Chapter 5: Hydrology of the South Florida Environment

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SUMMARY

Given hydrology's significance to the entire South Florida environmental restoration and water management functions of the South Florida Water Management District (District or SFWMD), it is presented as a separate chapter in the *2006 South Florida Environmental Report – Volume I*. This chapter updates hydrologic data and analysis from the *2005 South Florida Environmental Report* with coverage on hydrology of the area within the District's boundaries, providing a more comprehensive overview of the South Florida hydrology. In this year's report, two sections are included in this chapter. The first section, "Hydrologic Variation in South Florida," presents an analysis on temporal and spatial variation of South Florida hydrology. The second section, "The 2004 Hurricane Season in South Florida," documents the hydrologic impact of the 2004 hurricane season on South Florida. The section includes historical records of hurricane events on South Florida. Rainfall, potential evapotranspiration, water levels, inflows, and outflows are presented for Water Year 2005 (WY2005) (May 1, 2004 to April 30, 2005). Hydrologic conditions in this water year were compared with the previous water year, WY2004. Historical hydrologic data also were analyzed and compared with the current and previous water year's hydrology. This chapter does not include comparisons of current hydrology with predevelopment hydrology.

South Florida experienced an extremely rare occurrence of a series of hurricane events in WY2005. It was hit by three hurricanes and a remnant of a fourth hurricane in less than seven weeks during August and September 2004. Hurricanes Charley (major hurricane), Francine, Jeanne (major hurricane), and Ivan had hydrologic impact on South Florida. From available records since 1871, this series of events on South Florida was a rare occurrence that has not been previously observed. The losses from these hurricanes were extremely high. High rainfall, high surface water flows, and rises in water levels in lakes were experienced during the hurricane events and following months. Despite this four-hurricane season, rainfall in WY2005 for the District area (50.67 inches) was lower than WY2004 (52.35 inches) and the historical average (52.75 inches). Generally in WY2005, the northern areas of the District had higher rainfall due to the 2004 hurricanes. Rainfall areas from Lake Okeechobee south to the Everglades National Park (ENP or Park) had below historical average rainfall for this water year. Because the above average rainfall occurred in the large rainfall areas of the Upper and Lower Kissimmee, the headwaters of Lake Okeechobee, rise in water levels and flows had significant impact on the water management system.

During WY2005, monthly average water levels in most of the lakes in the Upper Chain of Lakes (Lake Alligator, Lake Myrtle, Lake Mary Jane, Lake Gentry, Lake East Tohopekaliga, and Lake Tohopekaliga) were generally higher than the WY2004 levels and historical average levels except for Lake Tohopekaliga. The increase in water levels in the Upper Chain of Lakes was due to the high rainfall generated by the 2004 hurricanes. Lake Kissimmee average water level in WY2005 [50.43 ft National Geodetic Vertical Datum (NGVD)] was higher than that of WY2004 and historical average water levels, whereas Lake Istokpoga average water level in WY2005

(39.06 ft NGVD) was the same as the previous water year average water level but higher than the historical average. Lake Okeechobee average water level for WY2005 (14.75 ft NGVD) was lower than the WY2004 average water level (15.61 ft NGVD) but higher than historical average water level (14.42 ft NGVD). The 2004 hurricanes generated large inflows into Lake Okeechobee and raised the water level to 18.02 ft NGVD on October 13, 2004. Because the lake stage was at a low level of 12.17 ft NGVD on July 17, 2004, the average stage for the year was less than WY2004.

The average water level in Water Conservation Area 1 (WCA-1) for WY2005 was 15.85 ft NGVD. It was lower than the WY2004 average water level of 16.50 ft NGVD and higher than the historical average of 15.59 ft NGVD. In the current reporting year, the average water level in Water Conservation Area 2 (WCA-2) was 12.21 ft NGVD. It was lower than the WY2004 average water level of 12.40 ft NGVD and the historical average of 12.56 ft NGVD. During WY2005, the average water level in Water Conservation Area 3 (WCA-3) was 9.94 ft NGVD. It was lower than the WY2004 water level average of 10.30 ft NGVD but higher than the historical average of 9.51 ft NGVD. In WY2005, the average water level in the Park at site P33 was 6.26 ft NGVD which was lower than WY2004 average water level (6.68 ft NGVD). It was higher than the historical average of 5.96 ft NGVD. Average water level in the Park at site P34, for WY2005, was 2.59 ft NGVD. It was also lower than the WY2004 average water level of 3.09 ft NGVD but higher than the historical average of 2.04 ft NGVD.

During WY2005, surface water outflow through Lake Kissimmee was 1,397,106 acre-feet (ac-ft) which was higher than WY2004 (1,193,171 ac-ft) and historical average outflows (719,120 ac-ft). The increase in outflows was mainly due to the 2004 hurricanes. Lake Istokpoga discharge was 404,517 ac-ft, which was higher than WY2004 (401,637) and historical average outflows (214,936 ac-ft). Lake Okeechobee inflows were 3,501,889 ac-ft, which is comparable to the 1995 El Niño year annual inflow of 3,620,483 ac-ft, highest since 1972. Lake Okeechobee inflow for WY2004 was 2,920,448 ac-ft and the historical average inflow is 2,111,790 ac-ft. Lake Okeechobee outflow for WY2005 was 2,832,700 ac-ft compared to WY2004 outflow of 2,617,958 ac-ft and historical average outflow of 1,445,558 ac-ft. The high inflows and outflows to Lake Okeechobee were mainly due to the 2004 hurricanes.

The WY2005 discharge into the southern Indian River Lagoon and St. Lucie Estuary was 1,428,504 ac-ft, with 706,664 ac-ft discharged through the St. Lucie canal outflow structure S-80. Due to the 2004 hurricanes, flows were higher than WY2004 and historical average. Discharge into the Caloosahatchee Estuary through the S-79 structure was 2,001,901 ac-ft, which was lower than WY2004 outflow (2,463,862 ac-ft) and higher than the historical average (1,210,140 ac-ft).

Inflows to WCA-1 were 476,801 ac-ft for WY2005 compared to inflows of 334,957 ac-ft in WY2004 and historical average inflows of 592,378 ac-ft. For WY2005, outflows from WCA-1 were 411,243 ac-ft compared to 269,603 ac-ft for WY2004 and historical average of 534,487 ac-ft. Both WCA-1 inflows and outflows were higher than WY2004 but lower than the historical average. WY2005 inflows to WCA-2 were 980,424 ac-ft compared to 520,641 ac-ft inflows of WY2004 and the historical average of 667,783 ac-ft. WY2005 outflows from WCA-2 were 875,648 ac-ft compared to 749,663 ac-ft in WY2004 and the historical average of 689,175 ac-ft. WCA-2 inflows and outflows were higher than WY2004 and historical averages.

WY2005 inflows into WCA-3 were 1,366,925 ac-ft compared to 1,053,423 ac-ft in WY2004 and the historical average of 1,213,243 ac-ft. WY2005 outflows from WCA-3 were 971,722 ac-ft compared to 1,221,322 ac-ft in WY2004 and the historical average of 888,622 ac-ft. WY2005 inflows to the ENP were 802,791 ac-ft compared to 1,251,807 ac-ft in WY2004 and the historical average of 1,202,389 ac-ft. WY2005 inflows to the ENP were 64 percent of WY2004 and 67 percent of the historical average, which was significantly lower.

INTRODUCTION

The South Florida Water Management District (District or SFWMD) area extends from Orlando in the north to the Florida Keys in the south (**Figure 5-1**). The South Florida 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 the Upper Kissimmee Chain of Lakes, the Lower Kissimmee, Lake Okeechobee, Lake Istokpoga and Surface Water Management Basin, the Everglades Agricultural Area (EAA), the Caloosahatchee Basin, St. Lucie Basin, and the Everglades Protection Area (EPA).

The Upper Kissimmee Chain of Lakes (Lake Myrtle, Lake Alligator, Lake Mary Jane, Lake Gentry, Lake East Tohopekaliga, Lake Tohopekaliga, and Lake Kissimmee) are the principal sources of inflow to Lake Kissimmee. On the 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 square miles) 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 flow from the Caloosahatchee River, the St. Lucie Canal, and reverse flow from the Everglades Agricultural Area (EAA) (Abtew et al., 2002). Lake Istokpoga is a 43-square-mile shallow lake, with outflow through structure S-68 into the Surface Water Management Basin.

Lake Okeechobee is the center of the South Florida hydrologic system, with an area of 730 square miles and a mean depth of 8.86 feet (ft). Since 1931, the average water level elevation is 14.42 ft National Geodetic Vertical Datum (NGVD) with a maximum 18.77 ft NGVD set on November 2, 1947. The lowest water level in 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 (1972–2001) is about 2.1 million acre feet (ac-ft), while the average outflow is about 1.4 million ac ft. Outflows are mainly through the south, southeast, and southwest structures. 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 Everglades Agricultural Area is the main source of surface water inflow into the EPA. On the average, about 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).

The Everglades Protection Area begins at the southern and eastern edges of the EAA and extends south to Florida Bay. The EPA consists of several defined regions: the Arthur R. Marshall Loxahatchee National Wildlife Refuge (Refuge), which contains Water Conservation Area 1 (WCA-1) (221 sq mi); Water Conservation Areas 2A and 2B (WCA-2A and 2B) (210 sq mi); Water Conservation Areas 3A and 3B (WCA-3A and 3B) (915 sq mi); Everglades National Park (Park or ENP) (2,150 sq mi); and Florida Bay, as shown in Redfield et al. (2003). The extent and components of the EPA are depicted in **Figure 5-1**. The EPA receives additional surface water inflows from the urban areas in the east, from the southeast and northwest sources currently identified as non-Everglades Construction Project (non-ECP) stormwater flows. Surface water flow into 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 major hydrologic components of the District are depicted in **Figure 5-1**.

The South Florida Water Management District has an intensive 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), Everglades National Park (Park or ENP), Florida Forestry Service (FFS), Florida Department of Environmental Protection (FDEP), and others. Details of hydrometeorologic monitoring by the SFWMD are presented in Crowell and Mtundu (2000).

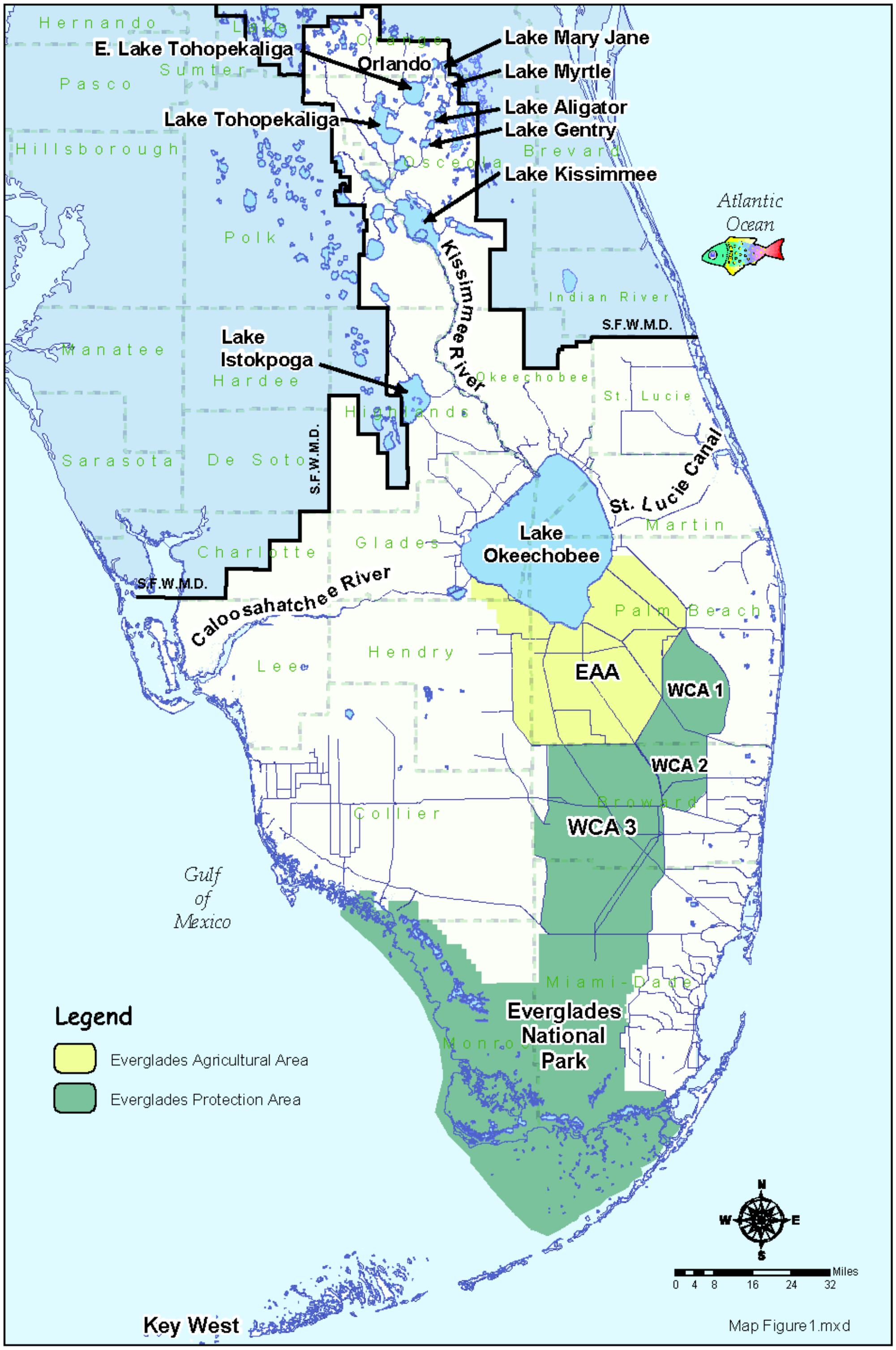


Figure 5-1. Major hydrologic components of the South Florida water management system.

HYDROLOGIC VARIATION IN SOUTH FLORIDA

BACKGROUND

South Florida experiences hydrologic variation that ranges from extreme drought to extreme wet conditions. The hydrology of the area is driven by rainfall, rainfall generated runoff/drainage of surface water 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. While surface and groundwater storage modulates short-term variations in rainfall and water supply, droughts have dried wetlands and lowered lake levels significantly. On the other extreme, wet conditions resulting in local flooding and massive discharge into storage and the coast also prevail. The dry season extends from November through May and on the average 35 percent of District rainfall occurs in this season. The percentage of dry season rainfall varies from rainfall area to rainfall area (**Figure 5-2**) with the highest in Palm Beach rainfall area (39 percent) to the lowest in the Southwest Coast (29 percent) as presented in Ali and Abtew (1999a).

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). 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. Statistical measures of year-to-year variation of monthly rainfall, average of multiple gauges over the District, are shown in **Table 5-1** (Ali and Abtew, 1999a).

In the District, 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 El Niño years, high rainfall falls 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. El Niño occurs about once every three to four years (Huebner, 2000). Tropical systems are a frequent occurrence. The general area of the District has been affected by 42 hurricanes, 32 tropical storms, and 9 tropical cyclones (a term used before modern hurricane categories were established) from 1871–1999 (Abtew and Huebner, 2000). Since 1999, four hurricanes and remnants of a fifth hurricane have affected the District area (**Table 5-2**). 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 region managed by the SFWMD is 52.8 inches (Ali and Abtew, 1999a). The SFWMD area is divided into 14 rainfall areas for operational purposes. **Figure 5-2** depicts these rainfall areas and the ENP. Spatial variation of annual rainfall over the District area is shown in **Figure 5-3** 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 (http://iweb/iwebB501/omd/weather/opswthr.htm). Spatially averaged over the District area, December is the driest month and June is the wettest month. Palm Beach rainfall area has the highest rainfall while the Lower Kissimmee and Lake Okeechobee rainfall areas have lowest rainfall. Historically, Palm Beach County rainfall area has the highest annual rainfall, followed by Broward County and Miami-Dade rainfall areas. 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 was close to the average. Because there are no large impoundments in the coastal area, runoff is discharged to the Atlantic Ocean.

Table 5-1. Temporal variation of monthly areal rainfall over the South Florida Water Management District area.

	Rainfall Statistics (inches)		
Month	Arithmetic average	Standard Deviation	Coefficient Of Variation
January	2.2	2.05	0.93
February	2.36	1.85	0.78
March	2.94	2.56	0.87
April	2.58	2.32	0.9
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	2.3	2.36	1.03
December	1.9	1.8	0.95

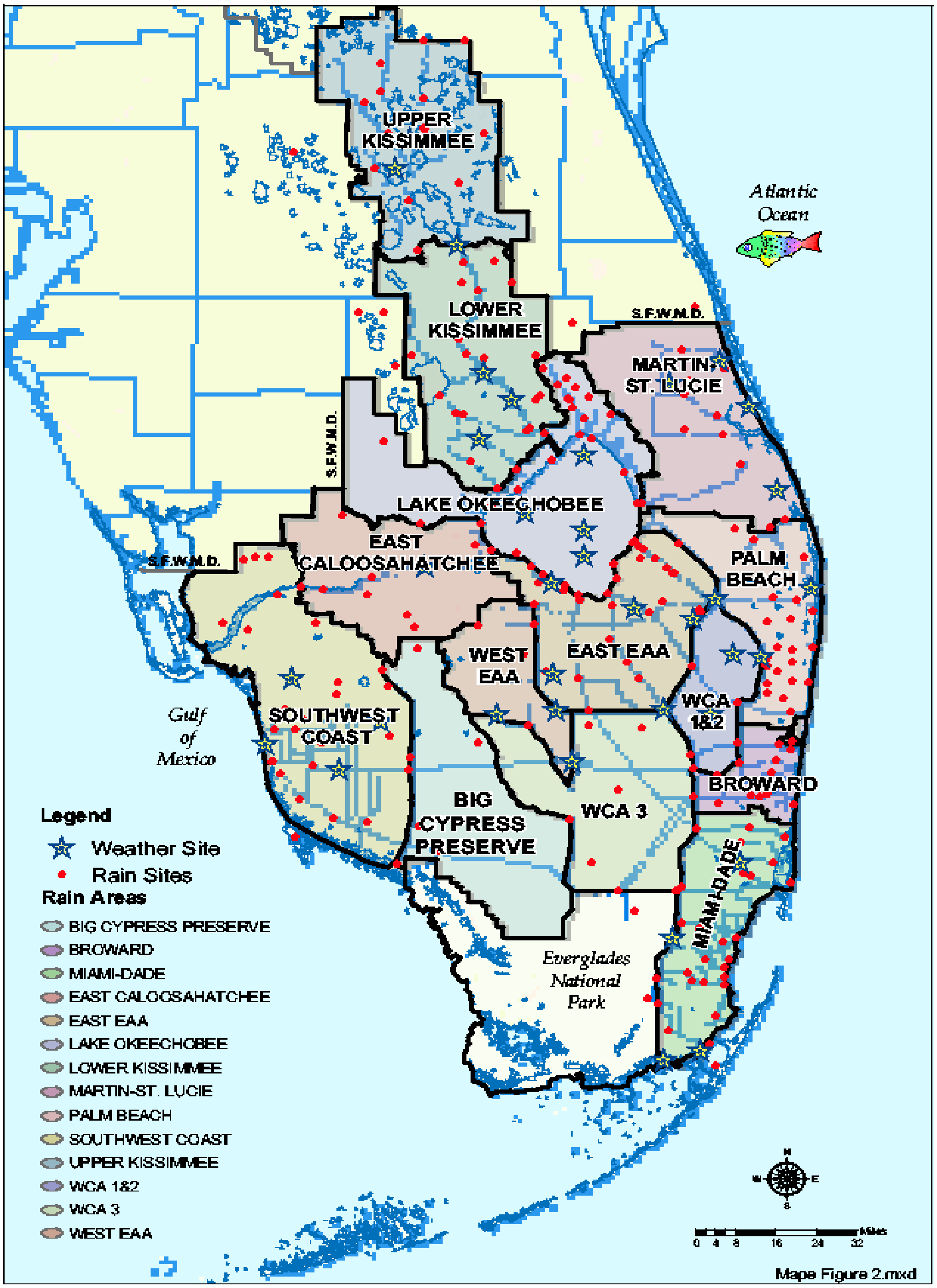


Figure 5-2. Rainfall areas of the South Florida Water Management District (SFWMD or District).

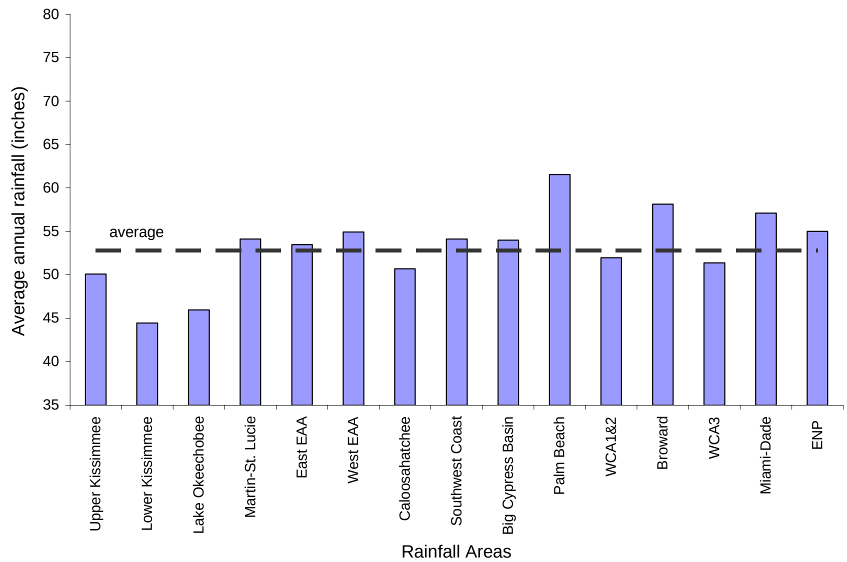


Figure 5-3. Spatial variation of annual rainfall in South Florida.

Extreme hydrologic events contribute to variation in the temporal and spatial distribution of the hydrology of South Florida. Droughts are extreme hydrologic events categorized as moderate, severe, and extreme droughts. Generally, droughts are regional or have significant spatial coverage and corresponding impacts. In South Florida, a minimum of 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 as tropical depressions, tropical storms, and hurricanes result in high rainfall and contribute to rainfall variation in South Florida. The general area of the South Florida Water Management District 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 resulting in 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 Palm Beach, Martin, and St. Lucie counties' coast (SFWMD, 1982a); the April 23–26, 1982 rainfall on Palm Beach, Broward and Miami-Dade counties (SFWMD, 1982b); the May 22–23, 1984 rainfall on Palm Beach Coast (SFWMD, 1984a); and the November 21–26, 1984 rainfall on Palm Beach Coast (SFWMD, 1984b).

Evapotranspiration (ET) 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 which have permanent or seasonal limitation to moisture have reduced evapotranspiration. Spatial variation of potential evapotranspiration or evaporation from wetlands and lakes over South Florida, as estimated by Abtew et al. (2003), is depicted in **Figure 5-4**. Generally evapotranspiration increases from north to south. Temporal variation in annual evapotranspiration in South Florida is slight compared to annual variation in rainfall. Seasonal variation of evapotranspiration over South Florida is depicted in **Figure 5-5** (Abtew et al., 2003).

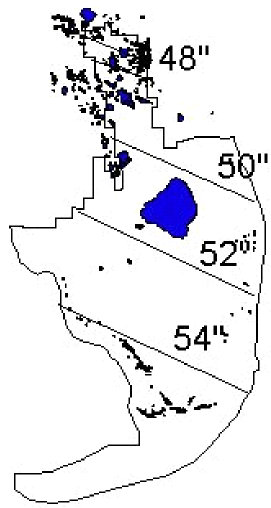


Figure 5-4. Estimated potential evapotranspiration isohyetal lines for the South Florida Water Management District.

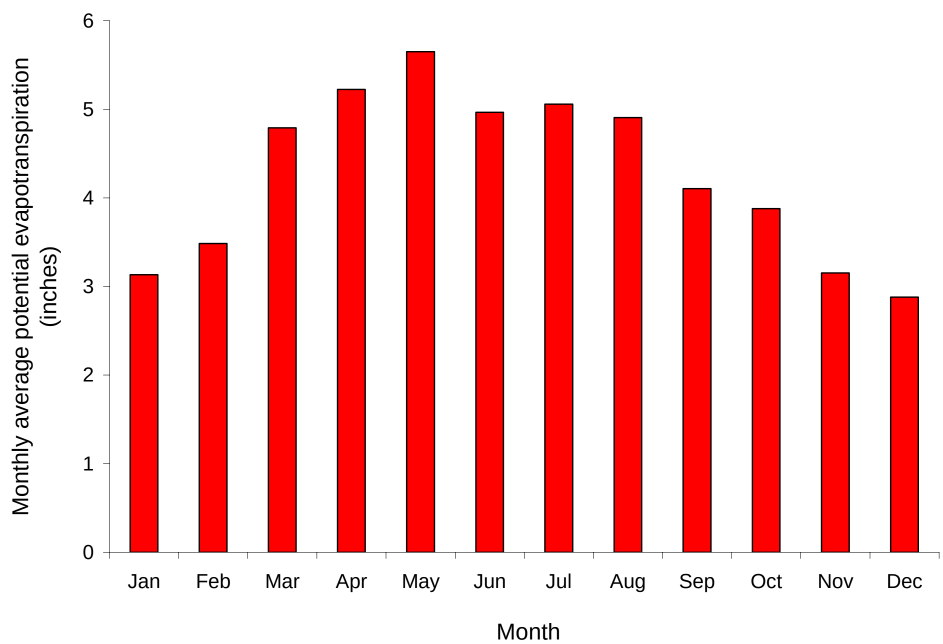


Figure 5-5. District-wide average potential evapotranspiration for 2001.

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. Temporal variation of annual rainfall is demonstrated by a sample rain gauge at the S-5A pump station in Palm Beach County. The annual rainfall variation is shown in **Figure 5-6**. The annual rainfall has a maximum of 81.7 inches, a minimum of 38.3 inches, a mean of 52.7 inches, and a standard deviation of 8.4 inches. Characteristic rainfall variation at a site is illustrated by the S-5A station with coefficient of variations in annual, monthly, and daily rainfall of 16 percent, 80 percent, and 296 percent, respectively.

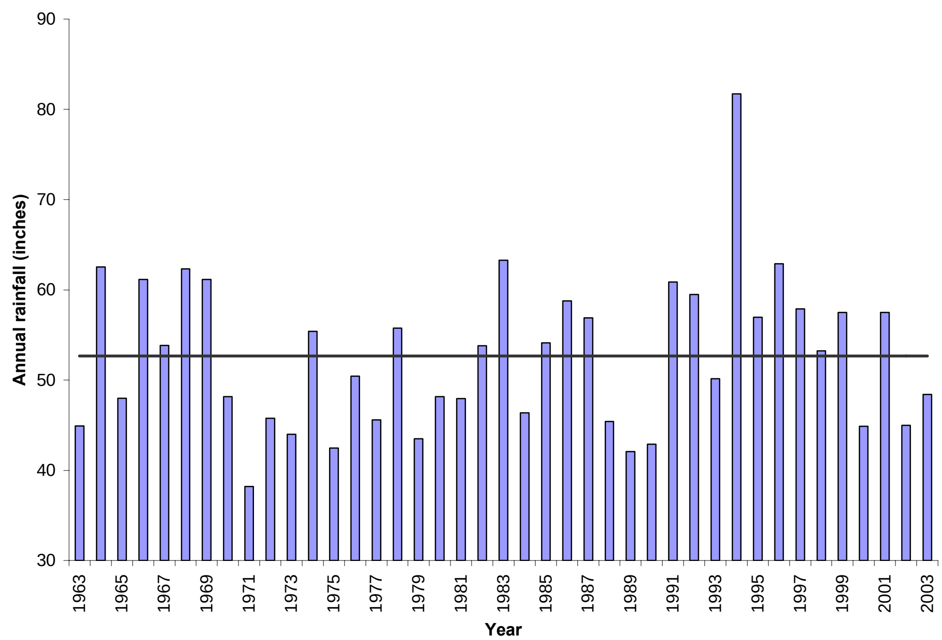


Figure 5-6. Annual variation of rainfall at the S-5A pump station.

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 between ±0.49; severe drought has an index value of -3 or less; and extreme drought events have -4 or less. The historical PDSI for Florida Climatic Division 5 (Lake Okeechobee, the Lower West Coast, the Everglades Agricultural Area, the East Coast, and the Everglades) is shown in **Figure 5-7**. A PDSI of greater than zero is on the wet side, with a magnitude of wetness indicated by higher 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.

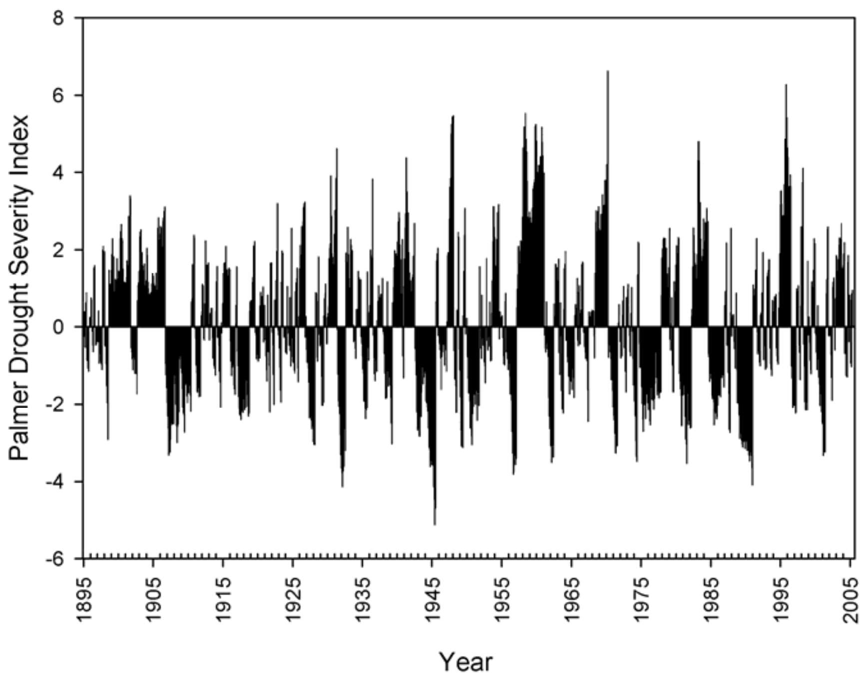


Figure 5-7. Palmer Drought Severity Index, Florida Climatic Division 5 (Lake Okeechobee, the Lower West Coast, the Agricultural Areas, and the Everglades), 1895–2005.

Droughts are characterized by a significant decline in annual rainfall. They also promote the development and spread of wildfires. 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. Historical droughts are identified by the historical Palmer Drought Severity Index, annual rainfall, lake water levels, groundwater levels, stream flow, and wildfire records. Fire is an important ecological process in the Everglades (Wu et al., 1996).

The variation in rainfall results in variations of groundwater level, lake water level, and surface water flow rates. Lake Okeechobee, at the center of the District, demonstrates surface water fluctuations by the extreme lake inflow rates, even though flows are regulated. Based on flow data from January 1, 1972 to December 31, 2004, annual Lake Okeechobee inflows fluctuated from 664,121 ac-ft in 2000, a severe drought year, to a maximum annual inflow of 3,620,483 ac-ft during an El Niño year, 1998. The Arbuckle Creek is an unregulated inflow to Lake Istokpoga. Flow records from 1940 to 2004 depict temporal hydrologic variation in South Florida. The average annual flow into Lake Istokpoga through the Arbuckle Creek was 223,729 ac-ft with a standard deviation of 127,843 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. Annual flows through Arbuckle Creek are shown in **Figure 5-8.**

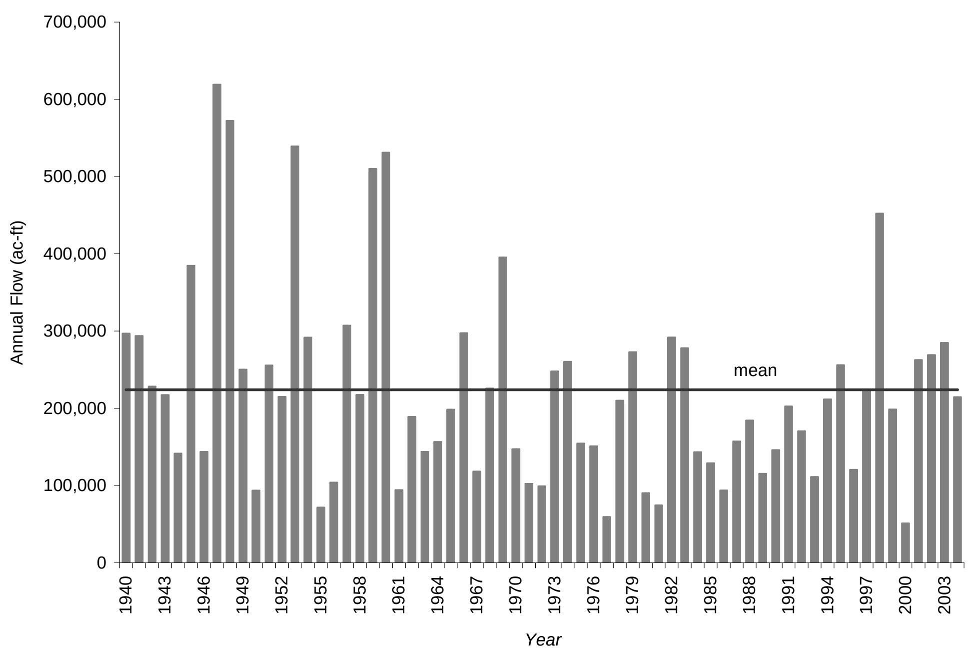


Figure 5-8. Annual variation of flows through Arbuckle Creek.

Lake water level fluctuations are indicators of hydrologic variation. Lake Okeechobee water level fluctuations 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 14.42 ft NGVD with a standard deviation of 1.61 ft. Historical daily average Lake Okeechobee stage variation is depicted in **Figure 5-9** and extreme hydrologic seasons are discernable.

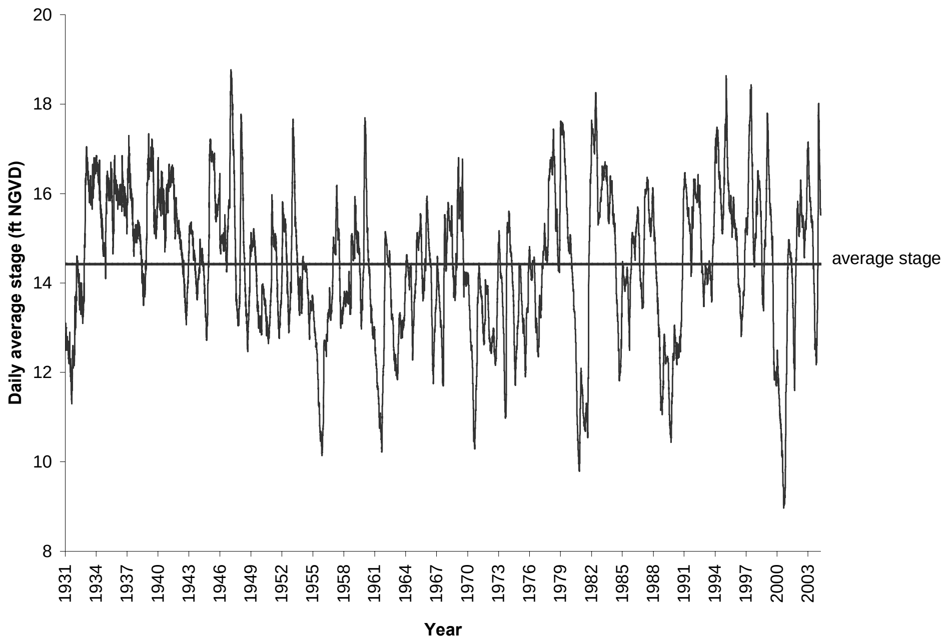


Figure 5-9. Lake Okeechobee historical daily water level variation.

Groundwater level fluctuation is also an indicator of hydrologic variation in South Florida. While the deeper aquifer might have a lag period to show changes in rainfall and recharge, the shallow aquifer shows a quicker response. A hydrograph for the sandstone aquifer monitoring well HE-556 in Hendry County is shown in **Figure 5-10**. The extreme drawdown due to the severe drought of 2000–2001 is clearly identified as well as seasonal and annual variations.

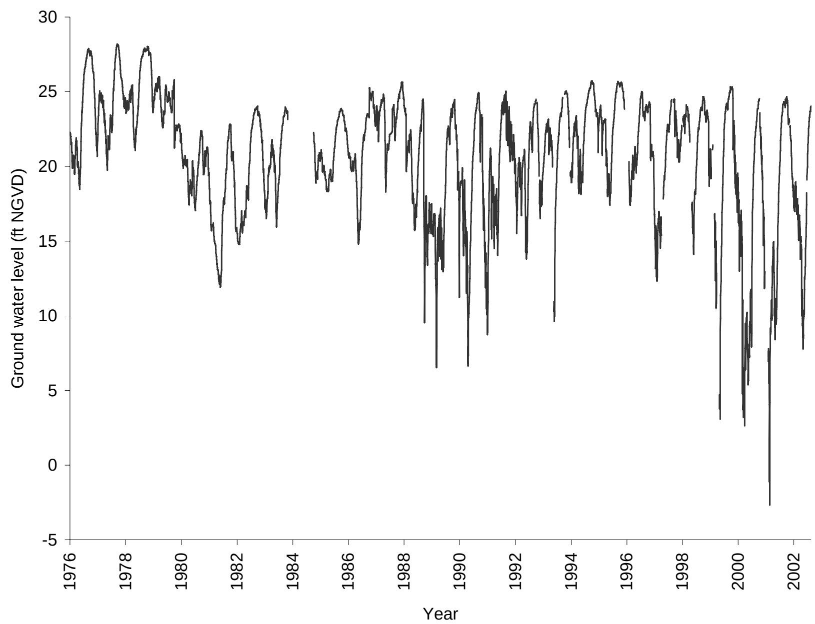


Figure 5-10. Hydrograph for the sandstone aquifer monitoring well HE-556 (1976–2002).

Wildfire records are also indicators of hydrologic variations. Wildfire statistics for Florida are kept by the Division of Forestry, Florida Department of Agriculture and Consumer Services. Published records are available since 1981. **Figure 5-11** depicts annual number of acres burned by wildfire (calendar year). Data for 2004 is available only through June. Generally, the largest burned acres correspond to drought years such as 1981, 1985, 1989, and 2001.

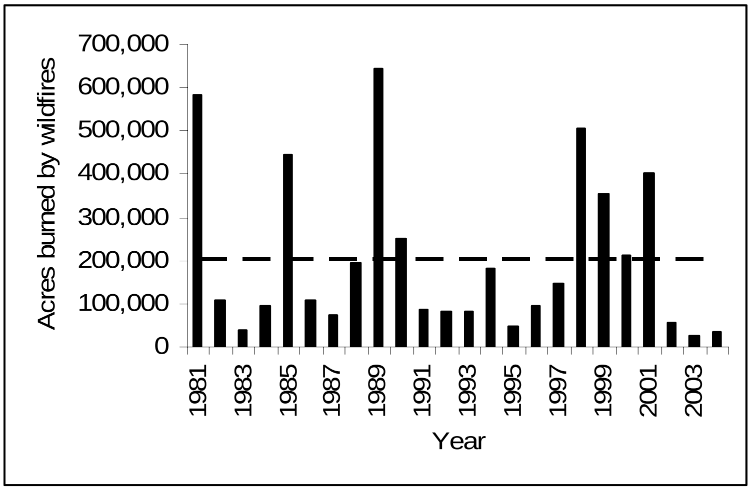


Figure 5-11. Acres burned by wildfire per year (January 1981–June 2004).

Hydrologic variation creates challenge in water management where multiple objectives have to be met. Too much water or too little water creates flooding, water shortage, or ecological impacts. Although South Florida is a wet area, serious droughts have occurred, and there is potential for periodic water shortages. Impacts from hydrologic variation can be mitigated with storage capacity during wet periods and water distribution capacity during water shortages.

THE 2004 HURRICANE SEASON IN SOUTH FLORIDA

Documenting hydrologic events such as hurricanes, storms, and droughts provides supporting information for water management decision making. This section covers the hydrologic impact of hurricanes Charley, Frances, Jeanne, and Ivan on the South Florida Water Management District area during 2004. Based on available data, the spatial distribution and the magnitude of rainfall from the hurricanes are presented along with an estimate for frequency of occurrence. Water level changes at key water management system locations and surface water flows through major structures are also presented.

BACKGROUND

According to Chaston (1996), the hurricane is nature's way of transporting heat energy, moisture, and momentum from the tropics to the poles in order to decrease the temperature differential and preserve the current climate of the earth. Records indicate that Atlantic hurricanes have been observed since Christopher Columbus's voyage to the New World in the 1490s (Attaway, 1999). Based on published records, the average annual number of subtropical storms, tropical storms, and hurricanes in the North Atlantic Ocean between 1886 and 1994 is 9.4; 4.9 were hurricanes (Tait, 1995). Between 1871 and 1996, 1,000 tropical storms have occurred in the North Atlantic, Caribbean Sea, and Gulf of Mexico, of which 184 have reached Florida and 74 were hurricanes (Williams and Duedall, 1997). Monthly frequency of tropical systems, excluding depressions, is shown in **Figure 5-12**. As shown in this figure, the probability of occurrence of a tropical storm or hurricane during August, September, and October is 79 percent (Neumann, et al., 1993).

There were 114 hurricanes and tropical storms affecting peninsular Florida between 1871 and 1996, with about half as hurricanes (Attaway, 1999). The occurrence is about one named storm every year and a hurricane every two to three years. As the spatial area of interest decreases, the frequency of being affected by a hurricane decreases. The general area of the District has been affected by 46 hurricanes, 33 tropical storms, and 9 tropical cyclones (hurricanes or tropical storms) from 1871 to 2004 (**Table 5-2)**. Since 1871, the Miami area was affected by hurricanes in 1888, 1891, 1904, 1906, 1909, 1926, 1935, 1941, 1945, 1948, 1950, 1964, 1965, 1966, 1972, 1992, and 1999 (Williams and Duedall, 1997). Between 1900 and 1996, Southeast Florida had 26 hurricanes directly hit (Herbert et al., 1997) and four additional hurricanes since 1997 (**Table 5-2**). Since 1997, Southeast Florida has had direct hits from Hurricane Georges, 1998; Hurricane Irene, 1999; and Hurricanes Frances and Jeanne, 2004 (**Table 5-2**). **Table 5-3** depicts Southeast Florida hurricanes between 1900 and 2004 by category.

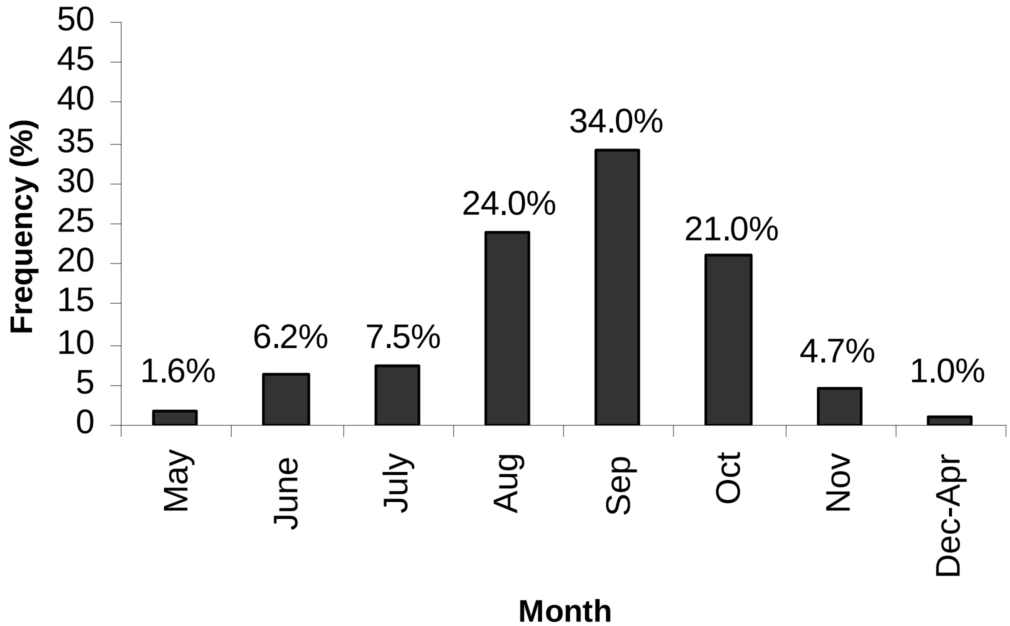


Figure 5-12. Frequency of North Atlantic hurricanes and tropical storms.

Table 5-2. Historical tropical cyclones, storms, and hurricanes affecting Central and South Florida from 1871 to 2004 (Attaway, 1999; Neumann et al., 1993; National Hurricane Center).

Year	Date	Type of Storm	Path	Rainfall (inches)	Remark
1871	August 17-18	Tropical Cyclone	Indian River to Jacksonville	13.7	Rainfall observed in Jacksonville
1872					
1873	October 6-7	Tropical Cyclone	Fort Myers to Melbourne		
1874					
1875					
1876	September 12-19	Tropical Cyclone	Along eastern coast line	14.9	Hurricane did not make landfall in Florida; rainfall was observed in Dade County
	October 19-20	Tropical Cyclone	Naples to Vero Beach	15.3	Rainfall was observed in Dade County
1877					
1878	July 1-3	Tropical Cyclone	Port Charlotte to Vero Beach	9.58	Rainfall was observed at Punta Rassa in Lee County
	September 8-11	Tropical Cyclone	Arcadia to St. Augustine		Dade had 25.12 inches for September monthly rainfall
1879	September 21-22	Tropical Cyclone	Tampa to Titusville	12.77	Rainfall was observed at Daytona
1880					
1881	August 17-18	Tropical Cyclone	Tampa to Vero Beach		
1882					
1883					
1884					
1885	August 23-24	Tropical Cyclone	Along eastern coast line		
1886					**Distinction was made between tropical storms and hurricanes (> 75 mph)**
1887	October 29-30	Tropical Storm	Sarasota to Titusville	12.17	Rainfall was observed at Titusville
1888	August 16-17	Hurricane	Homestead to Naples		
1889	October 5-6	Tropical Storm	Cape Sable to Palm Beach		
1890					
1891	September 24-25	Hurricane	Homestead to Naples		
	October 6-7	Tropical Storm	Naples to Melbourne		
	October 9-10	Tropical Storm	Sarasota to Daytona Beach		
1892	June 10-11	Tropical Storm	Fort Myers to Vero Beach		Dade County received high rainfall
	October 24-25	Tropical Storm	Tampa Bay to Melbourne		

Table 5-2. Continued.

Year	Date	Type of Storm	Path	Rainfall (inches)	Remark
1893					
1894	September 25-26	Hurricane	Tampa to Titusville	16.2	Rainfall was observed in Kissimmee
1895	October 16-17	Tropical Storm	Naples to West Palm Beach	24.39	Hypoluxo rainfall for the month
1896	October 8-9	Hurricane	Fort Myers to Melbourne		
1897	September 20-21	Tropical Storm	Fort Myers to Titusville		
	October 19-20	Tropical Storm	Tampa to St. Augustine		
1898	August 1-2	Hurricane	Fort Pierce to Clearwater		
	October 10-11	Tropical Storm	Naples to Melbourne		Rainfall from the storm was generally less than 1 inch
1899					
1900					
1901	August 10-11	Tropical Storm	West Palm Beach to Sarasota		
1902					
1903	September 11-12	Hurricane	Broward to Tampa		Heavy rain resulted from the hurricane
1904	October 17-18	Hurricane	Miami loop through Everglades	6.03	Rainfall was observed in Miami
1905					
1906	June 10-11	Tropical Storm	east of Panama City		
	June 16-18	Hurricane	Naples to West Palm Beach		
1907					
1908					
1909	October 11-12	Hurricane	Southern Dade to Atlantic Ocean	10.17	24-hour rainfall observed in Miami
1910	October 17-19	Hurricane	Cape Romano to Jacksonville		
1911					
1912					
1913					
1914					
1915					
1916					
1917					
1918					

Table 5-2. Continued.

Year	Date	Type of Storm	Path	Rainfall (inches)	Remark
1919	September 10-11	Hurricane	Key West		Hurricane went to Texas
1920					
1921	October 25-26	Hurricane	Tampa to north of Titusville		
1922					
1923					
1924	October 20-21	Hurricane	Naples to Fort Lauderdale	16.74	Rainfall observed in Fort Lauderdale
1925	November 30-December 1	Hurricane	Tampa to Titusville	15.1	Rainfall observed south of Miami
1926	July 27-28	Hurricane	Fort Pierce to Southern Georgia		
	September 18-19	Hurricane	Miami to Bonita Springs	8.02	Rainfall was observed in Fort Myers; high casualties in Moore Haven
1927					
1928	August 7-9	Hurricane	Vero Beach to N. W. Florida		
	September 16-17		Palm Beach to Jacksonville through Okeechobee		2000 died south of Lake Okeechobee
1929	September 28-29	Hurricane	Key West, southern tip of Florida	10.58	Rainfall was observed in Miami
1930					
1931					
1932	August 29-30	Tropical Storm	Key Largo to Fort Myers	10.24	Rainfall observed at Miami
1933	July 30-August 1	Tropical Storm	Stuart to Punta Gorda		
	September 3-5	Hurricane	Jupiter to Brooksville to Lake City		
1934	May 27-28	Tropical Storm	Fort Myers to Daytona Beach		
1935	September 2-4	Hurricane	Key West to North Florida along west coast of Florida	13.25	Narrow storm with high intensity, similar to Andrew of 1992 (rainfall observed at Punta Gorda)
	November 4-5	Hurricane	Miami to Cape Sable	11.8	Rainfall observed at Long Key
1936	June 15	Tropical Storm	Fort Myers to Miami	12.47	Rainfall observed at LaBelle
	July 28-29	Tropical Storm	Key Largo to Everglades City		
1937					
1938					
1939	August 11-12	Tropical Storm	Stuart to Tarpon Springs		
1940					

Table 5-2. Continued.

Year	Date	Type of Storm	Path	Rainfall (inches)	Remark
1941	October 6-7	Hurricane	Miami to Fort Myers		
1942					
1943					
1944	October 18-19	Hurricane	Sarasota to Jacksonville	7.49	Rainfall observed in Orlando
1945	September 15-16	Hurricane	Key Largo to St. Augustine though central Florida		
1946	October 7-8	Hurricane	Sarasota to Lake City		
	November 1-2	Tropical Storm	Palm Beach to Lakeland		
1947	September 17 -18	Hurricane	Fort Lauderdale to Fort Myers	8.72	Rainfall observed in Fort Myers
	October 11-18	Hurricane	Cape Sable to Pompano		
1948	**September 21-22**	**Hurricane**	**Everglades City to Stuart**	**11**	**Rainfall observed in Miami; path closely matched that of Hurricane Irene, October 1999**
	October 4-5	Hurricane	Miami to Fort Lauderdale	9.95	Rainfall observed in Miami
1949	August 26-27	Hurricane	Palm Beach to Brooksville to Lake City	8.81	Rainfall observed at Belle Glade Expt. Station
1950	October 17-19	Hurricane "King"	Miami to Georgia through Central Florida	14.19	Rainfall observed in Orlando
1951	October 1-3	Tropical Storm	Fort Myers to Vero Beach	15.72	Rainfall observed in Bonita Springs
1952	February 1-3	Tropical Storm	Cape Sable to Miami		
1953	October 8-9	Tropical Storm "Hazel"	Fort Myers to Vero Beach		
1954					
1955					
1956					
1957					
1958					
1959	October 18-19	Tropical Storm "Judith"	Fort Myers to Fort Pierce		
1960	September 9-11	Hurricane "Donna"	Naples to Flagler Beach	8.48	Three days of rainfall in Miami
1961					
1962	August 26-27	Tropical Storm "Alma"	Miami to Titusville		
1963					
1964	August 27-28	Hurricane "Cleo"	Miami to Jacksonville along the coast	6.8	Rainfall as observed in Miami
	October 14-15	Hurricane "Isabell"	Cape Sable to Palm Beach	5.09	Rainfall observed at Everglades Expt. Station

Table 5-2. Continued.

Year	Date	Type of Storm	Path	Rainfall (inches)	Remark
1965	September 8	Hurricane "Betsy"	Florida Keys and tip of Florida	10.89	Rainfall observed at Homestead AFB
1966	October 4-5	Tropical Storm "Inez"	Florida Keys and tip of Florida		
1967					
1968					
1969	September 6-7	Hurricane "Gerda"	Palm Beach to Vero Beach		Tropical storm while on land
1970					
1971					
1972	September 5	Tropical Storm "Dawn"	Southeast Florida Coast		
1973					
1974					
1975					
1976					
1977					
1978					
1979	September 3-4	Hurricane "David"	Palm Beach to Daytona Beach along the coast	8.92	Rainfall observed in Vero Beach
1980					
1981	August 17-19	Tropical Storm "Dennis"	Cape Sable to Cape Canaveral	20.38	Rainfall observed in Kendall
1982					
1983					
1984	September 26-28	Tropical Storm "Isidore"	Jupiter to Lakeland; turned north to Dade City	2.8	Rainfall observed in West Palm Beach
1985	July 23	Tropical Storm "Bob"	Naples to Vero Beach		
1986					
1987	October 12	Hurricane "Floyd"	Keys and tip of Florida	5.2	Rainfall observed in Naples
1988	November 23	Tropical Storm "Keith"	Sarasota to Melbourne	11	Rainfall observed in Largo
1989					
1990	October 11-12	Tropical Storm "Marco"	Keys to Cedar Key along the west coast	4.78	Rainfall observed at McDill AFB
1991					
1992	August 24	Hurricane "Andrew"	Homestead to Everglades City	6.9	Estimated at Homestead
1993					

Table 5-2. Continued.

Year	Date	Type of Storm	Path	Rainfall (inches)	Remark
1994	November 16	Tropical Storm "Gordon"		16.0	Rainfall observed in Andytown
1995	August 1-3	Hurricane "Erin"	Vero Beach to north of Tampa	8.81	Rainfall observed in Melbourne
	August 23-26	Tropical Storm "Jerry"	Jupiter to Cedar Key	16.18	Rainfall observed in Naples
1996					
1997					
1998	September 25	Hurricane "Georges"	Florida Keys to Biloxi, Mississippi		
1999	October 13-17	Hurricane "Irene"	Flamingo to Jupiter	17.46	Rainfall observed in Boynton Beach
2000					
2001	August 2-7	Hurricane “Gabrielle”	Hillsboro to Volusia	5.96	Rainfall observed at Kissimmee
2002					
2003					
2004	August 12-16	Hurricane “Charley”	Charlotte to Volusia	5.07	Rainfall observed at Kissimmee
	September 4-8	Hurricane “Frances”	Palm Beach to Pasco	15.57	Rainfall observed at WPB Airport
	September 19-23	Extratropical “Ivan”	Palm Beach to Collier	2.03	Rainfall observed at WPB Airport
	September 24-28	Hurricane “Jeanne”	Palm Beach to Hernando	10.32	Rainfall observed at WPB Airport

Table 5-3. Southeast Florida hurricanes between 1900 and 2004.

Category	Wind Speed (mph)	Number of Hurricanes
1	74-95	6
2	96-110	12
3	111-130	8
4	131-155	3
5	≥ 155	1

THE 2004 HURRICANE SEASON

During the 2004 hurricane season, the South Florida Water Management District area was hit by a hurricane (Frances), two major hurricanes (Charley and Jeanne) and by a remnant of a fourth hurricane (Ivan). Hurricane Ivan moved from the Gulf of Mexico through Alabama, to the northeast, and came back around to Southeast Florida to cross back to the Gulf of Mexico as an extratropical system. Based on the historical tropical systems record compiled in **Table 5-2**, such a hurricane season on the District area is a rare event occurring once in the past 100 years or more. The path of the 2004 hurricanes and estimates of radar rainfall are shown in **Figures 5-13a-d**.

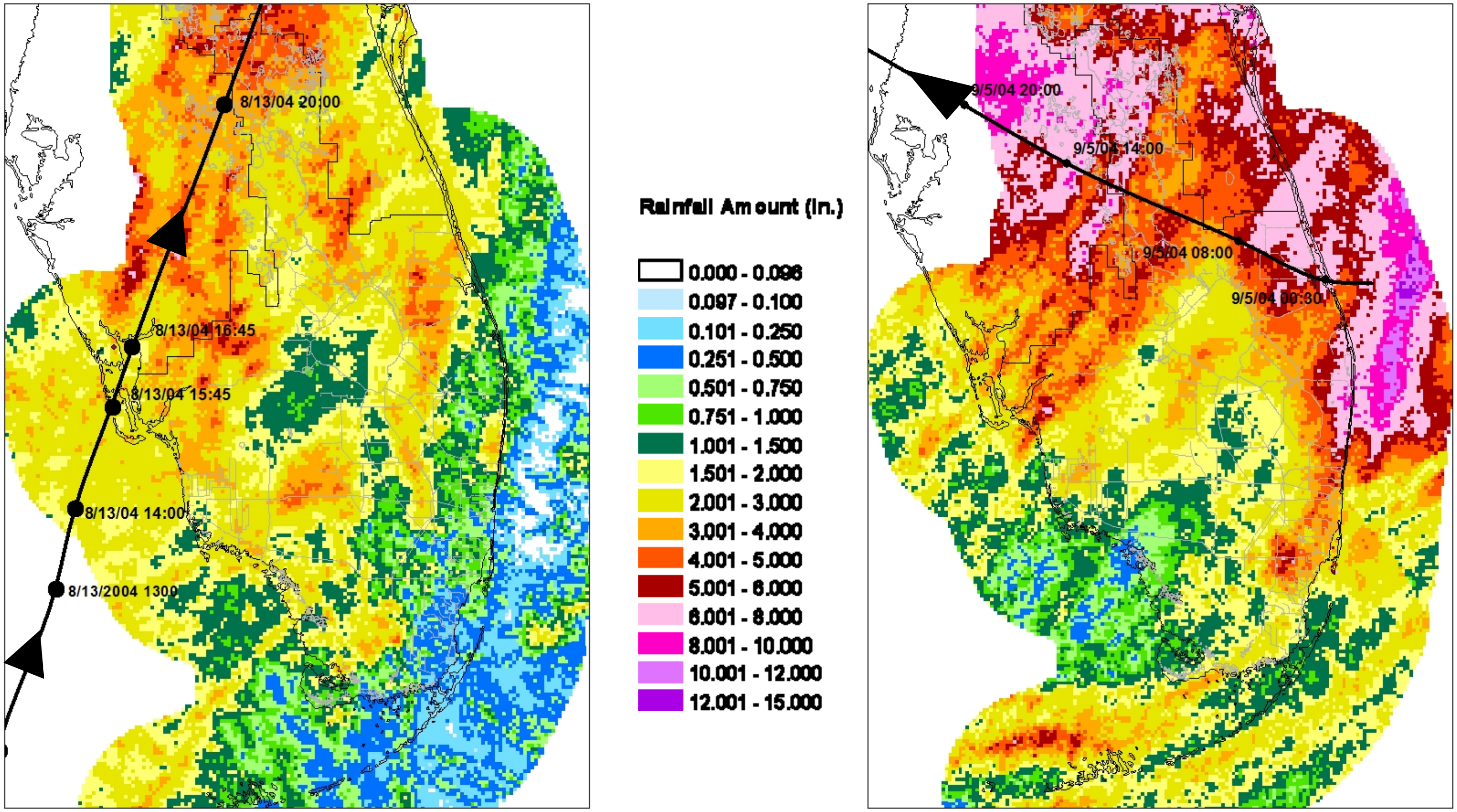
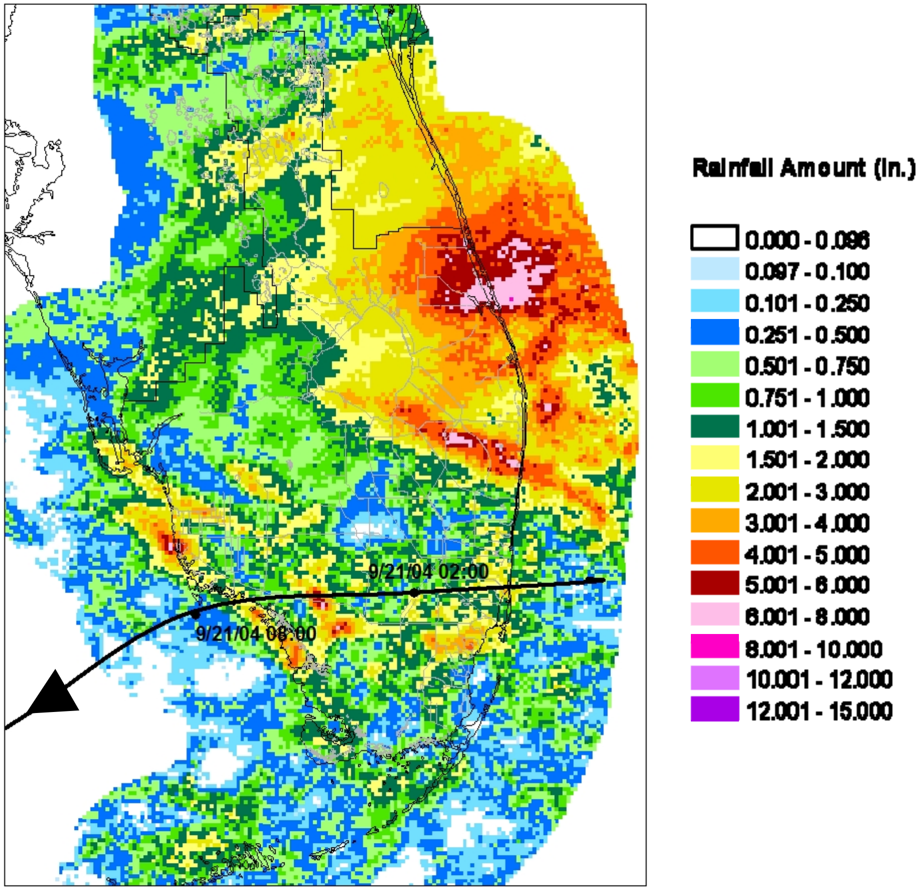


Figure 5-13a. Hurricane Charley's path and radar rainfall (August 12–16, 2004).

Figure 5-13b. Hurricane Frances's path and radar rainfall (September 4–8, 2004).



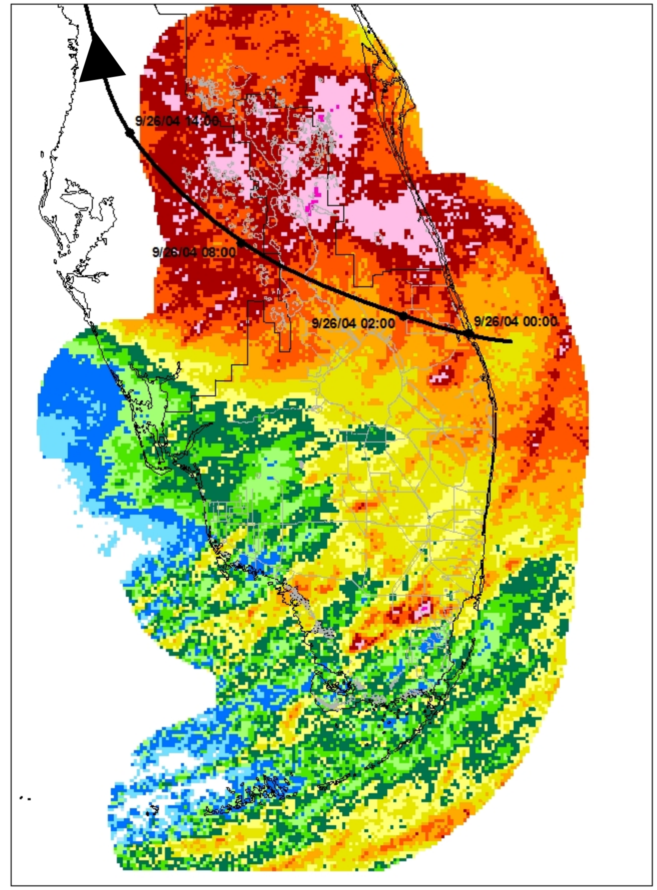


Figure 5-13c. Hurricane Ivan's path and radar rainfall (September 19–23, 2004).

Figure 5-13d. Hurricane Jeanne's path and radar rainfall (September 24–28, 2004).

According to the National Hurricane Center (Pasch et al., 2005), Hurricane Charley made landfall on the southwest coast of Florida near Cayo Costa on the evening of August 13, 2004 with a maximum sustained wind of 145 mph (a Category 4 hurricane). The center passed near Kissimmee and Orlando early on August 14 and crossed into the Atlantic at Daytona Beach (**Figure 5-13a**). For the purpose of hydrologic impact analysis of the 2004 hurricanes, the five-day cumulative rainfall around the landfall day of each hurricane is reported as the rainfall amount associated with each hurricane. For Hurricane Charley, the cumulative areal rainfall from August 12 through 16, 2004 is presented in **Figure 5-14** for each rainfall area of the District. The highest areal rainfall was observed in the Upper Kissimmee rainfall area followed by the East Caloosahatchee and Southwest Coast rainfall areas, and corresponds with the path of the hurricane. Areal rainfall is reported on the District's web site ((http://iweb/iwebB501/omd/weather/opswthr.htm) as the Thiessen average of a network of rain gauges. ENP area rainfall is computed from a simple average of four gauge readings (S174_R, TAMI AIR_R, S332_R, and Chekika). It should be noted that higher and lower point rainfall readings at single rain gauge stations were observed compared to the rain area average rainfall.

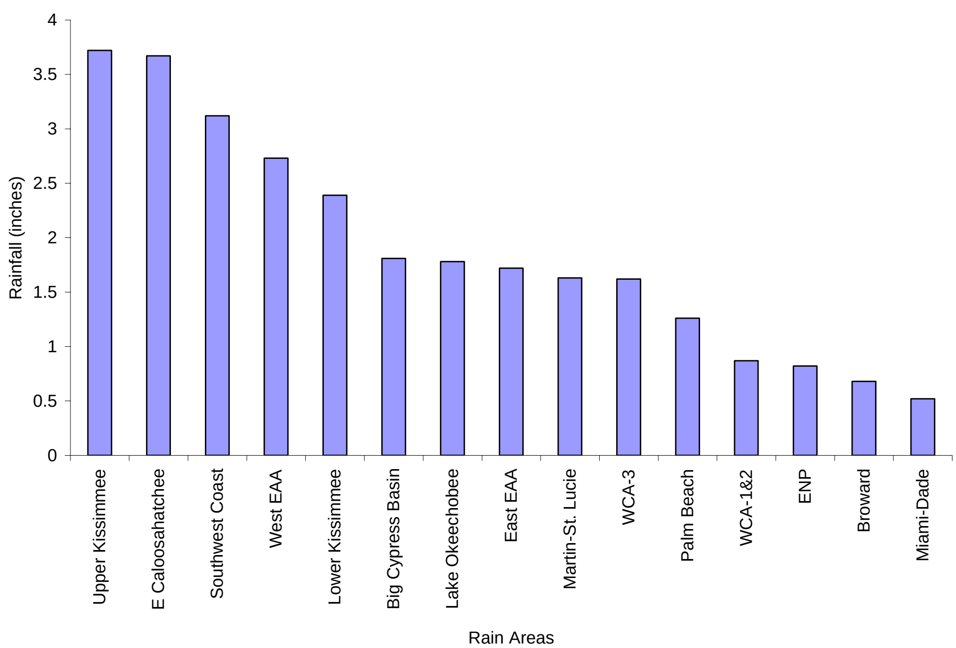


Figure 5-14. Hurricane Charley areal average rainfall (August 12–16, 2004).

According to the National Hurricane Center (NHC; Beven, 2004), Hurricane Frances made landfall over the southern end of Hutchinson Island on Florida's southeast coast on the evening of September 5, 2004, as a Category 2 hurricane; it traveled west-northwest through Central Florida, and entered the northeastern Gulf of Mexico on September 6, 2004 (**Figure 5-13b**). The five-day cumulative rainfall associated with this hurricane is depicted in **Figure 5-15**. The highest areal rainfall was observed in the Palm Beach rainfall area followed by the Martin-St. Lucie and Upper Kissimmee rainfall areas, corresponding with the hurricane's path.

According to the NHC (Lawrence and Cobb, 2005), Hurricane Jeanne made landfall on the southeast coast of Florida at the southern end of Hutchinson Island just east of Stuart early on September 26, 2004, as a Category 3 hurricane; it went west to 30 miles north of Tampa and moved north to Central Georgia (**Figure 5-13c**). The five-day cumulative rainfall associated with Hurricane Jeanne is depicted in **Figure 5-16**. The highest areal rainfall was observed in the Upper Kissimmee, Palm Beach, Martin-St. Lucie, and Lower Kissimmee rainfall areas, corresponding with the hurricane's path.

According to the NHC (Stewart, 2004), Hurricane Ivan made landfall west of Gulf Shores, Alabama on September 16, 2004, as a Category 3 hurricane. This hurricane moved through Alabama in a northeast direction and crossed the Delmarva Peninsula to the Atlantic Ocean as an extratropical low on September 18, 2004 (**Figure 5-13d**), and then moved southwest and crossed South Florida from east to west on September 21, 2004. The five-day cumulative rainfall with the preceding two days and following two days of Ivan's crossing South Florida is depicted in **Figure 5-17**. The highest areal rainfall was observed in the Martin-St. Lucie rainfall area, followed by the Palm Beach and East EAA areas, and generally corresponds with the path of the tropical system.

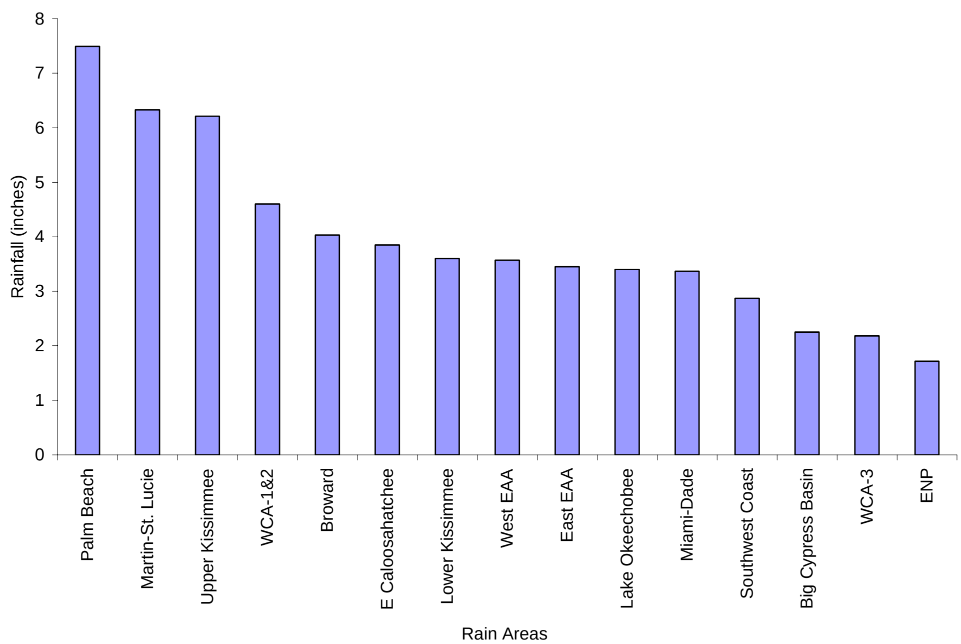


Figure 5-15. Hurricane Frances areal average rainfall (September 4–8, 2004).

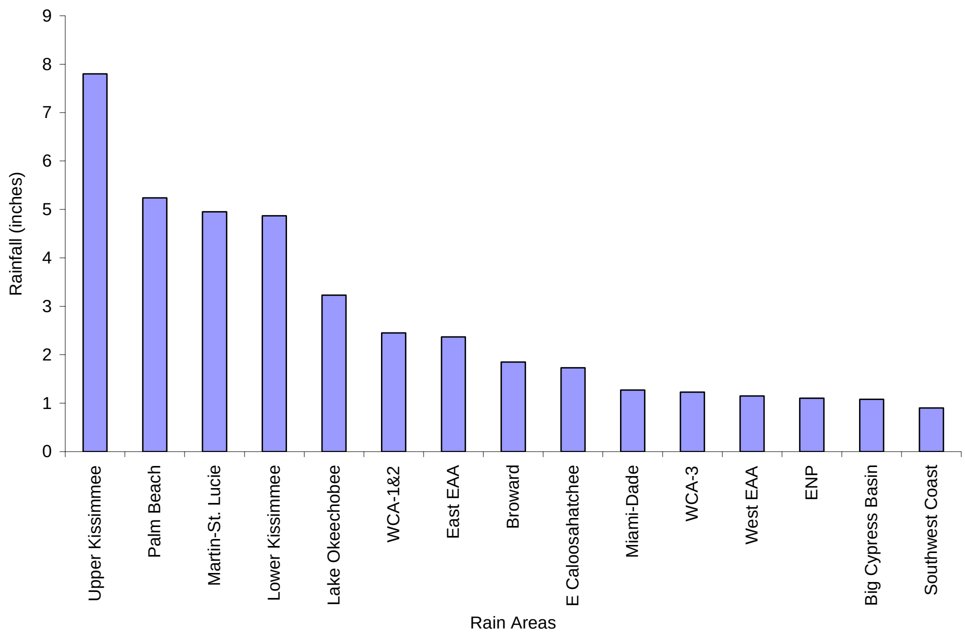


Figure 5-16. Hurricane Jeanne areal average rainfall (September 24–28, 2004).

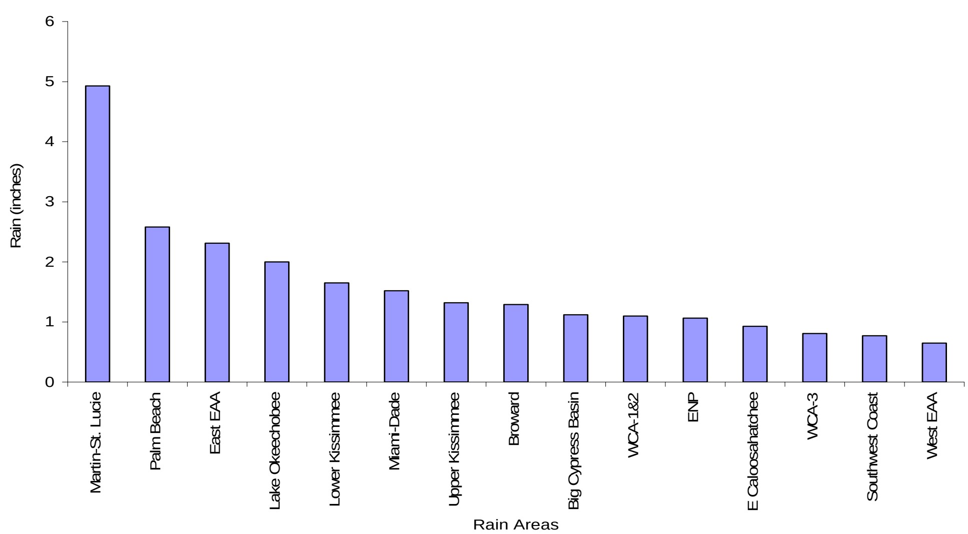


Figure 5-17. Areal average rainfall associated with tropical system Ivan (September 19–23, 2004).

The rainfall associated with each hurricane can be evaluated for frequency of occurrence by comparing the events with published probability tables or figures. Historical rainfall frequency analysis is available for areal rainfall characterization of the rainfall areas for monthly and annual durations. The areal rainfall is the best estimate of the depth of rainfall over each area. Because the five-day areal rainfall frequency reference is not available, the frequency analysis is reported for monthly rainfall during August and September 2004. For a single rain gauge and vicinity, frequency analysis is available for one-, two-, three-, and five-day and one-month durations. Rain gauges with a maximum five-day rainfall were selected from the network for each rainfall area, and the estimated five-day rainfall frequency of occurrence is presented. **Table 5-4** presents the five-day rainfall and return-period (rp) for the rainfall station with the maximum reading per hurricane per rainfall area (MacVicar, 1981).

Table 5-4. Maximum five-day rainfall at rain gauges associated with the 2004 hurricanes.

Hurricane	Charley		Frances		Ivan		Jeanne	
Rain Area	Rain gauge	Rainfall (in)	Rain gauge	Rainfall (in)	Rain gauge	Rainfall (in)	Rain gauge	Rainfall (in)
Upper Kissimmee	KISSIMMEEFS	5.07	KENANSVILLE	8.22	ORLANDOEXE	2.49	**KENANSVILLE**	11.99 (≈25)*
Lower Kissimmee	S-127	3.3	NEWSJUICE	9.55	S-65D	3.41	NEWSJUICE	10.2
Lake Okeechobee	FORTOGDEN	4.18	S-153	5.9	S-169	5.84	S-153	10.55
East EAA	CWEF1	3.25	ENR101	7.69	ENR401	5.96	ENR401	6.82
West EAA	BCIF1	3.99	ROTHWX	4.36	G-136	2.75	S-140	2
WCA-1&2	S-7	1.64	HILLSBORO	7.97	ENR301	2.49	ENR106	5.81
WCA-3	BCIF1	3.99	S-335	4.46	S-335	1.74	CHEKIKAEVER	2.21
Martin-St. Lucie	FTPIERCEFS	3.3	NEWSJUICE	9.55	**S-97 (≈5)***	9.22 (5)*	S-153	10.55
Palm Beach	S-40	3.53	**PBIA**	15.57 (≈50)*	JUNOBCH	4.27	S-153	10.55
Broward	PLANTATION	1.61	PEMBROKEPINES	5.97	S-33	2.83	HOLLYWOOD	3.35
Miami-Dade	S-27	1.17	PEMBROKEPINES	5.97	MIAMIINTL	2.93	NMIAMIBCH	2.98
E Caloosahatchee	S-78	5.02	ALVA	6.88	G-136	2.75	PALMDALE	3.75
Big Cypress Basin	TAMIAMICANAL	2.79	BCSI	4.17	TENRAW	3.02	RACCOONPOINT	2.09
Southwest Coast	**NRESV**	5.32 (<5)*	GATEWAY	5.14	MCIF1	2.65	RACCOONPOINT	2.09
ENP	Chekikaever	1.62	CHEKIKAEVER	2.36	S-174	2.48	CHEKIKAEVER	2.21

* Return Period in years

Surface water runoff volumes, storage capacity, and timely transmission capacity are impacted by cumulative seasonal rainfall. August and September 2004 were wet months, especially on the headwater of Lake Okeechobee and the Lower and Upper Kissimmee. The Martin-St. Lucie rainfall area also experienced high rainfalls. Monthly rainfall with rare return-periods (rp) was observed in September 2004 in the Upper Kissimmee (17.38 inches; > 100 year rp); the Lower Kissimmee (11.84 inches; 100 year rp); Martin-St. Lucie (17.86 inches; > 50 year rp); and Palm Beach (17.69 inches; > 50 year rp) rainfall areas. **Table 5-5** depicts monthly areal rainfall and rp for August and September 2004 in each rainfall area.

Table 5-5. Monthly areal rainfall with return-period for each rainfall area for August and September 2004.

	August	return period	September	return period
Rain Area	rainfall (in)	years	rainfall (in)	years
Upper Kissimmee	12.7	**50**	17.38	**> 100**
Lower Kissimmee	9.59	< 20	11.84	**100**
Lake Okeechobee	9.62	> 10	10.22	10
East EAA	10.63	< 10	10.05	5
West EAA	13.54	< 20	7.51	2
WCA-1&2	9.63	< 10	9.98	< 10
WCA-3	9.32	---	6.19	----
Martin-St. Lucie	9.65	< 10	17.86	**> 50**
Palm Beach	8.51	< 5	17.69	**> 50**
Broward	9.74	5	9.67	< 5
Miami-Dade	8.03	> 2	8.44	2
E Caloosahatchee	13.4	**50**	8.19	< 5
Big Cypress Basin	12.22	----	7.52	----
Southwest Coast	13.93	> 20	6.82	< 2

Additionally, relative magnitude inflows and outflows from the major lakes and through the canal system are indicators of the hydrologic impact of the hurricanes. Outflows from Lake Kissimmee through the S-65 structure, outflows from Lake Istokpoga through the S-68 structure, and inflows to Lake Okeechobee through the S-65E structure are shown in **Figure 5-18** for the hurricanes and following months. The October 1, 2004 outflow rate of 8,910 ac-ft/day for Lake Istokpoga through the S-68 structure is the highest on record. Inflow to Lake Okeechobee through the S-65E structure reached 35,457 ac-ft/day on September 27, 2004, a record high since 1972. Outflow from Lake Kissimmee also reached high levels; close to historical record high flow.

Discharge from Lake Okeechobee to the Caloosahatchee River and St. Lucie Canal are also indicators of the hydrologic impact of the 2004 hurricanes. Lake Okeechobee releases to the Caloosahatchee River through the S-77 structure reached a record high daily discharge of 17,786 ac-ft since 1972. Significant flows were discharged to St. Lucie Canal through the S-308 structure. **Figure 5-19** depicts discharge from Lake Okeechobee through the Caloosahatchee River and St. Lucie Canal during the hurricane and following months. **Figure 5-20** depicts flow from Lake Okeechobee into the Everglades Agricultural Area (EAA) via the S351_S, S352_S, and S354_S structures and the L-8 canal.

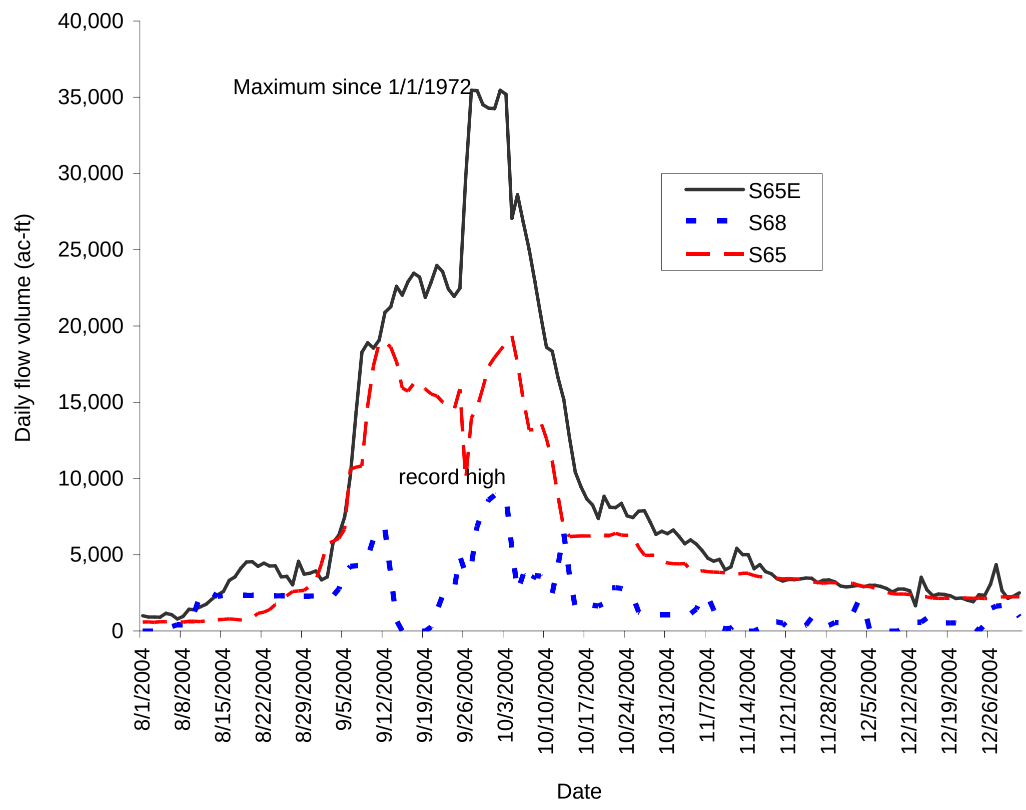


Figure 5-18. Lake Kissimmee (S-65), Lake Istokpoga (S-68), outflows and Lake Okeechobee (S-65E) inflows (August 1, 2004–December 31, 2004).

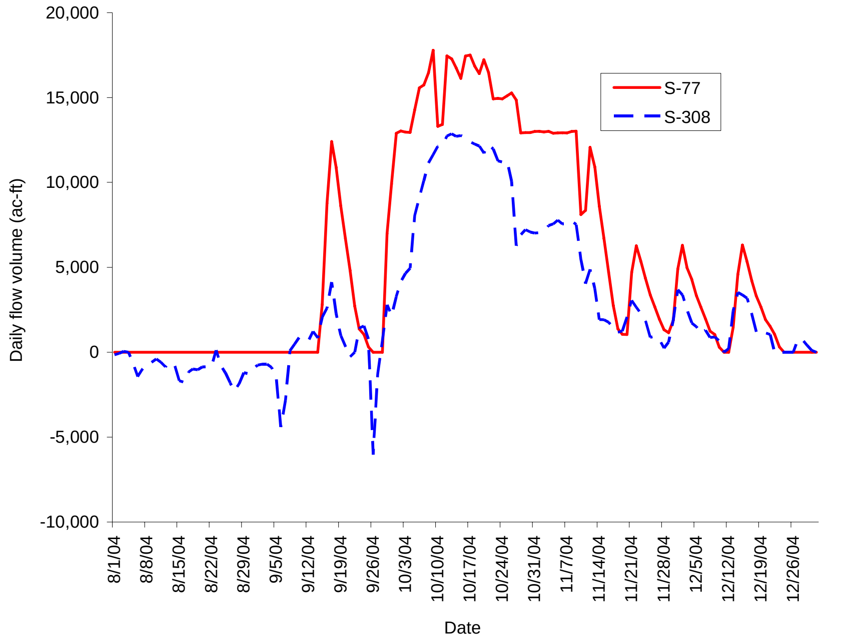


Figure 5-19. Lake Okeechobee discharge through the Caloosahatchee River (S-77) and St. Lucie Canal (S-308) (August 1–December 31, 2004).

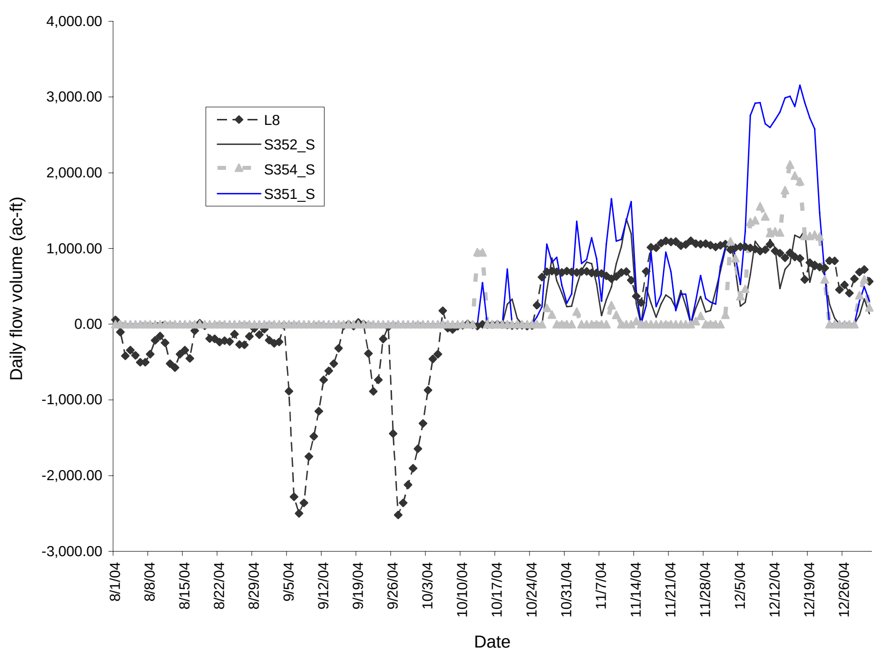


Figure 5-20. Lake Okeechobee discharge into the Everglades Agricultural Area (August 1–December 31, 2004).

A summary of monthly flows through the major structures in Upper and Lower Kissimmee and Lake Okeechobee is shown in **Table 5-6**. The September 2004 Lake Kissimmee outflow through S-65 (410,321 ac-ft) was an extreme event only exceeded by two months in a record of 855 months (1933 to 2004). The two exceeding months were March, 1998 (an El Niňo year) and October, 1948 (a hurricane year). The September 2004 Lake Istokpoga outflow through S-68 (100,298 ac-ft) was an extreme event only exceeded by five months in a record of 492 months (1964 to 2004). The September 2004 inflow into Lake Okeechobee through S-65E (610,694 ac-ft) was an extreme event only exceeded by four months in a record of 888 months (1928 to 2004). The September 2004 Lake Okeechobee outflow (469,723 ac-ft) through the S-77 structure to the Caloosahatchee River was extreme, representing the second highest monthly flow in 795 months (1938 to 2004). The September 2004 Lake Okeechobee outflow (306,012 ac-ft) through the S-308 structure to the St. Lucie Canal was extreme, representing the second highest monthly flow in 396 months (1972 to 2004).

Table 5-6. Monthly flows through major structures during the 2004 hurricane season.

Month	S-65 ac-ft	S-68 ac-ft	S-65E Ac-ft	S-77 ac-ft	S-308 ac-ft	S-351 ac-ft	S-352 ac-ft	S-354 ac-ft	L-8 ac-ft
Aug	37323	51644	84428	0	-28200	0	65	0	-7775
Sep	410321	100298	610694	77378	7288	0	0	0	-27911
Oct	291340	98410	472153	469723	306012	5148	3207	2245	-472
Nov	109284	18975	129117	215351	112123	20379	13333	732	24766
Dec	74439	22022	81412	63718	38944	48394	19214	26473	25926
Total	**922,707**	**291,349**	**1,377,804**	**826,170**	**436,167**	**73,921**	**35,819**	**29,450**	**14,534**

During the hurricane season and following months, the outflows from the Everglades Agricultural Area (EAA) were very high. Outflows through structures G-370 and G-372 into Stormwater Treatment Areas 3 and 4, outflows through S-6 into STA-2, and outflows through S-5A into STA-1W and WCA-1 totaled 924,109 ac-ft for the five months, August through December 2004. The estimated average annual runoff from the EAA is a million ac-ft per year. Cumulative outflows from the EAA and Lake Okeechobee discharges into the EAA (S-351, S3-52, and S-354) during the hurricane season and following months are shown in **Figure 5-21**. **Table 5-7** summarizes monthly outflows from the EAA by structure and total outflows.

Significant water level increases associated with the 2004 hurricane events are observed in Lake Kissimmee, along the reaches of the Kissimmee River, Lake Istokpoga, Lake Okeechobee, and Water Conservation Area 1. Water level rises in Lake Kissimmee at S-65 structure and along the reaches of the Kissimmee River (S-65A, S-65C, S-65D, and S-65E) during the hurricane events are shown in **Figures 5-22** through **5-26**.

A sharp rise in water level was observed in Lake Istokpoga during the hurricane events (**Figure 5-27**). Lake Okeechobee water level rose by 5.38 ft between August 12 and October 13, 2004 resulting in an increase in storage of 2.37 million ac-ft (**Figure 5-28**). The 18.02 ft NGVD, maximum stage of Lake Okeechobee on October 13, 2004 was within less than one percent probability of exceedance. A rise in water level in Water Conservation Area 1 (WCA-1) was also observed during the hurricane events (**Figure 5-29**).

Table 5-7. Monthly outflows from the EAA through Major structures (August–December 2004).

	S-6	G-370	G-372	S-5A	Total
Month	**ac-ft**	**ac-ft**	**ac-ft**	**ac-ft**	**ac-ft**
Aug	78,302	92,618	82,585	80,523	**334,028**
Sep	90,563	66,585	98,658	152,987	**408,793**
Oct	25,599	12,054	31,314	56,296	**125,263**
Nov	7,074	0	0	6,274	**13,348**
Dec	784	27,052	1,021	13,820	**42,677**
Total	**202,232**	**198,309**	**213,578**	**309,900**	**924,109**

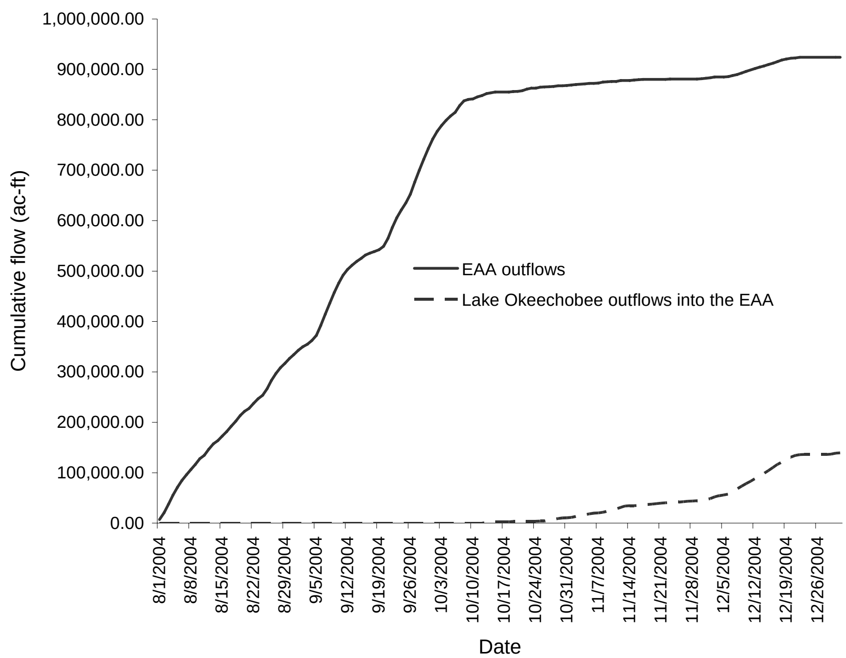


Figure 5-21. Cumulative outflows from the EAA and Lake Okeechobee (August–December 2004).

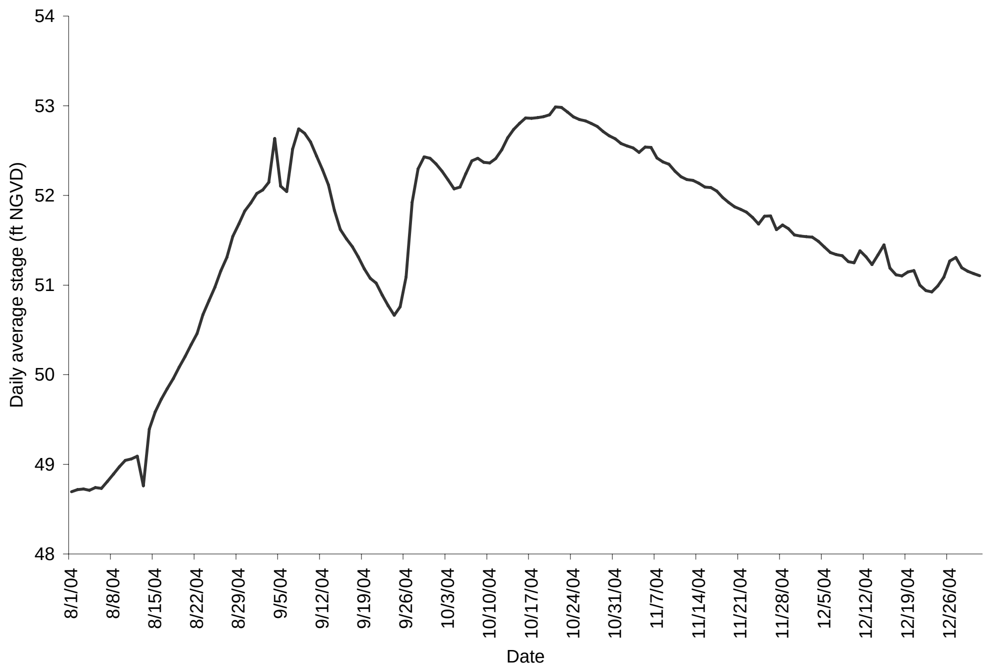


Figure 5-22. Water level changes in Lake Kissimmee during the 2004 hurricane events.

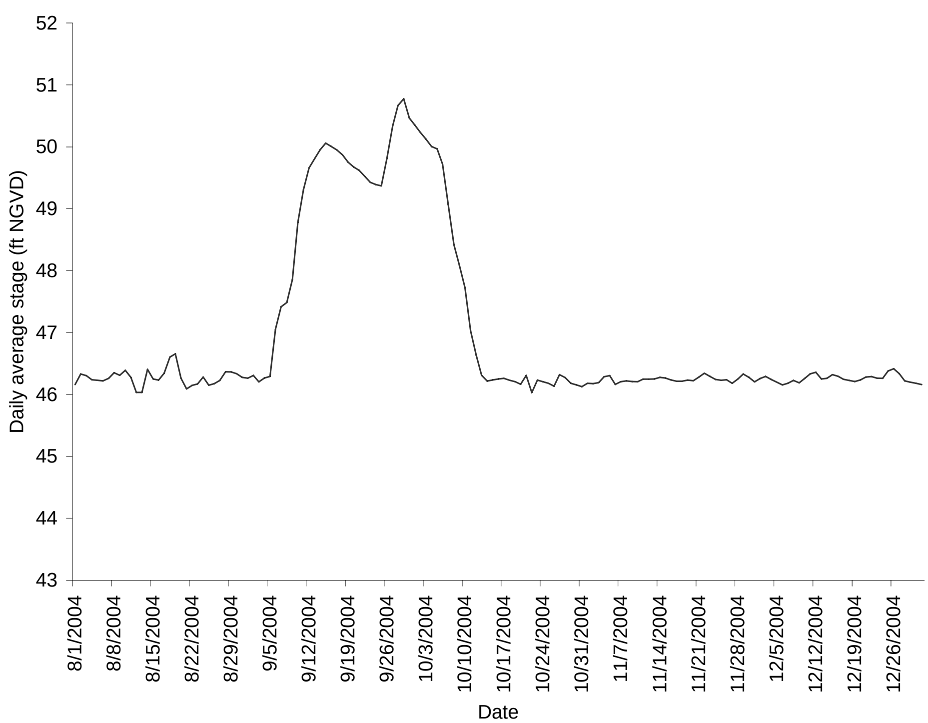


Figure 5-23. Water level changes on Kissimmee River pool S-65A during the 2004 hurricane events.

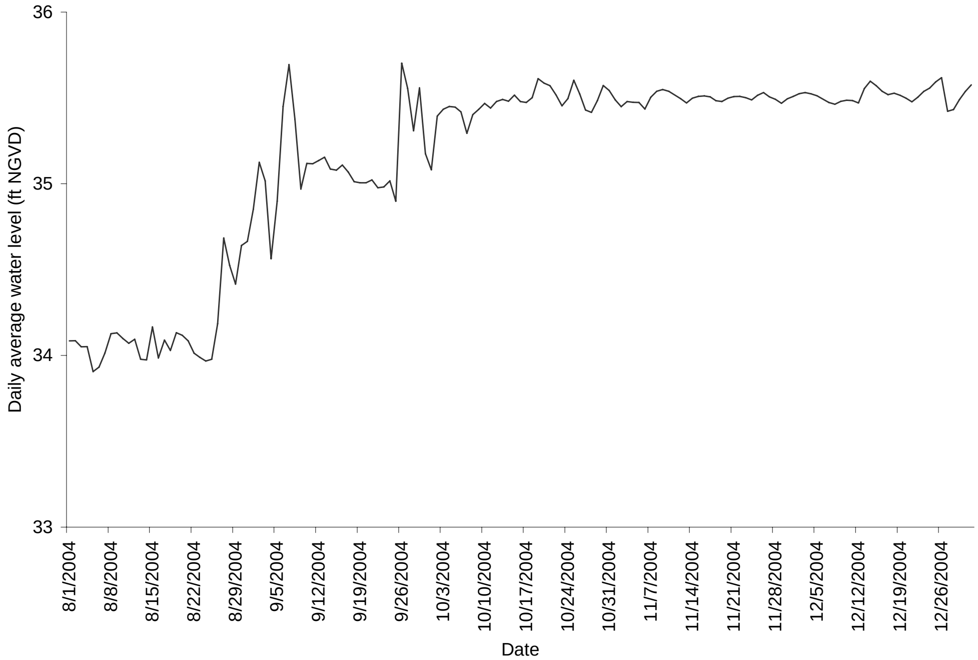


Figure 5-24. Water level changes on Kissimmee River pool S-65C during the 2004 hurricane events.

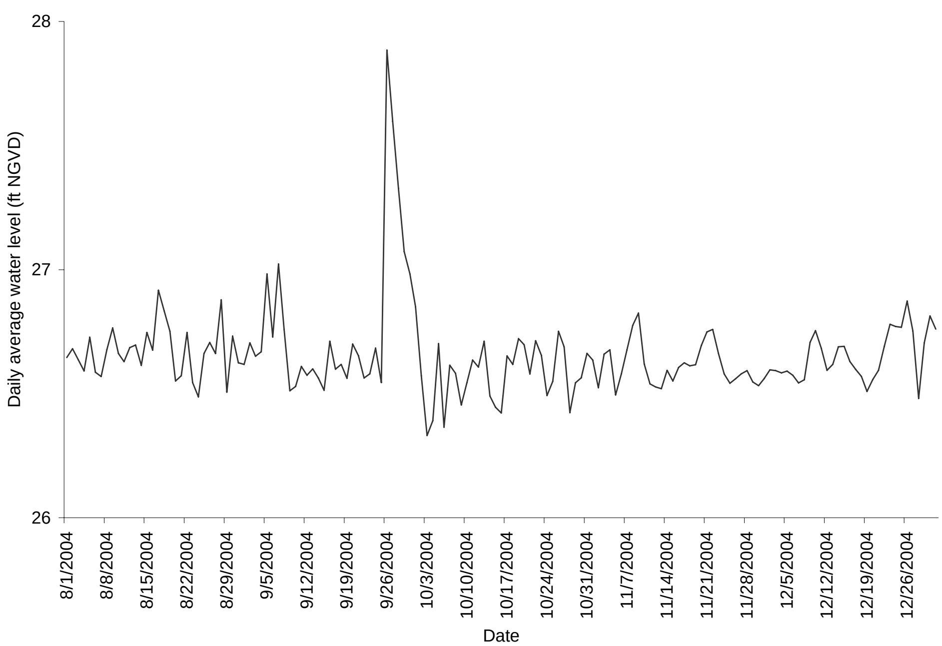


Figure 5-25. Water level changes on Kissimmee River pool S-65D during the 2004 hurricane events.

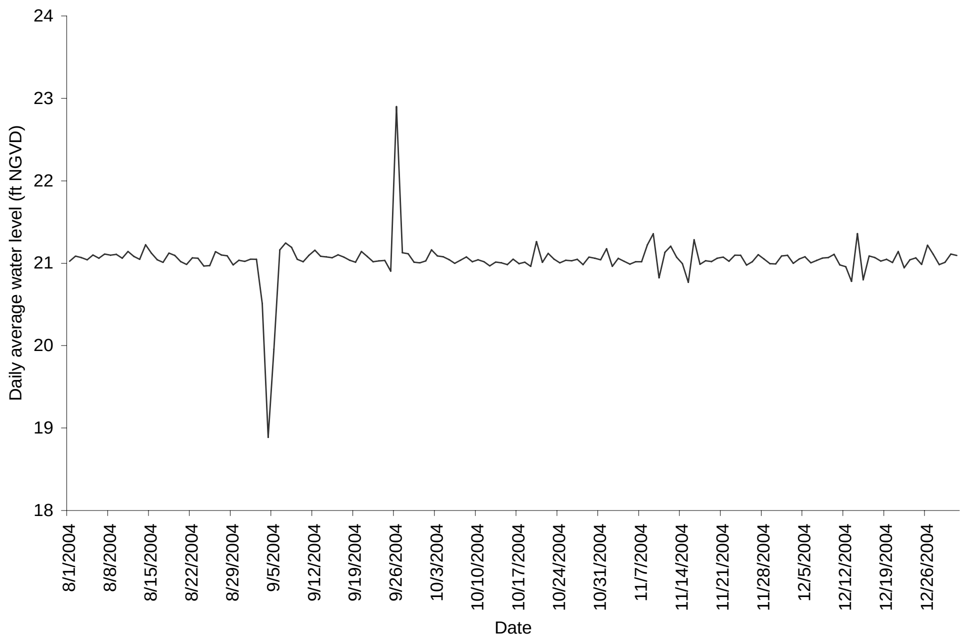


Figure 5-26. Water level changes on Kissimmee River pool S-65E during the 2004 hurricane events.

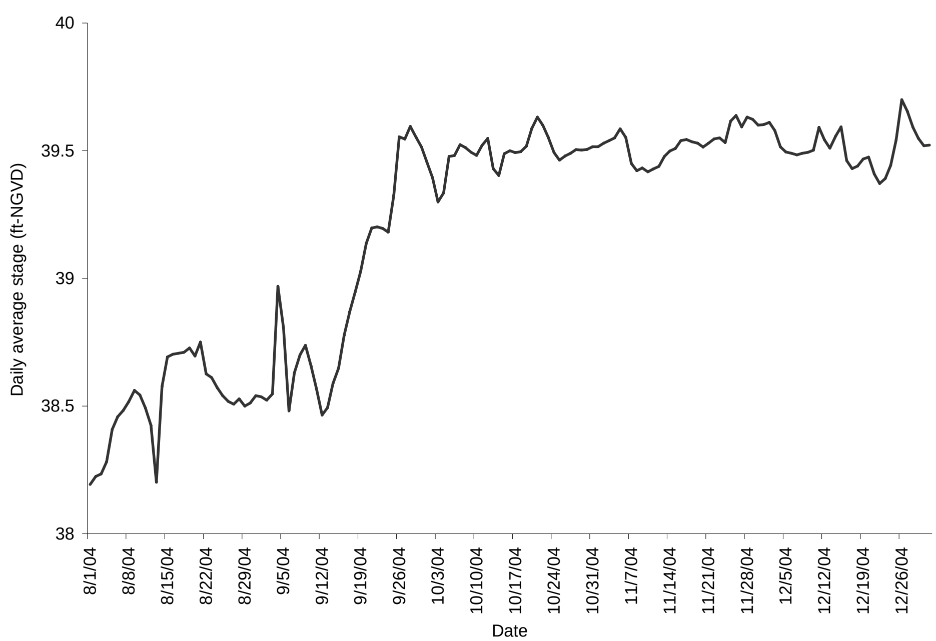


Figure 5-27. Water level changes in Lake Istokpoga during the 2004 hurricane events.

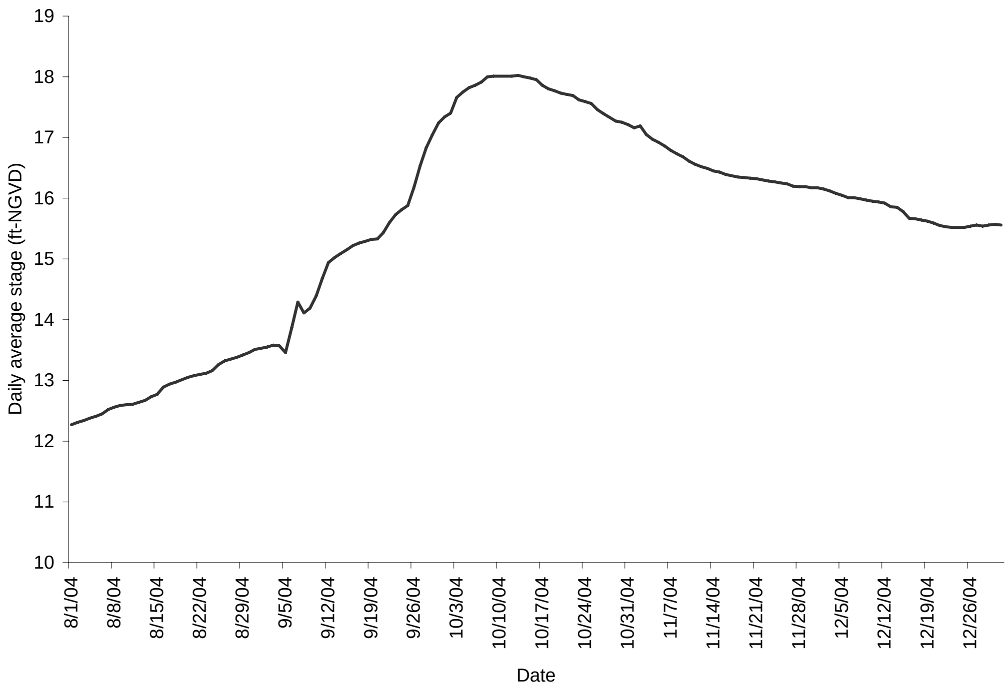


Figure 5-28. Water level changes in Lake Okeechobee during the 2004 hurricane events.

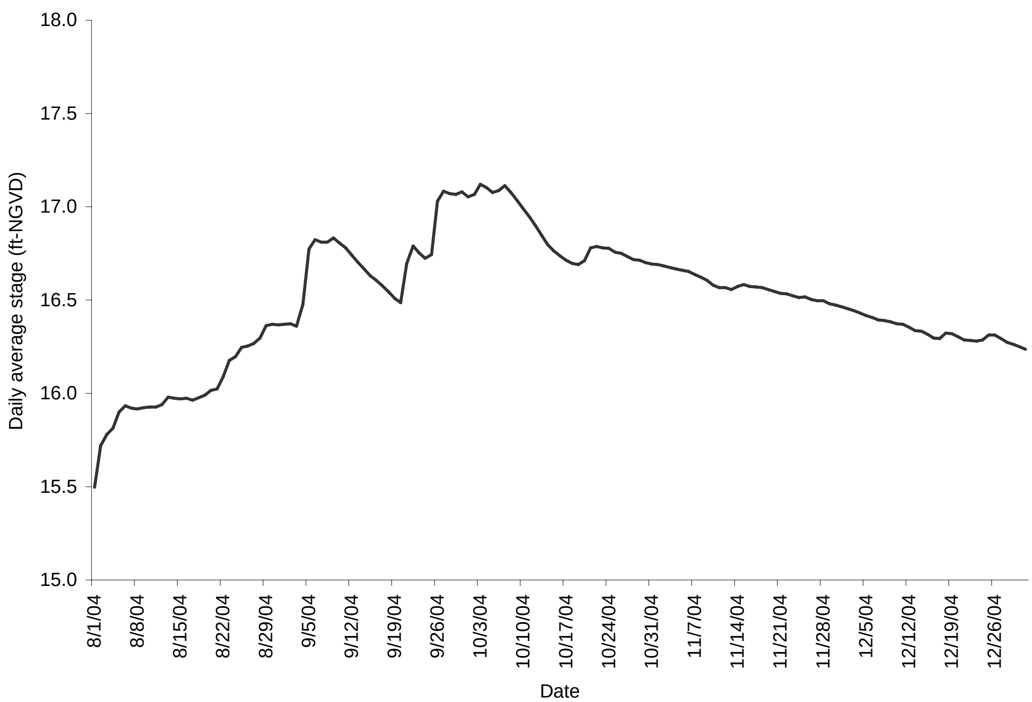


Figure 5-29. Water level changes in WCA-1 during the 2004 hurricane events.

WATER YEAR 2005 HYDROLOGY

RAINFALL

Despite the four-hurricane season during August and September 2004, rainfall for WY2005 for the District area (50.67 inches) was lower than WY2004 rainfall (52.35 inches) and the historical average rainfall (52.75 inches). Rainfall data computed as Thiessen averages of several stations was obtained from the District's Operations rainfall data report (http://iweb/iwebB501/omd/weather/opswthr.htm). The ENP area rainfall was estimated as the simple average of four stations: S174_R, TAMI AIR_R, S332_R, and Chekika. Generally for WY2005, the northern rainfall areas (**Figure 5-2**) had higher rainfall due to the 2004 hurricanes; otherwise, it was a little less than the average year. A comparison of WY2005, WY2004, and historical basin average rainfall is shown in **Table 5-8,** with above-average rainfalls shown in bold. Although the WY2005 rainfall was overall lower than WY2004 and the historical average, the rainfall areas which received above-average rainfall had a significant impact on surface water runoff generation and water management. The Upper Kissimmee and the Lower Kissimmee rainfall areas received significantly higher than average rainfall. The Upper Kissimmee received 14.10 inches of above-average rainfall and the Lower Kissimmee received 5.67 inches of above-average rainfall, with the bulk occurring in August and September 2004. The Martin-St. Lucie rainfall area had 2.85 inches, the East Caloosahatchee rainfall area had 3.42 inches above average, and the Southwest Coast rainfall area had 0.93 inches of above-average rainfall. The rest of the rainfall areas had lower than historical averages. **Figure 5-30** depicts WY2005, historical average rainfall; and 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 higher Lake Okeechobee water level coincides with higher rainfall in the headwaters, the result will be high water level with a cascading downstream effect. Additional details on water levels and flows are also summarized in this chapter.

Table 5-8 depicts WY2005, WY2004, historical average annual rainfall and WY2005 annual ETp for each rain area. **Table 5-9** depicts monthly rainfall for each rain for WY2005. Graphical comparison of WY2005 monthly potential evapotranspiration (ETp), WY2005, WY2004, and historical average rainfall for each rainfall area are depicted in **Figures 5-31** through **5-45**. For areas such as lakes, WCAs, and wetlands that are wet throughout the year, the ETp approximates the actual ET. The deviation in water year rainfall from the historical average is shown in the legends of these figures for the respective rainfall area. In these legends, an increase is shown as a "+", and a decrease is shown as a "-".

Table 5-8. Comparison of WY2005, WY2004, and historical average annual rainfall for each rainfall area and WY2005 potential evapotranspiration (ETp).

Rainfall Area	WY2005 Rainfall (inches)	WY2004 Rainfall (inches)	Historical Average Rainfall (inches)	WY2005 ETp (inches)
Upper Kissimmee	**64.19**	51.48	50.09	51.5
Lower Kissimmee	**50.12**	47.28	44.45	55.2
Lake Okeechobee	45.51	43.08	45.97	53.5
East EAA	46.16	43.61	53.48	50.7
West EAA	52.20	54.87	54.95	50.7
WCA -1 & 2	43.72	44.08	51.96	51.9
WCA-3	40.27	46.90	51.37	53.3
Martin-St. Lucie	**56.99**	47.85	54.14	50.8
Palm Beach	50.44	50.38	61.54	50.7
Broward	42.80	57.81	58.13	53.3
Miami-Dade	43.05	54.91	57.11	53.8
East Caloosahatchee	**54.10**	60.08	50.68	53.8
BCP	50.39	59.12	53.98	54.0
Southwest Coast	**55.05**	67.34	54.12	53.3
ENP	40.15	47.38	55.22	53.8
District	50.67	52.35	52.75	52.7

Table 5-9. WY2005 monthly rainfall (inches) for each rain area.

		Upper Kiss	Lower Kiss	Lake O	East EAA	West EAA	Conserv Area 1, 2	Conserv Area 3	Martin/St. Lucie	Palm Beach	Broward	Miami-Dade	East Caloos	BCP	SW Coast	District
2004	May	1.73	0.76	1.23	1.02	1.32	1.44	1.95	1.75	2.39	1.42	1.98	1.32	1.69	1.42	1.5
2004	June	8.78	6.72	6.03	6.1	7.59	4.1	6.07	5.8	3.15	2.6	3.38	6.56	7.58	8.21	6.37
2004	July	6.2	5.38	4.18	5.92	7.8	5.42	6.33	4.68	4.22	6.07	7.78	6.69	8.67	8.79	6.35
2004	Aug	12.7	9.59	9.62	10.63	13.54	9.63	9.32	9.65	8.51	9.74	8.03	13.4	12.22	13.93	10.92
2004	Sept	17.38	11.84	10.22	10.05	7.51	9.98	6.19	17.86	17.69	9.67	8.44	8.19	7.52	6.82	10.82
2004	Oct	1.14	1.93	1.54	1.76	3.19	2.99	2.17	2.1	2.85	3.44	5.45	2.31	2.42	2.22	2.31
2004	Nov	1.14	0.58	0.59	0.71	0.72	0.63	0.43	1.08	0.87	0.77	1.07	0.8	0.74	0.6	0.76
2004	Dec	2.65	2.3	1.12	0.66	1.05	0.85	0.61	1.55	0.85	0.93	0.29	1.18	0.7	1.5	1.26
2005	Jan	2.26	1.22	0.85	0.92	0.94	1.01	1.03	1.06	1.23	1.61	1.09	0.67	0.82	0.78	1.08
2005	Feb	2.85	2.72	2.04	1.27	0.98	0.43	0.35	2.17	1.09	0.24	0.28	3.09	0.53	1.82	1.62
2005	Mar	4.87	4.44	6.05	5.41	5.61	5.34	3.97	6.46	5.87	4.57	3.34	7.11	4.9	6.19	5.36
2005	Apr	2.49	2.64	2.04	1.71	1.95	1.9	1.85	2.83	1.72	1.74	1.92	2.78	2.6	2.77	2.32
Sum		**64.19**	**50.12**	**45.51**	**46.16**	**52.2**	**43.72**	**40.27**	**56.99**	**50.44**	**42.8**	**43.05**	**54.1**	**50.39**	**55.05**	**50.67**

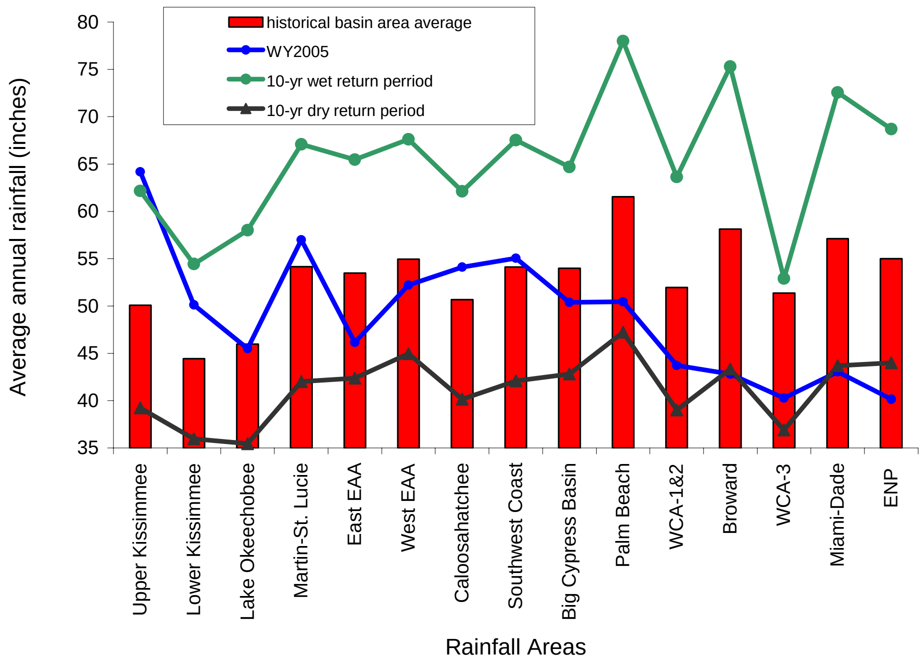


Figure 5-30. WY2005, historical average, the 10-year wet, and the 10-year dry return-period annual rainfall for each rainfall area.

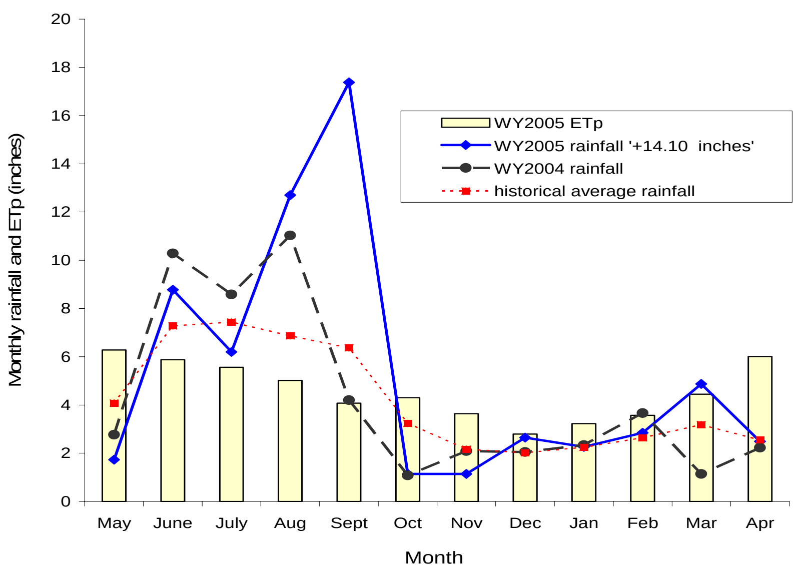


Figure 5-31. Monthly rainfall and potential evapotranspiration (ETp) for Upper Kissimmee rainfall area.

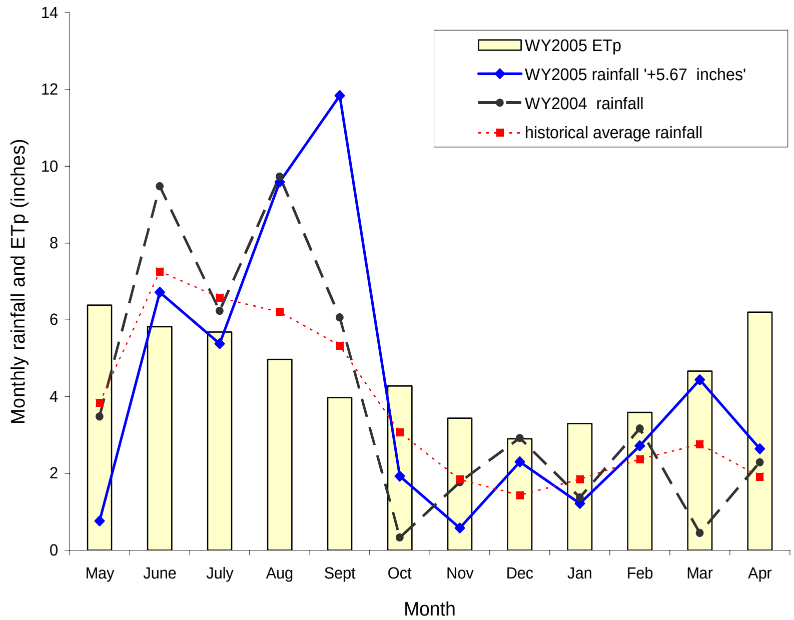


Figure 5-32. Monthly rainfall and ETp for Lower Kissimmee rainfall area.

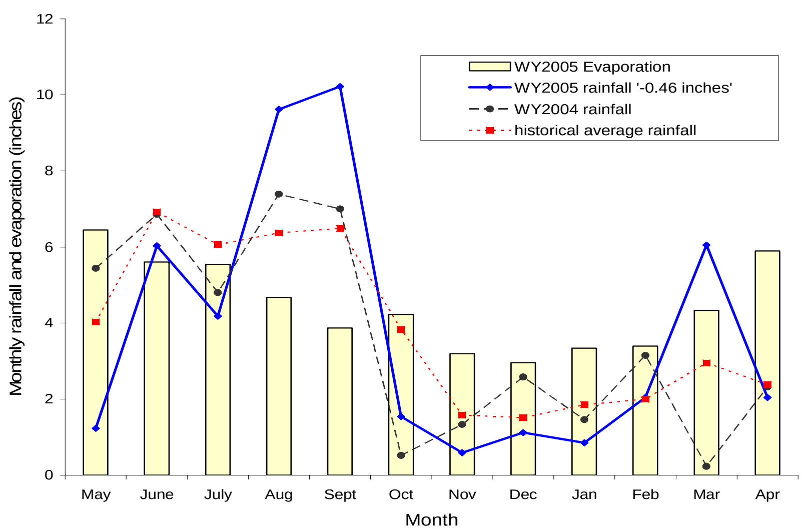


Figure 5-33. Monthly rainfall and ETp for Lake Okeechobee rainfall area.

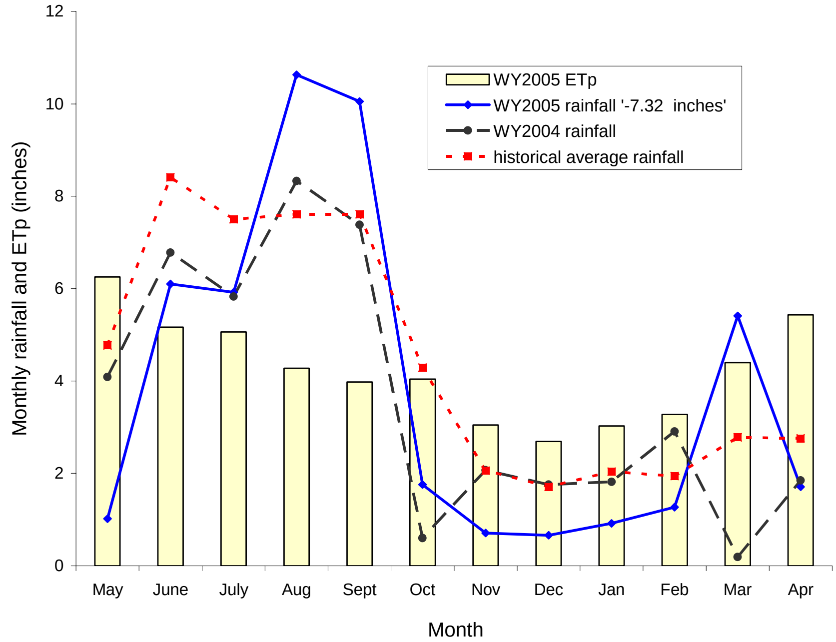


Figure 5-34. Monthly rainfall and ETp for East Everglades Agricultural Area (EAA) rainfall area.

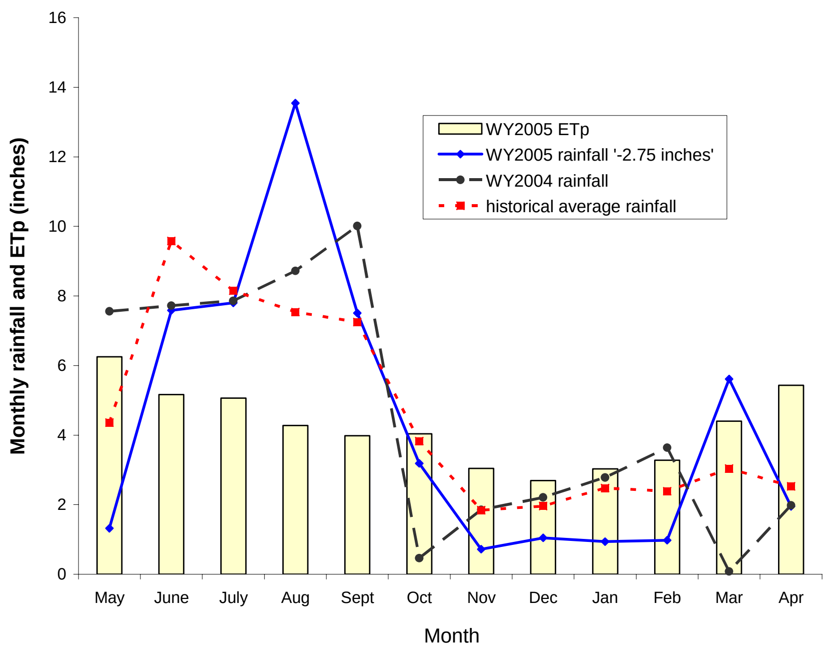


Figure 5-35. Monthly rainfall and ETp for West EAA rainfall area.

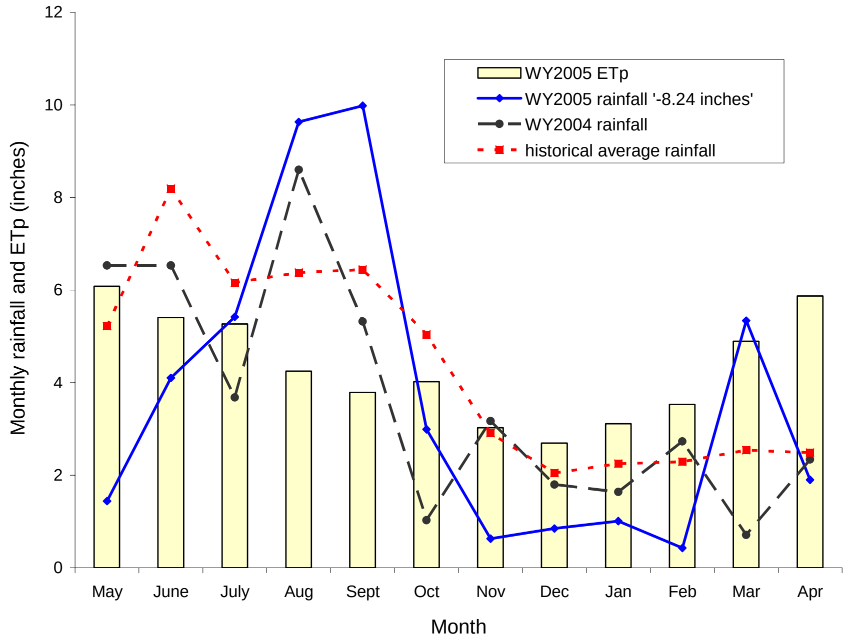


Figure 5-36. Monthly rainfall and ETp for Water Conservation Areas 1 and 2 (WCA-1 and WCA-2) rainfall areas.

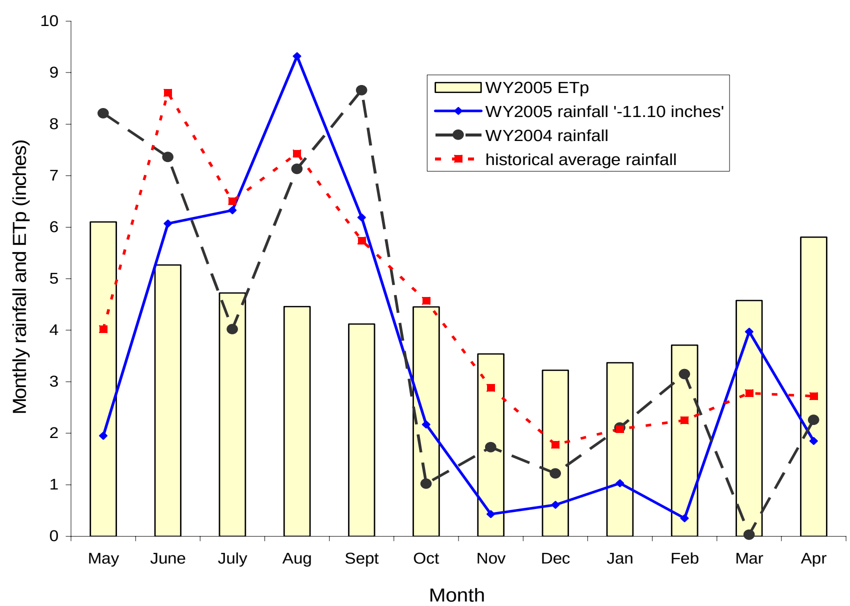


Figure 5-37. Monthly rainfall and ETp for WCA-3 rainfall area.

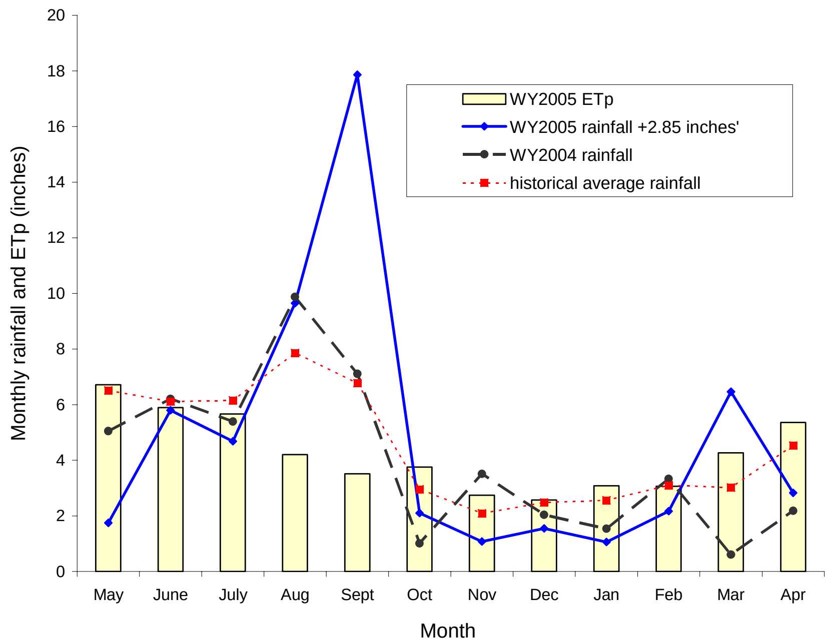


Figure 5-38. Monthly rainfall and ETp for Martin-St. Lucie counties rainfall areas.

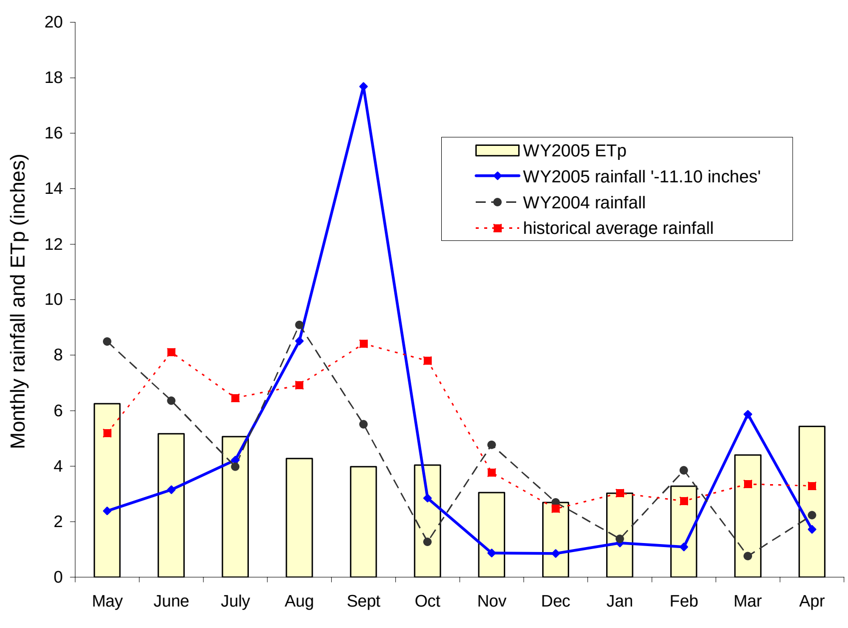


Figure 5-39. Monthly rainfall and ETp for Palm Beach County rainfall area.

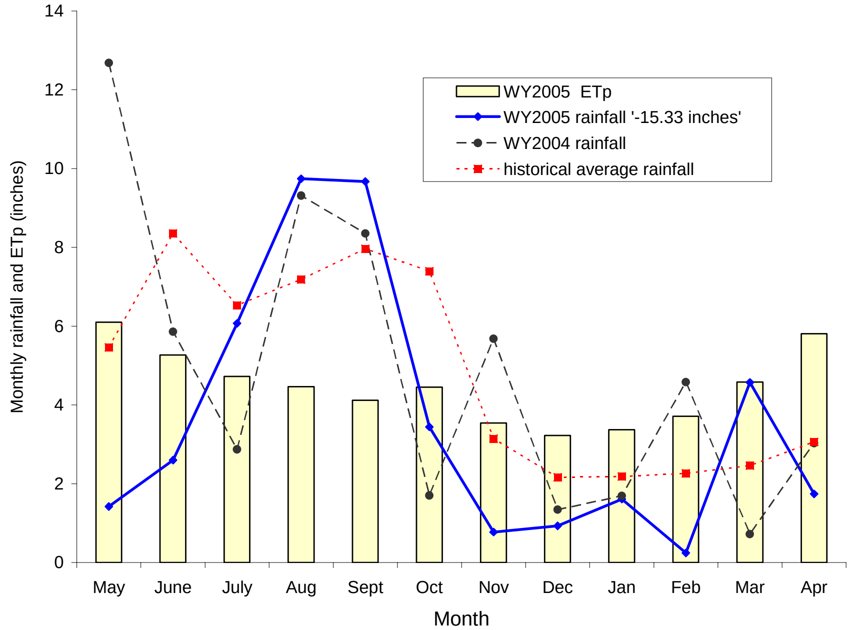


Figure 5-40. Monthly rainfall and ETp for Broward County rainfall area.

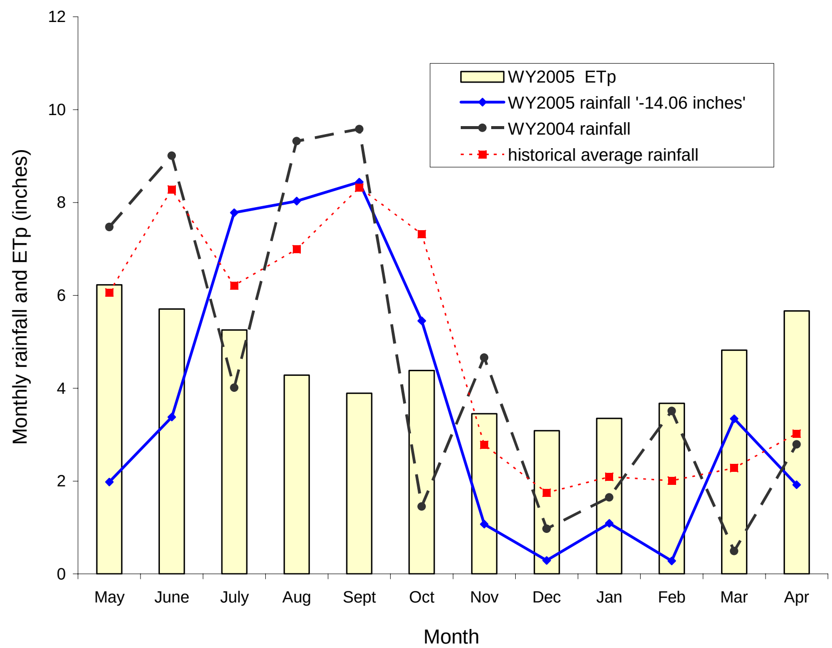


Figure 5-41. Monthly rainfall and ETp for Miami-Dade County rainfall area.

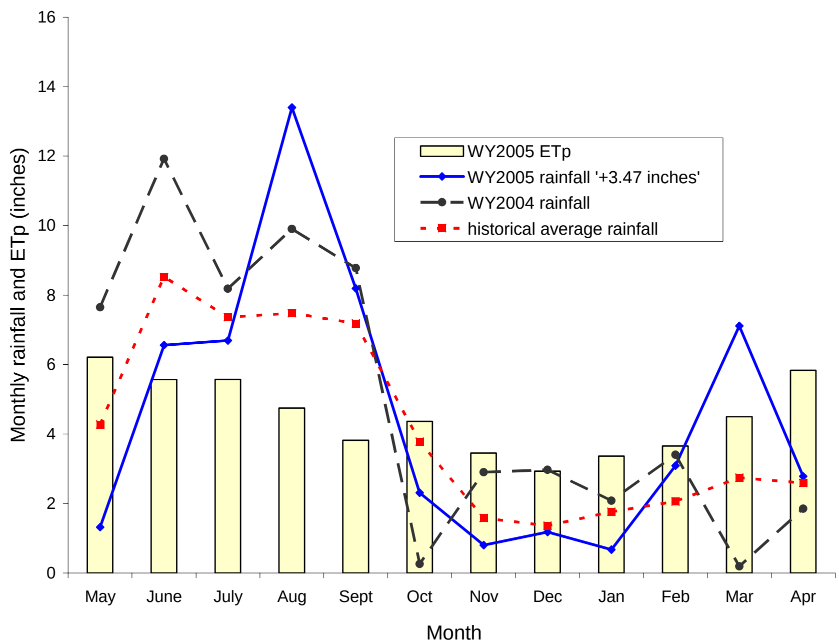


Figure 5-42. Monthly rainfall and ETp for Caloosahatchee rainfall area.

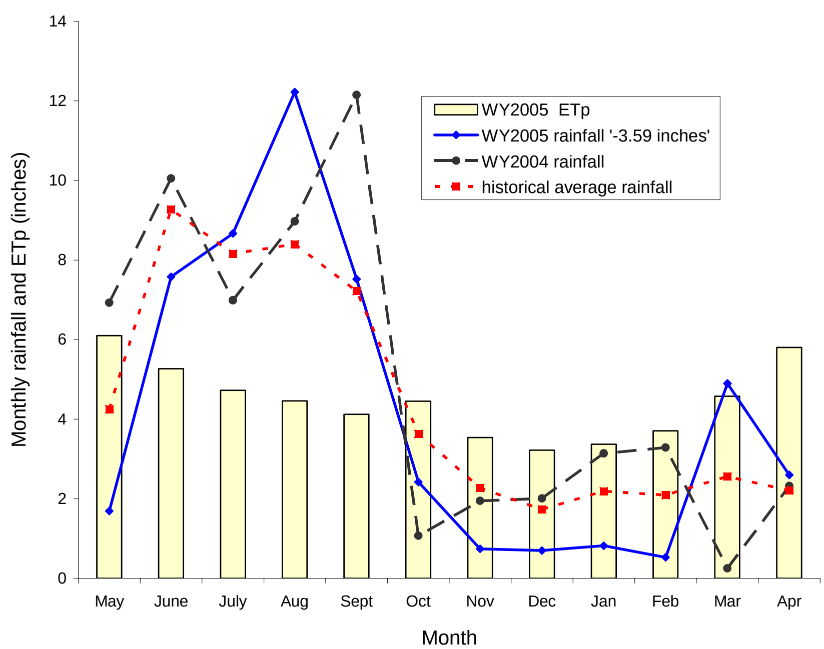


Figure 5-43. Monthly rainfall and ETp for Big Cypress Basin rainfall area.

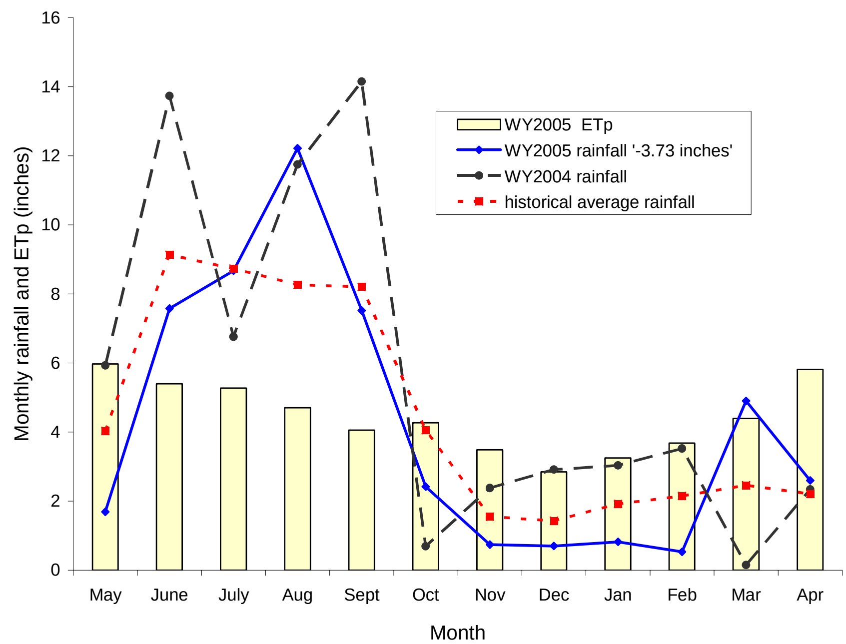


Figure 5-44. Monthly rainfall and ETp for Southwest Coast rainfall area.

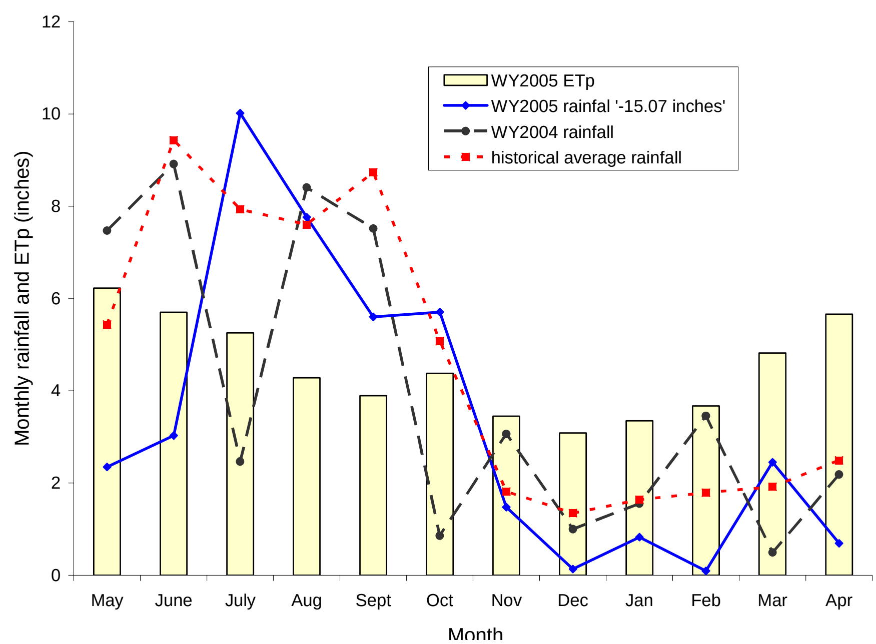


Figure 5-45. Monthly rainfall and ETp for the Everglades National Park (ENP or Park).

EVAPOTRANSPIRATION

Rainfall and evapotranspiration (ET) are the main parameters in the hydrologic balance of the Everglades. The delicate balance between rainfall and ET maintains the hydrology system 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 ET is explained by solar radiation (Abtew, 1996). Various measurements and estimates of ET have been reported in the literature for various locations in Central and South Florida. Regional estimates of ET 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). Model estimates of annual ETp from the SFWMD's database, DBHYDRO, are depicted in **Figures 5-31** through **5-45**. WY2005 monthly ETp for each rain area is shown in **Table 5-10**. 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 ET is presented as follows (Abtew, 1996; Abtew et al., 2003; Abtew, 2005).

$$ET = K_1 \frac{Rs}{\lambda} \qquad (1)$$

Where ET is daily ET from wetland or shallow open water (mm d^{-1}), Rs is solar radiation (MJ m^{-2} d^{-1}), λ is latent heat of vaporization (MJ kg^{-1}), and K_1 is a coefficient (0.53). Estimates for WY2005 are shown in **Table 5-8** and **Table 5-10**. 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.

Table 5-10. WY2005 monthly ETp (inches) for each rain area.

		Upper Kiss	Lower Kiss	Lake O	East EAA	West EAA	Conserv Area 1, 2	Conserv Area_3	Martin/ St. Lucie	Palm Beach	Broward	Miami-Dade	East Caloos	BCP	SW Coast
2004	May	6.28	6.39	6.45	6.25	6.25	6.08	6.10	6.72	6.25	6.10	6.22	6.21	6.10	5.97
2004	June	5.88	5.82	5.61	5.17	5.17	5.40	5.27	5.89	5.17	5.27	5.70	5.56	5.27	5.39
2004	July	5.57	5.68	5.54	5.06	5.06	5.27	4.72	5.66	5.06	4.72	5.25	5.57	4.72	5.27
2004	Aug	5.02	4.97	4.67	4.28	4.28	4.25	4.46	4.20	4.28	4.46	4.28	4.75	4.46	4.70
2004	Sept	4.08	3.97	3.87	3.98	3.98	3.79	4.12	3.52	3.98	4.12	3.89	3.82	4.12	4.06
2004	Oct	4.30	4.28	4.23	4.04	4.04	4.02	4.45	3.76	4.04	4.45	4.38	4.36	4.45	4.27
2004	Nov	3.63	3.44	3.19	3.05	3.05	3.03	3.54	2.74	3.05	3.54	3.45	3.45	3.54	3.49
2004	Dec	2.80	2.90	2.95	2.69	2.69	2.69	3.22	2.58	2.69	3.22	3.09	2.93	3.22	2.85
2005	Jan	3.22	3.30	3.34	3.03	3.03	3.11	3.37	3.08	3.03	3.37	3.35	3.36	3.37	3.24
2005	Feb	3.57	3.59	3.40	3.28	3.28	3.53	3.71	3.06	3.28	3.71	3.67	3.66	3.71	3.68
2005	Mar	4.44	4.67	4.34	4.40	4.40	4.89	4.58	4.27	4.40	4.58	4.82	4.50	4.58	4.39
2005	Apr	6.00	6.20	5.90	5.43	5.43	5.87	5.81	5.36	5.43	5.81	5.66	5.84	5.81	5.81
Sum		**54.79**	**55.20**	**53.48**	**50.65**	**50.65**	**51.94**	**53.35**	**50.84**	**50.65**	**53.35**	**53.77**	**54.00**	**53.35**	**53.12**

WATER LEVELS

Upper Kissimmee Chain of Lakes Water Levels

Lake Alligator has an average of 62.40 ft NGVD water level (stage) since 1993 (site S-60 headwater). 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 5-1, Figure 1). The daily average stage for WY2005 was 63.18 ft NGVD, compared to 63.08 ft NGVD for WY2004. **Figure 5-46** depicts WY2005, WY2004, and historical monthly average water levels. The regulation schedule, the operational guideline for maintaining periodic water levels in Lake Alligator, is shown in Appendix 5-2, Figure 1.

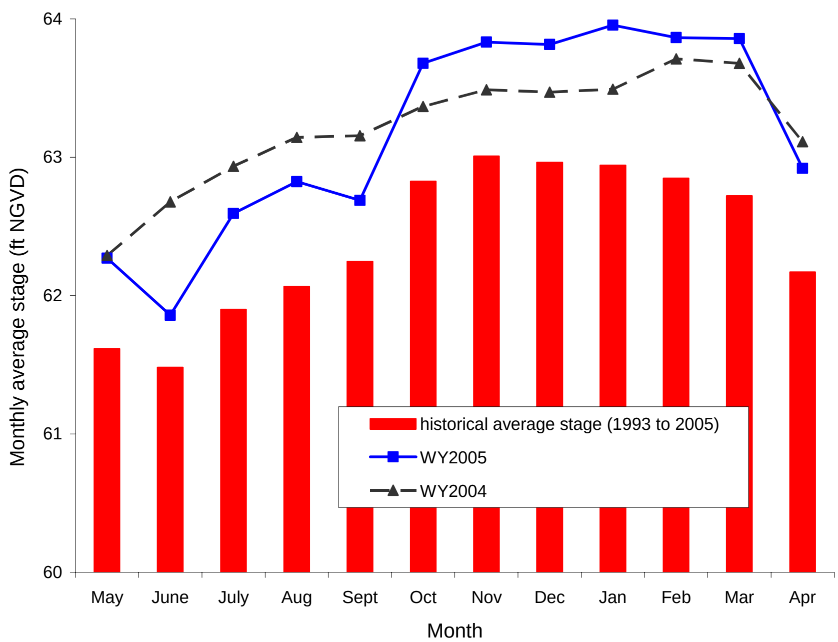


Figure 5-46. Monthly average water levels for Lake Alligator (site S60_H).

Lake Myrtle has an average of 60.88 ft NGVD water level (stage) since 1993 (site S-57 headwater). The maximum daily average water level was 64.98 ft NGVD, which was reached during the 2004 hurricane season (October 3 and 4, 2004). 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 5-1, Figure 2). The daily average stage for WY2005 was 61.60 ft NGVD, compared to 61.05 ft NGVD for WY2004. **Figure 5-47** depicts WY2005, WY2004, and historical monthly average water levels. The regulation schedule for Lake Myrtle is shown in Appendix 5-2, Figure 2.

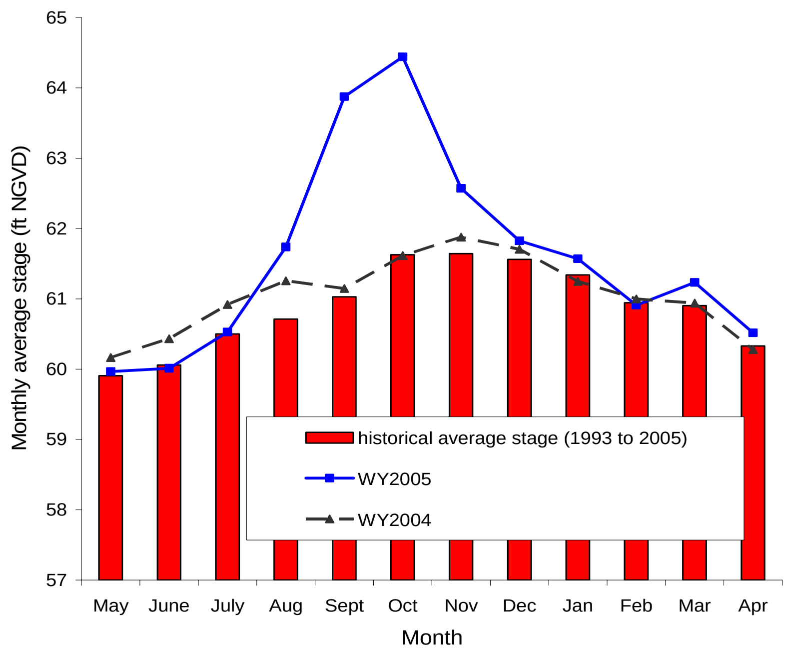


Figure 5-47. Monthly average water levels for Lake Myrtle (site S57_H).

Lake Mary Jane has an average of 60.04 ft NGVD water level (stage) since 1993 (site S-62 headwater). The maximum daily average water level was 61.91 ft NGVD, reached on December 30 and 31, 1997. 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 12 years show that the most significant drop in water level occurred in 2001 (Appendix 5-1, Figure 3). The daily average stage for WY2005 was 60.46 ft NGVD, compared to 60.36 ft NGVD for WY2004. **Figure 5-48** depicts WY2005, WY2004, and historical monthly average water level. The regulation schedule for Lake Mary Jane is shown in Appendix 5-2, Figure 3.

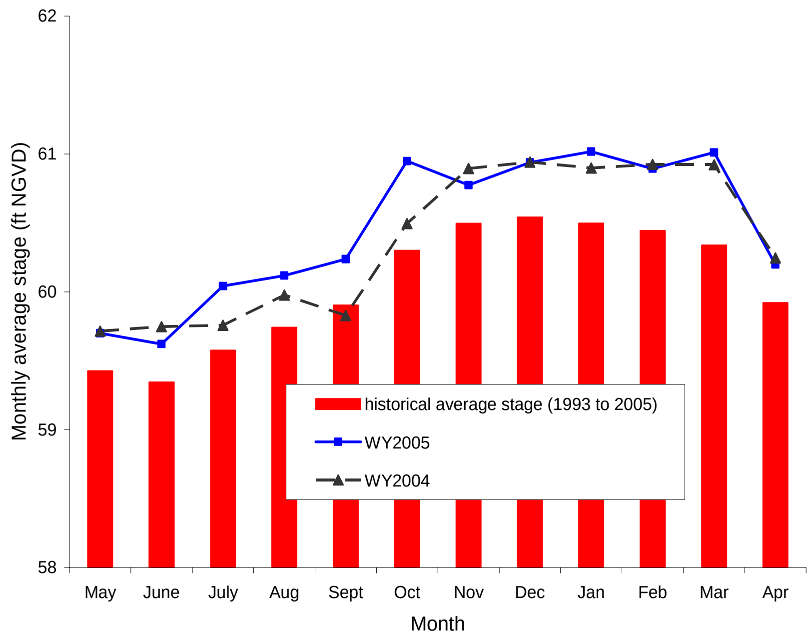


Figure 5-48. Monthly average water levels for Lake Mary Jane (site S62_H).

Lake Gentry has an average of 60.61 ft NGVD water level (stage) since 1993 (site S-63 headwater). The maximum daily average water level was 61.91 ft NGVD, which was reached in January 1993. 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 12 years show that the most significant drop in water level occurred in 2001 (Appendix 5-1, Figure 4). The daily average stage for WY2005 was 60.90 ft NGVD, compared to 60.94 ft NGVD for WY2004. **Figure 5-49** depicts WY2005, WY2004, and historical monthly average water levels. The regulation schedule for Lake Gentry is shown in Appendix 5-2, Figure 4.

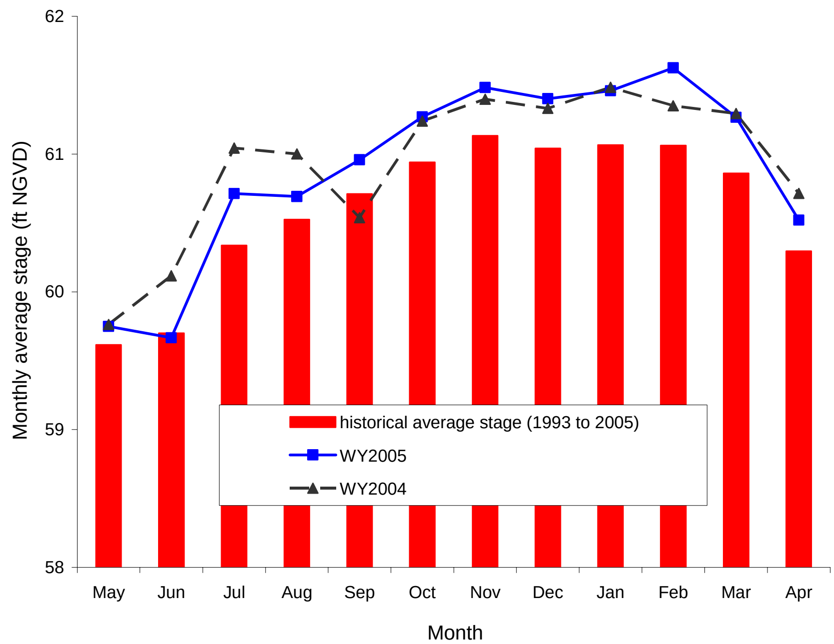


Figure 5-49. Monthly average water levels for Lake Gentry (site S63_H).

Lake East Tohopekaliga has an average of 56.67 ft NGVD water level (stage) since 1993 (site S-59 headwater). The maximum daily average water level was 59.12 ft NGVD, reached in December, 1997. The minimum was 54.41 ft NGVD, which was reached in June 1997. Daily water level observations for Lake East Tohopekaliga in the last 12 years are shown in Appendix 5-1, Figure 5. The daily average stage for WY2005 was 57.2 ft NGVD, compared to 57.13 ft NGVD for WY2004. **Figure 5-50** depicts WY2005, WY2004, and historical monthly average water levels. The regulation schedule for Lake East Tohopekaliga is shown in Appendix 5-2, Figure 5.

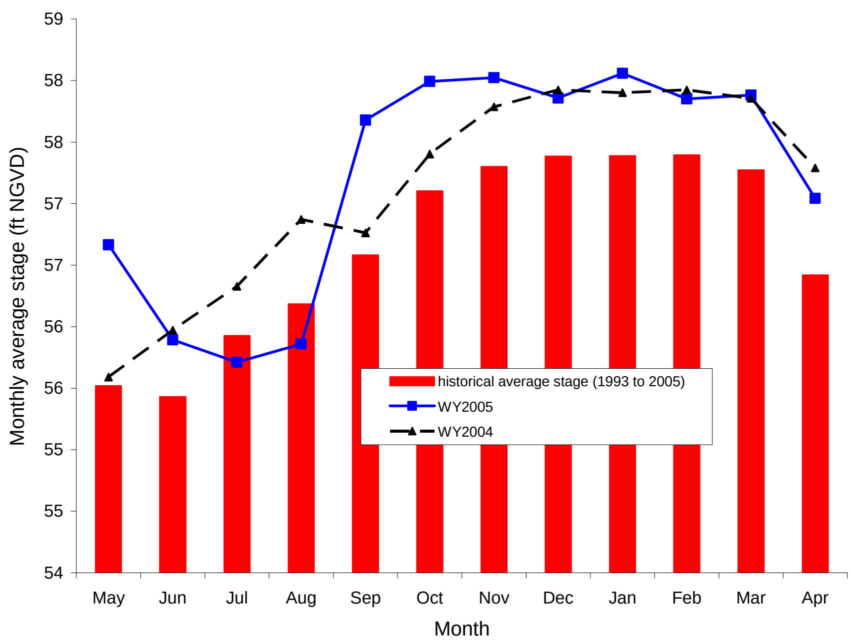


Figure 5-50. Monthly average water levels for East Tohopekaliga (site S59_H).

Lake Tohopekaliga has an average of 53.64 ft NGVD water level (stage) since 1993 (site S-61 headwater). The maximum daily average water level was 56.63 ft NGVD, reached during the 2004 hurricane season (October 1, 2004), and the minimum was 48.37 ft NGVD, which was reached in June 2004, following the implementation of lake drawdown. In cooperation with the Florida Fish and Wildlife Conservation Commission, the District accomplished a planned drawdown of water levels in Lake Tohopekaliga 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 12 years show that the most significant drop in water level occurred in 2004, during the lake drawdown (Appendix 5-1, Figure 6). The daily average stage for WY2005 was 53.12 ft NGVD, compared to 52.16 ft NGVD for WY2004. **Figure 5-51** depicts WY2005, WY2004, and historical monthly average water level. The regulation schedule for Lake Tohopekaliga is shown in Appendix 5-2, Figure 6.

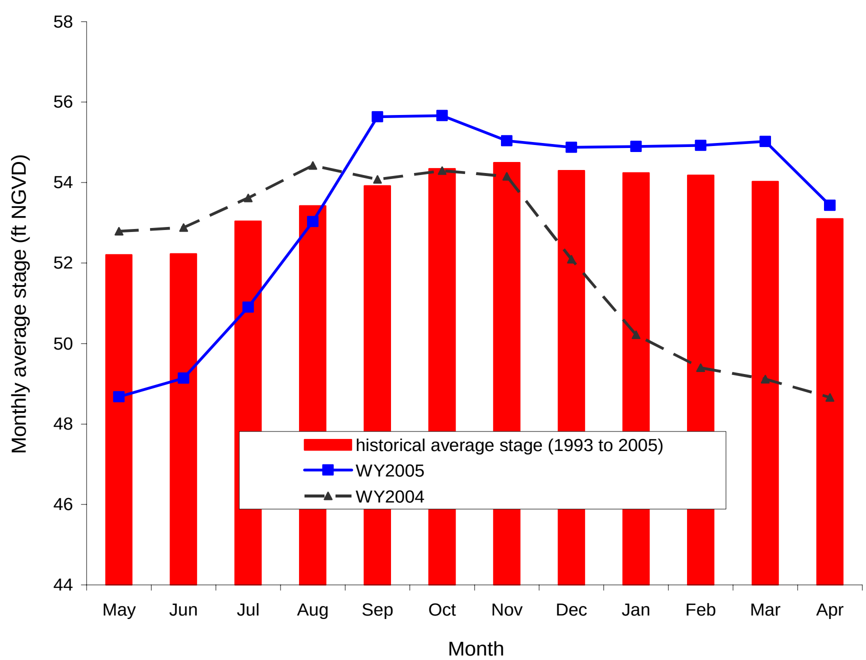


Figure 5-51. Monthly average water levels for Tohopekaliga (site S61_H).

Lake Kissimmee Water Levels

Lake Kissimmee covers an area of approximately 35,500 acres. The lake has an average water level (stage) of 50.38 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 WY2005 was 50.43 ft NGVD, compared to 50.24 ft NGVD for WY2004. **Figure 5-52** depicts monthly average water levels for WY2005, WY2004, and historical average. Appendix 5-1, Figure 7 shows daily water level for the period of record from 1929–2005. Regulation schedule, which is the operational guideline for maintaining periodic water levels in Lake Kissimmee, is shown in Appendix 5-2, Figure 7.

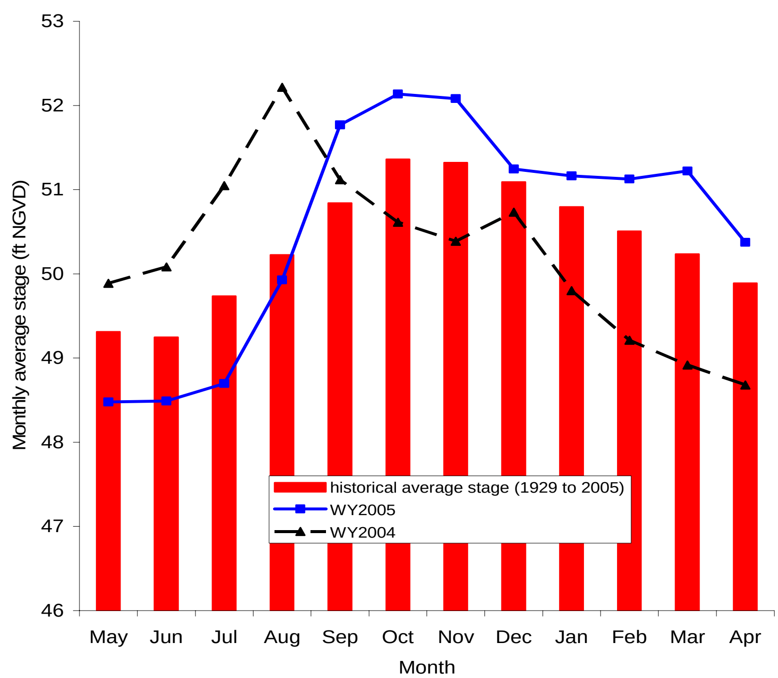


Figure 5-52. Monthly average water levels for Lake Kissimmee (site S65_H).

Lake Istokpoga Water Levels

Lake Istokpoga has a surface area of approximately 27,700 acres. It has an average water level (stage) of 38.08 ft NGVD, based on data collected since 1993 (site S-68 headwater). The maximum daily average water level was 39.74 ft NGVD (observed in 1998 during an El Niño year), and 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 WY2005 was 39.06 ft NGVD, which was also the average stage in WY2004. **Figure 5-53** depicts monthly average water levels for WY2005, WY2004, and historical average. Appendix 5-1, Figure 8 shows daily water level for the period from 1993–2005. The regulation schedule for Lake Istokpoga is shown in Appendix 5-2, Figure 8.

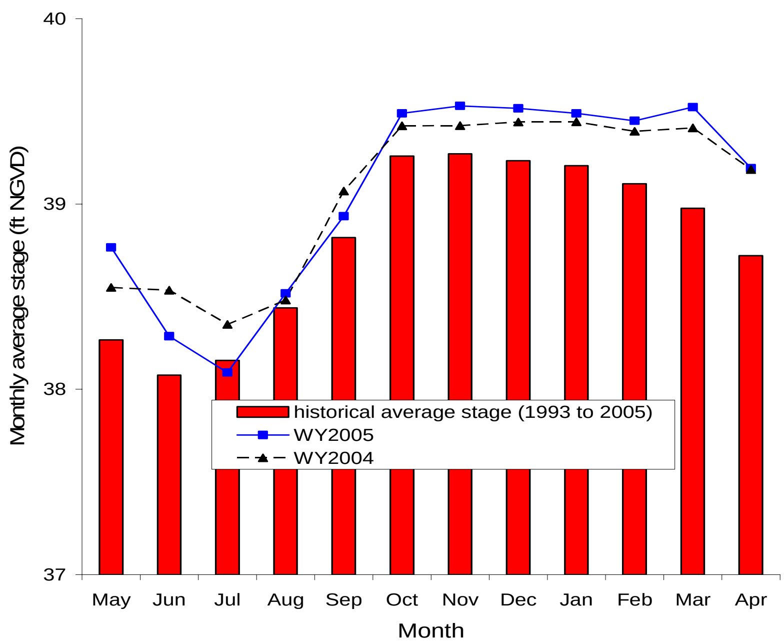


Figure 5-53. Monthly average water levels for Lake Istokpoga (site S68_H).

Lake Okeechobee Water Levels

Lake Okeechobee has an approximate surface area of 428,000 acres and an average water level (stage) of 14.42 ft NGVD, based on a period of record starting in 1931. The maximum daily average water level reached 18.77 ft NGVD, observed in 1947 during a hurricane season, and the minimum was 8.97 ft NGVD, recorded in the 2001 drought. The average daily water level in WY2005 was 14.75, which is lower than the 15.61 ft NGVD in WY2004. The average stage was less than WY2004 despite the increase in stage during the 2004 hurricane season. It was because the lake stage was at a low level of 12.17 ft NGVD in July 2004. **Figure 5-54** depicts monthly average water levels for WY2005, WY2004, and historical average. The sharp rise in water level from August to October 2004 was due the 2004 hurricanes. Appendix 5-1, Figure 9 shows daily water level for the period of record from 1931–2005. The regulation schedule for Lake Okeechobee is shown in Appendix 5-2, Figure 9.

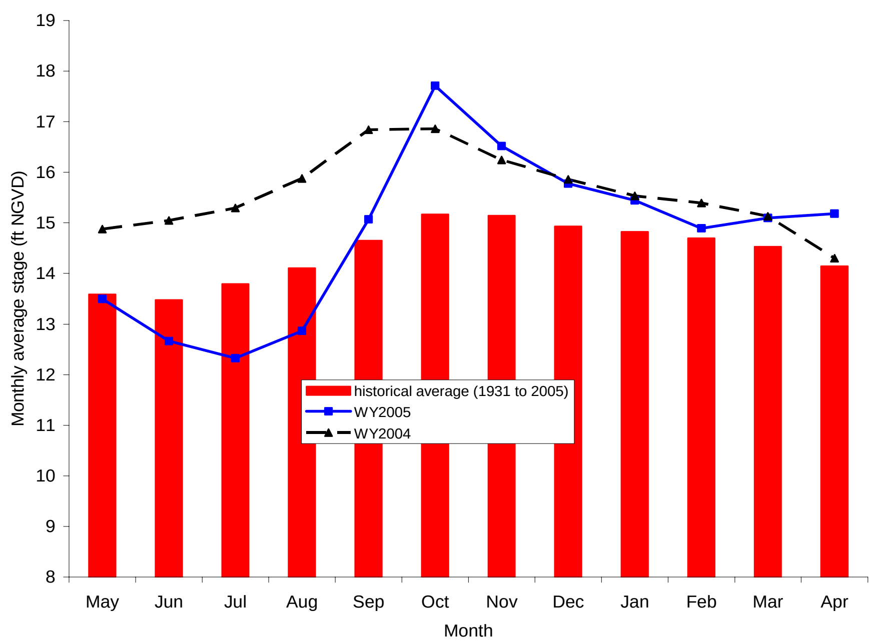


Figure 5-54. Monthly average water levels for Lake Okeechobee.

Everglades Protection Area Water Levels

The WCAs are shallow impoundments, with a total area of approximately 860,400 acres. Water levels in the WCAs change due to drought, rainfall, ET, 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. WCA-1 consists of 141,440 acres with a daily average water level of 15.59 ft NGVD. Daily water level was compiled from four sites, based on the regulation schedule uses of the following gauges: 1-8C, 1-7, 1-8T, and 1-9. From January 1–June 30, site 1-8C was used while the rest of the year average water level from sites 1-7, 1-8T, and 1-9 was used if the average was lower than 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 in WCA-1 was reached on June 1, 1962, a drought year. For WY2005, average stage in WCA-1 was 15.85 ft NGVD, which was lower than WY2004 (16.50 ft NGVD). Maximum daily average stage was 17.11 ft NGVD reached in October 2004, and minimum was 13.63 ft NGVD. Daily average historical water levels are shown in Appendix 5-1, Figure 10. **Figure 5-55** shows comparisons of historical monthly average, WY2005, and WY2004 water levels and station elevation (Price et al., 2001). Appendix 5-1, Figure 10 shows daily water level for the period of record from 1960–2005. The regulation schedule for WCA-1 is shown in Appendix 5-2, Figure 10.

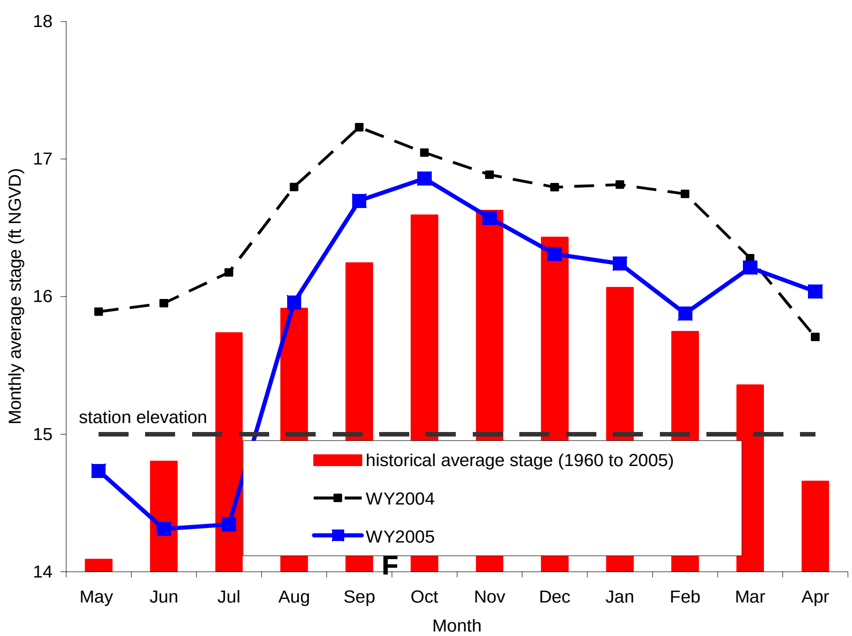


Figure 5-55. Monthly average water levels for WCA-1 (sites 1-8C, 1-7, 1-8T, and 1-9).

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 12.56 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. For WY2005, average stage in WCA-2 was 12.21 ft NGVD, which was lower than WY2004 (12.40 ft NGVD). The maximum daily average stage was 14.60, and the minimum was 10.73 ft NGVD. **Figure 5-56** shows comparisons of historical monthly average, WY2004, and WY2005 water levels and station elevation (Price et al., 2001). Appendix 5-1, Figure 11 shows daily water level for the period of record from 1961–2005. The regulation schedule for WCA-2 is shown in Appendix 5-2, Figure 11.

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 9.51 ft NGVD. Maximum water level of 12.79 ft NGVD was reached on January 22, 1995, during an El Niño year, and minimum level of 4.78 ft NGVD was reached on June 6, 1962, during a drought year. For WY2005, average stage in WCA-3 was 9.94 ft NGVD, which was lower than WY2004 (10.30 ft NGVD). The maximum daily average stage was 11.74 and the minimum was 8.51 ft NGVD. Daily average historical water levels are shown in Appendix 5-1, Figure 12. **Figure 5-57** shows comparisons of historical monthly average, WY2005, and WY2004 water levels and station elevations. Site elevation is averaged for sites 63, 64, and 65 (Price et al., 2001; USGS, personal communication, 2000). The regulation schedule for WCA-3 is shown in Appendix 5-2, Figure 12.

The ENP is approximately 1,376,000 acres (Redfield et al., 2003). Water level monitoring at sites P-33 and P-34 has been used in previous Everglades 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, as shown in Sklar et al. (2000). Historical water level data for sites P-33 (1952–2004) and P-34 (1953–2004) was obtained from DBHYDRO, and from the ENP's database. For WY2005, the average stage at site P-33 in the ENP was 6.26 ft NGVD, which was lower than WY2004 (6.68 ft NGVD) but higher than the historical average stage (5.96 ft NGVD).

For WY2005, maximum daily average stage at site P-33 was 7.16 ft NGVD, and the minimum was 5.51 ft NGVD. **Figure 5-58** shows comparisons of historical monthly average water level, WY2005 average water levels, WY2004 average water levels, and station elevation at site P-33. For WY2005, the average stage at site P-34 in the ENP was 2.59 ft NGVD, which was far lower than WY2004 (3.09 ft NGVD) and higher than the historical average stage (2.05 ft NGVD). For WY2005, maximum daily average stage was 3.77 ft NGVD, and minimum was 0.8 ft NGVD. **Figure 5-59** depicts the historical monthly average water level, the monthly average water level for WY2005 and WY2004, and station elevation for station P-34. Daily average historical water levels for sites P-33 and P-34 are shown in Appendix 5-1, Figures 13 and 14.

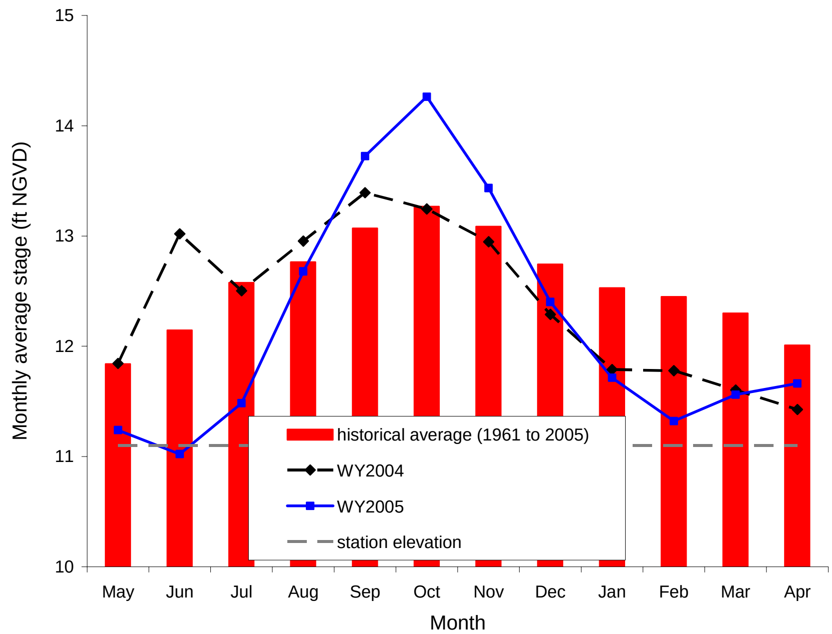


Figure 5-56. Monthly average water levels for WCA-2 (sites 2–17).

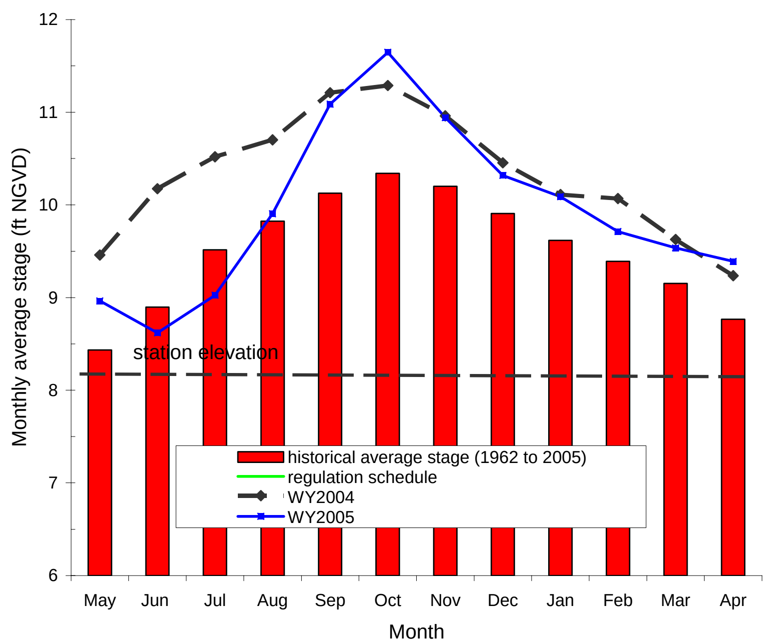


Figure 5-57. Monthly average water levels for WCA-3 (CA3AVG).

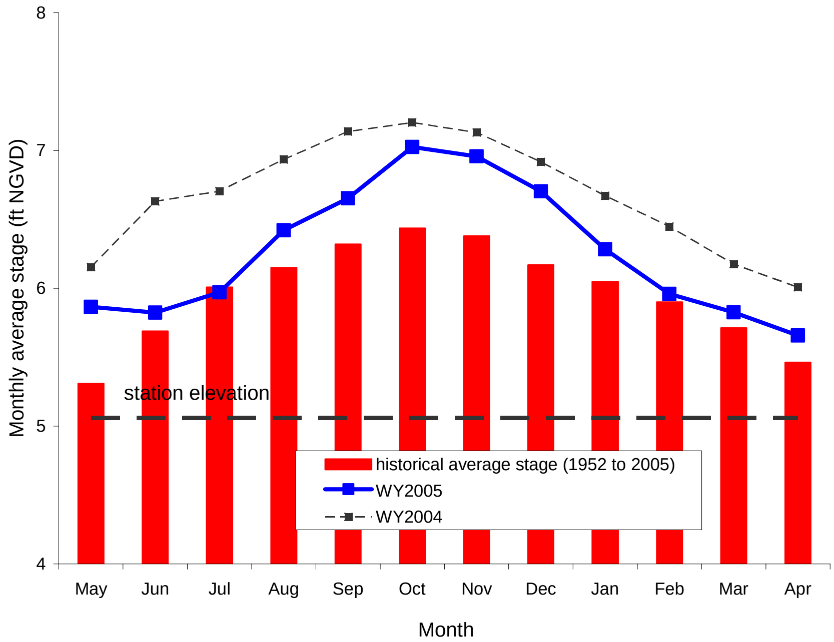


Figure 5-58. Monthly average water levels for site P-33 in the ENP.

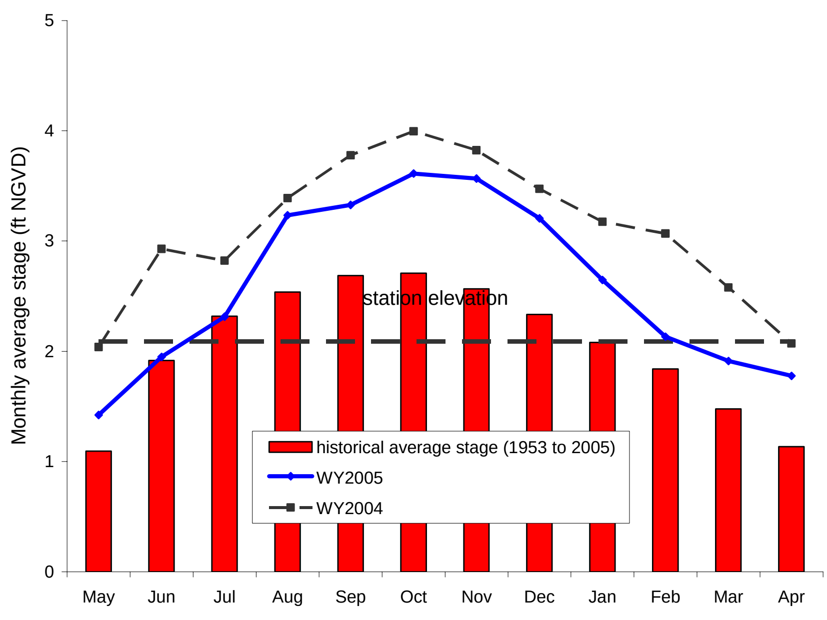


Figure 5-59. Monthly average water levels for site P-34 in the ENP.

SURFACE WATER INFLOWS AND OUTFLOWS

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. 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. Inflows and outflows through the major systems are summarized below.

Lake Kissimmee Flows

Lake Kissimmee outflow is regulated through structure S-65. The lake's regulation schedule varies between 49 and 52.5 ft NGVD. Based on flow data from January 1, 1972–April 30, 2005, the average annual outflow from Lake Kissimmee was 719,120 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 WY2005, the flow volume from Lake Kissimmee was 1,397,106 ac-ft, over 1.9 times the historical average flow and higher than the WY2004 flows (1,193,153 ac-ft). The 2004 hurricane season has contributed to the increased annual flow from Lake Kissimmee for the current water year. **Figure 5-60** shows monthly outflow from Lake Kissimmee for WY2005, WY2004, and the historical monthly average outflow. Appendix 5-3, Table 1 depicts monthly flow volumes for WY2005.

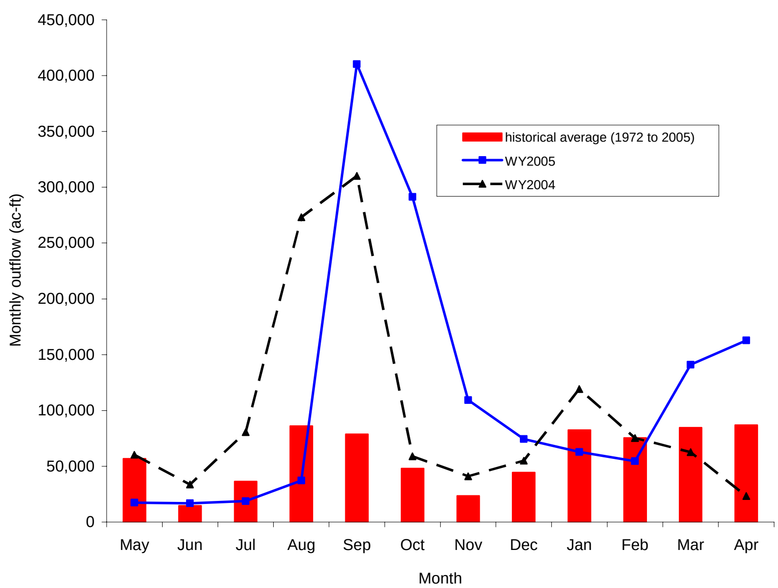


Figure 5-60. Monthly outflow from Lake Kissimmee.

Lake Istokpoga Flows

Lake Istokpoga outflow is regulated through structure S-68. The lake's regulation schedule varies between 37.0 ft NGVD and 39.5 ft NGVD. Based on flow data from January 1, 1972–April 30, 2004, the average annual outflow from Lake Istokpoga was 214,936 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 WY2005, the flow volume from Lake Istokpoga was 404,517 ac-ft. This was 1.9 times the average annual outflow, but close to the flow in WY2004 (401,631 ac-ft). Figure 5-61 shows monthly outflow from Lake Istokpoga for WY2005, WY2004, and the historical monthly average outflow. Appendix 5-3, Table 1 depicts monthly flow volumes for WY2005 for Lake Kissimmee and Lake Istokpoga outflows.

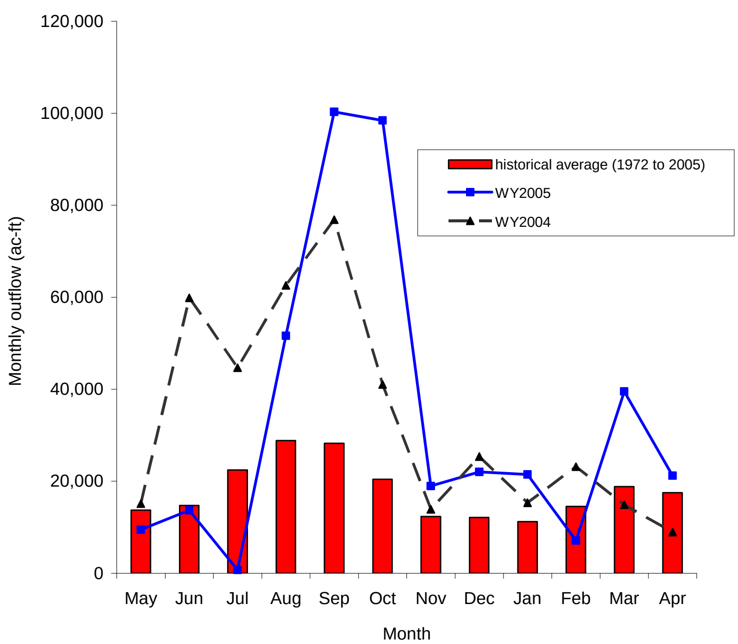


Figure 5-61. Monthly outflow from Lake Istokpoga.

Lake Okeechobee Flows

Based on flow data from January 1, 1972–April 30, 2005 records, annual average inflow into Lake Okeechobee is 2,111,790 ac-ft, with a maximum annual inflow of 3,620,483 ac-ft in 1998, during an El Niño year. A similar volume of inflow also occurred during the 1995 El Niño year. The minimum annual inflow of 664,121 ac-ft occurred in 2000, during the drought. The volume of inflow to Lake Okeechobee in WY2005 was 3,501,889 ac-ft, which was higher than the historical average and WY2004 inflows (2,920,448 ac-ft). The WY2005 inflows are one of the largest annual inflows to Lake Okeechobee since 1972. The 2004 hurricane season made a large contribution to the increased inflow to Lake Okeechobee.

The volume of outflow from Lake Okeechobee in WY2005 was 2,832,700 ac-ft. During WY2004, 2,617,958 ac-ft of water was released from the lake. Based on data from 1972–2005, the historical annual average discharge from Lake Okeechobee is 1,445,558 ac-ft, with a maximum annual discharge of 3,965,257 ac-ft in 1995. The minimum annual discharge of 349,978 ac-ft occurred in 1991. **Figures 5-62** and **5-63** respectively show monthly inflow and outflow into and from the lake for WY2005, WY2004, and the historical monthly average inflow and outflow. Appendix 5-3, Table 2 depicts monthly inflows, and Appendix 5-3, Table 3 depicts outflows for WY2005.

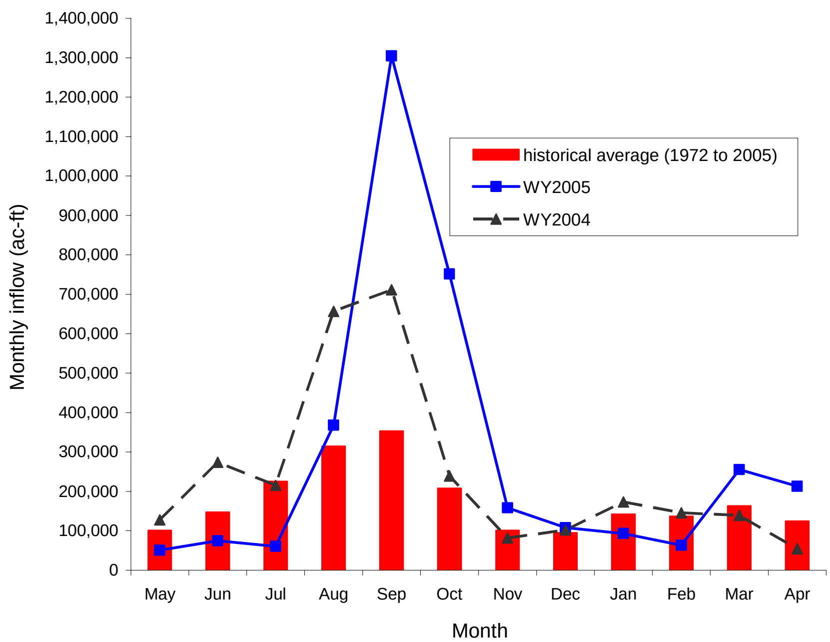


Figure 5-62. Monthly inflow to Lake Okeechobee.

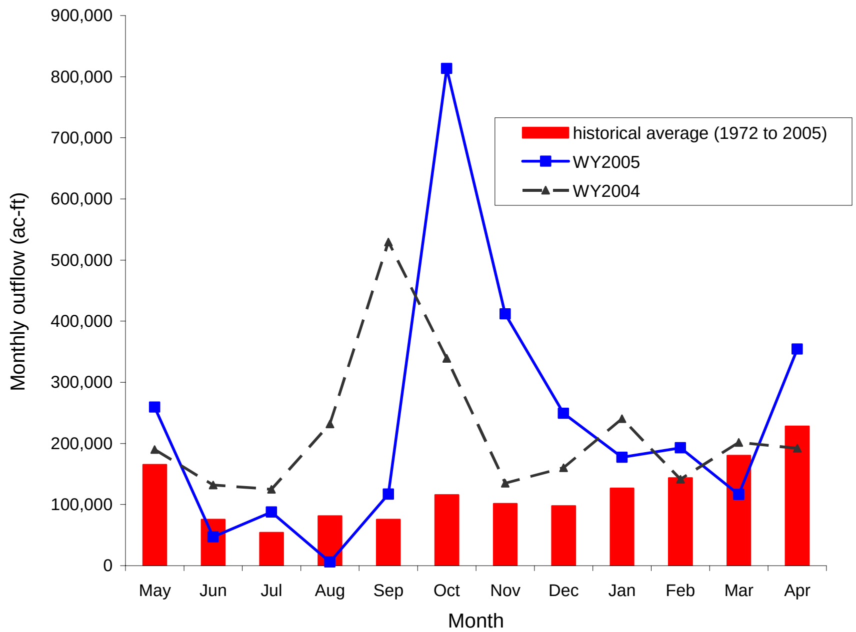


Figure 5-63. Monthly outflow from Lake Okeechobee.

St. Lucie Canal and Estuary Flows

The C-23 canal discharges into the North Fork of the St. Lucie River at structure S-48. During WY2005, 232,808 ac-ft of water was released at S-48, which was 1.66 times the historical average discharge of 140,220 ac-ft (1995–2005). In WY2004, 139,689 ac-ft of water was discharged at S-48. The C-24 canal discharges into the North Fork of the St. Lucie River at S-49. During WY2005, 239,513 ac-ft of water was discharged at S-49, which was 1.8 times the historical average flow (132,313 ac-ft). In WY2004, 155,813 ac-ft was discharged at S-49. The C-25 canal discharges into the southern part of the Indian River Lagoon at structure S-50. In WY2005, 249,519 ac-ft of water was released at this site. This was 1.84 times the historical average discharge at S-50 (135,661 ac-ft), and 2.1 times the flow volume released in WY2004 (119,307 ac-ft).

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 discharges into the St. Lucie Canal through structure S-308 were 629,632 ac-ft for WY2005. In WY2005, 706,664 ac-ft was discharged at S-80. This was 1.34 times the average historical flow of 526,801 ac-ft (1952 to 2005). During WY2004, 688,528 ac-ft was discharged at the S-80 structure. **Figures 5-64** through **5-67** show the monthly outflow volumes for WY2005, WY2004, and the period of record monthly average flows at S-48, S-49, S-50, and S-80. Appendix 5-3, Table 4 depicts monthly flow volumes for WY2005 for each structure.

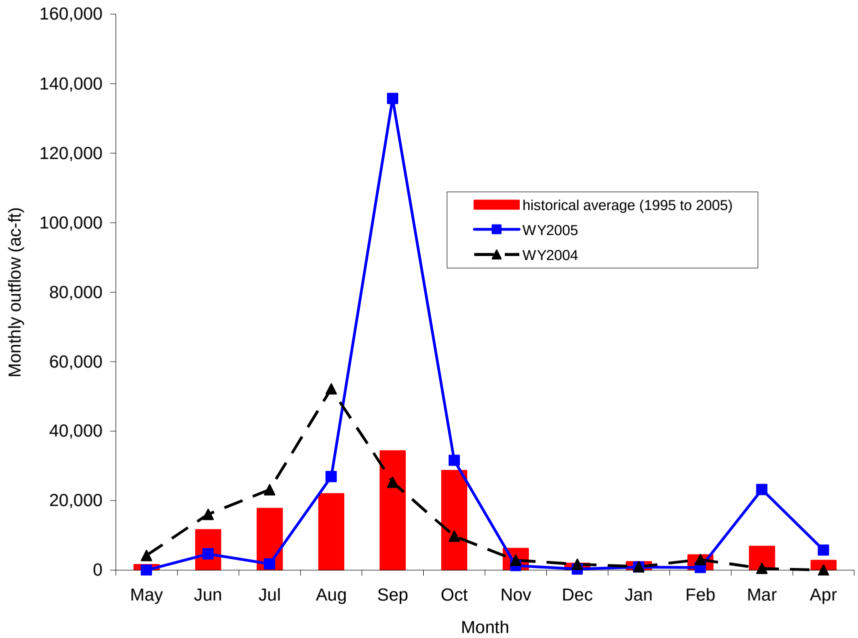


Figure 5-64. Monthly outflow from C-23 (site S-48).

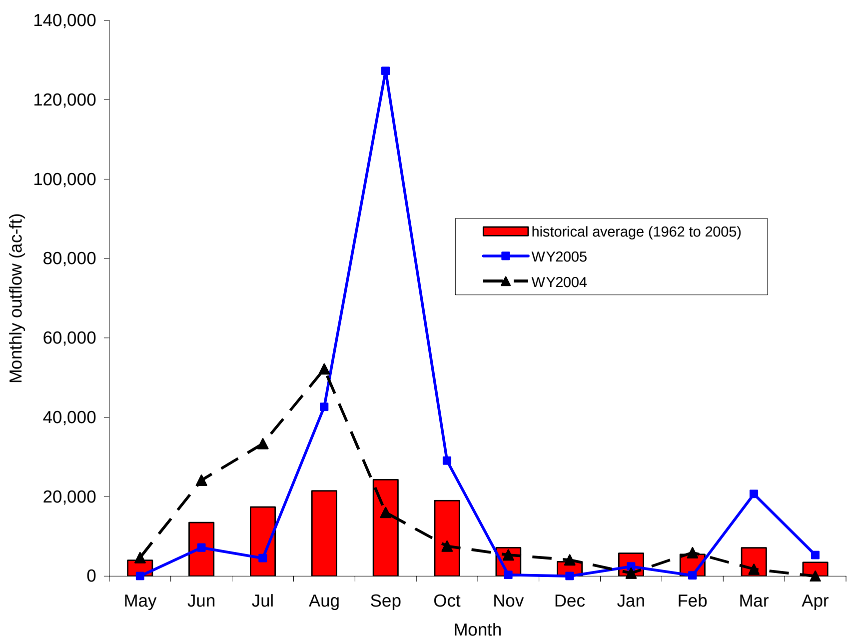


Figure 5-65. Monthly outflow from C-24 (site S-49).

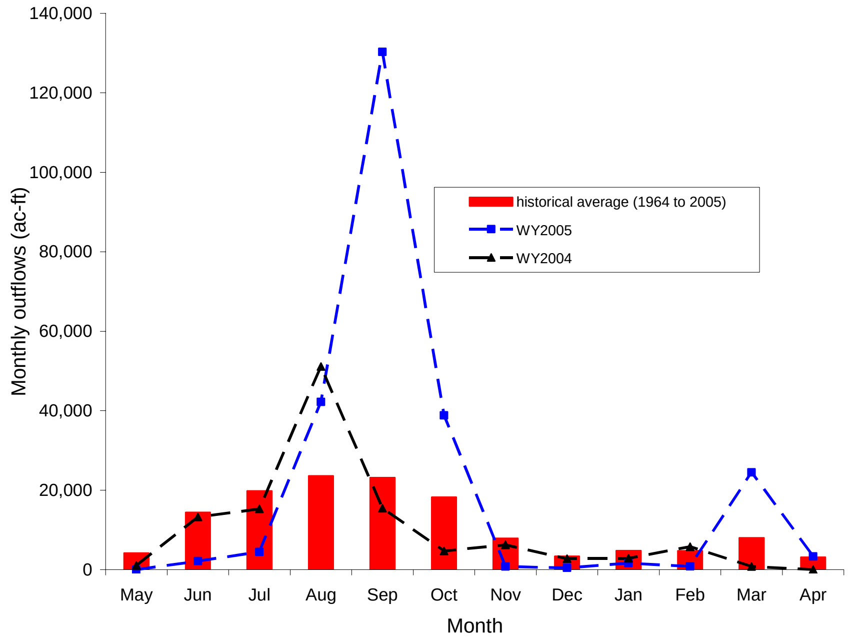


Figure 5-66. Monthly outflow from C-25 (site S-50).

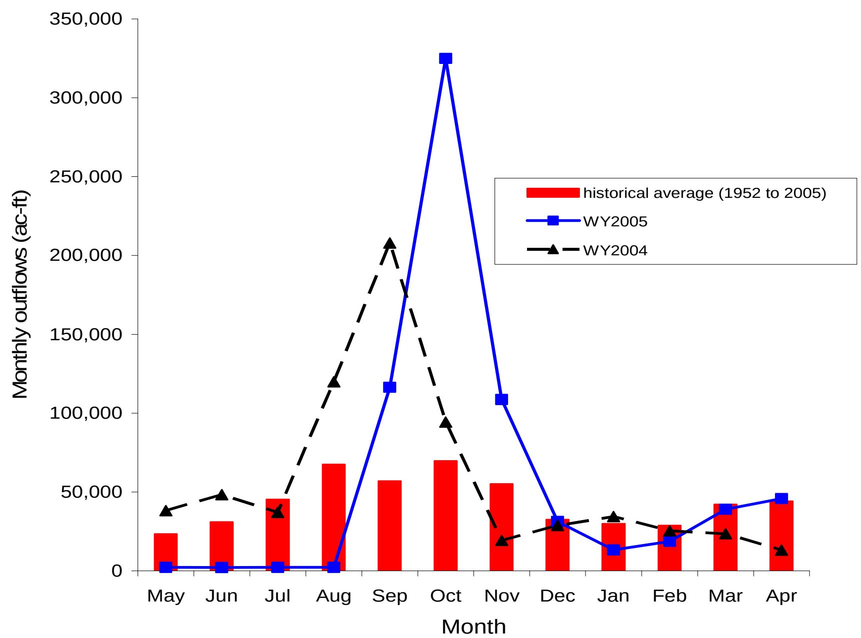


Figure 5-67. Monthly outflow from C-44 (site S-80).

Caloosahatchee River and Estuary Flows

The last structure on the Caloosahatchee River that controls discharges into its estuary is S-79. The average annual flow volume at S-79 is 1,210,140 ac-ft, based on the 1972–2005 record. In WY2005, 2,001,901 ac-ft of water was discharged through the spillway at S-79, and 2,441,923 ac-ft was discharged in WY2004. For WY2005, Lake Okeechobee discharges into the Caloosahatchee River through the S-77 structure were 1,210,447 ac-ft. **Figure 5-68** shows the monthly discharge at S-79 for WY2005, WY2004, and the historical monthly average discharge. Appendix 5-3, Table 5 depicts the monthly flow volumes for WY2005 at this site.

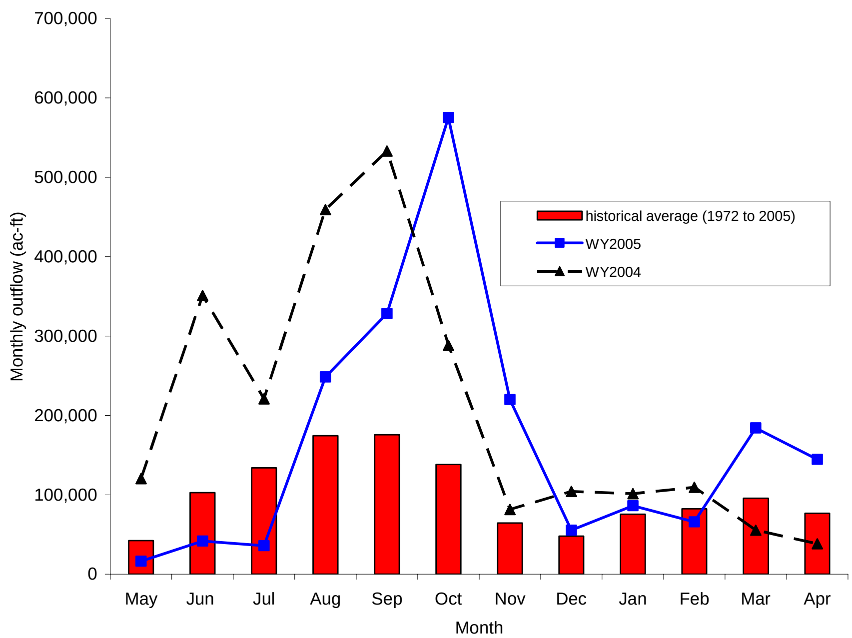


Figure 5-68. Monthly outflow at S-79 in the Caloosahatchee River.

Everglades Protection Area Flows

Inflow and outflow structures throughout the WCAs are operated based on regulation schedules. Historical flows through each structure have varying lengths of period of records 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 Stormwater Treatment Areas are relatively recent additions. Time-weighted average historical inflows and outflows were computed from 1978–2005. WCA-1 is regulated from between 14 and 17.50 ft NGVD. The average historical inflow in WCA-1 was 592,378 ac-ft. The total inflow to WCA-1 for WY2005 was 476,801 ac-ft, which was 80 percent of the historical average, and was 142 percent of the WY2004 inflows (334,957 ac-ft). **Figure 5-69** depicts historical monthly average inflows, WY2005 and WY2004 inflows to WCA-1. The major inflows (80 percent) were from STA-1W through pump stations G-310 and G-251. ACME 1 and ACME 2 sources from Wellington to the east contributed 3.5 percent of the total inflow. Inflows through structures G-300 and G-301 accounted for 14.5 percent of the total inflows. G-300 and G-301 discharge from the inflow and distribution impoundment of Stormwater Treatment Area 1 West (STA-1W), where most of the flow is S-5A pump discharge bypassing STA-1W. Monthly inflows to WCA-1 by water control structures are shown in Appendix 5-3, Table 6. 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 (73 percent); and into the Hillsboro Canal through the S-39 structure (13 percent) and discharge to the Lake Worth Drainage District through structures G-94A, B, and C (12 percent). The remaining 2 percent of outflows for this reporting year were mostly backflows to the STA-1W inflow and distribution basin through structures G-300 and G-301. The total outflow for WY2005 was 411,243 ac-ft, which was 1.5 times the total outflows in WY2004 (269,603 ac-ft). The average historical outflow is 534,487 ac-ft**. Figure 5-70** depicts historical monthly average outflows, WY2005 and WY2004 outflows from WCA-1. Monthly outflows from WCA-1 by water control structures are shown in Appendix 5-3, Table 7.

The total inflow to WCA-2 for WY2005 was 980,424 ac-ft, compared to 520,641 ac-ft for WY2004 and 667,783 ac-ft historical averages. The major inflows (38 percent) were from STA-2 through pump station G-335. WCA-1 discharges through the S-10A, C, D, and E structures are inflows to WCA-2A (31 percent). The remaining 31 percent of the inflow was from the EAA through the S-7 structure. Inflows through structure G-339, a bypass structure at STA-2, were minimal. **Figure 5-71** depicts historical monthly average inflows, WY2005 and WY2004 inflows into WCA-2. Monthly inflows to WCA-2 by water control structures are shown in Appendix 5-3, Table 8.

Outflows from WCA-2 are primarily into WCA-3A through structures S-11A, B, and C (74 percent); into the North New River Canal through structure S-34 (10 percent). There was no discharge to the North New River Canal through structure S-143. Discharge to canals 13 and 14 through structure S-38 was 16 percent. There was no backflow to the EAA through the S-7 structure. The total outflow for WY2005 was 875,648 ac-ft, which is 117 percent of the total outflows in WY2004 (749,663 ac-ft). The average historical outflow is 689,175 ac-ft. **Figure 5-72** depicts historical monthly average outflows, WY2005 and WY2004 outflows from WCA-2. Monthly outflows from WCA-2 by water control structures are shown in Appendix 5-3, Table 9.

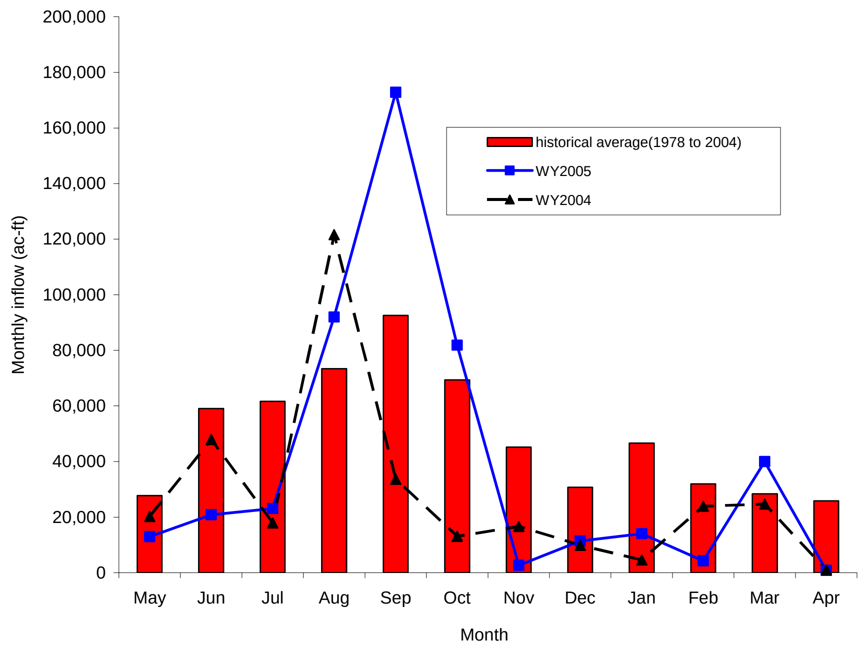


Figure 5-69. Monthly inflow into WCA-1.

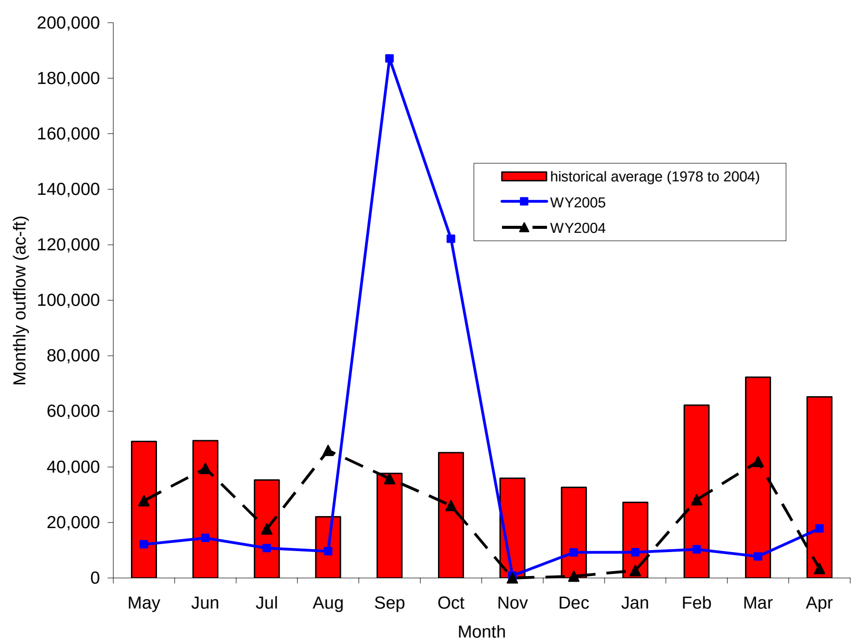


Figure 5-70. Monthly outflow from WCA-1.

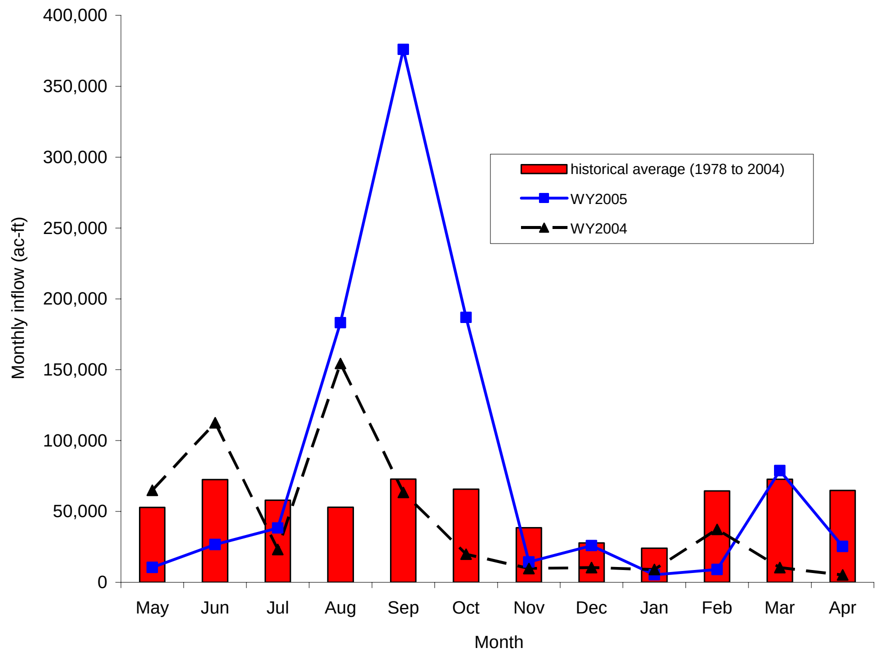


Figure 5-71. Monthly inflow into WCA-2.

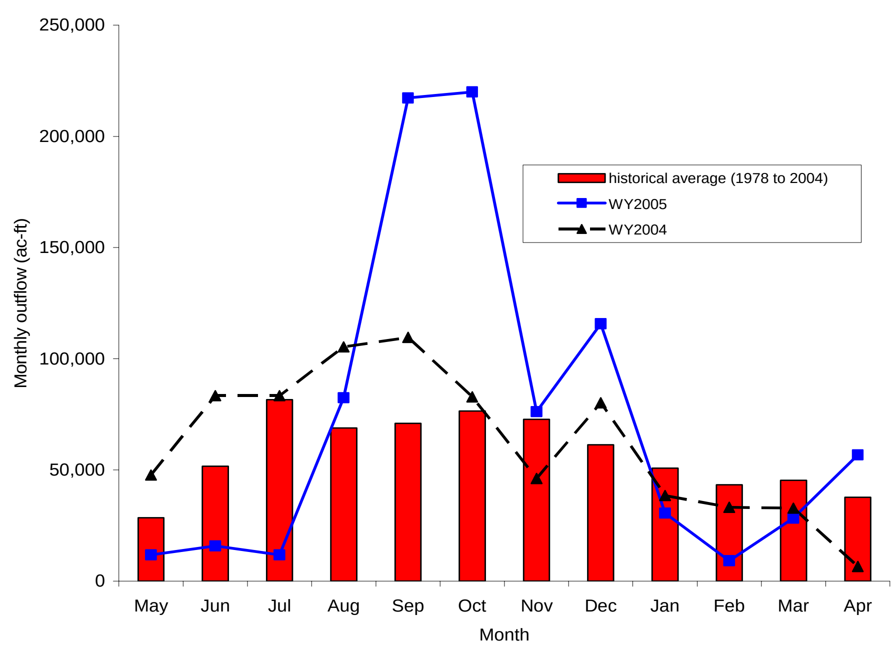


Figure 5-72. Monthly outflow from WCA-2.

The WY2005 inflows to WCA-3A were 1,366,925 ac-ft, which was 130 percent of WY2004 inflows (1,053,423 ac-ft). The historical average inflow is 1,213,243 ac-ft. The major inflows were through S-11A, B, and C (46 percent) from WCA-2 and from STA-3/4 through structures S-8 and S-150 (30 percent). Discharges from the east through structure S-9 accounted for 7 percent of the total inflow. The S-140 and S-190 structures to the northwest contributed 10 percent and 7 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 3.0 ft NGVD (SFWMD, 2002). **Figure 5-73** depicts historical monthly average inflows, WY2005 and WY2004 inflows into WCA-3. Monthly inflows to WCA-3 by water control structures are shown in Appendix 5-3, Table 10.

Outflows from WCA-3A are mainly into the ENP through structures S-12A, B, C, D, and E (57 percent). S-333 discharged 19 percent, with potential directions of flow to 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 9 percent of the total outflow, and S-31 discharge was 10 percent of the total outflow. There are minor outflows through structures S-344, S-30, S140, and G-69. The total outflow for WY2005 was 971,722 ac-ft, which is 80 percent of the total outflows in WY2004 (1,221,322 ac-ft). The average historical outflow is 888,622 ac-ft. **Figure 5-74** depicts historical monthly average outflows, WY2005 and WY2004 outflows from WCA-3. Monthly outflows from WCA-3 by water control structures are shown in Appendix 5-3, Table 11.

Inflow into the ENP is mainly through structures S-12A, B, C, D, and E; S-18; S-197; S-332; S-174; S-175; S-332D; S-333; and S-334. The major inflow (69 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. 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 Interim Operation Plan (IOP) for Protection of the Cape Sable Seaside Sparrow (http://hpm.saj.usace.army.mil/issueweb/Sparrow/fiopeis.htm). Flows through S-18 accounted for 13 percent of the total flow. Structure S-332D contributed 10 percent. Structures S-333 and S-334 contributed 5 percent with S-197 and S-174 adding minor inflows. The total surface water inflow to the ENP for WY2005 was 802,791 ac-ft, which is 64 percent of WY2004 inflows (1,251,807 ac-ft). The historical average inflow is 1,202,369 ac-ft. **Figure 5-75** depicts historical monthly average inflows, and WY2005 and WY2004 inflows into the ENP. Monthly inflows to the ENP by water control structures are shown in Appendix 5-3, Table 12. **Figure 5-76** shows WY2005 total surface water inflows and outflows of major hydrologic components of the South Florida Water Management system.

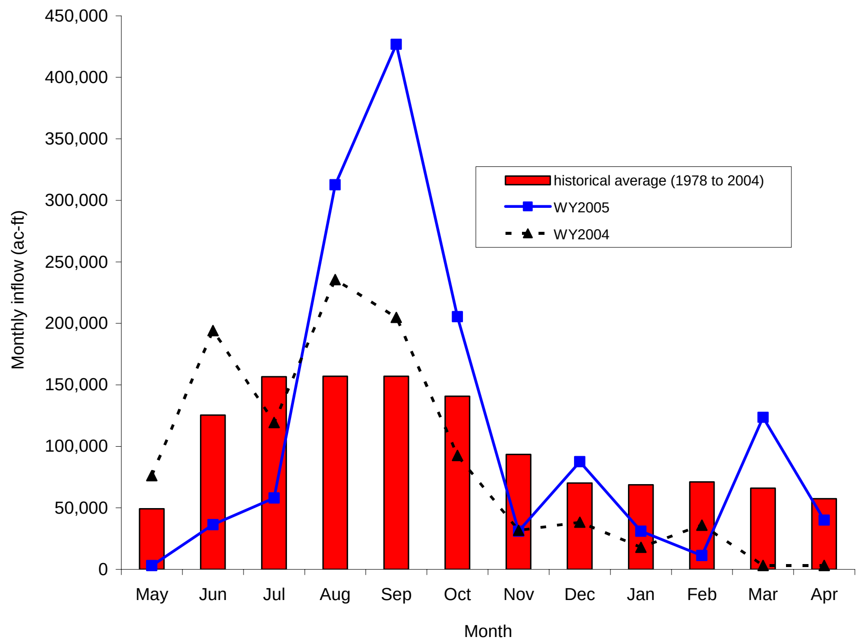


Figure 5-73. Monthly inflow into WCA-3.

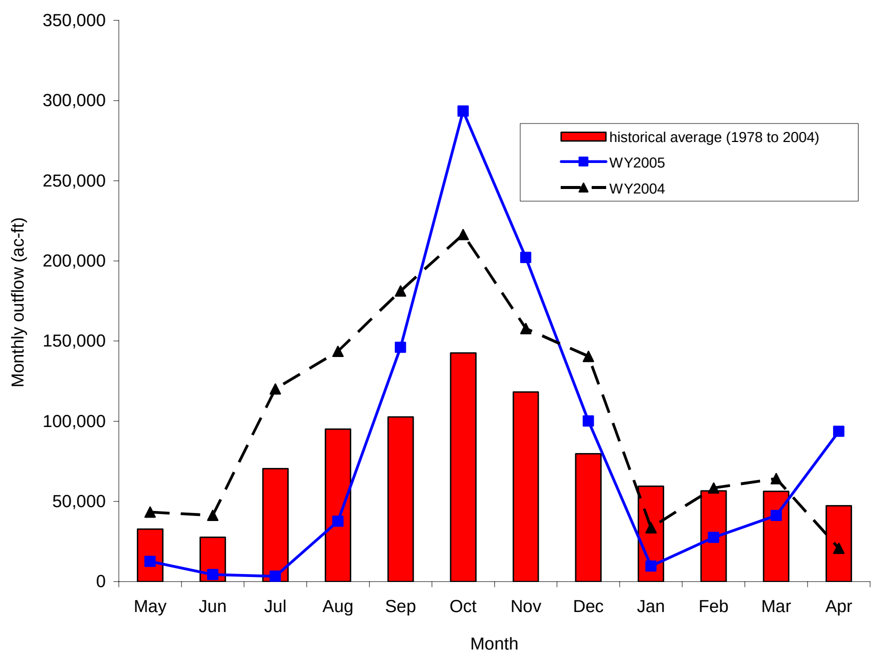


Figure 5-74. Monthly outflow from WCA-3.

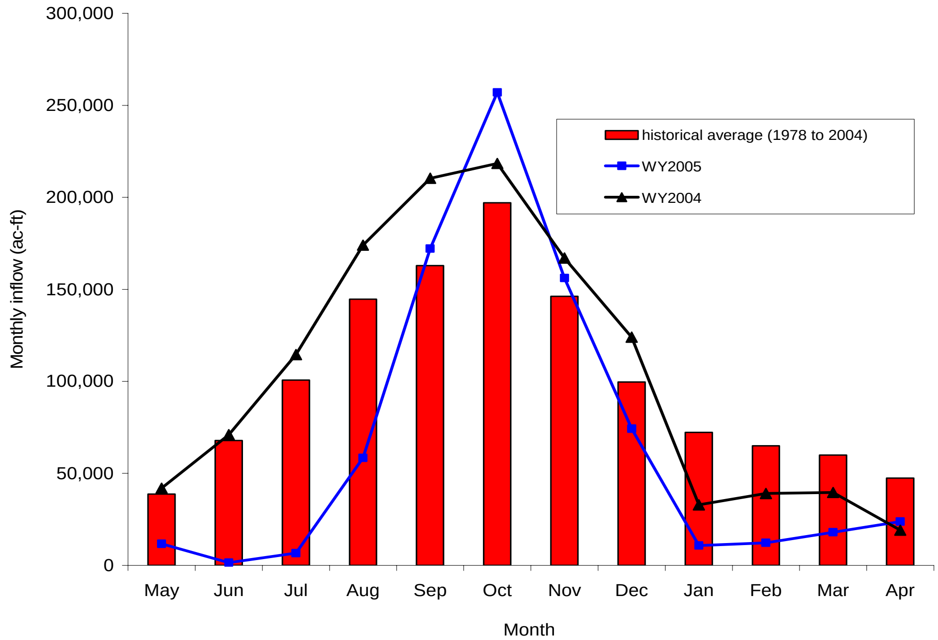
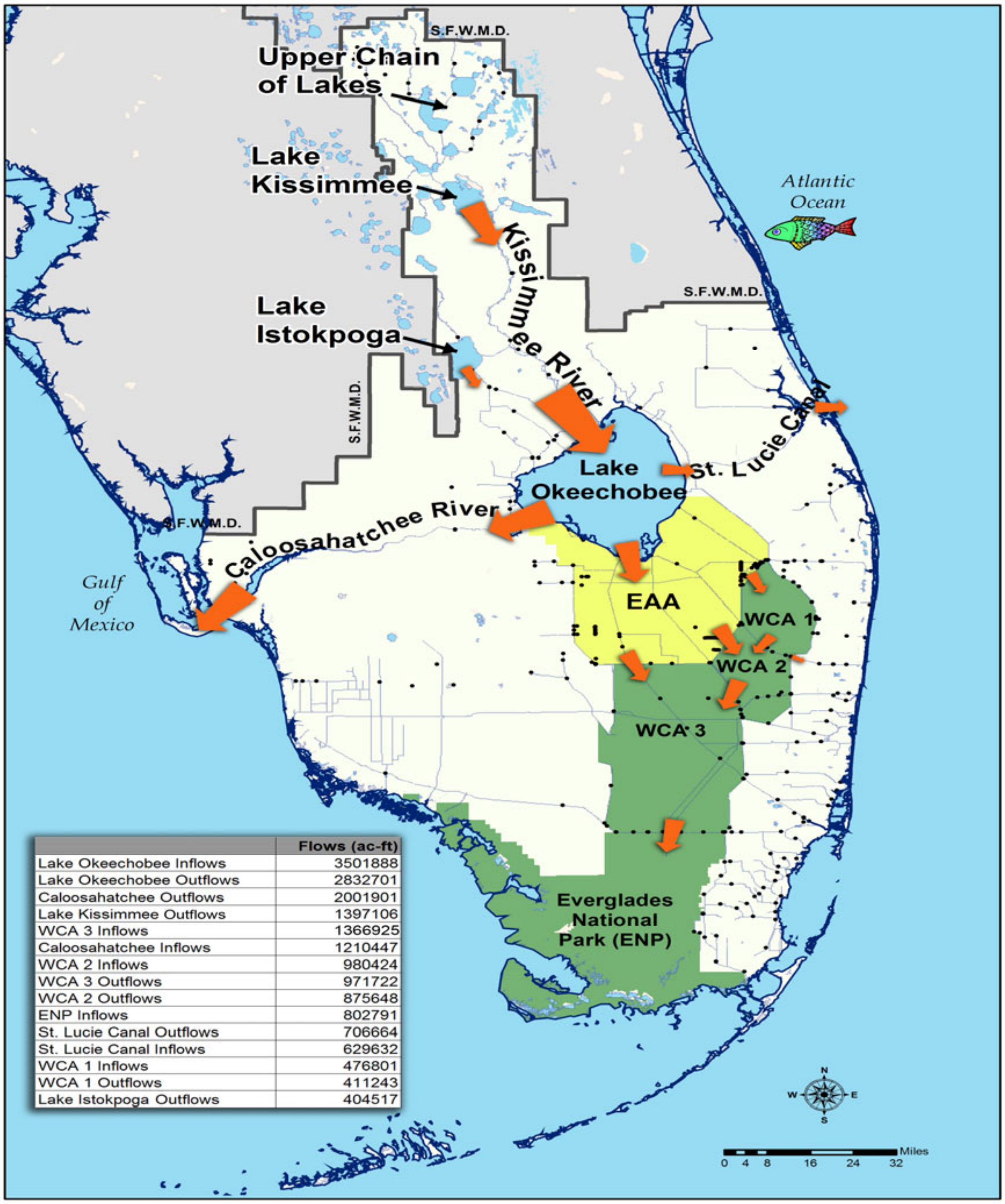


Figure 5-75. Monthly inflow into the ENP.



	Flows (ac-ft)
Lake Okeechobee Inflows	3501888
Lake Okeechobee Outflows	2832701
Caloosahatchee Outflows	2001901
Lake Kissimmee Outflows	1397106
WCA 3 Inflows	1366925
Caloosahatchee Inflows	1210447
WCA 2 Inflows	980424
WCA 3 Outflows	971722
WCA 2 Outflows	875648
ENP Inflows	802791
St. Lucie Canal Outflows	706664
St. Lucie Canal Inflows	629632
WCA 1 Inflows	476801
WCA 1 Outflows	411243
Lake Istokpoga Outflows	404517

Figure 5-76. WY2005 inflow and outflows (ac-ft) into major hydrologic components.

CONCLUSIONS

South Florida experienced an extremely rare occurrence of a series of hurricane events in WY2005. It was hit by three hurricanes and a remnant of a fourth hurricane in less than seven weeks time during August and September 2004. Hurricanes Charley (major hurricane), Francine, Jeanne (major hurricane), and Ivan had hydrologic impact on South Florida. From available records since 1871, this series of events on South Florida was a rare occurrence that has not been observed before. The property losses from these hurricanes were extremely high. High rainfall, high surface water flows, and rises in water levels in lakes and canals were experienced during the hurricane events and following months. Despite the four-hurricane season, rainfall for WY2005 for the District area (50.67 inches) was lower than WY2004 rainfall (52.35 inches) and the historical average rainfall of 52.75 inches. Generally in WY2005, the northern areas of the District had higher rainfall due to the 2004 hurricanes. Rainfall areas from Lake Okeechobee south to the Everglades National Park had below historical average rainfall for this water year. Because the above average rainfall occurred in the large rainfall areas of the Upper and Lower Kissimmee, the headwaters of Lake Okeechobee, rise in water levels and flows had significant impact on the water management system.

During WY2005, monthly average water levels in most of the lakes in the Upper Chain of Lakes were generally higher than the WY2004 levels and historical average levels except lake Tohopekaliga. The increase in water levels in the Upper Chain of Lakes was due to the high rainfall generated by the 2004 hurricanes. Lake Kissimmee average water level in WY2005 (50.43 ft NGVD) was higher than that of WY2004 and historical average water levels, whereas Lake Istokpoga average water level in WY2005 (39.06 ft NGVD) was the same as previous water year average water level but higher than the historical average. Lake Okeechobee average water level for WY2005 (14.75 ft NGVD) was lower than WY2004 average water level (15.61 ft NGVD) but higher than historical average (14.42 ft NGVD). The 2004 hurricanes generated large inflows into Lake Okeechobee and raised the water level to 18.02 ft NGVD on October 13, 2004. Because the lake stage was at a low level of 12.17 ft NGVD on July 17, 2004, the average stage for the year was less than WY2004.

The average water level in WCA-1 for WY2005 was 15.85 ft NGVD. It was lower than the WY2004 average water level (16.50 ft NGVD) and higher than the historical average (15.59 ft NGVD). In the current reporting year, the average water level in WCA-2 was 12.21 ft NGVD. It was lower than the WY2004 average water level (12.40 ft NGVD) and the historical average (12.56 ft NGVD). During WY2005, the average water level in WCA-3 was 9.94 ft NGVD. It was lower than the WY2004 average water level (10.30 ft NGVD), but higher than the historical average (9.51 ft NGVD). In WY2005, the average water level in the Park at site P33 was 6.26 ft NGVD which was lower than WY2004 average water level (6.68 ft NGVD). It was higher than the historical average (5.96 ft NGVD). Average water level in the Park at site P34, for WY2005, was 2.59 ft NGVD. It was also lower than the WY2004 average water level (3.09 ft NGVD) but higher than the historical average (2.04 ft NGVD).

During WY2005, surface water outflow through Lake Kissimmee was 1,397,106 ac-ft which was higher than WY2004 (1,193,171 ac-ft) and historical average outflows (719,120 ac-ft). The increase in outflows was mainly due to the 2004 hurricanes. Lake Istokpoga discharge was 404,517 ac-ft which was higher than WY2004 (401,637) and historical average outflows (214,936 ac-ft). Lake Okeechobee inflows were 3,501,889 ac-ft, which is comparable to the highest annual inflow of 3,620,483 ac-ft during the 1995 El Niño year, highest since 1972. Lake Okeechobee inflow for WY2004 was 2,920,448 ac-ft and the historical average inflow is 2,111,790 ac-ft. Lake Okeechobee outflow for WY2005 was 2,832,700 ac-ft compared to WY2004 outflow of 2,617,958 ac-ft and historical average outflow of 1,445,558 ac-ft.

The WY2005 discharge into the southern Indian River Lagoon and St. Lucie Estuary was 1,428,504 ac-ft with 706,664 ac-ft discharged through the St. Lucie canal outflow structure S-80. Due to the 2004 hurricanes, flows were higher than WY2004 and the historical average. Discharge into the Caloosahatchee Estuary through the S-79 structure was 2,001,901 ac-ft, which was lower than WY2004 outflow (2,463,862 ac-ft) and higher than the historical average (1,210,140 ac-ft).

Inflows to WCA-1 were 476,801 ac-ft for WY2005 compared to WY2004 inflows (334,957 ac-ft) and the historical average inflows (592,378 ac-ft). For WY2005, outflows from WCA-1 were 411,243 ac-ft compared to 269,603 ac-ft for WY2004 and historical average of 534,487 ac-ft. Both inflows and outflows of WCA-1 were higher than WY2004 but lower than historical average. WY2005 inflows to WCA-2 were 980,424 compared to 520,641 ac-ft inflows of WY2004 and historical average of 667,783 ac-ft. WY2005 outflows from WCA-2 were 875,648 ac-ft compared to 749,663 ac-ft in WY2004 and the historical average of 689,175 ac-ft. WCA-2 inflows and outflows were higher than WY2004 and the historical averages.

WY2005 inflows into WCA-3 were 1,366,925 ac-ft compared to 1,053,423 ac-ft in WY2004 and historical average of 1,213,243 ac-ft. WY2005 outflows from WCA-3 were 971,722 ac-ft compared to 1,221,322 ac-ft in WY2004 and historical average of 888,622 ac-ft. WY2005 inflows to the Park were 802,791 ac-ft compared to 1,251,807 ac-ft in WY2004 and historical average of 1,202,389 ac-ft. Inflows to the Park were significantly lower than WY2004.

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