Chapter 2: Hydrology of the South Florida Environment

Wossenu Abtew, Chandra Pathak, R. Scott Huebner and
Violeta Ciuca

SUMMARY

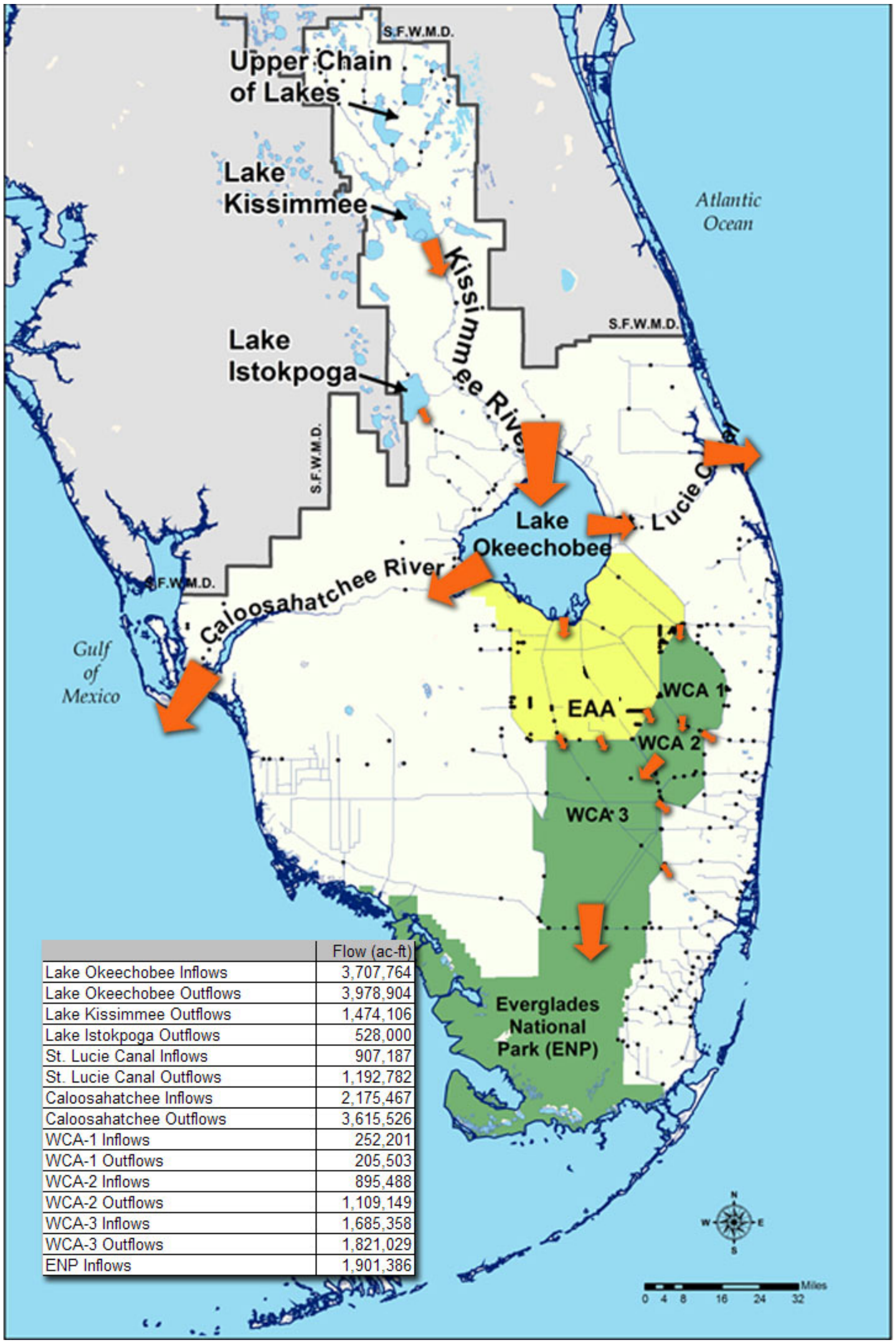
Given hydrology's significance to the entire South Florida ecosystem, this chapter updates hydrologic data and analysis for Water Year 2006 (WY2006) (May 1, 2005—April 30, 2006). WY2005 hydrology is available in the *2006 South Florida Environmental Report – Volume I* (Abtew et al., 2006). This report includes a section on the active 2005 hurricane season (part of WY2006) followed by the hydrology of WY2006. Based on reviewers' suggestions and other hydrologic information needs, additional sections have been added. For instance, a section on stage-storage and stage-area relationships of major lakes and impoundments has been integrated. This section provides information on storage volume that can also be used to compute water residence time in storage. In this chapter, water management decisions and meeting water management goals for the South Florida region is discussed. A summary on the South Florida Hydrologic Monitoring Network is included with a draft document regarding the monitoring network (Appendix 2-4). Also summarized is a draft document on Consideration of Long-Term Climatic Variation in SFWMD Planning and Operations (Appendix 2-3).

Challenges in multi-objective water management are created by hydrologic variation. Too much or too little water creates flooding, water shortage, or ecological impacts. Although South Florida is a wet region, serious droughts have occurred, and there is potential for periodic water shortages. Impacts from hydrologic variation can be mitigated with storage capacity and conveyance capacity increases.

The hydrology of South Florida for WY2006 can be summarized as a wetter than average year with two peaks in rainfall and surface water flows in many areas in June and October 2005. Even though water year rainfall amounts were higher than average, there were significantly dry months, particularly January and March 2006 in most areas, and December 2005 and April 2006 in some areas. Drier winter and spring months dampened out the hydrologic impact of the high summer and fall rainfall. The combined impact of the 2004 and 2005 hurricane season on Lake Okeechobee was significant, with an annual inflow of 3,707,764 acre-feet (ac-ft) and outflow of 3,978,904 ac-ft both being the maximum on record since 1972. The high stage and volume of Lake Okeechobee resulted in high discharge through the St. Lucie Canal (907,187 ac-ft) and the Caloosahatchee River (2,175,467 ac-ft). The inflows and outflows of Water Conservation Area 3 were higher than average. Inflows to the Everglades National Park were more than twice those that were reported for WY2005.

The 2004 and 2005 hurricane seasons were very active for South Florida with major impacts. Based on a historical record of tropical systems, the combined impact of the 2004 and 2005 hurricane seasons on the South Florida Water Management District area was a series of rare events (Abtew and Huebner, 2006; Abtew et al., 2006; Appendix 2-1). Similar to WY2005, South Florida received rainfall from four hurricanes in WY2006: Hurricane Dennis in July, Hurricane Katrina in August, Hurricane Rita in September, and Hurricane Wilma in October. The

hydrologic impact of these hurricanes on the South Florida Water Management District during the 2005 hurricane season is presented in Appendix 2-1. **Figure 2-1** presents surface water flows for the entire system for major hydrologic components.



	Flow (ac-ft)
Lake Okeechobee Inflows	3,707,764
Lake Okeechobee Outflows	3,978,904
Lake Kissimmee Outflows	1,474,106
Lake Istokpoga Outflows	528,000
St. Lucie Canal Inflows	907,187
St. Lucie Canal Outflows	1,192,782
Caloosahatchee Inflows	2,175,467
Caloosahatchee Outflows	3,615,526
WCA-1 Inflows	252,201
WCA-1 Outflows	205,503
WCA-2 Inflows	895,488
WCA-2 Outflows	1,109,149
WCA-3 Inflows	1,685,358
WCA-3 Outflows	1,821,029
ENP Inflows	1,901,386

Figure 2-1. WY2006 inflow and outflow into major hydrologic components.

INTRODUCTION

THE SOUTH FLORIDA REGIONAL WATER MANAGEMENT SYSTEM: A REGIONAL OVERVIEW

The South Florida Water Management District (SFWMD or District) area extends from Orlando in the north to the Florida Keys in the south (**Figure 2-2**). The District's water management system consists of lakes, impoundments, wetlands, and canals that are managed under a water management schedule based on flood control, water supply, and environmental restoration. The general surface water direction is from the north to the south, but there are also water supply and coastal discharges to the east and the west. The major hydrologic components comprise of the Upper Kissimmee Chain of Lakes, Lake Okeechobee, Lake Istokpoga, the Everglades Agricultural Area (EAA), the Caloosahatchee Basin, St. Lucie Basin, the Lower East Coast, and the Everglades Protection Area (EPA).

The Upper Kissimmee Chain of Lakes (Lake Myrtle, Lake Alligator, Lake Mary Jane, Lake Gentry, East Lake Tohopekaliga, Lake Tohopekaliga, and Lake Kissimmee) are a principal source of inflow to Lake Okeechobee. On average, 48 percent of inflow into Lake Okeechobee is through the Kissimmee River (C-38 Canal) (Abtew et al., 2002). The Upper Kissimmee watershed has an area of approximately 1,620 square miles (sq mi). The Lower Kissimmee River basin (727 sq mi) also contributes inflows to Lake Okeechobee. Additional inflows to Lake Okeechobee are from the Lake Istokpoga Surface Water Management Basin (418 sq mi), Fisheating Creek, the Taylor Creek-Nubbin Slough Basin, reverse flows from the Caloosahatchee River, the St. Lucie Canal, and the EAA (Abtew et al., 2002). Lake Istokpoga is a 43-sq-mi shallow lake with outflow through structure S-68 into the Surface Water Management Basin.

Lake Okeechobee is in the center of the South Florida hydrologic system with an area of 730 sq mi and a mean depth of 8.86 feet (ft). Since 1931, the average water level elevation has been 14.44 feet National Geodetic Vertical Datum (ft NGVD) with a maximum 18.77 ft NGVD set on November 2, 1947. The lowest water level on record for the lake was 8.97 ft NGVD set on May 24, 2001, during the 2000–2001 drought. The annual average inflow to Lake Okeechobee (based on data from 1972 through 2006) is about 2.1 million acre-feet (ac-ft), while the average outflow is about 1.5 million ac-ft. Outflows are mainly through the south, southeast, and southwest structures. The EAA is the main source of surface water inflow into the EPA. An average of 900,000 ac-ft of water is discharged from the EAA to the south and southeast, mostly discharging into the EPA (Abtew and Khanal, 1994; Abtew and Obeysekera, 1996). About 10 percent of the outflow is lake water flow through the EAA, with most of it reaching the EPA (Abtew and Khanal, 1994; Abtew et al., 2002).

The EPA begins at the southern and eastern edges of the EAA and extends south to the Florida Bay. The EPA consists of several defined regions: Water Conservation Area 1 (WCA-1) (221 sq mi), which contains the Arthur R. Marshall Loxahatchee National Wildlife Refuge (Refuge); WCA-2A and WCA-2B (210 sq mi); WCA-3A and WCA-3B (915 sq mi); Everglades National Park (ENP) (2,150 sq mi); and Florida Bay, as shown in Redfield et al. (2003). The EPA receives additional surface water inflows from the urban areas in the east and the southeast and northwest sources currently identified as non-Everglades Construction Project (non-ECP) stormwater flows. Surface water flow in and out of the EPA is determined by weather-related factors and multi-objective water management decisions that include fixed regulation schedules, deviations, commitments, and emergency management. Emergency management includes flood control during high rainfall events, water supply during drought periods, saltwater intrusion, and environmental issues. From north to south, flood control and water supply are managed through a system of canals, stormwater detention ponds, lakes, impoundments, and water control structures. The extent of the EPA and major hydrologic components are shown in **Figure 2-2**.

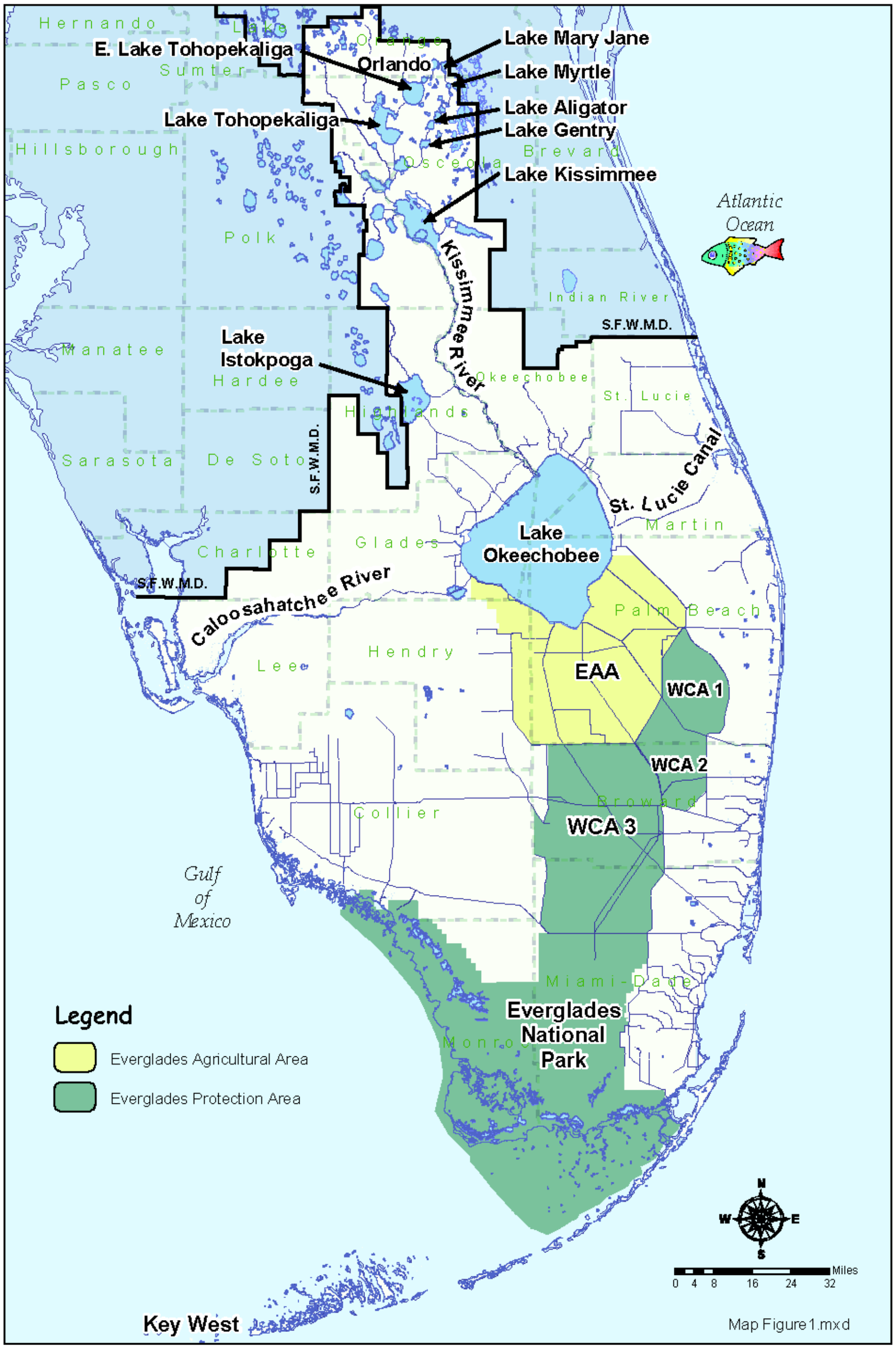


Figure 2-2. The Everglades Protection Area (EPA) and major hydrologic components of the South Florida water management system.

The hydraulic components of the water management system are composed of storage and conveyance systems. The major storage components are lakes, impoundments, ponds and wetlands. The conveyance system is composed of canal networks and water control structures. Water is moved throughout the water management system by gravity and pumps. **Table 2-1** shows the volumes of water pumped by the District for Fiscal Years 1996–2005 (FY1996–FY2005); the District's fiscal year is from October 1 to September 30. The general hydraulic gradient as represented by average water levels is from north to south, from Lake Tohopekaliga to the Florida Bay with a drop of 54 ft in elevation for a distance of about 250 miles. On average, the water level drop from Lake Okeechobee to the Caloosahatchee Estuary, 70 miles to the west, is 14.44 ft. From Lake Okeechobee to the St. Lucie Estuary, the average water level drop 35 miles to the east is 14.44 ft.

Table 2-1. District water pumping volumes for Fiscal Years 1996–2005 (FY1996–FY2005).

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

The District has an exhaustive hydrologic monitoring network and database. The District's hydrometeorologic database, DBHYDRO, also stores data from other agencies such as the U.S. Geological Survey (USGS), the U.S. Army Corps of Engineers (USACE), National Oceanographic and Atmospheric Administration (NOAA), ENP, Florida Forestry Service (FFS), Florida Department of Environmental Protection (FDEP), and others. Details of hydrometeorologic monitoring by the District are presented in Appendix 2-4.

HYDROLOGIC VARIATION IN SOUTH FLORIDA

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 coast.

Rainfall in South Florida varies temporally and spatially with a seasonal pattern. South Florida is a high-rainfall region, with frontal, convective, and tropical system-driven rainfall events. The heaviest rains in South Florida are produced by mesoscale convective systems, extratropical in the dry season and tropical in the rainy season (Rosenthal, 1994). The dry season extends from November through May and, on average, 35 percent of District rainfall occurs during this season. The percentage of dry season rainfall varies among rainfall areas, with the highest in Palm Beach (39 percent) and the lowest in the Southwest Coast (29 percent) (Ali and Abtew, 1999a).

In Central and South Florida (excluding the Florida Keys), 57 percent of total summer rainfall falls on undisturbed sea breeze days, 39 percent on disturbed days, and 4 percent on highly disturbed days (Burpee and Lahiff, 1984). Point rainfall measurement at a rain gauge station could fluctuate from 30 inches to 100 inches annually, although areal rainfall fluctuation is relatively smaller. **Table 2-2** shows the temporal variation of historical monthly areal rainfall over the SFWMD area (Ali et al., 2000).

Table 2-2. Temporal variation of historical monthly areal rainfall over the SFWMD area.

	Rainfall Statistics (inches)		
Month	Arithmetic Average	Standard Deviation	Coefficient of Variation
January	2.20	2.05	0.93
February	2.36	1.85	0.78
March	2.94	2.56	0.87
April	2.58	2.32	0.90
May	4.66	3.13	0.67
June	7.85	4.18	0.53
July	6.98	3.19	0.46
August	7.03	3.18	0.45
September	7.23	3.78	0.52
October	4.72	3.82	0.81
November	2.30	2.36	1.03
December	1.90	1.80	0.95

In the District area, June is generally the wettest month and December is the driest. The wet season runs from June through October and accounts for 65 percent of annual rainfall (Abtew et al., 2002). During an El Niño year (which occurs about once every three to four years), high rainfall amounts fall in the dry season, resulting in water level rises and discharge through canals (Huebner, 2000). Extreme hydrometeorological and related events have significant effects on the region. El Niño conditions, hurricanes, and tropical systems are associated with high-rainfall events or seasons, and La Niña conditions and drought events result in dry conditions. Tropical systems are a frequent occurrence.

From 1871 through 1999, the general area of the District has been affected by 42 hurricanes, 32 tropical storms, and nine tropical cyclones (a term used before modern hurricane categories were established) (Abtew and Huebner, 2000). Since 1999, nine hurricanes and the remnants of a tenth have affected the District area (Appendix 2-1). Other conditions, such as local convective systems and regional frontal systems, have also been associated with high rainfall events.

The annual average rainfall on the entire SFWMD region is 52.8 inches (Ali and Abtew, 1999a). For operational purposes, the SFWMD area is divided into 14 rainfall areas and the ENP (**Figure 2-3**). Spatial variation of annual rainfall over the District area is shown in **Figure 2-4** by region (rainfall area). The source of annual rainfall statistics (Ali and Abtew, 1999a) includes all rain areas except the Big Cypress Basin and WCA-3, which are from the meteorological analysis section of the District's Operations Control, Engineering and Vegetation Management Department. The annual basin rainfall for the ENP was estimated from an average annual rainfall isohyetal map for Central and South Florida (MacVicar, 1981) and from basin rainfall statistics (Sculley, 1986). The areal rainfall statistics were developed from varying lengths of record for each rainfall station and from a varying number of rainfall stations. The periods of record were 1900–1995 (Ali and Abtew, 1999a), 1901–1980 (MacVicar, 1981), 1941–1985 (Sculley, 1986), and 1971–2000 (see October 9, 2006, data on the District's web site at www.sfwmd.gov under W*eather & Water Conditions, District Rainfall Data* section). Based on **Figure 2-4**, the Palm Beach rainfall area had the highest rainfall while the Lower Kissimmee and Lake Okeechobee rainfall areas had the lowest. Historically, the Palm Beach County rainfall area has had the highest annual rainfall, followed by Broward and Miami-Dade counties. The District's east coast receives higher rainfall levels than the inland and west coast areas. Even during drought years, there were cases where the coastal rainfall in these areas was close to the average. Because there are no large impoundments in the eastern coastal rainfall areas, runoff is discharged into the Atlantic Ocean.

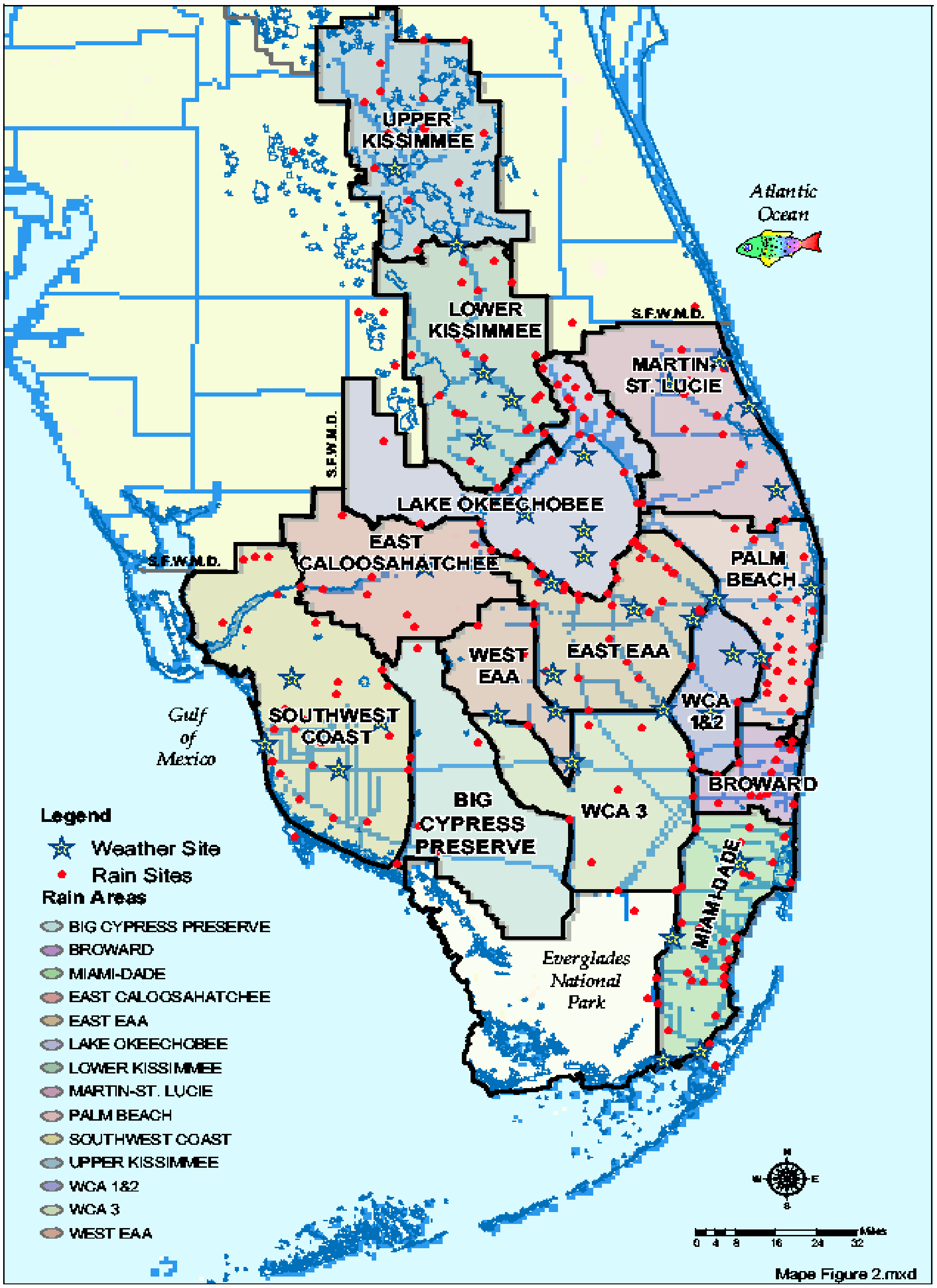


Figure 2-3. Rainfall areas of the SFWMD.

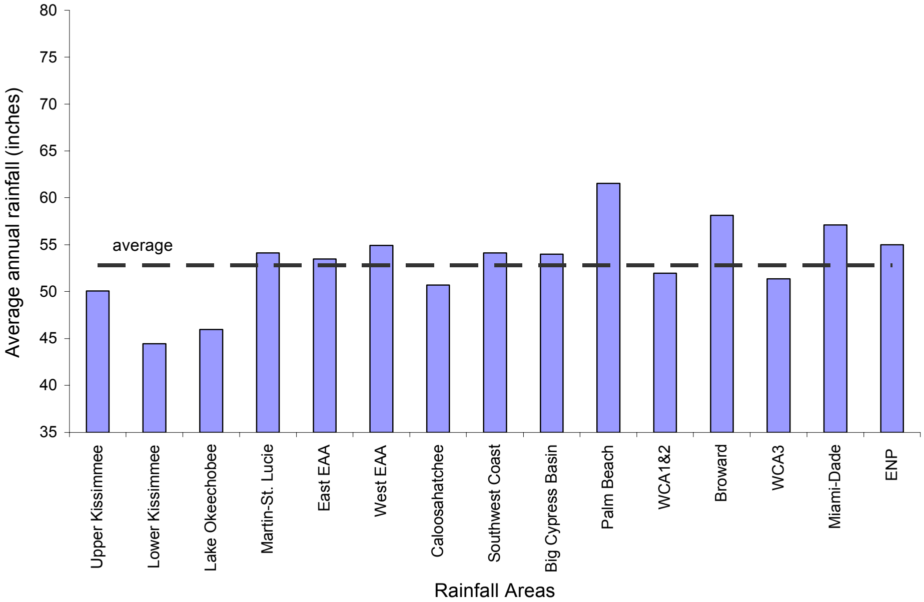


Figure 2-4. Annual rainfall over the SFWMD area by region.

Extreme hydrologic events contribute to variations in the temporal and spatial distribution of the hydrology of South Florida. Droughts are extreme hydrologic events categorized as moderate, severe, or extreme. Generally, droughts are regional or have significant spatial coverage and corresponding impacts. In South Florida, at least one severe drought occurs every 10 years. El Niño weather patterns result in greater than average rainfall in Central and South Florida, while La Niña patterns have the opposite effect. Tropical systems such as tropical depressions, tropical storms, and hurricanes result in high rainfall and contribute to rainfall variation in South Florida. The general area of the SFWMD has experienced tropical systems at a rate of two every three years (Abtew and Huebner, 2000).

Other frontal or convective rainfall systems have resulted in major rainfall events, causing subregional and local flooding. Extremely high local or subregional rainfall events also occur in the dry season. Such events include the January 15–17, 1991, rainfall in Palm Beach County (SFWMD, 1991); the January 2–3, 1999, rainfall on northeast Palm Beach County (Ali and Abtew, 1999b); the March 28–29, 1982, rainfall on the coasts of Palm Beach, Martin, and St. Lucie counties (SFWMD, 1982a); the April 23–26, 1982, rainfall on Palm Beach, Broward, and Miami-Dade counties (SFWMD, 1982b); and the May 22–23 and November 21–26, 1984, rainfall on Palm Beach coast (SFWMD, 1984a and 1984b).

Evapotranspiration varies spatially and temporally over South Florida. A significant area of South Florida is covered by lakes, wetlands, and impoundments. These areas have evapotranspiration losses equal to potential evapotranspiration. Areas with permanent or seasonal limitation to moisture have reduced evapotranspiration. Estimated spatial variation of potential evapotranspiration or evaporation from wetlands and lakes over South Florida is shown in **Figure 2-5** (Abtew et al., 2003). Generally, evapotranspiration increases from north to south. Temporal variation in annual evapotranspiration in South Florida is slight compared to annual variation in rainfall. **Figure 2-6** shows a calendar year seasonal variation of District-wide areal average potential evapotranspiration (Abtew et al., 2003).

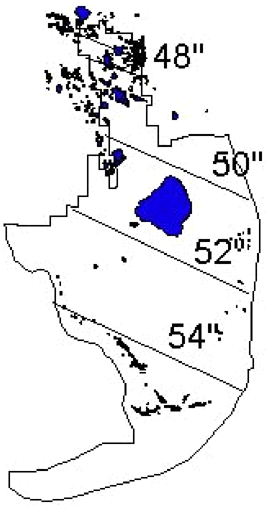


Figure 2-5. Estimated potential evapotranspiration isohyetal lines for the SFWMD.

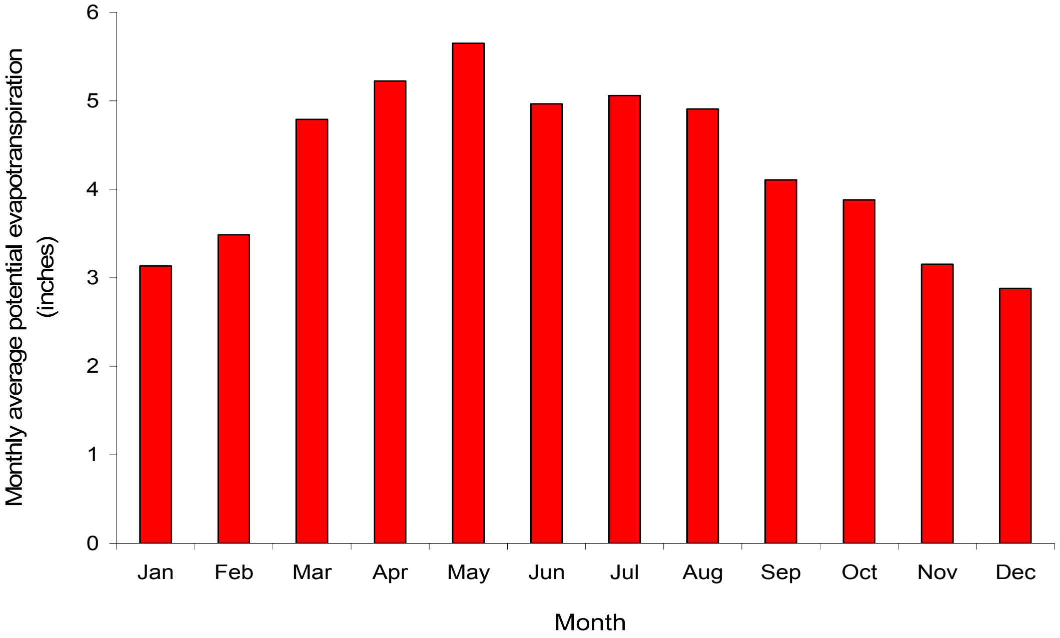


Figure 2-6. District-wide aerial average potential evapotranspiration for 2001.

Hydrologic Variation Indicators

Point and areal temporal variation of rainfall amount is an indicator of hydrologic variation. Lake water levels, groundwater levels, and stream flow rates are directly related to rainfall amount. **Figure 2-7** demonstrates temporal variation of annual rainfall at a sample site, Miami in Miami-Dade County, for the period 1914 to 2005. The annual rainfall in this figure has a maximum of 89.33 inches, a minimum of 33.84 inches, a mean of 58.89 inches, and a standard deviation of 12.4 inches. Characteristic rainfall variation at a site is also illustrated by a rain gauge station in Palm Beach County (S-5A station) with a coefficient of variation in annual, monthly, and daily rainfall of 16 percent, 80 percent, and 296 percent, respectively, for the period of record of 1963 to 2005.

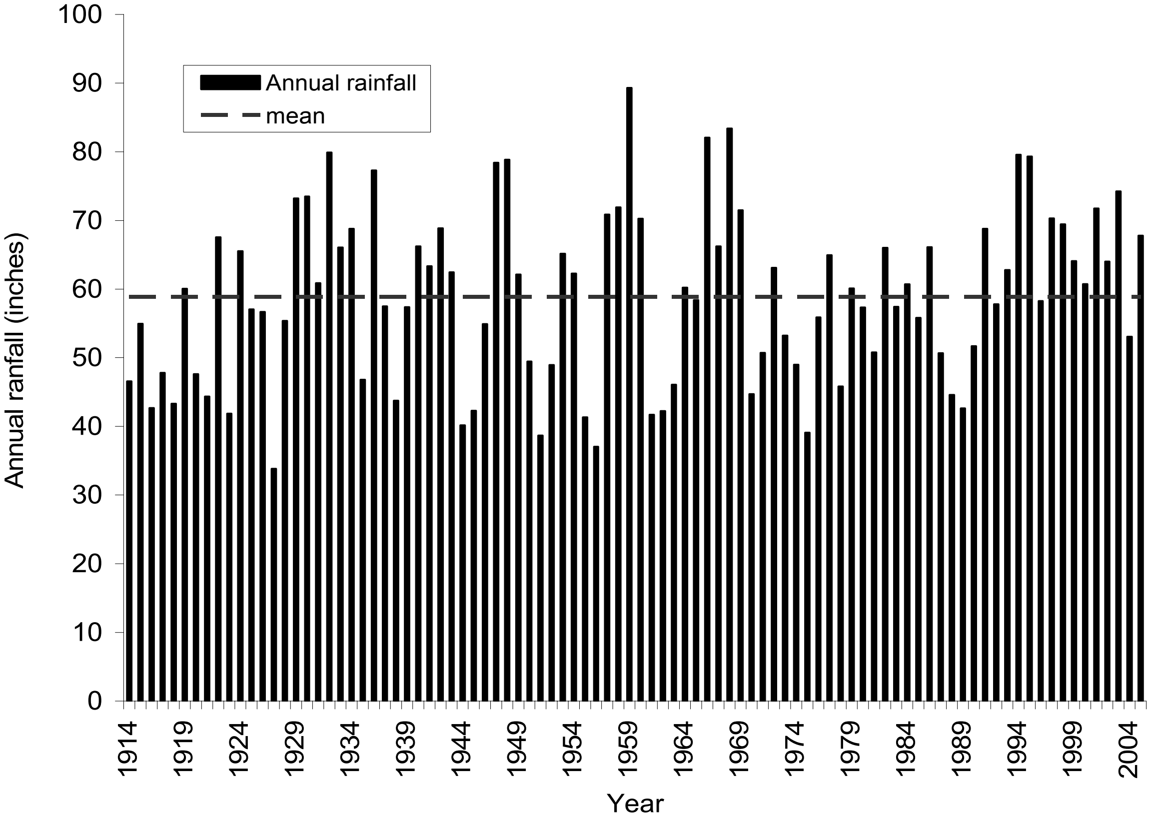


Figure 2-7. Annual rainfall variation at a site in Miami.

The Palmer Drought Severity Index (PDSI) is commonly used to determine the occurrence of drought and its magnitude. The PDSI uses antecedent moisture conditions, precipitation, temperature, field capacity, and weather trends to compute an index value. Near normal conditions are represented by an index value of ±0.49; severe drought has an index value of -3 or less; and extreme drought has a value of -4 or less. The historical PDSI for Florida Climatic Division 5 (Lake Okeechobee, the Lower West Coast, the EAA, the East Coast, and the Everglades) is shown in **Figure 2-8.** A PDSI of greater than zero is considered on the wet side, with a magnitude of wetness indicated by sequentially higher (that is, positive) numbers. Dry periods in Florida result from stable atmospheric conditions that are often associated with high-pressure systems (Winsberg, 1990). These conditions can occur in any season, but are most common in the winter and spring.

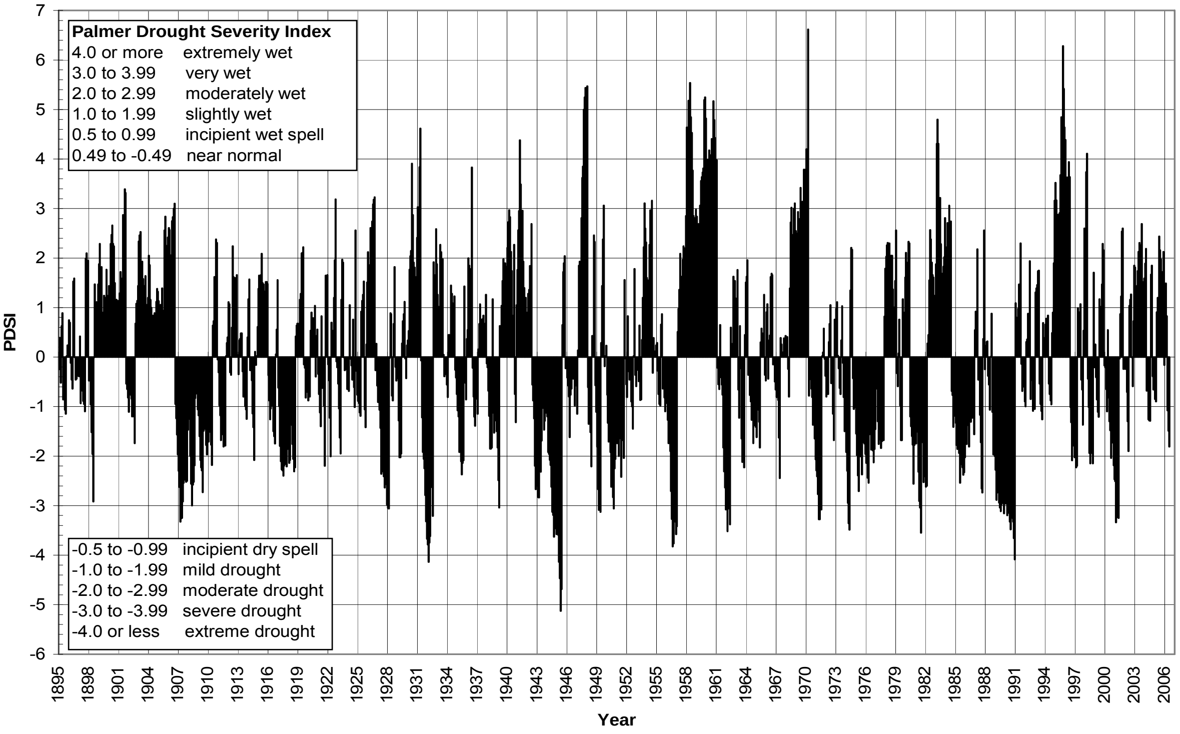


Figure 2-8. The historical Palmer Drought Severity Index for Florida Climatic Division 5 (Lake Okeechobee, the Lower West Coast, the EAA, the East Coast, and the Everglades).

Drought is generally associated with a shortage of water for a given duration of time for a designated activity. They are classified as agricultural, meteorological, hydrological, and water management. In Central and South Florida, severe droughts were reported in 1932, 1955–1957, 1961–1963, 1971–1972, 1973–1974, 1980–1982, 1985, 1988–1989, 1990, and 2000–2001 (Abtew et al., 2002). A minimum of one severe drought can be expected every 10 years. Historic droughts are identified by the historical PDSI, annual rainfall, lake water levels, groundwater levels, stream flow, and wildfire records. Because droughts are characterized by a significant decline in rainfall, they also promote the development and spread of wildfires. However, wildfire is also an important ecological process in the Everglades (Wu et al., 1996).

Variable rainfall amounts result in variations of groundwater level, lake water level, and surface water flow rates. Lake Okeechobee, at the center of the District area, demonstrates surface water fluctuations by the extreme lake inflow rates, even though flows are regulated. Based on flow data from January 1, 1972, through December 31, 2005, annual Lake Okeechobee inflows fluctuated from 680,686 ac-ft in calendar year 2000, a severe drought year, to a maximum annual inflow of 3,976,592 ac-ft in calendar year 2005 (January through December 2005), following two active hurricane seasons.

The Arbuckle Creek is an unregulated inflow to Lake Istokpoga. The creek's annual flow records from 1940 through 2005 depict temporal hydrologic variation in South Florida (**Figure 2-9**). The average annual flow into Lake Istokpoga through the Arbuckle Creek was 225,975 ac-ft with a standard deviation of 127,920 ac-ft. The maximum annual flow of 619,062 ac-ft occurred in 1947 during a two-hurricane year, and the minimum annual flow of 51,224 ac-ft occurred in 2000 during a severe drought year.

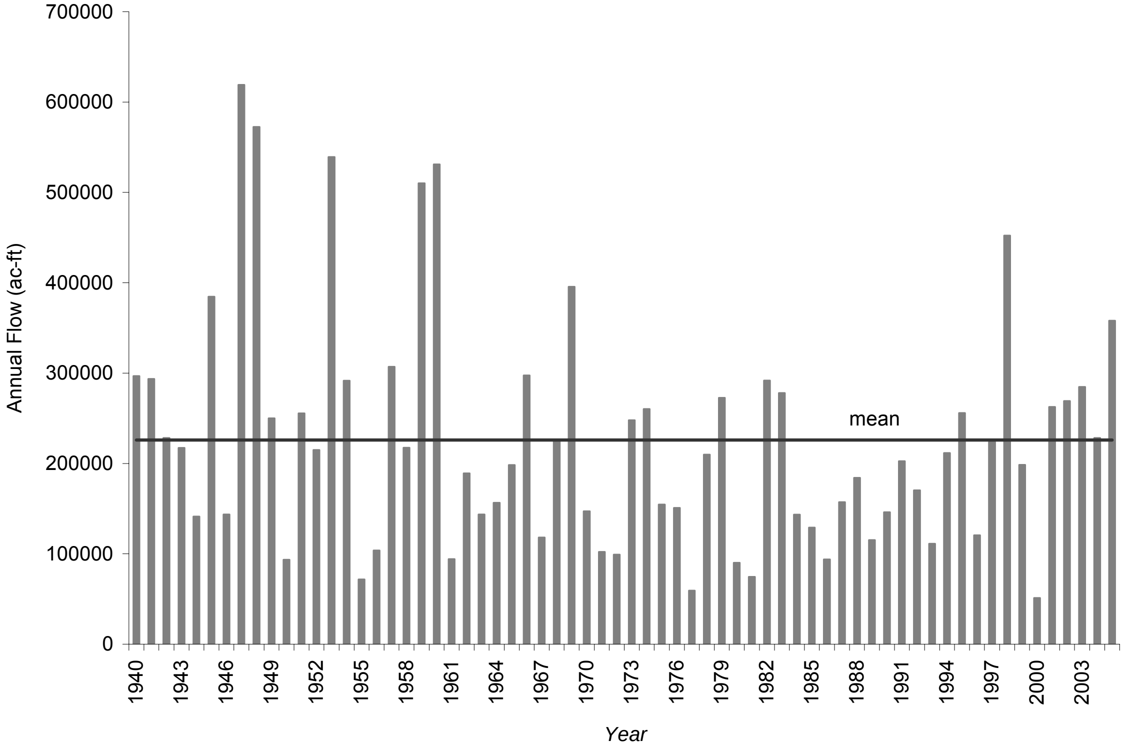


Figure 2-9. Annual variation of flows through Arbuckle Creek.

Lake water level fluctuations are indicators of hydrologic variation. Water level fluctuations in Lake Okeechobee are also good indicators of hydrologic extremes. Since 1931, Lake Okeechobee reached the highest water level of 18.79 ft NGVD in 1947 during a hurricane season. The lowest water level of 8.97 ft NGVD was reached in 2001 during a severe drought year. The average daily lake water level was 14.44 ft NGVD with a standard deviation of 1.61 ft. Historical daily average Lake Okeechobee stage variation is depicted in **Figure 2-10** and extreme hydrologic seasons are discernable.

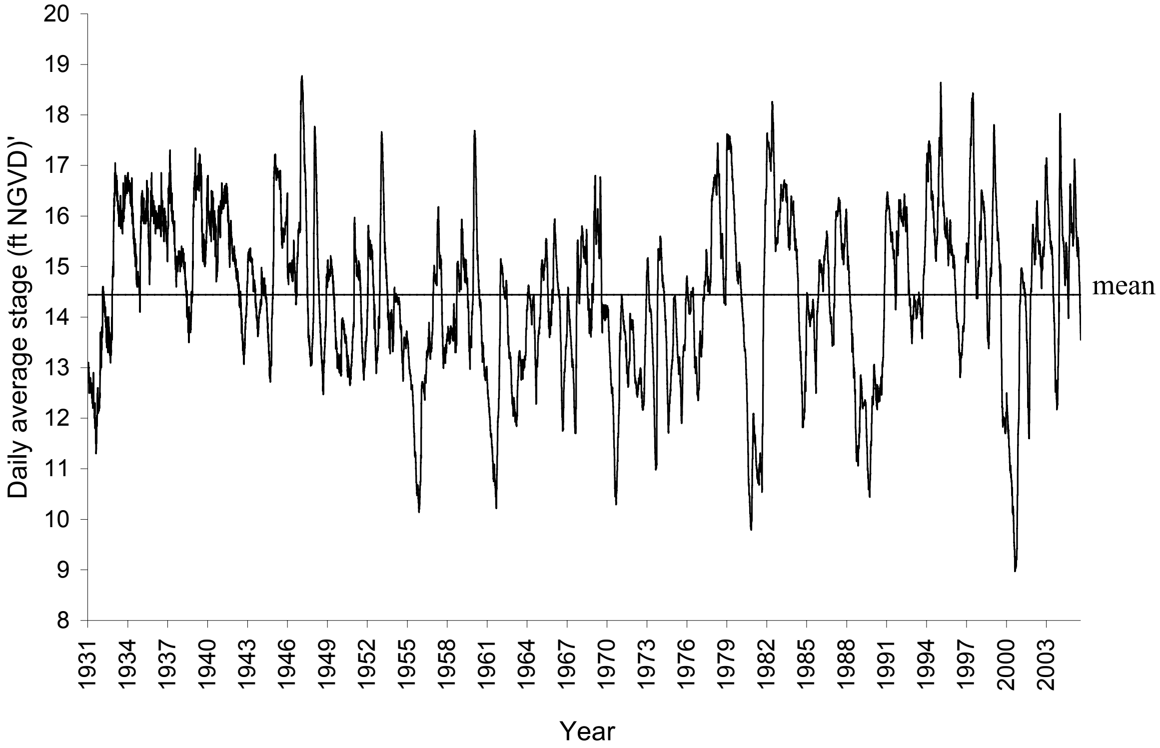


Figure 2-10. Historical daily water level variation of Lake Okeechobee.

Groundwater level fluctuation is also an indicator of hydrologic variation in South Florida. While the hydrograph of a deeper aquifer might have a lag period before showing changes in rainfall and recharge, a shallow aquifer shows a quicker response. A hydrograph for the sandstone aquifer monitoring well HE-556 in Hendry County is shown in **Figure 2-11**. The extreme drawdown due to the severe 2000–2001 drought is clearly identified as well as seasonal and annual variations.

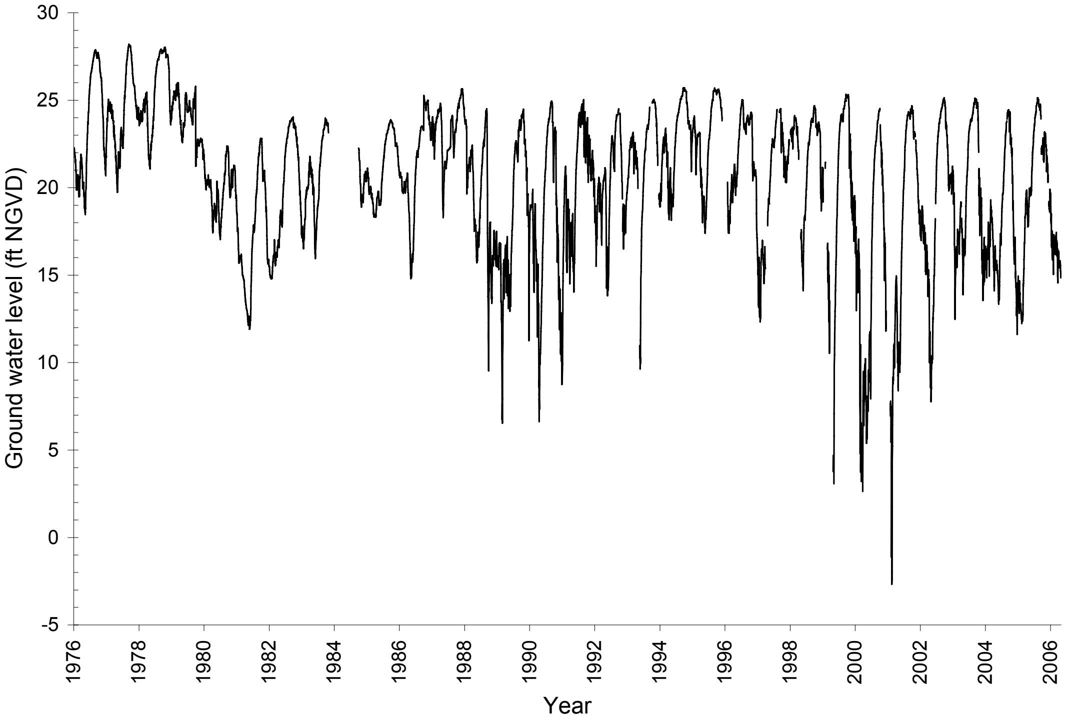


Figure 2-11. Hydrograph for the sandstone aquifer monitoring well HE-556 (1976–2006).

Another indicator of hydrologic variations is wildfire. Wildfire statistics for Florida are maintained by the Florida Department of Agriculture and Consumer Services, Division of Forestry. Records since 1981 were provided to the District. **Figure 2-12** shows the number of acres burned per calendar year by wildfires that were 10 acres or larger in the 16 counties that are served by the District. Larger number of acres burned by wildfire is indicative of low moisture conditions over the year. Peak years in the number of fires, 1981, 1985, 1989, and 2001, were also drought years. The number of acres burned by wildfires larger than 10 acres (ac) in calendar year 2005 was 16,808, the third lowest in the 25-year period of record, slightly higher than 2003 (14,480 ac) and 1983 (15,451 ac).

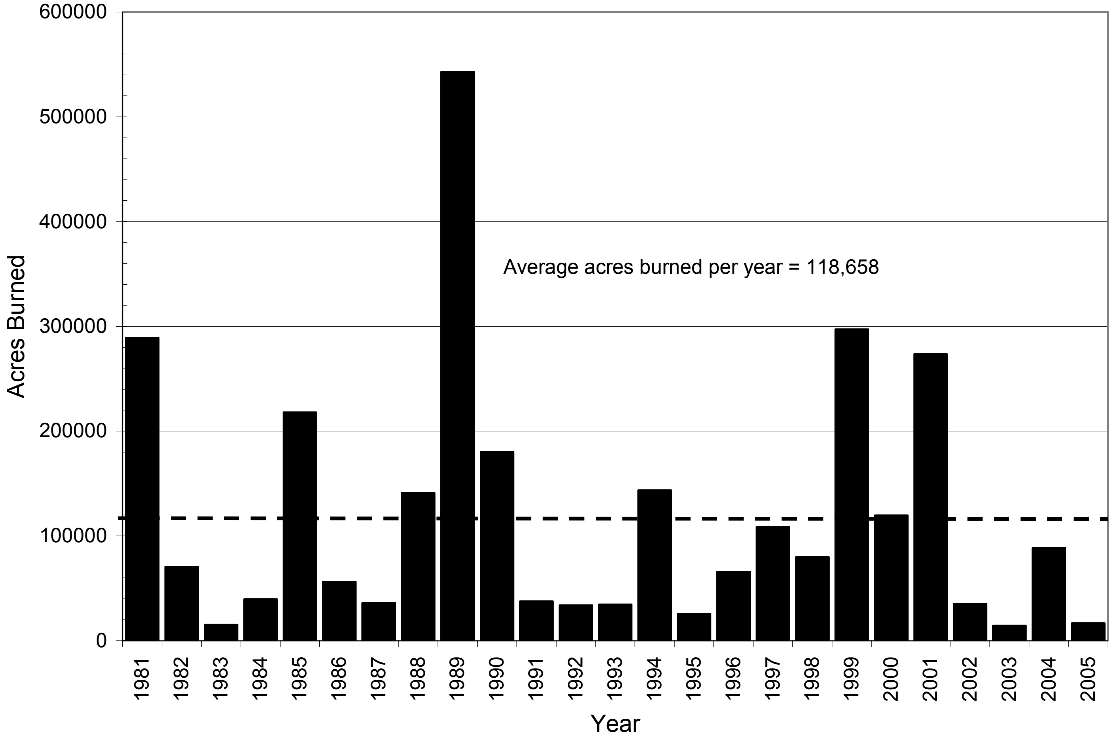


Figure 2-12. Number of acres burned per year in the SFWMD area from wildfires that were 10 acres or larger (1981–2005).

Water Management and Hydrologic Variation

The South Florida water management system is a network of natural and constructed storage and water conveyance systems. In many cases, due to extraordinarily increased cost, water management storage and conveyance systems are designed and built to handle a fixed, limited degree of hydrologic variation. Temporary storage and timely removal of excess water is the key for water management in South Florida. As discussed in the previous section of this chapter, the hydrologic variations in South Florida and the regional hydrologic variation indicators are key elements that impact water management. In South Florida, rainfall varies at any given site from 30 inches annually during drought years to 100 inches annually during wet years. Not only does the magnitude of annual rainfall impacts water management but also the spatial and temporal distribution of the rainfall. The amount of runoff generated during wet periods is also dependent on antecedent and precedent conditions. These conditions determine amount of sub-surface and surface storage available, conveyance capacities and state of areas used for temporary storage.

WATER MANAGEMENT

Water management is accomplished by operating hundreds of water control structures across the District. It is complicated by many factors including surface water groundwater interaction, rainfall-runoff relationships, topography, errors in measurements, and/or estimates of hydrologic components such as flow, rainfall, evapotranspiration, storage and seepage, multiple competing objectives, 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 is performed for meeting various purposes by using previously established regulation schedules that integrates different purposes. Regulation schedules are rule curves designed to manage the regional storage available. 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 USACE in cooperation with other agencies and stakeholders.

A group of water managers, scientists, and engineers from the District, USACE, and other federal and state agencies meet via telephone weekly to discuss the state of the water management system and possible operational scenarios. The focus is on making recommendations that consider the environmental impacts of operational decisions. Weather reports that include the previous week’s rain amounts and upcoming week’s rain forecast are presented in the meeting. In addition, longer-term climatic outlooks for rainfall produced by NOAA’s Climatic Prediction Center (CPC) are reviewed. Reports on the ecological and hydrological status of different areas of the system, such as the Kissimmee Basin, the estuaries, and the Everglades, are presented. Considering all the reports and predictions, an operational recommendation for the week is prepared by the team and submitted to District managers for their approval. The Weekly Environmental Recommendation for System Operations is then provided to USACE and used to guide decisions on regulatory discharges from major impoundments including Lake Okeechobee (see October 9, 2006, report at http://www.sfwmd.gov/org/pld/hsm/reg_app/lok_reg/arch_summaries_access.html).

Purposes of Water Management

Flood control and water supply are the two major purposes of water management at the District. During the wet season, the primary purpose is flood control. During the dry season, the water management system operates primarily to satisfy various water supply demands that include environmental deliveries, irrigation and utilities requirements, and the prevention of salt water intrusion in groundwater.

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 volume generated from rainfall runoff and water demands. For any given year, up to 30 to 40 percent of the Standard Project Flood 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 USACE in cooperation with other agencies and stakeholders. These regulation schedules are designed to balance the multiple and sometimes competing purposes of the system. The regulation schedules account for physical capacities of the upstream and downstream levees, canals, and water control structures. In addition, appropriate and relevant constraints, such as salinity intrusion and water quality, are also incorporated in the regulation schedule. These regulation schedules are revised when necessary to better balance system objectives.

Occasionally, temporary deviations from the normal regulation schedules are granted. This is to accommodate changing weather, hydrologic and ecological conditions, structure malfunction, and/or emergency conditions for a short interval with 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 for the majority of the system. The USACE maintains flood control and navigation operating authority for the primary waterway structures. **Table 2-3** shows a list of major water control structures operated by the USACE.

Table 2-3. Water control structures operated by the USACE.

Basin or Area	Water Control Structures
Lake Okeechobee	CULV 1, CULV 1A, CULV 2, CULV 3, CULV 4A, CULV 5, CULV 5A, CULV 6, CULV 7, CULV 8, CULV 9, CULV 10, CULV 10A, CULV 11, CULV 12, CULV 12A, CULV 13, CULV 14, and CULV 16 S351, S352, S354 (only during a hurricane) S310 Lock (only during a hurricane) S77, S78, S79 S308, S308B, S308C, S80
Water Conservation Areas	S10A, S10C, S10D S11A, S11B, S11C S12A, S12B, S12C, S12D S356
Lower East Coast	S332C

Operation of Water Control Structures

The operation of structures is performed on a daily basis by using the current 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.

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 housed at the respective pump stations, while some of the unmanned pump stations are operated by the dispatched field station. Although these stations are typically operated during regular work hours, some must be operated after hours during extreme weather events and during most of the wet season.

Tools Used for Operations and Water Management

Currently, there are two tools used in OCC operations. The first is a computer-based system called the Supervisory Control and Data Acquisition (SCADA) system, also known as Telvent. This system provides real-time data acquired from field sensors that is then graphically displayed 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, the Auxiliary Operator Display, displays real-time data on computer monitors for a specific structure or site. This display provides detailed information about the structure, including upstream and downstream stages, gate openings, pump speed, flow, alarm setting, and power availability.

Use of Data and Decision Making for Operations

Several pieces of data and information are used in operational decision making. The most important data is 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 when 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 water bodies have 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 the 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 Canal, and southward to the Everglades.

Since the early 1900s until the middle of 2000, the lake was operated using a variety of calendar-based regulation schedules. During the 1990s, the District and USACE conducted a study to develop and implement a more robust regulation schedule. Instituted in July 2000, the Water Supply and Environment (WSE) Lake Okeechobee regulation schedule has several major constraints which makes it complex. The schedule includes tributary hydrologic conditions and climatic forecasts into operational guidelines for use with the WSE Operational Guideline Decision Tree, and integral part of the regulation schedule. Part 1 of the Decision Tree defines Lake Okeechobee discharges to the WCAs. Part 2 defines Lake Okeechobee discharges to estuaries or tidewater. The Decision Tree also provides essential supplementary information to be used in conjunction with the WSE regulation schedule. The operational flexibility of the WSE regulation schedule allows for adjustments to be made in the magnitude and timing of the Lake Okeechobee regulatory discharges based on conditions in the lake, in the tributary basins, and long term climatic outlooks. These conditions are valuable for determining whether the appropriate window of opportunity exists to “hedge” water management practices by taking advantage of climatic forecasting. For example, if forecasts suggest that a drought is likely, water might be held back in the lake; conversely, if forecasts suggest higher than average rainfall, water might be released.

The schedule is divided into five zones (A, B, C, D, and E). Flood control zone A of the WSE regulation schedule for Lake Okeechobee describes maximum, practicable discharge of floodwater from the lake. Flood flow releases from flood zones A, B, C, and D are performed in conjunction with the conditions that are described in Water Control Plan for Lake Okeechobee and EAA (USACE, 2000). In flood zones B, C, and D, three levels of 10-day pulse releases are made for the St. Lucie and the Caloosahatchee estuaries. The pulse release emulates a natural rain storm event within the basins. Similarly, the receiving estuary is expected to respond to the pulse release as if a storm had generated runoff from the upstream watershed.

Water supply releases are made in zone E for various beneficial uses that includes water supply for municipal and industrial use, irrigation of agriculture, ENP, salinity control, and estuarine management. No flood releases are required in zone E. Releases are made to the St. Lucie Canal and Caloosahatchee River to maintain navigation depths if sufficient water is available in Lake Okeechobee. The outflows from Lake Okeechobee are received by the St. Lucie Canal, Caloosahatchee Canal, EAA, and WCAs. The details of these sub-regions flows are provided in the *Water Levels, Flows and Water Management* section of this chapter. A more detailed presentation on the features and capabilities of WSE regulation schedule is presented in USACE (2000) and Trimble et al. (2006). The USACE is in the process of revising the current Lake Okeechobee regulation schedule. The document to revise the regulation schedule, the Supplemental Environmental Impact Statement, was made available for public comment in August 2006.

The normal Lake Okeechobee operation level is below 16.5 ft NGVD. Levee inspections at intervals of 7 to 30 days are initiated when water levels are between 16.5 and 17.49 ft. When water levels are in the range of 17.5 to 18.5 ft NGVD, levee inspections are conducted at intervals of one to seven days, depending upon location. Levees are inspected daily when levels are above 18.5 ft NGVD.

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

STAGE-STORAGE RELATIONSHIPS OF LAKES AND IMPOUNDMENTS AND NOMINAL HYDRAULIC RESIDENCE TIME

Stage-storage relationships of lakes and impoundments are critical information for managing water levels, storage, and compute average water residence time. Stage-storage and stage-area charts, tables, and data were acquired from the USACE – Jacksonville District Office and the SFWMD. Appendix 2-2 presents the compiled charts for stage-storage for the major lakes and impoundments and stage-area relationships where data is available. Estimates of storage capacity and surface area at the respective average stage for each lake or impoundment are shown in **Table 2-4**. Based on average storage volume and average historical inflows and outflows, residence time was estimated. Hydraulic residence time is computed by dividing storage volume by the average of daily inflows and outflows. Estimated nominal residences time for Lake Kissimmee, Lake Istokpoga, and Lake Okeechobee are 133, 284, and 739 days, respectively.

Table 2-4. Surface area and storage at average water level for major lakes and impoundments.

Lake/Impoundment	Average Stage (ft NGVD)	Surface Area (acres)	Storage (ac-ft)
Lake Alligator	62.4	3,940	35,600
Lake Myrtle	60.88	1,476	8,320
Lake Mary Jane	60.04	3,400	21,000
Lake Gentry	60.61	1,660	15,000
East Lake Tohopekaliga	56.67	12,470	116,000
Lake Tohopekaliga	53.64	20,160	113,00
Lake Kissimmee	50.38	35,140	273,000
Lake Istokpoga	39.05	---	174,000
Lake Okeechobee	14.44	443,000	3,726,000
WCA-1	15.59	---	120,000
WCA-2A	12.56	---	154,000
WCA-3A	9.51	---	562,000

EMERGING TOPICS

LONG-TERM CLIMATIC VARIABILITY

Climatic change and variability due to natural and anthropogenic causes are not fully understood and their prediction carries large uncertainties. Climatic change and variability, principal concerns of SFWMD, have become increasingly important during the last two decades. Investigations conducted and supported by the SFWMD have been published in peer-reviewed literature and recognized by other researchers, agencies, and institutions. Results from these studies have been selectively incorporated into SFWMD water resource modeling, planning, and operational programs (Appendix 2-3).

Several climate indicators such as global sea temperatures [including the data that derive the Atlantic Multidecadal Oscillation (AMO) and the Pacific Decadal Oscillation (PDO) periods], rainfall, soil moisture, solar radiation were considered by the SFWMD. El Niño/Southern Oscillation (ENSO), AMO, and PDO are large-scale climatic indicators that have implications for water resources and planning in South Florida. Of these three indicators, ENSO, which follows a 3- to 7-year cycle, has the strongest effect on South Florida climatic conditions and has received the most study. The PDO may last for decades and affect South Florida weather in a manner similar to ENSO but with much less influence. The AMO has a weaker effect on South Florida than ENSO but could last up to several decades. The AMO warm phase is associated with slightly higher, but possibly more variable, rainfall conditions in South Florida. Research on AMO and PDO influences indicates a significant variability in the periodicity, duration, and magnitude of these multidecadal climatic indicators and their effects on South Florida weather. Furthermore, the relationships between these cycles and regional weather patterns or rainfall conditions in South Florida cannot be accurately predicted. Hydrologic variation not only changes the amount of rainfall but also the spatial and temporal distribution (Appendix 2-3).

The SFWMD has incorporated consideration of climatic trends into its modeling and operations decision-making processes. Notable examples include application of the WSE schedule and position analysis techniques to guide the regulation of water releases into and out of Lake Okeechobee. The SFWMD is also proceeding cautiously to address long-term climatic changes in its planning processes through an adaptive management approach, collecting new data and periodically reviewing project designs and operation based on new information (Appendix 2-3).

The SFWMD uses complex regional models as tools to aid in water resources planning and management in conjunction with standard engineering practices. Its regional model, the South Florida Water Management Model, incorporates a period of the South Florida hydrologic record (1965–2000) that includes a broad range of wet and dry years. The SFWMD will continue to expand the modeling period forward to include the current AMO warm cycle as new data become available. By periodically extending the simulation period, the SFWMD can continually incorporate recent climatic trends and re-evaluate proposed infrastructure changes, including Comprehensive Everglades Restoration Plan (CERP) projects that will be designed and constructed over a period of several decades. This adaptive approach follows standard engineering and operational planning practices and provides a means to reduce the risks of facility implementation when climatic changes are inherently uncertain (Appendix 2-3).

THE SOUTH FLORIDA HYDROLOGIC MONITORING SYSTEM

The District collects, validates, and archives hydrologic data used for real-time water management and data analysis. This is accomplished by using the hydrologic monitoring network of the District that is divided into five parts: (1) the rainfall monitoring network; (2) the meteorological monitoring network; (3) the surface water stage monitoring network; (4) the surface water flow monitoring network; and (5) the groundwater monitoring network. Appendix 2-4 details the sensors and instrument(s) used; the number and location of instruments; frequency of data collection; time interval of the available data; and optimization or design of the network. How the monitoring networks at the District have evolved over the years and have been periodically optimized as the result of numerous studies is also detailed in Appendix 2-4.

As of December 31, 2005, the District operated an extensive network of 279 active rain gauges. The District has been acquiring radar rainfall (NEXRAD) data coverage from OneRain, Inc. since 2002. The District also has a meteorological monitoring network that includes 41 active weather stations. Meteorological data such as air temperature, barometric pressure, humidity, solar radiation, wind speed, and water temperature are collected and are available on breakpoint (instantaneous) and daily time intervals. In addition, daily potential evapotranspiration (ETp) data are available for 18 weather stations. The ETp data were estimated using the Simple Method (Abtew, 2005).

As of December 31, 2005, a network of 1,195 active surface water stage gauges provides the data for various water bodies. Additionally, the District maintains a network of 425 active surface water flow monitoring sites that provide data for 15-minute instantaneous and mean daily flow estimates.

The groundwater monitoring network contains a total of 975 groundwater wells that are monitored on a 15-minute continuous, monthly, or greater than 1-month interval basis as of December 31, 2005. The District is solely responsible for monitoring, maintenance, Quality Assurance/Quality Control, data archival, and funding for 613 of these wells. The USGS is responsible for the remaining 362 wells (Appendix 2-4).

The data from these networks are collected, summarized, stored, and published. The data are stored in two different databases. Breakpoint data are stored in the Data Collection/Validation Pre-Processing database, while daily summary and 15-minute data are published in the District's hydrometeorological database DBHYDRO.

THE 2005 HURRICANE SEASON IN SOUTH FLORIDA

Documenting hydrologic events such as hurricanes, storms, and droughts provides supporting information for water management decision making. The calendar years 2004 and 2005 were extreme hurricane seasons for South Florida. Based on a historical record of tropical systems, the combined impact of the 2004 and 2005 hurricane seasons on the District was a series of rare events. The hydrologic impact of hurricanes Dennis, Katrina, Rita, and Wilma on the District during the 2005 hurricane season is documented in Appendix 2-1. The appendix, which is also summarized in this section, presents rainfall data from the hurricanes, along with an estimate for frequency of occurrence of extreme rainfall events. Analysis of wind direction and magnitude from Hurricane Wilma are included, as well as an estimate for the highest wave run-up, or surge, on the Herbert Hoover Dike (Lake Okeechobee levee) from Hurricane Wilma. Hydrologic impact of the hurricanes on the water management system is presented along with Hurricane Wilma’s damage to the Herbert Hoover Dike.

HURRICANE DENNIS

Hurricane Dennis began as a tropical wave that moved westward from the coast of Africa in late June 2005. It made landfall on southeastern Cuba as a Category 4 hurricane. On July 9, 2005, Dennis crossed over water and made landfall on western Cuba, weakening to a Category 3 (Beven, 2005). As it crossed the Gulf of Mexico to the Florida panhandle, it contributed rainfall to the Florida Keys and south-southwest Florida.

HURRICANE KATRINA

Hurricane Katrina developed as a tropical depression in the Bahamas, about 175 miles southeast of Nassau, on August 23, 2005. Katrina moved toward South Florida, making landfall on the Broward/Miami-Dade County line on August 25, 2005, as a Category 1 hurricane (Knabb et al., 2006). The hurricane caused fatalities and damages to trees, power lines, homes, and businesses. As the hurricane moved west-southwestward through the southern tip of Florida, it produced over a foot of rainfall on some areas. It remained six hours over land, mostly over the Everglades wetlands, and crossed to the Gulf of Mexico just north of Cape Sable on August 26. Most of the rainfall was observed in the southeast and southwest quadrants as it crossed South Florida. A high-intensity rainfall was observed in Homestead totaling 13.24 inches in a 24-hour period, causing flooding. This amount of rainfall on the area in a 24-hour period is a rare frequency of a 1-in-100-year return period. On August 25, there was a high rainfall intensity of almost seven inches over two hours, which resulted in heavy flooding. Katrina made landfall again on August 29 at the mouth of the Pearl River at the Louisiana/Mississippi border causing catastrophe to New Orleans, Louisiana, Mississippi, and Alabama.

HURRICANE RITA

Hurricane Rita developed as a tropical depression, just east of the Turks and Caicos Islands, on September 17, 2005 (http://www.nhc.noaa.gov). On September 19, Rita became a tropical storm and moved through the Central Bahamas. According to NOAA’s National Hurricane Center, the storm reached Category 2 hurricane status on September 20 as it passed through the Florida Straits to the Gulf of Mexico. Although the hurricane’s center did not pass through the Florida Keys, it downed trees and created high storm surge and flooding. As the hurricane moved southwest through the Florida Straits, it contributed rainfall to the keys and South Florida. The highest areal rainfall was observed in the ENP followed by Miami-Dade, the Big Cypress Basin, Broward, and WCA-3. Rainfall for Key West was 7.35 inches during September 2005 compared to the monthly average of 5.45 inches.

HURRICANE WILMA

Hurricane Wilma formed as a tropical depression on October 15, 2005, east-southeast of Grand Cayman. On October 18, Wilma became a hurricane moving west-northwestward. On October 19, Wilma strengthened to a Category 5 hurricane with a record low pressure (882 millibars) for an Atlantic hurricane. On October 21, it made landfall on the island of Cozumel, Mexico, as a Category 4 hurricane. On October 22, Wilma crossed to the Yucatan Peninsula and, after prolonged battering of the northeastern section, it emerged in the Gulf of Mexico on October 23. Heading toward South Florida, it made landfall as a Category 3 hurricane near Cape Romano on October 24 and hit South Florida as a Category 2 hurricane, crossing to the Atlantic in four and a half hours (Pasch et al., 2006). The eye of Hurricane Wilma passed through South Florida, inflicting extensive damage from the front and back end of the hurricane. Most of the rainfall from the hurricane was on the headwaters of Lake Okeechobee and the southwest. Because the hurricane crossed South Florida quickly, the rainfall was not in extreme amounts. But the location of the rainfall, the amount of runoff generated, and the high antecedent water levels in lakes and impoundments impacted the water management system.

Hurricane Wilma passed over the six Stormwater Treatment Areas (STAs) at the south and southeastern edges of the EAA. As such, the STAs were impacted significantly. The impacts included resuspension of settled sediment, vegetation damage, dislocation of wetland vegetation, and vegetation pushed onto levee banks, lack of power, and levee and pump station damages. The downed power lines on levees and roads also limited access to facilities.

In the Upper Kissimmee Basin, lakes Myrtle, Mary Jane, Gentry, Tohopekaliga, and Kissimmee were above regulation schedule following Hurricane Wilma, which generated over six inches of areal average rainfall over the basin. The rainfall from Hurricane Wilma in the Upper Kissimmee Chain of Lakes region caused a sharp increase in the water level of Lake Kissimmee. This was accompanied by a sharp increase in surface water flow in the Kissimmee and surrounding basins and sharp increases in outflows from Lake Kissimmee (S-65), outflows from Lake Istokpoga (S-68), and inflows into Lake Okeechobee through the Kissimmee River (C-38 Canal) through structure S-65E. Inflow into Lake Okeechobee through the Kissimmee River (S-65E) between October 24, 2005 (landfall of Hurricane Wilma) and December 31, 2005, was 525,369 ac-ft. There are additional inflow points to the lake. Kissimmee River floodplain water levels at the restoration area climbed over seven feet due to surface water flow increases from the hurricane rainfall. The weather station with the lowest maximum gust wind speed from Hurricane Wilma was WRWX [50 miles per hour (mph)], located in the Upper Kissimmee Basin at the Disney Wilderness Preserve. Wind speed during Hurricane Wilma was also relatively lower in the Lower Kissimmee Basin. Maximum instantaneous wind gust speed of 117 mph was recorded at Belle Glade just south of Lake Okeechobee. Wind speed was generally very high from Lake Okeechobee in the north to Miami-Dade in the south.

Lake Okeechobee was fully impacted by Hurricane Wilma. Lake Okeechobee is impounded with an earthen levee with numerous inflow and outflow water control structures, except at Fisheating Creek where there is an open water connection. The impact of wind-generated waves on Lake Okeechobee depends on the path of the hurricane, wind speed, wind direction, and duration of impact. There are four weather stations within Lake Okeechobee. Three of the weather stations (except for L005) had gust wind speed, average wind speed, and wind direction data collected during Hurricane Wilma. Weather station L001, at the northern side of the lake, registered instantaneous maximum gust wind speed of 107 mph; weather station L006, at the south side of the lake, registered instantaneous maximum gust wind speed of 112 mph. Instantaneous maximum gust wind speed (sampled every 10 seconds; maximum in 15 minutes) and 15-minute average wind speed and direction over the lake correspond with the area of levee erosion and high water levels. Wind direction over the lake was east-northeast on the front side of the hurricane and northwest on the backside of the hurricane. Both the gust and average wind speed data show that the backside of the hurricane had higher wind speed than the front side. Hurricane winds blow vegetation from the lake toward the levee banks. Water control structures built in the levees became clogged with massive vegetation and debris impeding emergency operations. The wind wave action stirred up the lake, suspending settled sediment and impacting water quality. High suspended sediment concentrations reduced the depth of light penetration into water, limiting the growth and maintenance of submerged aquatic vegetation. High suspended sediment concentrations are also associated with increased nutrient concentrations. Due to the high water level in the lake, water had to be discharged. The quantity and quality of the discharge impacted the receiving systems.

Figure 2-13. Wave erosion damage to the Herbert Hoover Dike from Hurricane Wilma (Bromwell et al., 2006).

Structural damage from hurricanes can occur in several ways. High rainfall on the lake's watershed from hurricanes results in high surface water inflows. This results in rising water level in the lake when outflow conveyance capacity is lower than inflow. A high water level in the lake increases seepage through the levee, which could result in levee failure. Seepage is an inherent problem of earthen dams. Due to the hydrostatic force created by high water level within the lake, seepage is the slow movement of water from the lake through the levee. When the rate of seepage increases, soil material moves through the levee along with the seepage water (i.e., "boiling"). Boiling starts with fine material movement followed by coarse material movement that results in a levee breach. It was reported that there will be problems when the stage approaches 18.5 ft NGVD, and levee breach is likely expected at 21 ft NGVD (Appendix 2-1). Increased flow rates from high rainfall can also create failure at a water control structure.

Hurricane winds can generate high waves, and the energy from the back-and-forth battering can cut through an earthen levee (**Figure 2-13**). Also, failure can occur around structures on the levee. A high water level creates the potential for high winds to generate high waves that could wash the lake-side of the levee or even overtop and erode the outside of the levee. According to newspaper reports, there were five or six eroded areas along the lake shore after Hurricane Wilma. The major levee erosion is confirmed to be from hurricane generated wave action. Had the hurricane stayed longer, levee integrity could have been compromised. A recent technical evaluation on the risk of Herbert Hoover Dike failure is presented in an expert review panel report (Bromwell et al., 2006).

The wave run-up from Hurricane Wilma exceeded the maximum reading capacity of some of the water level recorders on the perimeters of Lake Okeechobee. A recent survey of the highest level of wave setup at a watermark preserved at the S-2 pump station indicated the highest instantaneous water level was 30.6 ft NGVD. This water level was generated by a 15 feet wave run-up. Hurricane Wilma's impact on Lake Okeechobee is not limited to the impact during the hurricane. Runoff associated with the hurricane rainfall has lingering impact on the lake. Subsequently, the lake's overall water level rose following Hurricane Wilma, leading to high rate discharges to manage the lake water level. The hurricane moved quickly through the area. Slow movement of the hurricane might have had extensive hydrologic impact that would have included flooding and compromise to structural integrity.

WATER YEAR 2006 HYDROLOGY

RAINFALL AND EVAPOTRANSPIRATION

Similar to WY2005, South Florida received rainfall in WY2006 from four hurricanes. The significant rainfall patterns for the water year were a wet June, a wet October, and a drier winter and spring District-wide. January and March were dry months in most areas while December and April were drier in some rain areas. District-wide rainfall for WY2006 (54.75 inches) was higher than the historical average by 2 inches, and it was higher than WY2005 rainfall (50.67 inches). Rainfall data of several stations computed as Thiessen averages was obtained from the District's Operations rainfall data report (see October 9, 2006 data at the District web site www.sfwmd.gov under the W*eather & Water Conditions, District Rainfall Data* section). The District Operations rainfall database accumulates daily rainfall between 7:00 am Eastern Standard Time (EST) of previous day to 7:00 am (EST) of data registration day. The ENP area rainfall was estimated as a simple average of eight stations: S332, S174, S18C, HOMESTEADARB, JBTS, S331W, S334, and S12D.

The balance between rainfall and evapotranspiration maintains the hydrology system of South Florida in either a wet or dry condition. In South Florida, most of the variation in evapotranspiration is explained by solar radiation (Abtew, 1996). Regional estimates of evapotranspiration from open water and wetlands that do not dry out range from 48 inches in the District's northern section to 54 inches in the Everglades (Abtew et al., 2003; Abtew, 2005). ETp is the actual evaporation for lakes, wetlands, and any feature that is wet year round and approaches the ETp. Available ETp data from the closest site to a rainfall area was used to estimate ETp for the area.

Five rain areas experienced wetter and drier monthly rainfall with a return period of 20 years or more (**Table 2-5**). **Table 2-6** shows WY2006, WY2005, historical average annual rainfall, and WY2006 annual ETp for each rain area. A significant increase in rainfall was observed in the Southwest Coast. The Upper and Lower Kissimmee basins also received higher than average rainfall. Since these basins are the headwaters of Lake Okeechobee, any increase in rainfall to these basins has an impact on the lake inflow. Drier winter and spring months reduced the hydrologic impact of the high summer and fall rainfall. In April 2006, there were signs of water shortage on the Southwest Coast where the water year total rainfall was six inches higher than the historical average. Wildfires, which are indicators of dry condition, were prevalent in spring 2006.

Table 2-5. Rain areas with monthly rainfall wetter or drier than a 20-year or more return period.

	Upper Kissimmee	Lower Kissimmee	Martin-St. Lucie	Big Cypress Preserve (BCP)	Southwest (SW) Coast
June rainfall (in.)	13.82		14.04	19.18	19.00
Return Period	20-yr wet		>20-yr wet	≈100-yr wet	≈100-yr wet
October rainfall (in.)	9.89	8.00			
Return Period	>50-yr wet	>20-yr wet			
January rainfall (in.)			0.21		
Return Period			>20-yr dry		
March rainfall (in.)	0.18		0.39		
Return Period	>50-yr dry		20-yr dry		

Table 2-6. Comparison of WY2006, WY2005, historical average annual rainfall (inches) for each rainfall area, and WY2006 potential evapotranspiration (ETp). (* = Above average rainfall amounts)

	WY2006	WY2005	Historical♣ Average	WY2006 ETp
Upper Kissimmee	52.91*	64.19*	50.09	52.43
Lower Kissimmee	48.50*	50.12*	44.45	53.79
Lake Okeechobee	47.33*	45.51	45.97	54.91
East EAA	48.24	46.16	53.48	50.72
West EAA	58.29*	52.20	54.95	52.18
WCA-1 and WCA-2	47.96	43.72	51.96	51.47
WCA-3	53.39*	40.27	51.37	51.42
Martin-St. Lucie	61.70*	56.99*	54.14	52.43
Palm Beach	57.80	50.44	61.54	51.73
Broward	56.67	42.80	58.13	51.42
Miami-Dade	57.44	43.05	57.11	52.91
East Caloosahatchee	56.91*	54.10*	50.68	54.00
Big Cypress Preserve (BCP)	58.75*	50.39	53.98	52.30
Southwest (SW) Coast	60.56*	55.05*	54.12	52.36
ENP	57.27*	40.15	55.22	52.91
District	54.72*	50.67	52.75	52.47

♣ Refer to the *Hydrologic Variation in South Florida* section of this chapter.

Generally for WY2006, most of the rain areas received higher than average rainfall except WCA-1, WCA-2, Palm Beach County, Broward County, and Miami-Dade County. **Table 2-7** shows the WY2006 monthly rainfall for each rain area. Although the WY2006 rainfall was overall higher than WY2005 and the historical average, there were signs of drought in late spring due to a below average rainfall. The Upper Kissimmee, the Lower Kissimmee, and Lake Okeechobee rain areas received higher than average rainfall that resulted in record inflow into Lake Okeechobee. **Figure 2-14** graphically shows WY2006, historical average rainfall, the 10-year dry and wet return-period rainfall for each rainfall area.

In the South Florida water management system, the impact of rainfall is not only dependent on the amount but also on the temporal and spatial distribution of rainfall. Lake Okeechobee is at the center of the water management system. When a higher Lake Okeechobee water level coincides with a higher rainfall in the headwaters, the result will be a high water level with a cascading downstream effect. Additional details are in the *Water Levels, Flows and Water Management* section in this chapter.

Table 2-8 presents monthly ETp for each rain area for WY2006. Graphical comparison of WY2006 ETp, WY2006, WY2005, and historical average monthly rainfall for each rainfall area are depicted in **Figures 2-15** through **2-29.** For areas such as lakes, WCAs, and wetlands that are wet throughout the year, the ETp approximates the actual evapotranspiration. The deviation in water year rainfall from the historical average is shown in the inserted legends of these figures for the respective rainfall area. In these legends, the positive (+) and negative (-) signs indicate an increase or decrease, respectively.

Table 2-7. WY2006 monthly rainfall (inches) for each rainfall area.

	Upper Kiss	Lower Kiss	Lake O	East EAA	West EAA	WCA-1 & WCA-2	WCA-3	Martin/ St. Lucie	Palm Beach	Broward	Miami-Dade	East Caloos	BCP	SW Coast	District
May	4.85	7.19	4.03	5.69	4.59	5.08	5.48	4.79	5.72	4.36	4.32	4.29	3.35	3.46	4.73
June	13.82	9.76	11.44	12.31	17.06	11.24	16.20	14.04	12.45	14.44	14.76	13.57	19.18	19	14.35
July	5.85	4.99	4.61	5.69	7.58	6.25	6.49	5.71	4.84	5.48	5.62	9.02	7.61	9.37	6.47
Aug	6.94	5.92	5.71	5.76	8.48	5.98	6.76	7.65	6.70	7	10.98	7.01	7.68	6.88	7.05
Sept	3.51	3.97	3.45	5.25	5.51	4.70	5.81	5.93	7.75	5.64	8.13	4.39	7.47	5.56	5.35
Oct	9.89	8.00	8.05	6.28	8.02	6.04	6.76	9.66	7.23	8.32	5.94	8.84	7.13	9.05	7.98
Nov	1.38	2.93	4.34	1.93	2.36	2.05	1.12	6.84	4.51	4.24	1.08	4.21	1.09	3.26	2.98
Dec	2.20	0.52	0.43	0.34	0.22	0.62	0.30	1.27	1.44	1.07	0.8	0.33	0.29	0.15	0.7
Jan	0.38	0.32	0.22	0.19	0.23	0.41	0.38	0.21	0.67	0.83	0.39	0.25	0.32	0.29	0.33
Feb	2.50	3.70	3.56	2.45	2.52	2.47	2.69	3.16	2.8	3.84	3.16	3.64	3.09	2.88	3.05
Mar	0.18	0.44	0.70	1.36	0.96	2.09	0.44	0.39	1.31	0.40	0.75	1.09	0.27	0.34	0.65
Apr	1.41	0.76	0.79	0.99	0.76	1.03	0.96	2.05	2.38	1.05	1.51	0.27	1.27	0.32	1.08
SUM	**52.91**	**48.5**	**47.33**	**48.24**	**58.29**	**47.96**	**53.39**	**61.7**	**57.8**	**56.67**	**57.44**	**56.91**	**58.75**	**60.56**	**54.72**

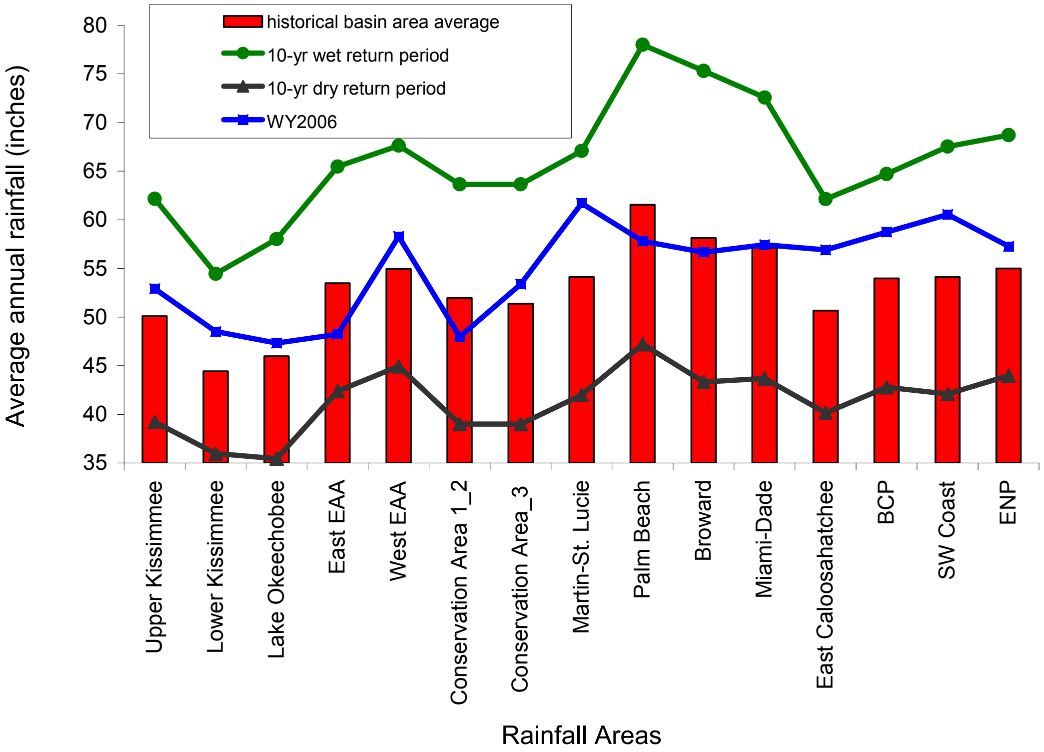


Figure 2-14. WY2006, historical average, the 10-year wet and the 10-year dry return period annual rainfall for each rainfall area.

Table 2-8. WY2006 monthly ETp (inches) for each rainfall area.

	Upper Kiss	Lower Kiss	Lake O	East EAA	West EAA	WCA-1 & WCA-2	WCA-3	Martin-St. Lucie	Palm Beach	Broward	Miami-Dade	East Caloos	Big Cypress Preserve	Southwest Coast	ENP
May	5.56	5.60	5.89	5.51	5.55	5.57	5.44	6.08	5.36	5.44	5.52	5.78	5.56	5.69	5.52
June	4.13	4.24	4.34	3.97	3.88	3.84	3.78	4.51	3.95	3.78	3.94	4.16	3.79	4.01	3.94
July	5.58	5.39	5.35	5.07	5.22	5.38	5.21	5.50	5.29	5.21	5.62	5.24	5.18	5.21	5.62
Aug	5.44	5.39	4.87	4.88	4.76	4.88	4.56	4.34	4.89	4.56	4.78	5.22	4.86	5.22	4.78
Sept	4.37	4.54	4.27	4.20	4.26	4.11	4.18	4.10	4.16	4.18	4.51	4.61	4.22	4.26	4.51
Oct	3.75	3.89	4.08	3.70	3.63	3.71	3.71	3.30	3.71	3.71	3.78	3.81	3.67	3.66	3.78
Nov	3.12	3.24	3.38	3.11	3.10	3.23	3.50	3.16	3.17	3.50	3.40	3.39	3.21	3.19	3.40
Dec	2.77	3.12	3.21	2.92	3.12	3.05	3.22	2.70	2.99	3.22	3.31	3.10	3.30	3.10	3.31
Jan	3.36	3.55	3.51	3.10	3.50	3.31	3.56	3.57	3.21	3.56	3.50	3.44	3.54	3.39	3.50
Feb	3.56	3.68	3.92	3.56	3.85	3.67	3.71	3.86	3.76	3.71	3.83	3.84	3.81	3.62	3.83
Mar	5.20	5.45	5.79	5.20	5.50	5.25	5.11	5.52	5.44	5.11	5.07	5.41	5.53	5.25	5.07
Apr	5.59	5.71	6.31	5.50	5.81	5.46	5.42	5.78	5.81	5.42	5.63	5.99	5.64	5.77	5.63
Sum	**52.43**	**53.79**	**54.91**	**50.72**	**52.18**	**51.47**	**51.42**	**52.43**	**51.73**	**51.42**	**52.91**	**54.00**	**52.30**	**52.36**	**52.91**

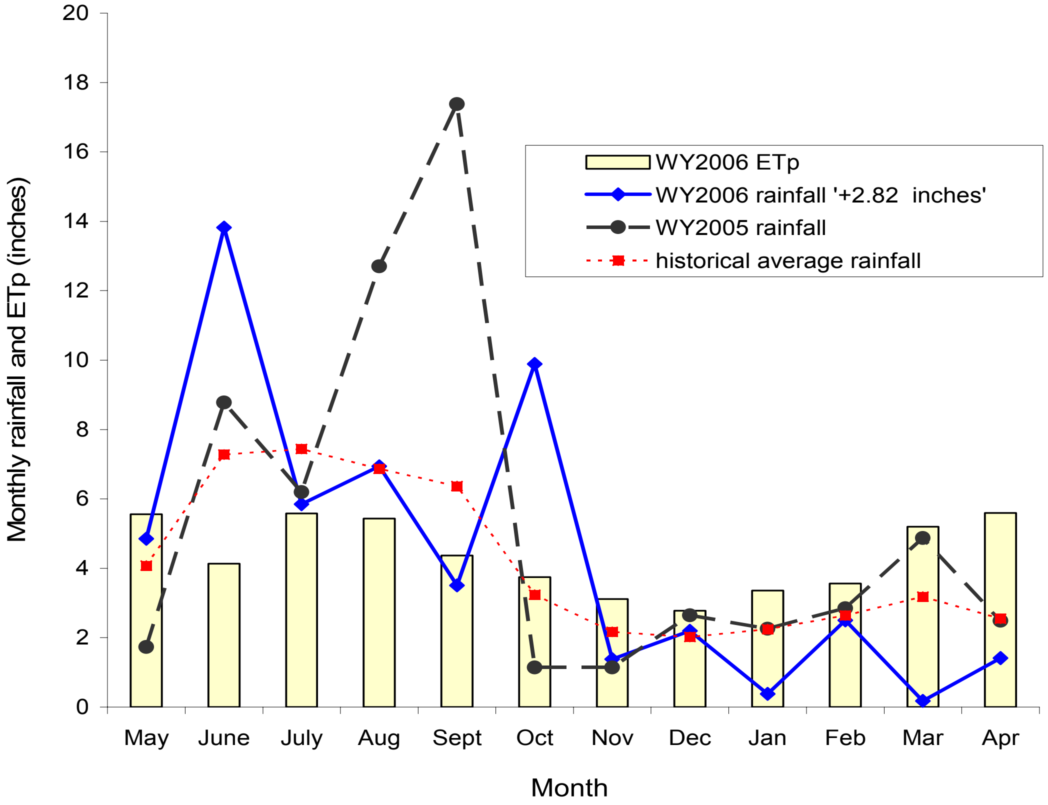


Figure 2-15. Monthly rainfall and potential evapotranspiration (ETp) for the Upper Kissimmee rainfall area.

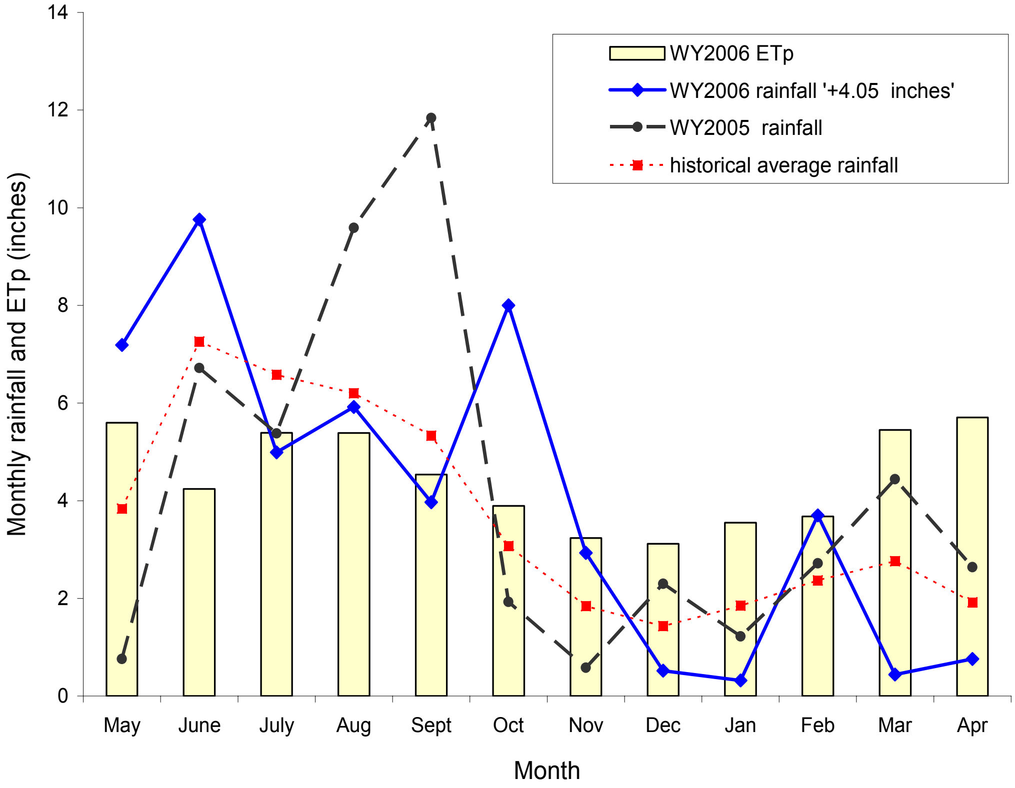


Figure 2-16. Monthly rainfall and ETp for the Lower Kissimmee rainfall area.

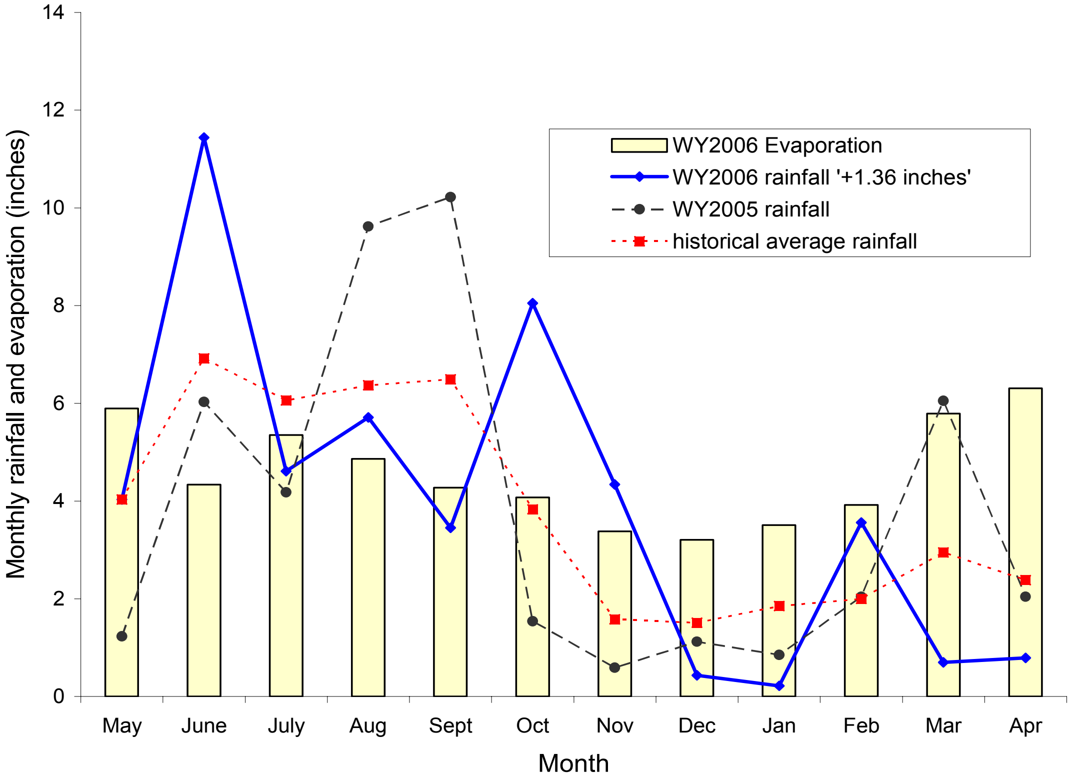


Figure 2-17. Monthly rainfall and ETp for the Lake Okeechobee rainfall area.

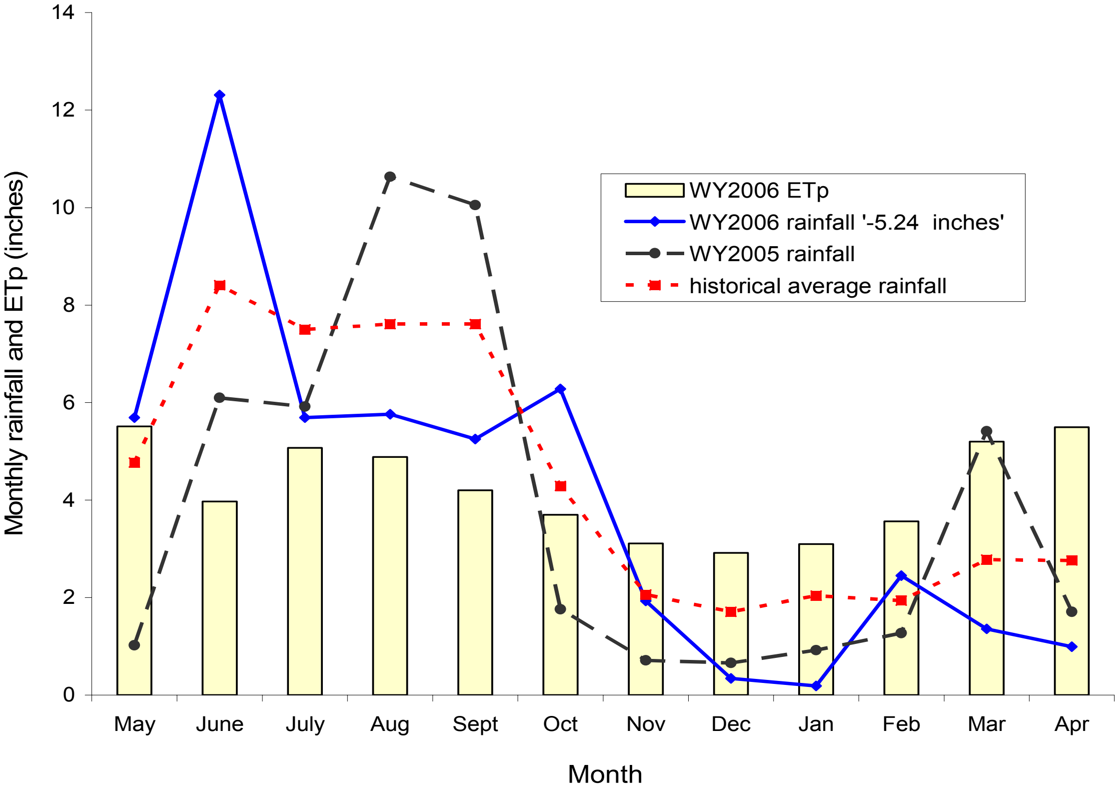


Figure 2-18. Monthly rainfall and ETp for the East Everglades Agricultural Area (EAA) rainfall area.

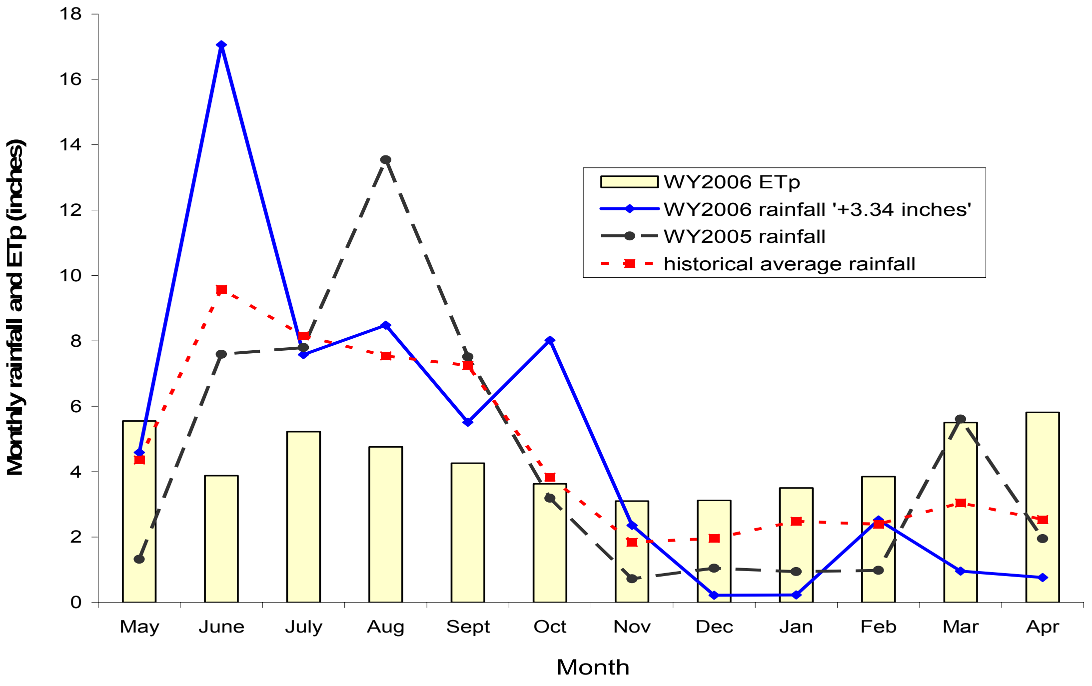


Figure 2-19. Monthly rainfall and ETp for the West EAA rainfall area.

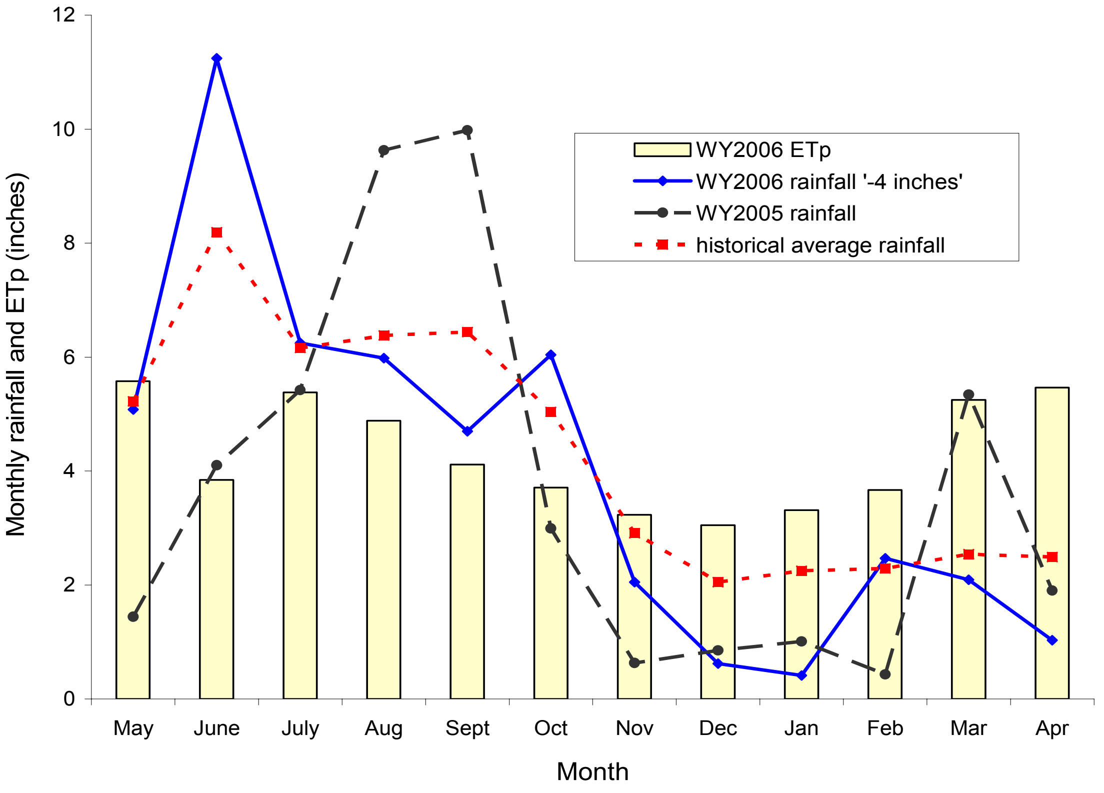


Figure 2-20. Monthly rainfall and ETp for Water Conservation Areas 1 and 2 (WCA-1 and WCA-2) rainfall areas.

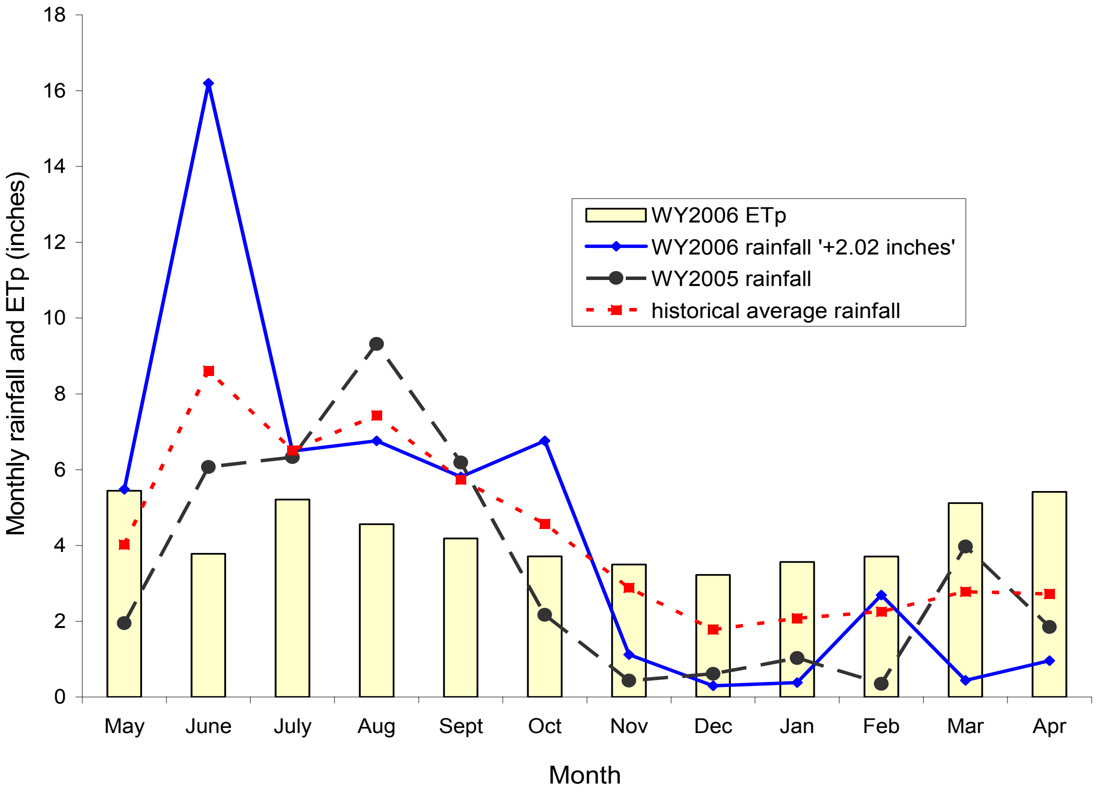


Figure 2-21. Monthly rainfall and ETp for the WCA-3 rainfall area.

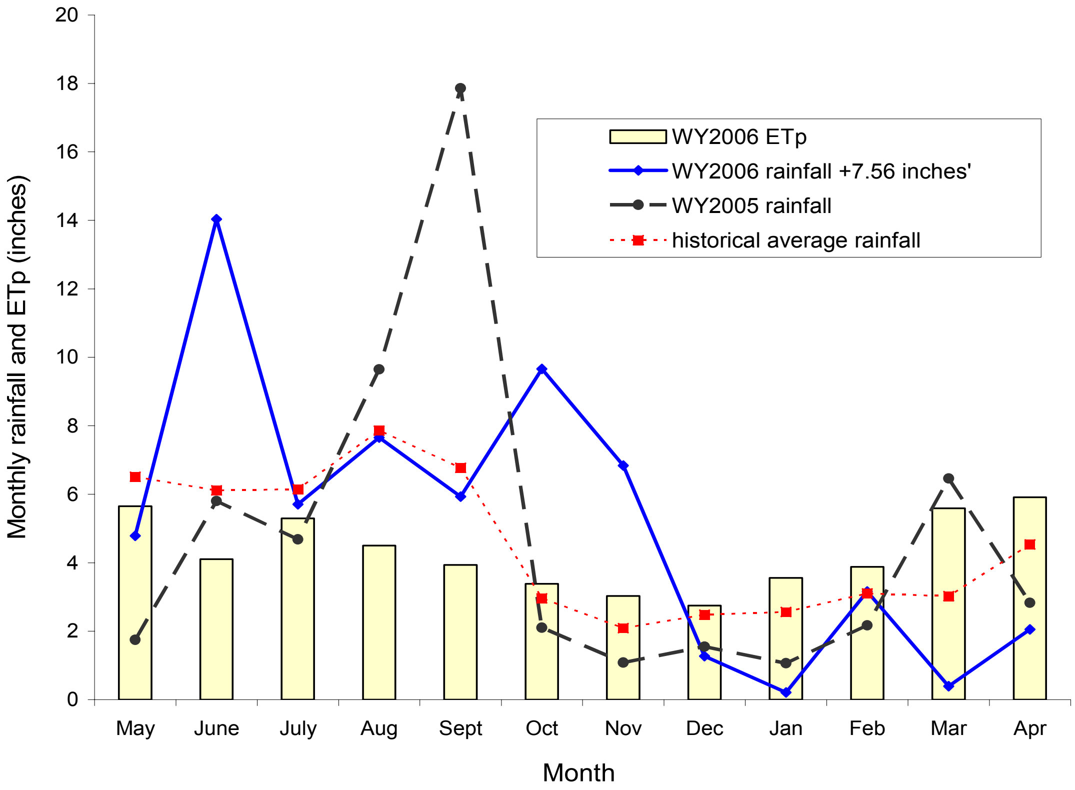


Figure 2-22. Monthly rainfall and ETp for the Martin and St. Lucie counties rainfall areas.

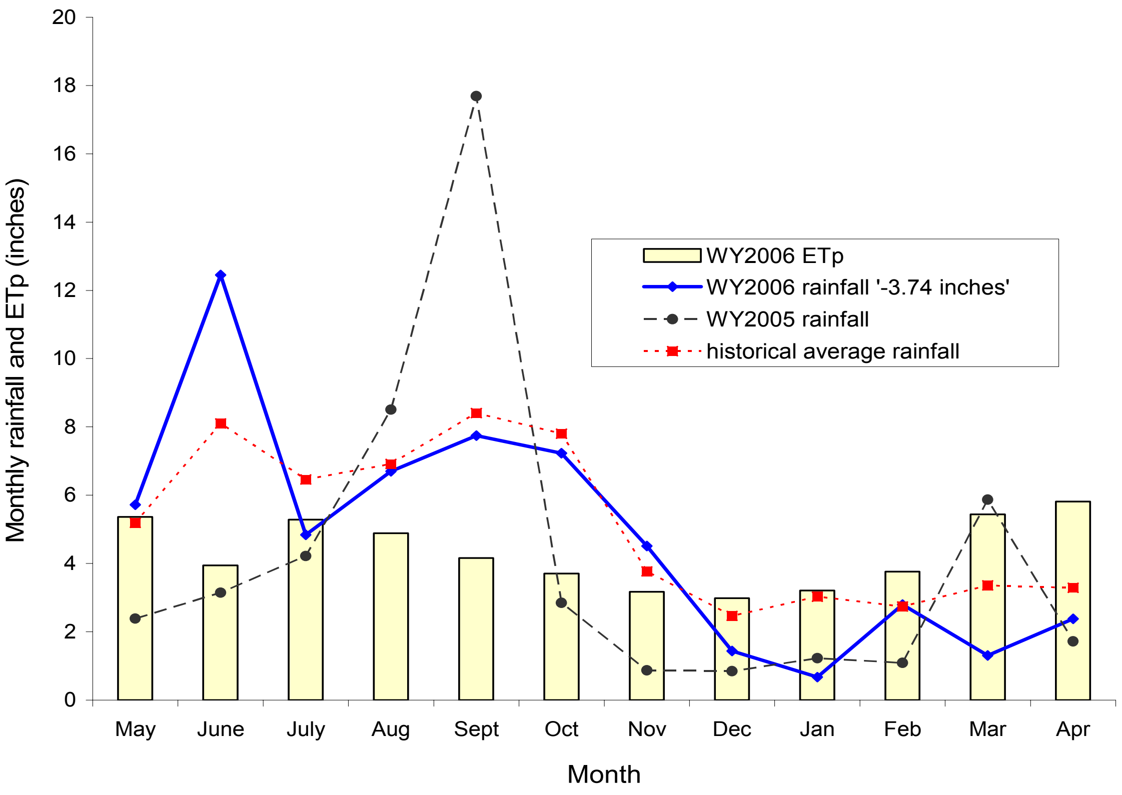


Figure 2-23. Monthly rainfall and ETp for the Palm Beach County rainfall area.

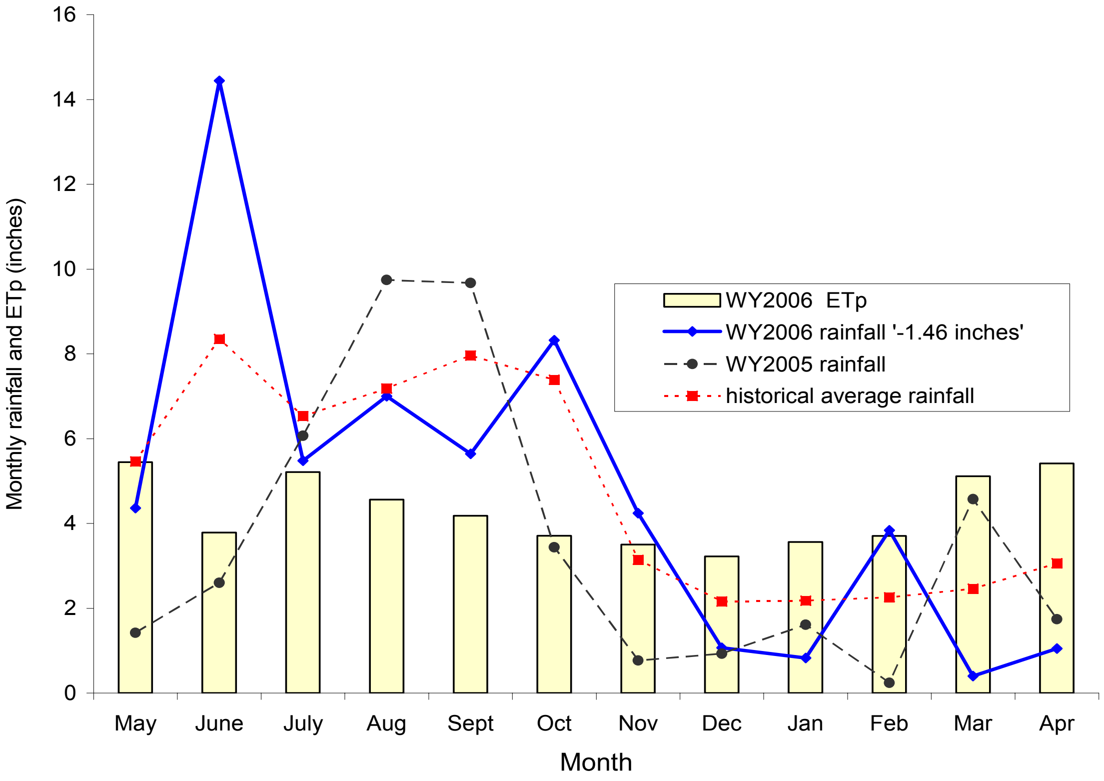


Figure 2-24. Monthly rainfall and ETp for the Broward County rainfall area.

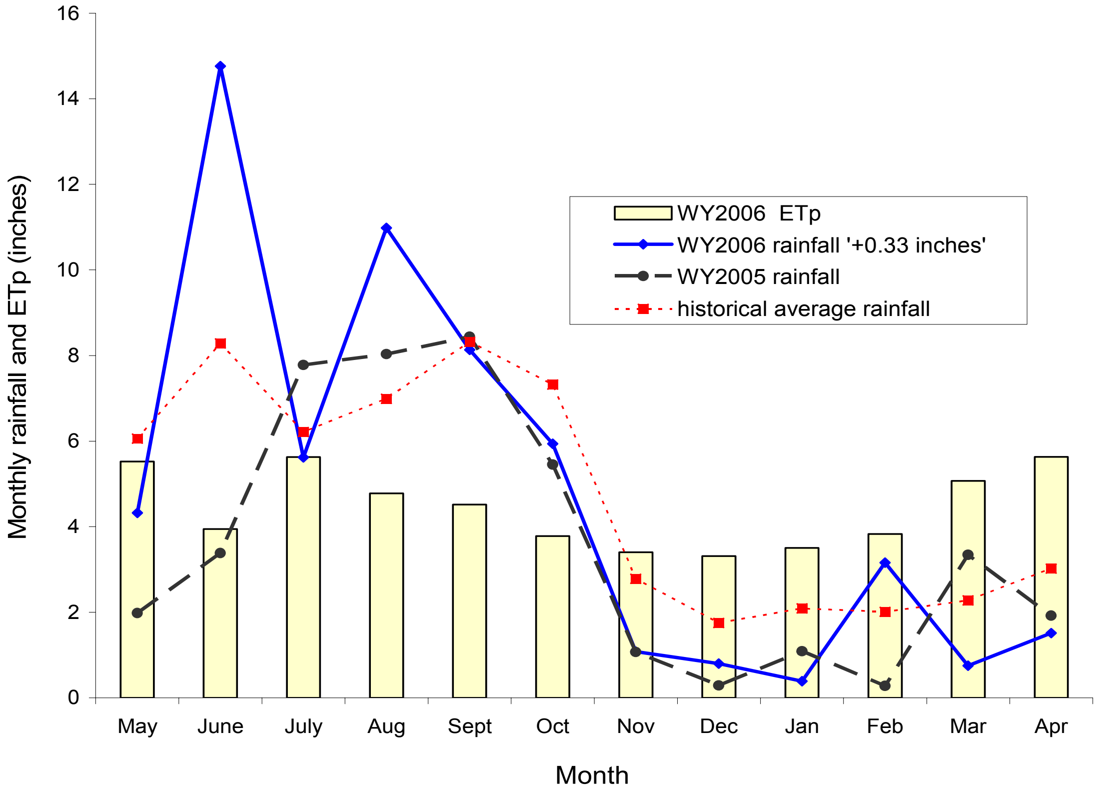


Figure 2-25. Monthly rainfall and ETp for the Miami-Dade County rainfall area.

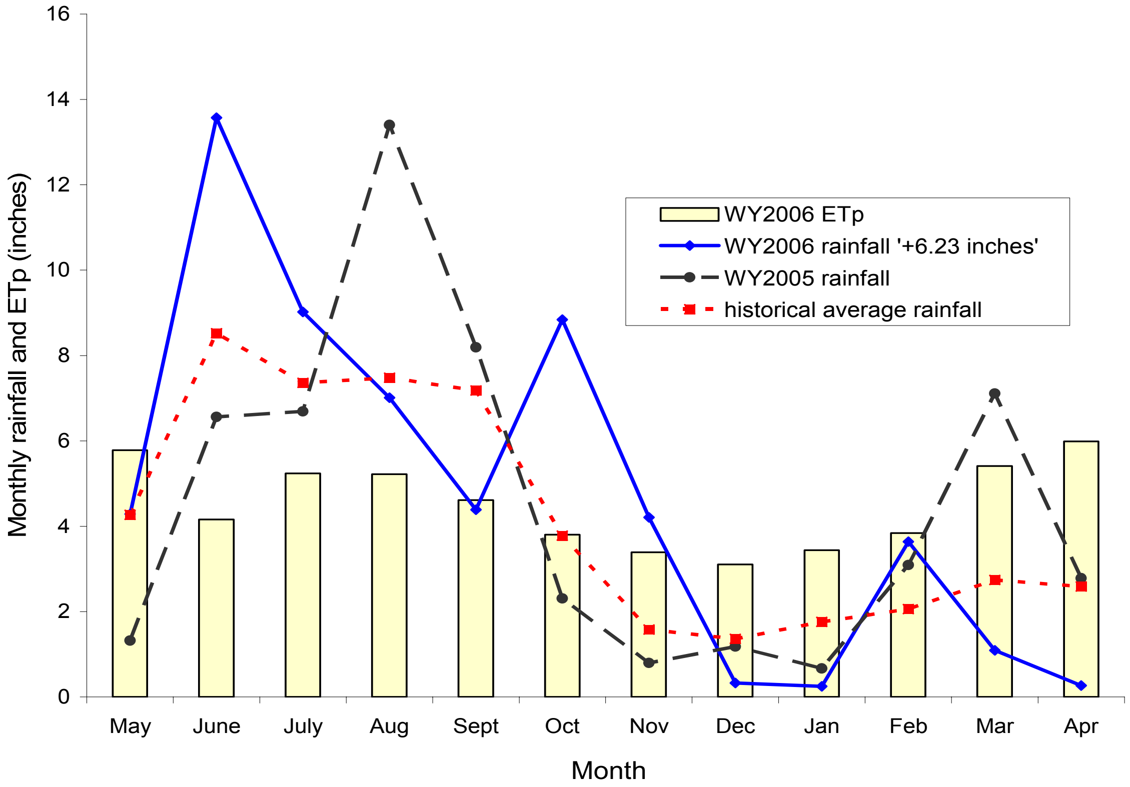


Figure 2-26. Monthly rainfall and ETp for the Caloosahatchee rainfall area.

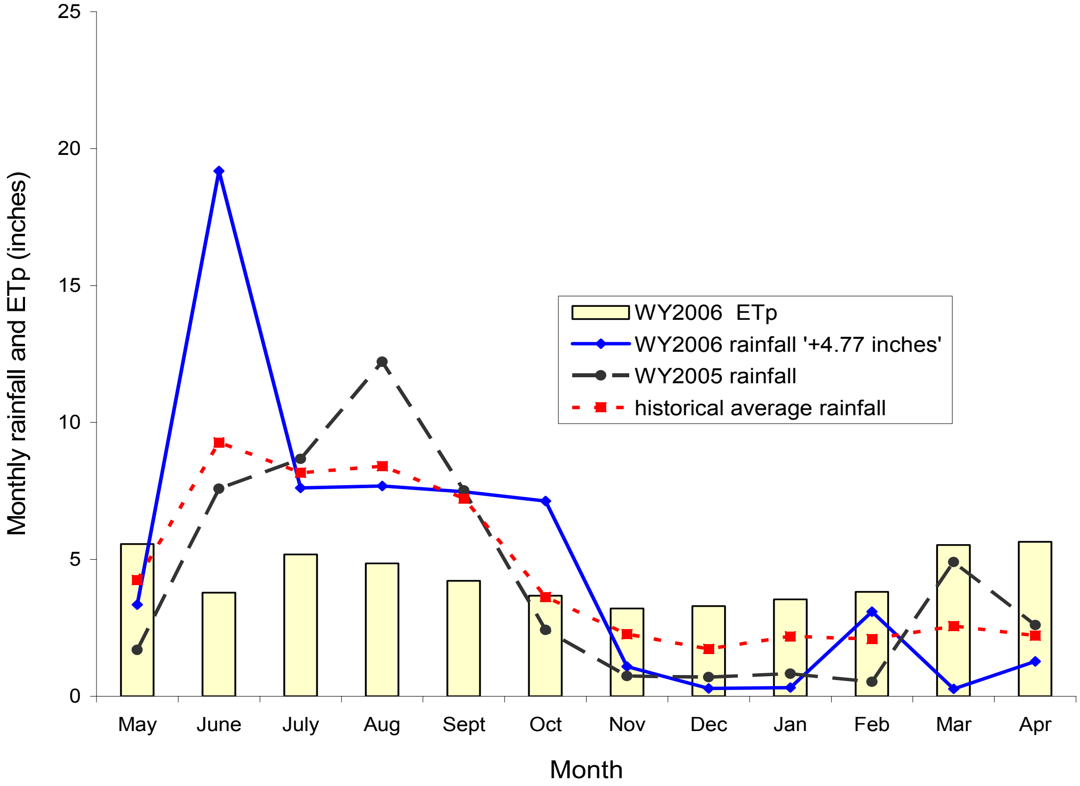


Figure 2-27. Monthly rainfall and ETp for the Big Cypress Basin rainfall area.

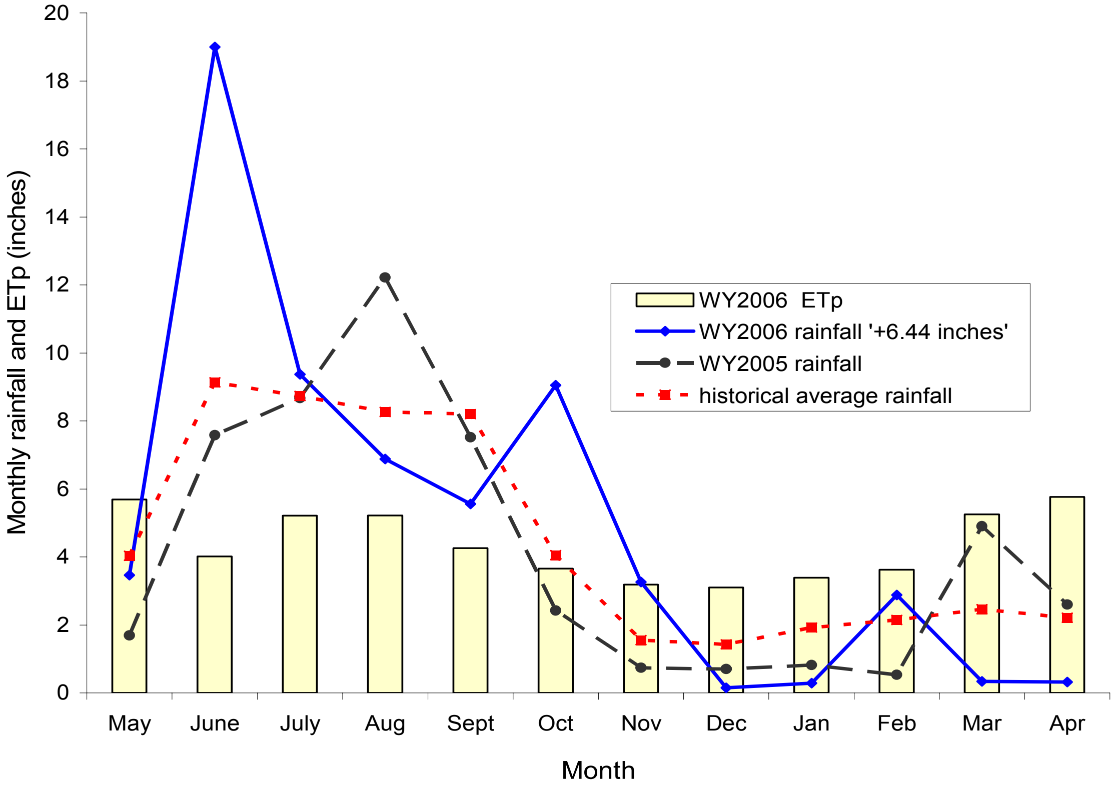


Figure 2-28. Monthly rainfall and ETp for the Southwest Coast rainfall area.

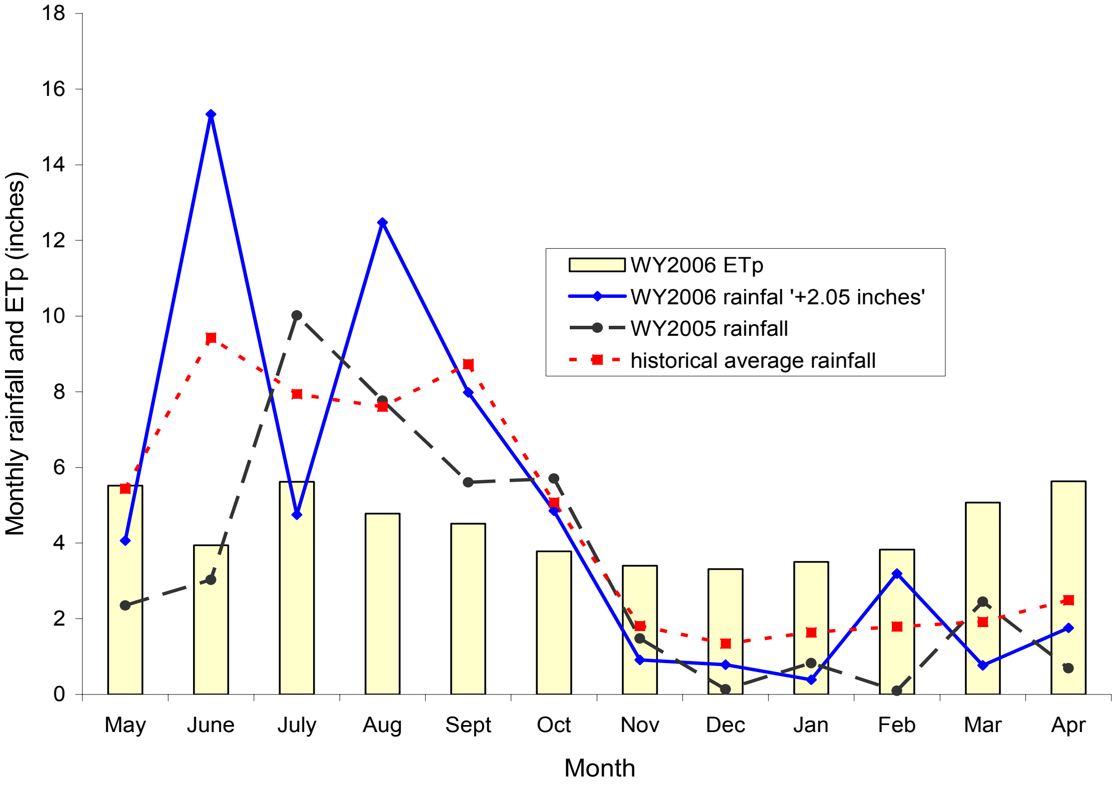


Figure 2-29. Monthly rainfall and ETp for the ENP rainfall area.

Rainfall and evapotranspiration are the main parameters in the hydrologic balance of the Everglades. The delicate balance between these two parameters maintains the hydrological system of South Florida in either a wet or dry condition. Evaporation from open water and transpiration from vegetation are functions of solar radiation, temperature, wind speed, humidity, atmospheric pressure, characteristics of the surrounding environment, and type and condition of vegetation. In South Florida, most of the variation in evapotranspiration is explained by solar radiation (Abtew, 1996). Various measurements and estimates of evapotranspiration have been reported in the literature for various locations in Central and South Florida. Regional estimates of evapotranspiration from open waters and 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). Model estimates of annual ETp from the District's hydrometeorologic database, DBHYDRO, are depicted in **Figures 2-15** through **2-29**. WY2006 monthly ETp for each rain area is shown in **Table 2-8**. The closest site to a rainfall area with available ETp data was used to estimate ETp for the area. ETp is actual evaporation for lakes, wetlands, and any feature that is wet year-round. The model that is used to estimate potential or wetland and open water evapotranspiration (ET) is presented as follows (Abtew, 1996):

$$ET = K_1 \frac{Rs}{\lambda}$$

ET is daily evapotranspiration from wetland or shallow open water (millimeters per day), where R_s is solar radiation [mega joules (MJ) per square meters per day], λ is latent heat of vaporization (MJ per kilogram), and K_1 is a coefficient (0.53). Estimates for WY2006 are shown in **Tables 2-6** and **2-8**. Generally, ETp increases north to south and decreases with cloud cover duration and timing. The quality of solar radiation data at the weather station where ETp is computed from determines the quality of the ETp estimates.

WATER LEVELS, FLOWS AND WATER MANAGEMENT

Water levels are the measure of regulation schedules for lakes, impoundments, wetlands, and canals. Period of record (POR) daily mean water levels (stage) graphs and regulation schedules are presented for lakes, impoundments, and ENP in Appendices 2-5 and 2-6, respectively. In this section, daily average water levels and corresponding regulation schedules are presented for the major lakes and impoundments. All water levels are expressed in ft NGVD. Also, current year water level statistics is compared to the previous water year and historical water level records. Comparison of monthly historical average, WY2005 and WY2006 water levels are shown in Appendix 2-7.

In the District's water management system, surface water flow is generally regulated through water control structures and operational guidelines, such as the different regulation schedules for the major lakes, impoundments, and canals (Appendix 2-6). It is a delicate system that can change from a flooding state to a water shortage, or to situations of environmental impact, in a relatively short period. Water levels and flows are regulated from the Upper Kissimmee Chain of Lakes to the Everglades. At times, temporary deviations are requested to operate the system outside of the bounds of the regulation schedule to manage water quantity, quality, and storage and conveyance system integrity. For example, Lake Okeechobee was being operated under a temporary planned deviation from the regulation schedule for the period January 26, 2006, to December 31, 2006 (USACE, 2006). The objective of the deviation was to minimize the risk of high lake levels by expanding the conditions under which releases were made. Another example is WCA-1 that operated under temporary deviation since April 22, 2005, and expired on July 31, 2006. The main element of this deviation was to suspend the requirement of an equivalent volume of inflow into WCA-1 before the release of water supply under the conditions of the schedule (USACE, 2005). Appendix 2-8 contains tables of WY2006 monthly flow volumes for the systems discussed below. Appendix 2-9 presents comparisons of historical monthly average, WY2005 and WY2006 monthly flows for each lake or impoundment. In most areas, the impact of the wet month of June and the 2005 hurricanes is distinct in generating peak flows. Inflows and outflows through the major systems are summarized below.

Upper Kissimmee Chain of Lakes

The Kissimmee Basin is an integrated system consisting of several lakes with interconnecting canals and flow control structures (**Figure 2-30**). The Upper Kissimmee Basin structures are operated according to the regulation schedules. The details of the water control plan for Kissimmee River can be obtained from Master Water Control Manual for Kissimmee River – Lake Istokpoga (USACE, 1994).

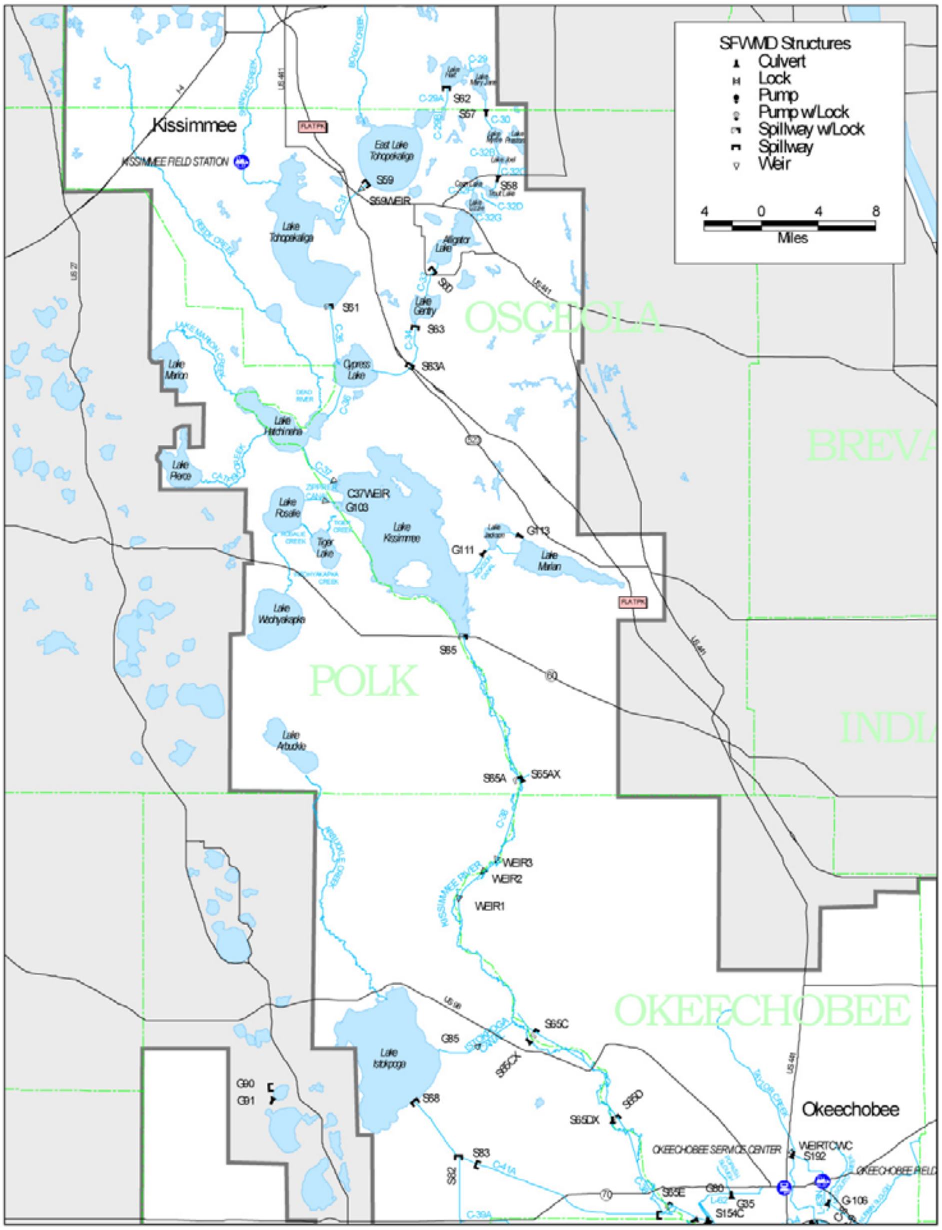


Figure 2-30. Upper and Lower Kissimmee System, Lake Istokpoga, and Harney Prairie areas.

Lake Alligator

The outflows from lakes Alligator, Center, Coon, Trout, Lizzie, and Brick are controlled by two structures, S-58 and S-60. S-58 is located in the C-32 Canal that connects lakes Trout and Joel, and S-60 is located in the C-33 Canal between lakes Alligator and Gentry. S-58 maintains stages in Lake Alligator upstream from the structure, while S-60 maintains the optimum stage on Lake Alligator. All of these lakes are regulated between elevations 61.5 and 64.0 ft NGVD on a seasonally varying schedule. Lake Alligator has had an average water level (stage) of 62.47 ft NGVD since 1993 (site S-60 headwater). The daily average stage for WY2006 was 63.29 ft NGVD, compared to 63.18 ft NGVD for WY2005. The maximum daily average water level was 64.17 ft NGVD (December 20, 1999) and the minimum was 58.13 ft NGVD; the minimum stage was reached during the 2000–2001 drought in South Florida. Daily water level observations for Lake Alligator in the last 12 years show that the most significant change in water levels occurred in the 2000–2001 drought (Appendix 2-5, Figure 1). The regulation schedule, the operational guideline for maintaining periodic water levels in Lake Alligator, is shown in Appendix 2-6, Figure 1. **Figure 2-31** shows the daily averages stages at the headwater of S-60 and the regulation schedule level for Lake Alligator during WY2006. During October 2005, the stages exceeded the regulation due to significant rain amounts from Hurricane Wilma. Maximum practicable releases were made to return stages to the regulation schedule as soon as possible. In spring 2006, the stage recession started earlier than the regulation schedule due to previously scheduled maintenance related to construction work for the inflow and outflow structures of S-60, S-63, and S-63A. Monthly historical average, WY2005 and WY2006 water levels are shown in Appendix 2-7, Figure 1.

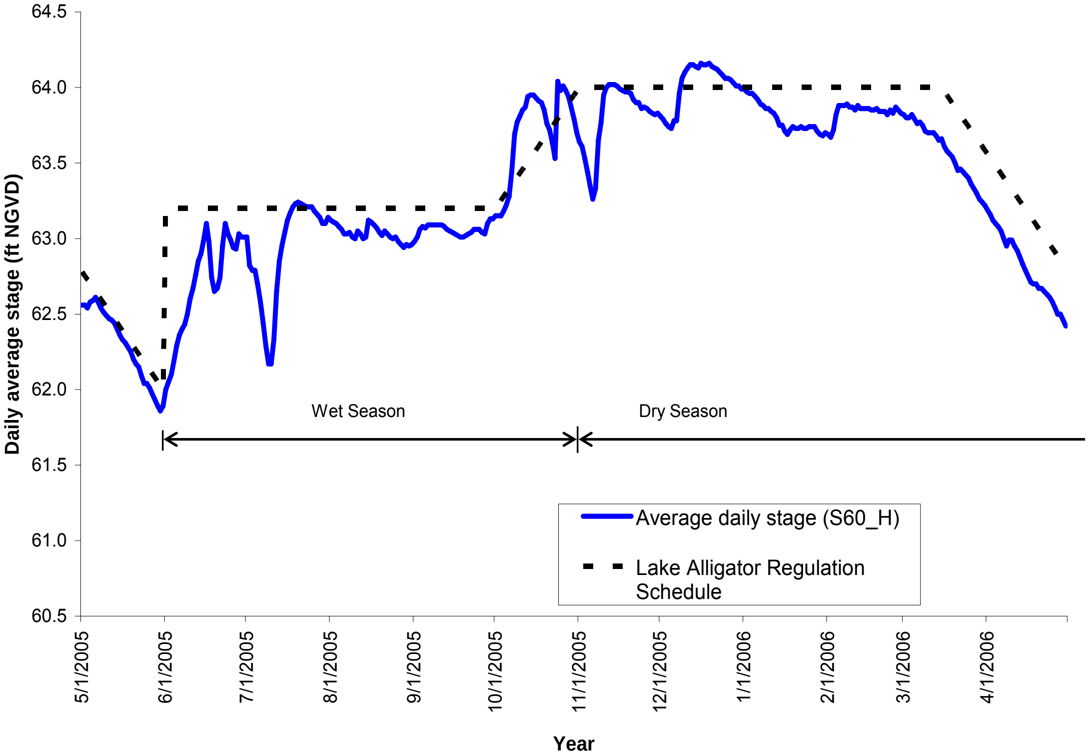


Figure 2-31. Average daily water levels and regulation schedule for Lake Alligator.

Lakes Joel, Myrtle, and Preston

Lakes Joel, Myrtle, and Preston are regulated by structure S-57, which is located in the C-30 Canal that connects lakes Myrtle and Mary Jane. All three lakes are regulated between 59.5 and 62.0 ft NGVD on a seasonally varying schedule. **Figure 2-32** shows the daily averages stages at the headwater of S-57 and the regulation schedule for Lake Myrtle during WY2006. During June and October, the stages exceeded the regulation due to significant rain amounts in the month of June and in October due to Hurricane Wilma. Maximum practicable releases were made during these periods to bring stages back to the regulation schedule level.

Lake Myrtle has had an average water level (stage) of 60.92 ft NGVD since 1993 (site S-57 headwater). The maximum daily average water level of 65.22 ft NGVD was reached during the 2005 hurricane season (WY2006). The minimum stage was 58.45 ft NGVD, which was reached during the 2000–2001 drought. Daily water level observations for Lake Myrtle in the last 12 years show that the most significant drop in water level occurred in 2001 (Appendix 2-5, Figure 2). The regulation schedule for Lake Myrtle is shown in Appendix 2-6, Figure 2. The daily average stage for WY2006 was 61.48 ft NGVD, compared to 61.60 ft NGVD for WY2005. Monthly historical averages, WY2005 and WY2006 water levels are shown in Appendix 2-7, Figure 2**.**

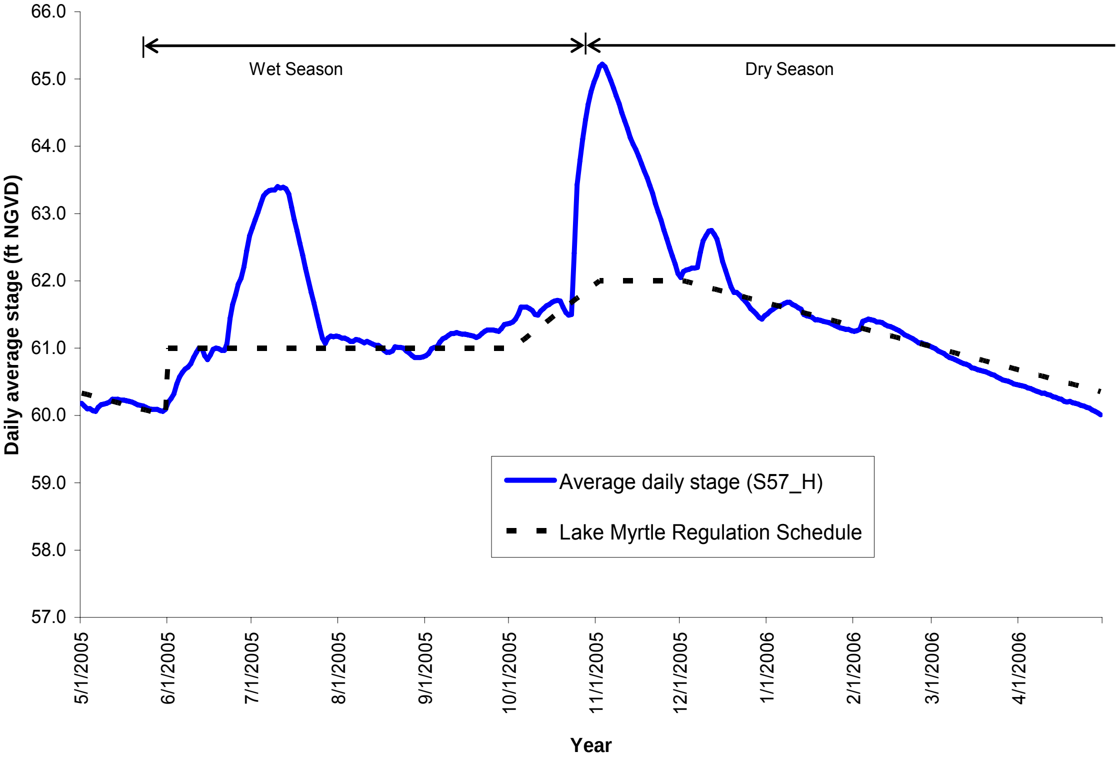


Figure 2-32. Average daily water levels and regulation schedule for Lake Myrtle.

Lakes Hart and Mary Jane

Lakes Hart and Mary Jane are regulated by structure S-62. S-62 is located in the C-29 Canal that discharges into Lake Ajay. The lakes are regulated between elevations 59.5 and 61.0 ft NGVD according to a seasonally varying schedule. **Figure 2-33** shows the daily averages stages at the headwater of S-62 and regulation schedule for Lake Mary Jane during WY2006. During the latter half of October 2005, the stage exceeded significantly due to Hurricane Wilma. Maximum practicable releases were made during this period to bring stages back to the regulation schedule level.

Lake Mary Jane has had an average water level (stage) of 60.07 ft NGVD since 1993 (site S-62 headwater). The maximum daily average water level was 62.16 ft NGVD, reached on October 28, 2005, during the 2005 hurricane season (WY2006). The minimum was 57.19 ft NGVD, which was reached during the 2000–2001 drought. Daily water level observations for Lake Mary Jane in the last 13 years show that the most significant drop in water level occurred in 2001 (Appendix 2-5, Figure 3). The regulation schedule for Lake Mary Jane is shown in Appendix 2-6, Figure 3. The daily average stage for WY2006 was 60.44 ft NGVD, compared to 60.46 ft NGVD for WY2005. Monthly historical average, WY2005 and WY2006 water levels are shown in Appendix 2-7, Figure 3.

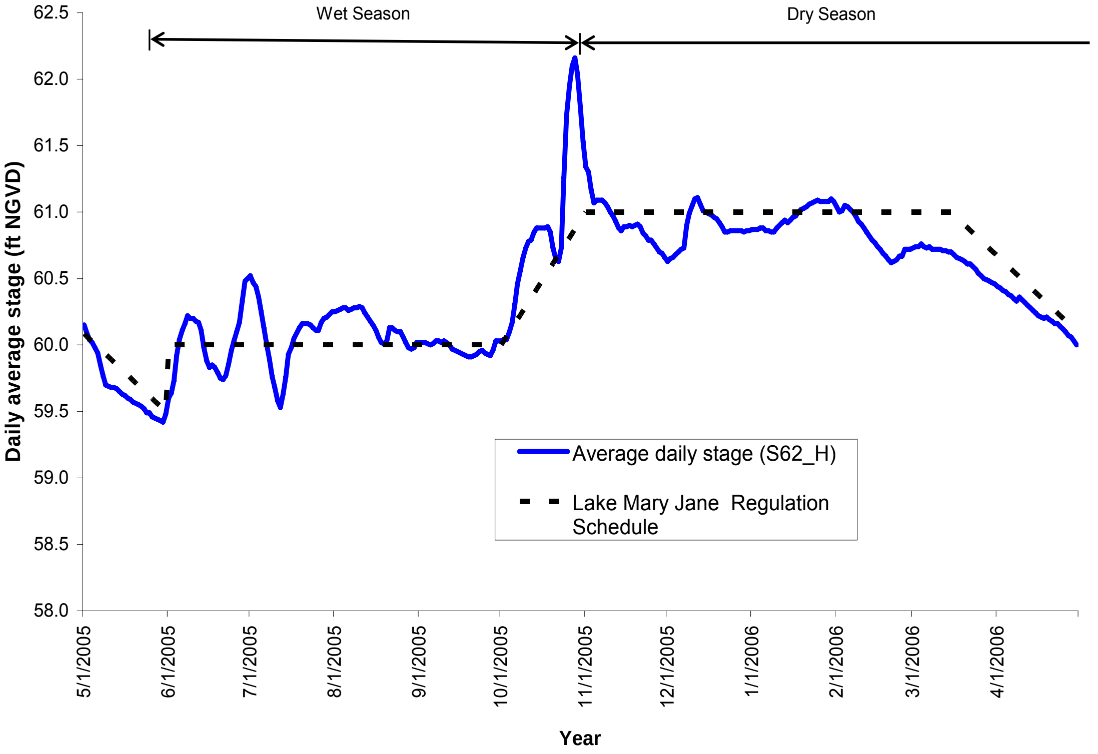


Figure 2-33. Average daily water levels and regulation schedule for Lake Mary Jane.

Lake Gentry

Lake Gentry is regulated by structure S-63, 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. Lake Gentry is regulated between elevations 59.0 and 61.5 ft NGVD according to a seasonally varying schedule. **Figure 2-34** shows the daily averages stages at headwater of S-63 and regulation schedule for Lake Gentry during WY2006. During June and October, the stages exceeded the regulation schedule level due to significant rain amounts in the month of June and Hurricane Wilma in October. Maximum practicable releases were made to bring stages back to the regulation schedule level as soon as possible. In spring 2006, the stage recession started earlier than the regulation schedule due to previously scheduled maintenance related construction work for inflow and outflow structures S-60, S-63, and S-63A.

Lake Gentry has had an average water level (stage) of 60.64 ft NGVD since 1993 (site S-63 headwater). The maximum daily average water level was 61.97 ft NGVD, which was reached in October 2005 during the 2005 hurricane season (WY2006). The minimum was 57.31 ft NGVD, which was reached during the 2000–2001 drought. Daily water level observations for Lake Gentry in the last 13 years show that the most significant drop in water level occurred in 2001 (Appendix 2-5, Figure 4). The regulation schedule for Lake Gentry is shown in Appendix 2-6, Figure 4. The daily average stage for WY2006 was 61.01 ft NGVD, compared to 60.90 ft NGVD for WY2005. **Figure 2-34** depicts average daily water levels and regulation schedule level for Lake Gentry. Monthly historical average, WY2005 and WY2006 water levels are shown in Appendix 2-7, Figure 4.

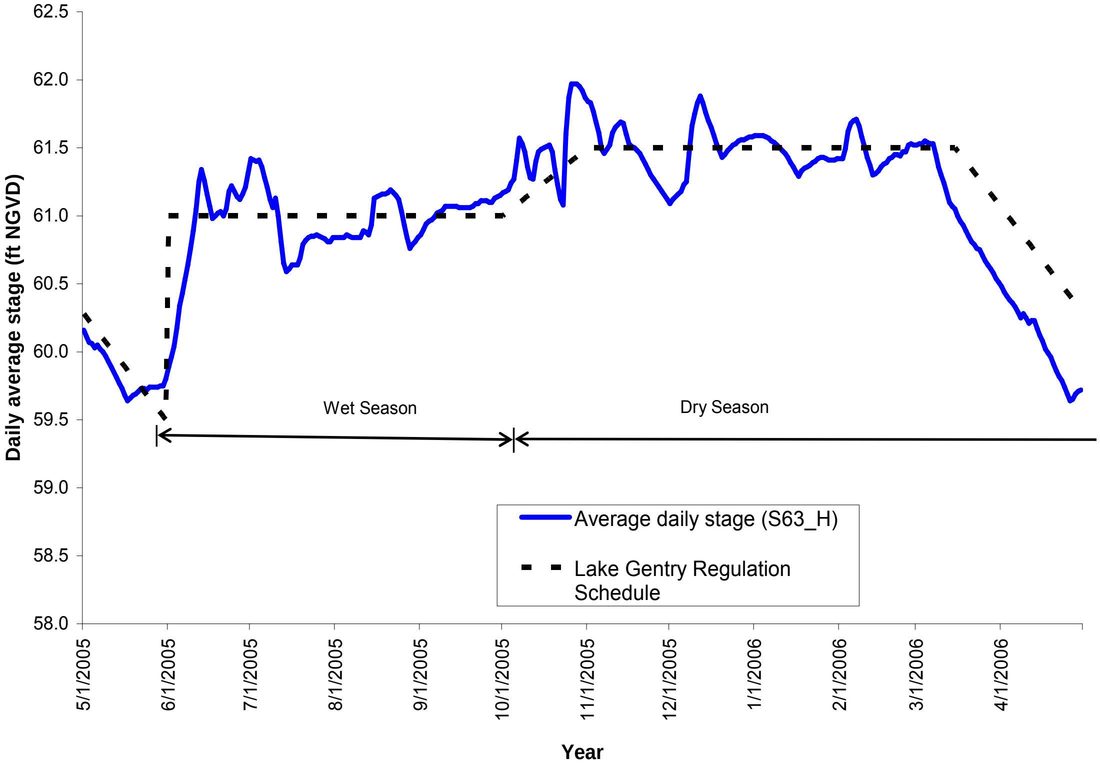


Figure 2-34. Average daily water levels and regulation schedule for Lake Gentry.

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 S-59 to control the tailwater elevation at S-59. The weir crest is at elevation 51.0 ft NGVD. The weir is often submerged and, therefore, the tailwater influences the headwater of S-59. **Figure 2-35** shows the daily averages stages at headwater of S-59 and regulation schedule for East Lake Tohopekaliga during WY2006. During June and October, the stages exceeded the regulation due to significant rain amounts in the month of June and Hurricane Wilma during October. In spring 2006, the stage recession started earlier than the regulation schedule to meet the water supply needs as the rainfall for the months of January, March, and April were lower than normal.

East Lake Tohopekaliga has had an average water level (stage) of 56.7 ft NGVD since 1993 (site S-59 headwater). The maximum daily average water level was 59.12 ft NGVD, reached in December 1997 during an El Niño year. The minimum was 54.41 ft NGVD, which was reached in May 1997. Daily water level observations for East Lake Tohopekaliga in the last 13 years are shown in Appendix 2-5, Figure 5. The regulation schedule for East Lake Tohopekaliga is shown in Appendix 2-6, Figure 5. The daily average stage for WY2006 was 57.03 ft NGVD, compared to 57.2 ft NGVD for WY2005. Monthly historical average, WY2005 and WY2006 water levels are shown in Appendix 2-7, Figure 5.

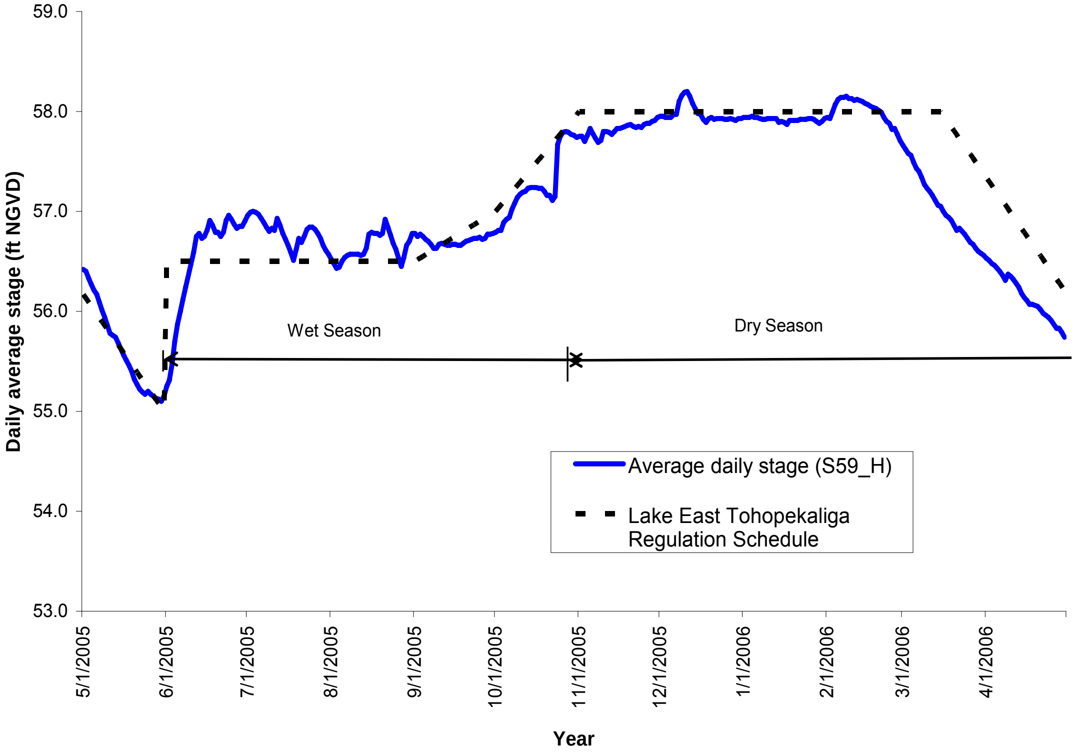


Figure 2-35. Average daily water levels and regulation schedule for East Lake Tohopekaliga.

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 elevations 51.5 and 55.0 ft NGVD on a seasonally varying schedule. S-61 is used to maintain the optimum stage in Lake Tohopekaliga. **Figure 2-36** shows the daily averages stages at the headwater of S-61 and regulation schedule level for Lake Tohopekaliga during WY2006. During June and July, stages exceeded the regulation due to significant rainfall amounts in the month of June. Maximum practicable releases were made during this period to bring stages back to the regulation schedule level. In spring 2006, the stage recession started earlier than the regulation schedule to meet the water supply needs as the rainfall for the months of January, March, and April were lower than normal.

Lake Tohopekaliga has had an average water level (stage) of 53.68 ft NGVD since 1993 (site S-61 headwater). The maximum daily average water level was 56.63 ft NGVD, reached during the 2004 hurricane season (WY2005). The minimum was 48.37 ft NGVD, which was reached in June 2004, following the implementation of a planned lake drawdown completed in cooperation with the Florida Fish and Wildlife Conservation Commission in November 2003 to facilitate muck and tussock removal from the lake bed. The target drawdown water elevation of 49.0 ft NGVD was reached in late February 2004. Daily water level observations for Lake Tohopekaliga in the last 13 years show that the most significant drop in water level occurred in 2004 during the lake drawdown (Appendix 2-5, Figure 6). The regulation schedule for Lake Tohopekaliga is shown in Appendix 2-6, Figure 6. The daily average stage for WY2006 was 54.15 ft NGVD, compared to 53.12 ft NGVD for WY2005. Monthly historical average, WY2005 and WY2006 water levels are shown in Appendix 2-7, Figure 6.

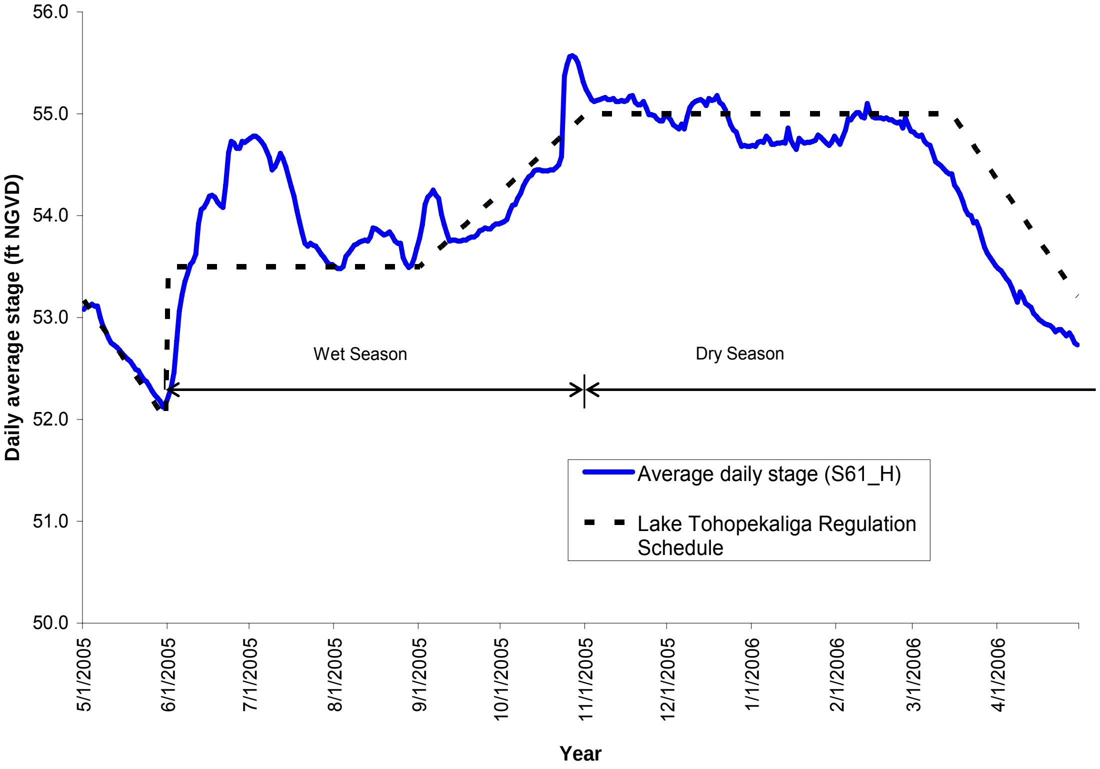


Figure 2-36. Average daily water levels and regulation schedule for Lake Tohopekaliga.

Lakes Kissimmee, Hatchineha, and Cypress

Lakes Kissimmee, Hatchineha, and Cypress are regulated by structure S-65, located at the outlet of Lake Kissimmee and at the head of the C-38 Canal. Lake Kissimmee is regulated between elevations 48.5 and 52.5 ft NGVD on a seasonally varying schedule. **Figure 2-37** shows the daily average stages at the headwater of S-65 and the regulation schedule level for Lake Kissimmee during WY2006. During the month of June, stages exceeded the regulation schedule due to significant rainfall amounts. Maximum practicable releases were made during this period to bring stages back to regulation schedule. During the months of September and October, the stages were lower than the regulation schedule level due to environmental releases required for supporting Kissimmee River flows. In the spring of 2006, the stage recession was started earlier than the regulation schedule due to beginning of snail kite nesting season.

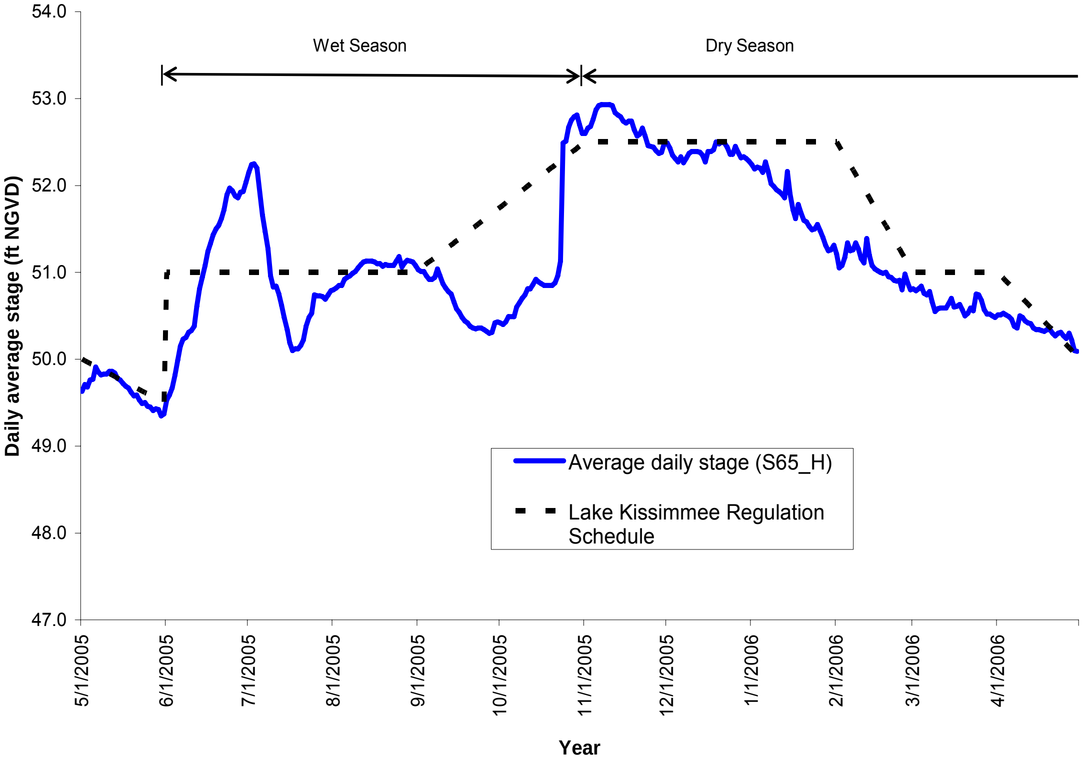


Figure 2-37. Average daily water levels and regulation schedule for Lake Kissimmee.

Lake Kissimmee covers an area of approximately 35,000 acres. The lake has had an average water level (stage) of 50.39 ft NGVD, based on data starting in 1929 (site S-65 headwater). The maximum daily average water level was 56.64 ft NGVD observed in 1953, and the minimum was 42.87 ft NGVD observed in 1977. The average daily water level in WY2006 was 51.11 ft NGVD, compared to 50.43 ft NGVD for WY2005. The impact of the wet month of June and the October hurricane (Wilma) is distinct. Appendix 2-5, Figure 7, shows daily water level for the POR from 1929 to 2006. The regulation schedule for Lake Kissimmee is shown in Appendix 2-6, Figure 7. Monthly historical average, WY2005 and WY2006 water levels are shown in Appendix 2-7, Figure 7.

Lake Kissimmee outflow is regulated through structure S-65. Based on flow data from January 1, 1972, through April 30, 2006, the average annual outflow from Lake Kissimmee was 750,700 ac-ft. The minimum annual flow of 7,900 ac-ft occurred during the 1981 drought in South Florida, and the maximum annual outflow of 1,523,275 ac-ft occurred in 2003. During WY2006, the flow volume from Lake Kissimmee was 1,474,547 ac-ft, higher than the WY2005 flows (1,397,106 ac-ft) and more than twice the historical average flow. The 2005 hurricane season contributed to the increased annual flow from Lake Kissimmee for WY2006.

The Lower Kissimmee System

The Lower Kissimmee System consists of the Kissimmee River (C-38 Canal) and four structures (S-65A, S-65C, S-65D, and S65-E) that form four pools (A, BC, D, and E). These structures are operated according to the optimum stages. The optimum stages for S-65A, S-65-C, S-65D, and S-65E are 46.3, 34.4, 26.8, and 21.0 ft NGVD, respectively. The pool BC contains three weirs (Weir 1, 2, and 3) that divert water to historic oxbows of natural channel where marshland existed prior to Kissimmee River channelization project.

Pool A

Downstream of S-65, stages in Pool A are controlled by S-65A, 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 located through the east tieback levee at the natural channel of the Kissimmee River. The structure is made of 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 structure also provides water to the oxbows of the natural river channel. **Figure 2-38** shows the daily averages stages at the headwater of S-65A and optimum stage schedule for Pool A during WY2006. Stages exceeded the optimum due to significant rainfall amounts in the months of June and October (Hurricane Wilma). Maximum practicable releases were made during these periods to return stages to the optimal of 46.3 ft NGVD. During WY2006, headwater stages at S-65A ranged from 46.01 to 47.98 ft NGVD.

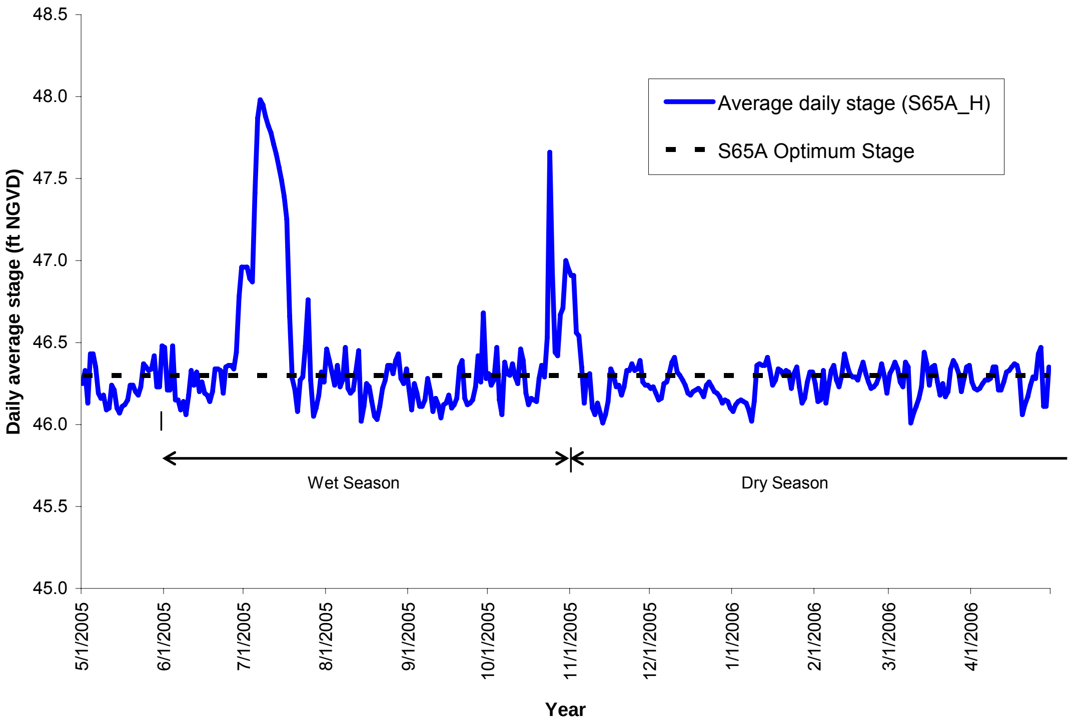


Figure 2-38. Average daily stages and optimal stage schedule at S-65A.

Pool BC

Stages in Pool BC are controlled by S-65C, located downstream of S-65A. S-65C is a gated spillway and lock structure that normally maintains an optimum headwater elevation at 34.0 ft NGVD. In addition to S-65C, there is a culvert structure located through the east tieback levee at the natural channel of the Kissimmee River. During WY2006, headwater stages at S-65C ranged from 35.04 to 35.96 ft NGVD.

Pool D

Stages in Pool D are controlled by S-65D, located downstream of S-65C. S-65D is a gated spillway and lock structure that normally maintains an optimum headwater elevation at 26.8 ft NGVD. During WY2006, headwater stages at S-65D ranged from 26.30 to 27.46 ft NGVD.

Pool E

Stages in Pool E are controlled by S-65E, located downstream of S-65D. S-65E is a gated spillway and lock structure that normally maintains an optimum headwater elevation at 21.0 ft NGVD. During WY2006, headwater stages at S-65E ranged from 20.18 to 21.35 ft NGVD.

Lake Istokpoga

Stages in Lake Istokpoga (**Figure 2-39**) are regulated by the S-68 spillway located at the south end of the lake. Lake Istokpoga is regulated in accordance with the regulation schedule that varies seasonally (Appendix 2-6, Figure 8). The S-68 spillway maintains the optimum water stages in Lake Istokpoga and discharges water to C-41A (the Slough Canal). The Harney Pond Canal (C-41 Canal), Indian Prairie Canal (C-40 Canal), and State Road 70 Canal (C-39A) provide secondary conveyance capacity for the regulation of floods in Lake Istokpoga. C-40 and C-41 flow into Lake Okeechobee whereas C-41A 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 2-39** shows the daily averages stages at the headwater of S-68 and the regulation schedule level for Lake Istokpoga during WY2006. During the month of June, stages exceeded the regulation due to significant rain amounts. Maximum practicable releases were made between June and September to bring stages back to the regulation schedule level. In the spring of 2006, the stage recession was started in March, earlier than the regulation schedule to meet water supply needs as the rainfall for the months of January, March, and April were lower than normal.

Lake Istokpoga has a surface area of approximately 27,700 acres with an average water level (stage) of 38.83 ft NGVD, based on data collected since 1993 (site S-68 headwater). The maximum daily average water level was 39.78 ft NGVD reached during the 2005 hurricane season (WY2006). The minimum was 35.84 ft NGVD, observed during the 2001 drought. The low water level observed in June 2001 coincided with the environmental enhancement project that removed muck and tussocks from the lake bed. The average daily water level in WY2006 was 39.06 ft NGVD, which was also the average stage in WY2005. Appendix 2-5, Figure 8, shows daily water level for the period from 1993 through 2005. The regulation schedule for Lake Istokpoga is shown in Appendix 2-6, Figure 8. Monthly historical average, WY2005 and WY2006 water levels are shown in Appendix 2-7, Figure 8.

Lake Istokpoga outflow is regulated through structure S-68. The lake's regulation schedule level varies between 37.0 and 39.5 ft NGVD. Based on flow data from January 1, 1972, through April 30, 2006, the average annual outflow from Lake Istokpoga was 223,728 ac-ft. The maximum discharge of 561,924 ac-ft occurred during the 1998 El Niño year. Minimum annual flow of 17,790 ac-ft occurred during the 1981 drought in South Florida. During WY2006, the flow volume from Lake Istokpoga was 528,000 ac-ft. This volume was 2.4 times greater than the average annual outflow and higher than the flow in WY2005 (404,417 ac-ft).

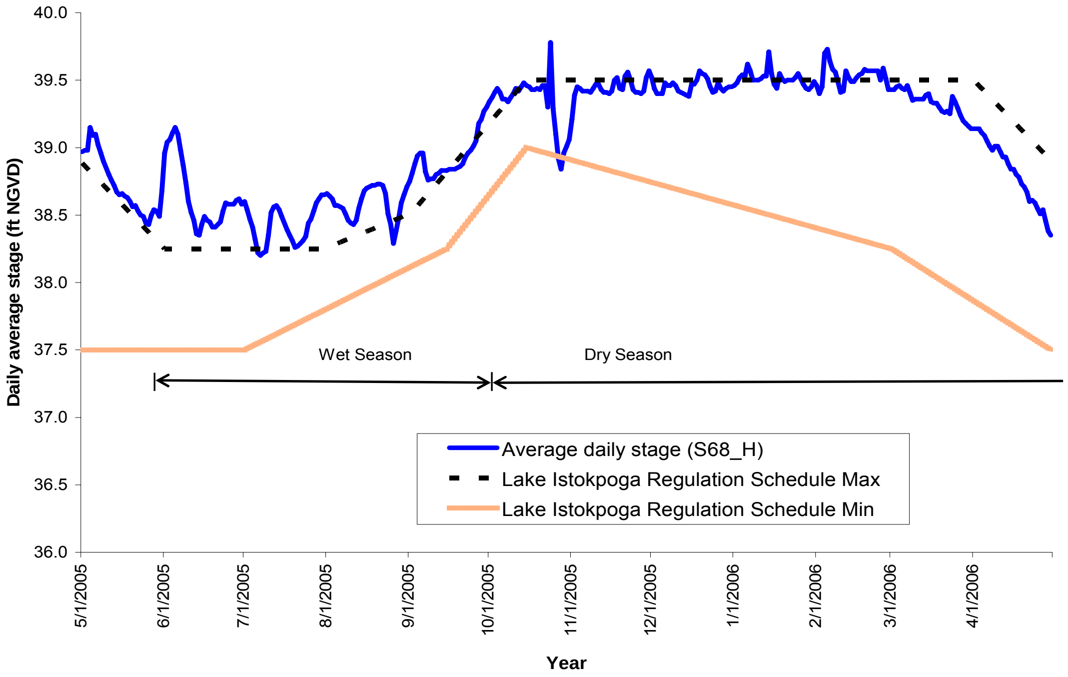


Figure 2-39. Average daily water levels and regulation schedule for Lake Istokpoga.

Lake Okeechobee

Lake Okeechobee (**Figure 2-40**) water is regulated to provide flood control; navigation; water supply for agricultural irrigation, municipalities and industry, EPA, regional groundwater control, and salinity control; enhancement of fish and wildlife, and recreation. The regulation schedule accounts for varying and often conflicting purposes. The regulation schedule for Lake Okeechobee is shown in Appendix 2-6, Figure 9. The details of regulation schedule can be obtained from the Water Control Plan for Lake Okeechobee and Everglades Agricultural Area (USACE, 2000).

Lake Okeechobee has an approximate surface area of 443,000 acres at the historical average stage of 14.44 ft NGVD (1931–2006). The maximum daily average water level was 18.77 ft NGVD, observed in 1947 during an active hurricane season, and the minimum was 8.97 ft NGVD, recorded in the 2001 drought. The average daily water level in WY2006 was 15.53 ft NGVD, which is higher than the 14.75 ft NGVD in WY2005 and the historical average of 14.44 ft NGVD. **Figure 2-41** shows the daily average stages and regulation zones for Lake Okeechobee during WY2006. This figure distinctly shows significant changes in stage. Early summer high rainfall events and the associated runoff sharply increased the lake stage. Hurricane Wilma's rainfall in October and associated runoff also resulted in a sharp increase of stage during the fall. A winter recession due to discharges from the lake and a sharp decline in stage during the spring is associated with dry conditions and withdrawal. Lake Okeechobee has operated under a temporary planned deviation from the WSE regulation schedule since January 26, 2006. The current planned deviation for the purpose of lowering the lake stage ran through December 31, 2006 (USACE, 2006). Appendix 2-5, Figure 9, shows daily water level for Lake Okeechobee for the POR of 1931–2006. Monthly historical average, WY2005 and WY2006 water levels are shown in Appendix 2-7, Figure 9.

Based on flow data records dating from May 5, 1972, through April 30, 2006, the annual average inflow into Lake Okeechobee is 2,158,730 ac-ft with a maximum annual inflow of 3,707,764 ac-ft for the active hurricane year during WY2006. In the past three years, a significant increase of inflow has been observed. During the 2000 drought, the minimum historical annual inflow of 664,121 ac-ft occurred. In WY2006, the volume of inflow to Lake Okeechobee was 3,707,764 ac-ft, higher than the historical average and WY2005 inflows (3,501,889 ac-ft). The WY2005 and WY2006 inflows were two of the largest annual inflows to Lake Okeechobee on record since 1972. A large contribution to the increased inflow was the 2004 and 2005 hurricane seasons. During WY2005, 2,832,700 ac-ft of water was released from the lake. The volume of outflow from Lake Okeechobee in WY2006 was 3,978,904 ac-ft, which was a record high water year discharge since 1972. Based on data from 1972 through 2006, the historical annual average discharge from Lake Okeechobee is 1,521,702 ac-ft with the minimum annual discharge level of 349,978 ac-ft occurring in 1991.

Upper East Coast and the St Lucie Canal and Estuary

Inflows to St. Lucie Canal are from Lake Okeechobee by operation of structure S-308, a gated spillway (S-308C), the Port Mayaca lock (S-308B), and the basin watershed (**Figure 2-40**). Three levels of 10-day pulse releases are made to the St. Lucie Canal in flood zones B, C, and D of the Lake Okeechobee regulation schedule. The pulse release emulates a natural rain storm event within the basin. The optimum water control elevations for St. Lucie Canal range between 14.0 and 14.5 ft NGVD. The outflow from the St. Lucie Canal is discharged into the estuary via S-80 structure, a gated spillway and operated by USACE. The operation of S-80 includes the storm runoff from C-44 basin and tidal St. Lucie watersheds. S-80 operations use regulation procedures that vary with zones A, B, C, D, and E of the Lake Okeechobee regulation schedule (USACE, 2000). Since salinity is an important measure of estuary viability, freshwater flow at S-80 is an important feature of water management activities. WY2006 flows are presented in the *Water Levels, Flows and Water Management* section of this chapter.

The C-23 Canal discharges into the North Fork of the St. Lucie River at structure S-48. In WY2005, 232,808 ac-ft of water was discharged at S-48. During WY2006, 297,214 ac-ft of water was released at S-48, which was 1.9 times the historical average discharge of 155,115 ac-ft (1995–2006) and the largest volume since 1995. The C-24 Canal discharges into the North Fork of the St. Lucie River at S-49. In WY2005, 239,513 ac-ft was discharged at S-49. During WY2006, 259,534 ac-ft of water was discharged at S-49, which was 1.9 times the historical average flow of 134,757 ac-ft (1962–2006). The C-25 Canal discharges into the southern part of the Indian River Lagoon at structure S-50. In WY2005, 249,519 ac-ft was discharged at S-50. During WY2006, 227,680 ac-ft of water was released at this site. This amount was 1.66 times the historical average discharge of 137,212 ac-ft (1965–2006).

Structure S-80 discharges water from the St. Lucie Canal into the South Fork of the St. Lucie River. Flow at this structure comes from the C-44 basin and Lake Okeechobee. Lake Okeechobee discharged 907,187 ac-ft into the St. Lucie Canal through structure S-308 in WY2006. During WY2005, 706,664 ac-ft was discharged at the S-80 structure. In WY2006, 1,192,782 ac-ft was discharged at S-80, an amount 2.23 times the average historical flow of 533,984 ac-ft (1953–2006).

Figure 2-40. The Lake Okeechobee, Upper East Coast, and St. Lucie Canal and Estuary system.

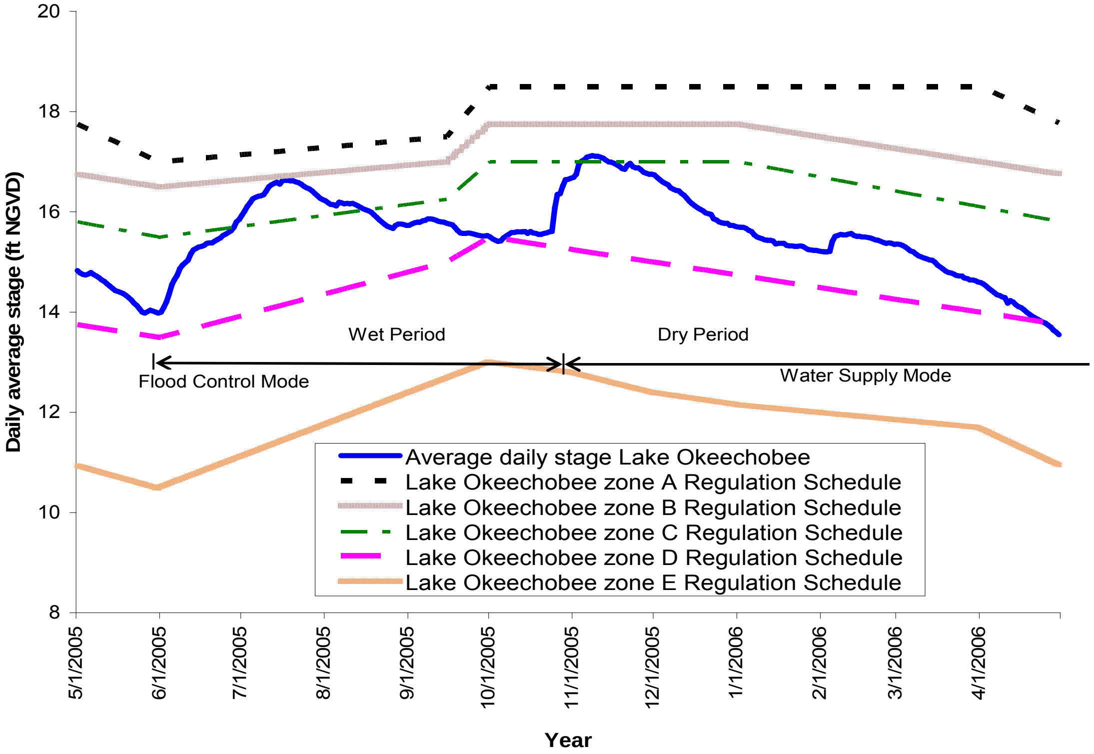


Figure 2-41. Average daily water levels and regulation schedule for Lake Okeechobee.

The Caloosahatchee Canal and Estuary

Inflows to the Caloosahatchee Canal (C-43) are received from the basin watershed and from Lake Okeechobee by operation of S-77, is a gated spillway and lock (**Figure 2-42**). S-77 operations use regulation procedures described in USACE (2000). In flood zones B, C, and D of Lake Okeechobee, three levels of 10-day pulse releases are made to the Caloosahatchee Canal. The pulse release emulates a natural rain storm event within the basin. Downstream of S-77 is S-78, a gated spillway that also receives inflows 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 discharge into the estuary via S-79, a gated spillway and lock, and operated by USACE. The operations of S-79 include the storm 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. Daily averages flows for WY2006 are in the *Water Levels, Flows and Water Management* section of this chapter.

The last structure on the Caloosahatchee Canal that controls discharges into its estuary is S-79. The average annual flow volume at S-79 is 1,280,886 ac-ft, based on the 1972–2006 record. During WY2005, 2,001,901 ac-ft was discharged through the spillway at S-79. In WY2006, 3,615,526 ac-ft of water was discharged. The WY2006 discharge amount is over 2.8 times the average discharge and the largest volume amount recorded since 1972. Through the S-77 structure, Lake Okeechobee discharged discharged 1,210,447 ac-ft in WY2005; in WY2006, 2,175,467 ac-ft were discharged into the Caloosahatchee Canal.

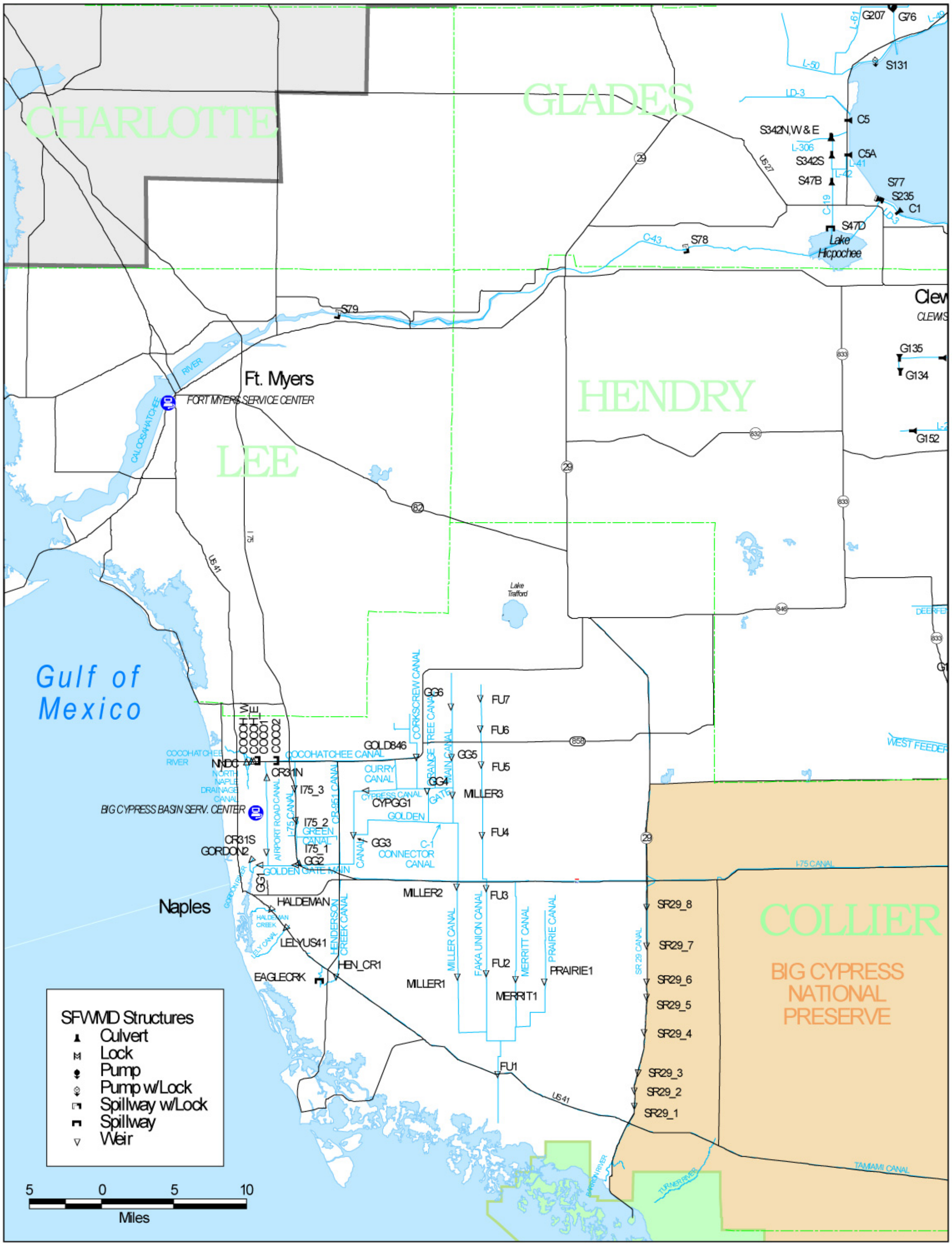


Figure 2-42. The Caloosahatchee Canal and Estuary, Big Cypress Basin, and Southwest Area.

The Everglades Agricultural Area

There are four major canals that pass through the EAA (**Figure 2-43**): Hillsboro Canal, North New River Canal, West Palm Beach Canal, and Miami Canal. Flows from Lake Okeechobee and runoff from the EAA to the Stormwater Treatment Areas (STAs) are discharged 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 WY2006, elevations ranged from 9.09 to 12.76 ft NGVD. The outflows from the four canals to the STAs are provided by pump structures S-5A, S-319, S-6, G-370, and G-372. Outflows for STAs are into the WCAs. During the dry season, water supply for agricultural irrigation uses is provided by these four primary canals. Farmers utilize a set of secondary and tertiary farm canals to distribute water from several gated culverts and pumps to their respective fields.

The Everglades Protection Area

The WCAs are shallow impoundments with a total area of approximately 860,400 acres (**Figure 2-43)**. Water levels in the WCAs change due to drought, rainfall, evapotranspiration, seepage, and surface water management. Surface water management in the WCAs is based on regulation schedules that vary with the time of year, hydrologic conditions, and other needs.

The primary objective of the WCAs is to provide flood control; water supply for agricultural irrigation, municipalities, industry, and the ENP; regional groundwater control and prevention of saltwater intrusion; enhancement of fish and wildlife; and recreation. The second objective is to maintain marsh vegetation in the WCAs, which provides a dampening effect on hurricane-induced wind tides. The regulation schedule represents the monthly and seasonal storage limits for planning purposes. The regulation schedules vary from high stages in the late fall and winter to low stages at the beginning of the wet season. The seasonal range allows the runoff storage during the wet season and water supply use during the dry season. The regulation schedule must take into account various and often conflicting purposes (USACE, 1996). There are also several major constraints for WCA regulation.

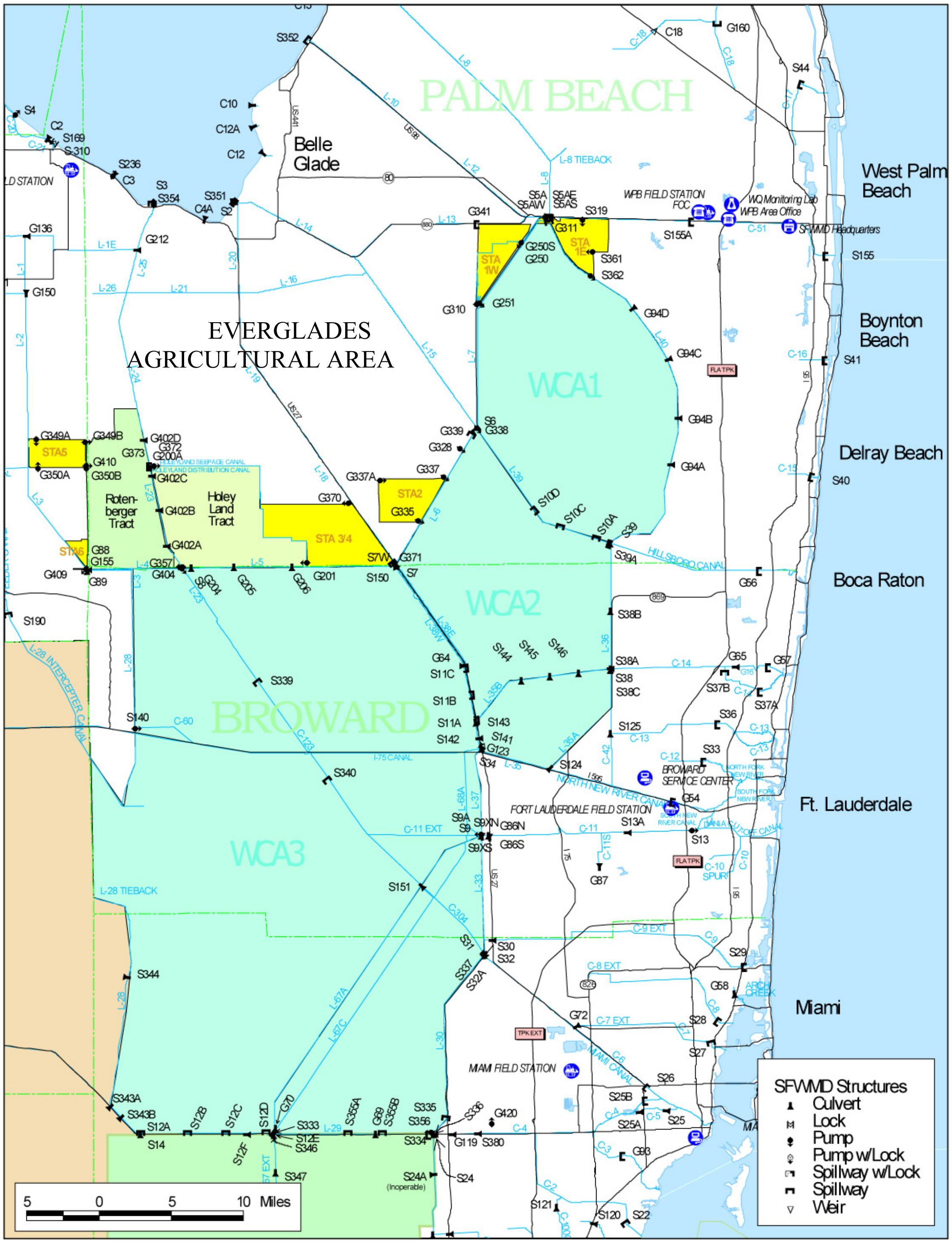


Figure 2-43. The EAA, WCA-1, WCA-2, and WCA-3.

Water Conservation Area 1

WCA-1 consists of 141,440 acres with a daily average water level of 15.58 ft NGVD. WCA-1 is regulated by outflow structures S-10A, S-10C, S-10D, and S-10E; the regulation schedules for WCA-1 are provided in the Master Water Control Plan – Water Conservation Areas, Everglades National Park, and ENP-South Dade Conveyance System – Volume 4 (USACE, 1996). The regulation schedule for WCA-1 is shown in Appendix 2-6, Figure 10. These structures outflow into WCA-2A. Water can also be discharged through S-39 to the east into the Hillsboro Canal using four stage gauges (1-8C, 1-7, 1-8T, and 1-9) as indicator gauges. Different stage gauges are used in different months and conditions. For example, daily water levels were compiled from the four stage gauges based on their regulation schedule uses. Site 1-8C was used from January 1, 2006, through June 30, 2006, 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 calculated from site 1-8C. A maximum daily average water level of 18.38 ft NGVD was reached on October 17, 1999, during Hurricane Irene. A minimum water level of 10 ft NGVD was reached on June 1, 1962, a drought year. For WY2006, average stage in WCA-1 was 16.18 ft NGVD, which was higher than WY2005 (15.85 ft NGVD). For WY2006, the maximum daily average stage of 16.87 ft NGVD was reached in December 2005 and the minimum of 15.17 ft NGVD was reached in July 2005. **Figure 2-44** depicts the WY2006 daily average water level and regulation schedule level for WCA-1. Daily average historical water levels are shown in Appendix 2-5, Figure 10, for the POR from 1960 through 2006. Monthly historical average, WY2005 and WY2006 water levels are shown in Appendix 2-7, Figure 10.

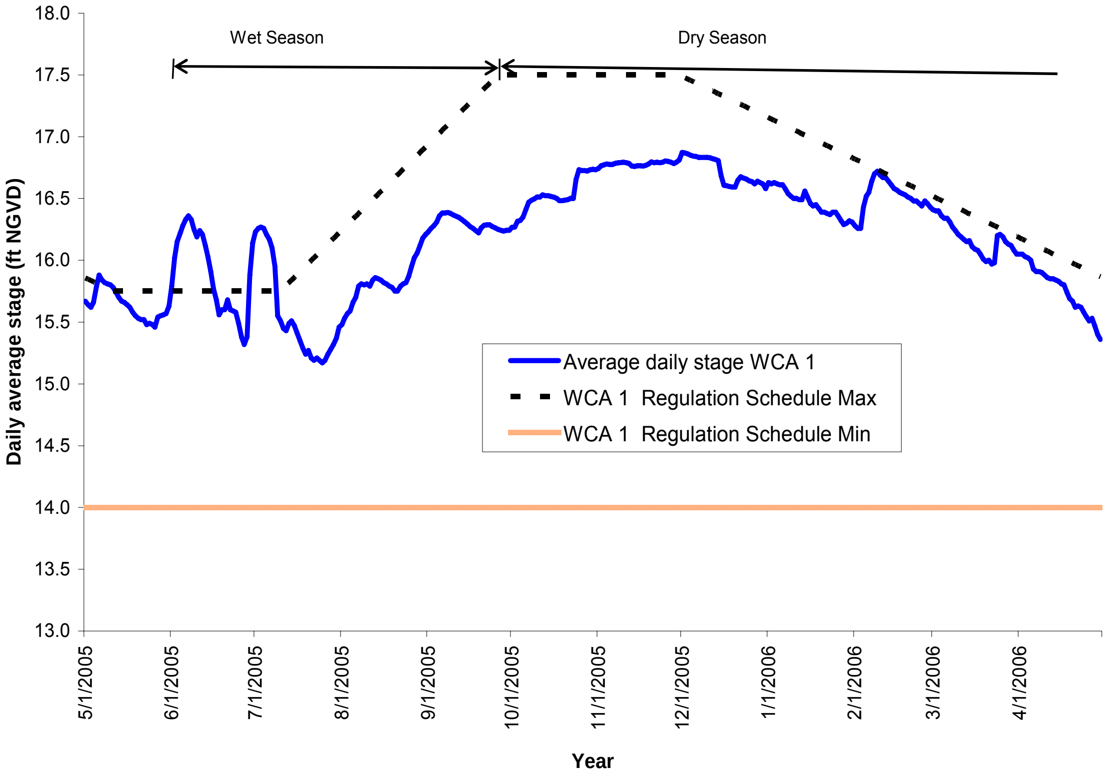


Figure 2-44. WY2006 daily average water level and regulation schedule for WCA-1.

Inflow and outflow structures throughout the WCAs are operated based on regulation schedules. Historical flows through each structure have varying lengths of PORs because of new structures coming online or existing structures that no longer contribute to the inflow and outflow of a system. The structures related to the STAs are relatively recent additions. Time-weighted average historical inflows and outflows were computed from 1978 through 2004. WCA-1 is regulated between 14 and 17.50 ft NGVD. The average historical inflow was 592,378 ac-ft. The total inflow for WY2006 was 252,201 ac-ft, less than half of the historical average, and 52 percent of the WY2004 inflows (476,801 ac-ft). The major inflows (55 percent) were from STA-1W through pump stations G-310 and G-251. ACME1 and ACME2 sources from the Village of Wellington to the east contributed 11 percent of the total inflow. Structures G-300 and G-301 contributed 18 percent of the total inflows, discharging from the inflow and distribution impoundment of STA-1W where most of the S-5A pump discharge is bypassed. The inflow from STA-1E through the new structure S-362 was 16 percent. There was no diversion of flow from S-6 to WCA-1 through structure G-338. S-6 pump discharge has been diverted from WCA-1 into STA-2 since May 2001.

Outflows from WCA-1 were mainly into WCA-2A through structures S-10A, C, and D (57 percent) and into the Hillsboro Canal through the S-39 structure (28 percent) and discharge to the Lake Worth Drainage District through structures G-94A, B, and C (15 percent). There were very small backflows to the STA-1W distribution basin through structures G-301. The total outflow for WY2006 was 205,503 ac-ft, which was half of the total outflows in WY2005 (411,243 ac-ft). The average historical outflow is 534,487 ac-ft.

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 schedules for WCA-2A are provided in USACE (1996). A regulation schedule is not used for WCA-2B because of high seepage rates. Release 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 area are made from spillway structure S-141 to North New River Canal when pool elevation in WCA-2B exceeds 11.0 ft NGVD. The regulation schedule for WCA-2 is shown in Appendix 2-6, Figure 11.

WCA-2A and WCA-2B combined have a total area of 133,400 acres, with 80 percent of the area in WCA-2A. WCA-2A has a historical average water level of 12.57 ft NGVD (site 2-17). A maximum water level of 15.64 ft NGVD was reached on November 18, 1969, and a minimum level of 9.33 ft NGVD was reached on April 29, 1989, during a severe drought year. Appendix 2-5, Figure 11, shows the daily water level for the POR from 1961 through 2006. For WY2006, the average stage in WCA-2 was 12.62 ft NGVD, higher than WY2005 (12.21 ft NGVD). WY2006 maximum daily average stage was 14.27 ft NGVD, and the minimum was 10.84 ft NGVD. **Figure 2-45** depicts the WY2006 daily average water level and regulation schedule level for WCA-2A. Monthly historical average, WY2005 and WY2006 water levels are shown in Appendix 2-7, Figure 11.

The total inflow to WCA-2 for WY2006 was 895,488 ac-ft, compared to 980,424 ac-ft for WY2005 and 667,783 ac-ft for historical averages. The major inflows (51 percent) was through the S-7 pump station with 97 percent of the flow from STA-3/4. STA-2 discharges through pump station G-335 and accounted for 36 percent of the inflows into WCA-2A. WCA-1 discharges through the S-10A, C, D, and E structures are inflows to WCA-2A (13 percent). Inflows through structure G-339, a bypass structure at STA-2, were minimal.

Outflows from WCA-2 are primarily into WCA-3A through structures S-11A, B, and C (65 percent) and into the North New River Canal through structure S-34 (17 percent). Discharge to canals 13 and 14 through structure S-38 was 18 percent. Discharge to the North New River Canal through structure S-143 was 1 percent. There was little backflow to the EAA through the S-7 structure. The total outflow for WY2006 was 1,109,149 ac-ft, which is 127 percent of the total outflows in WY2005 (875,648 ac-ft). The average historical outflow is 689,175 ac-ft.

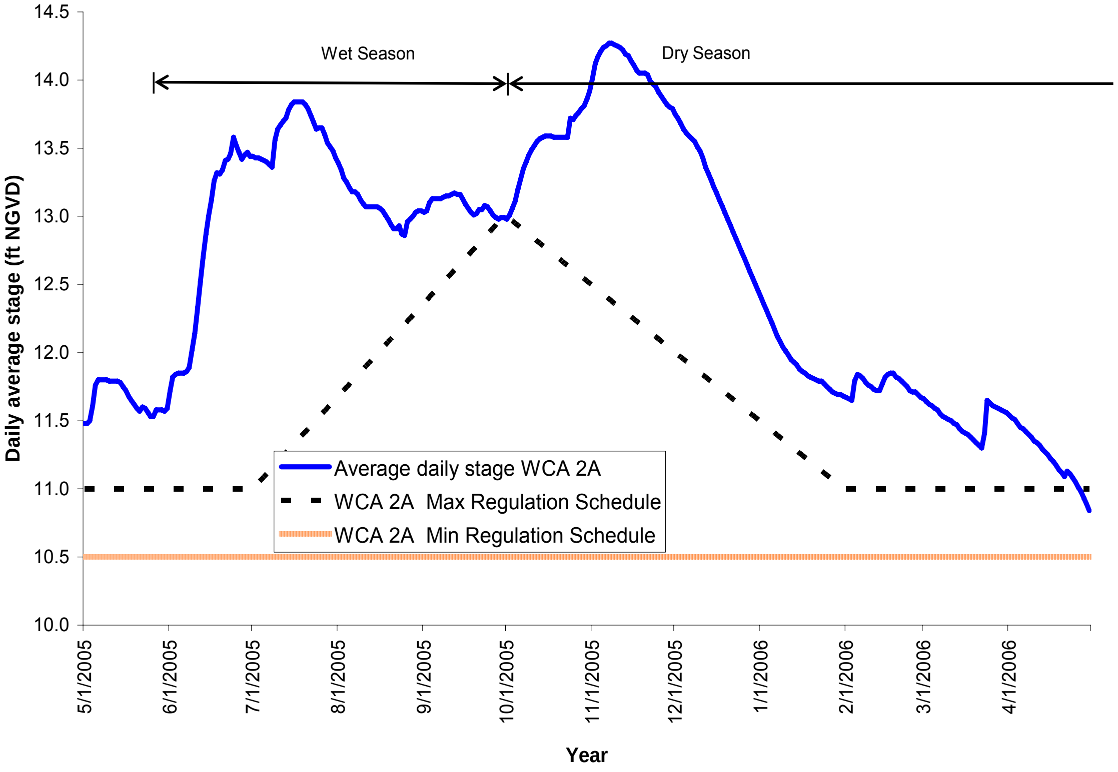


Figure 2-45. WY2006 daily average water level and regulation schedule for WCA-2A.

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 schedules for WCA-3A are 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 the WCA-3B are from S-142 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. Daily average historical water levels for WCA-3A are shown in Appendix 2-5, Figure 12, for the POR from 1961 through 2006. The regulation schedule for WCA-3A is shown in Appendix 2-6, Figure 12.

WCA-3A and WCA-3B combined have a total area of 585,560 acres, with 83 percent of the area in WCA-3A. WCA-3A has a historical average water level of 9.54 ft NGVD. The maximum water level of 12.79 ft NGVD was reached on January 22, 1995, during an El Niño year, and the minimum level of 4.78 ft NGVD was reached on June 6, 1962, during a drought year. Daily average historical water levels are shown in Appendix 2-5, Figure 12. For WY2006, average stage in WCA-3 was 10.58 ft NGVD, which was higher than WY2005 (9.94 ft NGVD). The

WY2006 maximum daily average stage was 11.72 ft NGVD and the minimum was 8.95 ft NGVD. **Figure 2-46** depicts WY2006 daily average water level and regulation schedule for WCA-3A. Monthly historical average, WY2005 and WY2006 water levels are shown in Appendix 2-7, Figure 12.

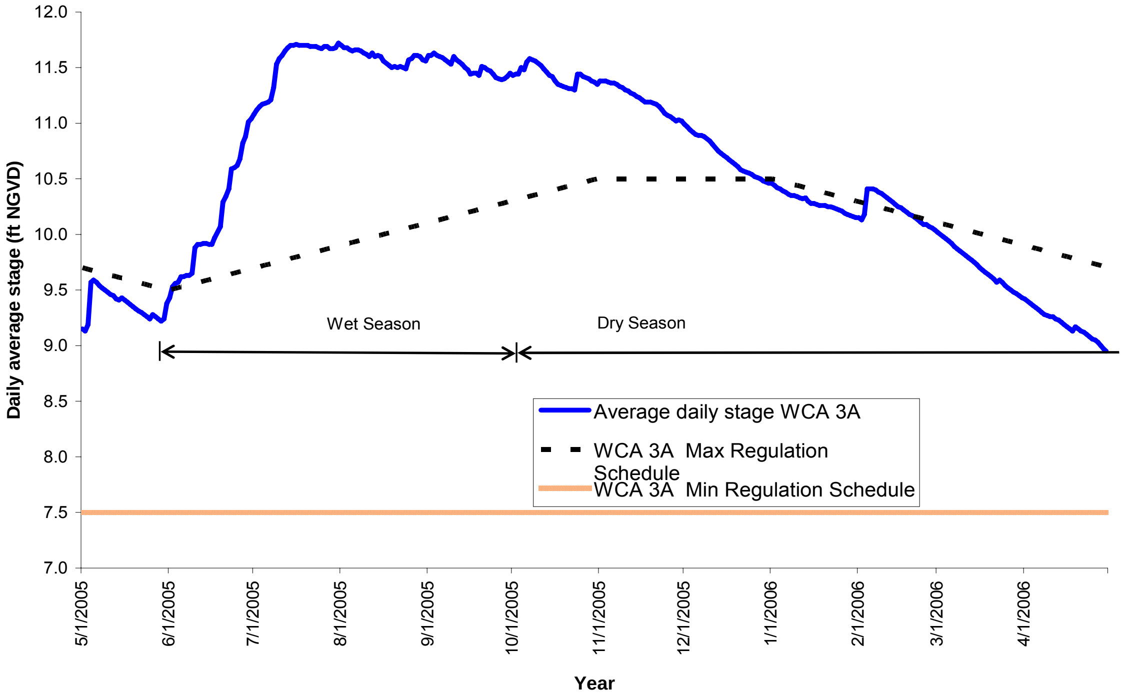


Figure 2-46. WY2006 daily average water level and regulation schedule for WCA-3A.

The WY2006 inflows to WCA-3A were 1,685,358 ac-ft, which was 123 percent of WY2005 inflows (1,366,925 ac-ft). The historical average inflow is 1,213,243 ac-ft. The major inflows were through S-11A, B, and C (43 percent) from WCA-2, and from STA-3/4 through structures S-8 and S-150 (29 percent). Discharges from the east through structure S-9 accounted for 8 percent of the total inflow. The S-140 and S-190 structures to the northwest contributed 12 percent and 9 percent of the inflow to WCA-3A, respectively. Minor inflows were through structures G-69 and S-142. There are currently ungauged potential inflows to WCA-3A through the L-4 borrow canal breach into the L-3 extension canal. The breach has a bottom width of 150 ft, at an elevation of 3 ft NGVD (SFWMD, 2002).

Outflows from WCA-3A are mainly into the ENP through structures S-12A, B, C, D, and E (70 percent). S-333 discharged 9 percent, with potential directions of flow to the south and east, Shark River Slough, and Taylor Creek in the ENP. Discharges into the North New River Canal through structure S-142 accounted for 8 percent of the total outflow, S-31 discharge was 6 percent, and S-343 discharge was 6 percent. The remaining smaller outflows were through structures S-344 and G-69. The total outflow for WY2006 was 1,821,029 ac-ft, which is 119 percent of the total outflows in WY2005 (971,722 ac-ft). The average historical outflow is 888,622 ac-ft.

Everglades National Park

The ENP is located south of WCA-3A and WCA-3B (**Figure 2-47**). The land is a federal property operated and maintained by the ENP, a federal entity within the jurisdiction of the U.S. Department of Interior, National Park Service. The original operational criteria that were used by the District and USACE are presented in USACE (1996). Later, it was modified and presented in the Interim Operational Plan (IOP) (USACE, 2002). The IOP 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 signed (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 the IOP (USACE, 2002).

The ENP water delivery goals are connected to water levels upstream and downstream, and rainfall amounts in WCA-3A. Flows to ENP are made via S-333 and S-12A, B, C, and D. The operational plan for these structures is the Rain-Driven Plan also known as the "Rainfall-Based Management Plan of WCA-3A" that integrates the target flows required to be released from these structures. Because of complexities involved with IOP, regulation schedules are not developed or used for the ENP.

The Rainfall-Based Management Plan of WCA-3A is used to operate water control structures that discharges from WCA-3A to the ENP. The objective of the plan is to restore a more natural hydroperiod and hydropattern in the Northeast Shark River Slough and Everglades National 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) details 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 Canal Project. Their operation plans are presented in the IOP (USACE, 2002). Water deliveries to the eastern panhandle are made via C-111 Canal. The S-18C maintains a desirable freshwater head against saltwater intrusion through 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 overland flow to the panhandle. S-197 releases flows during major flood events according to established guidelines in the IOP (USACE, 2002).

The ENP is approximately 1,376,000 acres in size (Redfield et al., 2003). Water level monitoring at sites P-33 and P-34 has been used in previous consolidated 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, respectively (Sklar et al., 2000). Historical water level data for sites P-33 (1952–2006) and P-34 (1953–2006) was obtained from the District's hydrometeorologic database DBHYDRO and from the ENP's database. For WY2006, the average stage at site P-33 in the ENP was 6.65 ft NGVD, which was higher than WY2005 (6.26 ft NGVD) and the historical average stage (5.96 ft NGVD). For WY2006, the maximum daily average stage at site

P-33 was 7.59 ft NGVD, and the minimum was 5.47 ft NGVD. **Figure 2-48** depicts daily average water level at P-33 for WY2006. Daily average historical water levels for P-33 and P-34 are shown in Appendix 2-5, Figures 13 and 14.

For WY2006, the average stage at site P-34 in the ENP was 3.22 ft NGVD, which was higher than WY2005 (2.59 ft NGVD) and higher than the historical average stage (2.05 ft NGVD). For WY2006, maximum daily average stage was 7.1 ft NGVD, and minimum was 0.83 ft NGVD. **Figure 2-49** depicts daily average water level at P-34 for WY2006. Monthly historical average, WY2005 and WY2006 water levels for P-33 and P-34 are shown in Appendix 2-7, Figures 13 and 14.

Inflow into the ENP is mainly through structures S-12A, B, C, D, and E; S-18; S-332B; S-332C; S-174; S-332D; S-333 and S-334. The major inflow (67 percent) was through the S-12 structures. These structures are operated by the District for the USACE, in accordance with the Rain-Driven Water Deliveries Plan to the ENP and the Regulation Schedule of WCA-3A. This plan determines discharges through the S-333 and through S-12 structures a week in advance using a computer program. A weekly report is posted by the SFWMD, and is available online at http://www.sfwmd.gov/org/ema/reports/sharkriver/index.html (October 9, 2006) or through the District's web site at www.sfwmd.gov under the *What We Do*, *Environmental Monitoring*, *Reports* section, and the *WCA-3A* tab. The objective of this plan is to restore a more natural hydroperiod and hydropattern in the northeast Shark River Slough. Structural and operational modifications were also incorporated into the delivery plan based on the IOP for Protection of the Cape Sable Seaside Sparrow (http://www.saj.usace.army.mil/h2o/lib/documents/index.htm, October 9, 2006). Flows through S-18 accounted for 10 percent of the total flow. Structure S-332D contributed 8 percent of the inflows, S-332B contributed 7 percent, and structure S-332C contributed 4 percent. Inflow from S-333 via structure S-334 was 4 percent. There were minor inflows through S-174. The total surface water inflow to the ENP for WY2006 was 1,901,386 ac-ft, which is more than twice of WY2005 inflows (802,791 ac-ft). The historical average inflow is 1,202,369 ac-ft.

Figure 2-47. Map showing the ENP and Lower East Coast.

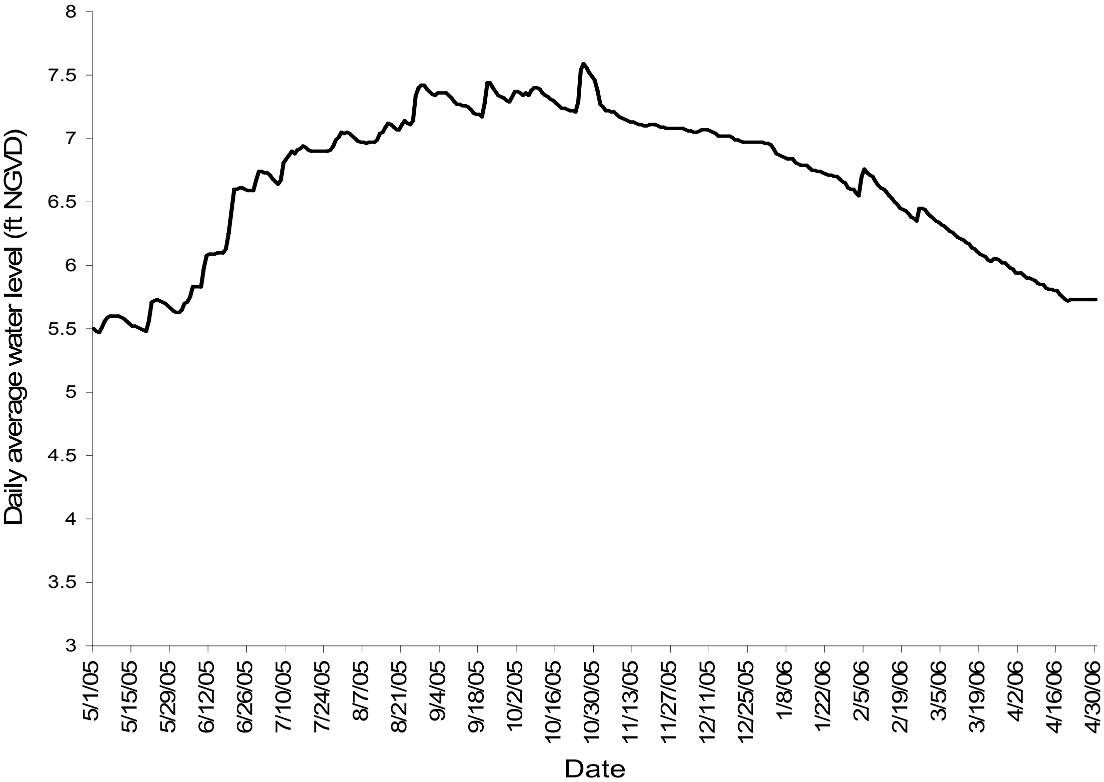


Figure 2-48. WY2006 daily average water level for gauge P-33 in ENP.

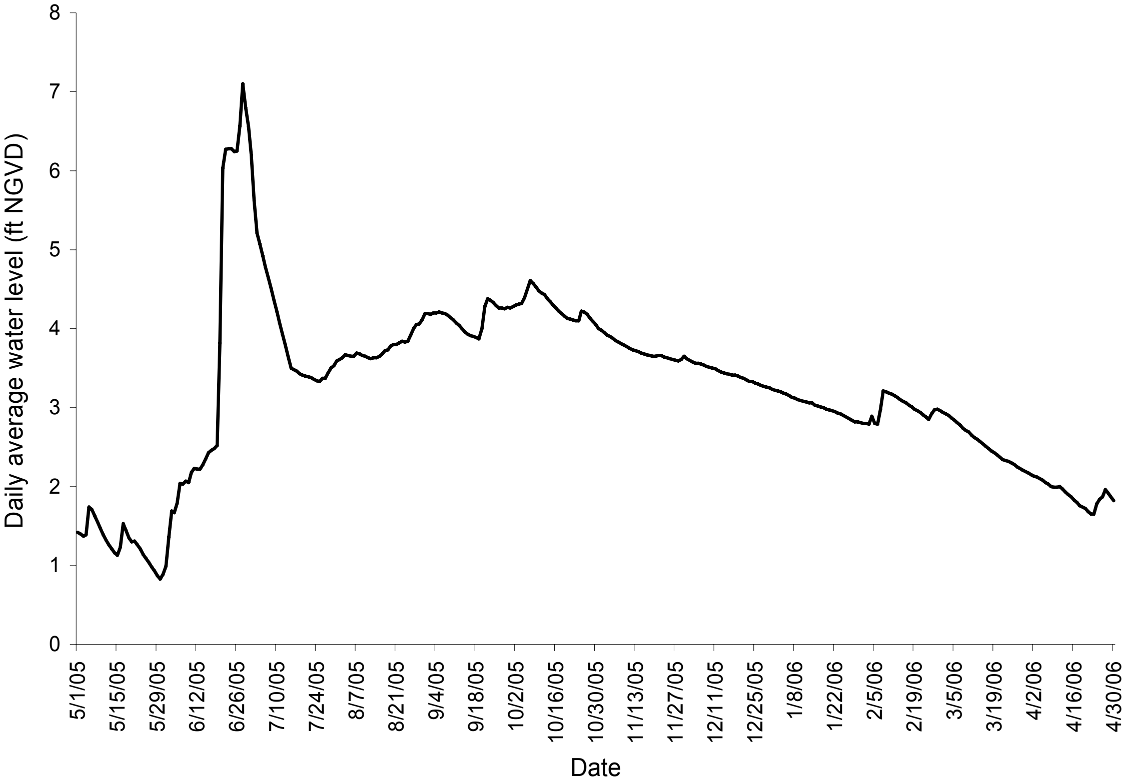


Figure 2-49. WY2006 daily average water level for gauge P-34 in ENP.

THE LOWER EAST COAST

The Lower East Coast System includes the South Dade Conveyance System (**Figure 2-47**). The purpose of the system is to control flood from the drainage area. The system provides water control to prevent over drainage in the area; prevent saltwater intrusion; and provide facilities to convey runoff to the ENP when available. The purpose of 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. Based on operational experience, the stages in canals are usually allowed to recede before supplemental water is introduced into the system. Flow releases during major flood events are made according to established guidelines in USACE (1995).

CONCLUSIONS

For a second year in a row, South Florida experienced a rare series of hurricane events during WY2006. The area was directly hit by two hurricanes and impacted by two others that passed through the region. Hurricanes Dennis (July), Katrina (August), Rita (September), and Wilma (October) hydrologically impacted South Florida. From available records since 1871, the WY2005 and WY2006 series of hurricane events on South Florida was a rare occurrence that had not been observed before. The property losses from Hurricane Wilma were very high. High rainfall, high surface water flows, and rises in water levels in lakes and canals were experienced during the hurricane events and the months that followed. Rainfall for WY2006 in the District area (54.72 inches) was higher than WY2005 rainfall (50.67 inches) and the historical average rainfall of 52.75 inches. Generally in WY2006, the southwestern and western areas of the District had higher rainfall. The general rainfall pattern can be characterized as a wet June and October followed by a dry January and April.

During WY2006, monthly average water levels in most of the Upper Chain of Lakes were generally higher than the WY2005 levels and historical average levels. Lake Kissimmee average water level in WY2006 (51.11 ft NGVD) was higher than that of WY2005 and historical average water levels, whereas Lake Istokpoga average water level in WY2006 (39.06 ft NGVD) was the same as in the previous two water years but higher than the historical average. Lake Okeechobee’s average water level for WY2006 (15.53 ft NGVD) was higher than WY2005 average water level (14.75 ft NGVD) and higher than historical average (14.44 ft NGVD). The wetter than normal June and rainfall from Hurricane Wilma generated record inflows into Lake Okeechobee.

The average water level in WCA-1 for WY2006 was 16.18 ft NGVD. It was higher than the WY2005 average water level (15.85 ft NGVD) and higher than the historical average (15.59 ft NGVD). For WY2006, the average water level in WCA-2 was 12.62 ft NGVD. It was higher than the WY2005 average water level (12.21 ft NGVD) and the historical average (12.57 ft NGVD). The average water level in WCA-3 for WY2006 was 10.58 ft NGVD. It was higher than the WY2005 average water level (9.94 ft NGVD) and the historical average (9.54 ft NGVD). In WY2006, the average water level in the ENP at site P-33 was 6.65 ft NGVD, which was higher than the WY2005 average water level (6.26 ft NGVD) and higher than the historical average (5.96 ft NGVD). Average water level in the ENP at site P-34, for WY2006 was 3.32 ft NGVD. It was also higher than the WY2005 average water level (2.59 ft NGVD) and the historical average (2.04 ft NGVD).

During WY2006, surface water outflow through Lake Kissimmee was 1,474,574 ac-ft, which was higher than WY2005 (1,397,106 ac-ft) and historical average outflows (750,700 ac-ft). The increase in outflows was mainly due to the wetter than average June and Hurricane Wilma in October. Lake Istokpoga discharge was 528,000 ac-ft, which was higher than WY2005

(404,417 ac-ft) and historical average outflows (223,728 ac-ft). Lake Okeechobee inflows were 3,707,764 ac-ft, which was a record high since 1972. In WY2005, Lake Okeechobee inflow was 3,501,889 ac-ft and the historical average inflow is 2,158,720 ac-ft. Outflow for Lake Okeechobee in WY2006 was 3,978,904 ac-ft, which is a record high since 1972. WY2005 outflow was 2,832,700 ac-ft and historical average outflow is 1,521,702 ac-ft.

The WY2006 discharge into the Indian River Lagoon – South and St. Lucie Estuary was 1,977,210 ac-ft with 1,192,901 ac-ft discharged through the St. Lucie canal outflow structure S-80. WY2006 flows were higher than WY2005 and the historical average. Discharge into the Caloosahatchee Estuary through the S-79 structure was 3,615,526 ac-ft, which was a record high since 1972 and higher than the WY2005 outflow (2,001,901 ac-ft) and far higher than the historical average (1,280,886 ac-ft).

Inflows to WCA-1 were 252,201 ac-ft for WY2006 far lower than WY2005 inflows (476,801 ac-ft) and the historical average inflows (592,378 ac-ft). For WY2006, outflows from WCA-1 were 205,503 ac-ft compared to 411,243 ac-ft for WY2005 and historical average of 534,487 ac-ft. WY2006 inflows to WCA-2 were 895,448 compared to 980,424 ac-ft inflows for WY2005 and the historical average of 667,783 ac-ft. WY2006 outflows from WCA-2 were 1,109,149 ac-ft compared to 875,648 ac-ft in WY2005 and the historical average of 689,175 ac-ft. WCA-2 inflows were lower and outflows were higher compared to WY2005.

WY2006 inflows into WCA-3 were 1,685,358 ac-ft compared to 1,366,925 ac-ft in WY2005 and historical average of 1,213,243 ac-ft. WY2006 outflows from WCA-3 were 1,821,029 ac-ft compared to 971,722 ac-ft in WY2005 and historical average of 888,622 ac-ft. WY2006 inflows to the ENP were 1,901,386 ac-ft compared to 802,791 ac-ft in WY2005 and the historical average of 1,202,389 ac-ft. Inflows to the ENP were significantly higher than for WY2005.

LITERATURE CITED

Abtew, W. 1996. Evapotranspiration Measurements and Modeling for Three Wetland Systems in South Florida. *J. of Amer. Water Res. Assoc.*, 32(3): 465–473.

Abtew, W. 2005. Evapotranspiration in the Everglades: Comparison of Bowen Ratio Measurements and Model Estimations. Proceedings of the Annual International Meeting of American Society of Agricultural Engineers, July 17–20, 2005, Tampa, FL, available on CD-ROM, Paper Number 052118.

Abtew, W. and R.S. Huebner. 2000. Hydrologic Impact of Hurricane Irene on South Florida (October 13–17, 1999). Technical Publication EMA-386. South Florida Water Management District, West Palm Beach, FL.

Abtew, W. and R.S. Huebner. 2006. Hydrologic Impact of the 2004 Hurricane Season on South Florida. Randall Graham (ed.). World Environmental and Water Resources Congress 2006. ASCE CD-ROM.

Abtew, W., R.S. Huebner and V. Ciuca. 2006. Chapter 5: Hydrology of the South Florida Environment. Redfield, G., ed. In: *2006 South Florida Environmental Report*, South Florida Water Management District, West Palm Beach, FL.

Abtew, W., R.S. Huebner and S. Sunderland. 2002. Part I: Hydrological Analysis of the 2000–2001 Drought in South Florida. South Florida Water Management District, West Palm Beach, FL.

Abtew, W. and N. Khanal. 1994. Water Budget Analysis for the Everglades Agricultural Area Drainage Basin. *Water Res. Bull.*, 30(3): 429–439.

Abtew, W. and J. Obeysekera. 1996. Drainage Generation and Water Use in the Everglades Agricultural Area Basin. *J. of Amer. Water Res. Assoc.*, 32(6): 1147–1158.

Abtew, W., J. Obeysekera, M. Irizarry-Ortiz, D. Lyons and A. Reardon. 2003. Evapotranspiration Estimation for South Florida. P. Bizier and P. DeBarry, eds. In: *Proceedings of World Water and Environmental Resources Congress 2003*, American Society of Civil Engineers, June 23–26, 2003, Philadelphia, PA. (Available on CD ROM.).

Ali, A., W. Abtew, S. VanHorn and N. Khanal. 2000. Temporal and Spatial Characterization of Rainfall over Central and South Florida. *J. of the Amer. Water Res. Assoc.*, 36(4): 833–848.

Ali, A. and W. Abtew. 1999a. Regional Rainfall Frequency Analysis. Technical Publication WRE-380. South Florida Water Management District, West Palm Beach, FL.

Ali, A. and W. Abtew. 1999b. Rainfall Estimation at S-44 Site (January 2, 3, and 17, 1999 Events). Technical Note EMA-389. South Florida Water Management District, West Palm Beach, FL.

Beven, J. 2005. Tropical Cyclone Report Hurricane Dennis 4–13 July 2005. National Weather Service. National Hurricane Center. Tropical Prediction Center. Online at http://www.nhc.noaa.gov/.

Bromwell, L.G., R.G. Dean and S.G. Vick. 2006. Report of Expert review Panel Technical Evaluation of Herbert Hoover Dike Lake Okeechobee, Florida. Prepared for South Florida Water Management District. BCI Engineers and Scientists, Lakeland, FL.

Burpee, R.W. and L.N. Lahiff. 1984. Area-averaged Rainfall Variation on Seabreeze Days in South Florida. *Monthly Weather Rev.*,112: 520–534.

Huebner, R.S. 2000. Hydrologic Impacts of the 1997–98 El Niño and La Niña on Central and South Florida. Technical Publication EMA-384. South Florida Water Management District, West Palm Beach, FL.

Knabb, R.D., J.R. Rhome and D.P. Brown. 2006. Tropical Cyclone Report Hurricane Katrina.

23-30 August 2005. National Weather Service. National Hurricane Center. Tropical Prediction Center. Online at http://www.nhc.noaa.gov/.

MacVicar, T.K. 1981. Frequency Analsyis of Rainfall Maximums for Central and South Florida. Technical Publication DRE-129. South Florida Water Management District, West Palm Beach, FL.

Pasch, J.R., E.S. Blake, H.D. Cobb III and D.P. Roberts. 2006. Tropical Cyclone Report Hurricane Wilma 15–25 October 2005. National Weather Service. National Hurricane Center. Tropical Prediction Center. Online at http://www.nhc.noaa.gov/ (October 9, 2006).

Pathak, C.S., and S. Palermo. 2006. Rainfall Based Management Plan for Water Conservation Area 3A in Florida Everglades. ASCE/EWRI World Water & Environmental Congress, Annual Conference, May 21–25, 2006. Omaha, Nebraska. Proceedings.

Redfield, G., K. Burns and G. Goforth. 2003. Chapter 1: Introduction to the 2003 Everglades Consolidated Report. Redfield, G., ed. In: *2003 Everglades Consolidated Report*, South Florida Water Management District, West Palm Beach, FL.

Rosenthal, S.L. 1994. Statistical Aspects of the Precipitation Regimes at Miami International Airport (MIA) and Palm Beach International Airport (PBIA): 1961–1990. NOAA Technical Memorandum, ERL AAOML-80.

Sculley, P.S. 1986. Frequency Analysis of SFWMD Rainfall. Technical Publication 86-6. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 1982a. Preliminary Report on Rainstorm March 28–29. Technical Publication DRE-141. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 1982b. Preliminary Report on Rainstorm April 23–26, 1982. Technical Publication DRE-143. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 1984a. Preliminary Report of Rainstorm May 23–31, 1984 Lower East Coast. Technical Publication DRE-184. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 1984b. Preliminary Report of Rainstorm November 21–26, 1984 – So. Florida Coast Area. Technical Publication DRE-203. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 1991. Storm Event of January 15–17, 1991. Technical Publication DRE-297. South Florida Water Management District, West Palm Beach, FL.

SFWMD. 2002. Operation Plan Stormwater Treatment Area 6. South Florida Water Management District, West Palm Beach, FL.

Sklar, F.H., L. Brandt, D. DeAngelis, C. Fitz, D. Gawlik, S. Krupa, C. Madden, F. Mazzotti, C. McVoy, S. Miao, D. Rudnick, K. Rutchey, K. Tarboton, L. Vitchek and Y. Wu. 2000. Chapter 2: Hydrological Needs – Effects of Hydrology on the Everglades. Redfield, G., ed. In: *2000 Everglades Consolidated Report*, South Florida Water Management District, West Palm Beach, FL.

Sklar, F.H., C. Coronado, G. Crozier, M. Darwish, B. Garrett, D. Gawlik, A. Huffman, M. Korvela, J. Leeds, C.J. Madden, C. McVoy, I. Mendelssohn, S. Miao, S. Nueman, R. Penton, D. Rudnick, K. Rutchey, S. Senarath, K. Tarboton and Y. Wu. 2003. Chapter 6: Ecological Effects of Hydrology on the Everglades Protection Area. Redfield, G., ed. In: *2003 Everglades Consolidated Report*, South Florida Water Management District, West Palm Beach, FL.

Trimble, Paul, J. Obeysekera, L. Cadavid and E.R. Santee, 2006. Application of Climate Outlooks for Water Management in South Florida. In: *Climate Variations, Climate Change, and Water Resources Engineering*, edited by J.D. Garbrecht and T.C. Piechota, ASCE.

U.S. Army Corps of Engineers, 1994. Master Water Control Manual for Kissimmee River – Lake Istokpoga. Jacksonville, FL.

U.S. Army Corps of Engineers, 1995. Master Water Control Manual – East Coast Canals, Jacksonville District, FL.

U.S. Army Corps of Engineers, 1996. Master Water Control Manual – Water Conservation Areas, Everglades National Park, and ENP-South Dade Conveyance System. Jacksonville, FL.

U.S. Army Corps of Engineers, 2000. Water Control Plan for Lake Okeechobee and the Everglades Agricultural Area. Jacksonville, FL.

U.S. Army Corps of Engineers, 2002. Final Environmental Impact Statement – Interim Operational Plan (IOP) for Protection of the Cape Sable Seaside Sparrow. Jacksonville, FL.

U.S. Army Corps of Engineers. 2005. Environmental Assessment Water Conservation Area No. 1 Palm Beach County, FL. Jacksonvillee District, FL.

U.S. Army Corps of Engineers. 2006. Lake Okeechobee Water Control Plan-Temporary Planned Deviation Request for 29 January 2006 through 31 December 2006. Memorandum for Commander, South Atlantic Division (CESAD-RBT). Jacksonvillee, FL.

Winsberg, M.D. 1990. *Florida Weather*. University of Central Florida Press, Orlando, FL.

Wu, Y., F.H. Sklar, K. Gopu and K. Rutchey. 1996. Fire Simulations in the Everglades Landscape Using Parallel Programming. *Ecol. Modeling*, 93: 113–124.