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Hydrologic Impact of the 2004 Hurricane Season on South Florida

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by

Wossenu Abtew
R. Scott Huebner

South Florida Water Management District
3301 Gun Club Road
West Palm Beach, FL 33406

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Wossenu Abtew[1] and R. Scott Huebner[2]

[1]South FL Water Management District, 3301 Gun Club Road, West Palm Beach, FL 33406; PH (561) 682-6326; FAX (561) 682-6051; email:wabtew@sfwmd.gov

[2]South FL Water Management District; email:huebner@sfwmd.gov

Abstract

South Florida was hit by one hurricane, two major hurricanes, and a remnant of a fourth hurricane in less than a seven-week period in 2004. Hurricanes Charley, Frances, and Jeanne along with remnants of Hurricane Ivan had hydrologic impact on South Florida. A similar series of events had not been observed in records dating back to 1871. The property losses from these hurricanes were extremely high. High rainfall, high surface water flows and a rise in lake water levels were experienced. Most of the rainfall occurred on the Upper and Lower Kissimmee Basins, the headwaters of Lake Okeechobee, which is the central component of the South Florida water management system. In these basins, the 100-year return period of monthly rainfall was observed for September 2004. The resulting surface water flow raised the water level in Lake Okeechobee, a 433,000 acre lake, by 5.38 ft between August and October 2004 resulting in a storage increase of 2.37 million ac-ft. It impacted surface water management in South Florida. This paper presents an analysis for the individual and combined hydrologic impacts of the 2004 hurricanes on South Florida.

Introduction

Documenting hydrologic events such as hurricanes, storms, and droughts provides supporting information for water management decision making. This paper presents the hydrologic impacts of hurricanes Charley, Frances, Ivan, and Jeanne on the South Florida Water Management District (District) area. 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 rises at key water management system locations and surface water flows through major structures are also presented.

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. Based on published records, the average annual number of subtropical storms, tropical storms, and hurricanes in the North Atlantic Ocean between 1886 and 1994 was 9.4 of which 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 reached Florida and 74 were hurricanes (Williams and Duedall, 1997). Monthly frequency of tropical systems, excluding depressions, is shown in Figure 1. 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 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 (Abtew and Huebner, 2000; Abtew et al., 2005). 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, Abtew et al., 2005). Between 1900 and 1996, Southeast Florida had 26 hurricanes directly hit (Herbert et al., 1997) and four additional hurricanes since 1997. Since 1997, Southeast Florida had direct impacts from Hurricane Georges, 1998; Hurricane Irene, 1999; and Hurricanes Frances and Jeanne, 2004.

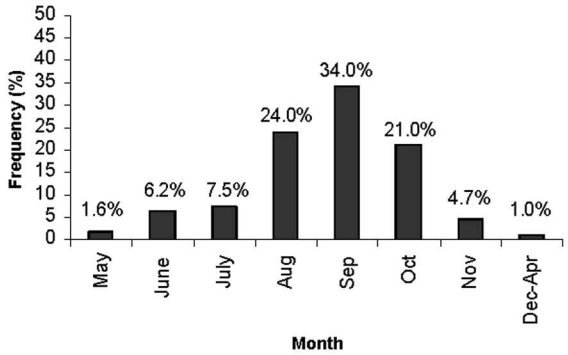

Figure 1. Frequency of North Atlantic hurricanes and tropical storms.

Table 1. 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 in South Florida

During the 2004 hurricane season, the South Florida Water Management District area was hit by three hurricanes: Charley, Frances, and Jeanne. Hurricane Ivan, which entered the Alabama Coast from the Gulf of Mexico as a major hurricane and moved on to the northeast and the Atlantic Ocean; and looped back to Southeast Florida crossing back to the Gulf of Mexico as an extra-tropical system. Based on the historical tropical systems record, such a hurricane season on the District area is a rare event occurring once in more than 100 years (Abtew et al., 2005). The path of the 2004 hurricanes and estimates of radar rainfall are shown in Figures 2a-d.

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 Ocean at Daytona Beach (Figure 2a). For the purpose of hydrologic impact analysis of the 2004 hurricanes, the five-day cumulative rainfall before, during and after the landfall

day of each hurricane is reported as the rainfall amount from the hurricane. The District is divided into fourteen rain areas and the Everglades National Park for the purpose of regional rainfall monitoring and operational decision making (Figure 3). For Hurricane Charley, the cumulative areal rainfall from August 12 through 16, 2004, is presented in Figure 4 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://www.sfwmd.gov/org/omd/ops/weather) as the Thiessen average of a network of rain gauges. Everglades National Park area rainfall is computed from a simple average of four gauge readings (S174_R, TAMIAMI_R, S332_R, and Chekika Ever). It should be noted that higher and lower point rainfall readings at single rain gauge stations were observed.

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 2b). The five-day cumulative rainfall associated with this hurricane is depicted in Figure 5. 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 (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 as an extra-tropical low on September 18, 2004 (Figure 2c), 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 remnant crossing South Florida is depicted in Figure 6. The highest areal rainfall was observed in the Martin-St. Lucie rainfall area, followed by the Palm Beach and East EAA (Everglades Agricultural Area) areas, and generally corresponds with the path of the tropical system.

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 2d). The five-day cumulative rainfall associated with Hurricane Jeanne is depicted in Figure 7. 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.

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 2 presents the five-day rainfall and return-period for the rainfall station with the maximum reading per hurricane per rainfall area (MacVicar, 1981).

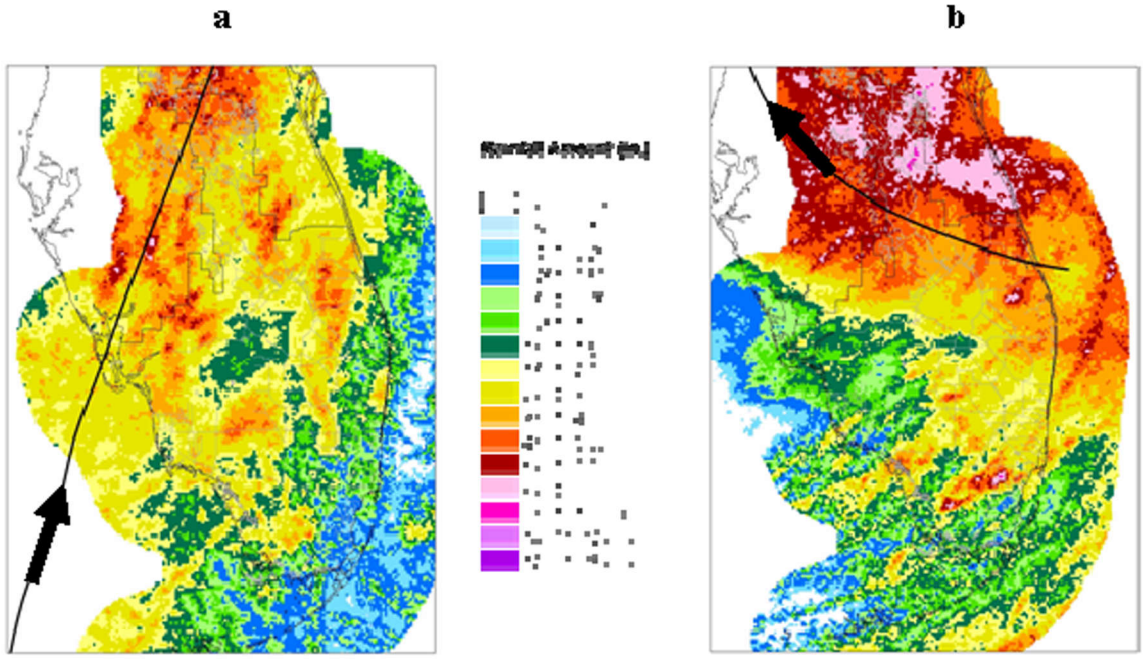

Figure 2. Hurricane Charley (a), August 12-16, 2004; Hurricane Frances (b), September 4-8, 2004, radar estimated rainfall.

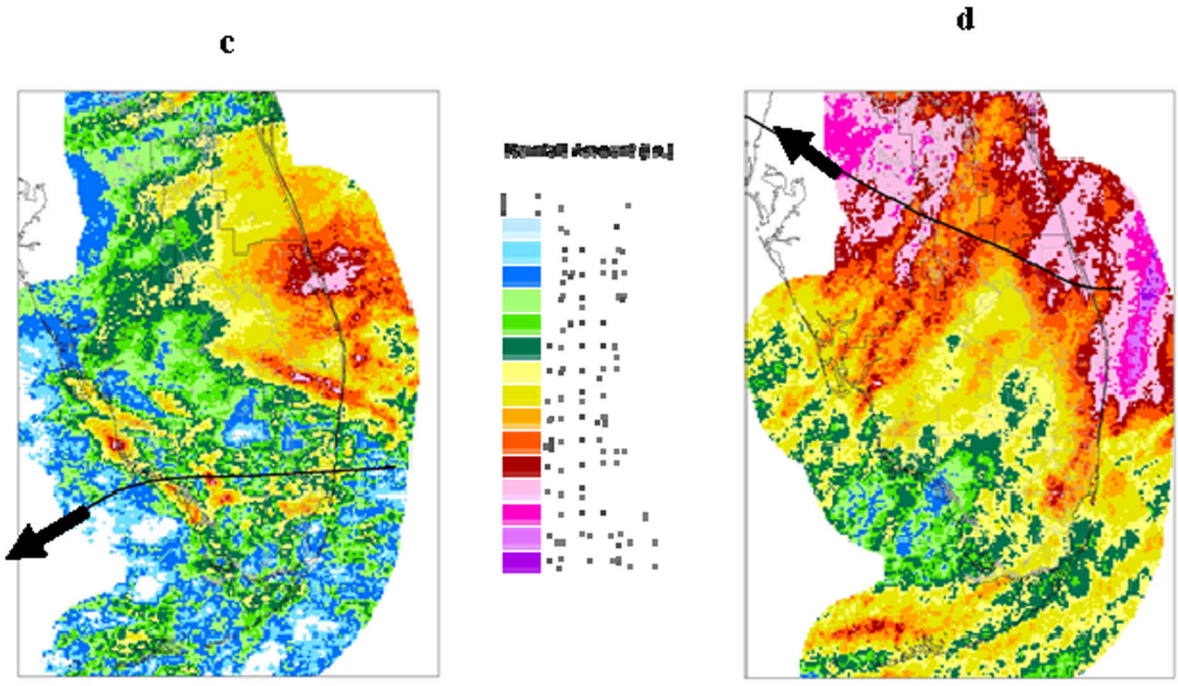

Figure 2. Extra-tropical system Ivan (c), September 19-23, 2004; Hurricane Jeanne (d), September 24-28, 2004, radar estimated rainfall.

Figure 3. Rainfall areas of the South Florida Water Management District.

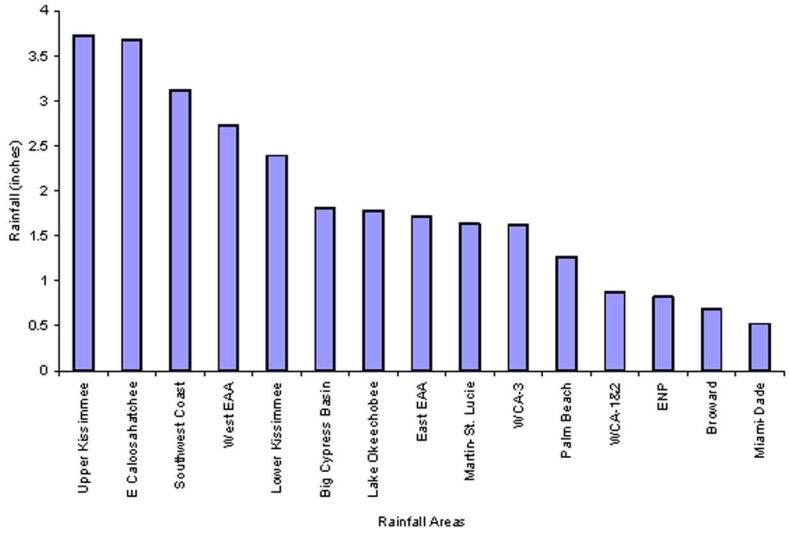

Figure 4. Hurricane Charley areal average rainfall (August 12-16, 2004).

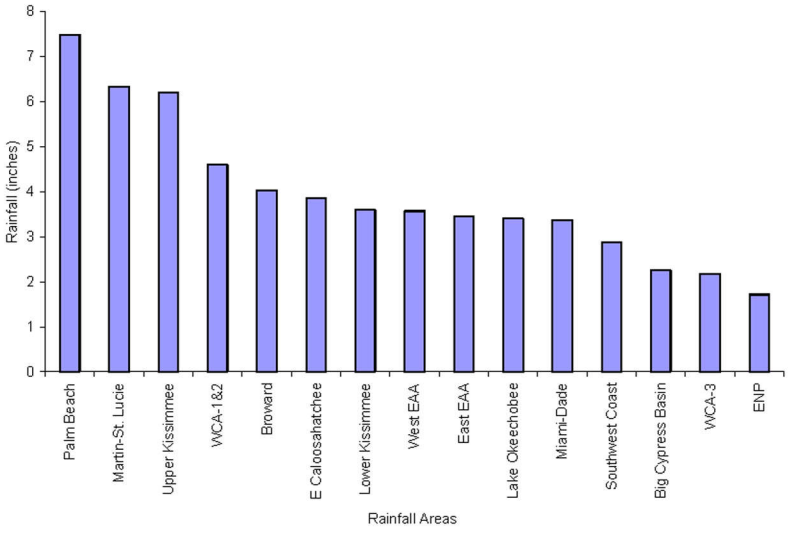

Figure 5. Hurricane Frances areal average rainfall (September 4–8, 2004).

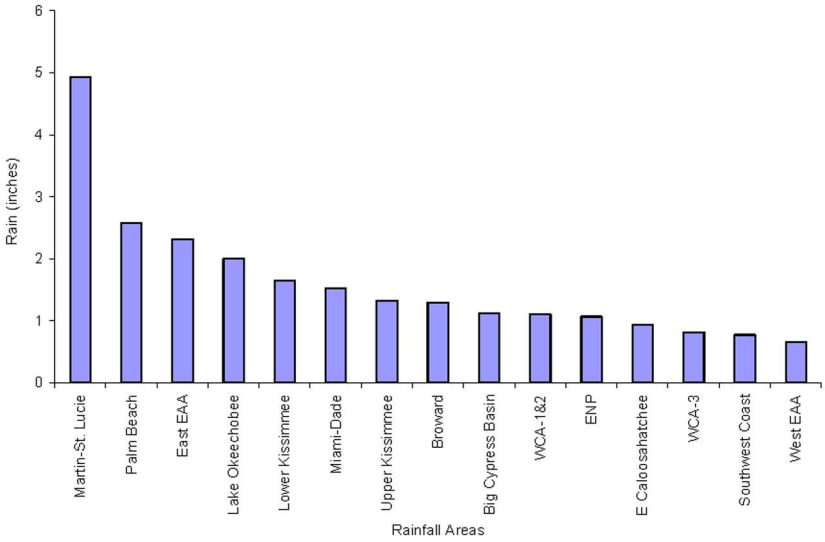

Figure 6. Areal average rainfall associated with tropical system Ivan (September 19-23, 2004).

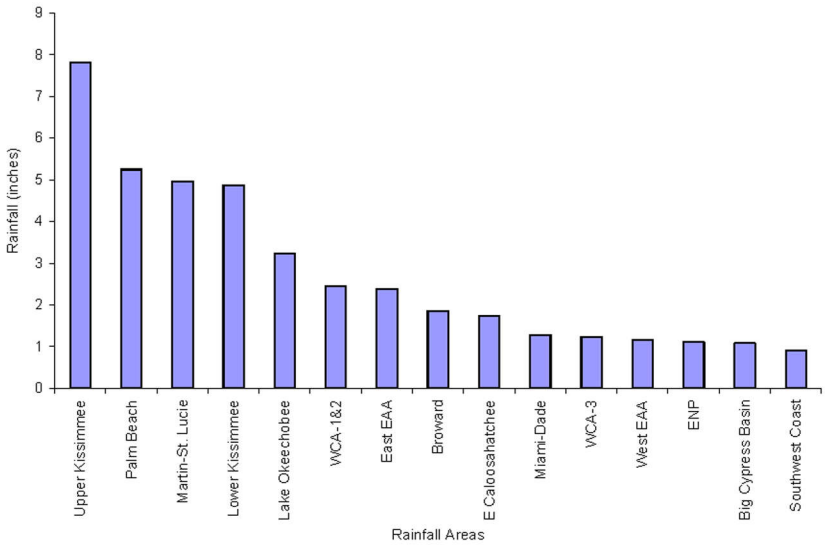

Figure 7. Hurricane Jeanne areal average rainfall (September 24–28, 2004).

Table 2. Maximum rainfall at rain gauges associated with 2004 hurricanes.

Hurricane	Charley		Frances		Ivan		Jeanne	
Rainfall 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**	PEMBROKEPINE	**5.97**	S-33	**2.83**	HOLLYWOOD	**3.35**
Miami-Dade	S-27	**1.17**	PEMBROKEPINE	**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**	RACCOONPOIN	**2.09**
Southwest Coast	**NRESV**	**5.32 (<5)***	GATEWAY	**5.14**	MCIF1	**2.65**	RACCOONPOIN	**2.09**
ENP	CHEKIKAEVER	**1.62**	CHEKIKAEVER	**2.36**	S-174	**2.48**	CHEKIKAEVER	**2.21**

* Return Period in years

Table 3. Monthly areal rainfall with return period for each rainfall area for August and September of 2004.

Rainfall Area	August rainfall (in)	return period years	September rainfall (in)	return period 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

Surface water runoff volumes, storage capacity, and timely transmission capacity are impacted by cumulative seasonal rainfall. August and September 2004 were wet months, especially for 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 August 2004 in the Upper Kissimmee (12.7 inches; 50 year rp); East Caloosahatchee (13.4 inches; 50 year rp). In September 2004, several rainfall areas observed extreme rainfall, 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). Table 3 depicts monthly areal rainfall and rp for August and September 2004 in each rainfall area.

Significant water level increases associated with the 2004 hurricane events were observed in Lake Kissimmee, along the reaches of the Kissimmee River, Lake Istokpoga, Lake Okeechobee, and Water Conservation Area 1. A sharp rise in Lake Okeechobee water level was observed (5.38 ft between August 12th and October 13th of 2004 with an increase in storage of 2.37 million ac-ft). Figure 8 shows the daily average water level in Lake Okeechobee for August through December of 2004. The 18.02 ft NGVD maximum stage on October 18, 2004, was within less than one-percent probability of exceedence since 1931.

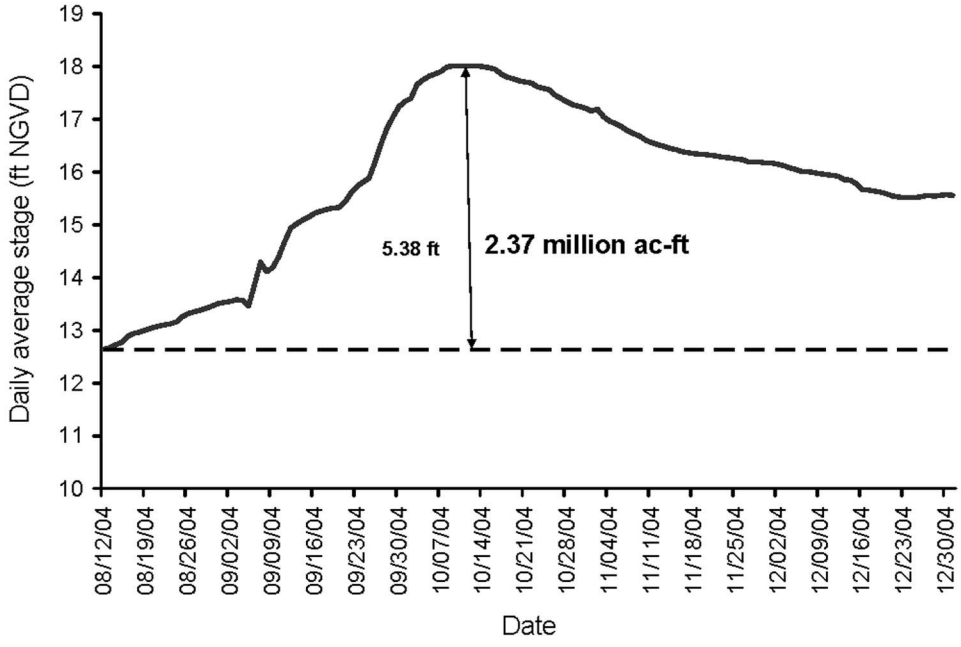

Figure 8. Water level changes in Lake Okeechobee during the 2004 hurricane events.

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, outflows from Lake Istokpoga, and inflows to Lake Okeechobee through the Kissimmee River, and outflows from Lake Okeechobee are shown in Figure 9 for the hurricanes and following months. On October 1, 2004 an outflow rate of 8,910 ac-ft/day was observed from Lake Istokpoga. This rate was the highest on record. Inflow to Lake Okeechobee through the Kissimmee River was 35,457 ac-ft/day on September 27, 2004, a record high since 1972. Outflow from Lake Kissimmee also reached high levels, although no record was achieved.

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 attained a record high daily discharge of 17,786 ac-ft since 1972. Significant flows were discharged to St. Lucie Canal.

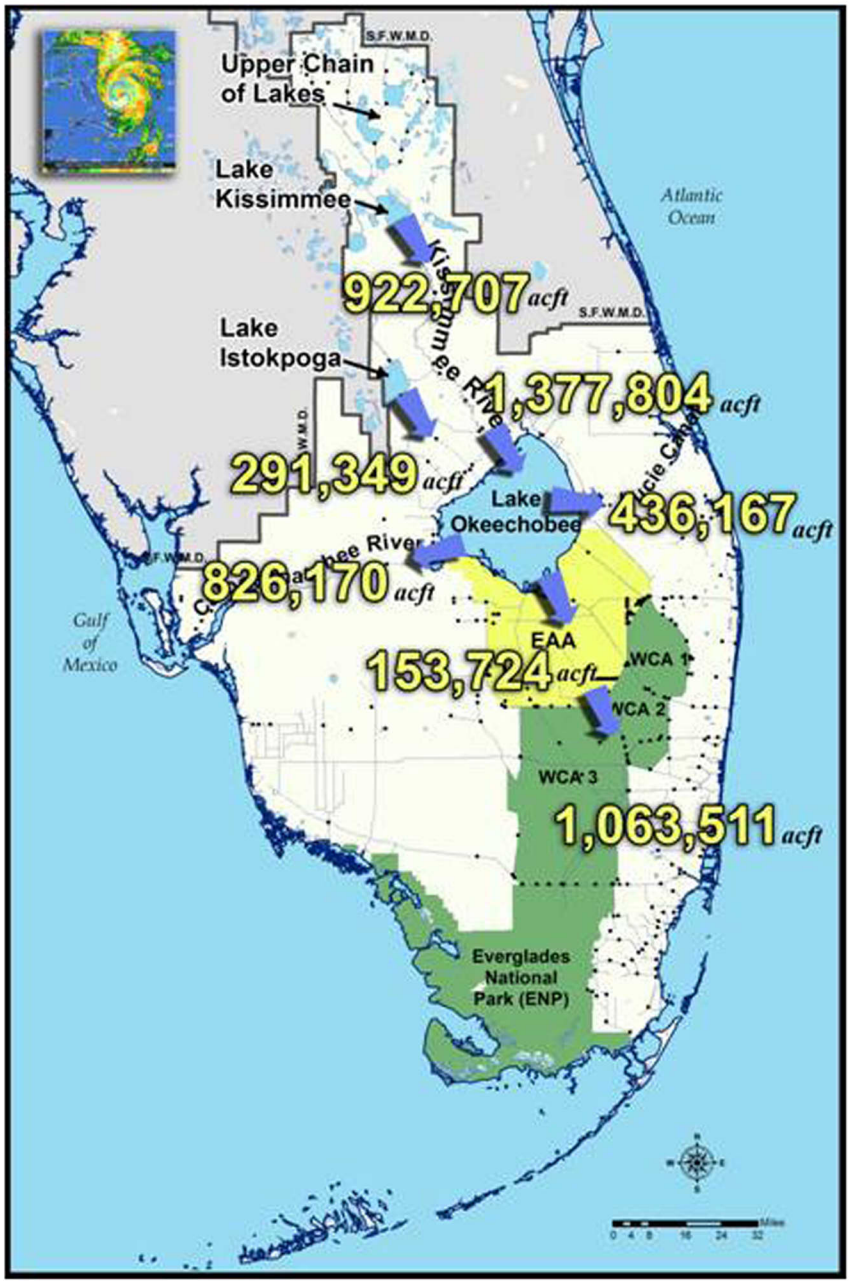

Figure 9. Major surface water flows during the 2004 hurricanes and following months (August to December, 2004).

Summary

Tropical systems are part of the hydrometeorology of South Florida. Although tropical systems can break long-term drought and replenish surface and sub-surface storage, there is potential of flooding due to the high intensity, long duration and large areal coverage of rainfall. The impact of rainfall from tropical systems on South Florida is higher when the

event occurs with soils saturated and available surface water storage is limited. The 2004 hurricane events in South Florida were a rare sequence of events. The South Florida water management system was impacted for a longer period because most of the rainfall was on the upper reaches of the system. Significant rise in lake water levels and surface water discharge had hydraulic, ecological and water quality impacts and potential for flooding. Some basins received the 50-year and 100-year return period monthly rainfall in August and September 2004. The resulting surface water flow raised the water level in Lake Okeechobee by 5.38 ft between August and October 2004 resulting in a storage increase of 2.37 million ac-ft. It impacted surface water management in South Florida for months after the hurricane events.

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