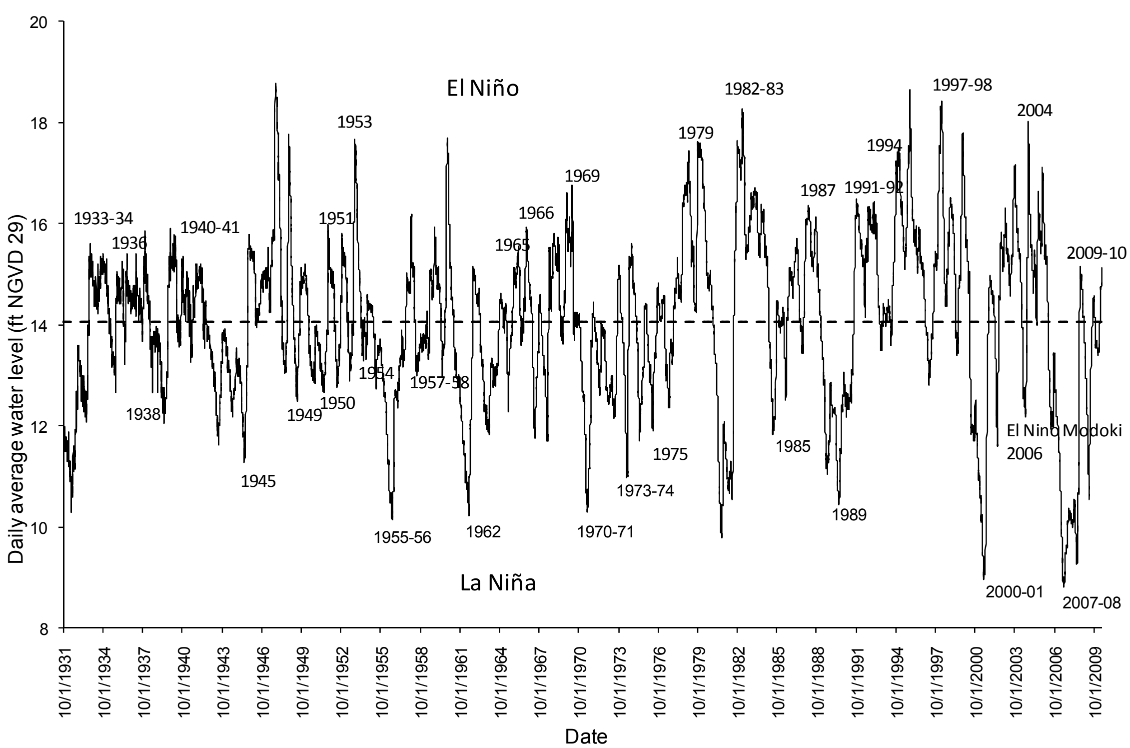


Figure 2-7. ENSO events and Lake Okeechobee water level fluctuation.

Upper Kissimmee Dry Season Rainfall Deviations and El Niño–Southern Oscillation Relationships

Since the effect of ENSO on the Lake Okeechobee Watershed starts from the north, comparing Upper Kissimmee Basin rainfall to ENSO events can provide true relationships between ENSO and hydrology of the watershed. Annual rainfall in the Upper Kissimmee Basin averages 50 inches with a standard deviation of 9.2 inches (1901–2008). Comparison of annual rainfall deviations relationship to strong ENSO events demonstrates that the strength of ENSO is a factor in the relationship of ENSO events and watershed hydrology. Since the impact of El Niño rainfall is in the dry season, Upper Kissimmee Basin dry season rainfall deviations are expected to correspond with ENSO events better than annual rainfall deviations. The average dry season (November–May) rainfall in the Upper Kissimmee is 18.7 inches with a standard deviation of 6.1 inches (1901–2008). The wettest dry season rainfall was 37 inches (1997–1998 El Niño). Dry season rainfall anomalies correspond to ENSO events. As shown in **Table 2-7**, Upper Kissimmee dry season rainfall is generally higher than average during strong El Niño events and decreases in rainfall correspond to La Niña events.

Table 2-7. Upper Kissimmee Basin dry season rainfall anomalies and strong ENSO events.

El Niño Year	Change in dry season rainfall (in)	La Niña Year	Change in dry season rainfall (in)
1902	6.00	1916	-1.46
1905	9.67	1945	-2.43
1914	8.08	1950	-3.02
1919	4.92	1954	-5.45
1930	2.44	1955	-4.97
1940	6.02	1964	-6.01
1941	3.67	1971	-1.50
1957	16.67	1973	-8.43
1958	6.49	1974	-1.37
1963	9.22	1975	-3.89
1965	4.32	1984	-7.18
1969	5.92	1985	-4.69
1972	2.84	1989	-1.29
1977	1.99	1999	-8.84
1983	4.41	2000	-5.34
1987	5.45	2007	-5.23
1993	2.98		
1994	1.09		
1997	18.28		
2002	9.61		
2004	2.62		
2009	8.58		

THE 2009 EL NIÑO EVENT IMPACT ON SOUTH FLORIDA HYDROLOGY

The 2009 El Niño started developing late in the spring of 2009. A negative SST pattern persisted from January through March, approaching neutral conditions in April 2009. A positive SST index started in May 2009 and progressively strenghtened. This January–May pattern is the same as the weaker El Niño event of 2006. But from June through the end of the year, the positive SST index climbed, resulting in strong El Niño event by the end of the year. Comparison of the 2006 and 2009 El Niño events using the cumulative SST index approach is shown in **Figure 2-8**. Dry season rainfall positive anomaly for WY2010 (November 2009–April 2010) indicates a clear impact of the El Niño on South Florida's hydrology.

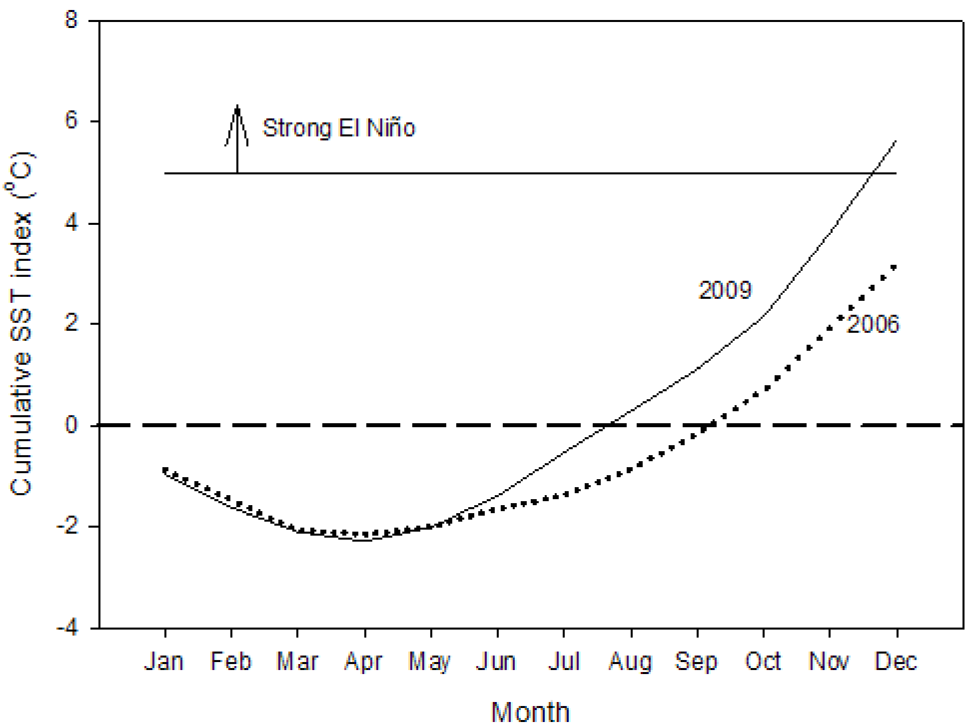


Figure 2-8. Comparison of the 2006 and 2009 El Niño events.

WATER YEAR 2010 EL NIÑO-ASSOCIATED RAINFALL

El Niño-related dry season rainfall is associated with cold fronts coming from the north and northwest. There were six major rainfall events with large amounts of rainfall; two in December 2009 (Dec. 2–6 and Dec. 15–19), two in March 2010 (March 11–13 and March 28–30) and two in April 2010 (April 11–14 and April 26–27). Generally, an El Niño event impact on rainfall is highest in the northern part of the District because the fronts usually come through that area. **Figure 2-9** depicts rainfall accumulation from a frontal rainfall passing from north to south of the District from March 28 (7:00 am) to March 29 (7:00 am), 2010. In cases where the front blows through at a faster speed and slows in the south or retreats back, the southern half of the District gets more rainfall. In WY2010, there were fronts that moved fast through the northern half of the District and slowed down in the south. **Table 2-8**, **Table 2-9**, and **Table 2-10** show for each major frontal rainfall event total rain catches over each rainfall area and a single day maximum rainfall at a site. **Figure 2-10** depicts total rainfall from the six major frontal rainfall events. WY2010 monthly rainfall complete data and analysis are presented in the *Water Year 2010 Hydrology* section of this chapter.

A characteristic of frontal rainfall is that the coverage area is large and the total volume of water gained is high. As a result, regional groundwater is recharged, pond and lake water levels are unseasonably high, agricultural and urban irrigation water demand is low and Lake Okeechobee and the WCAs water levels rise while normally expected to recede in the dry season.

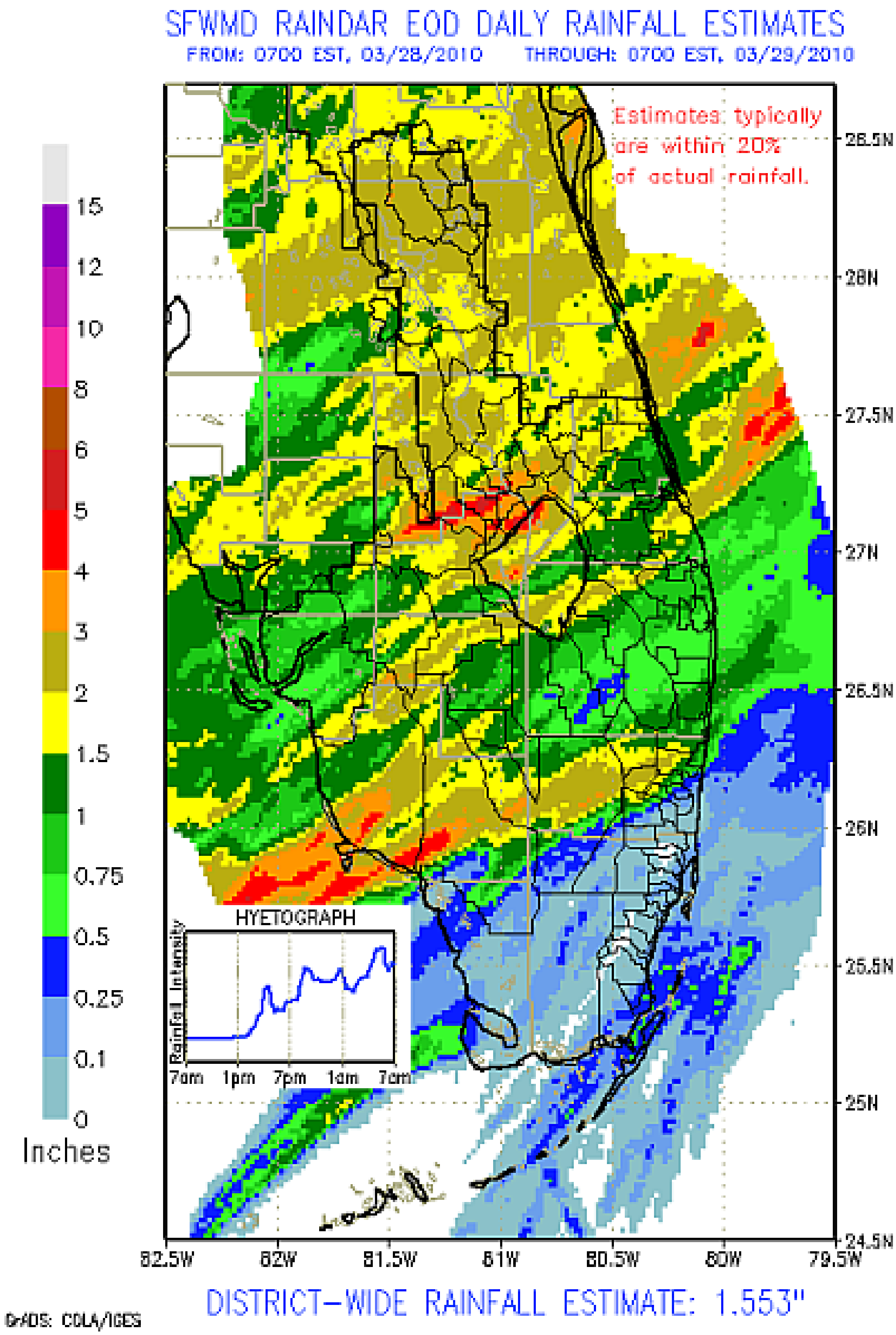


Figure 2-9. Frontal rainfall March 28–March 29, 2010 (7:00 am to 7:00 am).

Table 2-8. Major frontal rainfall events in December 2009.

Rainfall Areas	Rainfall Dec. 2–6, 2009		Rainfall[1] Dec. 15–19, 2009	
	Total (in)	one-day max (in)	Total (in)	one-day max (in)
Upper Kissimmee	3.23	2.48 (KissimmeeFS)	0.56	0.75 (KissimmeeSP)
Lower Kissimmee	2.82	2.64 (S75WX)	0.72	1.24 (S65E)
Lake Okeechobee	2.02	2.82 (Palmdale)	1.02	1.91 (S2)
East EAA	0.84	1.21 (Mialk)	1.88	3.83 (G200)
West EAA	0.95	0.88 (Okals)	2.56	3.51 (BCSI)
WCAs 1,2	0.54	0.78 (S39)	3.23	4.66 (S39)
WCA-3	0.79	0.91 (BCSI)	1.65	3.51 (BCSI)
Martin/St. Lucie	1.73	2.47 (Newsjuice)	3.81	12.99(C24SE)
Palm Beach	0.77	1.33 (S44)	4.31	7.42 (S37B)
Broward	0.34	0.57 (S125)	4.92	14.25(S29)
Miami-Dade	0.49	0.85 (MiamiFS)	3.25	14.25(S29)
East Caloosahatchee	2.62	2.82 (Palmdale)	1.31	2.11 (Immokalee)
Big Cypress Preserve	1.08	1.20 (BCA4)	1.88	3.51 (BCSI)
Southwest Coast	1.97	2.5 (Colgov)	1.68	2.75 (Coco1)
District	1.68		1.91	

[1]Note: Some areas of Port St. Lucie, Broward, and Dade counties were flooded on December 18-19, 2009. Damage to property, evacuations, school closings, and flight delays were reported. For details, see *Flooding in Parts of Port St. Lucie 'Looks like a Hurricane Hit'*, December 18, 2009, Scripps Treasure Coast Newspapers; *Flooding Forces Dozens to Florida Shelters*, December 18, 2009, Disaster News Network; *Round Two of Storms Flood South Florida*, December 19, 2009, WSVN-TV, online version; and *Expected a Season of Sun? You're All Wet*, December 19, 2009, The Palm Beach Post.

Table 2-9. Major frontal rainfall events in March 2010.

Rainfall Areas	Rainfall[1] March 11–13, 2010		Rainfall March 28–30, 2010	
	Total (in)	one-day max (in)	Total (in)	one-day max (in)
Upper Kissimmee	4.15	4.74 (KissimmeeSP)	2.64	3.05 (Scrg)
Lower Kissimmee	3.05	2.98 (Elmax)	2.51	4.47 (S127)
Lake Okeechobee	3.89	4.48 (S3)	2.47	4.47 (S127)
East EAA	3.97	4.53 (S5AY)	1.16	2.78 (S169)
West EAA	3.72	4.11 (G136)	1.79	3.16 (Okals)
WCAs 1,2	2.62	4.07 (S5A)	1.94	3.05 (S38)
WCA 3	1.25	2.18 (Sixl3)	1.26	2.82 (BCA15)
Martin/St. Lucie	3.76	4.63 (Sirg)	1.96	2.89 (Mobl)
Palm Beach	4.85	6.97 (Pbia)	1.47	3.05 (S38)
Broward	1.28	2.16 (Pembrokepines)	1.8	3.05 (S38)
Miami-Dade	0.77	2.16 (Pembrokepines)	0.66	1.52 (S174)
East Caloosahatchee	4.56	3.47 (Hendryfill)	1.53	3.16 (Okals)
Big Cypress Preserve	1.52	2.37 (Immokalee)	2.06	4.19 (Ochopee)
Southwest Coast	3.38	4.5 (Fairways)	1.81	4.27 (Mcif1)
District	3.29		1.86	

[1]Note: On March 11 and 12, there was flooding in Palm Beach County and in Vero Beach. Standing water was reported extensively in both areas by local news media. For details see: *South Florida Gets a Month of Rain in 36 Hours*, March 13, 2010, Palm Beach Post; and *Record Rainfall in Vero*, Palm Beach County, March 13, 2010, WPTV-TV.

Table 2-10. Major frontal rainfall events in April 2010.

Rainfall Areas	Rainfall[1] April 11–14, 2010		Rainfall April 26–27, 2010	
	Total (in)	one-day max (in)	Total (in)	one-day max (in)
Upper Kissimmee	0	0.05 (SCRG)	2.51	3.66 (KissimmeeSP)
Lower Kissimmee	0.02	0.2 (Archbold)	1.73	2.86 (S71)
Lake Okeechobee	0.19	1.09 (S47B)	2.64	4.61 (LZ40)
East EAA	0.89	2.15 (ENR105)	2.05	3.55 (CWEF1)
West EAA	1.3	2.19 (BCSI)	2.2	3.55 (CWEF1)
WCAs 1,2	1.74	4.1 (S37)	2.3	2.74 (S38)
WCA-3	0.7	2.19 (BCSI)	2.22	3.22 (S12D)
Martin/St. Lucie	0.53	1.36 (Blueg)	2.52	3.6 (S308)
Palm Beach	1.84	4.1 (S38)	2.2	4.02 (S153)
Broward	2.97	3.76 (S36)	2.21	2.74 (S38)
Miami-Dade	1.42	3.66 (S27)	2.21	2.96 (NWSFIU)
East Caloosahatchee	0.5	1.23 (Cecil)	2.63	3.85 (Palm)
Big Cypress Preserve	0.78	2.19 (BCSI)	1.84	2.8 (BCA10)
Southwest Coast	1.23	3.78 (Colsem)	2.19	3.45 (Fairways)
District	0.79		2.26	1.43

[1]Note: In Broward county, minor flooding was caused by thunderstorms on April 12. For details, see: *In South Florida, It's Not Your Normal Spring Weather*, April 26, 2010, The South Florida Sun-Sentinel.

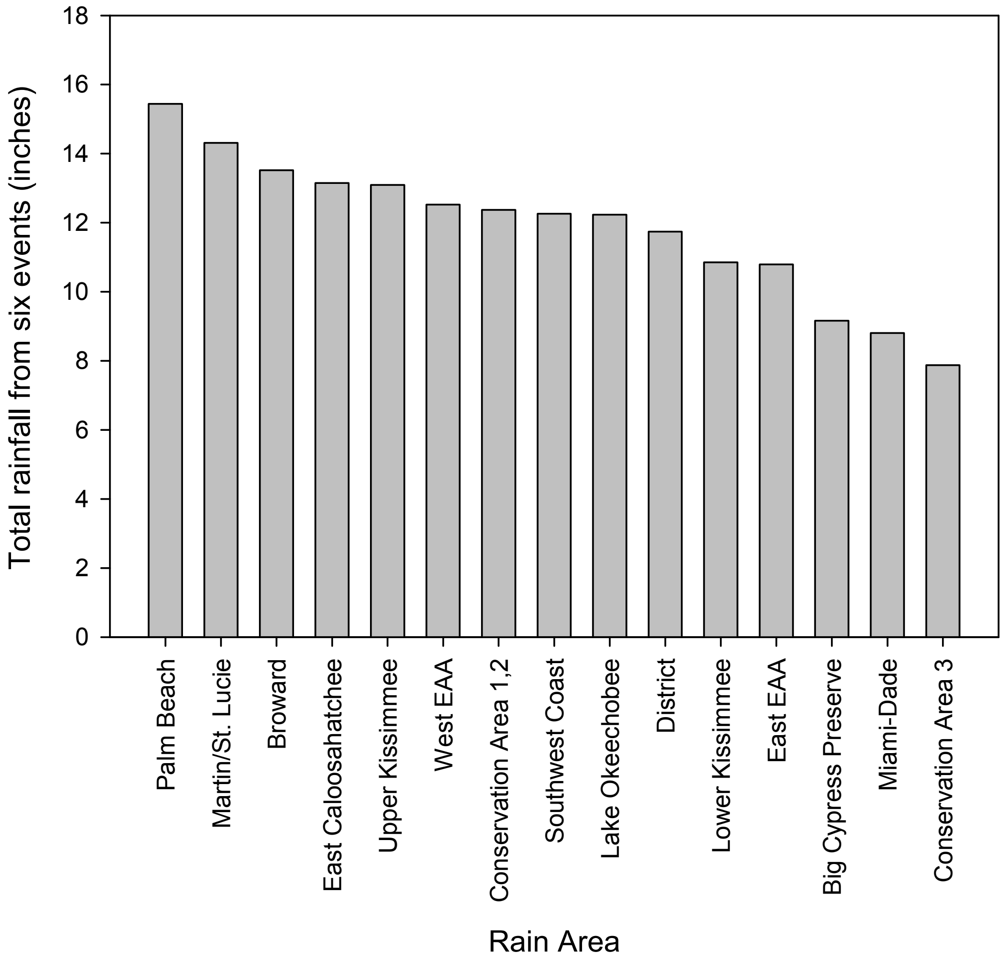


Figure 2-10. Rainfall from six frontal rainfall events in December 2009 and March and April 2010.

HISTORICAL AND WATER YEAR 2010 EL NIÑO EVENT IMPACTS ON LAKE OKEECHOBEE'S WATER LEVEL

In most years, Lake Okeechobee water levels recede in the dry season months of November through May. During this period, rainfall is typically low and net water demand, especially for agriculture, is high. Seasonal recession of the lake's water level is ecologically preferable and storage is created for the wet season (June–October). Although the wet season formally begins on June 1 each year, rainfall activities generally start around mid-May. One of the strongest El Niño patterns, the 1997–1998 event, impacted the dry season hydrology of South Florida. From November 1997 through March 1998, the District received a total of 23.9 inches of rainfall, more than twice the average of 11.7 inches. The watersheds of Lake Okeechobee and the Kissimmee Basin received above-average rainfall of 16.5 and 21.4 inches, respectively (Huebner, 2000). Most of the rise in the Lake Okeechobee water level from 15.17 ft NGVD on October 31, 1997, to 18.43 ft NGVD on March 26, 1998, was due to the increased rainfall and runoff from the 1997 El Niño event. The 18.43 ft NGVD lake stage is one of the highest recorded and has potential for levee damage through increased seepage. **Figure 2-11** depicts the daily water level rise during the 1997–1998 El Niño.

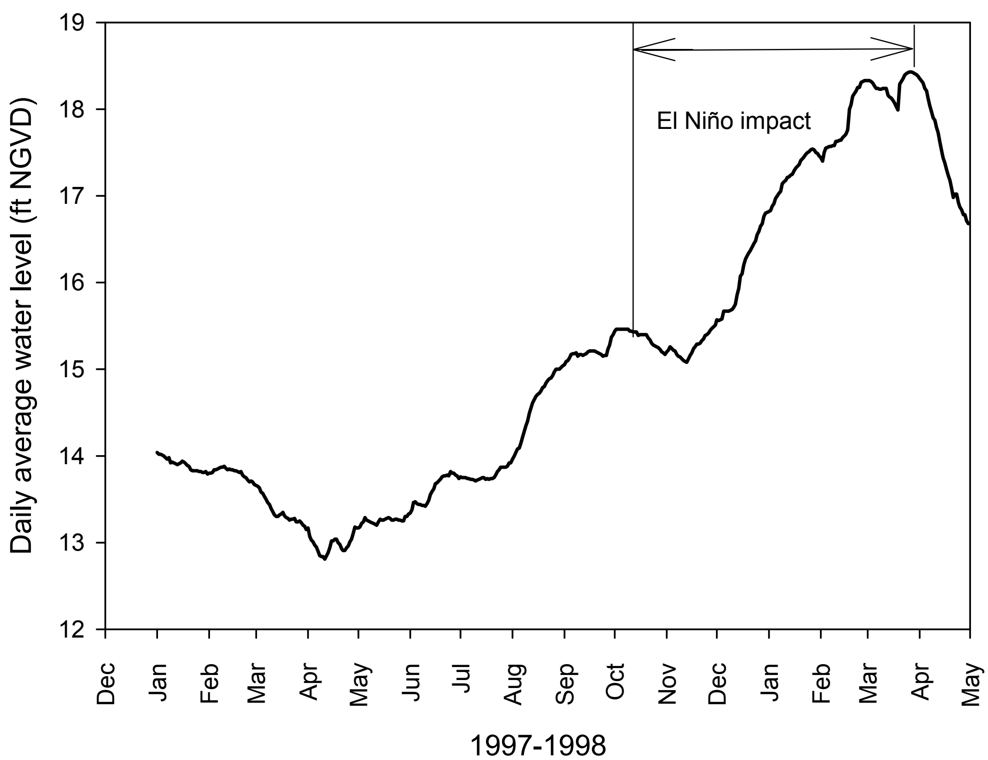


Figure 2-11. The 1997–1998 El Niño impact on Lake Okeechobee water levels.

WY2010 started with Lake Okeechobee's stage at 11.09 ft NGVD as a result of continuous drought since 2006 (see Abtew et al., 2010). The lake reached a minimum stage of 10.55 ft NGVD on May 18, 2009. Due to the early start of the wet season in May 2009, the lake stage continuously increased during this season to a maximum of 14.56 ft NGVD on September 25, 2009. October and November 2009 were drier in the Lake Okeechobee Watershed, but the increase in dry season rainfall started in December 2009. Rainfall over the lake watershed was less than average for January but March and April 2010 had increased rainfall and the resulting runoff raised the lake stage. Estuarine ecological and water quality constraints limited the lake discharge to the St. Lucie Estuary to the east, to the Caloosahatchee Estuary to the west, and to the EAA to the south. Due to frequent and sufficient rain, agricultural demand was very low and did not contribute to the seasonal recession of the lake. High runoff generated by increased El Niño-related dry season rainfall has the potential to create high water levels as shown in 1997–1998 (**Figure 2-11**) and WY2010 (2009–2010) El Niño events. **Figure 2-12** depicts Lake Okeechobee daily water level rise during the 2009–2010 El Niño event.

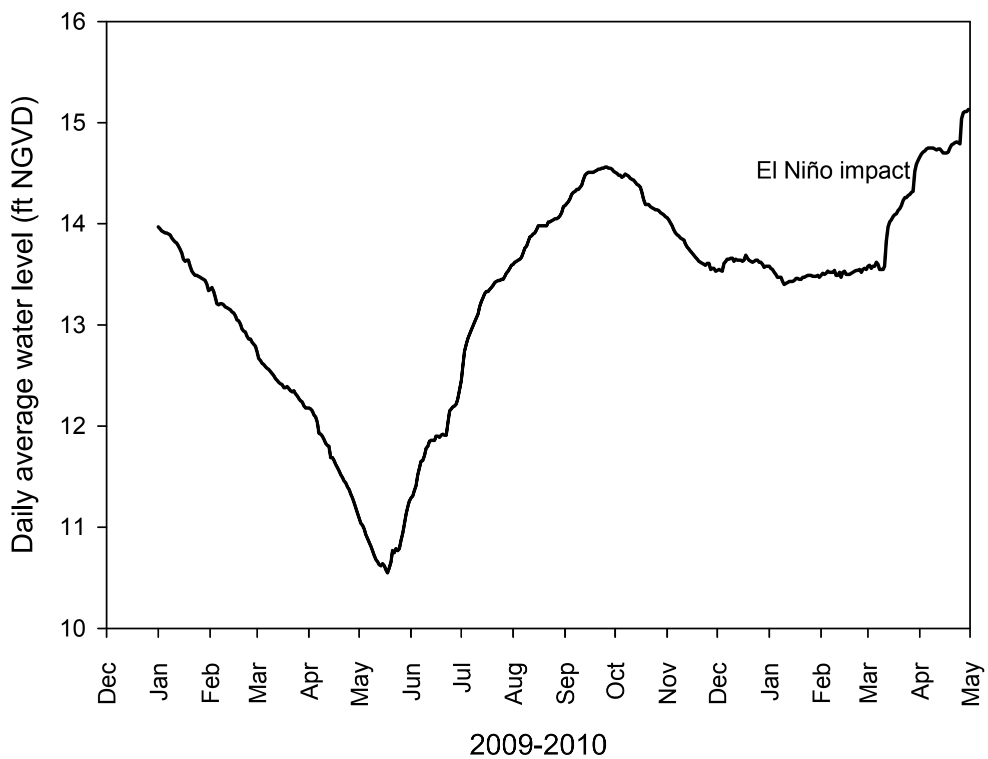


Figure 2-12. The 2009–2010 El Niño impact on Lake Okeechobee water levels.

WATER YEAR 2010 EL NIÑO AND GROUNDWATER LEVELS

Groundwater levels generally reflected the impact of El Niño-triggered rainfall events. Highlighted areas in **Figures 2-13** and **2-14** show the resulting increase in water levels for events that occurred in December 2009, and March and April 2010. **Figure 2-13** shows groundwater levels in a shallow well in Highland County north of Lake Okeechobee that is representative of the levels in the surficial aquifer in that region. **Figure 2-14** represents water levels in the Biscayne aquifer in Deerfield Beach, Broward County, for these events. In both wells, El Niño-related rainfalls resulted in significant increases in groundwater levels. Well locations are shown in **Figure 2-15**.

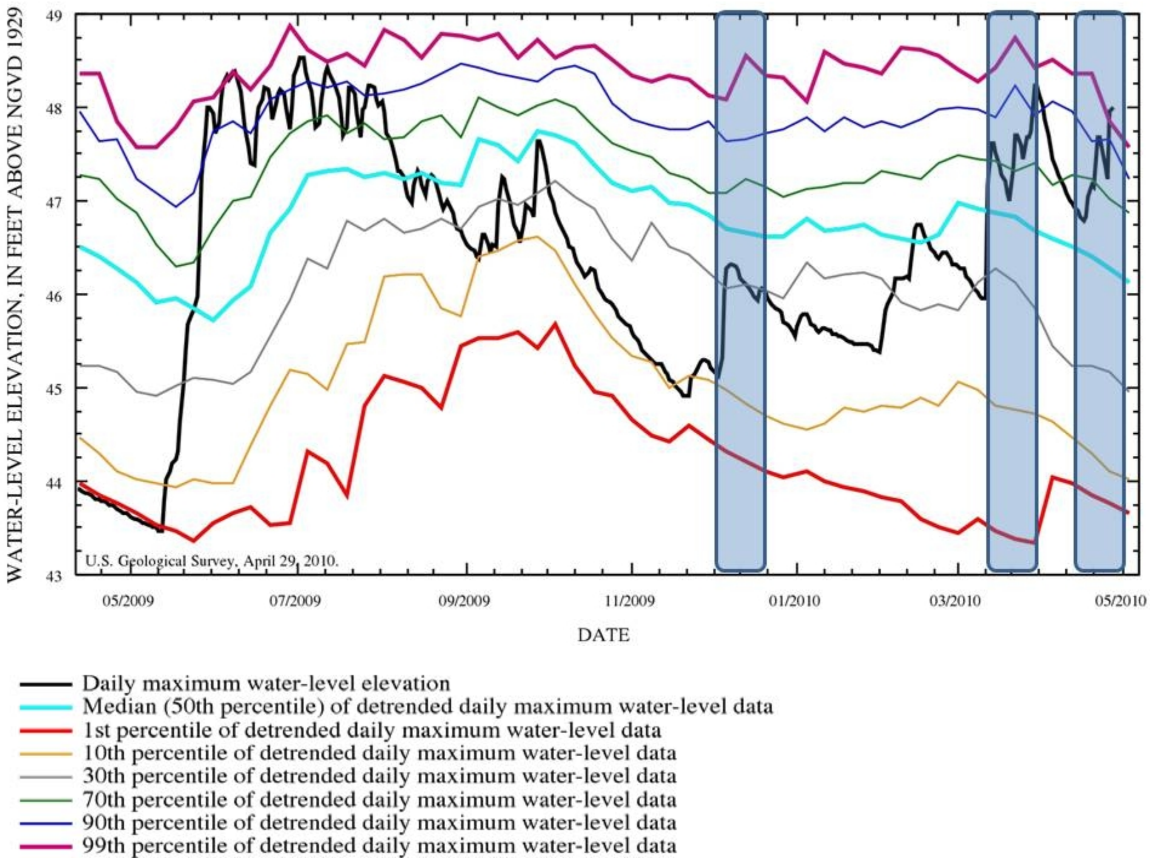


Figure 2-13. Groundwater levels in well H-11A in the surficial aquifer in Highland County. El Niño-related increases in water level are highlighted in blue.

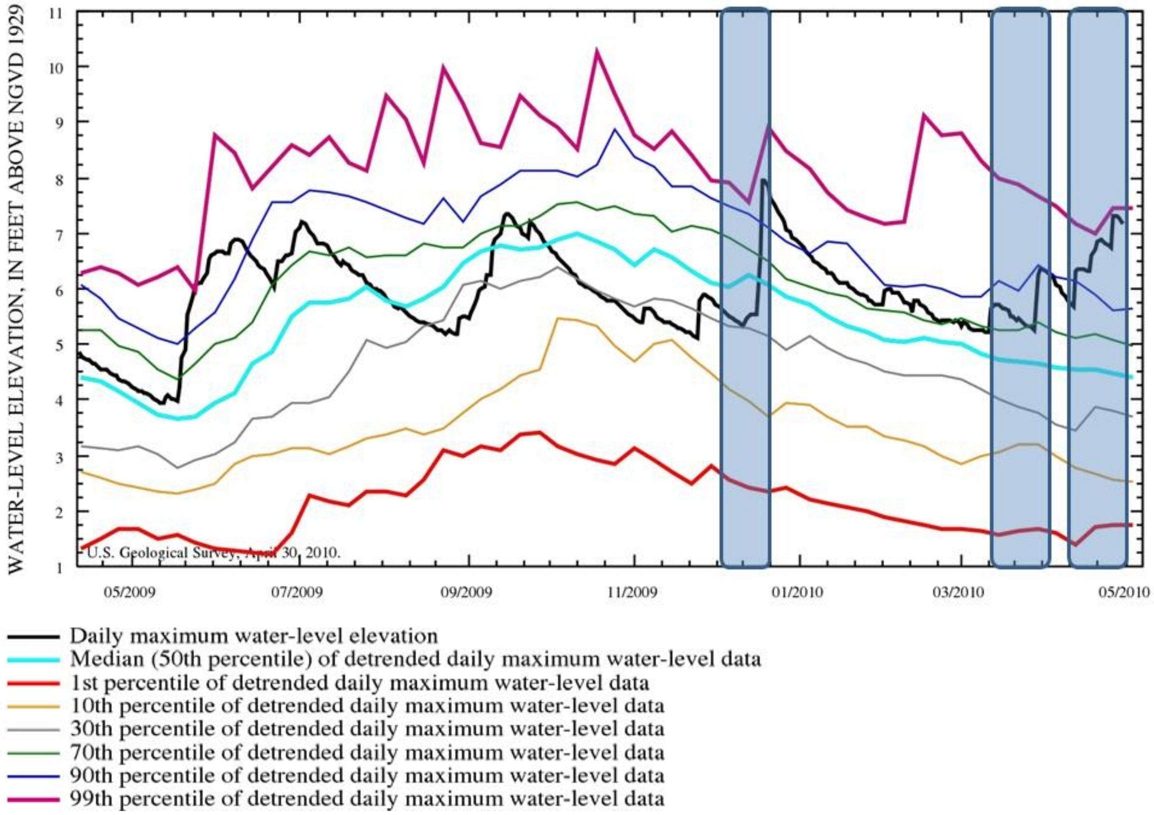


Figure 2-14. Groundwater levels in well G-1260 in the Biscayne Bay aquifer, Deerfield Beach, Broward County. El Niño-related increases in water level are highlighted in blue.

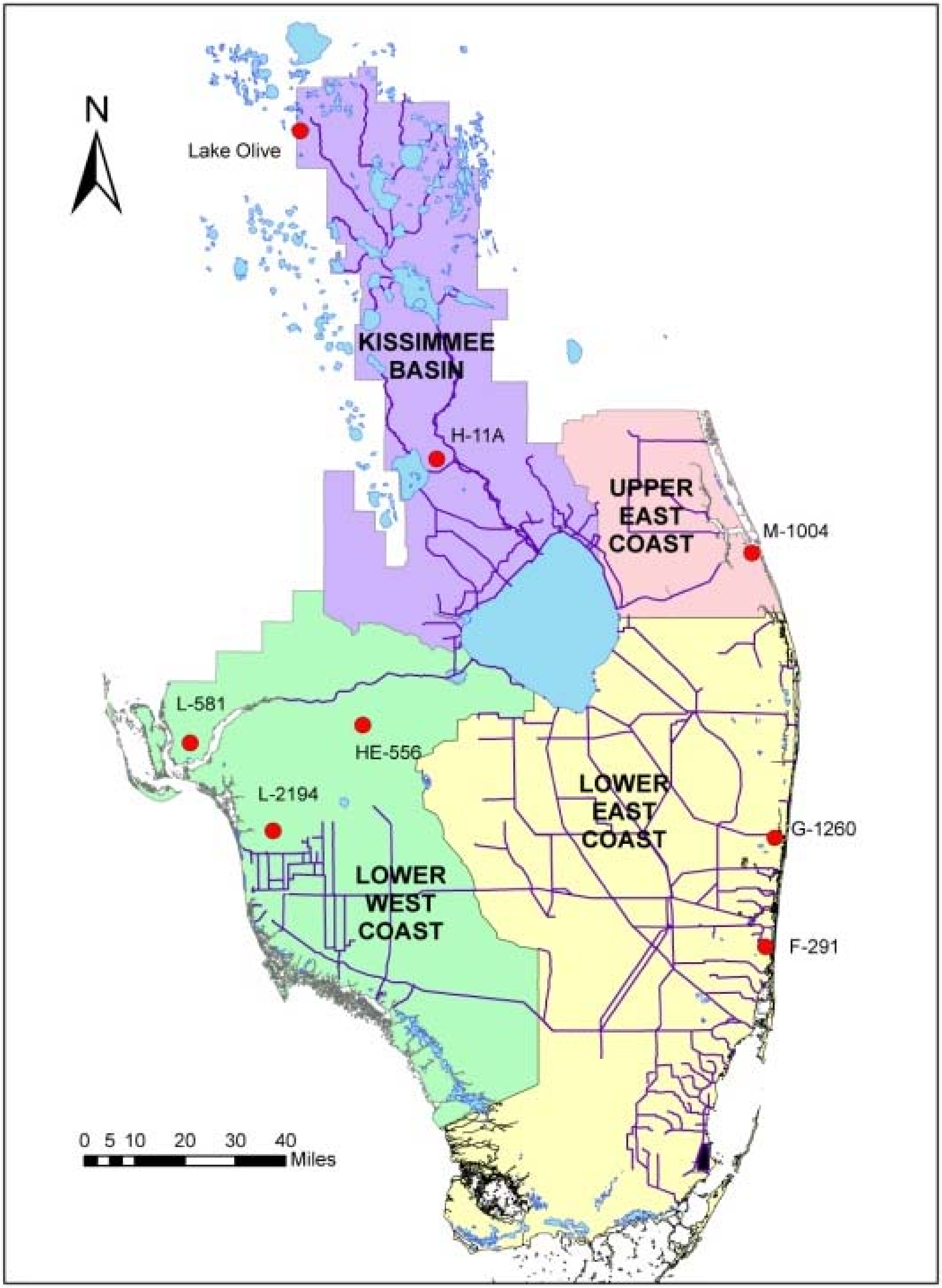


Figure 2-15. Groundwater monitoring well locations.

WATER YEAR 2010 INCREASED FLOWS AND DROUGHT RELIEF

The 2006–2009 drought in South Florida was one of the most severe droughts the area has experienced. Due to low rainfall in consecutive months and declining storage in Lake Okeechobee and other storage areas, agricultural and urban water shortages were experienced. Rainfall from Tropical Storm Fay (August 2008) contributed a large volume of water due to the high amount and large spatial coverage of the rainfall. By all measures, the effects of the drought were temporarily eliminated by the storm in summer 2008. But due to the continuation of far below-average rainfall after Fay, drought conditions returned within a few weeks. WY2009 ended with the lake stage at 11.14 ft NGVD, a low water level for water supply purposes. The water level decline continued to 10.55 ft NGVD by May 18, 2009 (the beginning of WY2010). Summer rains increased storage to a maximum level of 14.56 ft NGVD on September 25, 2010. The 2009–2010 dry season El Niño rains broke the droughts of the previous years' dry season months by raising groundwater level, saturating the watershed, and increasing flows into storage. Lake Okeechobee rose to a dry season high water level of 15.13 ft NGVD on April 30, 2010. **Figure 2-16** depicts increased outflows from Lake Kissimmee in comparison to the historical monthly averages for the dry season months of November through April. The increase in flow was 164 percent of historical average.

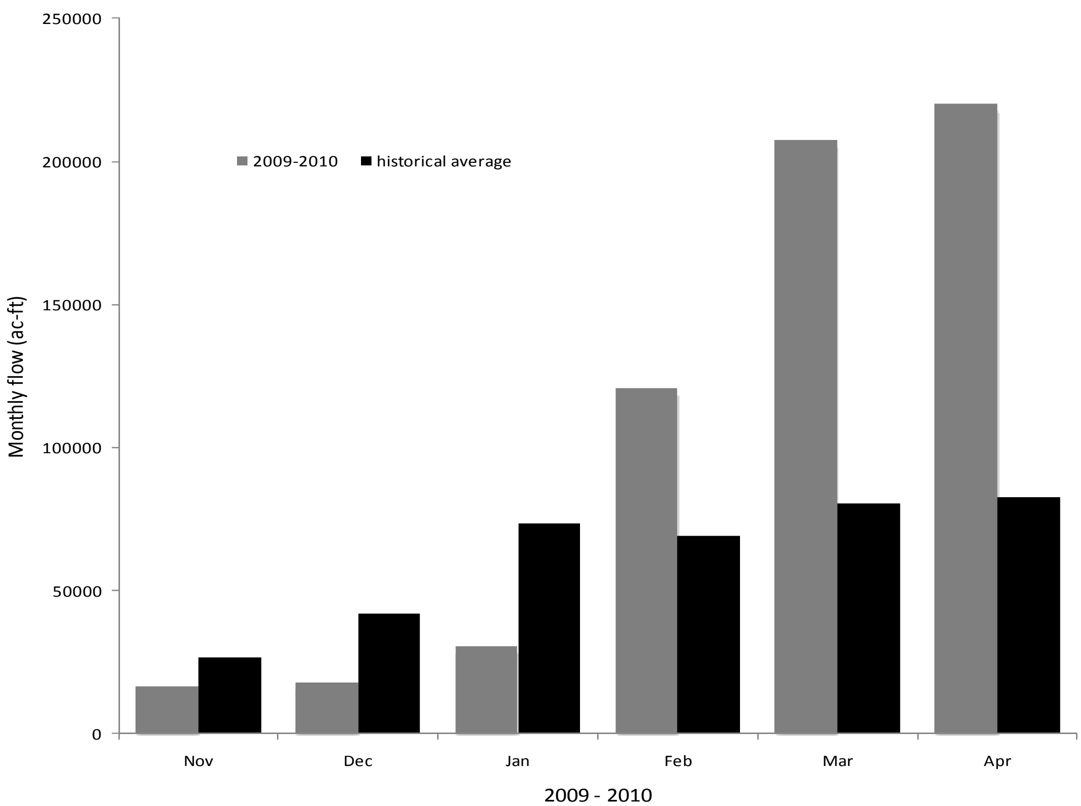


Figure 2-16. WY2010 dry seaon and historical average outflows from Lake Kissimmee.

WATER YEAR 2010 HYDROLOGY

RAINFALL AND EVAPOTRANSPIRATION

In WY2007, South Florida received 12 inches less rainfall than average; in WY2008, the rainfall was 3.8 inches below average and in WY2009, 7.5 inches below average. But in WY2010, the District-wide average rainfall was 8.68 inches above historical average. Historical average annual rainfall over the District area is 52.75 inches. The dry season extends from November through May and, on average, 35 percent of the annual rainfall occurs in the dry season (Abtew et al., 2007b). The percentage of dry season historical rainfall varies from rainfall area to rainfall area with the Palm Beach rainfall area getting the most (39 percent) and the Southwest Coast receiving the least (29 percent). In WY2010, rainfall in the dry season (May, November, and December 2009; January–April 2010) was higher than average District-wide. Percentage of dry season rainfall of the water year was 56 percent in the Palm Beach rainfall area, 55 percent in the Upper Kissimmee, 54 percent in Martin/St. Lucie, 44 percent for the Southwest Coast, and 49 percent District-wide. The dry season rainfall ended a three-year drought.

May 2009 was extremely wet with wet return periods of 100-yr (once every 100 years) for Upper Kissimmee and Big Cypress basins. **Table 2-11** depicts wet and dry return periods for each month's rainfall for each rainfall area. The table shows that October and November 2009 were dry months; May 2009 and March and April 2010 were wet months in almost all rainfall areas. Rainfall return periods for all rainfall areas except Everglades National Park (ENP or Park) were derived from Ali and Abtew (1999). The ENP's rainfall return periods were estimated from charts in Sculley (1986). For WY2010, Upper Kissimmee was the wettest with 19.93 inches above average rainfall, followed by, Broward (+16.57 inches), West EAA (+15.39 inches), Water Conservation Areas 1 and 2 (+13.67 inches), East Caloosahatchee (+10.93 inches), Southwest Coast (+9.57 inches), Water Conservation Area 3 (+9.23 inches), Lower Kissimmee (+8.51 inches), Miami-Dade (+7.98 inches), Big Cypress Basin (+7.93 inches), East EAA (+7.78 inches), ENP (+5.23 inches), Palm Beach (+4.85 inches), Lake Okeechobee (+4.3 inches), and Martin/St. Lucie (+2.04 inches). The WY2010 spatial average rainfall positive anomaly of 8.68 inches District-wide contrasts with the WY2009 deficit of 7.51 inches, the WY2008 rainfall deficit of 3.8 inches, and the WY2007 deficit of 12 inches. **Figure 2-17** depicts WY2010 monthly rainfall compared with the historical average, clearly showing the wet months.

The District's operations rainfall database 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). The ENP's rainfall was estimated as a simple average of eight stations: S-332, S-174, S-18C, HOMESTEADARB, JBTS, S-331W, S-334, and S-12D. **Table 2-12** depicts WY2010's monthly rainfall.

The balance between rainfall and evapotranspiration maintains the hydrologic system of South Florida 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). Regional estimates of ETp from open water and from wetlands that do not dry out range from 48 inches in the District's northern section to 54 inches in the 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. This year, ETp was lower than rainfall by 8.77 inches. **Table 2-13** shows ETp for each rainfall area, the ENP, and the District average. Comparison of WY2010 monthly rainfall, historical averages, WY2009 monthly rainfall, and WY2010 ETp are shown for each rainfall area in Appendix 2-2, Figures 1 through 4. Rainfall positive anomalies are shown in the legend for each figure. Comparison of WY2010, WY2009, historical average annual rainfall for each rainfall area, WY2010 ETp, and WY2010 rainfall anomalies are shown in **Table 2-14**.

Table 2-11. WY2010 monthly rainfall dry and wet return-periods for each rainfall area.

Month-Year	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
May-09	>100-yr wet	>10-yr wet	>10-yr wet	**>20-yr wet**	50-yr wet	10-yr wet	≈10-yr wet	>5-yr wet	>10-yr wet	<10-yr wet	<10-yr wet	**>20-yr wet**	**≈100-yr wet**	<5-yr wet
Jun-09	<5-yr wet	>average	>average	<5-yr wet	<5-yr wet	<5-yr wet	<5-yr wet	<average	>average	>5-yr wet	>5-yr wet	<average	≈5-yr wet	>average
Jul-09	>average	>average	>average	>average	>5-yr wet	>average	<average	<5-yr wet	>average	>average	<average	<10-yr wet	≈5-yr dry	≈5-yr dry
Aug-09	<average	≈average	<average	>average	≈average	<average	<average	>average	<average	<average	<average	<average	<average	>average
Sep-09	>average	<average	≈5-yr dry	<average	>average	≈5-yr wet	≈5-yr wet	≈5-yr dry	<average	>average	≈average	<average	<average	>average
Oct-09	>5-yr dry	≈20-yr dry	≈20-yr dry	≈10-yr dry	≈10-yr dry	≈10-yr dry	≈5-yr dry	≈20-yr dry	<100-yr dry	≈10-yr dry	>5-yr dry	<100-yr dry	<5-yr dry	>10-yr dry
Nov-09	<5-yr dry	≈5-yr dry	<5-yr dry	<5-yr dry	<5-yr dry	<5-yr dry	<5-yr dry	≈5-yr dry	<average	>average	>average	<average	<average	≈average
Dec-09	>10-yr wet	20-yr wet	≈10-yr wet	>5-yr wet	>5-yr wet	>10-yr wet	>average	**20-yr wet**	>10-yr wet	<20-yr wet	>10-yr wet	<20-yr wet	≈10-yr wet	>10-yr wet
Jan-10	<average	<average	<average	<average	<average	<average	<average	<5-yr dry	<5-yr dry	<5-yr dry	<5-yr dry	<5-yr dry	<average	<average
Feb-10	>average	>average	<average	≈5-yr wet	>5-yr wet	5-yr wet	>average	>average	>average	>5-yr wet	>10-yr wet	<average	>average	>average
Mar-10	**>20-yr wet**	<20-yr wet	**≈20-yr wet**	>10-yr wet	>10-yr wet	>10-yr wet	>5-yr wet	>10-yr wet	>10-yr wet	>5-yr wet	>average	>10-yr wet	<10-yr wet	>10-yr wet
Apr-10	5-yr wet	<5-yr wet	>5-yr wet	>5-yr wet	**≈20-yr wet**	<20-yr wet	<10-yr wet	<5-yr wet	>5-yr wet	<20-yr wet	>5-yr wet	<10-yr wet	>5-yr wet	>10-yr wet
dry months	4	3	5	4	3	4	5	4	4	3	4	6	6	3
extreme dry		1	1					1	1			1		
wet months	7	7	6	8	8	8	7	7	7	9	7	5	6	8
≈ average	1	1			1						1			1

extreme >= 20 yr

dry = < average

wet = > average

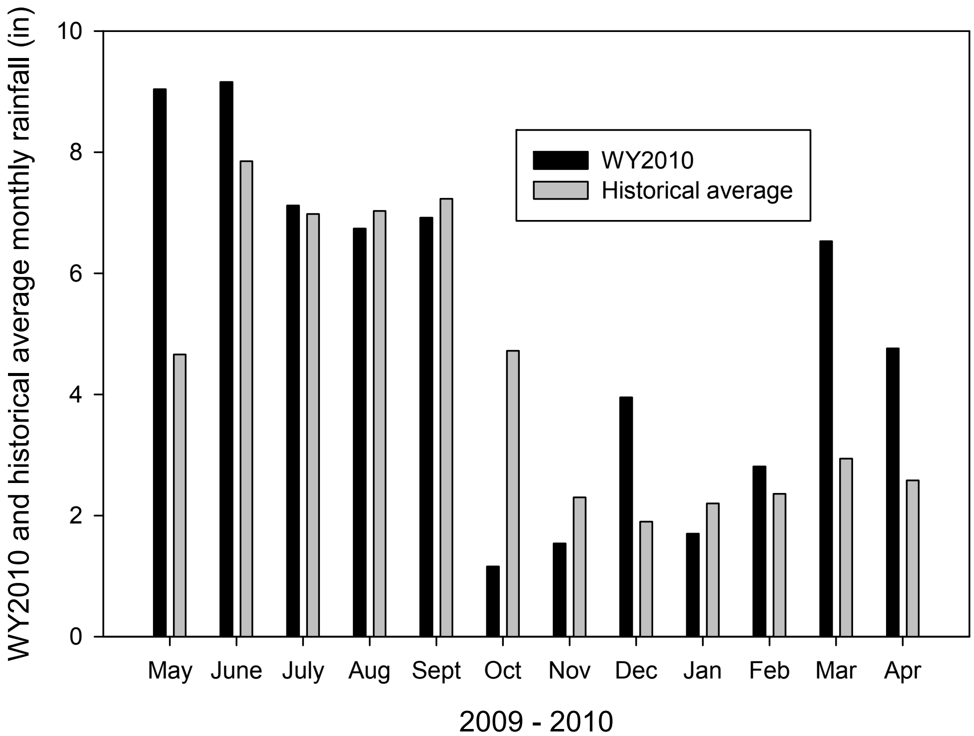


Figure 2-17. Comparison of WY2010 and historical monthly average District rainfall.

Table 2-12. WY2010 monthly rainfall (inches) for each rainfall area.

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	Everglades National Park	District-wide average
2009	May	14.26	7.64	7.13	9.59	10.76	9.15	9	7.5	10.12	9.71	10.05	9.93	9.18	5.66	9.64	9.04
2009	June	8.93	7.97	7.77	10.4	11.2	10.8	10.74	5.73	8.44	10.62	11.14	7.33	11.34	9.51	7.90	9.16
2009	July	8.55	7.5	6.75	6.41	8.4	6.43	5.55	7.68	6.57	7.19	5.86	10.08	6.28	6.61	6.61	7.12
2009	Aug	6.17	6.08	5.56	7.91	7.42	5.48	6.14	6.52	5.94	5.93	6.1	6.6	7.33	9.29	6.56	6.74
2009	Sept	6.92	4.97	3.78	6.35	8.62	8.02	8.53	4.97	6.9	9.87	8.06	6.94	7.28	9.71	7.86	6.92
2009	Oct	0.94	0.55	0.59	1.17	0.97	1.41	2.33	1.11	1.31	1.99	2.25	0.21	2.03	0.7	2.24	1.16
2009	Nov	1.28	0.72	0.79	1.13	1.16	1.6	1.73	1.01	2.93	4.06	3.76	1.2	1.67	1.59	4.25	1.54
2009	Dec	4.52	3.62	3.14	3.12	3.55	5.37	2.48	5.98	5.84	6.19	3.98	3.97	3.03	3.74	3.17	3.95
2010	Jan	2.16	1.42	1.31	1.57	2.14	1.56	1.59	1.32	1.66	1.54	1.21	1.32	2.14	2.34	1.47	1.7
2010	Feb	3.51	2.42	1.83	2.72	3.14	3.67	3	2.78	3.34	4.5	4.23	1.84	2.59	2.54	3.78	2.81
2010	Mar	8.84	6.97	7.62	6.02	6.54	5.97	4.38	7.1	7.72	4.91	3	7.19	5.12	6.76	2.93	6.53
2010	Apr	3.94	3.1	4	4.86	6.44	6.17	5.13	4.48	5.62	8.19	5.45	5	4.06	5.24	4.05	4.76
Sum	**(inches)**	**70.02**	**52.96**	**50.27**	**61.3**	**70.34**	**65.63**	**60.6**	**56.2**	**66.39**	**74.7**	**65.09**	**61.61**	**62.05**	**63.69**	**60.45**	**61.43**

Table 2-13. WY2010 monthly potential evapotranspiration (ETp) in inches for each rainfall area.

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	Everglades National Park	District-wide average
2009	May	5.70	5.87	5.91	5.48	5.24	5.22	5.35	5.47	5.48	5.35	5.37	5.39	4.99	5.19	5.37	5.42
2009	June	5.58	5.70	5.70	5.65	5.42	5.10	5.39	5.44	5.65	5.39	4.75	5.47	5.10	5.02	4.75	5.34
2009	July	5.42	5.73	5.49	5.05	5.53	5.12	5.49	5.56	5.05	5.49	4.84	5.35	5.18	5.11	4.84	5.28
2009	Aug	5.32	5.31	5.11	4.73	5.17	5.12	5.24	5.64	4.73	5.24	5.16	4.94	4.92	4.76	5.16	5.10
2009	Sept	4.64	4.68	4.63	3.89	4.43	3.97	4.53	4.76	3.89	4.53	3.95	4.44	4.18	4.58	3.95	4.34
2009	Oct	4.59	4.54	4.65	4.30	4.62	4.42	4.66	4.37	4.30	4.66	4.37	4.38	4.27	4.57	4.37	4.47
2009	Nov	3.24	3.25	3.25	3.12	3.46	3.19	3.59	3.28	3.12	3.59	3.49	3.13	3.45	3.15	3.49	3.32
2009	Dec	2.61	2.61	2.74	2.50	2.90	2.70	2.98	2.47	2.50	2.98	2.74	2.65	2.92	2.23	2.74	2.68
2010	Jan	3.34	3.32	3.10	3.06	3.28	3.03	3.37	3.20	3.06	3.37	3.24	3.22	3.32	2.78	3.24	3.20
2010	Feb	3.32	3.49	3.38	3.39	3.54	3.44	3.62	3.50	3.39	3.62	3.52	3.55	3.58	3.32	3.52	3.48
2010	Mar	4.83	5.11	4.73	4.73	4.71	4.51	4.82	4.82	4.73	4.82	4.72	5.07	4.83	4.79	4.72	4.80
2010	Apr	5.63	5.55	5.18	5.10	5.11	4.97	5.22	5.18	5.10	5.22	5.10	5.37	5.24	5.39	5.10	5.23
Sum	**(inches)**	**54.22**	**55.16**	**53.86**	**51.00**	**53.40**	**50.77**	**54.25**	**53.69**	**51.00**	**54.25**	**51.25**	**52.97**	**51.98**	**50.90**	**51.25**	**52.66**

Table 2-14. Comparison of WY2010, WY2009, historical average annual rainfall for each rainfall area, WY2010 ETp, and WY2010 rainfall anomalies.

Rainfall Area	WY2010 Rainfall (inches)	WY2009 Rainfall (inches)	Historical average rainfall (inches)	WY2010 ETp (inches)	WY2010 Rainfall anomaly (inches)
Upper Kissimmee	70.02	40.06	50.09	54.22	19.93
Lower Kissimmee	52.96	44.57	44.45	55.16	8.51
Lake Okeechobee	50.27	37.84	45.97	53.86	4.3
East Everglades Agricultural Area	61.26	44.41	53.48	51.00	7.78
West Everglades Agricultural Area	70.34	44.44	54.95	53.40	15.39
Water Conservation Area 1,2	65.63	47.4	51.96	50.77	13.67
Water Conservation Area 3	60.6	44.29	51.37	54.25	9.23
Martin/St. Lucie	56.18	45.08	54.14	53.69	2.04
Palm Beach	66.39	47.3	61.54	51.00	4.85
Broward	74.7	46.87	58.13	54.25	16.57
Miami-Dade	65.09	47.54	57.11	51.25	7.98
East Caloosahatchee	61.61	46	50.68	52.97	10.93
Big Cypress Preserve	62.05	49.45	54.12	51.98	7.93
Southwest Coast	63.69	50.9	54.12	50.90	9.57
Everglades National Park	60.45	42.6	55.22	51.25	5.23
SFWMD Spatial Average	**61.43**	**45.24**	**52.75**	**52.66**	**8.68**

HURRICANE SEASON

No hurricanes impacted South Florida during WY2007 and WY2008, but the WY2009 hurricane season (June 1–November 30, 2008) ended with 16 named storms – of which eight were hurricanes. Four of these systems, Gustav, Hanna, Ike and Fay, threatened the District area necessitating activation of emergency management. Hurricane Gustav passed through the Gulf of Mexico west of the District from August 31–September 1, 2008, and contributed rainfall to South Florida (Beven and Kimberlain, 2009). Hurricane Hanna passed east of South Florida on September 5 and 6, 2008, contributing rainfall to the coastal areas from Palm Beach to Indian River Counties (Brown and Kimberlain, 2008). Hurricane Ike, which devastated Galveston, Texas, contributed rainfall to South Florida as it passed through the Gulf of Mexico from Cuba to Galveston from September 8–13, 2008 (Berg, 2009). Tropical Storm Fay made direct landfall in South Florida, moving across the region longitudinally from the southwest to the northeast and impacting all 16 counties of the District.

Tropical activities in WY2010 were low in the Atlantic and Gulf of Mexico. There were only 11 named storms for the season (June 1–November 30, 2009). The decrease in tropical activities is mainly attributed to the strong El Niño weather pattern that persisted into spring 2010. Three hurricanes developed in the season, but only Hurricane Ida (November 4–10, 2009) passed through the Gulf of Mexico from Nicaragua to the Alabama Gulf coast and Florida panhandle, weakening to a tropical storm and later to an extratropical state as it moved inland (Avila and Cangialosi, 2010). It contributed some rainfall to the District from November 9–11, 2009. Out of the eight tropical storms and depressions, Tropical Storm Claudette (August 16–17, 2009) contributed some rainfall to South Florida. Claudette moved through the Florida Straits heading north-northwest and made landfall near Fort Walton Beach (Pasch, 2010). In conclusion, the contribution of tropical systems to rainfall of South Florida in WY2010 was small compared to the expected contribution of 15 to 20 percent (Walther and Abtew, 2007).

WATER MANAGEMENT

Water management operations of District facilities depend largely on the spatial and temporal distribution of rainfall. Although water management of the District facilities is performed according to prescribed operation plans, there are various constraints that need to be considered while developing and implementing shorter-term operating strategies.

During the wet and dry seasons of WY2010, most water control structures were operated under flood control mode due to excess rainfall conditions. Typically, during wet seasons the operations are performed under flood control mode, and during dry season the operations are made under water supply mode. During the dry season of WY2010, in addition to water supply deliveries for environmental, agricultural, and control of saltwater intrusion, the removal of excess runoff from rainfall was needed.

WY2010 and WY2009 received a total of 61.4 and 45.2 inches of rainfall, respectively (see **Table 2-14**). In WY2010, the wet season rainfall was 31.1 inches, and the dry season rainfall was 30.3 inches, 92 and 160 percent of normal rainfall amounts, respectively. In comparison, the WY2009 wet season had rainfall 15 percent above normal with a drier than normal dry season of approximately 33 percent of normal rainfall. The reversal of rainfall amounts and timing resulted in changes in water management operations during WY2010.

During WY2010, the wet and dry season amounts of rainfall in the Kissimmee Basin were 38.51 and 31.51 inches, respectively, and were 203 and 93 percent of the averages, respectively. The lake stages of the Kissimmee Upper Chain of Lakes, including Lake Tohopekaliga, Lake Kissimmee, and Lake Istokpoga were close to their respective regulation schedules during WY2010. However, the water levels of Lake Alligator, Lake Myrtle, Lake Mary Jane, Lake

Gentry, and East Lake Tohopekaliga were below the regulation schedule due to inspection and repairs of water control structures for most of the water year. Temporary deviations to the regulation schedules for these lakes were requested by the District and were approved by the USACE. Details on Lake Okeechobee operations are provided in the *Water Levels and Flows* section of this chapter.

Water supply releases are made for various beneficial uses that include water supply for urban and industrial use, agriculture, the ENP, salinity control, and estuarine management. Releases are also made to the St. Lucie and Caloosahatchee rivers 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 Canal, EAA, and Stormwater Treatment Areas. The details of these sub-regional flows are provided in the *Water Levels and Flows* section of this chapter.

Lake Okeechobee's stage fell from September 15, 2008, through May 18, 2009, due to flow releases for water supply purpose and evaporation. The lake stage was in the beneficial use zone of the Operational Band on January 1, 2009 at 13.97 ft NGVD. The lake stage remained in the beneficial use zone until the end of July 2009. Lake Okeechobee's stage was 11.09 ft NGVD on May 1, 2009. Due to above-average rainfall in May, June, and July 2009, the stages rose, reaching a peak of 14.56 ft NGVD on September 26, 2009.

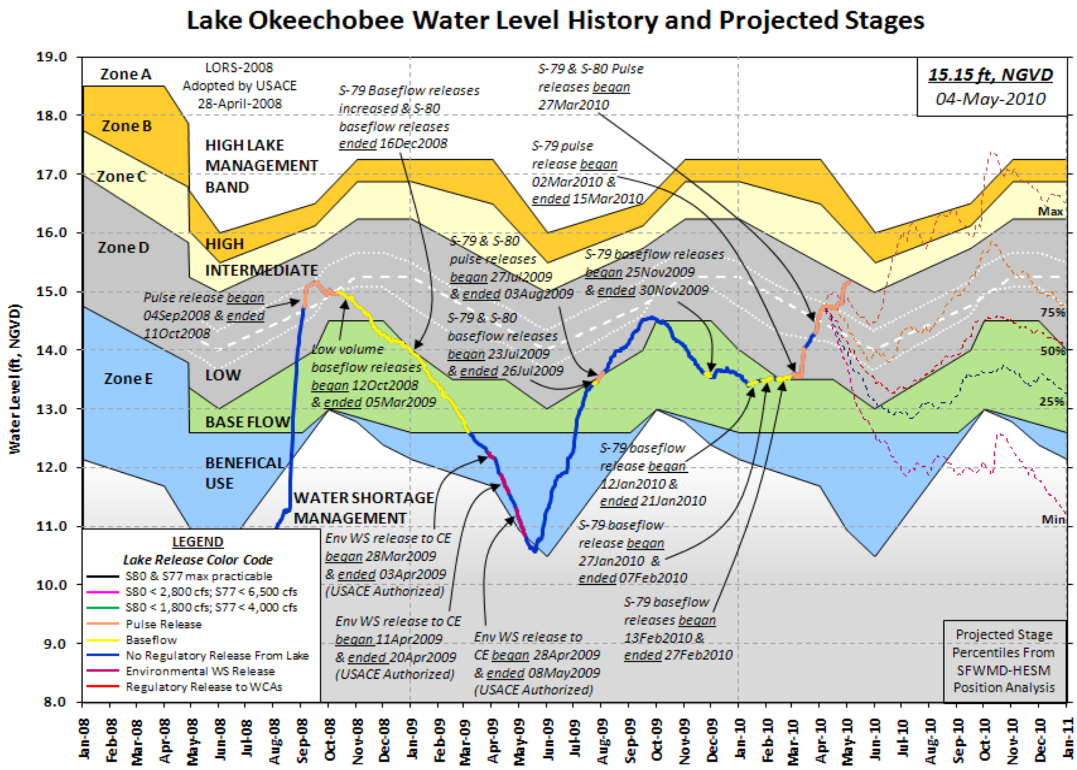
The USACE authorized environmental water supply releases as pulse releases from the lake to the Caloosahatchee Estuary from April 28, 2009 through May 8, 2009. In addition, five base-flow releases were made from the S-79 structure: July 23 and 26, 2009; November 25 and 30, 2009; January 12, 21, and 27, 2010; February 7, 13, and 27, 2010. Three more pulse releases were made to the Caloosahatchee Estuary at S-79 and to the St. Lucie Estuary at structure S-80. The first of these releases began on July 27, 2009, and ended on August 3, 2009. The second began on March 2, 2010, and ended on March 15, 2010. Third release began on March 27, 2010, and ended on May 3, 2010. The plots of lake stages from January 2008 through May 2010, water management decisions, the regulation schedule, and the water level projection through the end of calendar year 2010 are shown in **Figure 2-18**.

After September 26, 2009, lake stages continued receding, due to below-average rainfall in October and November. The lake receded to 13.53 ft NGVD by November 30, 2009, and remained relatively stable through the end of February 2010. December 2009 and February 2010 had above-average rainfall, necessitating flow releases; however, inflows to the lake were lower than might be expected since the drought-affected watershed had to saturate before runoff flowed into the lake. The water level did rise by about one foot to 14.63 ft by the end of March 2010 due to above-average rainfall in that month. By the end of WY2010, Lake Okeechobee's stage further increased to 15.13 ft NGVD on April 30, 2010, due to higher than normal rainfall in April. A total of 554,299 ac-ft of water was released from Lake Okeechobee in WY2010. During the wet season (June–October), a total of 106,213 ac-ft of water was released from the lake. In May 2009 and from November 2009 through April 2010, outflow from the lake was 448,086 ac-ft.

Water levels in Water Conservation Area 1 (WCA-1) started from close to the minimum regulation schedule in May 2009 and rose to higher than maximum regulation schedule through August 2009. The levels remained below maximum regulation schedule from September 2009 through the end of January 2010, and then stayed above the maximum regulation schedule for the remainder of the water year.

Water levels in Water Conservation Area 2 (WCA-2) began in May 2009 a quarter foot below the minimum regulation schedule. The water levels then rose from mid-May and remained above the maximum regulation schedule for all of WY2010.

Water levels in Water Conservation Area 3 (WCA-3) were below the maximum regulation schedules in May and mid-June 2009. From mid-June to October 2009, water levels were higher than the maximum regulation schedules. Then, the water levels were slightly lower than the maximum regulation schedule through March 2010. In April 2010, the water levels were at the maximum regulation schedule.



*Volume-to-depth conversion based on average lake surface area of 467,000 acres.
Note: The new regulation schedule as described in the water control plan is not limited to these three traditional pulse levels. Rather it has the flexibility to discharge pulses of variable duration and shape. See **Figure 2-25** for estuary releases decision making under the current regulation schedule.

Figure 2-18. Daily Lake Okeechobee stages, water management decisions, regulation schedule, and water level projection (current regulation schedule started May 1, 2008).

DROUGHT MANAGEMENT

WY2010 started as the extension of the previous three water years' drought. Lake Okeechobee was at 11.09 ft NGVD following a drier than average dry season. The early part of May 2009 was dry and temporary forward pumping of 2,746 ac-ft of water was needed at structure S-352 (on a canal between the lake and the EAA). The normal operation of gravity discharge limitation occurs at lower lake water levels. Forward pumping was also needed during the previous drought years. Discussion on droughts in South Florida and the 2006–2009 drought are presented in detail in Abtew et al. (2009).

WILDFIRES

One of drought's impacts on the South Florida environment is the development of conditions that promote and spread wildfires. The sizes and number of wildfires are generally correlated to dry moisture conditions. Generally, drought years have above-average area of acres burned and acres burned per fire. For instance, the area burned by wildfire in WY2007 was the third highest since 1982 when data first became available. **Figure 2-19** depicts number of acres burned in a water year in the SFWMD area from wildfires that were 10 acres or larger for WY1982–WY2010. Major droughts correspond to areas burned by wildfire. The effect of dry season El Niño-related rainfall is evident in WY2010 with the low number of acres burned (27,037 ac, the fifth lowest acreage since 1982).

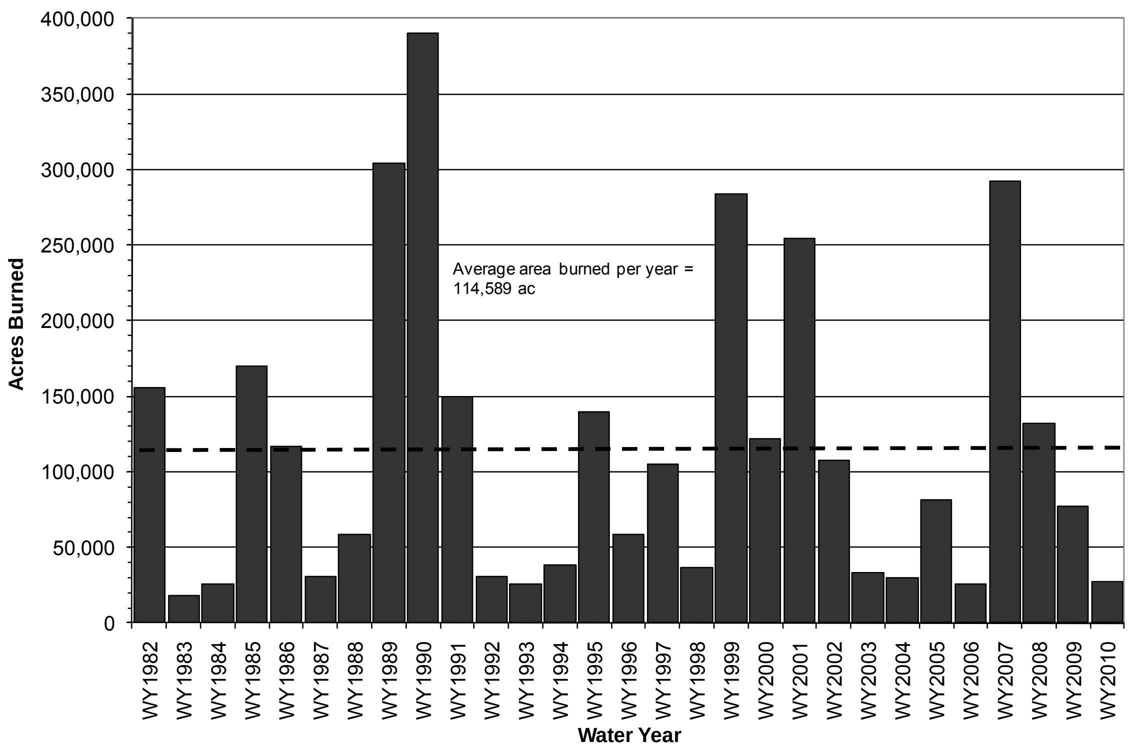


Figure 2-19. Number of acres burned per water year in the SFWMD area from wildfires that were 10 acres or larger (WY1982–WY2009).

GROUNDWATER

The District is divided into four major water resources planning regions (see **Figure 2-15**). Each has unique aquifers that provide water for agricultural, commercial, industrial, and domestic use. The Lower East Coast's (LEC) principal groundwater source is the Biscayne aquifer, a surficial aquifer. The Upper East Coast's (UEC) principal source of groundwater is the surficial aquifer. The Lower West Coast (LWC) relies on three aquifer systems for water supply, the Surficial Aquifer System (SAS), the Intermediate Aquifer System (IAS) and the Floridan Aquifer System (FAS). The Lower Tamiami aquifer is part of the SAS; the Sandstone and the Mid-Hawthorne aquifers are part of the IAS (SFWMD, 2006). The Kissimmee Basin is served by a surficial or shallow aquifer and a deep aquifer, the Floridan aquifer.

In general for WY2010, groundwater levels were above average for the latter part of the year reflecting the impact of the El Niño weather pattern on dry season rainfall. Representative groundwater level fluctuations are shown in Appendix 2-1 for the stations shown in **Figure 2-15**.

WATER LEVELS AND FLOWS

In this section, water levels, regulation schedules, and flows for WY2010 are discussed for the major lakes and impoundments. For parts of the wet and dry seasons of WY2010, most water control structures were operated under water supply mode due to rainfall deficit conditions. Period of record (POR) daily mean water levels (stage) graphs for lakes, impoundments, and the ENP are shown in Appendix 2-3. Regulation schedules for lakes and impoundments are published in *2007 SFER – Volume I, Appendix 2-6*. All water levels are expressed in ft NGVD in these and related publications. Also, the current year water level statistics reported are compared to the previous water year and historical water level records in **Table 2-15**. Comparison of monthly historical averages, WY2009, and WY2010 water levels are shown in Appendix 2-4 of this volume. Water levels are also a measure of the amount of stored water. Relationships of water levels (stage) and storage for lakes and impoundments was presented in the *2007 SFER – Volume I, Appendix 2-2* (Abtew et al., 2007).

Water levels and flows are regulated from the Kissimmee Chain of Lakes to the Everglades. Current water year flow statistics are compared to the previous water year and historical flow records in **Table 2-16**. At times, temporary deviations are requested to operate the system outside the bounds of the regulation schedule to manage water quantity, quality, and storage and conveyance system integrity. These are noted in the following subsections for each impoundment or lake. Water control structures used are shown in **Figures 2-3** through **2-6.**

Appendix 2-5 contains tables of WY2010 monthly flow volumes for the systems discussed below. Appendix 2-6 presents comparisons of WY2009, WY2010, and historical monthly average flows for each lake or impoundment. In most areas, the impact of the 2009–2010 El Niño event on dry season rainfall is distinctly shown by significant increases in rainfall and surface water flows.

Table 2-15. WY2009, WY2010, and historical stage statistics for major lakes and impoundments.

Lake or Impoundment	Beginning of Record	Historical Mean Stage (ft NGVD)	WY2010 Mean Stage (ft NGVD)	WY2009 Mean Stage (ft NGVD)	Historical Maximum Stage (ft NGVD)	Historical Minimum Stage (ft NGVD)
Lake Alligator	1993	62.53	62.89	62.77	64.17	58.13
Lake Myrtle	1993	60.88	60.81	60.97	65.22	58.45
Lake Mary Jane	1993	60.07	60.08	60.37	62.16	57.19
Lake Gentry	1993	60.66	60.92	61.51	61.97	58.31
East Lake Tohopekaliga	1993	56.65	56.86	56.81	59.12	54.41
Lake Tohopekaliga	1993	53.72	54.25	53.94	56.63	48.37
Lake Kissimmee	1929	50.38	50.95	50.37	56.64	42.87
Lake Istokpoga	1993	38.76	38.85	37.69	39.78	35.84
Lake Okeechobee	1931	14.05	13.47	12.59	18.77	8.82
Water Conservation Area 1	1953	15.63	16.33	16.26	18.16	10
Water Conservation Area 2A	1961	12.53	12.32	12.05	15.64	9.33
Water Conservation Area 3A	1962	9.56	9.9	10.28	12.79	4.78
Everglades National Park, Slough	1952	5.99	6.15	6.29	8.08	2.01
Eveglades National Park, Wet Praire	1953	2.12	2.59	2.86	7.1	-2.69

Table 2-16. WY2009, WY2010, and historical flow statistics for major impoundments, lakes, and canals.

Lake, Impoundment, Canal	Beginning of Record	Historic Mean Flow (ac-ft)	WY2010 Flow (ac-ft)	Percent of Historical Mean	WY2009 Flow (ac-ft)	Historical Maximum Flow (ac-ft)	Historical Minimum Flow (ac-ft)
Lake Kissimmee Ouflow	1972	714,363	1,307,625	183%	494,638	2,175,297	16,195
Lake Istokpoga Outflow	1972	215,159	180,353	84%	289,438	637,881	26,559
Lake Okeechobee Inflow	1972	2,111,593	2,400,337	114%	2,090,775	3,707,764	377,761
Lake Okeechobee Outflow	1972	1,446,334	554,299	38%	1,141,084	3,978,904	176,566
St. Lucie (C-44 Canal) Inflow at S-308	1972	260,395	75,928	29%	172,612	1,117,158	4,061
St. Lucie (C-44 Canal) Outflow at S-80	1953	502,134	130,693	26%	164,506	3,189,329	0
Caloosahatchee River (C-43 Canal) Inflow at S-77	1972	578,824	198,633	34%	375,722	2,175,765	42,301
Caloosahatchee River (C-43 Canal) Outflow at S-79	1972	1,225,608	1,087,299	89%	1,016,333	3,615,525	86,895
Water Conservation Area 1 Inflow	1972	475,759	310,183	65%	362,958	1,307,517	205,674
Water Conservation Area 1 Outflow	1972	457,921	521,037	114%	334,724	1,433,399	116,366
Water Conservation Area 2 Inflow	1972	642,948	1,299,071	202%	905,864	1,754,710	113,225
Water Conservation Area 2 Outflow	1972	626,331	884,433	141%	737,421	1,729,168	93,564
Water Conservation Area 3A Inflow	1972	1,209,782	1,470,963	122%	1,212,107	2,590,417	477,113
Water Conservation Area 3A Outflow	1972	1,209,782	1,136,952	94%	1,432,056	2,593,337	245,964
Everglades National Park Inflow	1972	985,658	1,355,548	138%	1,387,916	2,940,082	245,676
Upper East Coast C-23 Canal Outflow at S-48	1995	131,539	112,340	85%	114,822	297,214	38,332
Upper East Coast C-24 Canal Outflow at S-49	1962	132,999	160,082	120%	139,652	340,313	15,174
Upper East Coast C-25 Canal Outflow at S-50	1965	136,186	184,020	135%	148,191	264,074	21,154

Kissimmee Chain of Lakes

The Upper Kissimmee Basin is an integrated system consisting of several lakes with interconnecting canals and flow control structures (**Figure 2-3**). 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, surface area, storage at average stage, WY2010 storage, and change in storage for the Kissimmee Chain of Lakes are shown in **Table 2-4**.

In general, the lake stages of the Upper Chain of Lakes, including Lake Alligator, Lake Myrtle, Lake Mary Jane, Lake Gentry, East Lake Tohopekaliga, Lake Tohopekaliga, and Lake Kissimmee, were at or below their respective regulation schedules during WY2010. The Kissimmee Basin produced higher flow volumes since the rainfall was approximately 140 percent of the normal annual average during WY2010.

Alligator Lake

The outflows from lakes Alligator, Center, Coon, Trout, Lizzie, and Brick are controlled by two structures, S-58 and S-60. The S-58 structure is located in the C-32 canal that connects Lakes Trout and Joel and S-60 is located in C-33 canal between Lakes Alligator and Gentry. Culvert S-58 maintains stages in Alligator Lake upstream from the structure, while the S-60 spillway is operated to main the optimum stage lake-wide. These lakes are regulated between elevations 61.5 and 64.0 ft NGVD on a seasonally varying schedule. Daily water level observations for Alligator Lake during the last 17 years show that the most significant change in water levels occurred during the 2000–2001 drought (Appendix 2-3, Figure 1, of this volume). The regulation schedule for Alligator Lake is presented in *2007 SFER – Volume I, Appendix 2-6*. **Figure 2-20**, panel a, shows daily average stage at the headwater of S-60, daily rainfall, and the regulation schedule for Lake Alligator during WY2010. Through WY2010, the stages were below regulation under temporary deviation of regulation schedules, due to construction and repair of the S-60 water control structure. Flow releases, based on water supply needs, were made during this period to bring stages back to modified regulation schedule whenever possible. Monthly historical average, WY2009, and WY2010 water levels are shown in Appendix 2-4, Figure 1, of this volume.

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 NGVD on a seasonally varying schedule. **Figure 2-20**, panel b, shows daily average stage at the headwater of S-57, daily rainfall, and regulation schedule for Lake Myrtle during WY2010. Most often, the stages were below regulation even though the rainfall was above normal. Flow releases, based on water supply needs, were made during this period. In addition, flow releases were made to increase stages of other connected, smaller lakes such as Lake Lizzie, whenever possible. Daily water level observations for Lake Myrtle in the last 17 years show that the most significant drop in water level occurred in 2001 (Appendix 2-3, Figure 2, of this volume). Monthly historical average, WY2009, and WY2010 water levels are shown in Appendix 2-4, Figure 2, of this volume.

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 NGVD according to a seasonally varying schedule. **Figure 2-20**, panel c, shows daily average stage at the headwater of S-62, daily rainfall, and regulation schedule for Lake Mary Jane during WY2010. Most often, the stages were below regulation, due to construction and repair of the S-62 structure and under temporary deviation of regulation schedules. Flow releases, based on water supply needs, were made during this period to bring stages back to modified regulation schedule whenever possible. Daily water level observations for Lake Mary Jane in the last 17 years show that the most significant drop in water level occurred in 2001 (Appendix 2-3, Figure 3, of this volume). Monthly historical average, WY2009, and WY2010 water levels are shown in Appendix 2-4, Figure 3, of this volume.

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 NGVD according to a seasonally varying schedule. **Figure 2-20**, panel d, shows daily average stage at the headwater of the S-63 spillway, daily rainfall, and regulation schedule for Lake Gentry during WY2010. The S-63 structure was under temporary deviation of regulation schedules, however from May 2009 through April 2010, the stages were close to normal regulation schedule. Daily water level observations for Lake Gentry in the last 17 years show the most significant drop in water level occurred in 2001 (Appendix 2-3, Figure 4, of this volume). Monthly historical average, WY2009, and WY2010 water levels are shown in Appendix 2-4, Figure 4, of this volume.

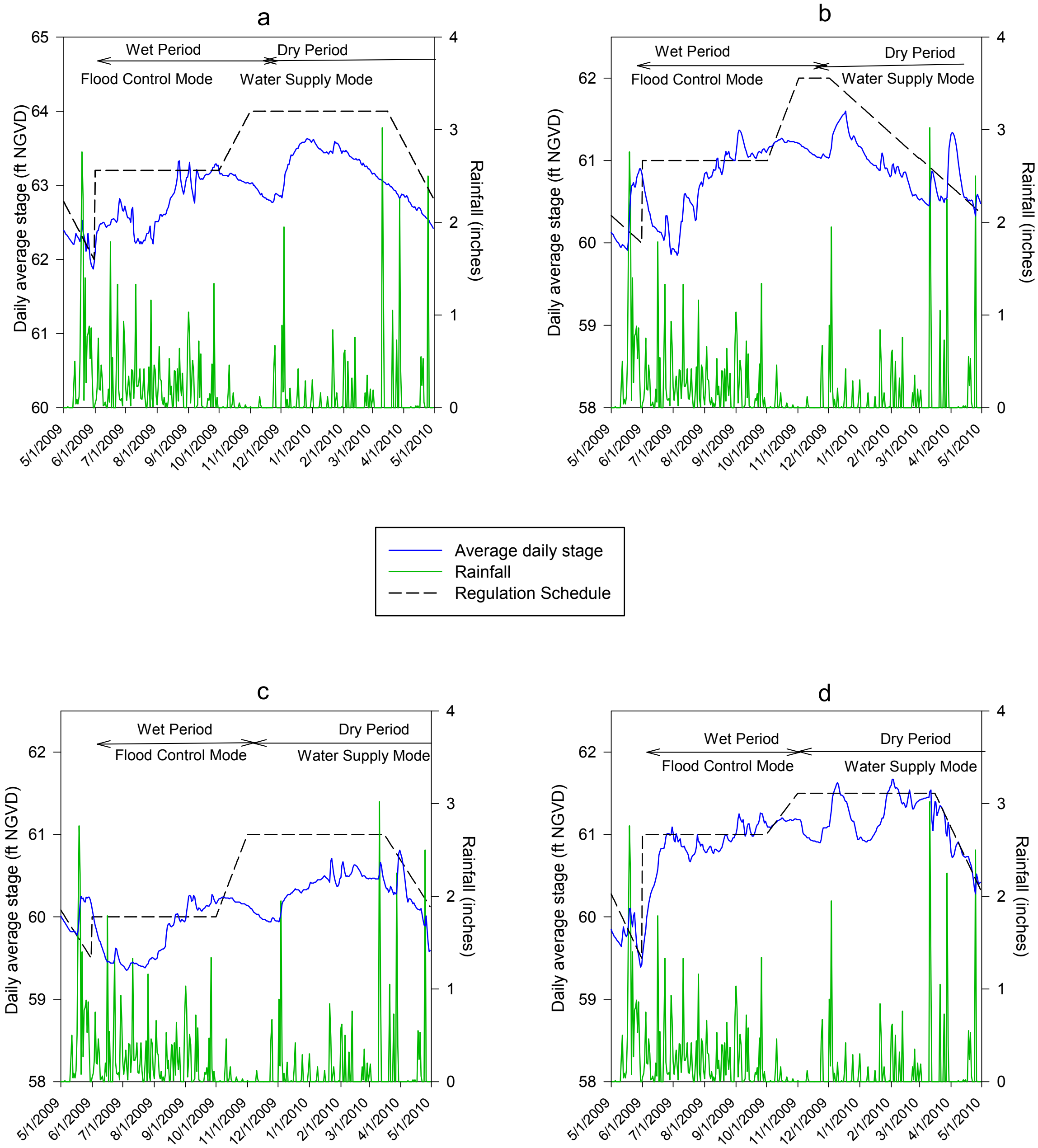


Figure 2-20. Average daily water levels (stage), regulation schedule, and rainfall for (a) Alligator Lake, (b) Lake Myrtle, (c) Lake Mary Jane, and (d) Lake Gentry.

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 regulated between 54.5 and 58.0 ft NGVD 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 NGVD. The weir is often submerged and therefore, the tailwater influences the headwater of S-59. **Figure 2-21**, panel a, shows daily average stage at the headwater of S-59, daily rainfall, and regulation schedule for East Lake Tohopekaliga during WY2010. Most often, the stages were below regulation due to construction and repair of the S-59 structure and under temporary deviation of the regulation schedule. Flow releases, based on water supply needs, were made during this period to bring stages back to modified regulation schedule whenever possible. Daily water level observations for East Lake Tohopekaliga in the last 17 years are shown in Appendix 2-3, Figure 5, of this volume. Monthly historical average, WY2009, and WY2010 water levels are shown in Appendix 2-4, Figure 5, of this volume.

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 NGVD on a seasonally varying schedule. The S-61 structure is used to maintain the optimum stage in Lake Tohopekaliga. **Figure 2-21**, panel b, shows the daily average stage at the headwater of S-61, daily rainfall, and regulation schedule for Lake Tohopekaliga during WY2010. From mid-May 2009 through June 2009, the stages were higher than the regulation. From August 2009 through April 2010, the lake's stages were close to regulation schedule. Daily water level observations for Lake Tohopekaliga in the last 17 years show the most significant drop in water level occurred in 2004, during the lake drawdown (Appendix 2-3, Figure 6, of this volume). Monthly historical average, WY2009, and WY2010 water levels are shown in Appendix 2-4, Figure 6, of this volume.

Lakes Kissimmee, Hatchineha and Cypress

Lakes Kissimmee, Hatchineha, and Cypress are regulated by the spillway and lock structure S-65, located at the outlet of Lake Kissimmee and the head of the Kissimmee River (C-38 canal). Lake Kissimmee is regulated between elevations 48.5 and 52.5 ft NGVD on a seasonally varying schedule. **Figure 2-21**, panel c, shows daily average stage at the headwater of S-65, daily rainfall, and the regulation schedule for Lake Kissimmee during WY2010. From May through mid-July 2009; from mid-July through September 2009; and from October 2009 through January 2010, the stages were lower than the regulation schedule. From February through April 2010, the lake's stages were close to regulation schedule. Minimum releases, based on water supply needs, were made.

Lake Kissimmee covers an area of approximately 35,000 acres. Appendix 2-3, Figure 7, of this volume shows daily water level for the period from 1929–2010. Historical average, WY2009, and WY2010 monthly water levels are shown in Appendix 2-4, Figure 7, of this volume.

Lake Kissimmee outflow is regulated through structure S-65. The Upper Kissimmee experienced a rainfall positive anomaly of 19.93 inches resulting in high outflows from Lake Kissimmee (1,307,625 ac-ft), 183 percent of the historical average compared to 494,638 ac-ft in WY2009. There has been discharge from Lake Kissimmee to the Kissimmee River since July 18, 2007, continuing through April 30, 2010. WY2010 monthly flows are shown in Appendix 2-5, Table 1, of this volume. Monthly historical average, WY2009, and WY2010 flows are shown in Appendix 2-6, Figure 1, of this volume.

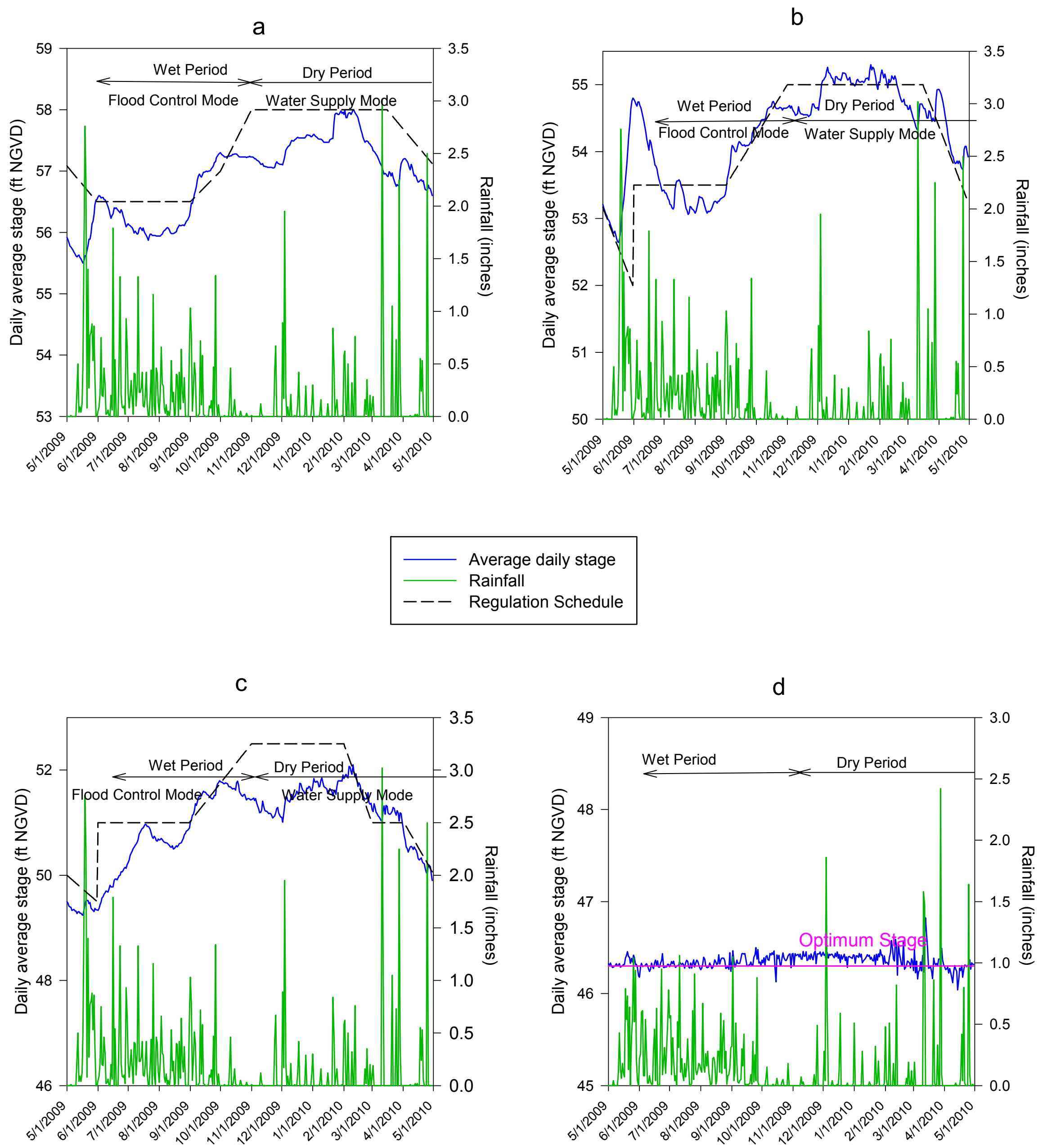


Figure 2-21. Average daily water levels (stage), regulation schedule and rainfall for (a) East Lake Tohopekaliga, (b) Lake Tohopekaliga, (c) Lake Kissimmee, and (d) Pool A (see *The Lower Kissimmee System* section of this chapter for Pool D).

The Lower Kissimmee System

The Lower Kissimmee System (**Figure 2-3**) 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, BC, 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 NGVD, respectively.

Pool A

Stages in Pool A are controlled by S-65A and the pool is located downstream of the S-65 structure. S-65A is a gated spillway and lock structure that normally maintains an optimum headwater at elevation 46.3 ft NGVD. In addition to S-65A, there is a culvert structure that is located through the east tieback levee at the natural channel of the Kissimmee River. The culverts are two 66-inch barrels each with slide gates. During water supply periods, minimum releases are made to satisfy irrigation demands and maintain navigation downstream. The culvert also provides water to the oxbows of the natural river channel. **Figure 2-21**, panel d, shows daily average stage at the headwater of S-65A, daily rainfall, and the optimum stage schedule for Pool A during WY2010. From May 2009 through April 2010, stages were mostly close to the optimum stage. Minimum releases, based on water supply needs and water level control, were made during the water year.

Pool BC

Stages in Pool BC are controlled by the S-65C structure which is located downstream of the S-65A structure. S-65C is a gated spillway and lock structure that normally maintains an optimum headwater at elevation 34.0 ft NGVD. 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 WY2010, minimum and maximum headwater stages at S-65C were 33.36 and 35.99 ft NGVD, respectively.

Pool D

Stages in Pool D are controlled by the S-65D structure located downstream of S-65C. Structure S-65D is a gated spillway and lock that normally maintains an optimum headwater at elevation 26.8 ft NGVD. During WY2010, headwater stages at S-65D ranged from 26.43 to 27.65 ft NGVD.

Pool E

Stages in Pool E are controlled by the S-65E structure which is located downstream of the S-65D. Structure S-65E is a gated spillway and lock that normally maintains an optimum headwater at elevation 21.0 ft NGVD. During WY2010, minimum and maximum headwater stages at S-65E were 20.56 and 21.22 ft NGVD, respectively.

Lake Istokpoga

Lake Istokpoga has a surface area of approximately 27,700 acres. Stages in Lake Istokpoga are regulated by the S-68 spillway located at the south end of the lake. Lake Istokpoga is regulated in accordance with a regulation schedule that varies seasonally. The S-68 maintains the optimum water stages in Lake Istokpoga. The S-68 discharges water from Lake Istokpoga to the C-41A canal (the Slough Canal). The C-41 canal (Harney Pond Canal), the C-40 canal (Indian Prairie Canal), and the 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. The details of the Lake Istokpoga water control plan can be obtained from the Master Water Control Manual for Kissimmee River – Lake Istokpoga Basin (USACE, 1994).

Figure 2-22, panel a, shows daily average stage at the headwater of S-68, daily rainfall, and regulation schedule for Lake Istokpoga during WY2010. Appendix 2-3, Figure 8, of this volume shows daily water levels for the period from 1993–2010. Monthly historical average, WY2009, and WY2010 water levels are shown in Appendix 2-4, Figure 8, of this volume. During May and June 2009, stages were within the minimum and maximum regulation schedules. However, from July through September 2009, the stages were at or close to the maximum regulation schedule. From October through April 2010, the stage receded but remained above the minimum regulation schedule. Minimum releases, based on water supply needs, were made during drier periods. The stage was brought to 0.2 ft below the maximum regulation schedule at the end of April 2010. WY2010 monthly flows are shown in Appendix 2-5, Table 1, of this volume. Monthly historical average, WY2009, and WY2010 flows are shown in Appendix 2-6, Figure 2, of this volume. Overall, water levels of Lake Istokpoga were closer to the maximum regulation schedule for most of WY2010.

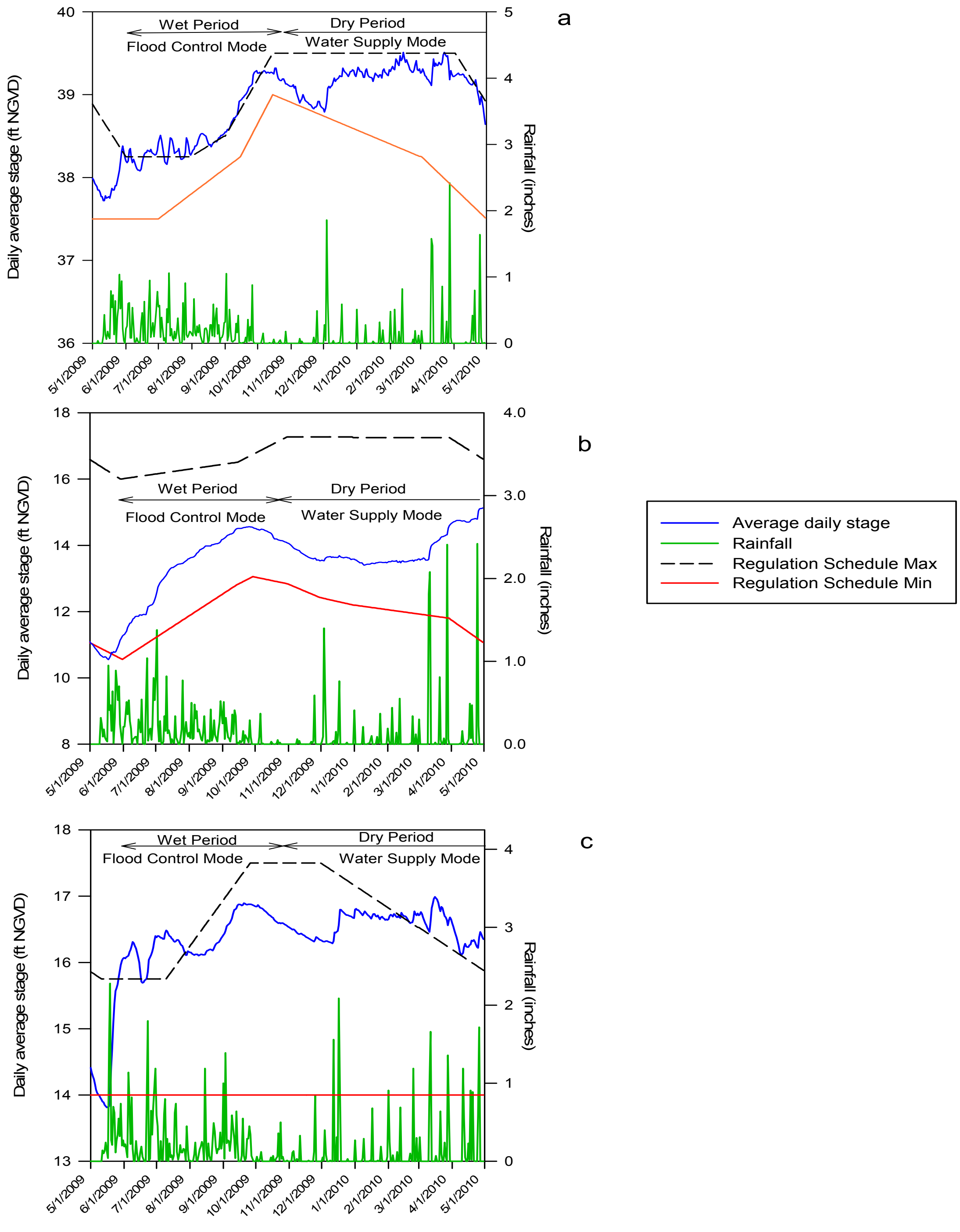


Figure 2-22. Average daily water levels (stage), regulation schedule and rainfall for (a) Lake Istokpoga, (b) Lake Okeechobee, and (c) Water Conservation Area 1.

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, and the Everglades Protection Area; (4) regional groundwater control; (5) salinity control; (6) enhancement of fish and wildlife; and (7) recreation. The regulation schedule accounts for varying and often conflicting purposes. Lake Okeechobee has been regulated under a different regulation schedule in previous water years (Abtew et al., 2007).

Lake Okeechobee has an approximate surface area of 437,400 ac at the historical average stage of 14.05 ft NGVD (1931–2010). Lake Okeechobee's stage was below the critical level of 11 ft NGVD for 24 days in May 2009. **Figure 2-22**, panel b, shows daily average stage, daily rainfall, and regulation zones for Lake Okeechobee during WY2010. An updated regulation schedule was adopted on April 28, 2008 for Lake Okeechobee which was implemented in WY2009 (USACE, 2008).

From January 2009 to mid-March 2009, the team's weekly recommendation included no releases to Caloosahatchee and St. Lucie Estuaries. Later, pulse releases to the Caloosahatchee Estuary began on March 28, 2009, and ended on April 3, 2009. Additional pulse releases to the Caloosahatchee Estuary were made that started on April 11, 2009, and ended on April 20, 2009. One week later, the USACE authorized pulse releases from the lake to the estuary from April 28, 2009, ending May 8, 2009. The plots of the lake stages from January 2008 through May 2010 are shown in **Figure 2-18**.

The lake stage fell from September 15, 2008, through May 18, 2009, due to flow releases for water supply and evaporation. The lake stage was in the beneficial use zone of the Operational Band on January 1, 2009, at 13.97 ft NGVD. The lake stage remained in this zone until the end of July 2009. Lake Okeechobee's stage fell to 10.55 ft on May 18, 2009. Due to above-average rainfall in May, June, and July 2009, the stages rose, reaching a peak of 14.56 ft NGVD on September 26, 2009.

Appendix 2-3, Figure 9, of this volume shows daily water levels for Lake Okeechobee for POR 1931–2010. Monthly historical average, WY2009, and WY2010 water levels are shown in Appendix 2-4, Figure 9, of this volume.

Based on a water-year-to-water-year comparison, WY2010 inflows of 2,400,337 ac-ft were 114 percent of the historical average inflows. WY2010 outflows of 554,299 ac-ft were 38 percent of the historical annual outflows (1972–2010). WY2010 monthly inflows and outflows are shown in Appendix 2-5, Table 2 and Table 3, respectively. Monthly historical average, WY2009, and WY2010 inflows and outflows are shown in Appendix 2-6, Figures 3 and 4, of this volume.

Lake Okeechobee Regulation Schedule 2008

A new regulation schedule (USACE, 2008) for Lake Okeechobee was adopted on May 1, 2008, which was implemented in WY2009 (**Figure 2-23**). The new regulation schedule is divided into three major bands: High Lake Management Band, Operational Band, and Water Shortage Management Band. In the High Lake Management Band, outlet canals may be maintained above the optimum water management elevations. In the Operational Band, 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. The new regulation schedule was developed by the USACE based on the following considerations:

- The Caloosahatchee and St. Lucie estuaries' environmental needs
- Lake Okeechobee ecology and environmental needs

- The Everglades (including the ENP) environmental needs
- Structural integrity of the Herbert Hoover Dike and potential danger from hurricane seasons

The new regulation schedule attempts to balance the multi-purpose objectives of flood control, water supply, navigation, enhancement of fish and wildlife resources, and recreation. The new regulation schedule's dominant objective is public health and safety related to the structural integrity of the Herbert Hoover Dike. The 2008 regulation schedule has expanded operational flexibility throughout the year and allows Lake Okeechobee to be managed at lower levels than the previous regulation schedule. The regulation schedule is implemented through decision trees that consider current Lake Okeechobee water level, Water Conservation Areas (WCAs) water levels, tributary hydrologic conditions, multi-season climatic and hydrologic outlook, and estuary conditions (USACE, 2008). **Figure 2-24** depicts the decision tree to establish allowable Lake Okeechobee releases to the WCAs. **Figure 2-25** depicts the decision tree to establish allowable Lake Okeechobee releases to tide (estuaries). Lake Okeechobee water level on the day of decision is the starting point for decision making.

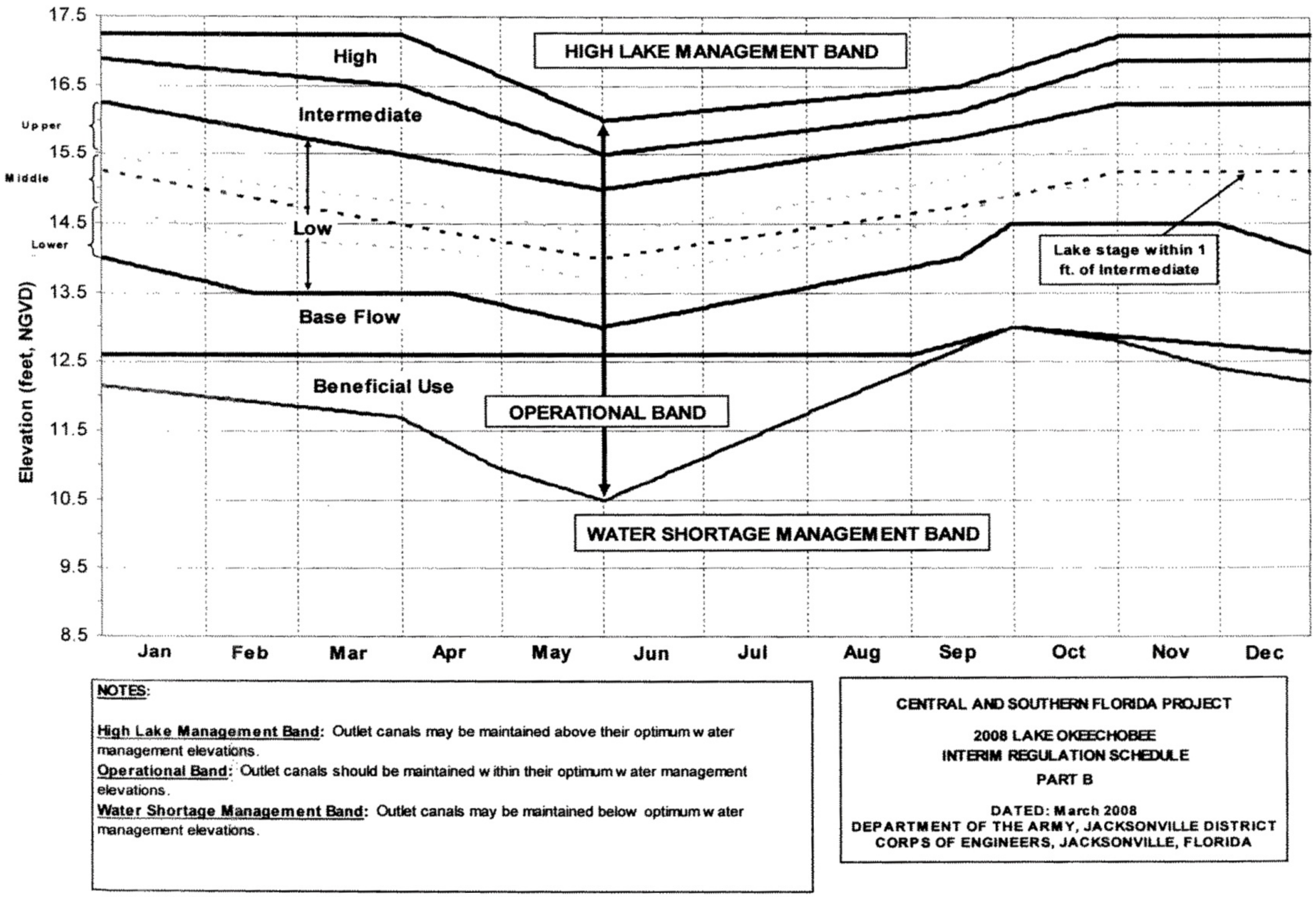


Figure 2-23. Lake Okeechobee's current regulation schedule.

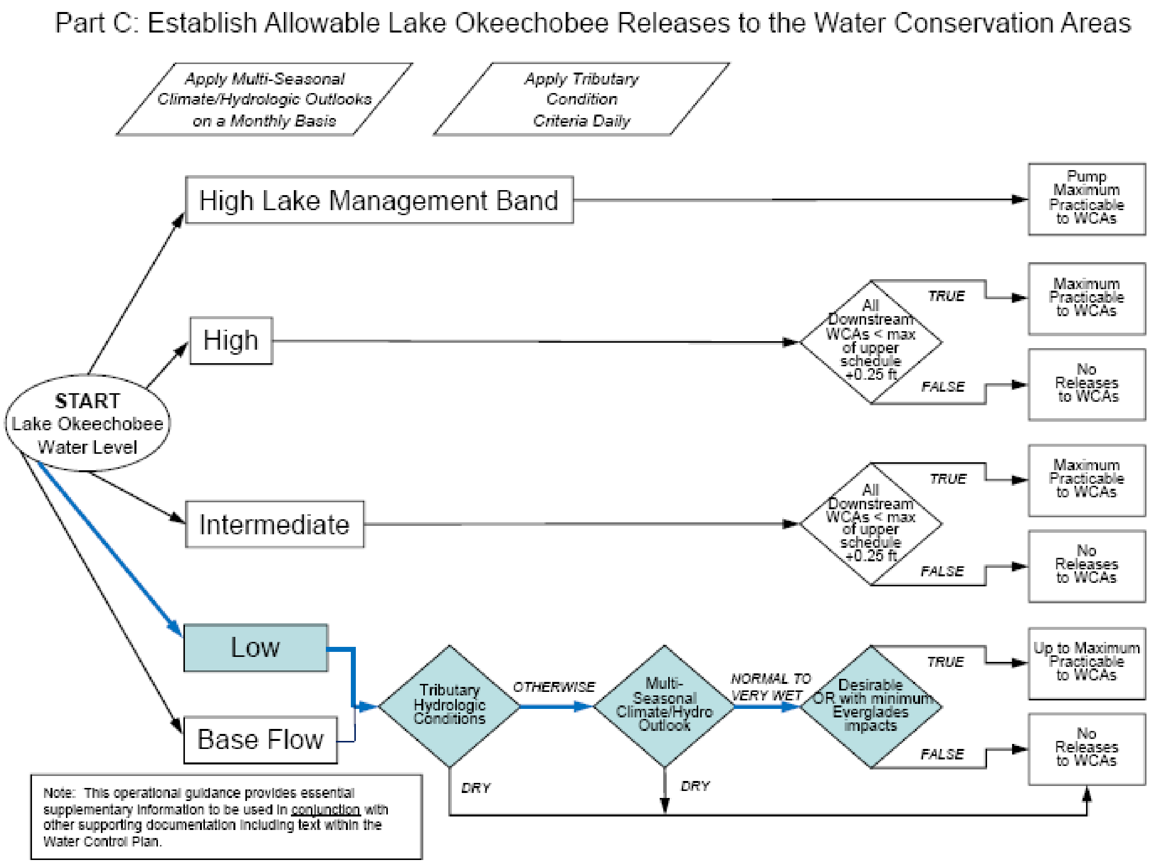


Figure 2-24. Decision tree for Lake Okeechobee water releases to the Water Conservation Areas (USACE, 2008).

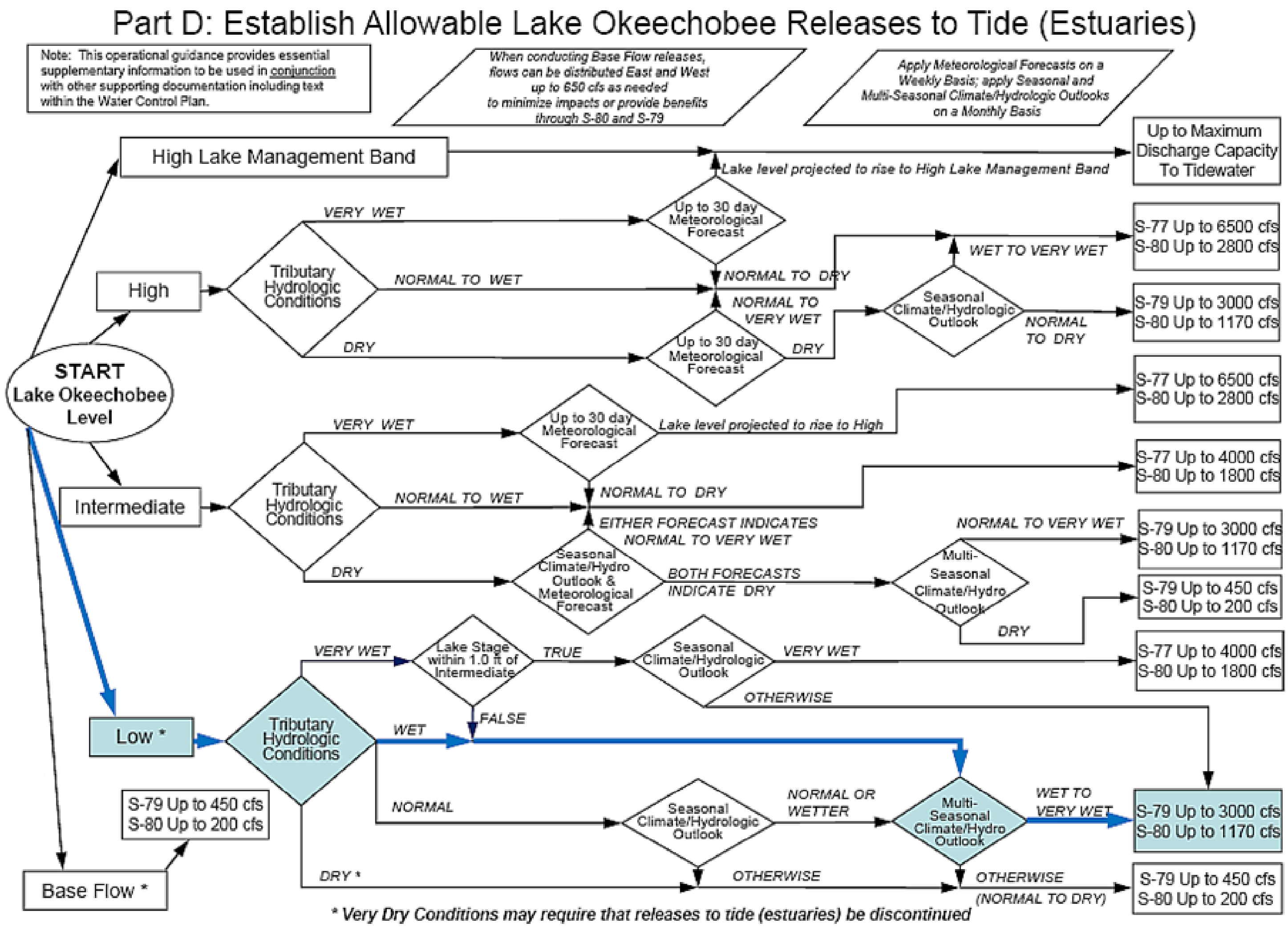


Figure 2-25. Decision tree for Lake Okeechobee water releases to the estuaries (USACE, 2008).

Upper East Coast and the St. Lucie Canal and Estuary

Inflows to the St. Lucie Canal are received from Lake Okeechobee by operation of S-308C, a gated spillway, the Port Mayaca lock (S-308B), and runoff from the basin. Three levels of 10-day pulse releases are typically made to the St. Lucie Canal to emulate natural rain storm events within the basin.

The optimum water control elevations for the St. Lucie Canal vary between 14.0 and 14.5 ft NGVD. The outflow from the St. Lucie Canal is discharged into the estuary via the S-80 structure. The pulse releases are measured at S-80 (**Figure 2-24**). Since salinity is an important measure of estuary viability, freshwater flow at S-80 is an important 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 North Fork of the St. Lucie River 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. WY2010 was a wet year, due to a wetter than normal dry season, flows through C-24 and C-25 canals were far higher than historical average (**Table 2-16**). WY2010 monthly flows for S-48, S-49, S-50, and S-80 are shown in Appendix 2-5, Table 4, of this volume. Monthly historical average, WY2009, and WY2010 flows are shown in Appendix 2-6, Figures 5–8, of this volume. WY2010 major flows and historical statistics are presented in **Table 2-16**.

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 (**Figure 2-6**). Structure S-77 operations use regulation procedures described in USACE (2008). USACE authorized environmental water supply releases (pulse releases) from the lake to the Caloosahatchee Estuary from April 28 through May 8, 2009. Five base flow releases were made from the S-79 structure, at the Caloosahatchee Estuary. They started and ended on: July 23–26, 2009; November 25–30, 2009; January 12–21, 2010; January 27–February 7, 2010; and February 13–27, 2010. Three pulse releases were made to the Caloosahatchee Estuary at S-79 and to the St. Lucie Estuary at S-80. These pulse releases began and ended on: July 27–August 3, 2009, March 2–15, 2010, and March 27–May 3, 2010. Pulse releases are measured at S-79 (**Figure 2-24**). WY2010 discharge from Lake Okeechobee through S-77 was 199,279 ac-ft (34 percent of average). WY2010 major flows and historical statistics are presented in **Table 2-16**.

Downstream of S-77 is S-78, 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 NGVD. 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 the USACE. The operations of S-79 include the runoff from west Caloosahatchee and tidal Caloosahatchee watersheds. The optimum water control elevations near S-79 range between 2.8 and 3.2 ft NGVD. Because salinity is an important measure of estuary viability, freshwater flow at S-79 is an important feature of water management activities. The WY2010 discharge through S-79 to the coast, 1,087,299 ac-ft, was 89 percent of the historical average (1972–2009) and close to WY2009 discharge. WY2010 monthly flows for S-77 and S-79 are shown in Appendix 2-5, Table 5, of this volume. Monthly historical average, WY2009, and WY2010 outflows at S-79 are shown in Appendix 2-6, Figure 9, of this volume.

Everglades Agricultural Area

There are four major canals that pass through the EAA: Hillsboro Canal, North New River Canal, West Palm Beach Canal, and Miami Canal. Flows from Lake Okeechobee and runoff from the EAA are discharged to the Stormwater Treatment Areas (STAs) via these four canals to relieve flooding from the local drainage area. 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 that does not exceed 12.0 ft NGVD for Lake Okeechobee operation. The optimum water control elevations for S-351 and S-354 range between 11.5 and 12.0 ft NGVD. During WY2010, elevations ranged from 8.71 to 12.03 ft NGVD. The outflows from the four canals to the STAs are discharged through pump structures S-5A, S-319, S-6, G-370, and G-372. 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. For WY2010, a total of 2,756 ac-ft of water was delivered by the temporary pumps during a critical water shortage period in May 2009. 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.

Everglades Protection Area

During WY2010, the SFWMD did not request any temporary deviation to regulation schedules from the USACE for Water Conservation Areas 1, 2A, and 3A in the 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 the 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. Water Conservation Area 1 (WCA-1) covers approximately 141,440 acres with a daily average water level of 15.63 ft NGVD (1960–2010). WCA-1 is regulated mainly by outflow structures S-10A, S-10C, S-10D, and S-10E; the regulation schedule for WCA-1 is provided by the USACE (1996). 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., 2007). The seasonal range allows runoff storage during the wet season and water supply during the dry season.

The main inflows into WCA-1 are from Stormwater Treatment Area 1 West (STA-1W) through the G-251 and G-310 pump stations and from Stormwater Treatment Area 1 East (STA-1E) via pump station S-362. There are three diversion structures which can flow in both directions (G-300, G-301, and G-338). The S-10 structures outflow into WCA-2A. The two diversion structures (G-300 and G-301) are also used to discharge water from WCA-1 to the north (the STA-1 inflow basin). Water can also be discharged through S-39 to the east into the Hillsboro Canal. The G-94A, B, and C structures are used to make water supply releases to the east urban area. Four stage gauges (1-8C, 1-7, 1-8T, and 1-9) are used for stage monitoring. Daily water levels were compiled from the four stage gauges based on their regulation schedule uses. Site 1-8C was used from January 1 through June 30, 2010, 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 2-22**, panel c, depicts the WY2010 daily average water level, daily rainfall, and regulation schedule level for WCA-1. Daily average historical water levels are shown in Appendix 2-3, Figure 10, of this volume for the POR 1960–2010. Monthly historical average, WY2009, and WY2010 water levels are shown in Appendix 2-4, Figure 10, of this volume. Water levels in WCA-1 started from a little above minimum regulation schedule at 14.41 ft NGVD on May 1, 2009, and fell until mid-month. The water level rise and stayed above maximum regulation schedule in June and July 2009. Then, the levels fell and remained below the maximum regulation schedule until February 2010. After February, water levels stayed above maximum regulation schedule for the remaining part of WY2010, with a final level of 16. 35 ft NGVD on April 30, 2010.

Inflow and outflow structures throughout the WCAs are operated based on regulation schedules. Historical flows through each structure have varying lengths of POR because new structures come online, or because existing structures may no longer contribute to the inflow and outflow of a system. The structures related to the STAs are relatively recent additions. WCA-1 is regulated between 14 and 17.50 ft NGVD. WY2010 inflows into WCA-1 (310,183 ac-ft) were 65 percent of the historical average. Seventy-one percent of the inflow in WY2010 was from STA-1W through pump stations G-310 and G-251; and 29 percent of the inflow was from STA-1E through pump station S-362. There was no inflow through structures G-301 and G-300.

WY2009 outflows from WCA-1 (521,037 ac-ft) were 114 percent of the historical average. Outflows from WCA-1 were mainly into Water Conservation Area 2 (WCA-2) to the south through the S-10 structures (94 percent) and very little to the north through structures G-300 and G-301 (1,814 ac-ft). Releases through the Hillsboro Canal through the S-39 structure (3 percent) and discharges to the Lake Worth Drainage District through structures G-94A and B were 3 percent. WY2010 monthly inflows and outflows are shown in Appendix 2-5, Tables 6 and 7, of this volume. Monthly historical average, WY2009, and WY2010 inflows and outflows are shown in Appendix 2-6, Figures 10 and 11, of this volume. WY2010 major flows and historical statistics are presented in **Table 2-16**.

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. The regulation schedule for WCA-2A is provided in 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 NGVD. Discharges from WCA-2B are made from spillway structure S-141 to North New River Canal when the pool elevation in WCA-2B exceeds 11.0 ft NGVD.

WCA-2A and WCA-2B combined have a total area of 133,400 acres, with 80 percent of the area in WCA-2A. Appendix 2-3, Figure 11, of this volume shows the daily water level for the period from 1961 through 2010. **Figure 2-26**, panel a, depicts WY2010 daily average water level, daily rainfall, and regulation schedule for WCA-2A. Water levels in WCA-2 began in May 2009 quarter foot below the minimum regulation schedule. The water levels rose from May 19, 2009 and remained above the maximum regulation schedules for entire WY2010. The water level was at 12.04 ft NGVD on April 30, 2010. Monthly historical average, WY2009, and WY2010 water levels are shown in Appendix 2-4, Figure 11, of this volume.

WY2010 inflows into WCA-2 (1,299,071 ac-ft) were 202 percent of the historical average. The major inflows to WCA-2A were through the S-10 structures, outflow from WCA-1 (38 percent); STA-3/4 discharges through the S-7 pump station (34 percent) and STA-2 discharges through pump station G-335 (28 percent). Inflows through structure G-339, a bypass structure at

STA-2, were insignificant. There was no flow from Water Conservation Area 3A (WCA-3A) to WCA-2 through structure S-142.

WY2010 outflows from WCA-2 (884,433 ac-ft) were 141 percent of the historical average. Outflows from WCA-2 were primarily into WCA-3A through structures S-11A, B, and C (82 percent) and discharge to canals 13 and 14 through structure S-38 (14 percent). Discharge through the North New River Canal through structure S-34 was 3 percent and backflow through the S-7 structure into the EAA was 1 percent. There was some discharge (5,623 ac-ft) to WCA-3A through the S-142 structure in March and April 2010. WY2010 monthly inflows and outflows are shown in Appendix 2-5, Tables 8 and 9, of this volume. Monthly historical average, WY2009, and WY2010 inflows and outflows are shown in Appendix 2-6, Figures 12 and 13, respectively. WY2010 major flows and historical statistics are presented in **Table 2-16**.

Water Conservation Area 3

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. The regulation schedule for WCA-3A is provided in 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 structure, while releases from WCA-3B are through S-31 or S-337. Discharges from WCA-3B are rarely made from culvert L-29-1 for water supply purposes.

WCA-3A and WCA-3B combined have a total area of 585,560 acres, with 83 percent of the area in WCA-3A. **Figure 2-26**, panel b, depicts WY2010 daily average water level, daily rainfall, and regulation schedule for WCA-3A. Water levels in WCA-3 were below the maximum regulation schedules in May and mid-June 2009. From mid-June through September 2009, water levels were higher than the maximum regulation schedules. Then, water levels were slightly lower than the maximum regulation schedule until March 2010. In April 2010, water levels were at the maximum regulation schedule. Appendix 2-3, Figure 12, shows the daily water level for the period from 1961 through 2010. Monthly historical average, WY2009, and WY2010 water levels are shown in Appendix 2-4, Figure 12, of this volume.

WY2010 inflows into WCA-3A (1,470,963 ac-ft) were 122 percent of average. The major inflows to WCA-3A in WY2010 were through S-11A, B, and C (49 percent) from WCA-2, and from Stormwater Treatment Area 3/4 through structures S-8 and S-150 (23 percent). Inflows from the east through structures S-9 and S-9A accounted for 12 percent of the total inflow. The S-140 and S-190 structures to the northwest contributed 9 percent and 6 percent of the inflow to WCA-3A, respectively. There are possible inflows to WCA-3A through the L-4 borrow canal breach into the L-3 extension canal that is currently not gauged. The breach has a bottom width of 150 ft, at an elevation of 3 ft NGVD (SFWMD, 2002).

WY2010 outflows from WCA-3A (1,137,001 ac-ft) were 94 percent of the historical average. Outflows from WCA-3A into the ENP were through structures S-12A, B, C, D, and E (39 percent) this water year. S-333 discharged 30 percent, with potential directions of flow to ENP to the south and east, Shark River Slough, and Taylor Creek. Outflow from WCA-3A through S-151 was 18 percent. Outflow through structure S-343 was 5 percent. Discharge through S-344 and S-31 were 3 percent each. S-337 and S-150 had minor outflows. There was no discharge into the North New River Canal through structure S-142. WY2010 monthly inflows and outflows are shown in Appendix 2-5, Tables 10 and 11, respectively. Monthly historical average, WY2009, and WY2010 inflows and outflows are shown in Appendix 2-6, Figures 14 and 15, of this volume. WY2010 major flows and historical statistics are presented in **Table 2-16**.

Everglades National Park

Everglades National Park is located south of WCA-3A and 3B (**Figure 2-1**). The land is a federal property operated and maintained as the Everglades National Park, a federal entity within the jurisdiction of the U.S. Department of the Interior, National Park Service. The original operational criteria are presented in (USACE, 1996). The criteria were subsequently modified and presented in the Interim Operation Plan for Protection of the Cape Sable Seaside Sparrow C-111 Emergency Final Order (C-111 EO #9) (USACE, 2002). The plan will be superseded when all the elements of the Modified Water Deliveries Project are built and capable of operating, and when the Record of Decision for the Combined Structural Operational Plan is approved (USACE, 2002).

The 1972 federal requirement for minimum monthly water deliveries to Shark River Slough was superseded in 1985 by an operational plan referred to as the Rain-Driven Plan. This plan addresses the overall objectives of providing water deliveries that vary in response to hydrometeorological conditions in the basin (USACE, 1996). The operation plans for S-333 and S-12A, B, C, and D are presented in USACE (2002).

The Park's water delivery goals are connected to water levels upstream and downstream, and rainfall amounts in WCA-3A. Flows to the ENP are made via structures S-333 and S-12A, B, C, and D. The operation plan for these structures is the Rain-Driven Plan that integrates the target flows required to be released from these structures. Because of complexities involved with the C-111 EO #9, a regulation schedule is not used for the ENP.

The Rain-Driven Plan is used to operate water control structures that discharge from WCA-3A to the ENP. The objective of the plan is to restore a more natural hydroperiod and hydropattern in northeast Shark River Slough and the Park. A mathematical model is being used to define flow targets for the operation of five water control structures (S-333 and S-12A, B, C, and D) along the southern boundary of WCA-3A, subject to upstream hydrologic conditions and downstream hydrologic and ecologic constraints. Pathak and Palermo (2006) detail the mathematical model used to compute target weekly flow volumes to be released from WCA-3A. The model uses weekly rainfall data from 10 rain gauges, weekly evaporation data from three pan evaporation gauges, and weekly average stage data from three water level gauges.

Water deliveries to Taylor Slough are made via several seepage reservoirs and structures including the S-332B, C, and D pump stations. These pump stations are components of the C-111 EO #9. Their operation plans are presented in USACE (2002). Water deliveries to the eastern panhandle are made via the C-111 canal. The S-18C structure maintains a desirable freshwater head against saltwater intrusion through the C-111 canal to act as a control point to the eastern panhandle of the ENP. The optimum water stages range between 2.0 and 2.6 ft NGVD upstream of S-18C while making minimum water discharges. Additionally, S-197 maintains optimum water control stages in C-111 canal and prevents saltwater intrusion during high tides. S-197 is closed most of the time and diverts water from S-18C via overland flow to the panhandle. S-197 releases flows during major flood events according to established guidelines in the C-111 EO #9.

The ENP is approximately 1,376,000 acres in size. 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 NGVD (Sklar et al., 2000). Historical water level data for sites P-33 (1952–2010) and P-34 (1953–2010) was obtained from the District's hydrometeorologic database, DBHYDRO, and from the ENP's database. **Figure 2-26**, panel c, depicts daily average water level and rainfall at P-33 for WY2010. Daily average historical water levels for P-33 and P-34 are shown in Appendix 2-3, Figures 13 and 14, respectively. **Figure 2-26**, panel d, depicts daily average water level and rainfall at P-34 for

WY2010. Monthly historical average, WY2009, and WY2010 water levels for P-33 and P-34 are shown in Appendix 2-4, Figures 13 and 14, of this volume.

WY2010 inflow into the ENP (1,355,548 ac-ft) was 138 percent of the historical average. Inflow into the ENP is mainly through structures S-12A, B, C, D, and E, S-18C, S-332B, S-332C, S-332D, S-174, S-175, and S-333. The major inflow (33 percent) was through the S-12 structures. Structure S-18C discharge into the ENP was 18 percent. The S-333 structure contributed 16 percent, S-332D contributed 13 percent, S-332B contributed 12 percent, and the S-332C contributed 7 percent of the inflows. These structures are operated by the District for the USACE, in accordance with the Rain-Driven Plan and the regulation schedule of WCA-3A. This plan determines discharges through the S-333 and S-12 structures a week in advance using a computer program. Structural and operational modifications were also incorporated into the delivery plan based on the C-111 EO #9. There was no inflow through S-175. WY2010 monthly inflows are shown in Appendix 2-5, Table 12, of this volume. Monthly historical average, WY2009, and WY2010 inflows are shown in Appendix 2-6, Figure 16, of this volume. WY2010 major flows and historical statistics are presented in **Table 2-16**.

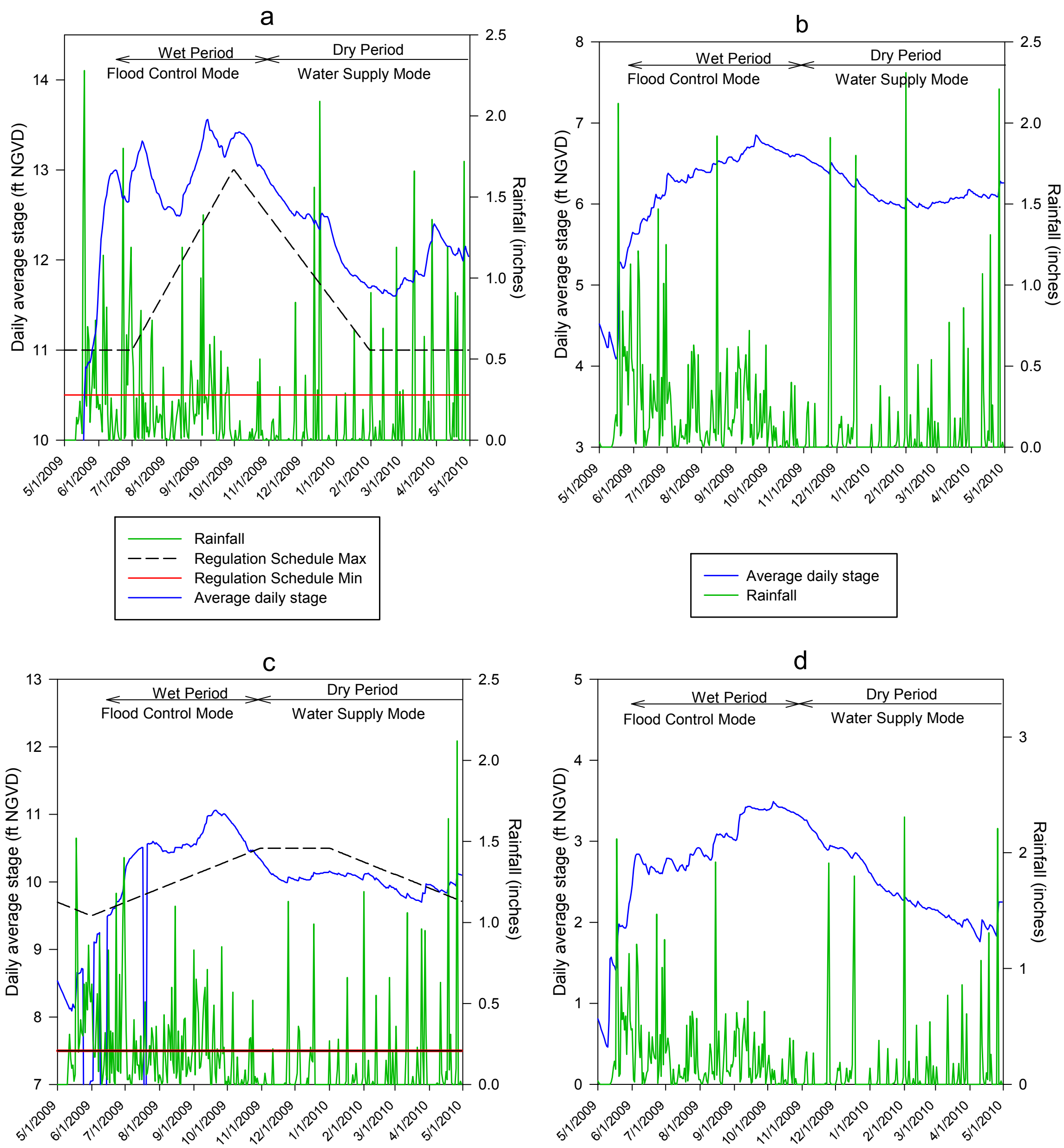


Figure 2-26. Average daily water levels (stage), regulation schedule, and rainfall for (a) WCA-2, (b) gauge P-33, (c) WCA-3, and (d) gauge P-34.

CONCLUSIONS

The hydrology of South Florida for WY2010 can be summarized as an El Niño year where dry season hydrology was wet. Meteorologically, the water year's rainfall was above average in all of the SFWMD's rainfall areas in contrast to WY2007 (-12 inches), WY2008 (-3.8 inches) and WY2009 (-12 inches), which were drought years with far below-average rainfall. Generally, the dry season of WY2010 was wetter than normal in all rainfall areas. WY2010 rainfall over the entire District area was 61.43 inches, which is 116 percent of historical average. There was a distinct dry season (November–May) rainfall positive anomaly due to El Niño. Generally, the dry season was wetter than normal. May and December 2009, and February and March of 2010 were wet. May had two times the average rainfall. The summer had average rainfall. October and November 2009 were drier than normal. The Upper Kissimmee rainfall area was the wettest with 19.93 inches above the average rainfall amount, followed by Broward (+16.57 inches), West EAA (+15.39 inches), WCAs1 and 2 (13.67 inches), East Caloosahatchee (+10.93 inches), Southwest Coast (+9.57 inches), WCA-3 (+9.23 inches), Lower Kissimmee (+8.51 inches), Miami-Dade (+7.98 inches), Big Cypress Basin (+7.93 inches), East EAA (+7.78 inches), Everglades National Park (+5.23 inches), Palm Beach (+4.85 inches), Lake Okeechobee (+4.3 inches), and Martin/St. Lucie (+2.04 inches). The spatial average District WY2010 rainfall positive anomaly of 8.68 inches compares to the WY2009 deficit of 7.51 inches, WY2008 rainfall deficit of 3.8 inches, and WY2007 deficit of 12 inches.

At the beginning of WY2010, the main storage of the system, Lake Okeechobee, continued to show record low water and storage levels from the three-year drought. Gravity discharge from the lake was restricted for a while in May 2009 due to low water levels (stage) and forward pumping was used briefly. The water year started with Lake Okeechobee's stage at 11.09 ft NGVD and receded to the water year low level of 10.55 ft NGVD on May 18, 2009. Wet conditions in the second-half of May 2009 and the following wet season reversed the decline in stage, with a maximum of 14.56 ft NGVD level reached on September 25, 2009. A decline in stage occurred in October and November 2009 due to dry conditions. Mainly, El Niño-related rainfall from December 2009 through April 2010 maintained higher lake stages than normal for the dry months. Rainfall from El Niño-related fronts was as high as 14.25 inches in one day at the S-29 station in North Miami. Runoff from El Niño-related fronts and other rains in the summer raised Lake Okeechobee's water level and replenished surface and subsurface storage, ending drought conditions that persisted from 2006–2009.

In summary, WY2010's hydrology was wetter than usual. Rainfall for most months of the dry season and the water year as a whole was above average throughout the District. Rainfall and runoff from the wet months' rains replenished subsurface storage, Lake Okeechobee, and the Water Conservation Areas' storage and kept water demand low.

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