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Hydrologic Impacts of the 1997-98 El Niño and La Niña on Central and South Florida

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by

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EXECUTIVE SUMMARY

This report presents the hydrologic impacts of the El Niño and of the onset of the La Niña- or El Viejo-induced weather patterns on Central and South Florida from November 1, 1997 to October 31, 1998. It offers a comprehensive, historic perspective of the hydrologic events that the South Florida Water Management District (District) experienced during this period.

El Niño-related weather patterns are caused by warming water surface temperatures in the Eastern Pacific Ocean near the coast of Peru. A complimentary cooling occurs in the Western Pacific. La Niña-related weather is associated with cooling equatorial waters in the Eastern Pacific. The pattern is usually observed every three to four years. It can occur infrequently at intervals of two to seven years (U.S. Dept. of Commerce). This report examines rainfall, evapotranspiration, lake and impoundment stages, groundwater elevations and flows into and out of major lakes and impoundments.

From November 1997 through March 1998, a total of 23.91 inches of rain fell throughout the South Florida Water Management District. This exceeded historic average rainfall for this period by 13.05 inches. The greatest deviation from historic average rainfall amounts was observed in the Upper and Lower Kissimmee rain areas. They received 16.53 and 21.38 inches of rain above average, respectively, during this period.

From April 1998 through October 1998, the District received an average of 30.98 inches of rain, 10.88 inches less than expected based on the historic record. The Dade rain area (Eastern Miami-Dade County) received 19.71 inches less than usual and the Palm Beach rain area (most of Palm Beach County), 18.85 inches less. For the entire year, from November 1997 through October 1998, the Upper Kissimmee area experienced the greatest net increase in rainfall, 20.91 inches above the historic average. The western agricultural area or West Ag rain area and the Dade rain area experienced lower than average rainfall for the year starting November 1997; -9.90 and –9.16 inches, respectively.

During the period November 1997 through March 1998, estimated potential evapotranspiration rates were generally lower than historic average values. The greatest deviations in evapotranspiration were observed at one station in Lake Okeechobee, 2.84 inches below average. During the El Niño period examined, the effect of excessive rainfall on increased flows and stages was compounded by the fact that evapotranspiration rates were lower.

In March 1998, the stage in Lake Okeechobee reached 18.43 feet NGVD, the third highest water surface elevation recorded since 1931. This record stage was due to excessive rainfall in the areas contributing flow to the Lake, principally the Upper and Lower Kissimmee rain areas. From mid-November 1997 through October 1998, water levels were consistently above historic monthly average values.

The El Niño- and La Niña-influenced weather patterns also affected groundwater table elevations in all of the key-indicator wells monitored by the District. These wells monitor groundwater elevations in all of the major aquifers underlying the District. The maximum deviation above historic average values was observed at Well L-731 in the Sandstone aquifer in the Southwest Coast rain area, Lee County. The recorded water level was 7.98 feet higher than the historic average in March 1998. The maximum deviation below historic groundwater table levels was observed at Station L-581, also in the Southwest Coast rain area. This well in the Mid-Hawthorn aquifer was 17.22 feet below historic average level in July 1998. The reported water levels in both of these wells reflect local pumping demand and long term trends as well as the response to the El Niño and La Niña events. Both wells are located in confined aquifers and respond quickly to stresses induced by pumping.

Four areas contributed 89 percent of the inflow to Lake Okeechobee in 1997-98. They were the Upper and Lower Kissimmee areas, the Fisheating Creek area, the area contributing flow to the S84 gate and the area contributing flow to the S71 structure. On average, the inflow to Lake Okeechobee was 2.4 times the historic mean flow. Two major waterways received 83 percent of the outflow from Lake Okeechobee in 1998. They were the Caloosahatchee River and the St. Lucie Canal. The Caloosahatchee Estuary received 479 percent of its historic average flow volume from approximately November 23, 1997 through May 29, 1998, based on the flow at S79. The St. Lucie Estuary received 305 percent of its historic average flow volume from December 1997 through June 1998 based on flows recorded at S49, S80 and S97.

The hydrologic effects of El Niño and La Niña-induced weather patterns observed in Central and South Florida from November 1997 through October 1998 were exceptional. They included extremes in rainfall, water surface elevations, groundwater table fluctuations, evapotranspiration and flows. They were consistent with the impacts experienced during previous El Niño and La Niña events. El Niño and La Niña weather patterns occur on an irregular but, predictable or foreseeable basis. The hydrologic impacts were regional in nature and are not well represented by District-wide summary statistics. In this report, the use of rain areas facilitated the regional analysis and presentation of data.

Taking a system-wide view of the impacts of the El Niño and La Niña weather on water resources, one overwhelming conclusion became apparent. By March 1998, water in the system managed by the South Florida Water Management District had nowhere to go. Lake Okeechobee was at dangerously high levels. All of the upper lakes including Kissimmee and Istokpoga were at regulation levels. The Water Conservation Areas could not accommodate additional flow. Flows that had the potential to negatively impact the Caloosahatchee and St. Lucie estuaries were being released.

The following recommendations resulting from the analysis and presentation of data in this report are offered:

- Planning should be undertaken based on a review of operational responses to the 1997-98 El Niño in order to examine alternative strategies to managing the system to minimize financial and environmental impacts.

- The monitoring network and database for District-wide assessment of rainfall, ground water and evapotranspiration should be reviewed and improved.

- Finally, it is recommended that the rain area boundaries be altered to coincide with the drainage area boundaries. This will also require changes in some drainage basin boundaries as well. The modifications would, in most cases, be minor. This would facilitate accessing information on a rain area basis from the District's corporate database, DBHYDRO.

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ACKNOWLEDGEMENTS

The author would like to thank the following for their assistance in preparing this report: Diane Bello-Smith, Madhav Pandey, Janet Wise, Eric Householder and Tim Scharff for their help in preparing maps; Madhav Pandey for the stage-storage relationship for Lake Okeechobee; Dan Bachand for extracting and formatting rainfall data and working with the U.S. Geological Survey (USGS) database; Alaa Ali for use of the rainfall averaging program; Linda Lindstrom, Wossenu Abtew, Nagendra Khanal, Chandra Pathak, Dan Bachand, John Raymond, Jeff Herr, Susan Bennett and Hedy Marshall for reviewing the drafts of the report and recommending needed improvements; George Hwa for help in accessing lake data from Water Resources Operations; Angela Chong for help in accessing DBHYDRO data; and Jeff Herr and Milton Switanek for their help with groundwater data. Scott Prinos at USGS-Miami reviewed and provided additional information used in the groundwater section of the report.

INTRODUCTION

Background

Significantly greater than average rainfall fell in Central and South Florida from November 1997 through March 1998. During the following months, April through October 1998, the area received less rainfall than expected. This report covers the period from November 1, 1997 to October 31, 1998. It presents the hydrologic impacts of the El Niño and of the onset of the La Niña- or El Viejo-induced weather patterns on Central and South Florida during this period. The Central and South Florida Region has been divided into 15 major watersheds[1] depicted in **Figure 1**. These areas are within the boundaries of the South Florida Water Management District and include Everglades National Park.

El Niño-related weather patterns are caused by warming water surface temperatures in the Eastern Pacific Ocean near the coast of Peru. A complimentary cooling occurs in the Western Pacific. La Niña-related weather is associated with cooling equatorial waters in the Eastern Pacific. Geoarchaeolgical evidence exists that El Niño events occurred as early as 5,000 years ago (Sandweiss, et al., 1996). The pattern is usually observed every three to four years. It can occur infrequently at intervals of two to seven years (U.S. Dept. of Commerce). Solow (1995) found that the timing of El Niño events is consistent with a model of a stationary renewal process[2]. He also found that the magnitude of the El Niño event based on a binary value (strong vs. weak) was independent of timing and followed a stationary first-order Markov chain with estimated transition matrix[2].

Figure 2 shows the Multivariate El Niño/Southern Oscillation (ENSO) Index for the years 1950 to 1999. K. E. Wolters and colleagues at the National Oceanic and Atmospheric Administration's Climate Diagnostics Center developed the index as a research tool. It is based on six key variables collected over the tropical Pacific Ocean, such as sea surface temperature and sea-level pressure. The spikes above zero indicate periods associated with El Niño weather patterns. In the Southeastern United States, this warming in the Eastern Pacific results in increased rainfall. The spikes below zero represent La Niña events.

The spikes above zero shown in **Figure 2** correspond with previously observed El Niño-induced, dry season rainfall patterns observed in the District in 1957-58, 1965-66, 1972-73, 1982-83, 1986-87, 1991-92, and 1997-98 and the extended wet season in 1994. The last positive spike on the right represents the event that triggered the rainfall amounts witnessed in the 1997-98 El Niño period in South Florida. Spikes below zero in **Figure 2** correspond with reported drought periods in 1970-71 and 1971-72, 1974, 1985, 1988-89 and 1989-90. The last negative spike on the right represents the onset of the 1998 La

[1] The South Florida Water Management District identifies the major watersheds as "rain areas." They constitute major drainage basins.

[2] The reader is referred to any of a number of statistical textbooks for a more detailed explanation of these concepts.

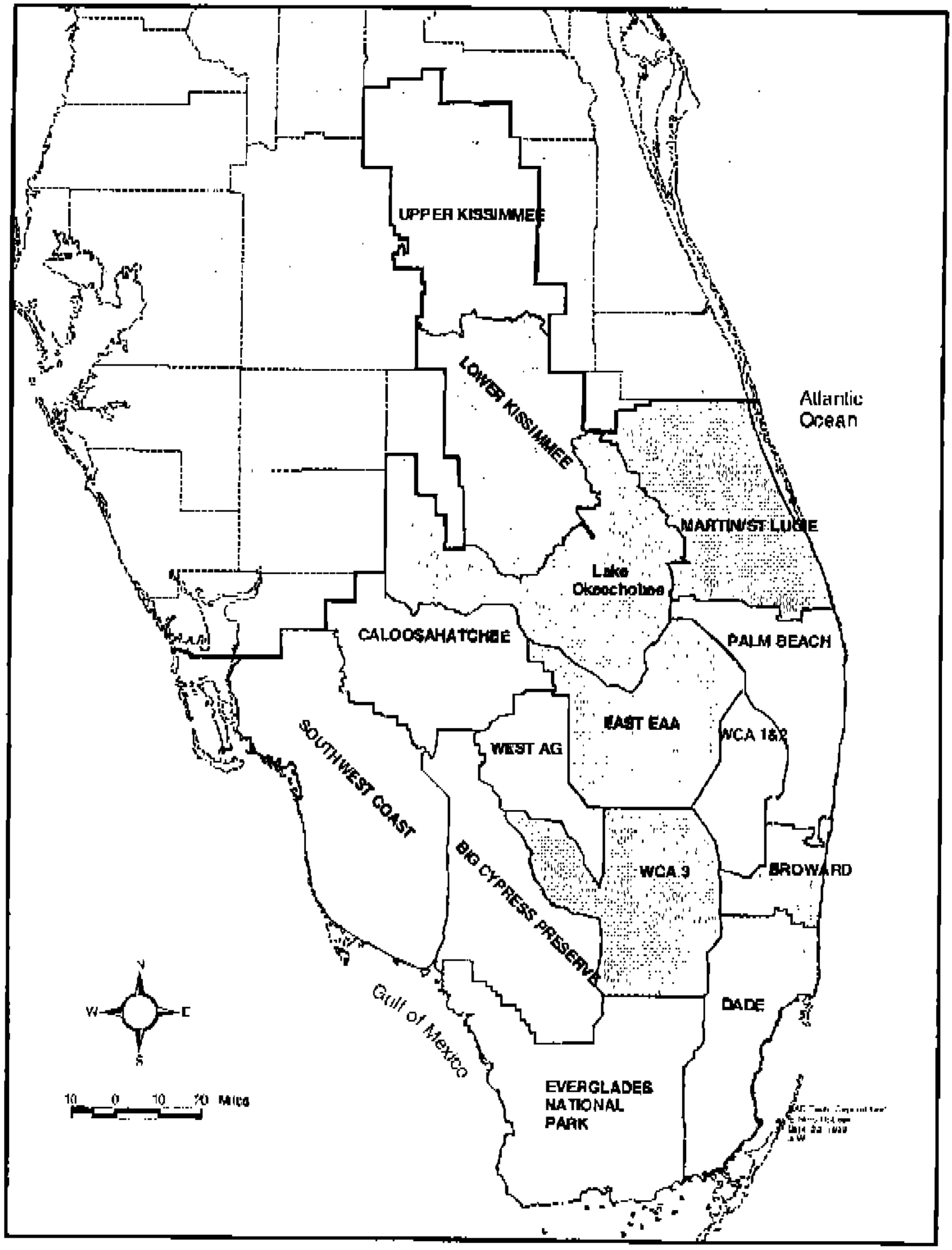

Figure 1. Major Basins or Rain Areas

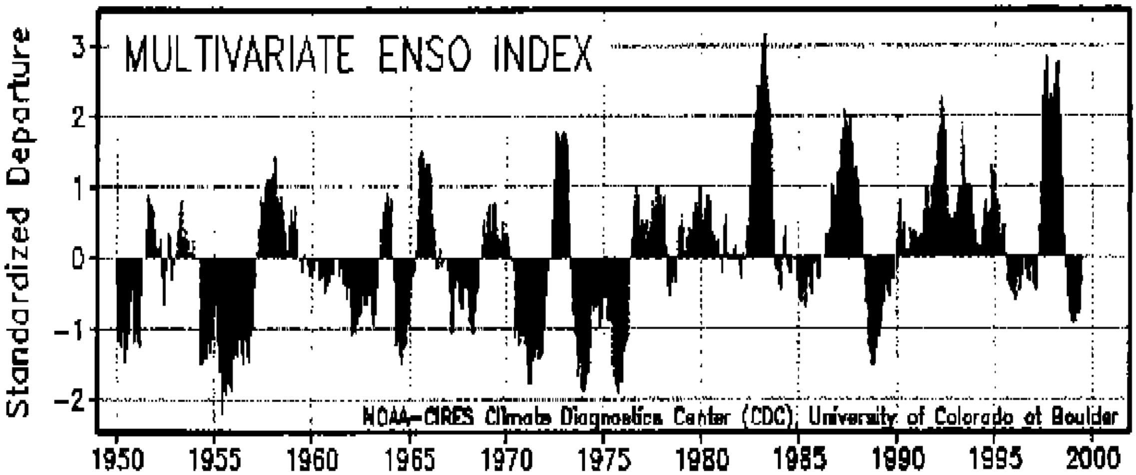

Figure 2. El Niño Cycle (Source: http://www.cdc.noaa.gov/~kew/MEI/mei.html)

Niña event. **Figure 3** shows the historic record of water surface elevations in Lake Okeechobee. During the last two decades, the majority of extreme stages (both minimum and maximum) have coincided with El Niño and La Niña events although not all extremes can be explained by El Niño- and La Nina-related weather. The variation in Lake Okeechobee stages is one example of the effect of El Niño and La Niña on water resources in Central and South Florida.

The 1997-98 event was characterized as having demonstrated "exceptional amplitudes" by researchers at the Center for Ocean-Atmospheric Prediction Studies (COAPS) at Florida State University. Winter precipitation over the southern third of the nation exceeded any of the "warm" (El Niño) events of the last 40 years, including the 1982 event, with "especially surprising increases" along the East Coast of the United States (Smith, et al., 1999).

Researchers at COAPS also found that an El Niño "greatly increased the probability of receiving greater than one standard deviation above the overall mean precipitation during the wintertime..." In addition, a La Niña "increased the probability of mean seasonal precipitation being one standard deviation below the overall mean during the winter." The impact of La Niña is as strong or stronger than that of the El Niño (Richards, 1994).

Summary of Operational Effects

The Monthly Surface Water Conditions Detail Report produced by Water Resources Operations (formerly the Operations and Maintenance Department, SFWMD, 1997-98) chronicle the evolution of the El Niño event in 1997-98 in South and Central Florida and some of the impacts on the systems operated by the District. In summary, the El Niño-enhanced rainfall started in November 1997 with 217 percent of the monthly historic rainfall. However, at the end of November, the year-to-date total rainfall was

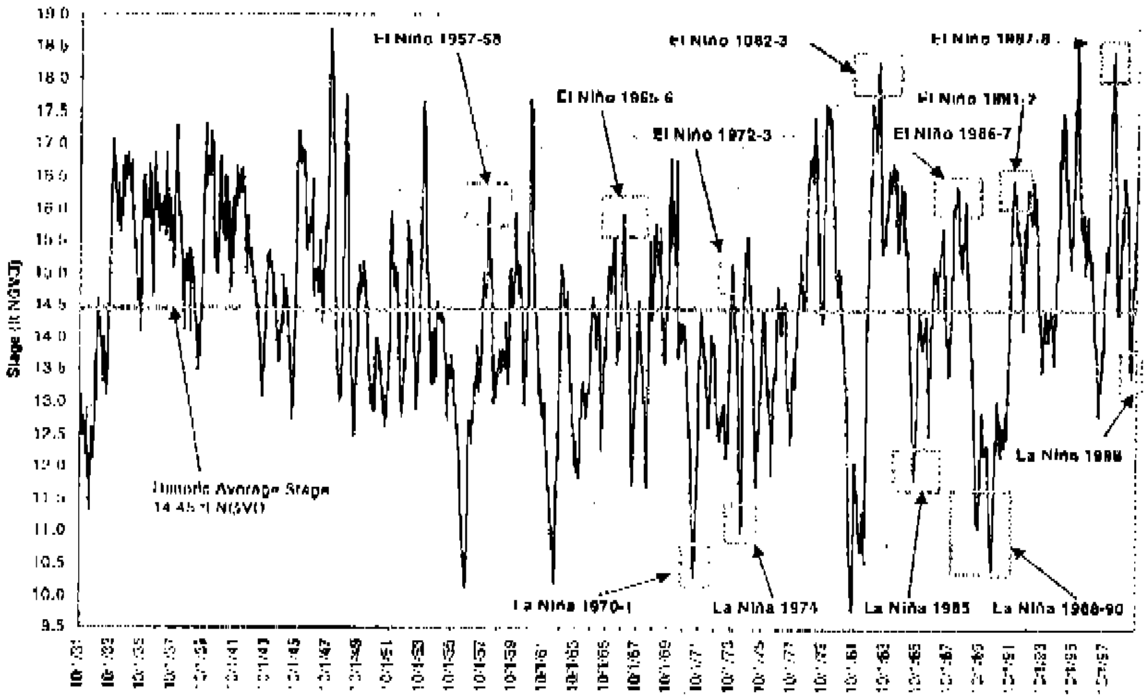

***Figure 3.** Lake Okeechobee Stages 1931 1999*

fractionally above average. All lakes in the system were operating at or near their normal schedules.

In December 1997, more than twice the monthly historic amount of rainfall fell across the District. This contributed to a foot increase in the water level in Lake Okeechobee. Releases to the Water Conservation Areas were stopped. All lakes in the Upper Kissimmee basin were significantly above their annual maximum scheduled stage.

In January 1998, District-wide rainfall again exceeded the historic monthly average. Flood control releases were made from the Caloosahatchee River to its estuary to accommodate local runoff and to release water from Lake Okeechobee.

During February 1998, the District received rainfall that was nearly three times the historic monthly average. Lake Okeechobee water surface elevations approached Zone A[3] levels. Canals C-23, C-24 and C 25 in the St. Lucie Basin were operated at the wet season levels. The U.S. Army Corps of Engineers made regulatory releases from Lake Okeechobee into the St. Lucie Estuary all month. Likewise, releases from Lake Okeechobee were made to the Caloosahatchee River. The Caloosahatchee River was near discharge capacity. Flood control pumping in the Everglades Agricultural Area was moderate in February.

[1] Zone A refers to the condition in which the maximum practical amount of water is pumped to the Water Conservation Areas and water is released at S-77 (Caloosahatchee River) and S 80 (St. Lucie Estuary) up to the capacity of those structures.

In March 1998, nearly twice the monthly historic average rainfall fell. This was the last month in the report period with rainfall significantly above average, signaling the end of the El Niño pattern. Lake Okeechobee water levels rose again. The Lake was operated in Zone A for the last half of the month. Releases from Lake Okeechobee were made to the Caloosahatchee and St. Lucie Rivers for flood control purposes.

April 1998 saw the beginning of a period of reduced rainfall due to the La Niña effect. Rainfall amounts were roughly half of the historic average for April, May, June and October and average or slightly above average for July, August and September 1998. In general, water levels in the District's lakes and Water Conservation Areas returned to normal levels[4].

Other El Niño/La Niña Effects on Southern and Central Florida

In addition to the effects of El Niño and La Niña events on rainfall amounts, lake levels and canal flows in South and Central Florida, tornado activity in the Florida peninsula is usually reduced during both El Niño and La Niña. Generally, the panhandle of Florida experiences a reduction of tornadoes during El Niño periods and an increase during La Niña events (Bove, 1997). However, on February 22, 1998, a series of tornadic thunderstorms hit Central Florida. Two of the tornadoes were possibly severe enough to rank among the six most severe tornadoes recorded in Florida's history. The development of these tornadoes was consistent with the observed 1997-98 El Niño weather patterns (Grenci, 1998). The thunderstorms on February 22 caused an estimated $62 million in damages. Thirty-nine people were killed and 250 injured. Other damages attributed to the 1997-98 El Niño reached $100 million in Florida (Farley, 1998). Nationally, insurance companies received $1 billion in weather-related claims during the first quarter of 1998 (Brostoff, 1998).

Brenner (DOACS, Florida Department of Agriculture and Consumer Services) found that there was a strong correlation between El Niño events and a reduction in acreage burned by wildfires in Florida and a corresponding correlation between La Niña events and an increase in the number of acres burned by wildfires in Florida. According to statistics from the Bureau of Forest Protection (DOACS), the total number of fires in 1998 ranked ninth in an 18-year period of record, from 1981 to 1998. However, the total number of acres burned in 1998 (506,970 acres) ranked third, exceeded only by the number of acres burned in 1981 (582,441 acres) and 1989 (645,331 acres) as shown in **Figure 4**.

[4] Water levels in WCA 3 were managed under a temporary deviation schedule to reduce the impacts to the Cape Sable Seaside Sparrow during the months of April and May 1998.

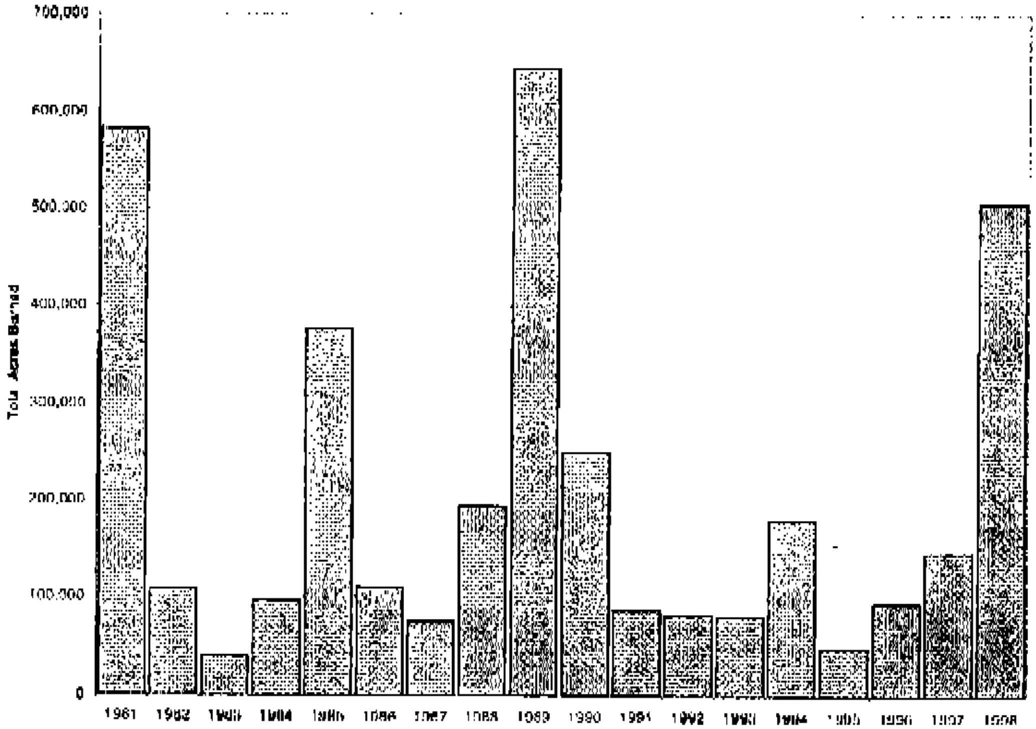

Figure 4. Total Acres Burned by Wildfires Each Year 1981-1998

This is in contrast to a total of 209,371 acres that were burned per year on average based upon the 18-year period of record examined. It should be noted that a major La Niña event was observed in 1989-90 as shown in **Figure 2**. In 1998, each wildfire burned on average of 103 acres, the highest average for the 18-year period as seen in **Figure 5**. The next highest average was in 1989 with 88 acres per fire. Not only were conditions drier in 1998 due to La Niña, but weather was more severe. In 1998, 31 percent (1,532) of all fires (4,899) were started by lightning (typically 10-20 percent). Although this might appear to be a modest increase, 79.2 percent (401,617 acres) of the total number of acres (506,970 acres) burned in Florida in 1998 were attributed to fires caused by weather related phenomena (lightning strikes). Typically, about 20-30 percent of the acreage burned by wildfires in any year are associated with lightning strikes.

Finally, Florida Keys researchers reported unusual damage to temperature-sensitive coral reefs (CNN) as a result of increased rainfall during El Niño events. Sea water levels rose an average of 20 mm worldwide as a result of the El Niño in 1997 (*Science News*, 1998). The earth's rotation was slowed by four-tenths of a millisecond due to the effect of El Niño induced winds on the planets angular momentum (Monastersky, 1998).

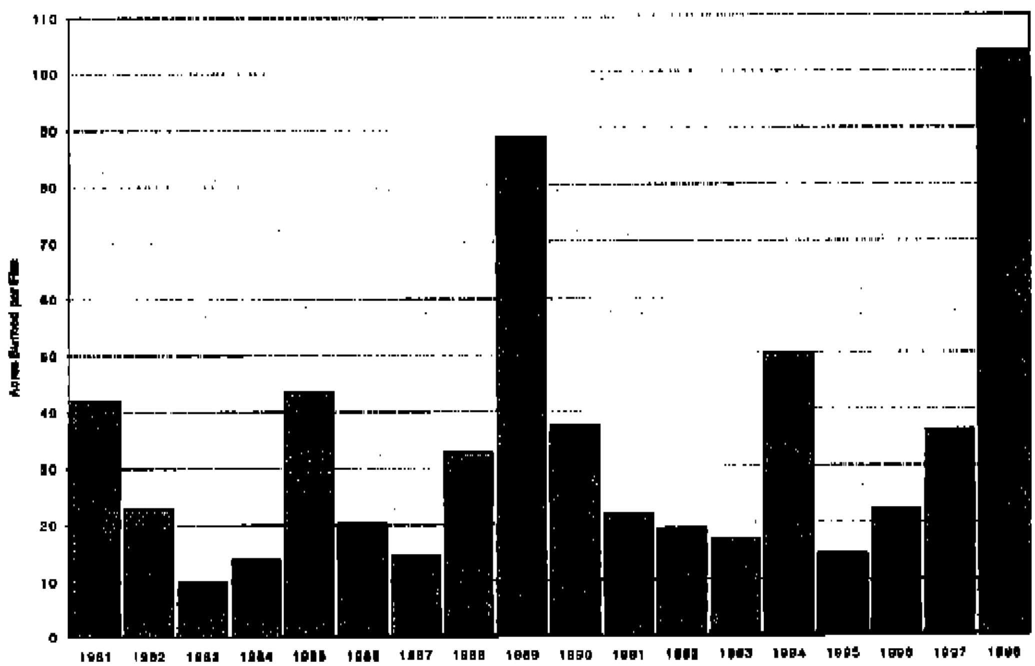

Figure 5. *Acres Burned per Fire by* ***Year*** *1981-1998*

System Description

There are seven rain areas or major basins that either provide water for Lake Okeechobee or that receive water directly from the Lake:

- Upper Kissimmee Basin
- Lower Kissimmee Basin
- Lake Okeechobee
- Everglades Agricultural Area – East
- West Agricultural Area
- St. Lucie Estuary
- Caloosahatchee Estuary

The Upper Kissimmee River watershed covers 1,596 square miles (Guardo, 1992). It consists of 18 surface water management basins in four counties: Orange, Lake, Osceola and Polk. It is characterized by the lakes that eventually discharge to Lake Kissimmee including Alligator Lake, Lake Lizzie, Coon Lake, Trout Lake, Lake Joel, Lake Myrtle, Lake Mary Jane, Lake Hart, Lake Gentry, Cypress Lake, Ajay Lake, East Lake Tohopekaliga, Lake Tohopekaliga and Lake Hatchineha. There are several drainage districts in the watershed, including the Reedy Creek Improvement District that contains Walt Disney World and is the most heavily populated area in the Kissimmee River watershed. The principal land uses are wetland, rangeland, agriculture, urban area and forest. Ground elevations range from 181 feet NGVD to 52 feet NGVD.

The Lower Kissimmee River watershed, including Lake Istokpoga, consists of 20 basins (Abtew, 1992) in five counties: Osceola, Polk, Highlands, Okeechobee and Glades. The watershed covers 1,270 square miles north and northwest of Lake Okeechobee. Ground elevations range from 126 feet NGVD to 18 feet NGVD. The principal land uses are for agriculture, rangeland, wetland, forest and urban areas. The agricultural uses include dairy, beef cattle, hay and citrus production. There is a growing use for tourism in basins surrounding Lake Okeechobee. Each basin is associated with a major canal, levee or structure. The canals, levees and structures provide flood protection, drainage, irrigation water, water for wetlands and navigation. Flood protection is provided for upstream areas. The C-38 canal is the major canal in the watershed. It extends 47.8 miles from the outlet of Lake Kissimmee to Lake Okeechobee. The Lower Kissimmee watershed provides 41.5 percent of the average inflow to Lake Okeechobee.

Lake Okeechobee is the second largest freshwater lake within the boundaries of the United States. At an average depth of 8.9 feet, it has a surface area of 680 square miles (Abtew, 1999). Mean annual rainfall is 46.6 inches. Mean annual evaporation from the Lake is approximately 50 inches per year. Historic annual, mean inflow to the Lake is 1,488,816 acre-feet and mean outflow is 1,113,099 acre-feet. The Lake is a multipurpose water resource providing flood protection, water supply (both urban and agricultural), recreation and wildlife habitat. Seven counties surrounding the Lake have portions that drain directly into it: Glades, Highlands, Okeechobee, St. Lucie, Palm Beach, Hendry and Martin. Ground surface elevations in the basin range from 154 feet NGVD to 9 feet NGVD.

The East Everglades Agricultural Area (EAA) is made up of those areas south and southeast of Lake Okeechobee that once were part of the Everglades but were drained and are now used for agricultural purposes (Cooper, 1989). East EAA includes areas in four counties: Palm Beach, Martin, Hendry and Glades. The watershed is comprised of eight surface water management basins covering 1,010.2 square miles. The principal land use is agriculture. The topography of the area is flat. Ground surface elevations average approximately 15 feet NGVD. The watershed contains the six Stormwater Treatment Areas. The canals, levees and associated structures provide flood protection, water control, agricultural water supply and water for the Everglades National Park (ENP). They also provide water to eastern Palm Beach, Broward and Dade counties for municipal water supply, to prevent saltwater intrusion and water for mandated releases to the Water Conservation Areas.

The West Agricultural Area covers 490 square miles in three counties: Hendry, Collier and Broward. It is made up of three surface water management basins. The principal land uses are related to agricultural production. The topography of the basin is flat. Ground surface elevations average approximately 15 feet NGVD.

The St. Lucie River watershed is comprised of two surface water management basins: the C-44 (St. Lucie Canal) basin and the Tidal St. Lucie basin (Cooper and Santee, 1988). They cover 259.6 square miles in Martin County. The C-44 canal has four functions:

1. Provide drainage and flood protection
2. To discharge water from Lake Okeechobee when the Lake is over schedule
3. Provide irrigation water during periods of drought
4. Provide navigable waterway between the Intracoastal Waterway and Lake Okeechobee

Ground elevations range from 0 feet NGVD to 72 feet NGVD. The principal land uses are mixed including residential, commercial, agricultural and industrial activities. Lake Okeechobee releases cause two significant problems in the St. Lucie River watershed. Flows into the Estuary (Tidal St. Lucie) are sediment laden and deposit sand, clays and organic mater at the outlet of the C-44 canal to the south fork of the St. Lucie River.

The Caloosahatchee Estuary covers 1,005 square miles in five counties: Hendry, Glades, Lee, Collier and Charlotte. It is comprised of four surface water management basins that exist in two rain areas, the Caloosahatchee and the Southwest Coast. Ground elevations range from 63 feet NGVD to 4 feet NGVD. The principal land uses are also mixed, characterized by residential, commercial and industrial activities near the Gulf Coast and agricultural uses further inland. The Caloosahatchee basin experiences the same problems as the St. Lucie basin in terms of sediment deposition and negative environmental impacts due to excessive fresh water releases from Lake Okeechobee (ibid.).

Monitoring System

Rain

The discussion of rainfall that follows is based upon an analysis of 357 rain gages located throughout the District. These locations are shown in **Figure 6** and listed in **Appendix A, Table A1**. These gages were active during the 1997-98 El Niño/La Niña event. They constitute the majority of rain gages located within the District. At sites where multiple rain gages are located, data from a single rain gage was used to represent rainfall at that point. In many instances, rainfall at a site with multiple rain gages was best represented by data from a <u>preferred</u> record. Preferred records (also known as preferred DB Keys) are developed and maintained with significant oversight by hydrologic reporting staff at the South Florida Water Management District. They contain data that has been reviewed in a post-processing, quality assurance and quality control (QA/QC) process. Daily rainfall data was summed for each month for each gage over the period from November 1, 1997 through October 31, 1998. This data was used in conjunction with a program developed by A. Ali to determine average values of rainfall for each of the fifteen rain areas examined in this study (Ali and Abtew, 1999). Modifications to this program were made by the author to include Everglades National Park and to apply the program to a single year. Historic rainfall averages were based upon values from Technical Publication WRE #380 by Ali and Abtew (1999). The author compiled historic rainfall averages for the Big Cypress Preserve rain area, Water Conservation Area (WCA 3) and Everglades National Park (ENP).

Evapotranspiration

Evapotranspiration (ET) is the combined consumptive and evaporative processes that release water to the atmosphere through vegetation and soil (Bras, 1990). It was calculated on a monthly average basis at five sites in the District where meteorological data was available. The location and station names of these sites are shown in **Figure 7** and listed in **Table A2** in **Appendix A.**

Stages

Stage or water surface elevation data was acquired for the Upper Kissimmee Chain of Lakes, Lake Kissimmee, Lake Istokpoga and Lake Okeechobee. The Upper Chain of Lakes data included stage values for Alligator Lake, Lake Hart, Lake Myrtle, East Lake Tohopekaliga, Lake Tohopekaliga and Lake Gentry. Stages for Water Conservation Areas 1, 2A and 3A (WCA 1, WCA 2A and WCA 3A) were also included. The gages used to report stage data are listed in **Table A3** in **Appendix A**. Their locations are shown in **Figure 8**.

Groundwater Elevations

Thirteen "key indicator" wells used to monitor groundwater supplies during drought conditions were used in this report to depict the effects of El Niño and La Niña weather patterns on Central and South Florida. The sites are listed in **Table A4** in **Appendix A** and shown on **Figure 9.**

Flows

Table A5 in **Appendix A** lists the 31 stations used to evaluate the flows into and out of Lake Okeechobee, the Caloosahatchee River and St. Lucie Canal for this report. The locations of these stations are shown in **Figure 10**. Of the 31 stations where flows into the Lake were monitored, seven are stations that control flow out of the Lake. These stations are also shown in **Figure 10.**

The following section of this report discusses the hydrologic impacts of the 1997 1998 El Niño/La Niña event with respect to rainfall, evapotranspiration (ET), lake levels or stages, groundwater table elevations and lake and estuary inflows and outflows in detail. A summary and set of conclusions and recommendations completes the report.

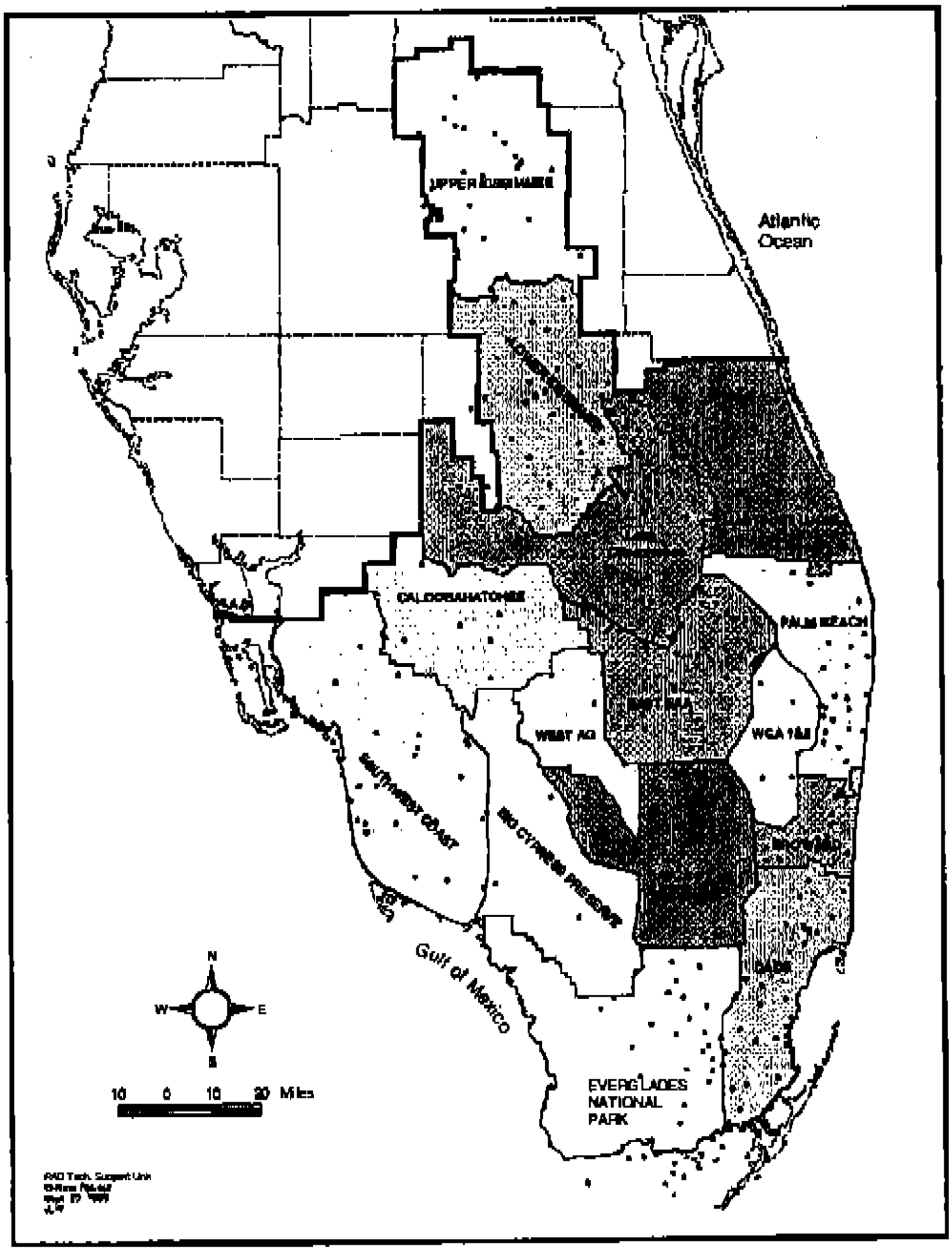

Figure 6. Location Map of Rain Gages Used to Calculate Rain Area Rainfall Amounts

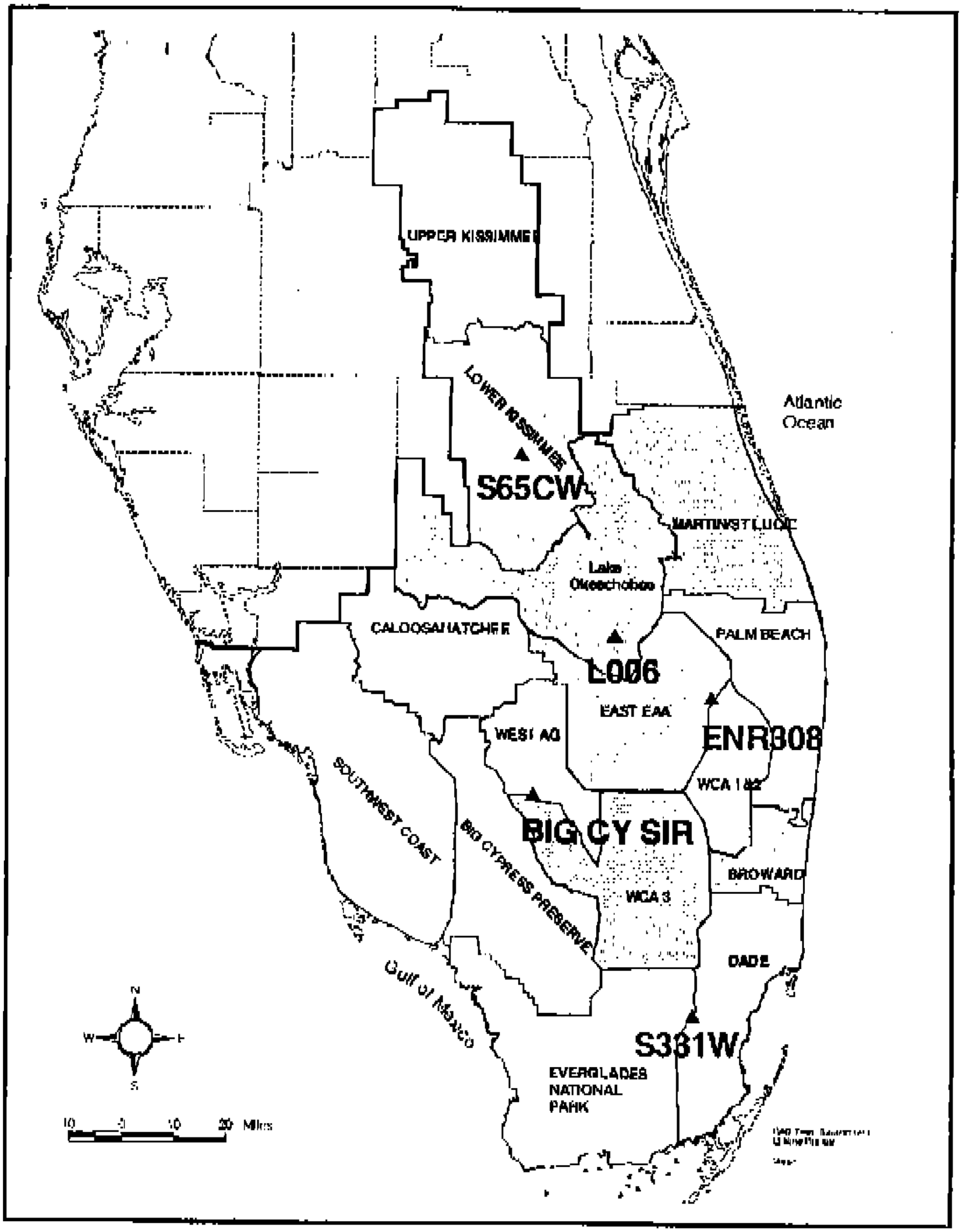

Figure 7. Location of Meteorological Data Stations Used to Calculate Evapotranspiration

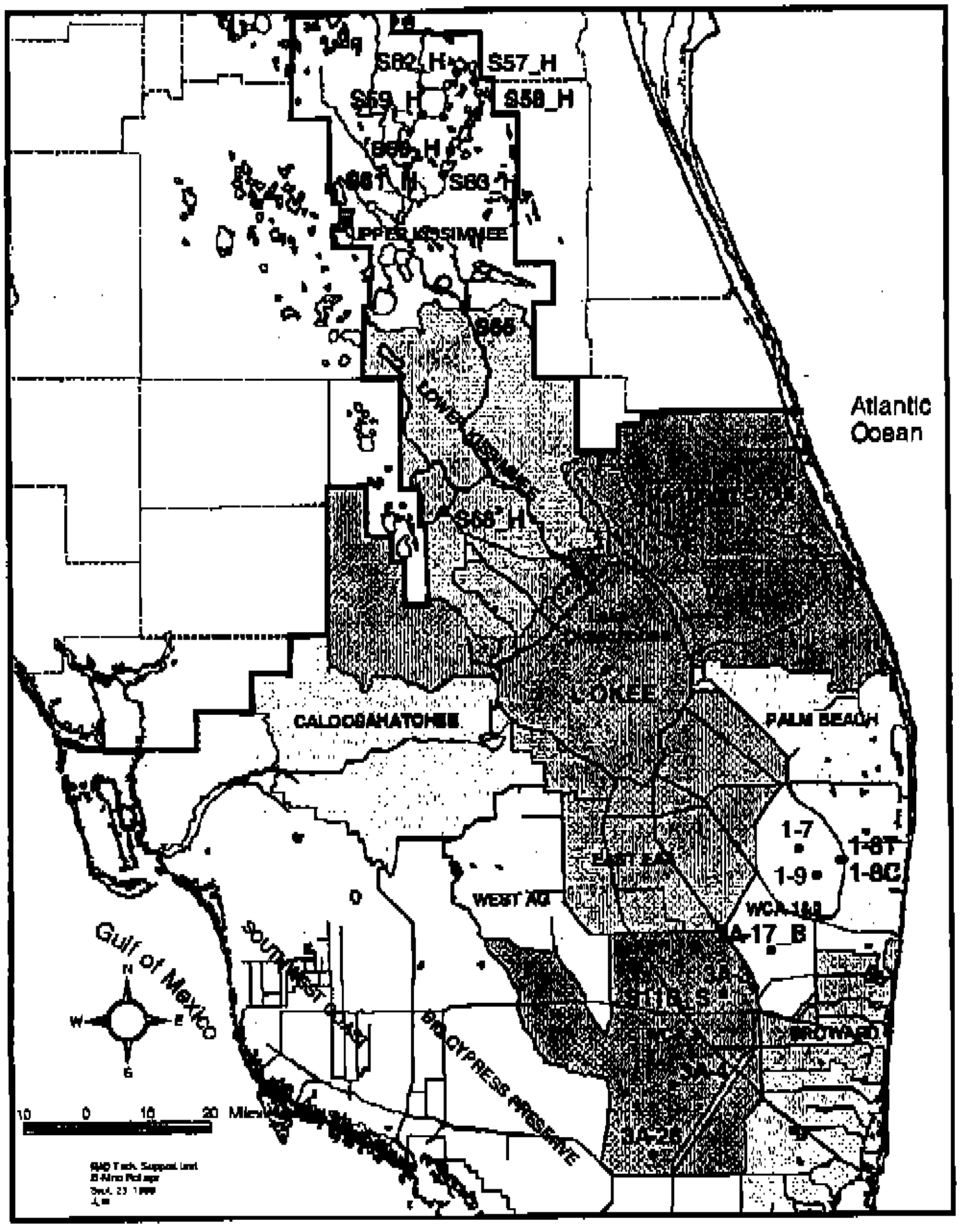

Figure 8. Location Map of Stage Recording Gages

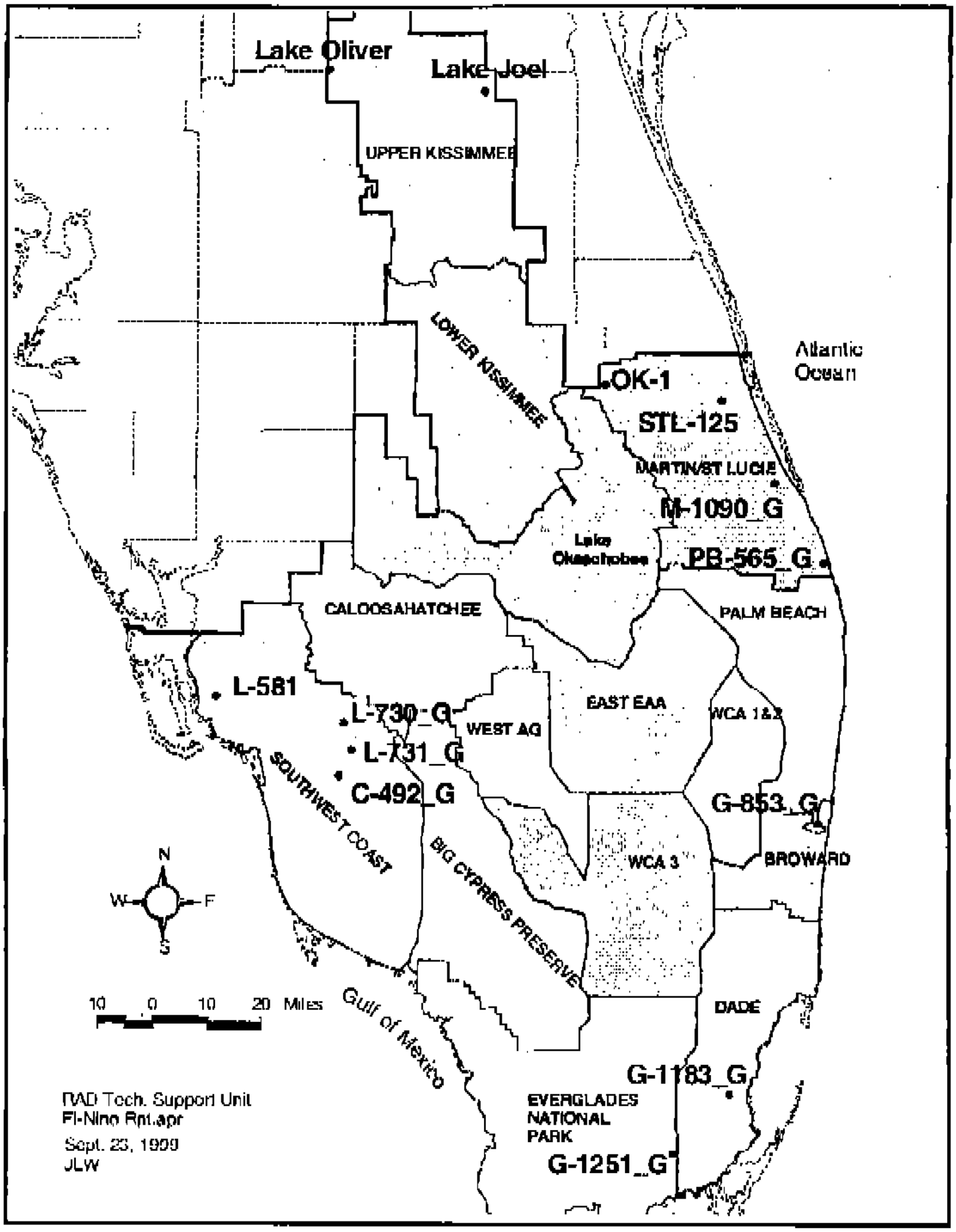

Figure 9. Location of 13 Key Indicator Wells

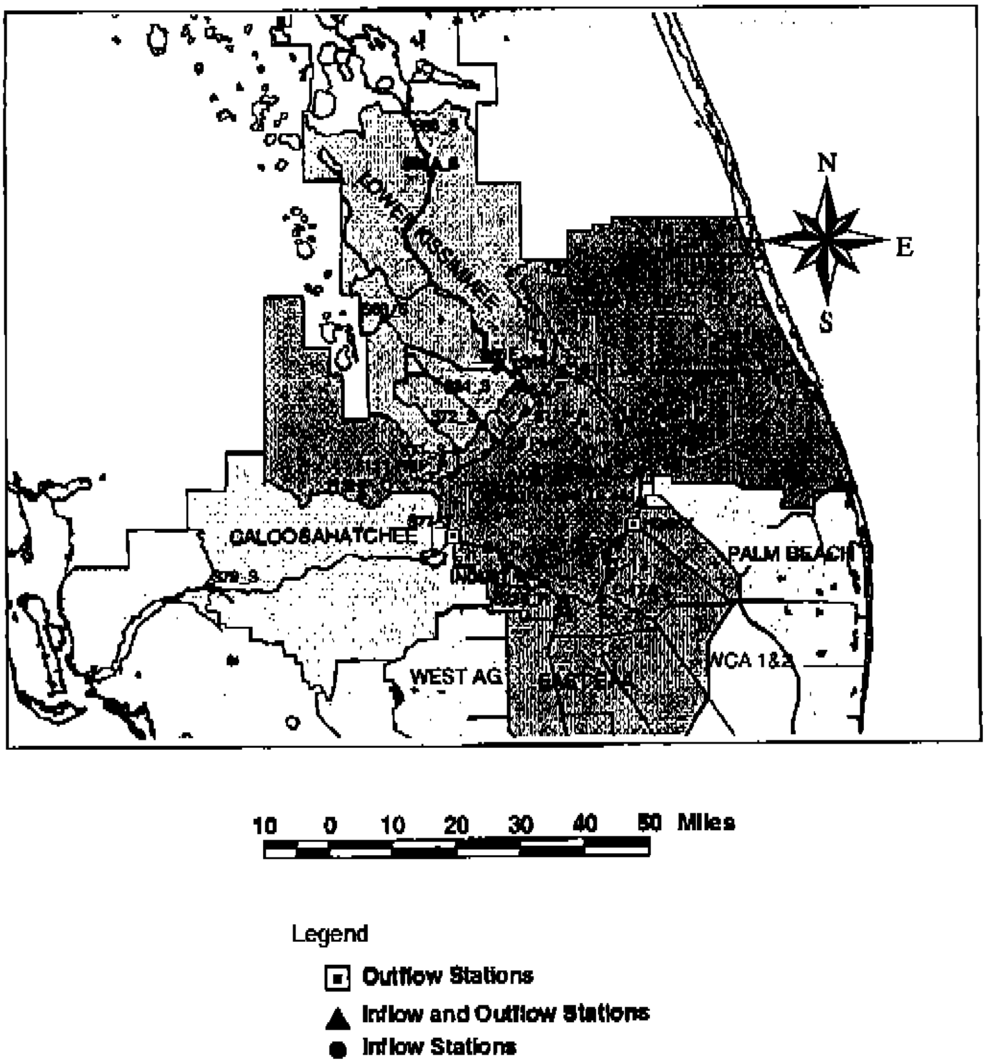

Figure 10. Location Map of Flow Recording Gages

HYDROLOGIC IMPACTS

Rainfall

District-wide

An average of 23.91 inches of rain fell over the 15 rain areas within the boundaries of the South Florida Water Management District from November 1, 1997 through March 31, 1998 (El Niño). According to the historic record, 10.86 inches would have been expected to fall over this area during this period. This resulted in a rainfall "surplus" of 13.05 inches. The greatest departure from historic monthly average rainfall occurred in December 1997 and February 1998. Rainfall amounts were 215 percent and 190 percent above historic averages, respectively. As discussed in the following sections, this excess rainfall affected the conveyance systems, estuaries and impoundments in South and Central Florida during the 1997-98 El Niño.

From April 1, 1998 through October 31, 1998 (La Niña), 30.98 inches of rain fell compared to a historic average of 41.86 inches for the same period. This resulted in a rainfall "deficit" of 10.88 inches. April, May, June and October 1998 were between 43 and 60 percent below historic monthly average rainfalls District-wide. July, August and September had only modest deviations from historic average monthly rainfalls.

From November 1997 through October 1998, the net, District-wide surplus in rainfall was 2.17 inches above the historic average. It should be noted that this number is misleading, because it presents an average for the entire District over the period of one year. The effects of the El Niño and the La Niña rainfalls were much more pronounced in smaller regions throughout the District and during each of the respective periods, El Niño and La Niña. This is presented in the next section and the sections on evapotranspiration, stage, groundwater elevations and flows that follow.

Rain Area Statistics

Figure 11 shows the rainfall surpluses for the El Niño period from November 1997 through March 1998 for the 15 rain areas in South and Central Florida. Note that the amounts of surplus, those rainfall amounts above historic average, vary considerably over the area from a maximum surplus of 21.38 inches in the Lower Kissimmee rain area to a minimum surplus of 8.68 inches in the Martin/St. Lucie rain area.

As shown in **Figure 12**, Lower Kissimmee had the lowest deficit during the period from April 1998 through October 1998, -0.47 inches. The Dade rain area experienced the greatest deficit during this period, -19.71 inches.

Appendix B contains additional figures for each rain area presenting monthly rainfall amounts compared to monthly historic averages and monthly deviation from the historic record in percent. Although monthly surpluses and deficits vary by month for each rain area, the patterns are similar. Significant rainfall surpluses were observed in December 1997 and February 1998 and significant deficits in June and October 1998. The greatest percentage surpluses were for December 1997 in the Upper Kissimmee rain area, 363 percent; the Lower Kissimmee rain area, 341 percent; the Southwest Coast rain area, 334 percent; and Water Conservation Area 3, 334 percent. The greatest monthly deficits compared to historic average rainfall occurred in April in the Dade rain area, 84 percent; in August 1997 in the West Ag rain area, 97 percent; and in September in the Martin/St. Lucie rain area, 87 percent.

Figure 13 shows the net difference between historic average annual rainfall amounts and the rainfall that occurred during the period from November 1997 through October 1998 for the 15 rain areas. In general for the year, surplus rainfall fell in rain areas north and west of a line extending from southwest to northeast through Lake Okeechobee, whereas deficits occurred in rain areas south and east of that line.

The greatest net difference in rainfall over the 12-month period from November 1997 through October 1998 was seen in the Lower Kissimmee rain area of 20.91 inches. The least net difference in rainfall was that for the West Ag rain area, a deficit of 9.9 inches. **Table 1** shows the net difference in rainfall amounts for each rain area with areas that experienced surpluses on the left and those with deficits for the 12-month period on the right.

Table 1. Net Rain Area Rainfall November 1997 through October 1998

Rain Area	**Rainfall above Average (in)**	**Rain Area**	**Rainfall below Average (in)**
Lower Kissimmee	20.91	West Ag	-9.90
Southwest Coast	7.52	Dade	-9.16
Lake Okeechobee	7.19	Martin/St. Lucie	-8.13
Caloosahatchee	5.46	Broward	-5.00
Upper Kissimmee	3.82	Palm Beach	-4.92
Big Cypress Preserve	2.24	East EAA	-2.43
WCA 3	2.16	Everglades National Park	-0.98
WCA 1 & 2	0.24		

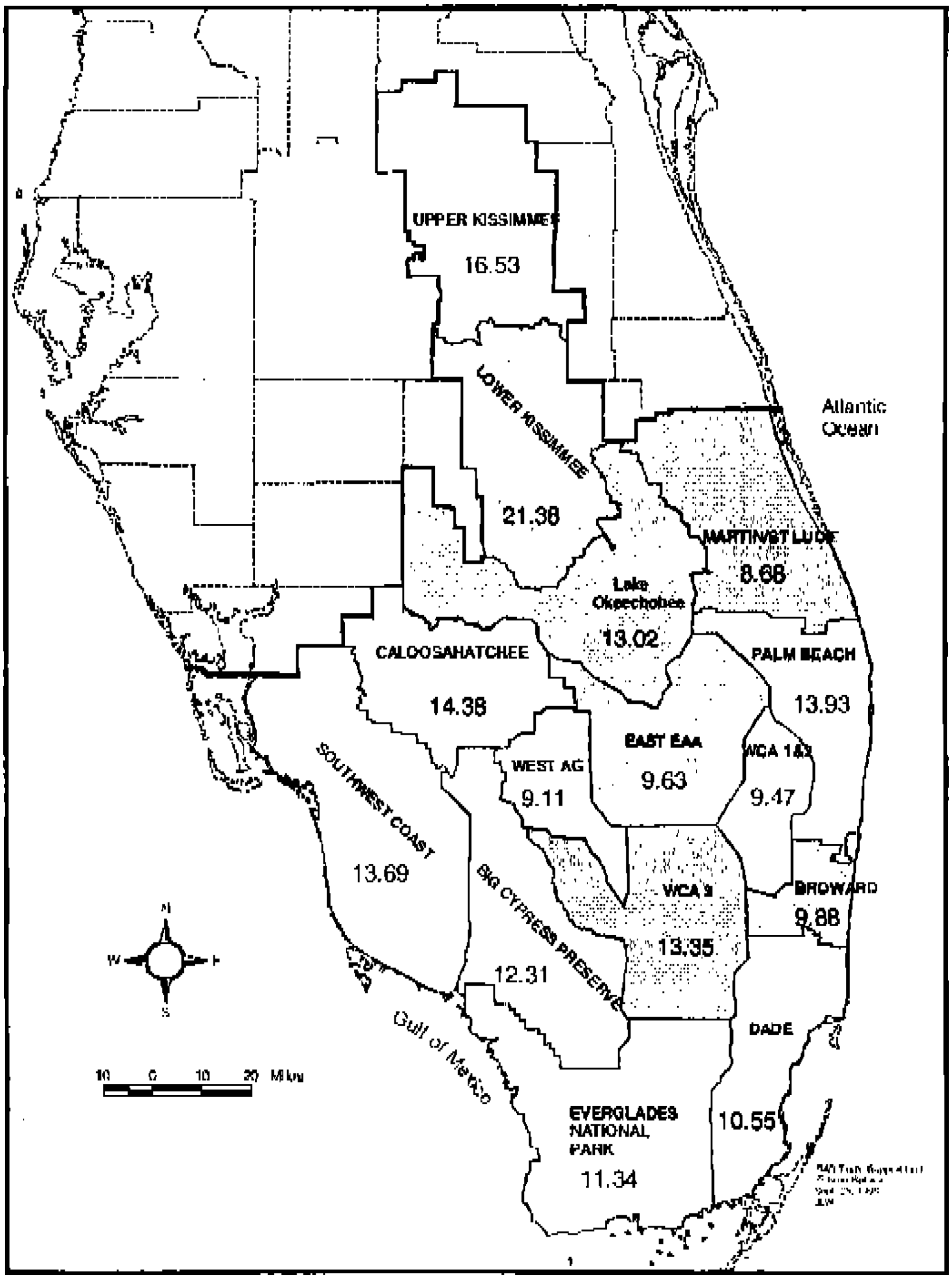

Figure 11. Map of Deviations from Average Rainfall November 1997 through March 1998

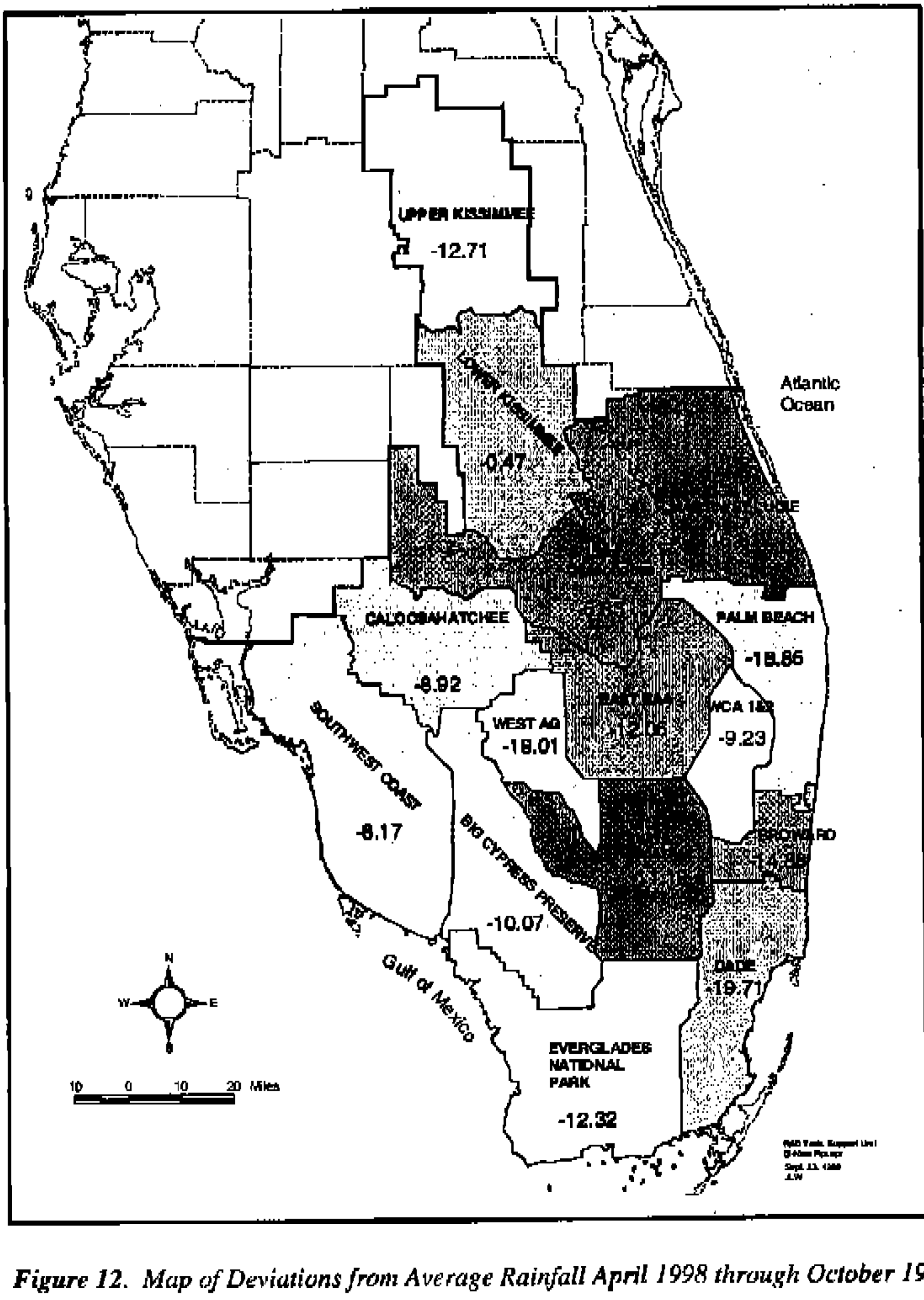

Figure 12. Map of Deviations from Average Rainfall April 1998 through October 1998

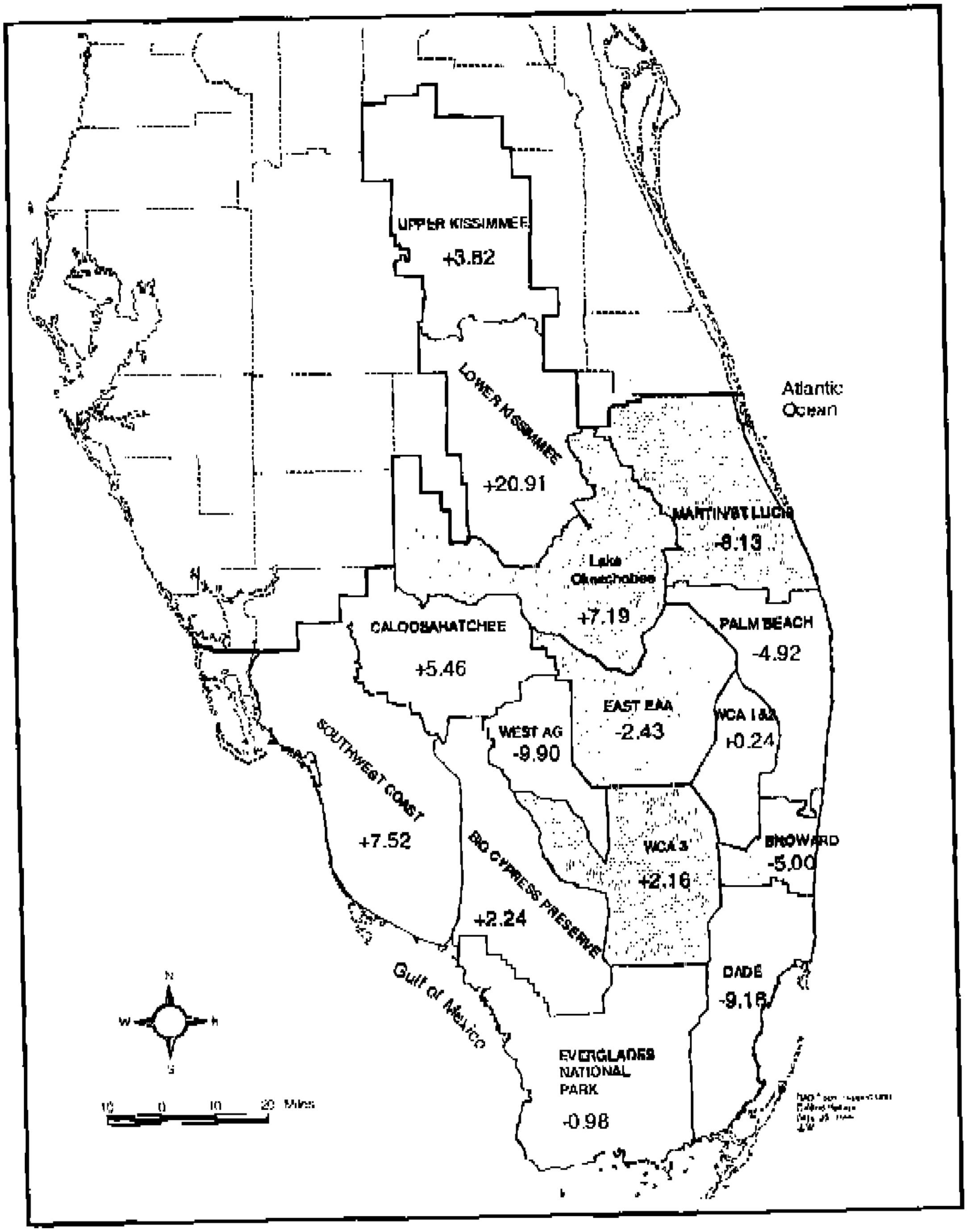

Figure 13. Net Rainfall by Rain Area November 1997 through October 1998

Evapotranspiration

Evapotranspiration is the loss of moisture to the atmosphere from evaporation at the ground or water surface interface and from the transpiration of organisms, largely plants (Bras, 1990). It is an important element in the water cycle and is essential component of a water budget or balance calculation. During the El Niño period from November 1997 through March 1998, lower than expected evapotranspiration occurred in most basins in the District. Less water was lost to the atmosphere and thus a greater amount of water was stored or conveyed by systems under the management of the District. The effect of greater rainfall and lower evapotranspiration rates on stages, groundwater table elevations and flow will be discussed in subsequent sections of this report. This section quantifies the annual evapotranspiration rate during this period and compares it to historic averages for the same period.

Potential evapotranspiration (ET) was calculated on a monthly average basis at 22 sites in the District where meteorological data was available for the reporting period. After analysis, five stations were selected for use in this report. The location and station identification numbers of these five sites was shown in **Figure 7**. Some of the rain areas used in the previous section to report watershed average rainfall do not have a meteorological data station that was collecting information from November 1997 through October 1998. Nine of the 15 rain areas had one or no recording meteorological stations during this period. Nevertheless, point values of annual ET deviations as well as monthly values are presented for the five stations. Another limitation was the period of record for the sites used. Extreme events like the 1994 wet season have a greater influence on the historic averages calculated than might otherwise be the case for stations with a longer period of record

Evapotranspiration cannot be measured directly. It is estimated using one of several equations (Abtew, 1999; Downey, 1998; Chow, et al., 1988, and others). When comparing methods of computing evapotranspiration in wetland areas, Abtew (1996) found that when data was limited, an energy balance equation could be applied to estimate potential evapotranspiration. An energy balance equation for evaporation is presented by Chow, et al., as:

$$E_r = \frac{R_n}{l_v \rho_w} \qquad \text{...Equation (1)}$$

where E_r = evaporation rate
R_n = net solar radiation
l_v = latent heat of vaporization
and ρ_w = density of water

Abtew used a similar equation that accounted for transpiration and used total solar radiation instead of net solar radiation, a quantity more easily measured in the field and thus more commonly recorded. This resulted in equation (2):

$$ET = K_1 \frac{R_s}{\lambda} \quad \text{...Equation (2)}$$

where ET = potential evapotranspiration rate
K_1 = empirical, dimensionless coefficient
R_s = total solar radiation
λ = latent heat of vaporization

Equations (1) and (2) are dimensionally equivalent. ET is typically reported in units of inches or millimeters per day. Abtew also found that K_1 ranged from 0.52 to 0.54 for the wetland systems that were studied depending upon vegetation type and density. Equation (2) is more sensitive to variations in solar radiation than to changes in air temperature. Air temperature is a variable affecting the latent heat of vaporization.

This report uses equation (2) and a K_1 value of 0.53 to compute potential ET. The value of 0.53 was chosen to represent an average value for all areas. Also, monthly average potential evapotranspiration rates were computed based upon monthly average air temperatures and monthly average total solar radiation values. A more accurate method would have been to calculate the ET values at a location on a daily basis using daily average temperature and daily total solar radiation values and sum the daily ET amounts for the entire month. The focus in this report is a comparison with historic average ET rates. Since the method of calculation is consistent for both the El Niño and La Niña periods and the historic average, the use of monthly average ET rates is considered appropriate.

Figure 14 shows the annual deviation in ET from historic values computed for the El Niño/La Niña period at the five meteorological data stations used in this report. No spatial pattern is obvious. The greatest deviation in annual ET amount from historic average was at station L006 in Lake Okeechobee, 2.84 inches. This means there was 2.84 inches less of ET than would have been expected had historic average ET occurred during this period. The lowest deviation from historic average potential evapotranspiration was at the Big Cypress Preserve Seminole Indian Reservation. At this station, there was no deviation from the total historic average ET.

Monthly deviations from historic averages at individual data collection sites are more useful in demonstrating the effect of the El Niño and La Niña weather patterns during 1997 and 1998. **Figure 15** shows the deviation in monthly ET from historic average values at Station L006 in Lake Okeechobee. It is typical of the patterns observed at other meteorological data stations. The ET values, in general, mimic the pattern shown in rainfall figures. The net effect on hydrologic systems is akin to a "one two punch." Rainfall was above average during the El Niño period and evapotranspiration was below average.

Appendix C presents a table used for the ET analysis and figures for each of the remaining four meteorological data stations.

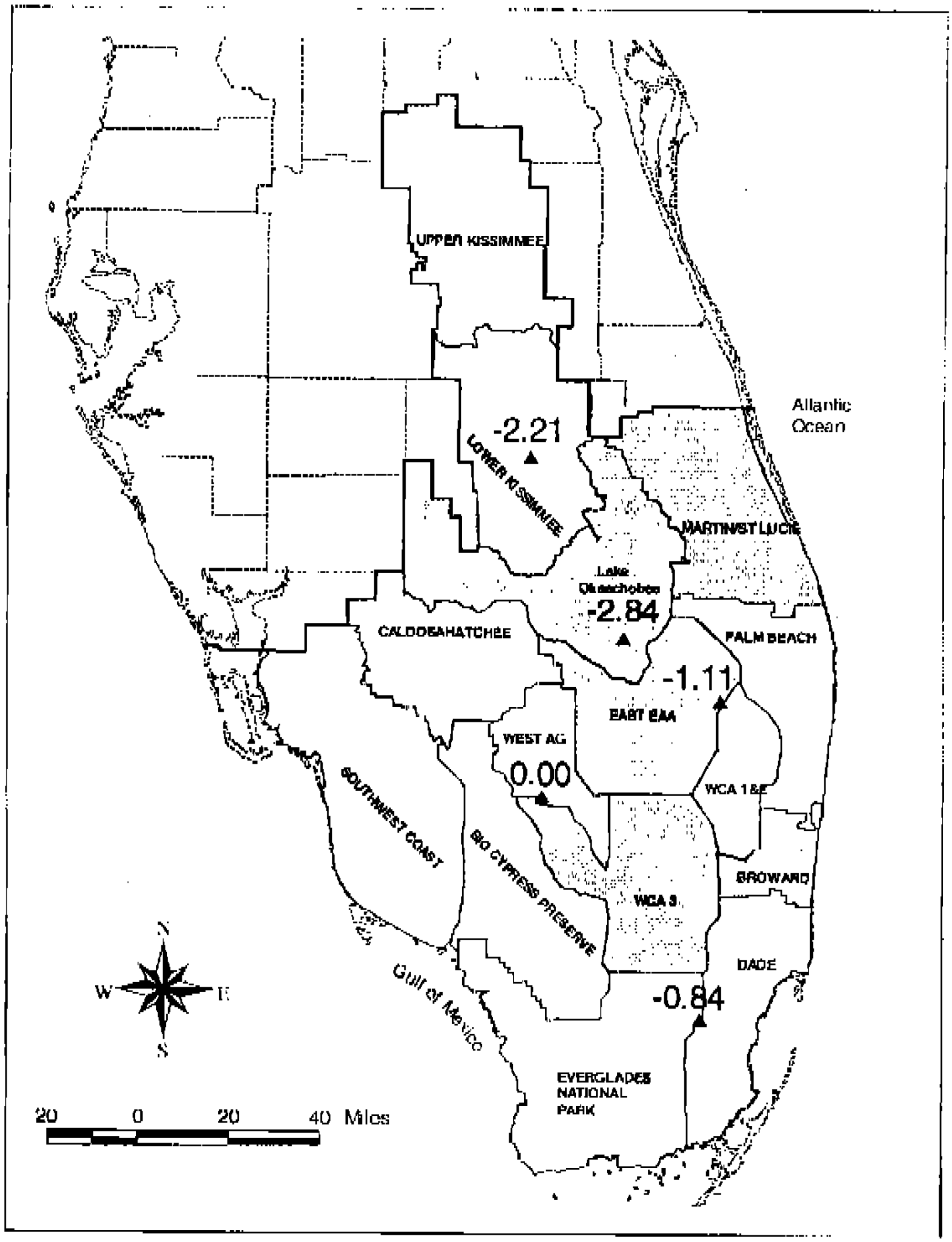

Figure 14. *Annual Deviation in Evapotranspiration from Historic Average Values at Five Meteorological Data Stations November 1997 through October 1998*

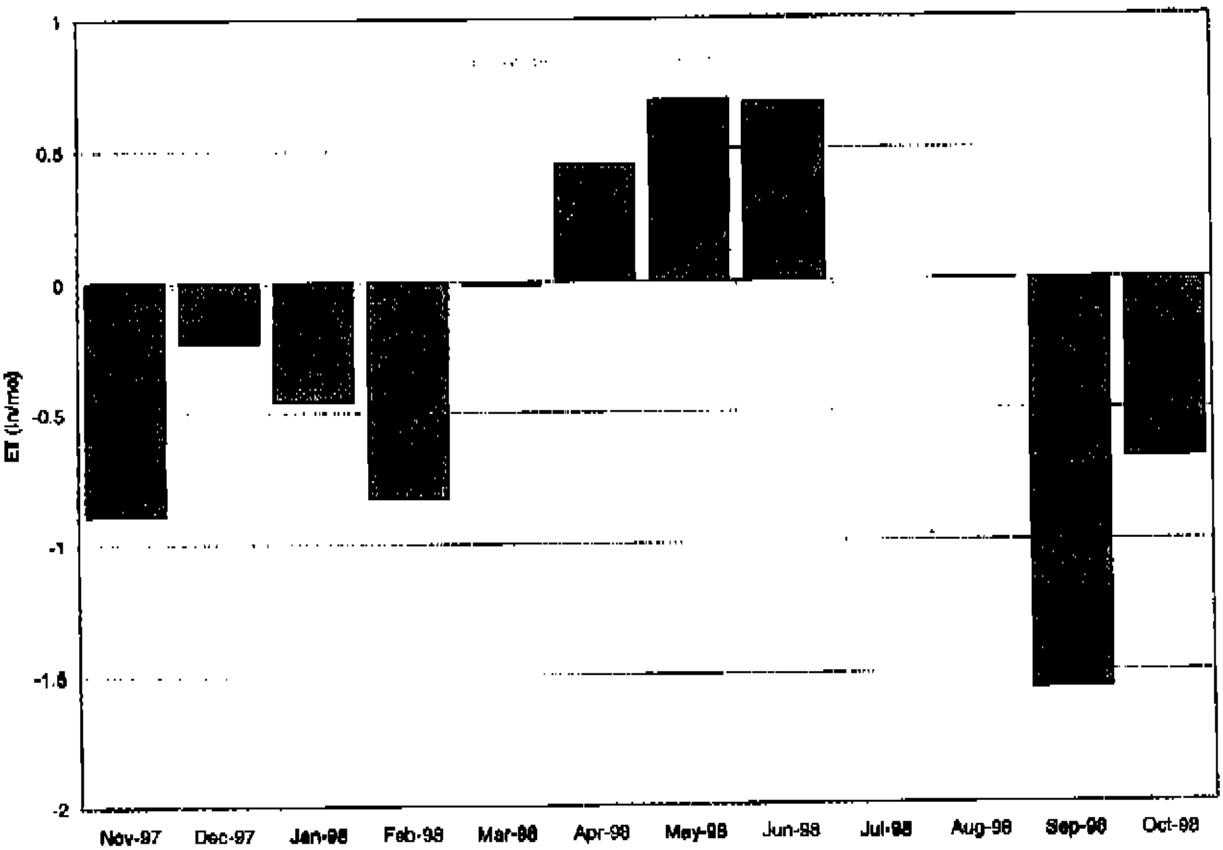

***Figure 15.** Deviation in Monthly Potential Evapotranspiration from Historic Average Values at Station L006 in Lake Okeechobee November 1997 through October 1998*

Stages

Upper Kissimmee Chain of Lakes

Figure 16 shows the variation in water surface elevation or stage from November 1, 1997 through October 31, 1998, for Alligator Lake. Alligator Lake is one of the lakes in the Chain of Lakes tributary to Lake Kissimmee. Also shown is the regulation level or target water surface elevation. The intent of the regulation level is to limit the effects of flooding in the areas surrounding Alligator Lake. Note that for the period through March 1998, the water levels in Alligator Lake exceeded the regulation level minimally four times. This was due to controlled releases to lower the water surface elevation in the Lake. The steep decline in stage starting in April 1998 is the result of these controlled releases. From May 1998 through June 1998, the stage continues to recede. This corresponds to the beginning of the La Niña weather pattern (resulting in less rainfall during the wet season). This is most pronounced after June 1998 when the regulation level increases to accommodate runoff from wet season rainfall and lake levels continue to recede and remain well below the regulation level.

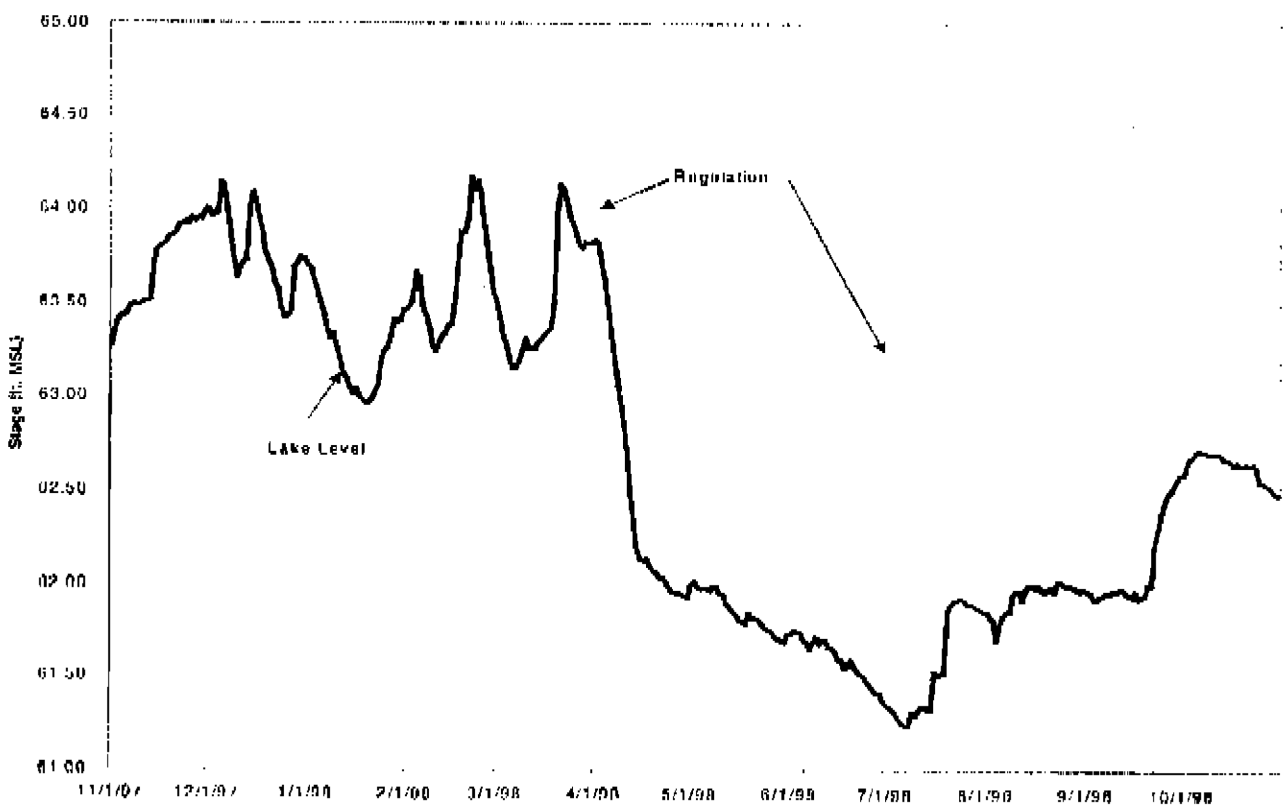

***Figure 16.** Alligator Lake Stage November 1997 though October 1998*

A similar pattern is evident for other tributary lakes in **Figures 17** through **21** for Lake Hart, Lake Myrtle, East Lake Tohopekaliga, Lake Tohopekaliga and Lake Gentry.

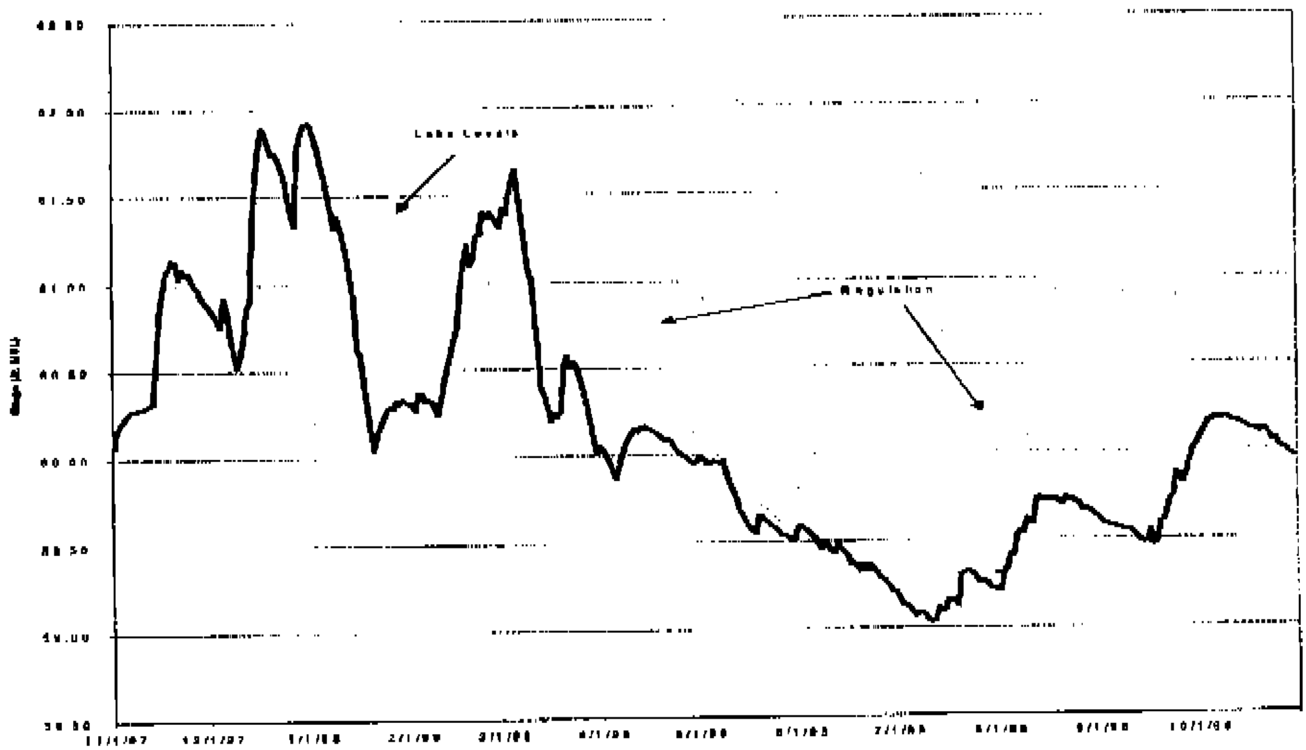

Figure 17. Lake Hart Stage - November 1997 through October 1998

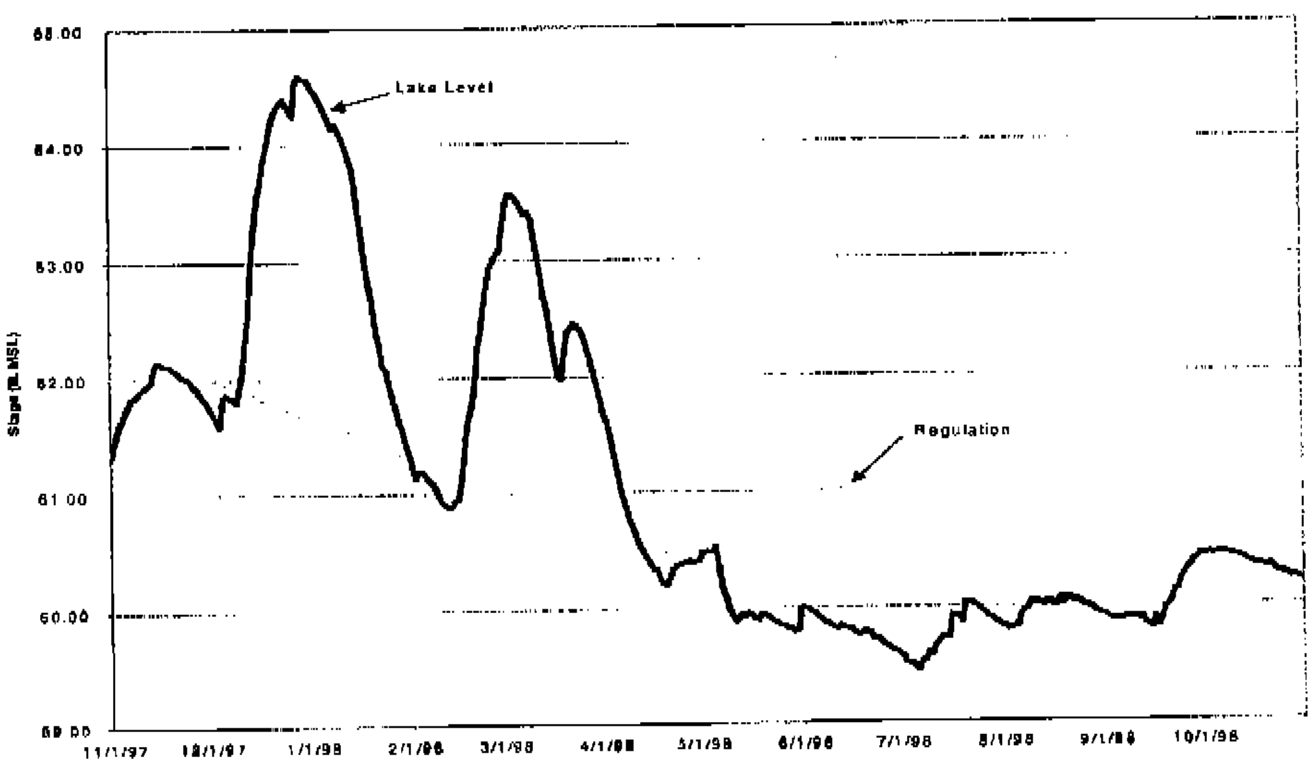

Figure 18. Lake Myrtle Stage - November 1997 through October 1998

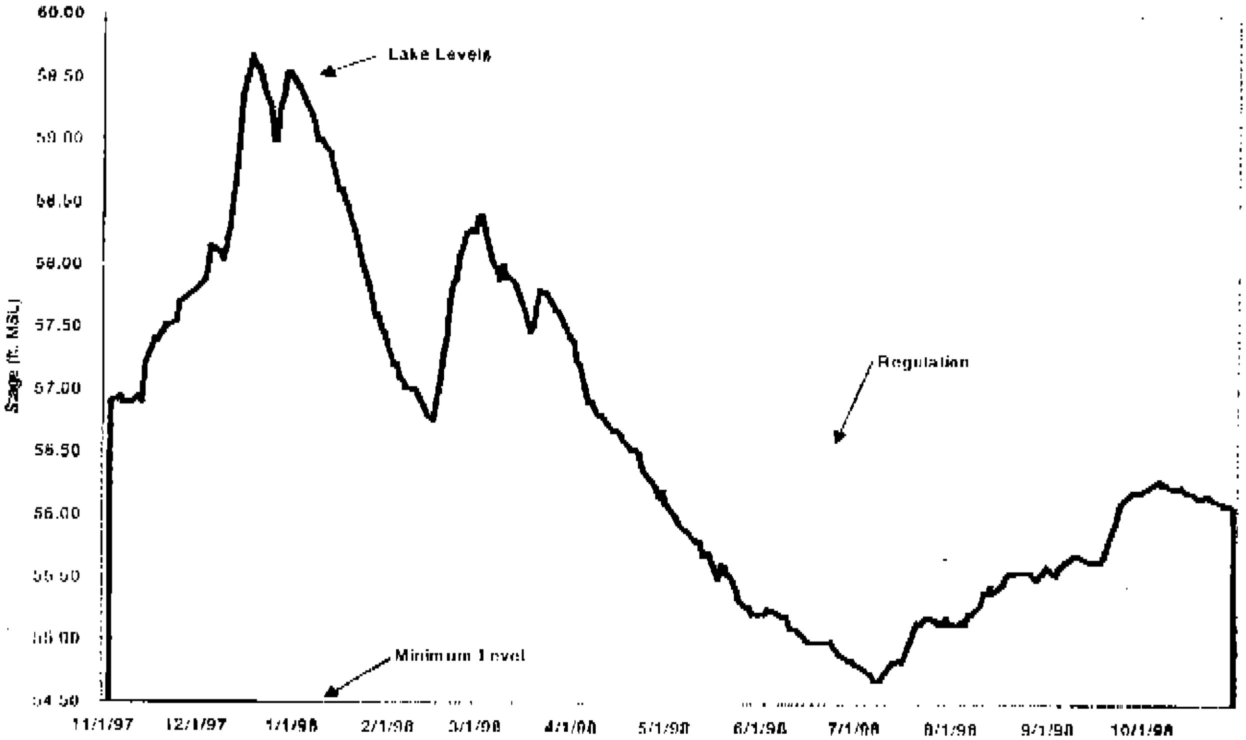

Figure 19. East Lake Tohopekaliga Stage - November 1997 through October 1998

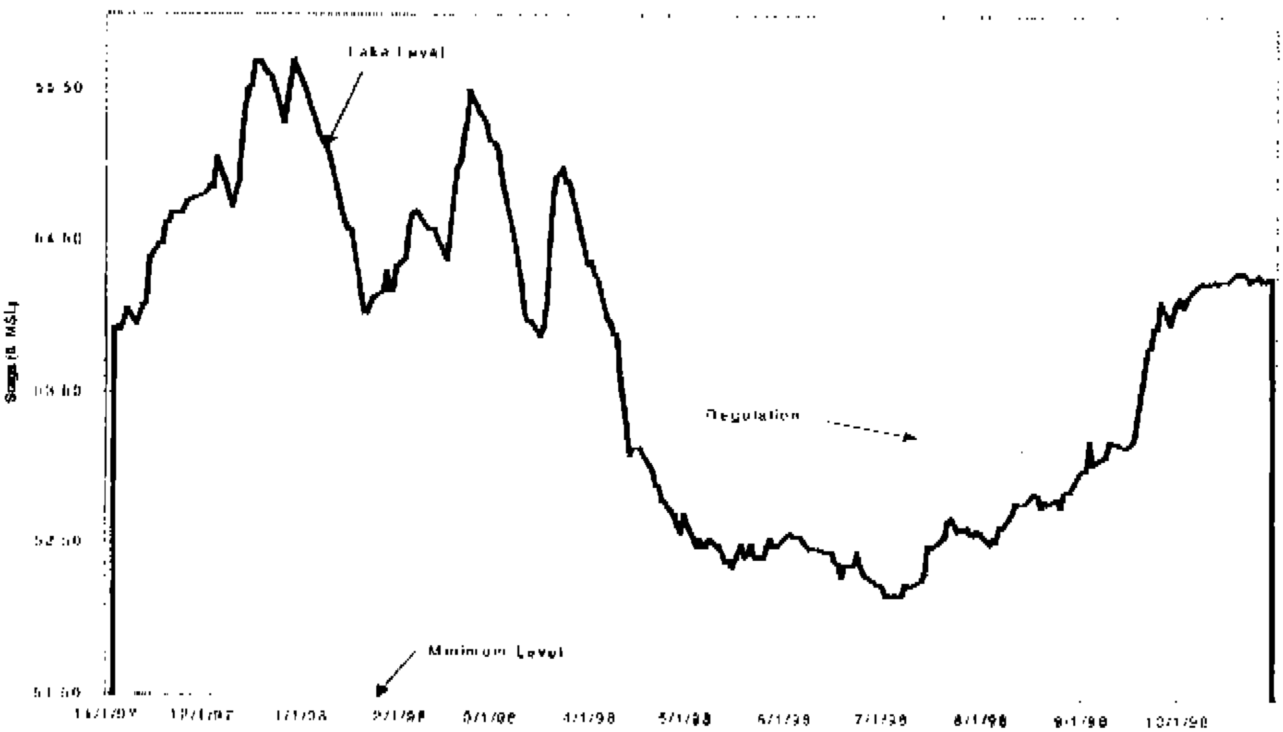

Figure 20. Lake Tohopekaliga Stage November 1997 through October 1998

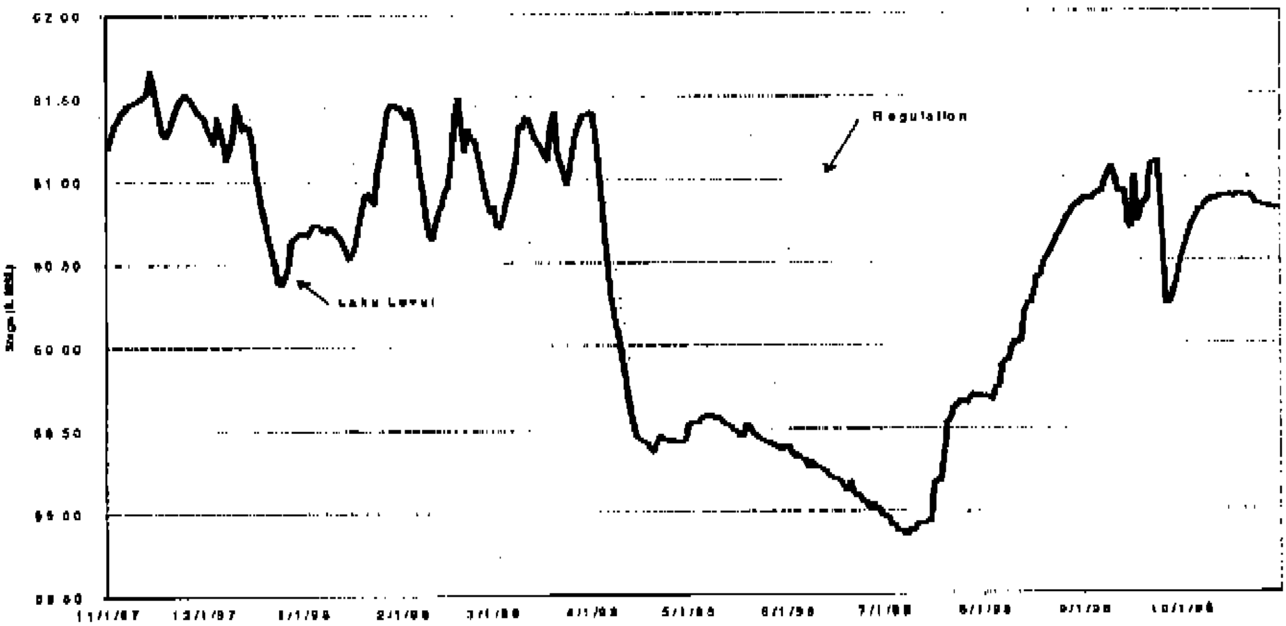

Figure 21. Lake Gentry Stage – November1997 through October1998

Lake Kissimmee

Figure 22 shows the water surface elevations in Lake Kissimmee during the El Niño/La Niña 1997-98 event. There were three periods during which water levels exceeded regulation levels; they were: 1) mid-December 1997 through mid-January 1998, 2) mid-February 1998 through mid-March 1998 and 3) late March 1998 through mid-May. The last period is one where lake levels are drawn down to accommodate spring and summer runoff. This was done but the decline in lake level continued past mid-May 1998 and through mid-July 1998 due to lower than expected rainfall amounts in the basin caused by La Niña. The Lake was 2 feet lower than regulation level by mid-July 1998. In addition, Lake Kissimmee provides nearly 50 percent of the flow into Lake Okeechobee. Flows discharged from Lake Kissimmee to reduce lake water levels eventually enter Lake Okeechobee. When flow is reduced in order to allow lake levels to recover, it affects water levels in Lake Okeechobee. This is discussed in the section on flow that follows.

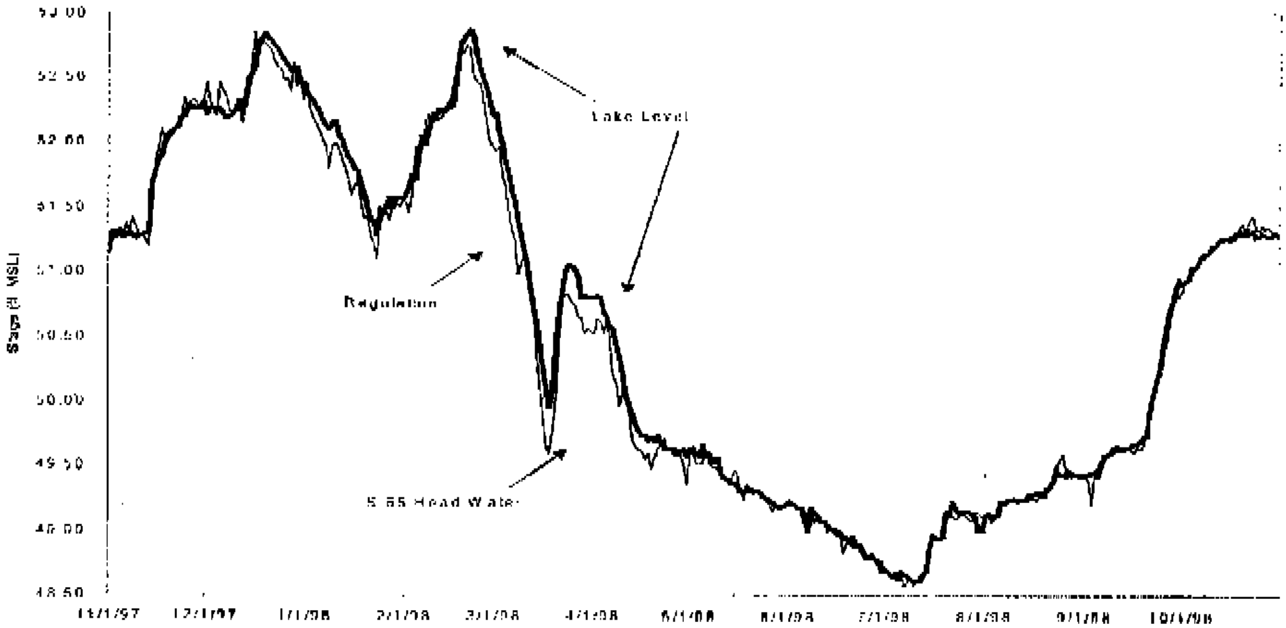

***Figure 22.** Lake Kissimmee Stage – November 1997 through October 1998* .

Lake Istokpoga

Lake levels in Lake Istokpoga were controlled during the 1997 98 El Niño as shown in **Figure 23**. However, the water level fell below the minimum lake level during the dry wet season that followed during the summer and early fall of 1998. Flow from two of the basins downstream of Lake Istokpoga contribute on average about 14 percent of the flow to Lake Okeechobee. One of the outcomes of keeping Lake Istokpoga stages close to regulation levels through March 1998 was to pass excess water on to Lake Okeechobee. The impact of this process is examined in the discussion on stages in Lake Okeechobee and in the following section on flow into the Lake.

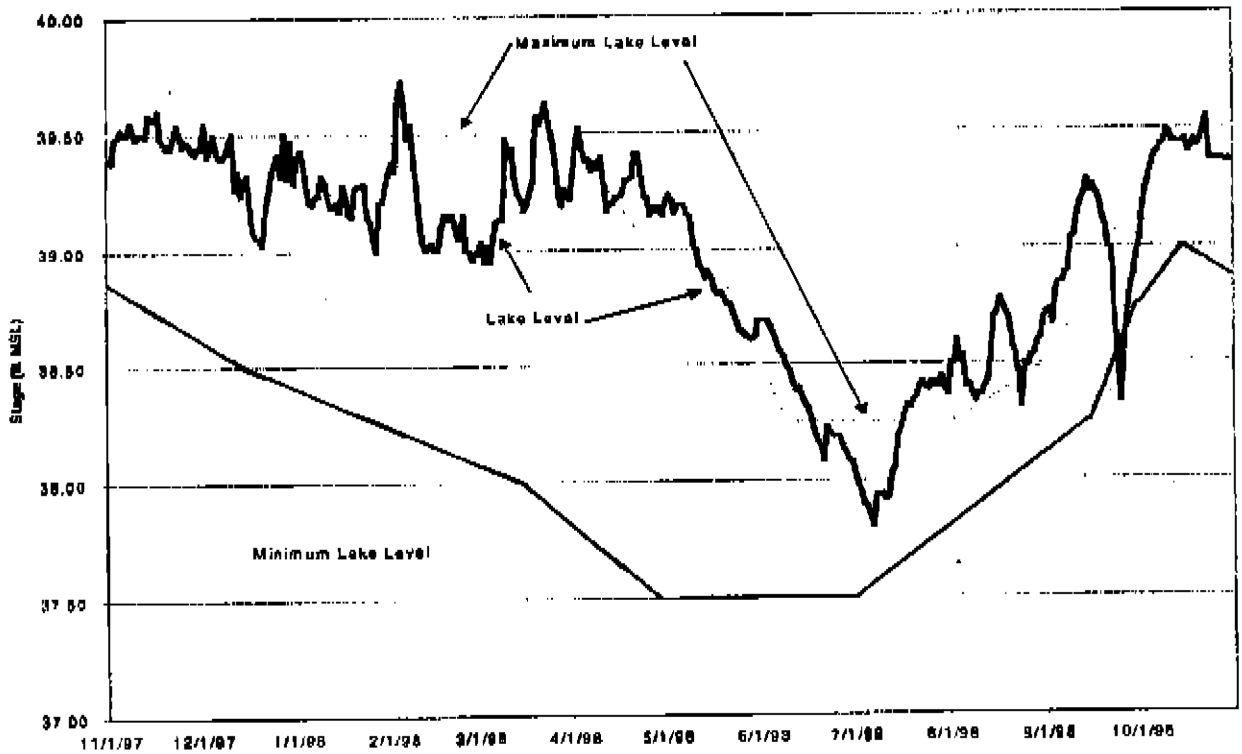

Figure 23. Lake Istokpoga Stage - November 1997 through October 1998

Lake Okeechobee

Variation in stage or water surface elevation from November 1, 1997 through October 31, 1998 for Lake Okeechobee is depicted in **Figure 24**. Lake levels rose from November 1997 through March 1998 reaching a maximum stage of 18.43 feet NGVD on March 26, 1998, the third highest stage in the lake's recorded history which started in 1931. The recorded stage remained at that level through March 28, 1998. A recent report (URS Greiner Woodward-Clyde, 1998) cited the problems with seepage and piping through the Lake's berm when the stage reached 18.5 feet NGVD. The 100-year stage has been estimated at 21.6 feet NGVD (SFWMD, Operations Structure Books). At the end of March 1998, water levels were in Release Zone A. Zone A operations require maximum capacity releases to the Caloosahatchee River (9,300 cubic feet per second or cfs) and the St. Lucie Canal (16,900 cfs) and the maximum practical releases to the Water Conservation Areas. On March 26, 1998, the day that the lake reached a maximum stage of 18.43 feet NGVD, approximately 5.4 million acre-feet of water[5] was stored in the lake. This amount is 44.3 percent higher than would have been expected based upon the historic record (3.7 million acre-feet). On April 1, 1998, the volume of water stored in Lake Okeechobee was 5,355,380 acre-feet, 49.0 percent more than the average volume traditionally stored during April of 3,592,355 acre-feet.

[5] These volumes are based upon area-capacity computations for Lake Okeechobee completed by staff at the Jacksonville District of the U.S. Army Corps of Engineers in 1962.

The increase in lake stage can be partially attributed to upstream impoundments that were maintained at regulation levels and impoundments downstream like the Water Conservation Areas that could not accommodate additional flows. Starting in March, however, the target or scheduled lake levels began to decrease, again operationally anticipating increased rainfall during the spring and summer months. Stages remained above historic monthly average values through October 1998.

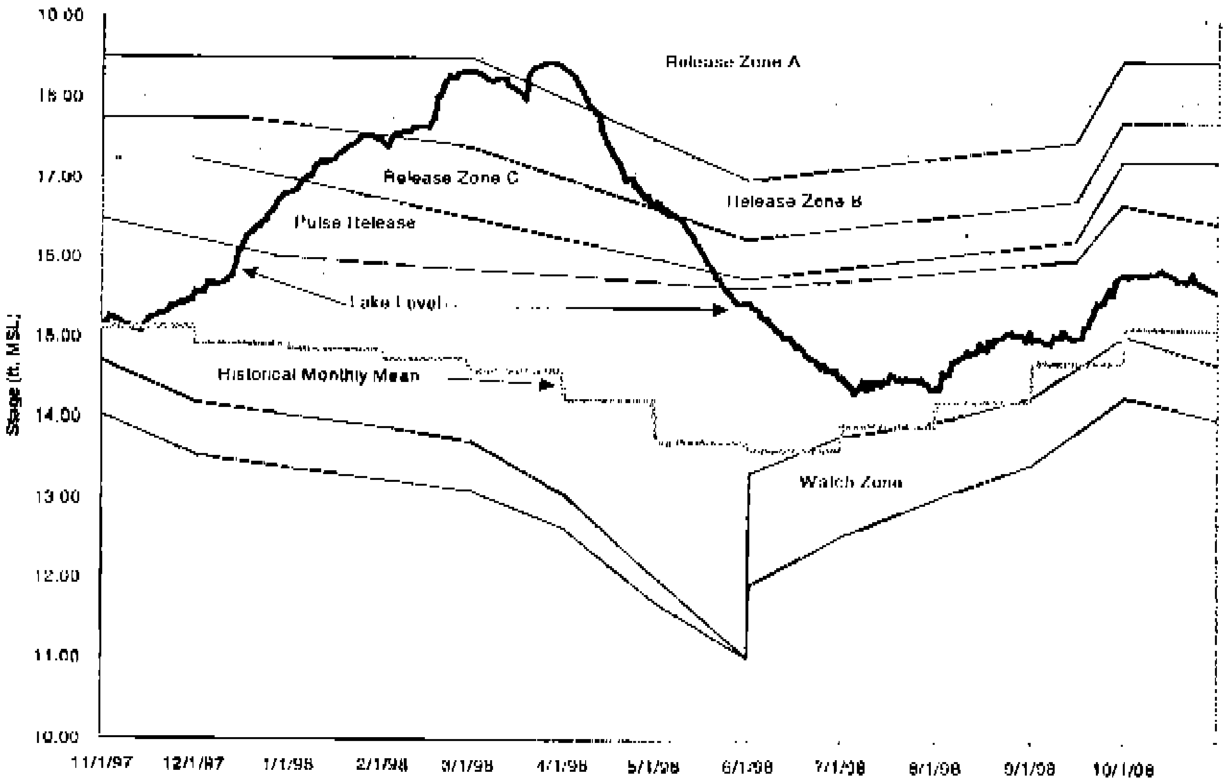

Figure 24. Lake Okeechobee Stage November 1997 through October 1998

Water Conservation Areas

Figure 25, 26 and **27** show the changes in stage in Water Conservation Areas 1 (WCA 1), 2A (WCA 2A) and 3A (WCA 3A). During the El Niño period, November 1997 through March 1998, water levels were maintained at or near regulation levels with the exception of WCA 3A. Starting in January 1998, the regulation level in WCA 3A decreased from 10.5 feet NGVD to 9.5 feet NGVD. During 1997-98, the stage was maintained between 10.5 and 11.0 feet NGVD until mid-April to accommodate excess rainfall and runoff. There was concern about increasing water levels in the Water Conservation Areas and the degradation of habitat for the Cape Sable Seaside Sparrow (SFWMD, 1997-98).

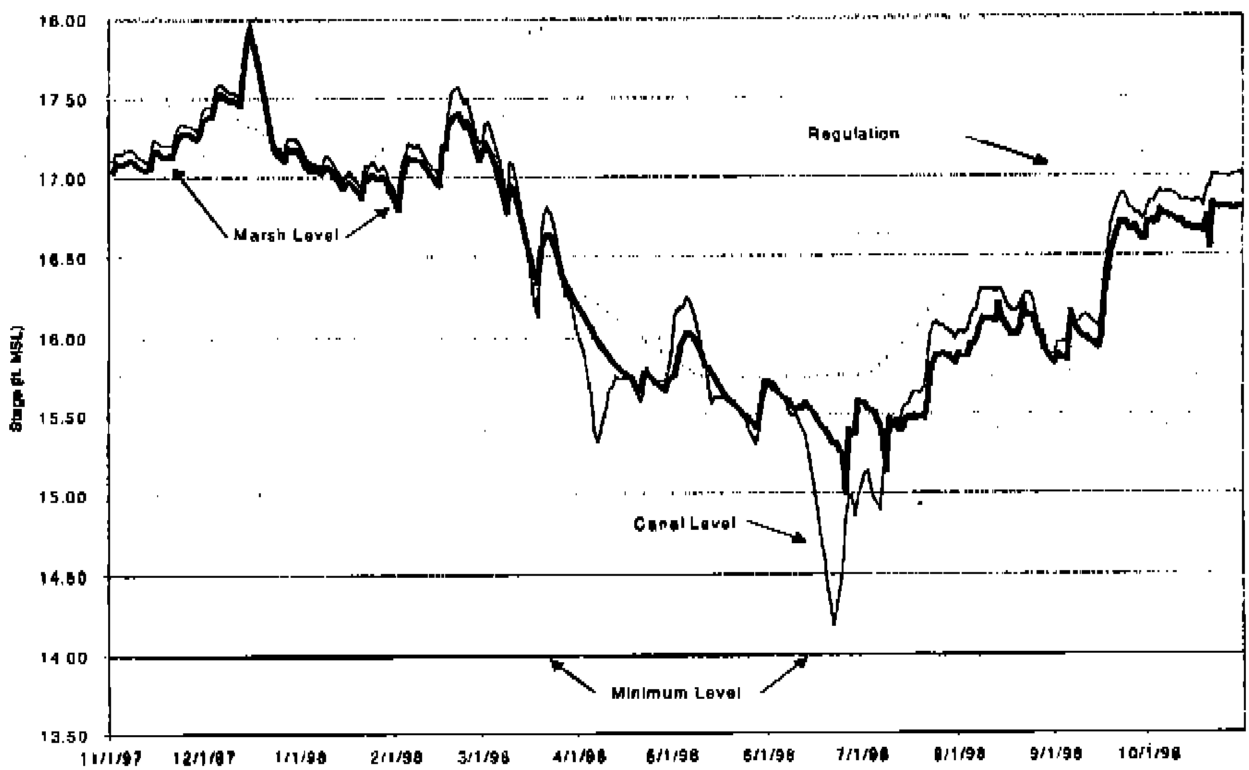

Figure 25. Water Conservation Area 1 Stage - November 1997 through October 1998

Figure 27 also shows historic monthly average stages for WCA 3A for the study period, November 1997 to October 1998. A maximum stage of 10.90 feet NGVD was observed on December 30, 1997. At this time, WCA 3A stored approximately 550,000 (5,352,685 vs. 4,802,684) more acre-feet of water[6] than it would have under historic average conditions during December. On April 1, 1998, the stage in WCA 3A had decreased to 10.75 feet NGVD, but the additional water stored based upon the historic monthly average stage for April had increased to approximately 1,016,465 acre-feet (5,279,024 vs. 4,262,505 acre-feet).

[6] The volumes reported here were computed assuming a constant surface area available for storage of 491,072 acres for WCA 3A.

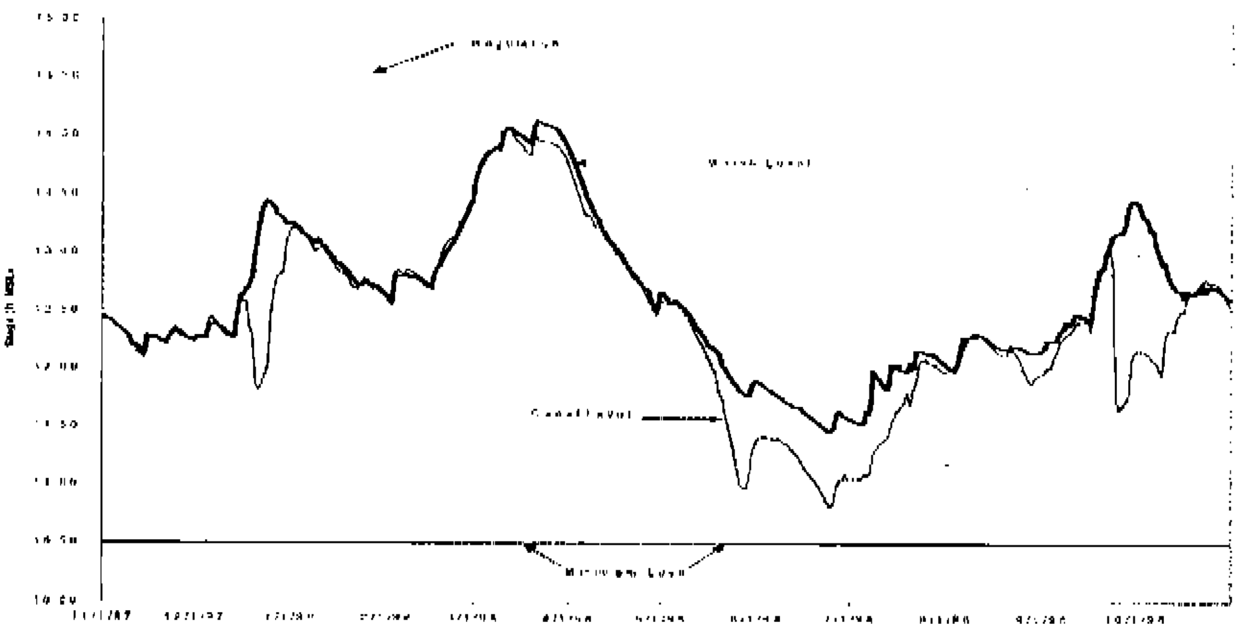

Figure 26. Water Conservation Area 2A Stage - November 1997 through October 1998

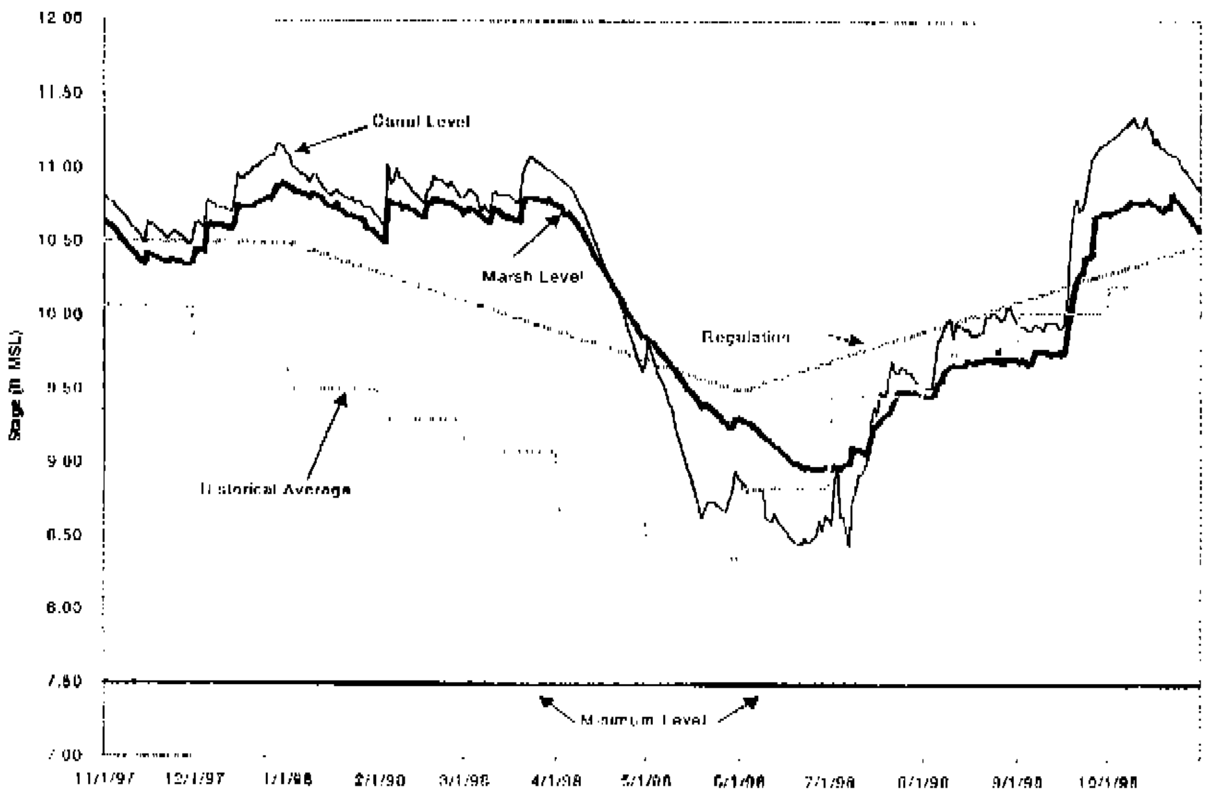

Figure 27. Water Conservation Area 3A Stage November 1997 through October 1998

Groundwater Elevations

Groundwater elevations are routinely monitored to assess changes in this critical resource. Infiltrating water from rainfall raises ground water table levels. During drought periods, the groundwater table falls. The effect of rainfall and infiltration on ground water tends to be less pronounced than that observed for surface water stages and flows. The changes in groundwater table levels are generally less extreme (except in confined aquifers in areas of high usage) and occur more slowly. In addition, the physical system that stores the water cannot be directly observed and is therefore more uncertain and harder to analyze than surface water systems. Rainfall events that have the greatest affect on surface water levels (short-duration, high-intensity) tend to affect groundwater levels less than long-duration, low-intensity events. During short-duration, high-intensity events more water is quickly lost to runoff and has little time to infiltrate to ground water.

Figure 28 depicts a typical East-West cross-section that shows a number of aquifers or groundwater reservoirs. The cross-section changes depending on location and orientation. In addition to showing the spatial relationship among various aquifers, it helps to demonstrate the complexity of the geology that affects groundwater storage and flow. In order to capture this complexity, groundwater table elevations should be reported by aquifer. To simplify the process of reporting trends in groundwater availability, the Hydrogeologic Assessment and Modeling Unit at the South Florida Water Management District uses 13 "key indicator" wells located throughout the District (shown in **Figure 9**) to report trends in groundwater resources especially under drought conditions. The 13 wells are located in four different aquifers. Most of them are in the surficial aquifer. The surficial aquifer lies directly beneath the ground surface and generally is the most responsive to rainwater that has infiltrated the ground's surface and evapotranspiration. It is labeled "Water Table Aquifer" in **Figure 28**. Water levels in deeper, confined aquifers (especially in Southwest Florida) often fluctuate more than levels in the water table aquifer. This is due to lower storativity and the effects of well pumpage rather than the direct affect of rainfall.

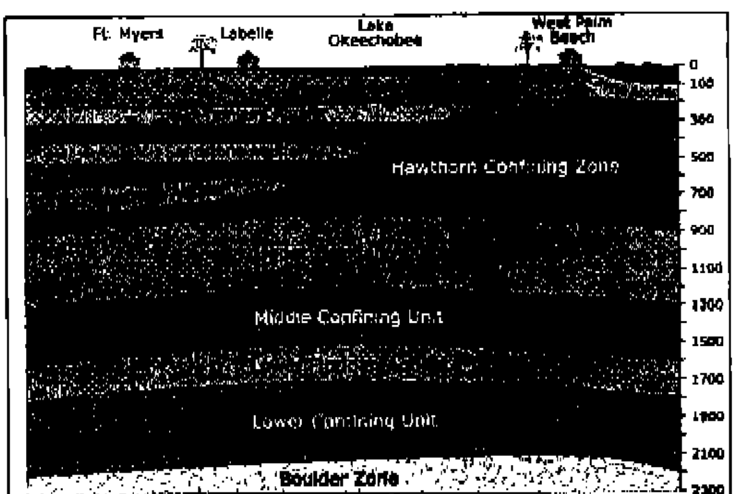

***Figure 28.** Generalized Hydrogeologic Cross-section of South Florida*

The impacts of rising and falling water tables vary. Along the coast, groundwater elevations and duration of time at a given level are the primary factors that control saltwater intrusion. In interior agricultural areas, water table levels affect crop production and the need for pumping and irrigation. Along the West Coast of Florida, groundwater levels are especially sensitive to well pumpage because of the lower productivity and storativity of the West Coast aquifers. Water table levels are the basis for drought watches and warnings. The 1997-98 El Niño and La Niña in Central and South Florida impacted groundwater tables significantly. The pattern shown in **Figure 29** is typical of the fluctuations in water levels recorded at wells throughout the District. The figure depicts the average monthly groundwater level deviation from monthly historic average values at Well PB-565 for November 1997 through October 1998. Well PB 565 is located in Palm Beach County and is used to monitor the surficial aquifer.

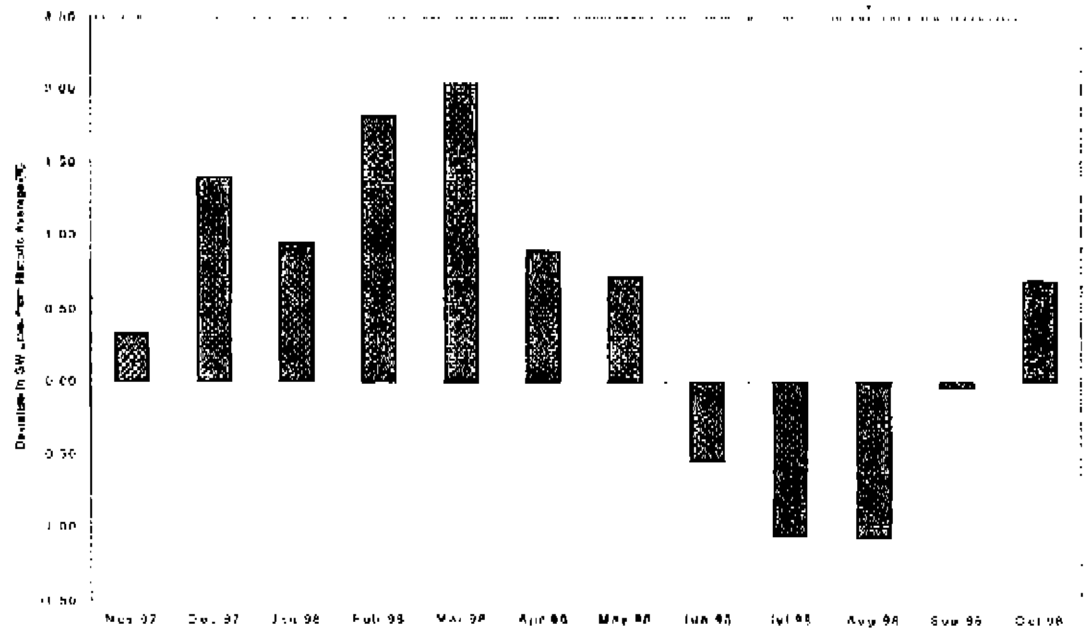

Figure 29. *Average Ground Water Level Deviation from Monthly Historic Average at Well PB-565 November 1997 through October 1998*

Similar figures for the other 12 key indicator wells are presented in **Appendix D.** Groundwater elevations increased above historic average in the first several months of the El Niño/La Niña period starting in November 1997 and fell below average levels in the later part of the period, through October 1998. Due to the variation in topography, the comparison to historic averages at each well is a convenient method of presenting and comparing the impact on groundwater table elevations at locations across the District. Some caution should be exercised in using the deviation from historic average as an indicator of the impact of a short-term event like El Niño. Preliminary investigations by the U.S. Geological Survey have shown long-term trends in some of the wells used in this study (Prinos, 1999). For instance, the water surface elevation in well L-581 in Lee County has been declining at the rate of about 1.0 feet per year for the last fifteen years. However, the relative impact of short term events can be depicted by examining the fluctuations over a shorter period as shown in **Figure 29** (November 1997 to October 1998).

Note that in **Figure 29**, groundwater levels remained above historic averages beyond March 1998. This also occurred at other well locations as shown in **Appendix D**. **Table 2** summarizes the patterns by averaging water table elevation deviations from historic average for the periods from November 1997 through May 1998 and June 1998 through October 1998. **Table 2** also contains columns for the periods used in other parts of this report which have been retained for consistency. Since the average deviations for the entire period do not effectively represent the extremes, the maximum monthly deviations for each period are presented in these columns in **Table 2**.

Table 2. Average Ground Water Level Deviation from Historic Average at Thirteen Key Indicator Wells

Well/ Aquifer/ County	11/97-5/98 Average Deviation from Historic (ft)	November 1997 to March 1998 Maximum Monthly Deviation (ft)	6/98-10/98 Average Deviation from Historic (ft)	April 1998 to October 1998 Maximum Monthly Deviation (ft)
G-1183 / Surficial Dade Co.	0.134	0.30	-0.12857	-0.29
G-1251 / Surficial Everglades Area	0.54	0.93	0.27	-0.09
G-853 / Surficial Broward Co.	3.13	4.52	1.12	-1.47
PB-565 / Surficial Palm Beach Co.	1.31	2.04	-0.06	-1.07
M-1090 / Surficial Martin Co.	0.88	1.65	-0.15	-0.90
STL-125 / Surficial St. Lucie Co.	0.90	1.36	0.32	-1.44
L-730 / Surficial Lower West Coast	-0.03	1.27	-0.34	-0.90
C-492 / Lower Tamiami Lower West Coast	0.79	1.50	-0.07	-0.49
L-731 / Sandstone Lower West Coast	5.48	7.98	0.75	-1.05
L-581 / Mid-Hawthorn Lower West Coast	-3.16	1.28	-12.32	-17.22
OK-1 / Floridan Okeechobee Co.	1.39	2.06	-0.58	-2.40
Lake Joel / Floridan Osceola Co.	1.44	2.59	-0.87	-2.93
Lake Oliver / Floridan Orange Co.	1.61	2.24	0.78	0.11

Inflows

Lake Okeechobee Inflows

Table 3 shows the four basins or watersheds that contributed the greatest inflow volumes to Lake Okeechobee in calendar year 1998. They were the Upper and Lower Kissimmee basins, Fisheating Creek, and the basins contributing flow to the S84 and S71 structures. Overall, they contributed 82 percent of the total inflow volume to the Lake that year. Based on a period of record from calendar years 1972 through 1998, the same four basins would have been expected to contribute 71 percent of the inflow volume to the Lake. Combined, the four areas contributed more than twice (2.05) their average flow volume to the Lake in 1998. This statistic demonstrates the dominance of these four basins with respect to their impact on Lake Okeechobee during the 1997 98 El Niño/La Niña.

On April 1, 1998, the stage in Lake Okeechobee was 18.35 feet NGVD after reaching a maximum stage of 18.43 feet NGVD on March 26-28, 1998. On April 1, the volume of water stored in Lake Okeechobee was 5,355,380 acre-feet, 49.0 percent more than the average volume traditionally stored during April of 3,592,355 acre-feet. This maximum difference in volume of water stored in April 1998 can be directly attributed to the significantly higher inflows to the Lake especially from the Upper and Lower Kissimmee watersheds during the El Niño period, November through March.

Table 3. Basins or Watersheds Contributing the Highest Percentage of Flow Volume to Lake Okeechobee 1997 98

AREA	Historic Annual Average Flow (cfs)	1997-98 Annual Average Flow (cfs)	% of Total Inflow 1997-98	% of Total Inflow Historic Average	1997-98 Inflow/ Average Inflow
Kissimmee Basins (upper and lower)	1,348	3,306	58.2	56.3	2.45
Basins tributary to S84	189	678	11.5	9.9	3.57
Fisheating Creek	236	652	11.9	7.9	2.76
Basins tributary to S71	205	400	7.1	8.6	1.95
Total (four areas)	**1,978**	**5,036**	**88.7**	**82.7**	**2.54**

Figure 30 shows the percentage increase or decrease in inflow to Lake Okeechobee by flow gaging station during 1998. Note that there was a decrease in inflow at several stations. These stations are also outflow stations or locations where flow can either enter or leave the Lake. The percentage increase/decrease during 1998 versus historic averages can be misleading in a practical sense, because the stations experiencing the greatest percentage increase or decrease may represent locations that contribute relatively small quantities of flow and thus may not warrant additional investigation. Thus, **Table 3** above and **Table 4** in the following section were provided to indicate the locations with the greatest inflows and

outflows. Nevertheless, **Figure 30** indicates the extremes that inflow locations around Lake Okeechobee experienced as the result of El Niño and La Niña weather patterns.

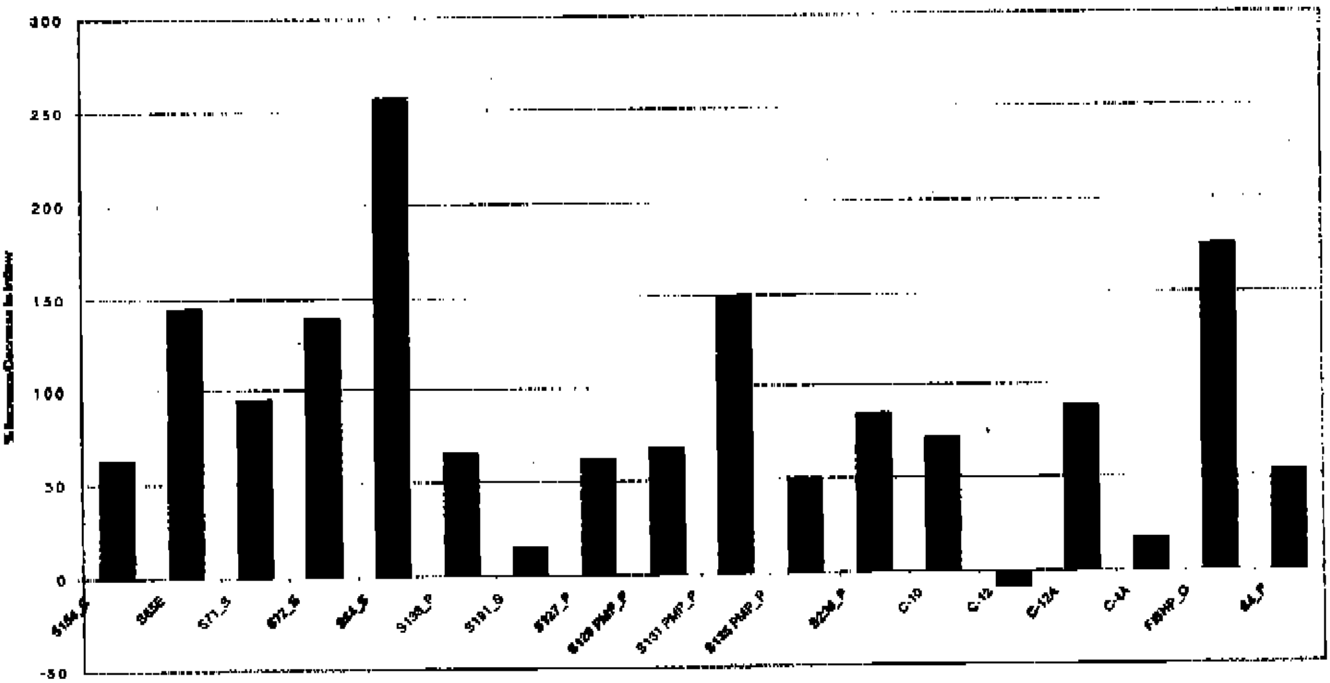

Figure 30. Percent Increase/Decrease in Inflows to Lake Okeechobee – 1997-98 vs. Historic Average

The consequence of increased flows to Lake Okeechobee and the Caloosahatchee and St. Lucie estuaries (discussed below) on water quality should be noted here. Water quality is reported using a number of measures. One is concentration usually measured in milligrams per liter (mg/l) or parts per million (ppm). These two units are equivalent at low concentrations in water. At very low concentrations, units of micrograms per liter (µg/l) and parts per billion (ppb) are used. Another measure used to monitor and report water quality is load or mass loading rate using units of pounds per day (lb/d) or tons per year (ton/yr). In the International System (SI), these units are kilograms per day (kg/d) or metric tons per year (tonne/yr). The mass loading rate is computed by multiplying the average concentration times the flow rate as shown in equation 3.

$$\mathbf{W = K\,Q\ c} \qquad \text{... Equation (3)}$$

where **W** = mass loading rate (kg/d, lb/d)
Q = flow rate (cms, cfs)
c = average concentration (mg/l)
and **K** = unit conversion factor

Water quality in lakes and estuaries are affected in two ways from greater rainfall. First, greater rainfall tends to increase the amount of sediment available to be transported by the conveyance system. Often water contaminants, like the nutrients phosphorous and nitrogen, are bound with the sediment. Second, higher flows are capable of carrying more sediment to receiving water bodies. These two processes generally result in greater loads of contaminants (W in Equation 3) being received by surface impoundments. During the El Niño in 1997-98, monthly loading of total phosphorus to Lake Okeechobee ranged from approximately 118 metric tons per month in December to 160 metric tons per month in January. Total phosphorous loadings for the same months in the following year were less than 10 metric tons per month (SFWMD, July 1999). Although a detailed discussion of water quality impacts on District lakes and impoundments is beyond the scope of this report, the impact of the El Niño and La Niña weather patterns on water quality can be significant.

Figure 31 shows average monthly inflows in cfs to Lake Okeechobee from November 1997 through October 1998 and compares these inflows to historic monthly averages. Note the significant increases in inflow to the Lake during the months of December 1997 through April 1998. Also note the inflow deficits during the months of June through October. These inflow patterns coincide with the weather patterns associated with El Niño and La Niña during 1997-98 and are an example of the impact of these phenomena on hydrologic systems in Central and South Florida.

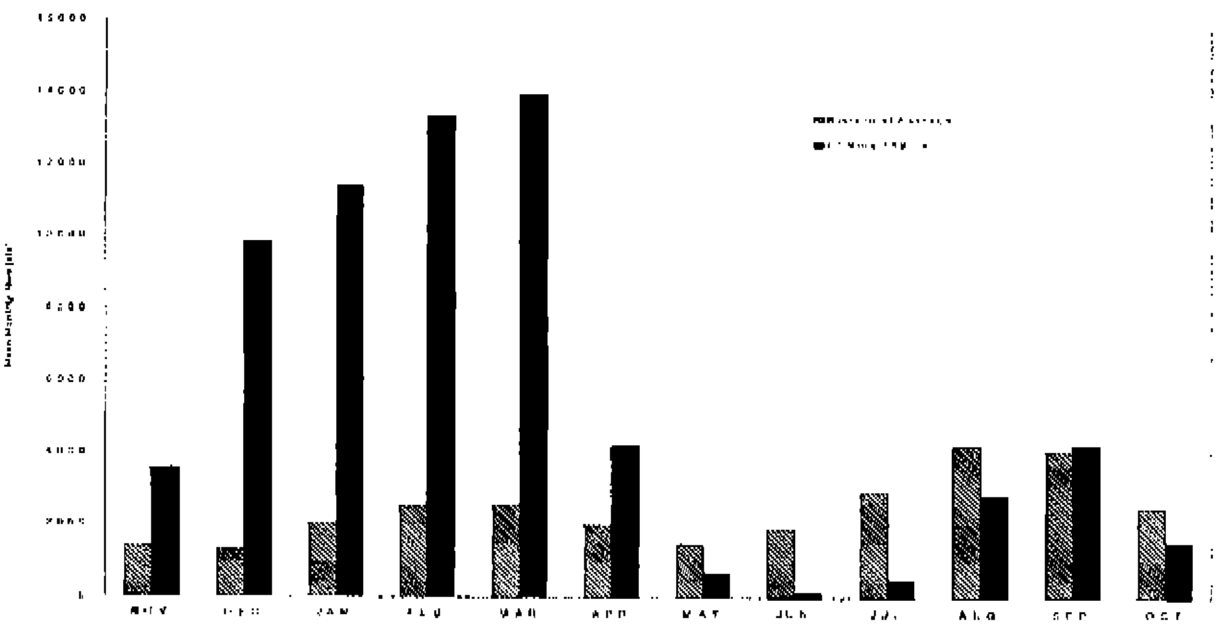

Figure 31. Average Monthly Inflow to Lake Okeechobee vs. Historic Average Monthly Inflow November 1997 through October 1998

Figures 32 through **35** show the El Niño/La Niña inflows to Lake Okeechobee by station for the period November 1997 - March 1998. The graphs have been ordered to show the stations that contribute the greatest inflows to the Lake first (**Figure 32**) to those that contribute the least (**Figure 35**). The historic average inflows are also shown in these figures. S65E is the station where flows from the Upper and Lower Kissimmee watersheds are measured before entering the Lake. The location of S65E was shown in **Figure 10**.

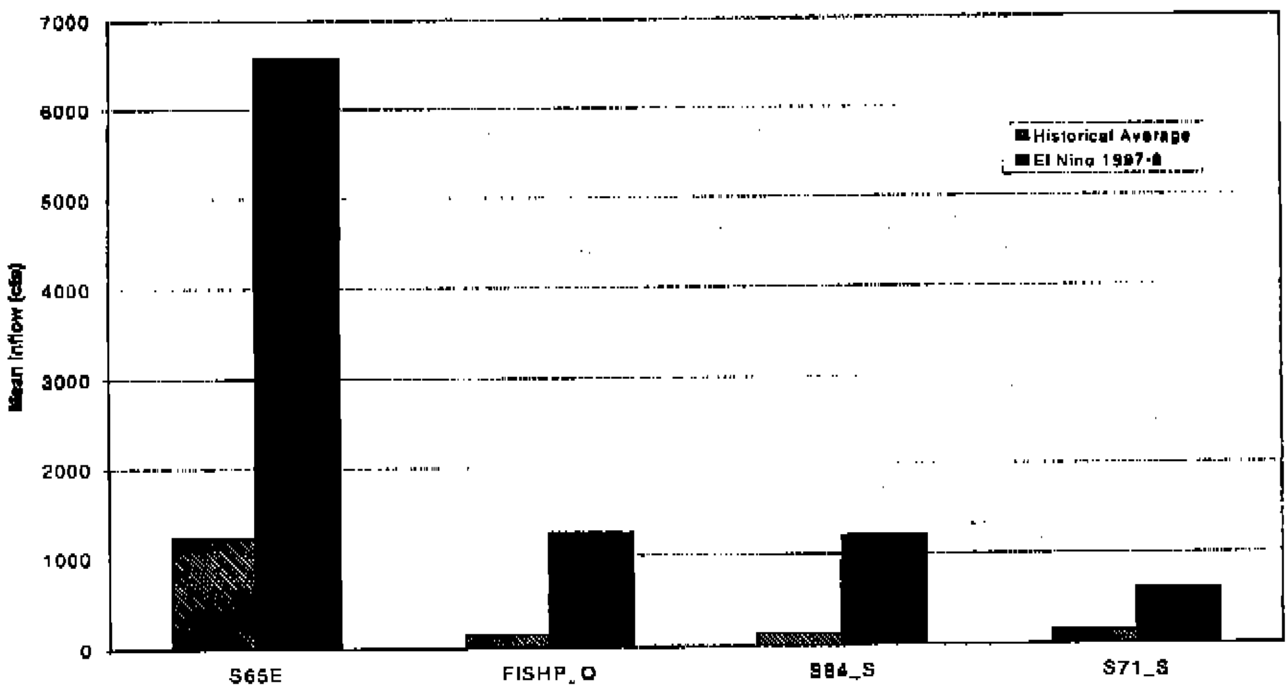

***Figure 32.** Inflow by Station vs. Historic Average Inflow November 1997 through March 1998*

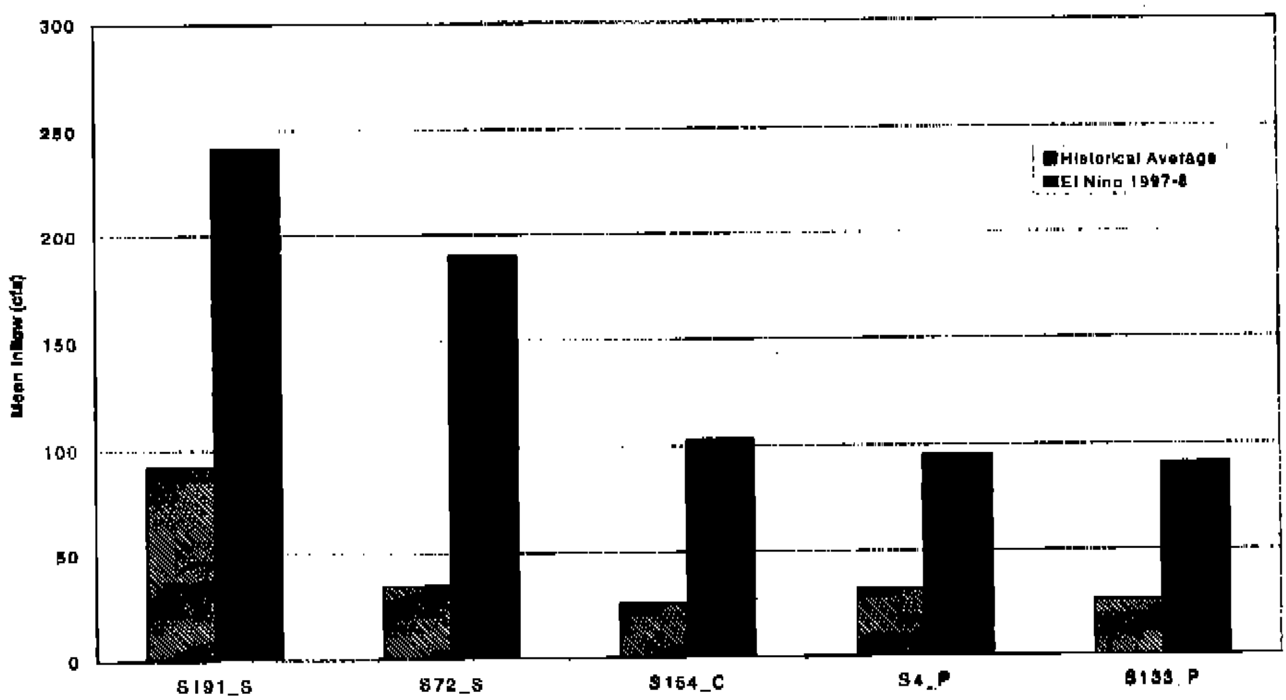

***Figure 33.** Inflow by Station vs. Historic Average Inflow November 1997 through March 1998*

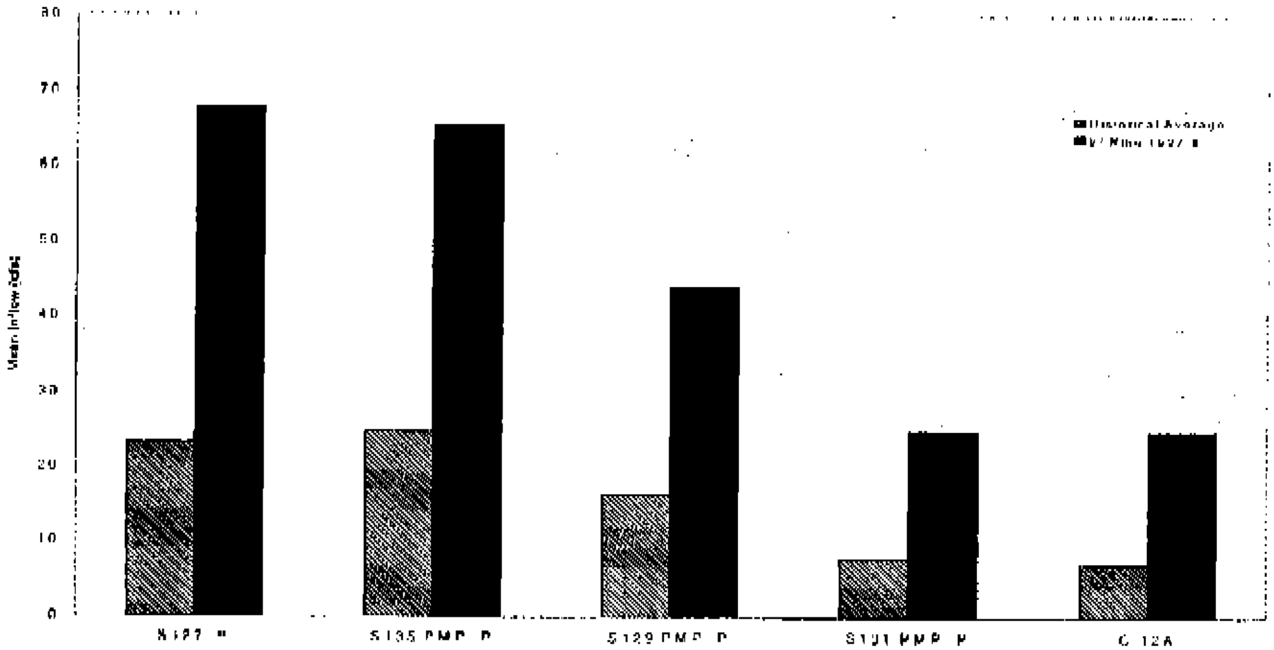

Figure 34. Inflow by Station vs. Historic Average Inflow November 1997 through March 1998

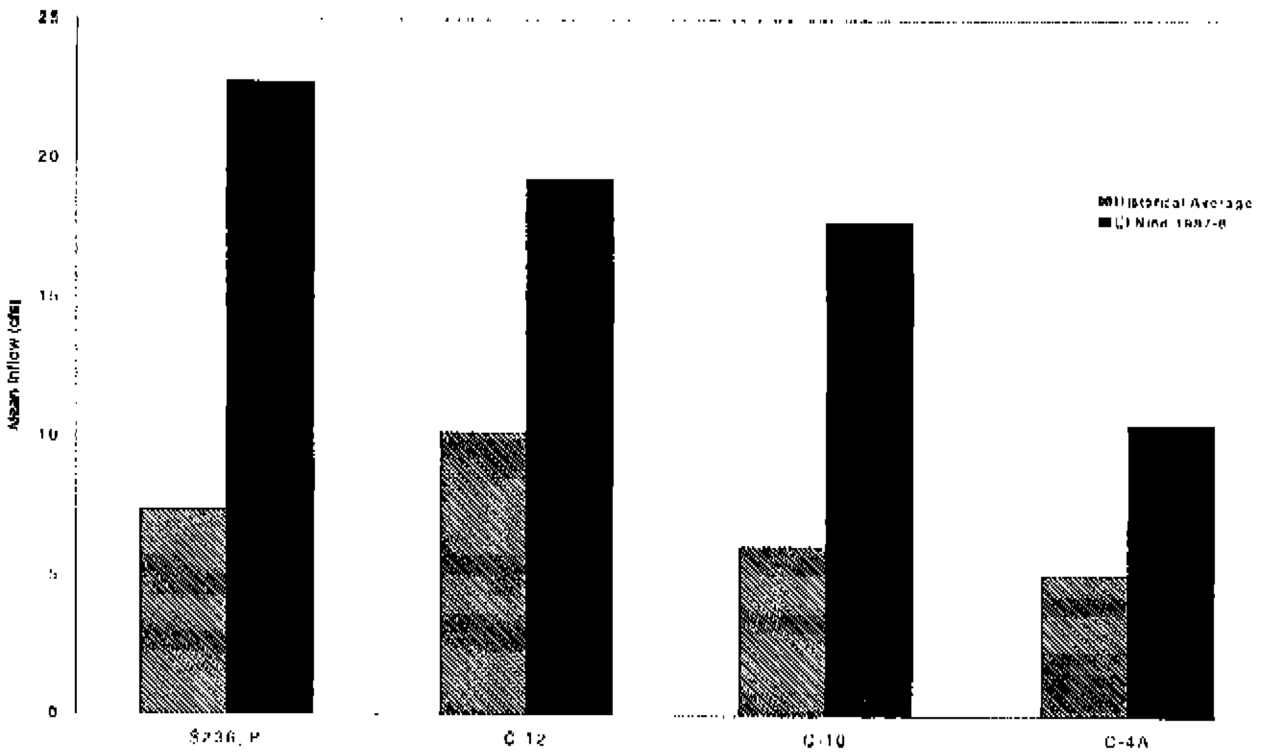

Figure 35. Inflow by Station vs. Historic Average Inflow November 1997 through March 1998

Figures 36 through 39 show the El Niño/La Niña inflows to Lake Okeechobee by station for the period April 1998 through October 1998. The graphs have been ordered to show the stations that contribute the greatest inflows during this period to the Lake first (Figure 36) to those that contribute the least (Figure 39). The historic average inflows are also shown in these figures.

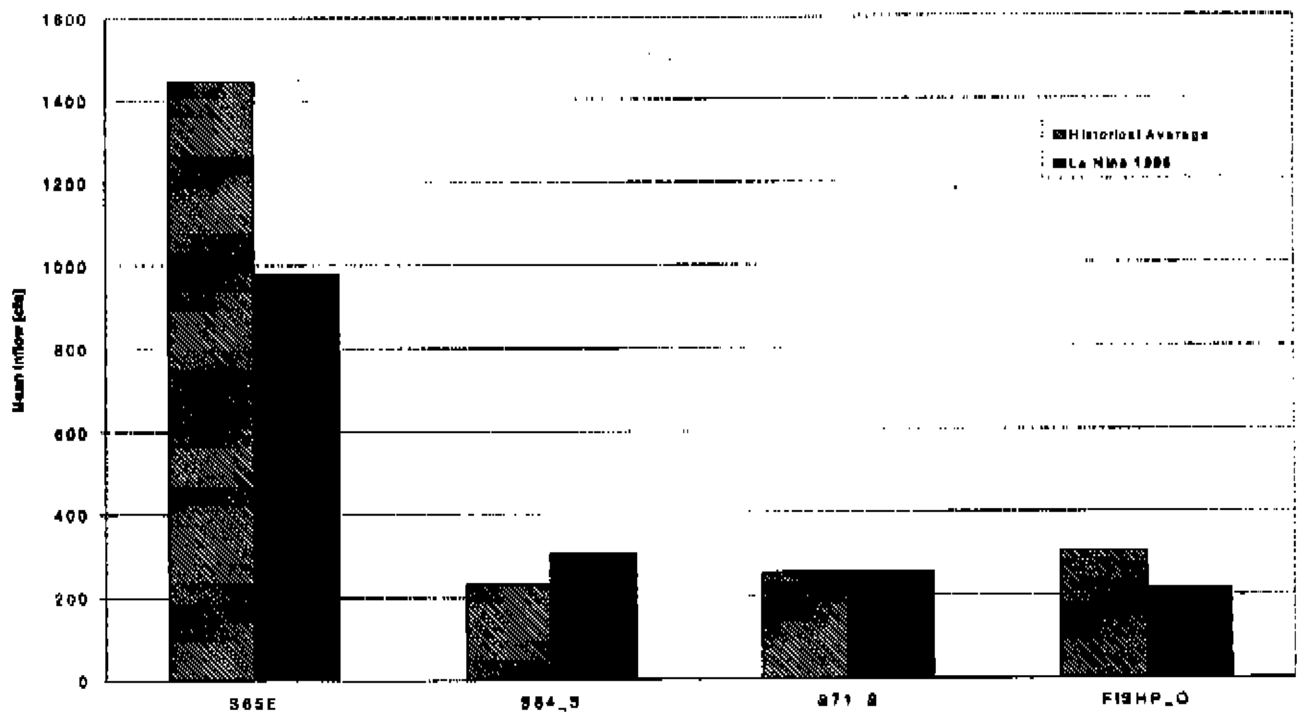

Figure 36. Inflow by Station vs. Historic Average Inflow April 1998 through October 1998

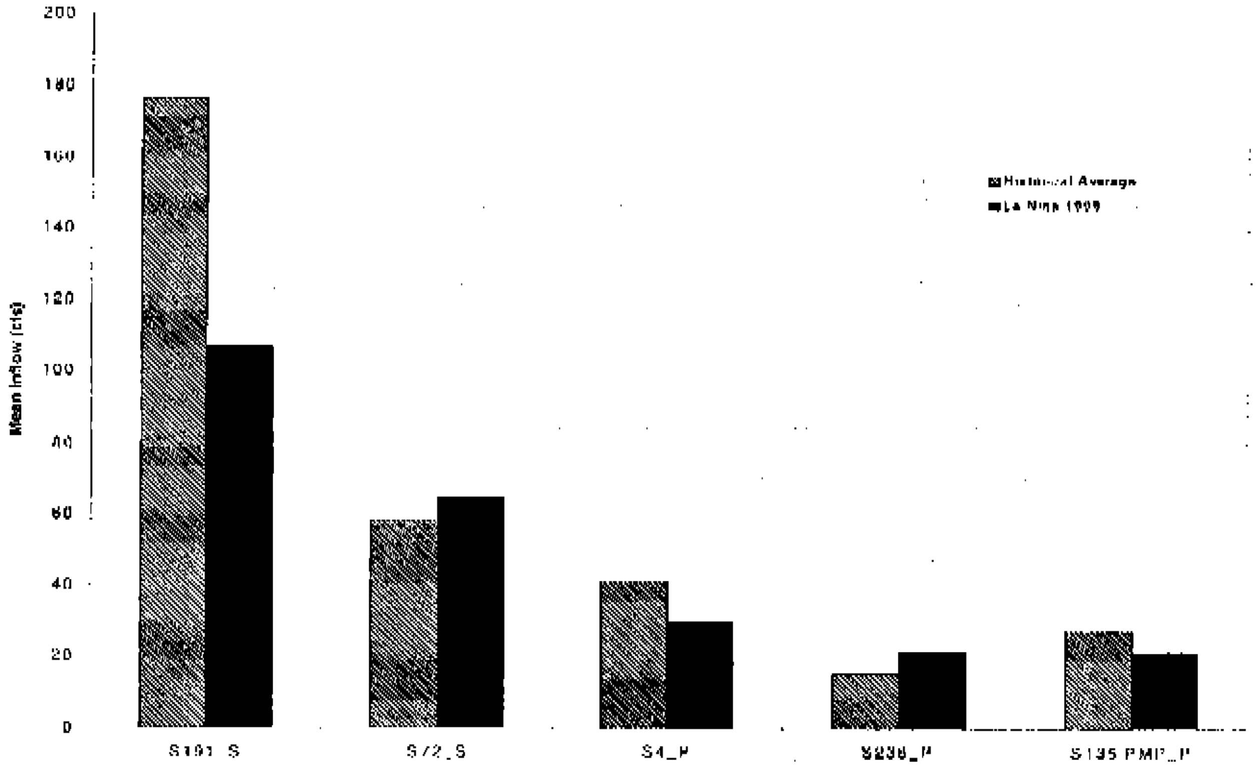

***Figure** 37. Inflow by Station vs. Historic Average Inflow April 1998 through October 1998*

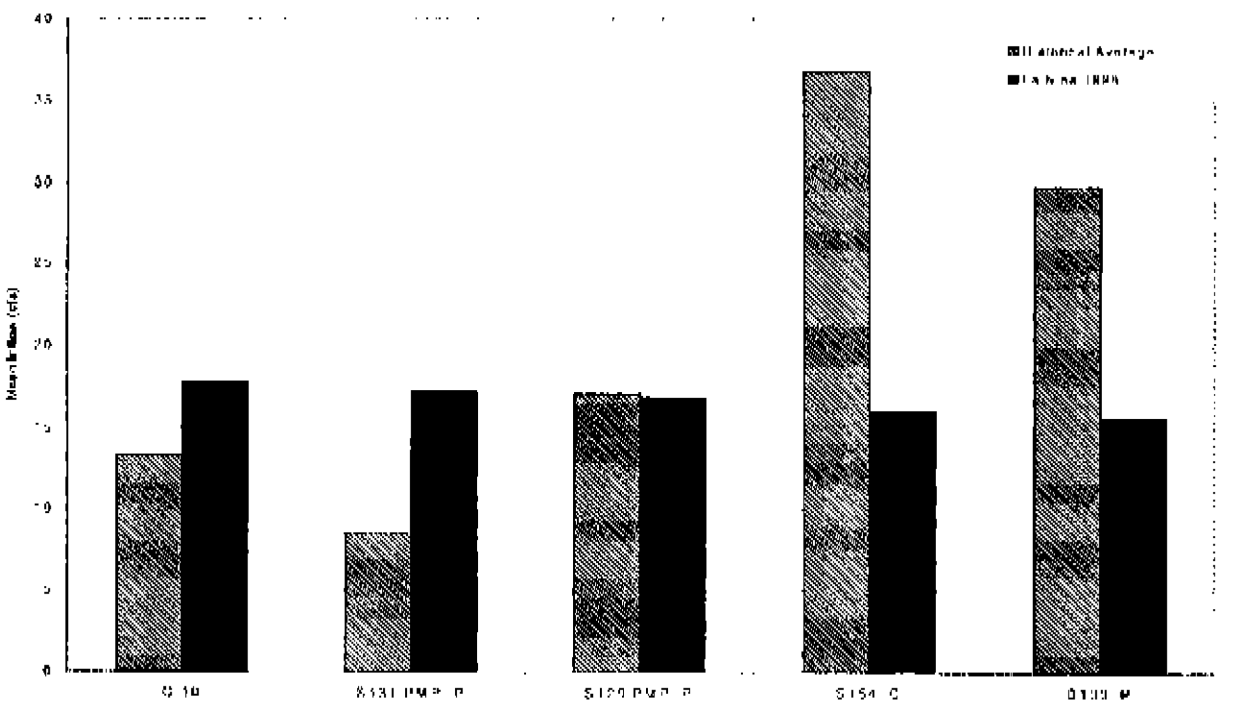

***Figure 38**. Inflow by Station vs. Historic Average Inflow April 1998 through October 1998*

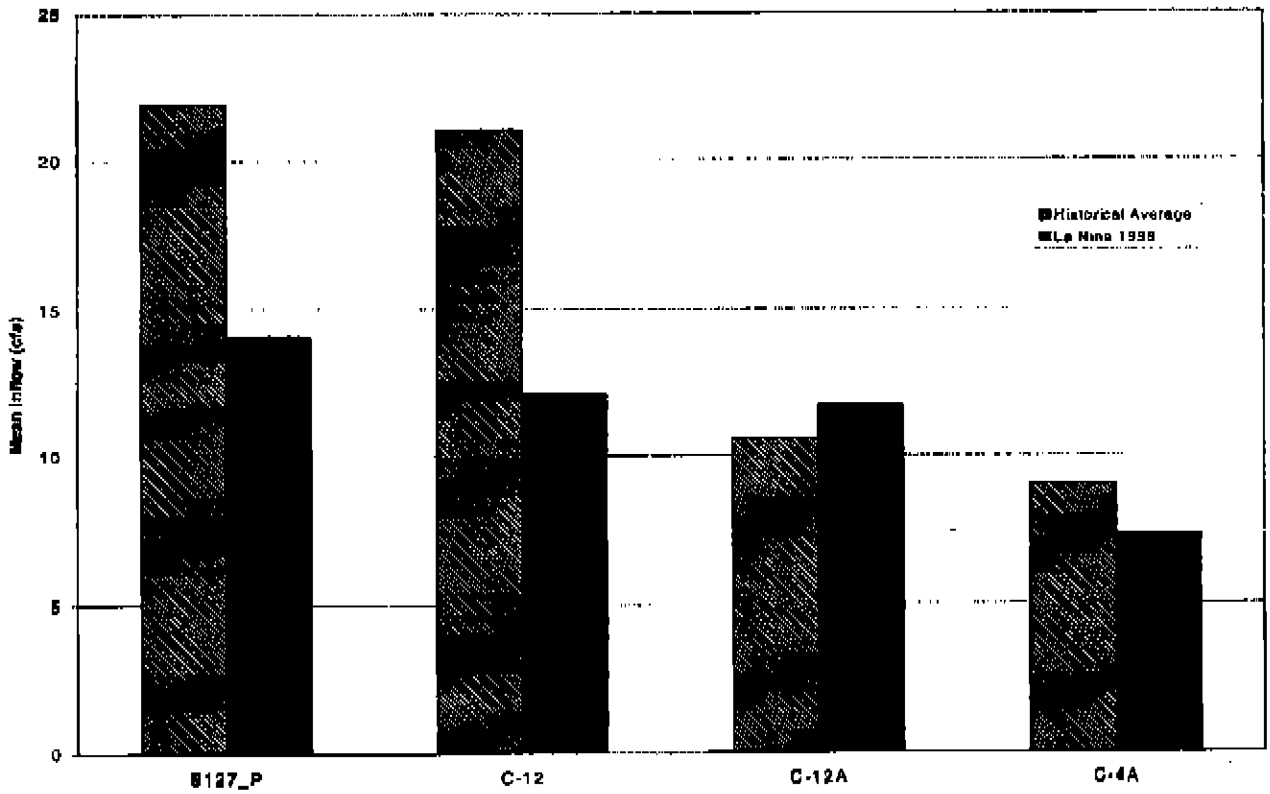

Figure 39. Inflow by Station vs. Historic Average Inflow April 1998 through October 1998

Caloosahatchee Estuary Inflows

Inflows to the Caloosahatchee Estuary downstream of the S79 spillway and lock for the El Niño and La Niña period in comparison to historic average inflows are shown in **Figure 40**. The S79 structure is located on the Caloosahatchee River approximately 6.5 miles east of the Interstate 75 bridge. Flows depicted in **Figure 40** are based upon mean monthly flows. The historic average was based on a period of record from May 1966 through August 1998 (DB Key 00865). Approximately 1.6 million acre-feet of water beyond what would have been expected based upon historic monthly average flows (2,064,674 vs. 422,253 acre-feet) entered the Caloosahatchee Estuary from Lake Okeechobee and tributary watersheds upstream of S79 from November 1997 through May 1998. This was 389 percent more water than would have been introduced to the Estuary had historic average flows occurred during this period. **Table E-1** in **Appendix E** contains the monthly average flows from November 1997 through October 1998 and the historic average monthly flows for the Caloosahatchee River at S79.

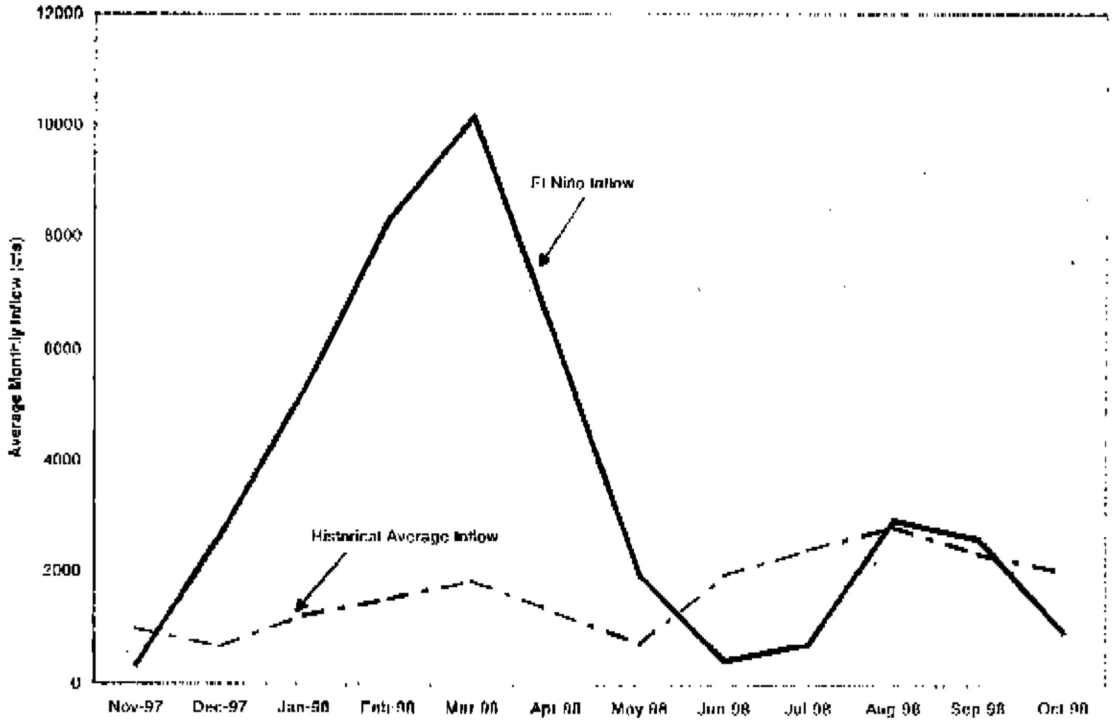

Figure 40. *Caloosahatchee Estuary Monthly Inflows November 1997 through October 1998 vs. Historic Monthly Average Flows at S79*

St. Lucie Estuary Inflows

Figures 41 through **43** show the inflows to the St Lucie Estuary downstream of the S49, S80 and S97 structures for the El Niño/La Niña period in comparison to historic average inflows. S49 is located on Canal 24, 2,400 feet west of the Sunshine State Parkway. The S80 structure is located on the St. Lucie Canal about 8 miles southwest of Stuart. Together with S-308 (on Lake Okeechobee), S80 controls the easterly discharge of Lake Okeechobee to the Estuary. The S97 structure is on Canal 23, 3,300 feet west of the Sunshine State Parkway.

Flows depicted in these figures are based upon mean monthly flows that are presented in **Appendix E, Tables E2-E4**. The historic averages for each of the stations were based upon varying periods of record (DB Keys 15777 (S49), DJ238 (S80) and 15780 (S97)). During the period November 1997 through June 1998, the St. Lucie Estuary received 912,149 acre-feet of water beyond expected flow volumes based upon historic average monthly flow (1,356,534 acre-feet versus 444,385 acre-feet) from Lake Okeechobee and local drainage upstream of these three flow-recording sites. The volume difference was somewhat reduced by lower than average inflows from S49 and S97 for several of the months during the El Niño event as depicted in **Figures 30a** and **30c**. The majority of the inflow to St. Lucie Estuary comes through S80 from Lake Okeechobee. The 912,149 acre-feet was 205 percent more water than would have been introduced to the estuary had historic average flows occurred during this period.

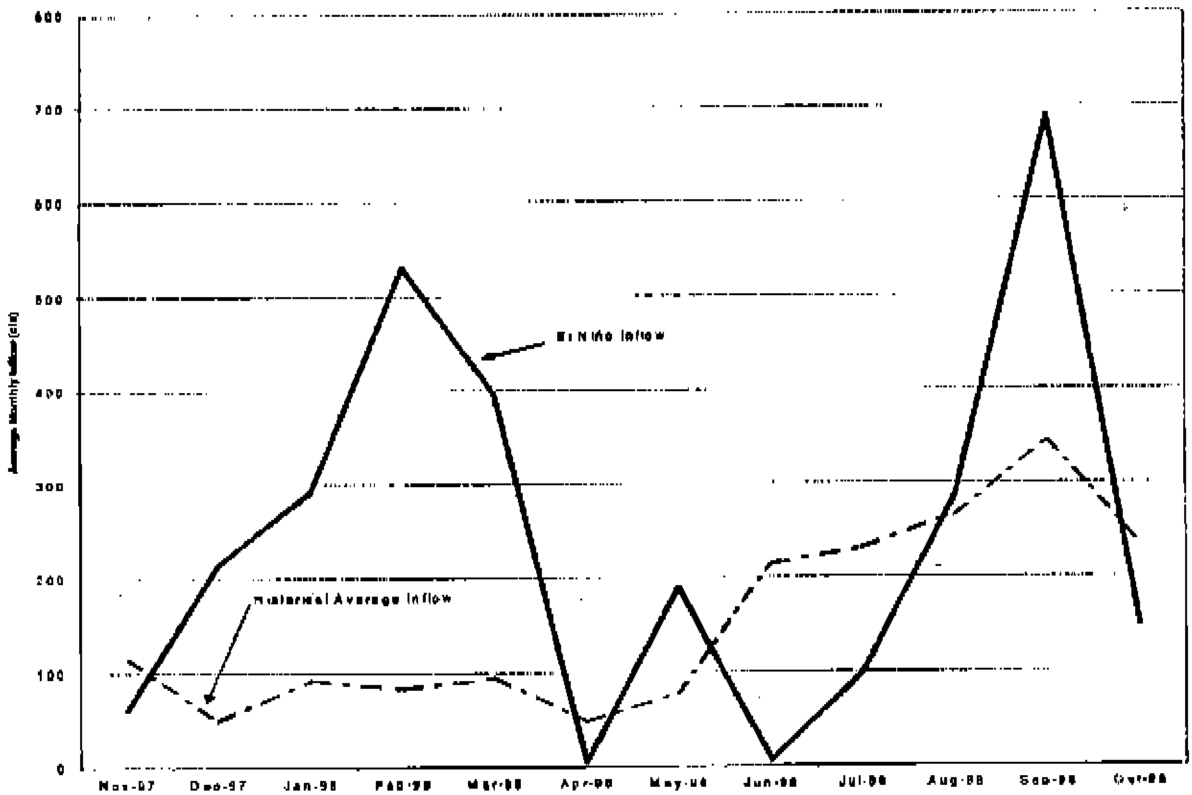

***Figure 41**. St. Lucie Estuary Monthly Inflows November 1997 through October 1998 vs. Average Monthly Flows at S49*

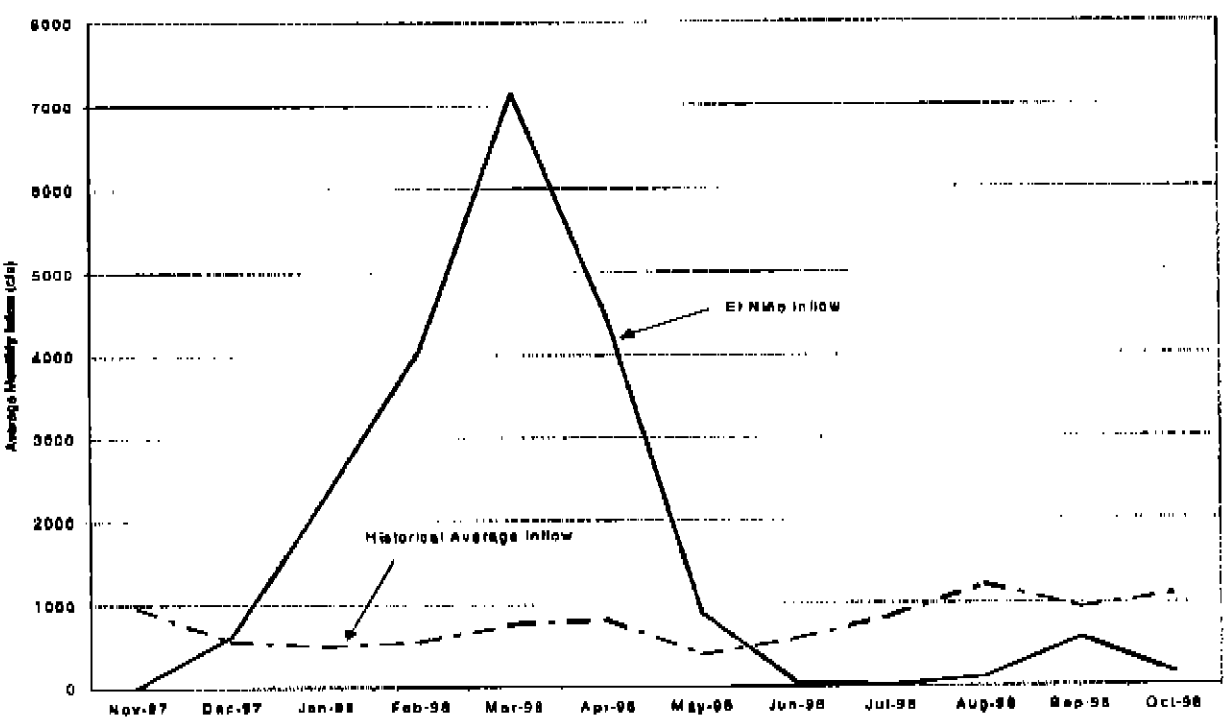

***Figure 42**. St. Lucie Estuary Monthly Inflows November 1997 through October 1998 vs. Average Monthly Flows at S80*

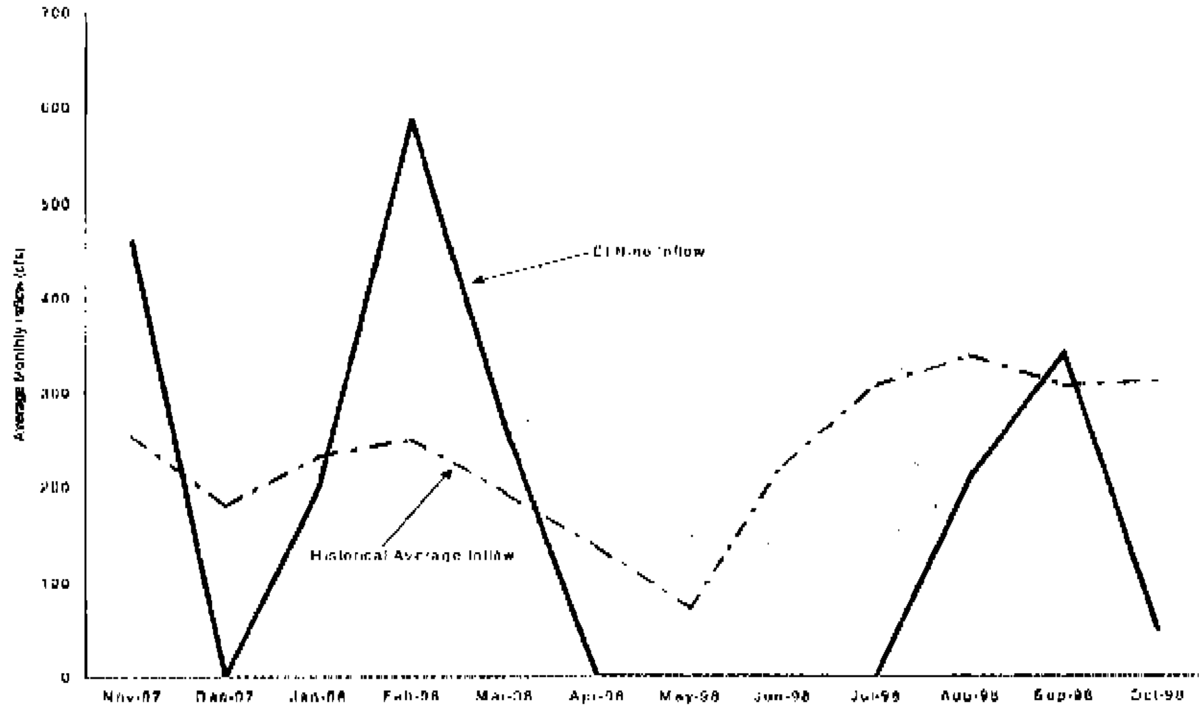

***Figure 43.** St. Lucie Estuary Monthly Inflows November 1997 through October 1998 vs. Average Monthly Flows at S97*

Outflows

Lake Kissimmee

Lake Kissimmee is the last of the Upper Kissimmee Chain of Lakes. Releases from Lake Kissimmee enter the C-38 Canal constructed in the 1960s to improve the conveyance and navigability of the Kissimmee River. The C-38 Canal is the major feeder to Lake Okeechobee and enters the Lake at the S65E. **Figure 44** shows the monthly average outflow from Lake Kissimmee during the 1997-98 El Niño/La Niña and compares it to historic monthly average outflow. As seen in the figure, outflow for December 1997 through April 1998 was significantly higher than the outflow based upon historic record. The effect on Lake Okeechobee stages was discussed above.

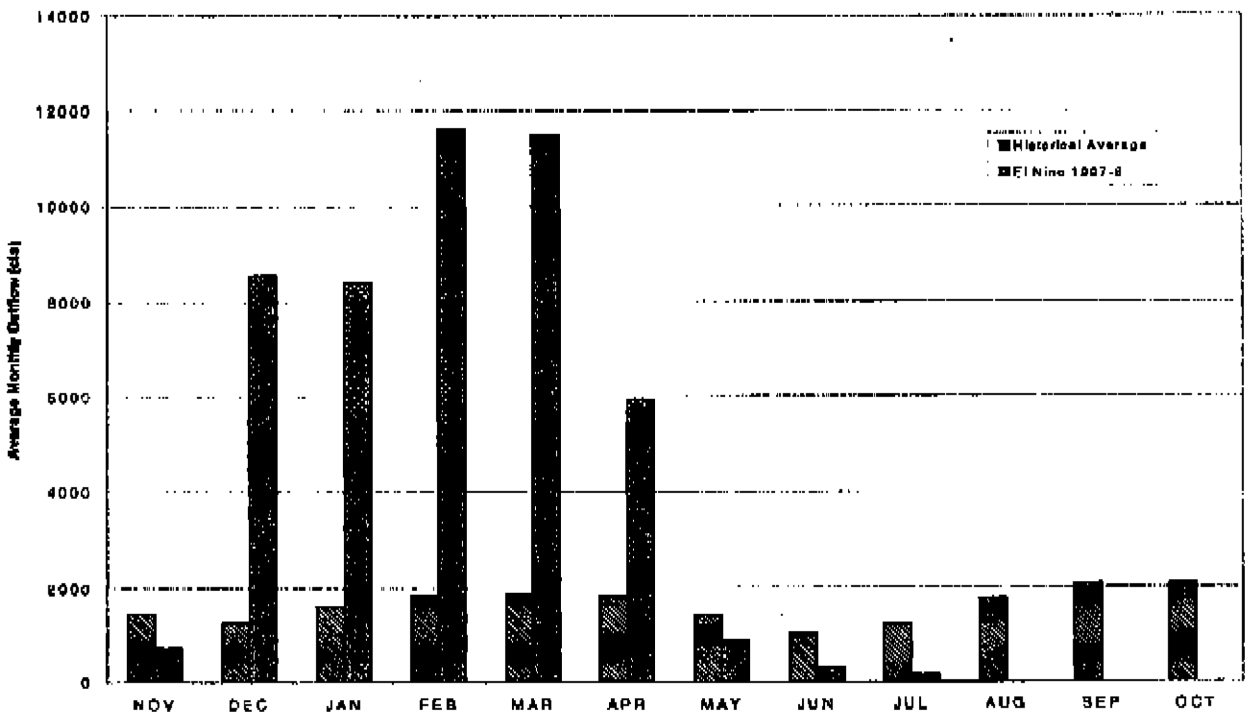

Figure 44. Lake Kissimmee Monthly Outflow November 1997 through October 1998 vs. Average Monthly Outflow at S65

Lake Istokpoga

The pattern of outflow from Lake Istokpoga, shown in **Figure 45**, is similar to that for Lake Kissimmee above with the exception that there were observable average monthly outflows from Lake Istokpoga during the months of August, September and October 1998.

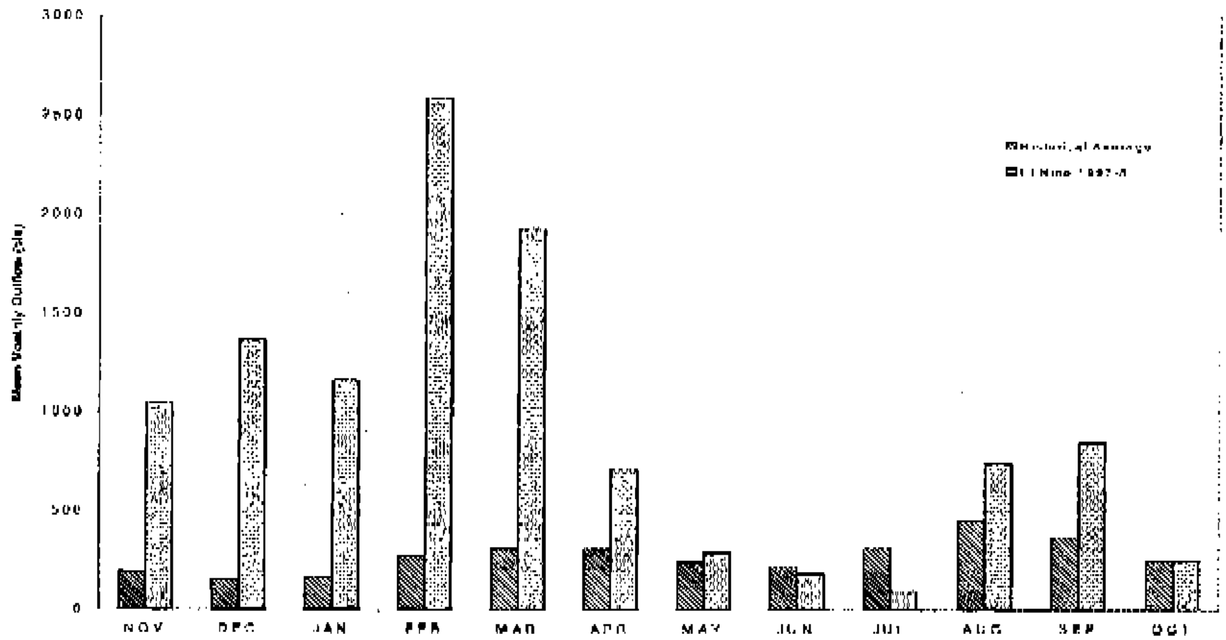

***Figure 45.** Lake Istokpoga Monthly Outflow November 1997 through October 1998 vs. Average Monthly Outflow at S68*

Lake Okeechobee

Table 4 shows the two basins that received the greatest flow volumes from Lake Okeechobee in calendar year 1998. Overall, the Caloosahatchee River and the St. Lucie Canal received 80.2 percent of the total outflow volume from the Lake that year. Based on a period of record from calendar year 1972 through calendar year 1998, the basins would have been expected to receive 53.8 percent of the total outflow volume from the Lake. The St. Lucie Canal and Estuary received 4.34 times the flow that it would have normally received from Lake Okeechobee. The Caloosahatchee River and Estuary received nearly three-and-a-half times the expected flow volume from Lake Okeechobee during 1998. The 1998 outflows from Lake Okeechobee at Stations S308_L and S77_T represented 68.9 percent and 64.3 percent of the total flow volumes entering the St. Lucie and Caloosahatchee Estuaries, respectively. The S308_L structure releases water to the St. Lucie Canal that eventually enters the St. Lucie Estuary at the S80 structure discussed above. Water from S77_T enters the Caloosahatchee River flowing into the Caloosahatchee Estuary at station S79 downstream.

Table 4. Basins or Watersheds Receiving the Highest Percentage of Flows from Lake Okeechobee – 1997-98

AREA (Station)	Historic Annual Average Flow (cfs)	1997-98 Annual Average Flow (cfs)	% of Total Outflow 1998	% of Total Outflow Average	1998 Outflow/ Average Outflow
St. Lucie Canal (S308_L)	266	1523	32.7	18.8	5.72
Caloosahatchee River (S77_T)	628	2336	50.1	44.3	3.72
Total (two areas)	894	3859	82.8	63.1	4.32

The percent increase or decrease in outflow from Lake Okeechobee in comparison to historic average values for the seven flow-recording stations at which outflow from the Lake occurs is shown in **Figure 46**. The largest differences are outflows at S308_L and S77_T. The largest percent decrease in outflow was at station L8.441. This structure governs flow to the L8 Canal that feeds the West Palm Beach Canal and Water Conservation Area 1 (WCA 1). The inability of the WCAs to accept additional water was discussed above.

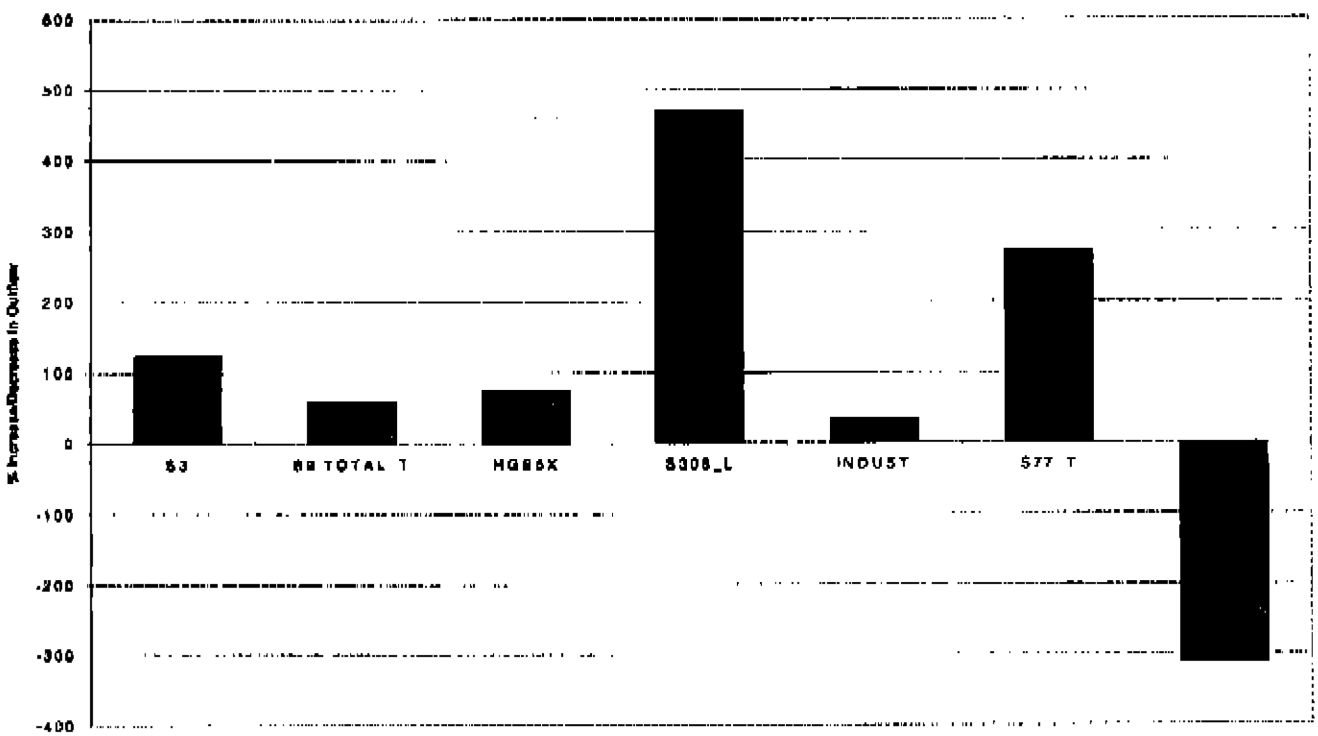

***Figure 46**. Percent Increase/Decrease in Outflows from Lake Okeechobee – 1997-98 vs. Historic Average*

Figure 47 shows the outflow from Lake Okeechobee by month and compares those values to historic monthly averages. Again, the difference between El Niño outflow and historic average is evident during January through June 1998. Also note, there is net inflow to the Lake during August and September 1998, a consequence of La Niña induced weather patterns.

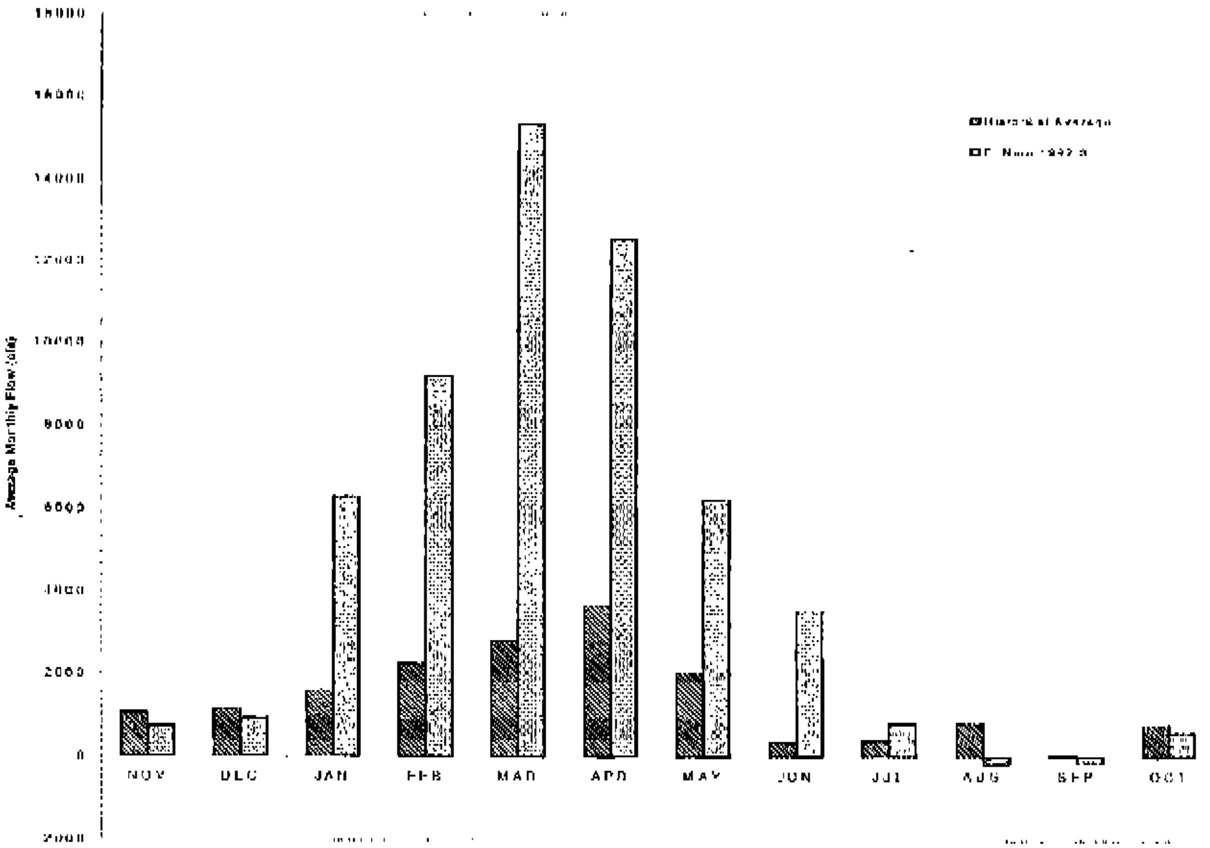

Figure 47. Average Monthly Outflow from Lake Okeechobee vs. Historic Average Monthly Outflow November 1997 through October 1998

Figures 48 and **49** are similar to **Figures 32** through **39** above, except they present data on outflow as opposed to inflow for each of the outflow recording stations on Lake Okeechobee. Note, in **Figure 48**, the greatest outflows during the El Niño period are at stations S308_L and S77_T, controlling flow to the St. Lucie Canal and Caloosahatchee River, respectively. During the La Niña months (April through October 1998), flows to the Caloosahatchee and St. Lucie continued to dominate outflows by significantly exceeding historic average outflow at S308_L and S77_T as shown in **Figure 49**.

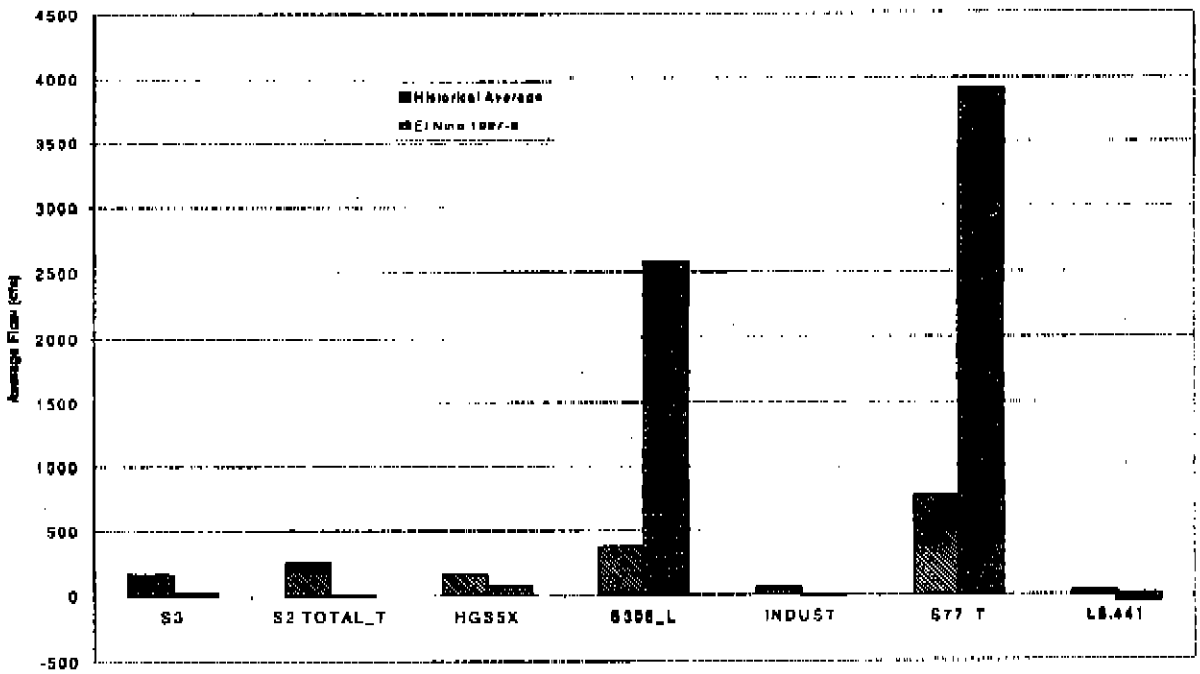

Figure 48. Outflow vs. Historic Average Annual Outflow by Station November 1997 through March 1998

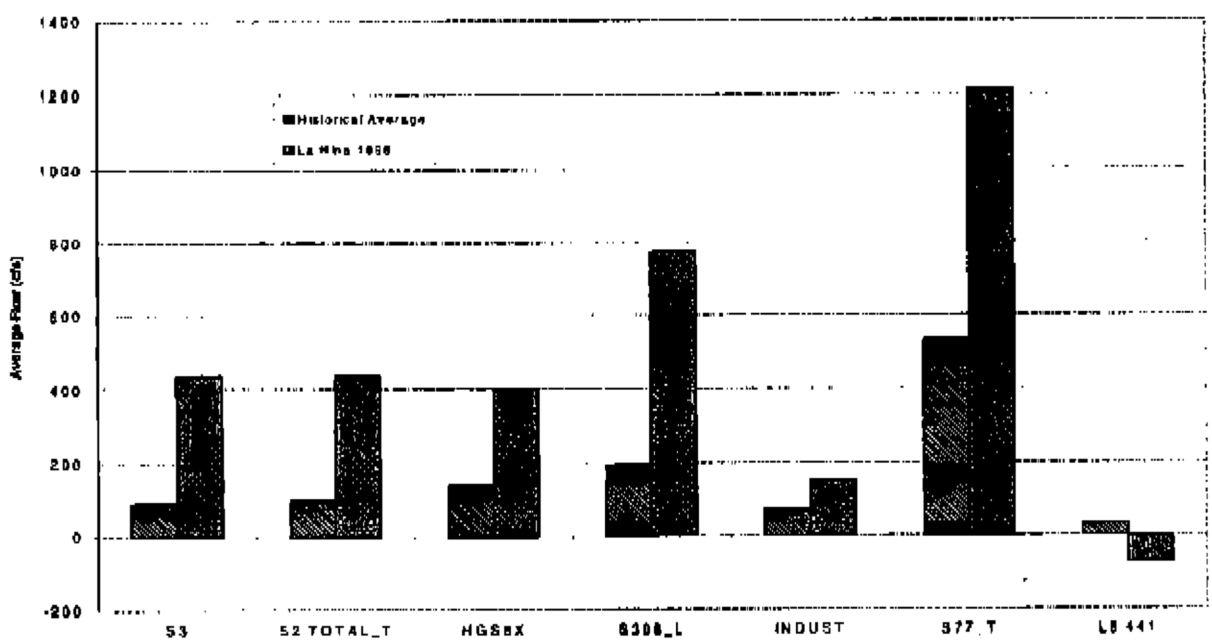

Figure 49. Average Outflow vs. Average Annual Outflow by Station April 1998 through October 1998

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

This report examined rainfall, evapotranspiration, lake and impoundment stages, groundwater table elevations and flows into and out of major lakes and impoundments from November 1997 through October 1998 in the region covered by the South Florida Water Management District. It assessed the hydrologic impacts of two important, repeating weather patterns on Central and South Florida water resources, El Niño and La Niña. In some instances, two periods were used, one from November 1997 through March 1998 and the other from April 1998 through October 1998. The first period captures the onset of an El Niño weather pattern; the second period, the effects of La Niña induced weather.

From November 1997 through March 1998, a total of 23.91 inches of rain fell throughout the District. This exceeded historic average rainfall for this period by 13.05 inches. The greatest deviation from historic average rainfall amounts was observed in the Upper and Lower Kissimmee rain areas. They received 16.53 and 21.38 inches of rain above average, respectively, during this period.

From April 1998 through October 1998, the District received an average of 30.98 inches of rain, 10.88 inches less than expected based on the historic record. The Dade rain area (Eastern Miami-Dade County) received 19.71 inches less than usual and the Palm Beach rain area (most of Palm Beach County), 18.85 inches less. For the entire year, from November 1997 through October 1998, the Upper Kissimmee area experienced the greatest net increase in rainfall, 20.91 inches above the historic average. The West Ag rain area and the Dade rain area experienced lower than average rainfall for the year starting November 1997, -9.90 and –9.16 inches, respectively.

During the period November 1997 through March 1998, estimated potential evapotranspiration rates were generally lower than historic average values. The greatest deviations in evapotranspiration occurred at one station in Lake Okeechobee, 2.84 inches below average.

In March 1998, the stage in Lake Okeechobee reached 18.43 feet NGVD, the third highest water surface elevation recorded since 1931. This record stage was due to excessive rainfall in the areas contributing flow to the Lake, principally the Upper and Lower Kissimmee rain areas. From mid November 1997 through October 1998, water levels were consistently above historic monthly average values.

The El Niño- and La Niña-influenced weather patterns also affected groundwater table elevations in all of the key-indicator wells monitored by the District. These wells monitor groundwater elevations in all of the major aquifers underlying the District. The maximum deviation above historic average values was observed at Well L-731 in the Sandstone aquifer in the Southwest Coast rain area. The recorded water level was 7.98 feet higher than the historic average in March 1998. The maximum deviation below historic groundwater table levels was observed at Station L-581 also in the Southwest Coast rain area. This well, in the Mid-Hawthorn aquifer, was 17.22 feet below historic average level in July 1998. The water levels in both of these wells reflect local pumping demand and long-term trends as well as the response to the El Niño and La Niña events. Both wells are located in confined aquifers and respond quickly to stresses induced by pumping.

Four areas contributed 89 percent of the inflow to Lake Okeechobee in 1998. They were the Upper and Lower Kissimmee areas, the Fisheating Creek area, the area contributing flow to the S84 gate and the area contributing flow to the S71 structure. On average, the inflow to Lake Okeechobee was 2.37 times the historic mean flow. Two major waterways received 83 percent of the outflow from Lake Okeechobee in 1998. They were the Caloosahatchee River and the St. Lucie Canal. The Caloosahatchee Estuary received 379 percent more water than expected from November 1997 through October 1998 based on the flow at S79. The St. Lucie Estuary received 205 percent more water than expected over the same period based on flows recorded at S49, S80 and S97.

Conclusions

The hydrologic effects of El Niño- and La Niña-induced weather patterns observed in Central and South Florida from November 1997 through October 1998 were exceptional and extreme. They were consistent with the impacts experienced during previous El Niño and La Niña events. El Niño and La Niña weather patterns occur on an irregular but, predictable or foreseeable basis. The effects on stages, flows, evapotranspiration and groundwater table elevations are regional in nature and are not well represented by District-wide summary statistics. In this report, rain areas facilitated the regional analysis and presentation of this data.

During the El Niño period examined, the effect of excessive rainfall on increased flows and stages was compounded by the fact that evapotranspiration rates were lower.

Taking a system-wide view of the impacts of the El Niño and La Niña weather on water resources, one overwhelming conclusion became apparent. By March 1998, water in the system managed by the South Florida Water Management District had nowhere to go. Lake Okeechobee was at dangerously high levels, all of the upper lakes including Kissimmee and Istokpoga were at regulation levels, the Water Conservation Areas could not accommodate additional flow and flows that had the potential to negatively impact the Caloosahatchee and St. Lucie estuaries were already being released.

Recommendations

If the stage in Lake Okeechobee is an indicator, the 1997-98 El Niño event had a return period of less than 100 years. Given that El Niño occurs on a fairly frequent basis (every two to five years) and that the frequency of extreme events is expected to increase, the District should expect to encounter events of similar magnitude and impact in the near future. It is recommended that a review of operational responses to the 1997-98 El Niño be conducted with an emphasis on examining strategies for managing the system to minimize financial and environmental impacts. In dealing with an event like the 1997-98 El Niño, a systematic response is appropriate and necessary. Information systems and decision tools that are adequate for prompt and correct operational responses on a system-wide basis are required for these types of events and should be prototyped, evaluated and implemented.

The monitoring network and database for District-wide assessment of rainfall, ground water and evapotranspiration should be reviewed and improved. Redundant rainfall and evapotranspiration stations need to be eliminated if possible. Frequency of database updates and availability of groundwater data in DBHYDRO should be examined. Overall, quality of data for rainfall, groundwater and evapotranspiration needs to be improved. A balance between District-wide and project-specific data needs should guide a systematic, periodic review process.

Finally, an inconsistency in the boundaries of drainage basins (used by the Watershed Research and Planning Department) and rain areas (used by the Water Resources Operations) exists. It is recommended that the rain area boundaries be altered to coincide with the drainage area boundaries. This will also require changes in some drainage basin boundaries as well. The modifications would, in most cases, be minor. This would facilitate accessing information from DBHYDRO on a rain area basis.

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APPENDICES

Appendix A

Hydrologic and Hydraulic Data Recording Stations

Table A1. Rain Gage Stations

DB Key	Station ID	Rain Area
5882	3A-SW_R	1
6166	TAMITR40_R	1
16278	SIX L 3_R	1
16623	EVERGL 2_R	1
16708	RACOON PT	1
G6147	NP 205	1
G6168	NP-OAS	1
H1988	NP-EVC	1
5797	S36_R	2
5801	G54_R	2
5807	GILL REA_R	2
5850	FT LAUD_R	2
6177	FORT LAU_R	2
15149	SBDD	2
16578	S124_R	2
16579	S13_R	2
16612	S37B_R	2
16613	FTL	2
16614	HOLLYWOOD	2
16680	S37A_R	2
16682	S33_R	2
5922	ALVA FAR_R	3
5952	LABELLE_R	3
6083	KERI TOW_R	3
6154	HGS1_R	3
15465	WHIDDEN3_R	3
15495	S78W	3
15749	S77	3
16203	RITTA (B_R	3
16668	CV5_R	3
5816	S20F_R	4
5817	S20_R	4
5818	S18C_R	4
6172	MIAMI BE_R	4
6174	MIAMI AP_R	4
6175	HIALEAH_R	4
7095	NP-EPR	4
15083	JBTS	4
15237	NP-EV8	4
15703	SYLVA_G	4
16020	HOMES.FS_R	4
16577	S123	4
16593	TAMI AIR_R	4
16596	PERRINE_R	4
16608	S30_R	4

Table A1. Rain Gage Stations - continued

DB Key	Station ID	Rain Area
16616	N DADE_R	4
16628	S27_R	4
16629	S29_R	4
16661	S338_R	4
16684	S28Z_R	4
16685	S29Z_R	4
16686	S26_R	4
16689	S21_R	4
16690	S21A_R	4
16691	S20G_R	4
16701	HOMES.AFB	4
16703	HIALEAH_W	4
16713	S336_R	4
DO555	MBTS	4
DU524	MIAMI.FS_R	4
H2003	NP-ROB	4
HB872	NP-IFS	4
HH352	PERRINE 4W	4
5835	EAST SHO_R	5
5837	PEL LAK1_R	5
5839	PAHOKEE2_R	5
5870	S2_R	5
5879	S4_R	5
5965	SFCD_R	5
6125	PEL LAK2_R	5
6157	CANAL P2_R	5
6188	CLEW_R	5
6227	S3_R	5
15182	EAA2	5
15183	EAA3	5
15184	EAA5	5
15198	MIAMI LO_R	5
15199	SOUTH BA_R	5
15200	BELLE GL_R	5
15201	PAHOKEE1_R	5
15202	S5A_R	5
15203	S6_R	5
15204	S7_R	5
15205	S8_R	5
15238	EAA4	5
15517	CFSW	5
15851	ENR101_R	5
15861	ENR105_R	5
15862	ENR401_R	5

Table A1. Rain Gage Stations - continued

DB Key	Station ID	Rain Area
15874	ENR203_R	5
15877	ENR301_R	5
15888	ENR308_R	5
16191	PEL 23_R	5
16205	TOWNSITE_R	5
16551	A310	5
16598	G136_R	5
16643	S5AY_R	5
16644	S5AX_R	5
16646	S6Z_R	5
16653	S8Z_R	5
16670	G201_R	5
16702	CANAL PT_R	5
DJ194	NNRC.SFS	5
DO542	DUP3_R	5
DO543	G200A_R	5
J5744	ENRP	5
JJ025	G600_R	5
5835	EAST SHO_R	6
5845	S133_R	6
5849	S135_R	6
5851	S129_R	6
5870	S2_R	6
5879	S4_R	6
5883	L OKEE.M_R	6
5962	EAST BEA_R	6
6020	OKEE FIE_R	6
6093	PALMDALE_R	6
6094	ARCHBOLD_R	6
6096	DESOTO T_R	6
6102	OKEE FOR_R	6
6137	DESOTO C_R	6
6153	HGS6_R	6
6157	CANAL P2_R	6
6205	ARCHBO 2_R	6
6227	S3_R	6
12515	L005	6
12524	L006	6
13081	LZ40	6
15151	INDIANPM	6
15575	JUDSON_R	6
15577	BASSETT_R	6
15580	OPAL_R	6
15582	ARS B0_R	6
15583	MOBLEY_R	6

Table A1. Rain Gage Stations - continued

DB Key	Station ID	Rain Area
15947	A308	6
16021	L001	6
16038	ABGL	6
16192	DAVIE2_R	6
16220	A127_R	6
16223	WILLIAMS	6
16284	S127_R	6
16285	OKEE F 2_R	6
16289	S308_R	6
16511	TAYLC_R	6
16550	AHYC	6
16551	A310	6
16568	RAULERS_R	6
16582	S153_R	6
16693	S352_R	6
F9544	S131_R	6
G2733	S191_R	6
5852	ELMAX_R	7
5854	AVON P_R	7
5855	SEBRING_R	7
5856	MICCO_R	7
5857	BASING_R	7
5858	PEAVINE_R	7
5871	MAXCEY N_R	7
5872	TICK ISL_R	7
5873	MCARTH_R	7
5875	GRIFFITH_R	7
5877	MAXCEY S_R	7
5878	GAC_R	7
5940	S65_R	7
5981	S65A_R	7
6024	S65C_R	7
6066	S68_R	7
7507	FLYING G_R	7
7522	LARSON1_R	7
7579	LAMB_R	7
7580	RUCKSWF_R	7
12457	DRYL.IR1_R	7
12556	LARSON2F_R	7
12777	G80_R	7
16281	S65D_R	7
16282	S65B_R	7
16599	S84	7
16655	S82_R	7
16656	S83_R	7

Table A1. Rain Gage Stations - continued

DB Key	Station ID	Rain Area
16663	S75_R	7
16666	S72_R	7
16667	S71_R	7
F9542	S65E_R	7
F9543	S70_R	7
FI286	KREFR	7
FZ609	KRBNR	7
5848	COW CREE_R	8
5888	JUPITER_R	8
5914	BLUEGOOS_R	8
6031	SCOTTO G_R	8
6043	HAYES_R	8
6116	FT PIERC_R	8
6151	FORT PIE_R	8
6187	STUART 1_R	8
15730	SIRG	8
16416	S80_R	8
16589	S49_R	8
16591	FTP ES_R	8
16627	S97_R	8
16672	S99_R	8
16673	S46_R	8
FI273	SVWX	8
G0859	JDWX	8
HD784	SCOTTO	8
5792	LWD.RANG_R	9
5793	LWD.POWE_R	9
5796	POMPANOF	9
5892	LWD.L38M_R	9
5893	LWD.L39R_R	9
5966	PLANT IN_R	9
6122	PRATT AN_R	9
6179	POMPANOB_R	9
6182	WPB AIRP_R	9
6276	LWD.GA_R	9
6290	LWD.E1.3_R	9
6298	LWD.MIL_R	9
6299	LWD.E2_R	9
6302	LWD.L28_R	9
6306	LWD.HQ_R	9
6321	LWD.E2.2_R	9
6322	LWD.L32_R	9
15202	S5A_R	9
16583	S155_R	9
16603	C18W_R	9

Table A1. Rain Gage Stations - continued

DB Key	Station ID	Rain Area
16611	G56_R	9
16630	DELRAY BCH	9
16674	S44_R	9
16675	S41_R	9
16676	S40_R	9
GA832	WPBFS_R	9
5916	CORK HQ_R	10
5972	NAPLES C_R	10
5978	COLLIER_R	10
5986	CCWWTP_R	10
6019	SILVER S_R	10
6022	FAKAHATC_R	10
6081	SLEE_R	10
6082	IMMOKA 2_R	10
6087	MILES CI_R	10
6089	COPELAND_R	10
6090	NAPLES T_R	10
6193	FT MEYER_R	10
15464	LEHIGH W_R	10
16414	S79_R	10
16594	FORT MEY_R	10
16600	BONITA S_R	10
16623	EVERGL 2_R	10
16633	NAPLES_R	10
DJ230	GOLD75	10
DJ231	NNAPFS42	10
DJ232	CORKISL	10
DO534	951EXT_R	10
DO535	COCO1_R	10
DO541	CORK_R	10
DU523	IMMOKALE_R	10
DU525	GOLDFS2	10
DU526	BCBNAPLE_R	10
DU533	COLLISEM	10
DU536	COLGOV_R	10
DU537	DANHP_R	10
FZ598	FPWX	10
H1988	NP-EVC	10
5790	REEDGW10_R	11
5841	CREEK_R	11
5862	KIRCHOFF_R	11
5868	S61_R	11
5876	PINE ISL_R	11
5884	L MARIO2_R	11
5902	CHAPMAN_R	11

Table A1. Rain Gage Stations - continued

DB Key	Station ID	Rain Area
5912	SNIVELY_R	11
5940	S65_R	11
5946	INDIAN L_R	11
5963	BEELINE_R	11
6021	POINCI_R	11
6042	TAFT_R	11
6147	KISS 2_R	11
6305	KISS.FS_R	11
6867	KENANSI_R	11
15323	SHING.RG	11
16567	S59_R	11
16590	KISS SP_G	11
16619	STCLOUD_R	11
16634	MC COY	11
FF846	WRWX	11
H2447	BEEK_R	11
H2450	MOONI_R	11
H6070	CHEST_R	11
HA469	ALL2R	11
HA471	EXOTR	11
15202	S5A_R	12
15204	S7_R	12
16175	3A-36_R	12
16578	S124_R	12
16639	CORAL SP W	12
16640	CORAL SP	12
16677	S39_R	12
16679	S38_R	12
DU515	ENR106_R	12
DU517	WCA1ME	12
DU551	LOXWS	12
5863	3A NW_R	13
5864	3A-NE_R	13
5865	3A-S_R	13
6055	S12D_R	13
6166	TAMITR40_R	13
13027	S9_R	13
15204	S7_R	13
15205	S8_R	13
15506	S140W	13
16592	TAMIAMI_CN	13
16632	MIAMI_2_R	13
16642	ANDYTOWN W	13
16683	S34_R	13
16705	MIRAMAR_R	13

Table A1. Rain Gage Stations - continued

DB Key	Station ID	Rain Area
16706	SWEETWATER	13
16707	COOPER_R	13
HC941	3A-S_R	13
15197	ALICO_R	14
15506	S140W	14
15685	BIG CY SIR	14
16598	G136_R	14
16671	G155_R	14
GE354	ROTNWX	14
IV150	DEVILS_R	14
IV151	PAIGE_R	14
5967	S331_R	15
5970	S332_R	15
6038	NP-P36	15
6039	NP-P38	15
6040	NP-203	15
6044	NP-201	15
6055	S12D_R	15
6166	TAMITR40_R	15
6202	ROYAL PA_R	15
6210	FLAMIN 2_R	15
16584	S174_R	15
16585	S177_R	15
16592	TAMIAMI_CN	15
16709	CHEKIKA EV	15
G6149	NP-202	15
G6152	NP-P33	15
G6155	NP-206	15
H1969	NP-127	15
H1974	NP-N10	15
H1975	NP-A13	15
H1994	NP-311	15
H1998	NP-P34	15
H1999	NP-P35	15
H2001	NP-P37	15
H2004	NP-RPL	15
H2005	NP-FMB	15
H2438	NP-CR2	15
H6053	NP-CHP	15
H6055	NP-OT3	15
H6056	NP-RG1	15
H6058	NP-RCR	15

Table A2. Evapotranspiration Stations

RADT DB Key	AIRT DB Key	Station	Station Description	X-coord	Y-coord	Period of Record
12522	12911	L006	LAKE OKEECHOBEE TOWER SOUTH (#6)	726990.438	904732.375	1989-1999
15469	15472	S65CW	WEATHER STATION NEAR S-65C SPILLWAY ON CANAL C-38	616924.062	1115114.925	1992-1999
15683	15682	BIG CY SIR	BIG CYPRESS @ SEMINOLE INDIAN RESERVATION	533944.188	722539.000	1993-1999
15560	15684	ENR308	WEATHER STATION NEAR INTERIOR LEVEE IN CELL3	839466.938	832377.812	1994-1999
16256	16260	S331W	S-331 WEATHER STATION ON L-31N	817707.688	464566.938	1994-1999

Table A3. Stage Recording Stations

Station ID	Station Description	DBHYDRO Key
3A-3	CA3A-2 Corps Well in C.A. 3A Marsh near S-11 (63)	15943[1]
3A-4	CA3A-4 Corps Well in C.A. 3A Marsh (64)	15943[1]
3A-28	CA3A-28 Corps Well in C.A. 3A Marsh near S-12 (65)	15943[1]
L OKEE	Lake Okeechobee FL	15611
S65	S-65 Spillway on Lake Kissimmee at Canal C-38	12585
S11B_S	S-11B Spillway in Levee L-38W from C.A. 2A > C.A. 3A	15259
S57_H	S-57 Culvert Headwater on Canal C-30 at Lake Mary Jane	15526
S58_H	S-58 Culvert on Canal C-32 at Fla. Highway 532	15529
S59_H	S-59 Spillway on Canal C-31 at E. Lake Tohopekaliga	15531
S60_H	S-60 Spillway on Canal C-33 at Lake Alligator	15534
S61_H	S-61 Spillway Headwater on Canal C-35 at Lake Tohopekaliga	15558
S62_H	S-62 Spillway on Canal C-29 at Lake Hart	15537
S63_H	S-63 Spillway on Canal C-34 at Lake Gentry	15540
1-7	CA1-7 Corps Rain/Well in Center of C.A. 1 Marsh (141)	15808
1-8C	CA1-8C Corps Stage in Levee L-40 near Boat Ramp	15810
1-8T	CA1-8T Corps Telemetry Stage East of C.A. 1 Marsh	15809
1-9	CA1-9 Corps Rain/Well in Southeast C.A. 1 Marsh	15811
S68_H	S-68 Spillway Headwater on Lake Istokpoga	15956
2A-17_B	CA2A-17 Corps Rain/Well South-central C.A. 2A Marsh	16016

Notes: [1] A single DB Key is used to report the average value from all three Stage gages for WCA 3A

Table A4. Key Indicator Wells

Station Name	USGS Station ID	DB Key	Station Description	X-Coord	Y-coord	Area	Aquifer
G-1183_G	252918080234201	00972	G-1183 USGS OBS WELL AT HOMESTEAD. FL	855807.062	420323.688	Dade Co.	Surficial
G-1251_G	251922080340701	08371	G-1251	798731.000	359935.188	Everglades Area	Surficial
G-853_G	261434080071901	02116	G- 853 USGS OBS WELL AT PMPNO BCH. FL	944051.938	695036.938	Broward Co.	Surficial
PB-565_G	265812080053901	02958	PB-565	951286.062	959445.812	Palm Beach Co.	Surficial
M-1090_G	271127080144701	03083	M-1090 LINCOLN PARK - STUART	901221.000	1039396.062	Martin Co.	Surficial
STL-125_G	272524080242801	03210	STL-125	848354.500	1123633.000	St. Lucie Co.	Surficial
L-730_G	263127081351601	02417	L-730	464040.188	796777.312	Lower West Coast	Surficial
C-492_G	262228081361901	02318	C-492	458061.344	742383.438	Lower West Coast	Lower Tamiami
L-731_G	262703081340201	02377	L-731	470643.906	770092.062	Lower West Coast	Sandstone
L-581_G	263532081592201	02461	L-581 CAPE CORAL	332884.312	822323.500	Lower West Coast	Mid-Hawthorn
OK-1	273127080481401		OK-1 WELL AT FORT DRUM, FL.	719795.986	1159881.72	Okeechobee Co.	Floridan
Lake Joel	281714081093001		LAKE JOEL WELL NEAR ASHTON, FL.	605278.492	1437266.516	Osceola Co.	Floridan
Lake Oliver	282202081384001		LAKE OLIVER DEEP WELL NEAR VINELAND, FL.	556728.030	1469677.626	Orange Co.	Floridan

Table A5. Flow Stations – Lake Okeechobee

Station ID	Station Description	DBHYDRO Key
S131 PMP_P	S-131 Pump (only) from N.W. Shore to Lake Okeechobee	15643
S71_S	S-71 Spillway on Canal C-41 at Lake Okeechobee	15633
S129 PMP_P	S-129 Pump (only) from N.W. Shore to Lake Okeechobee	15642
S72_S	S-72 Spillway on Canal C-40 at Lake Okeechobee	15634
S127_P	S-127 Pump (only) from N.W. Shore to Lake Okeechobee	15641
S84_S	S-84 Spillway on Canal C-41A at Lake Okeechobee	15636
S65E	S-65E Spillway/Lock on C-38 at Lake Okeechobee	15631
S154_C	S-154 Culvert thru Levee L-D4 near Okeechobee	15629
S133_P	S-133 Pump (only) from N.E. Shore to Lake Okeechobee	15637
S191_S	S-191 Spillway on Canal C-59 at Lake Okeechobee	15639
S135 PMP_P	S-135 Pump (only) from N.E. Shore to Lake Okeechobee	15638
S308_L *	Port Mayaca Lock (Corps of Engineers)	15626
L8.441*	L-8 Canal at US Hwy 441 near Canal Point FL	15640
C-10	Pump Station at SR441 in Pahokee	15645
C-12A	Pump Station 1.5 miles south of Pahokee on SR441	15647
C-12	Pump Station 2 miles south of Pahokee on SR441	15646
S2 TOTAL_T *	Combined S-2 and HGS-4 Stations at Hills & NNR Canals	15021
C-4A	Pump Station West of Belle Glade	15648
S3 *	Miami Canal at HGS-3 and S-3 at Lake Harbor FL	15018
S236-P	S-236 Pump from Levee LD-2 to Lake Okeechobee	15644
INDUST *	Industrial Canal at Clewiston	15628
S4_P	S-4 Pump from LD-1 & Canal C-20 to Lake Okeechobee	15630
FISHP_O	Fisheating Creek at Palmdale FL	15627
S77_T *	S-77 Spillway and Lock on Caloosahatchee River, Lake Okeechobee	15635
HGS5X *	HGS-5 Hurricane Gate on Lake Okeechobee to W.P.B. Canal	15068

Notes: 1) Stations L61W, L61E, L60W, L60E, L59W, L 59E and NICOD4 were omitted from the Table above since data was not available for the entire period of record 1972-1998. Their contribution to inflow to the lake is included for the period 1972-1993.
2) * - Outflow from Lake Okeechobee is recorded at these seven stations.

Table A5 – Other Flow Stations

Station No.	Station Description	DBHYDRO Key
S68_S	S-68 Spillway on Canal C-41A Lake Istokpoga	15632
S49_S	S-49 Spillway on Canal C-24 near Florida Turnpike	15777
S97_S	S-97 Spillway on Canal C-23 near Florida Turnpike	15780
S79_S	S-79 Spillway (ONLY) on Caloosahatchee R. @ Tidewater	DJ237
S80_S	S-80 Spillway (ONLY) on St. Lucie Canal at Tidewater	DJ238
S65_S	S-65 Spillway on Lake Kissimmee at Canal C-38	H0289

Appendix B

Monthly Rainfall Amounts El Niño/La Niña vs. Monthly Historic Averages and Deviation from Historic Record in Percent

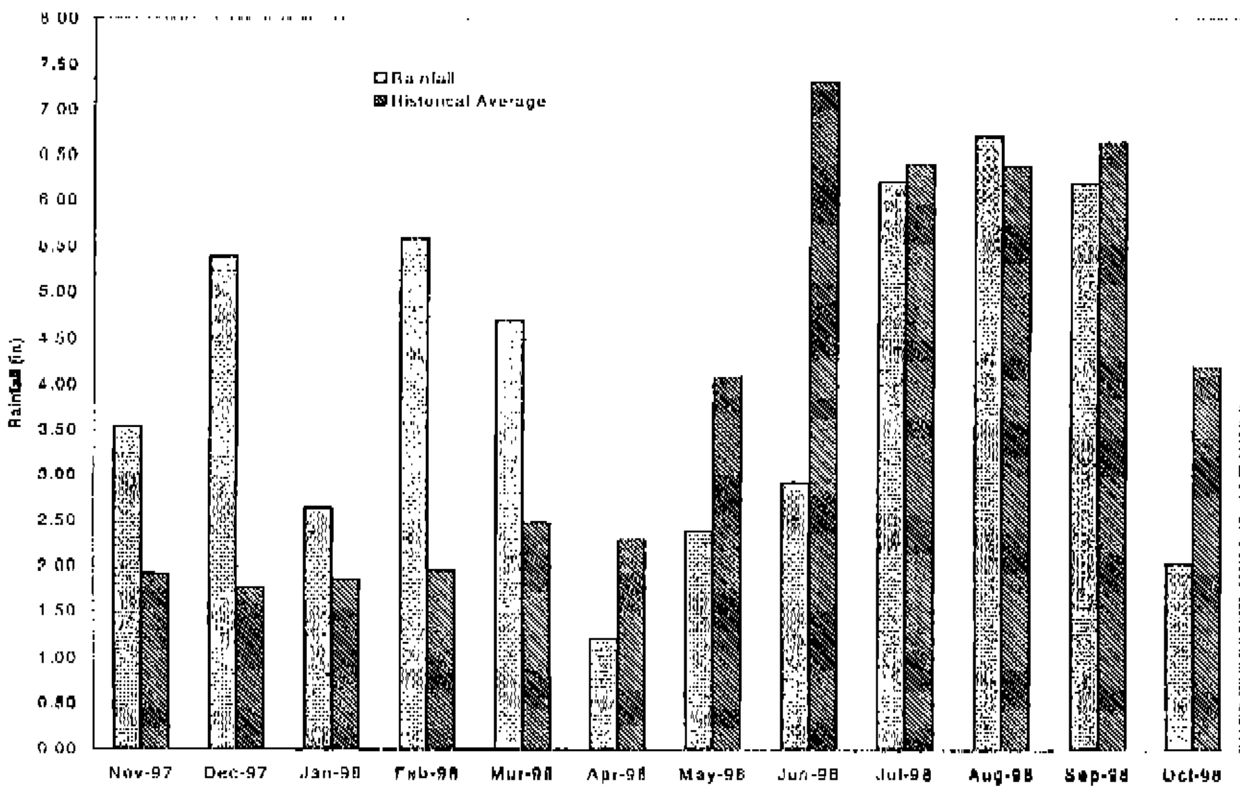

***Figure B1.** District-wide Monthly Rainfall November 1997 through October 1998 vs. Historic Monthly Average Rainfall*

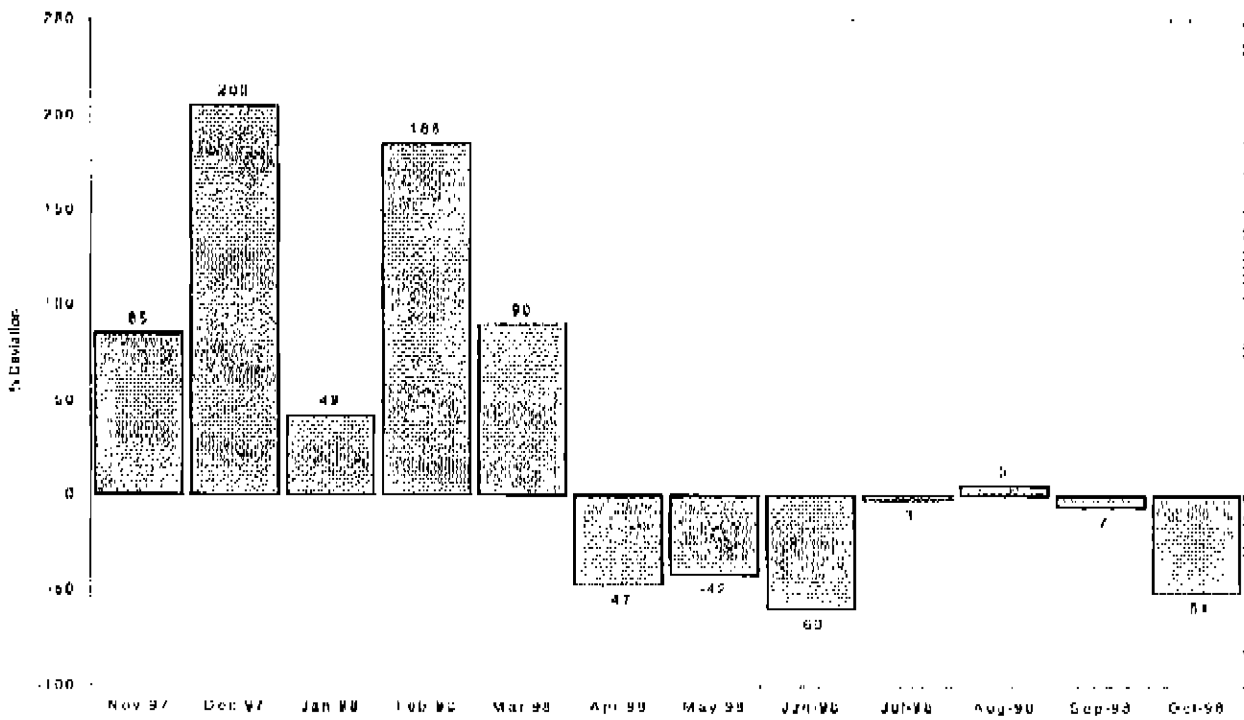

***Figure B2.** District-wide Percent Deviation from Historic Monthly Average Rainfall November 1997 through October 1998*

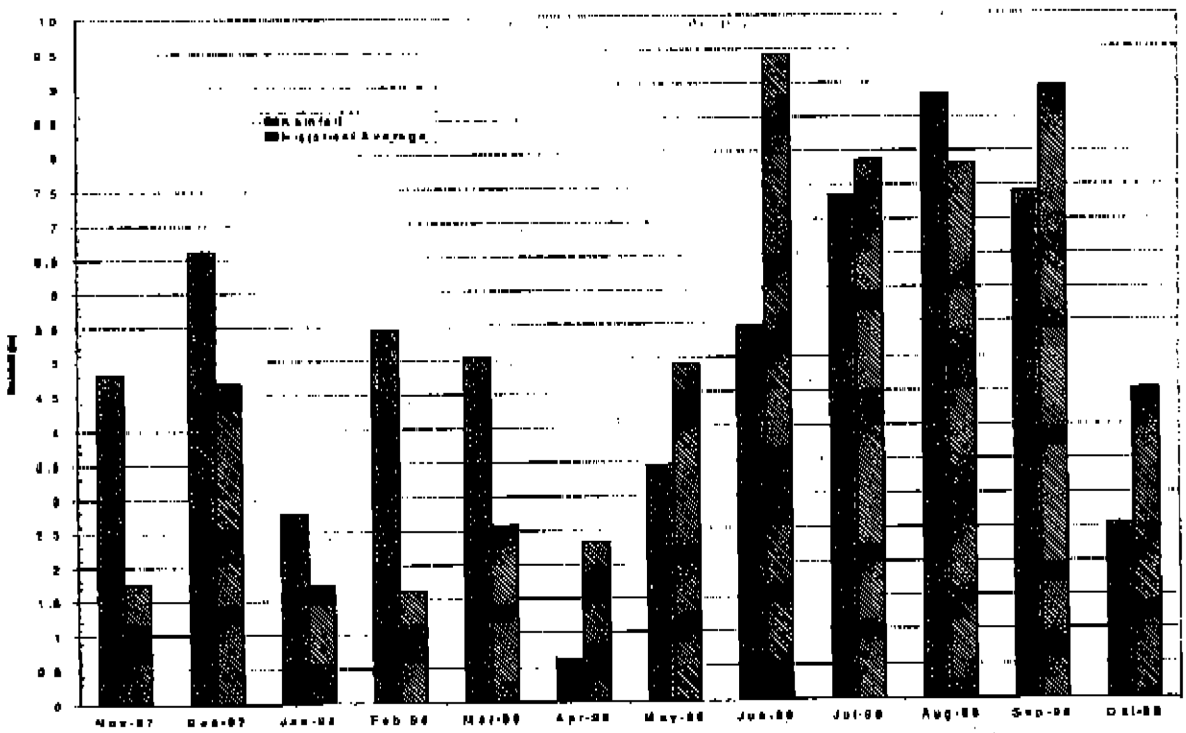

Figure B3. *Big Cypress Preserve Rain Area Monthly Rainfall November 1997 through October 1998 vs. Historic Monthly Average Rainfall*

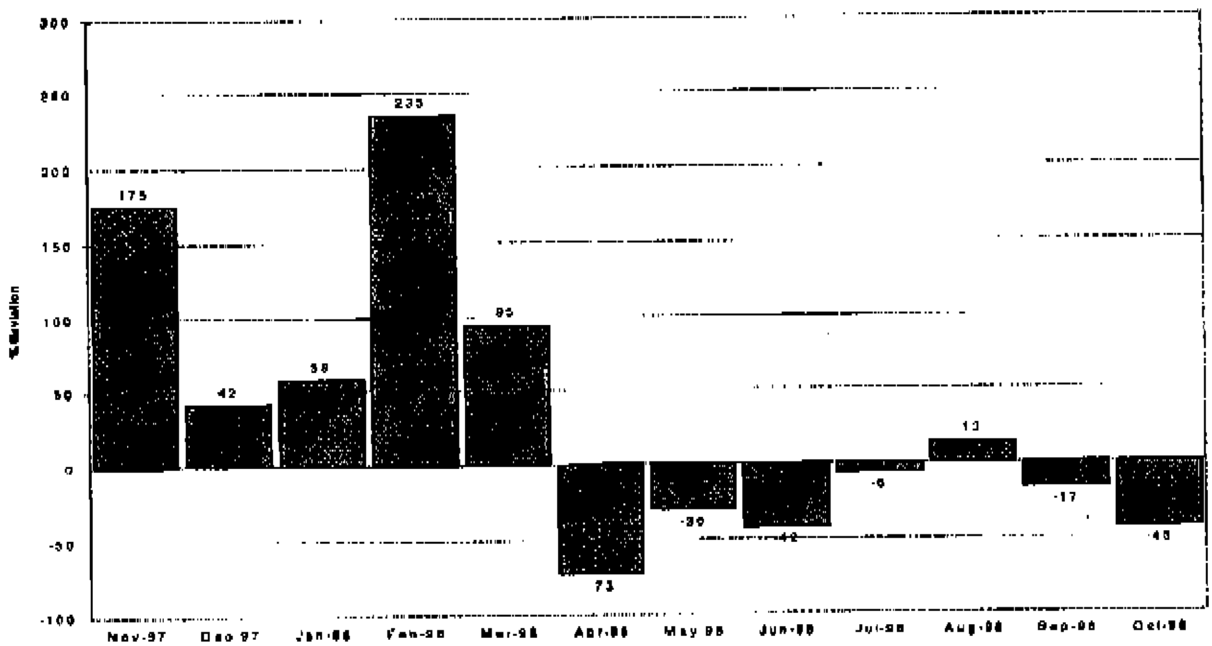

Figure B4. *Big Cypress Preserve Rain Area Percent Deviation from Historic Monthly Average Rainfall November 1997 through October 1998*

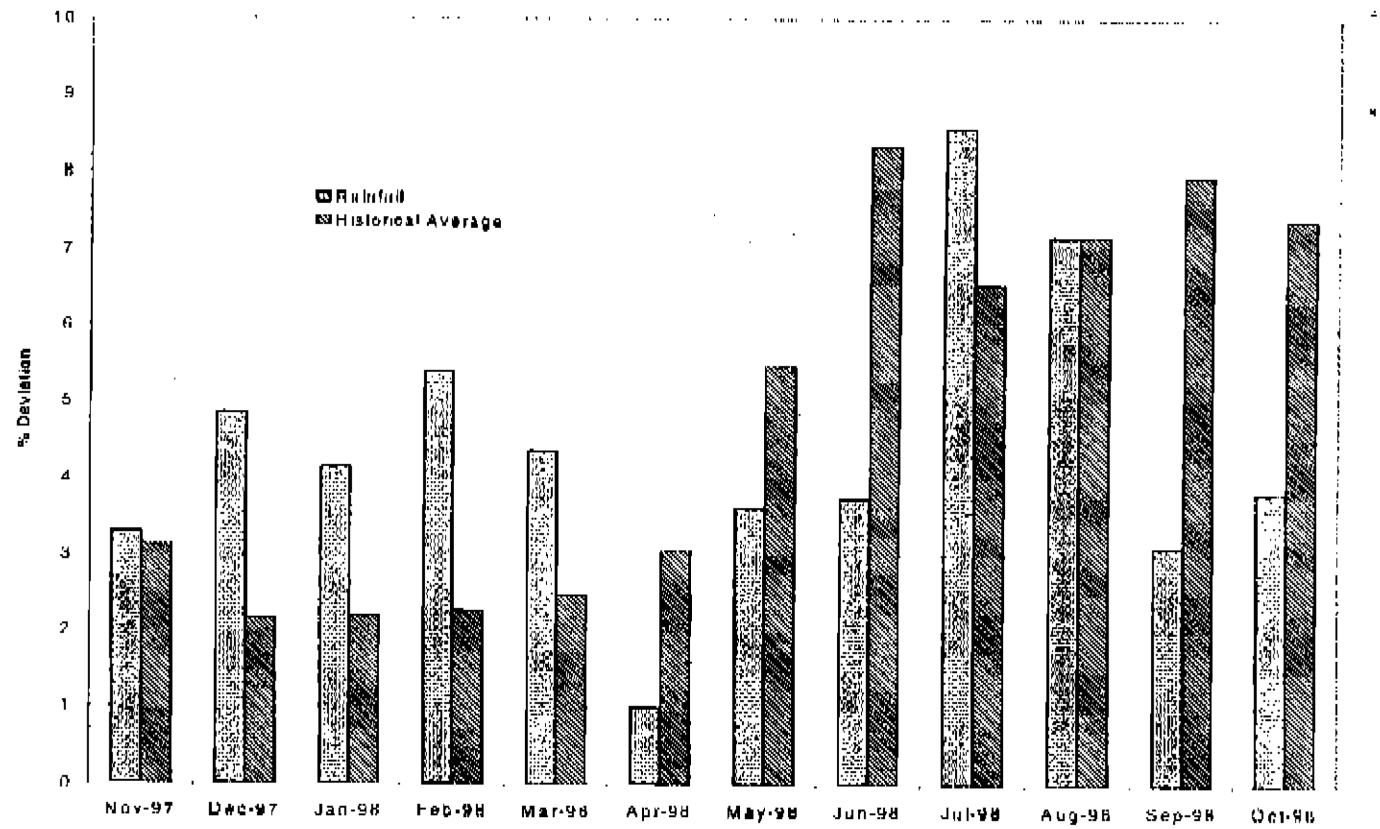

Figure B5. *Broward Rain Area Monthly Rainfall November 1997 through October 1998 vs. Historic Monthly Average Rainfall*

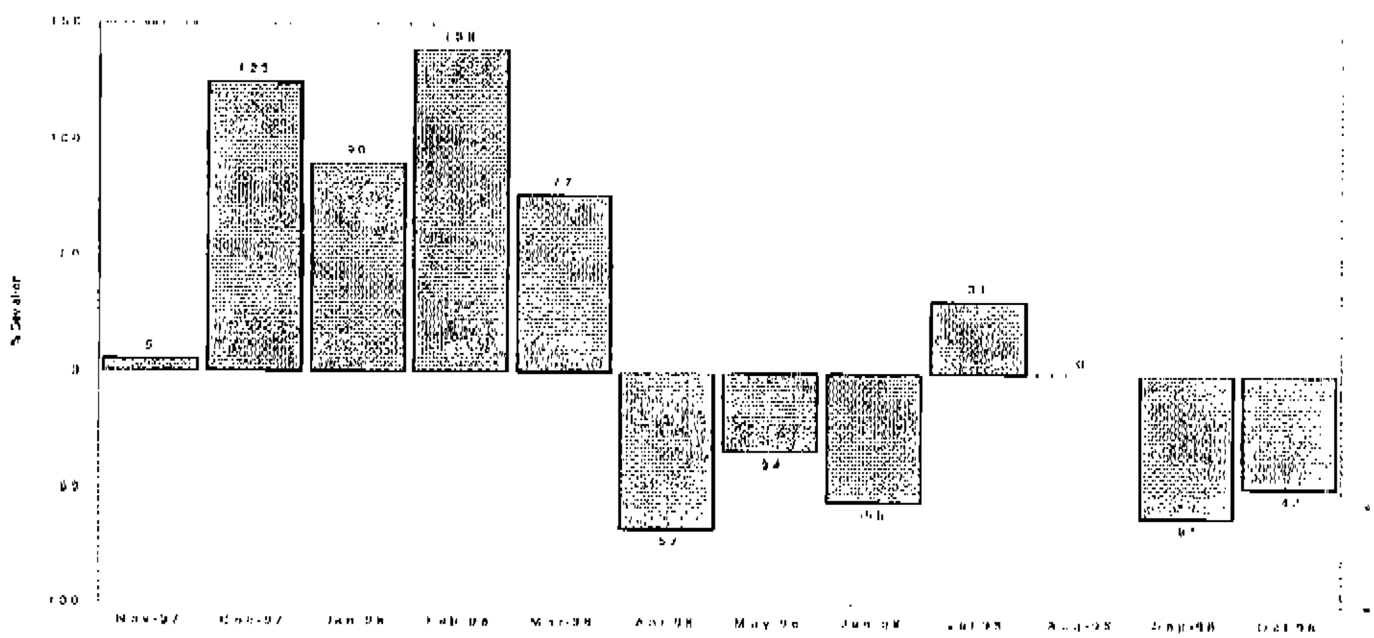

Figure B6 . *Broward Rain Area Percent Deviation from Historic Monthly Average Rainfall November 1997 through October 1998*

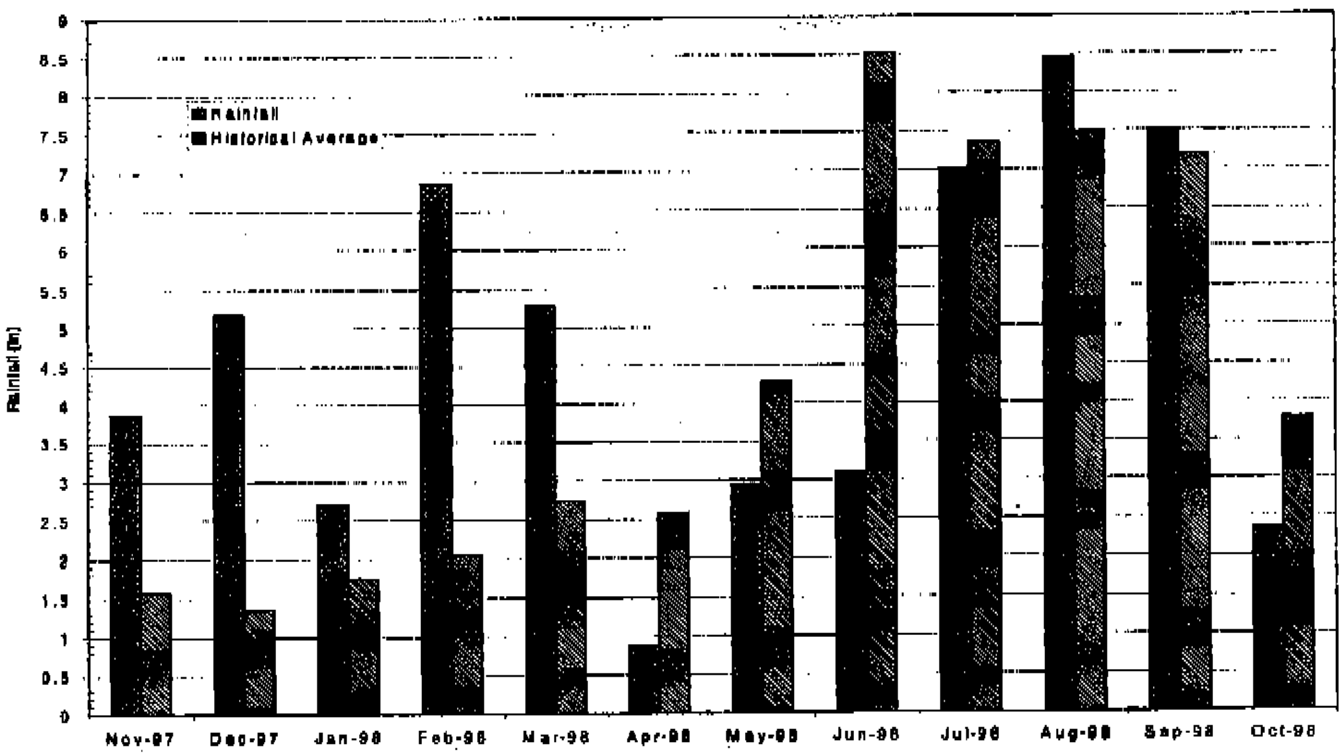

***Figure B7.** Caloosahatchee Rain Area Monthly Rainfall November 1997 through October 1998 vs. Historic Monthly Average Rainfall*

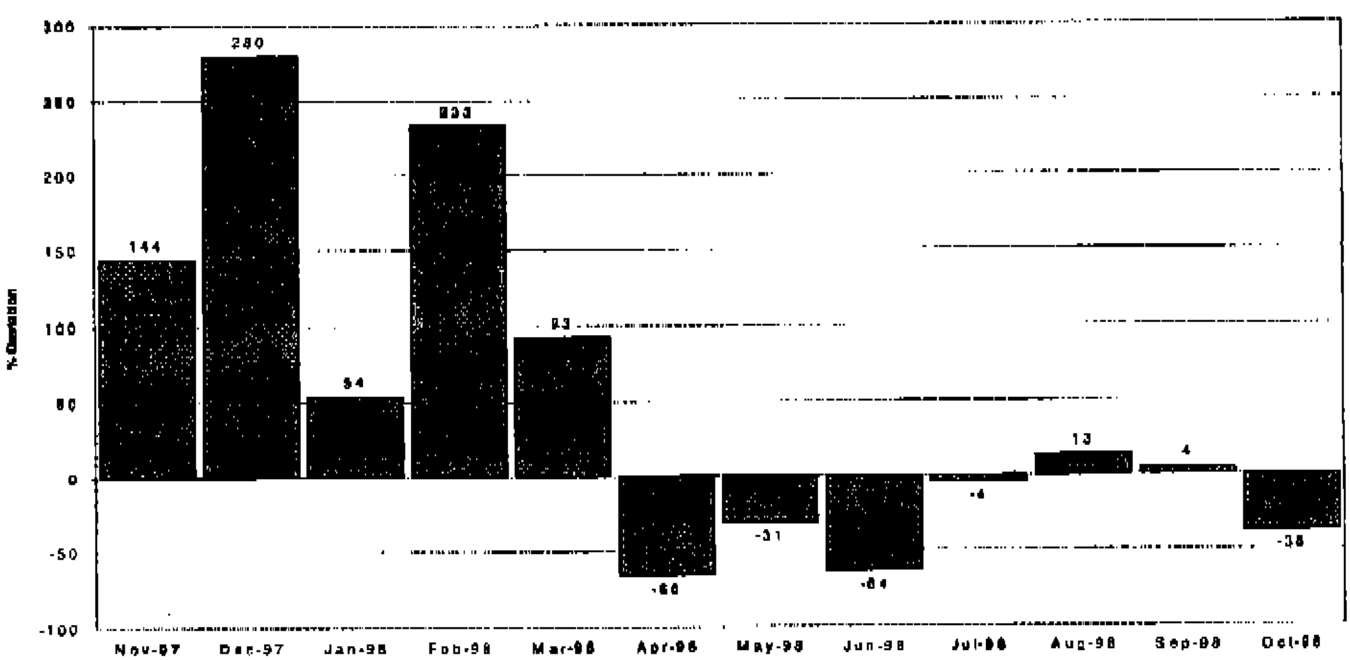

***Figure B8.** Caloosahatchee Rain Area Percent Deviation from Historic Monthly Average Rainfall November 1997 through October 1998*

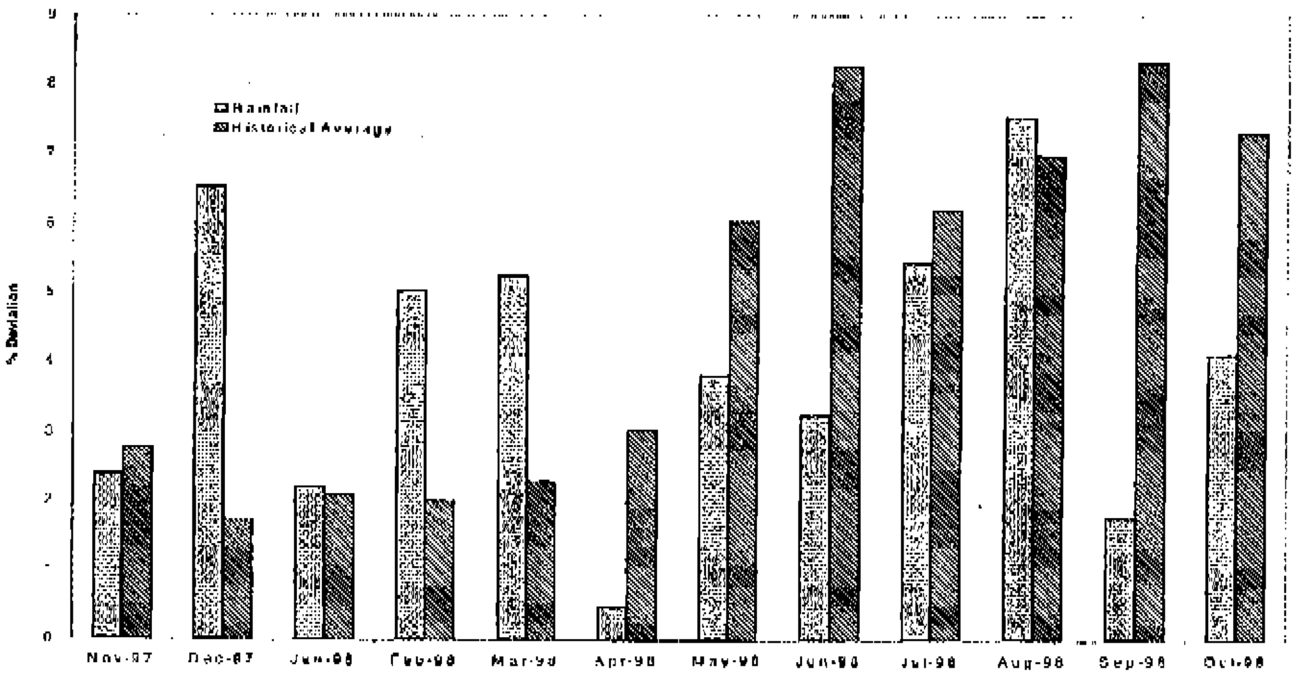

Figure B9. *Dade Rain Area Monthly Rainfall November 1997 through October 1998 vs. Historic Monthly Average Rainfall*

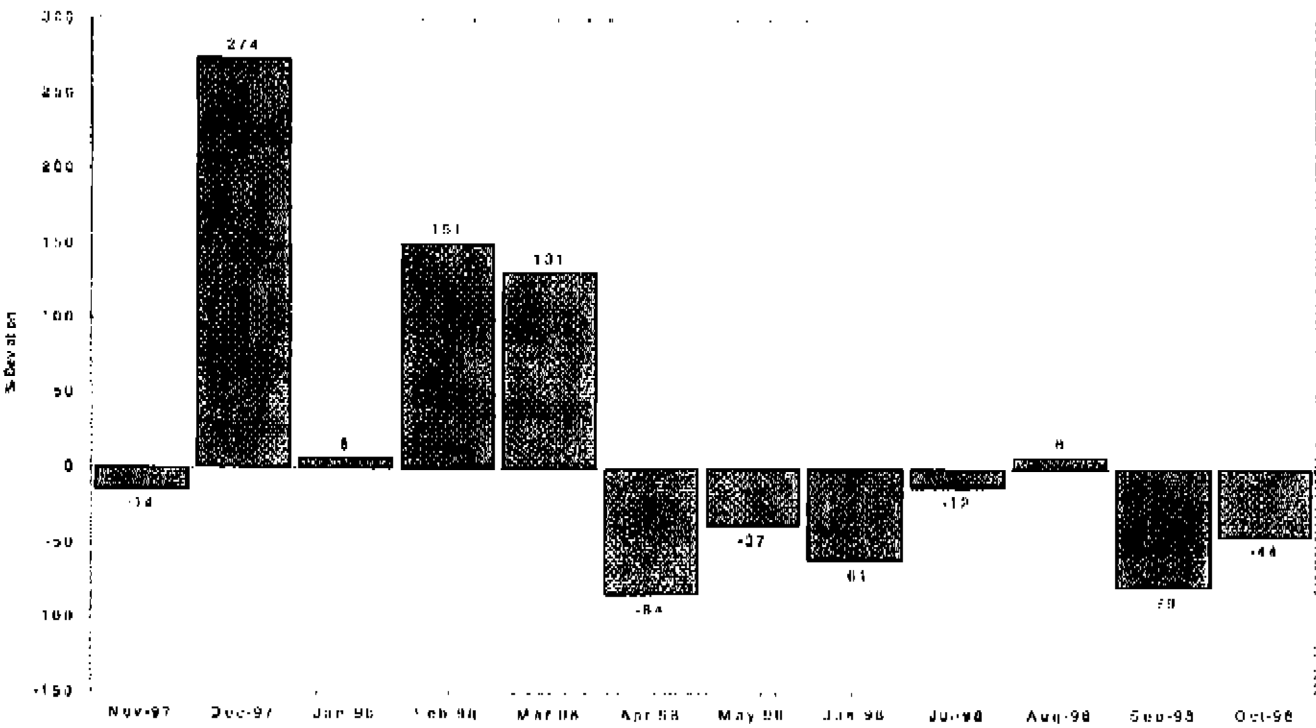

Figure B10. *Dade Rain Area Percent Deviation from Historic Monthly Average Rainfall November 1997 through October 1998*

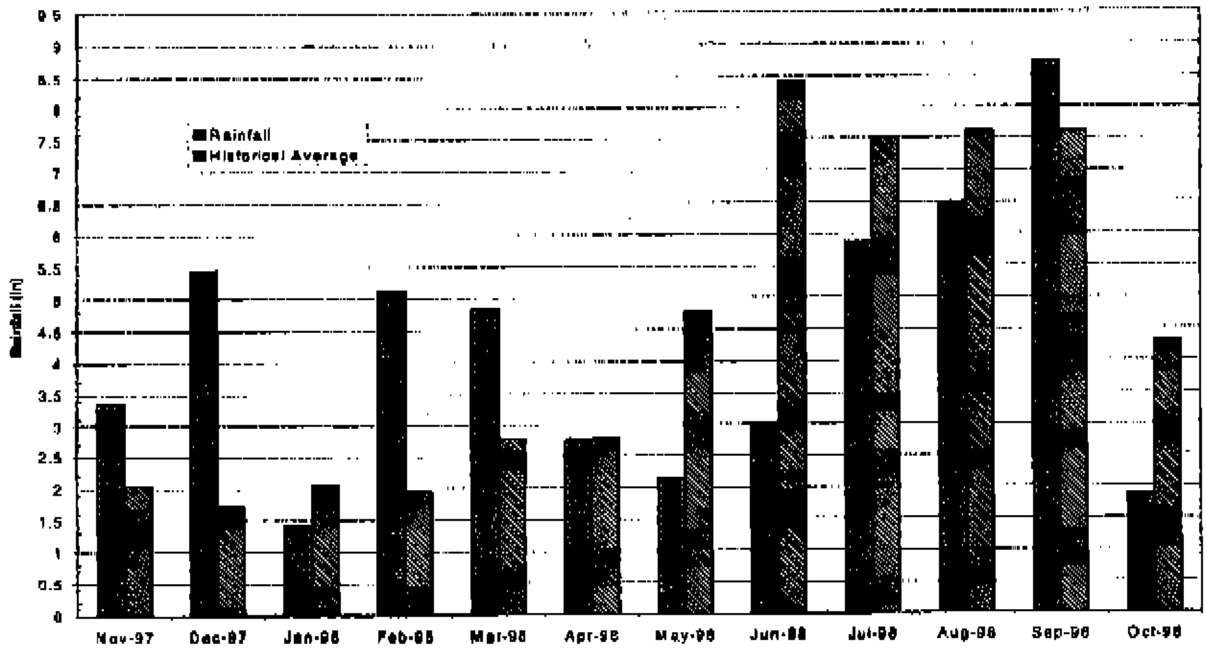

***Figure B11.** East EAA Rain Area Monthly Rainfall November 1997 through October 1998 vs. Historic Monthly Average Rainfall*

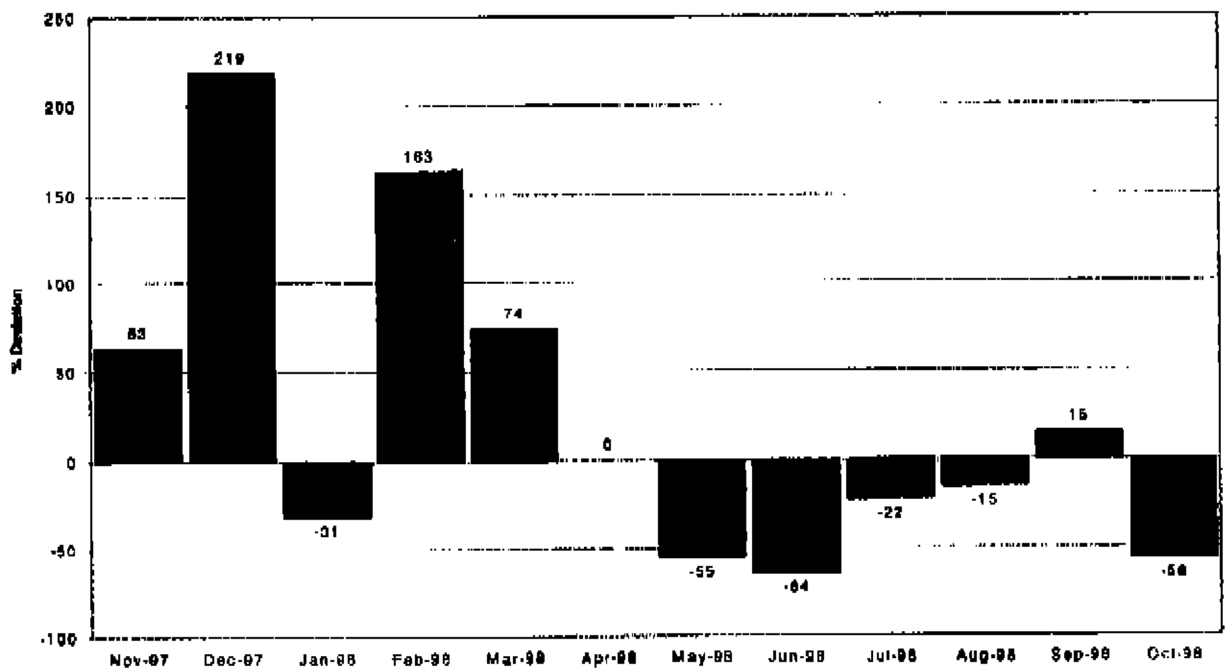

***Figure B12.** East EAA Rain Area Percent Deviation from Historic Monthly Average Rainfall November 1997 through October 1998*

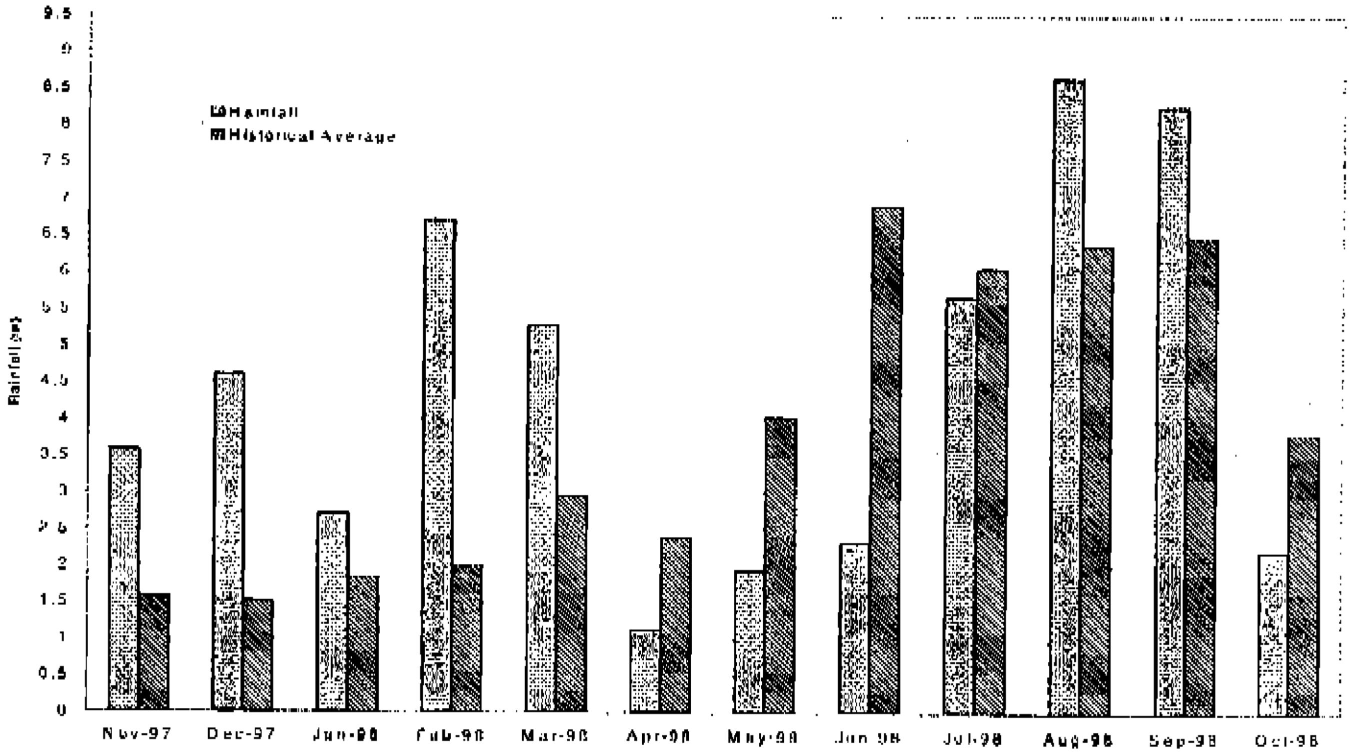

***Figure B13.** Lake Okeechobee Rain Area Monthly Rainfall November 1997 through October 1998 vs. Historic Monthly Average Rainfall*

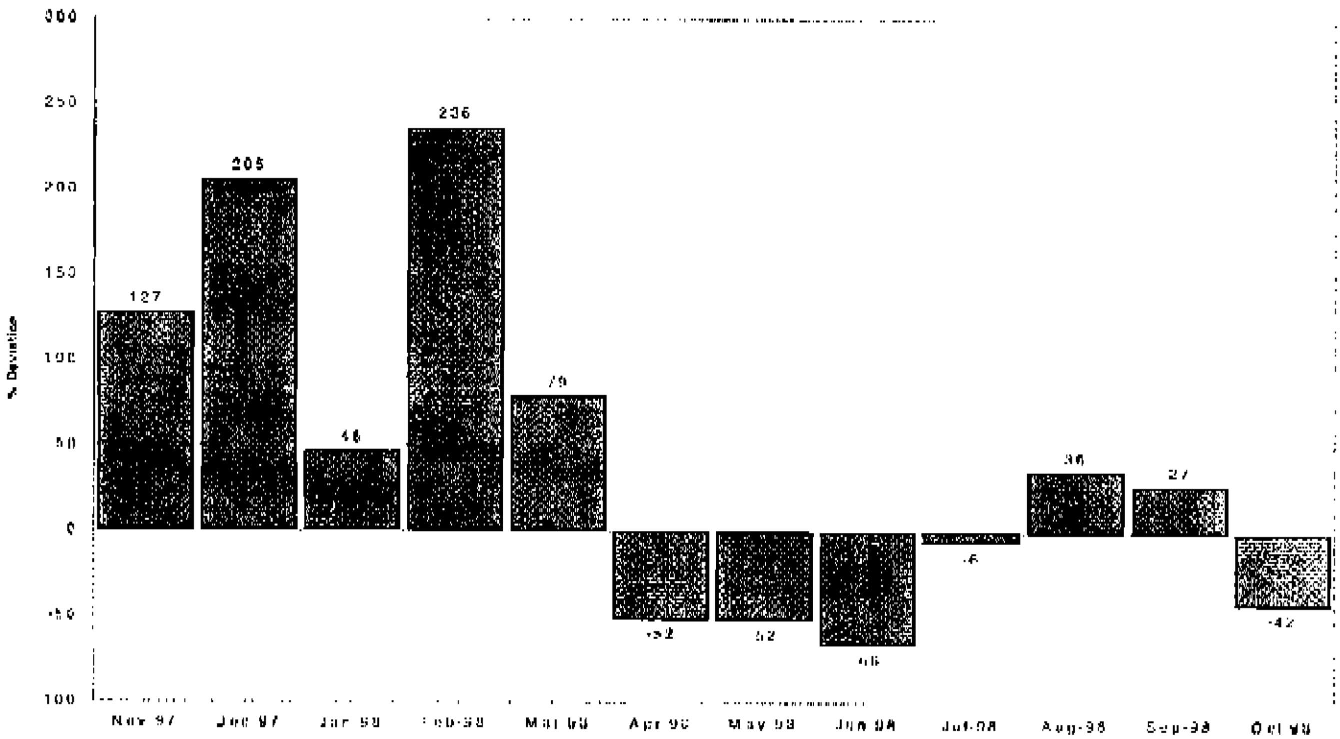

***Figure B14.** Lake Okeechobee Rain Area Percent Deviation from Historic Monthly Average Rainfall November 1997 through October 1998*

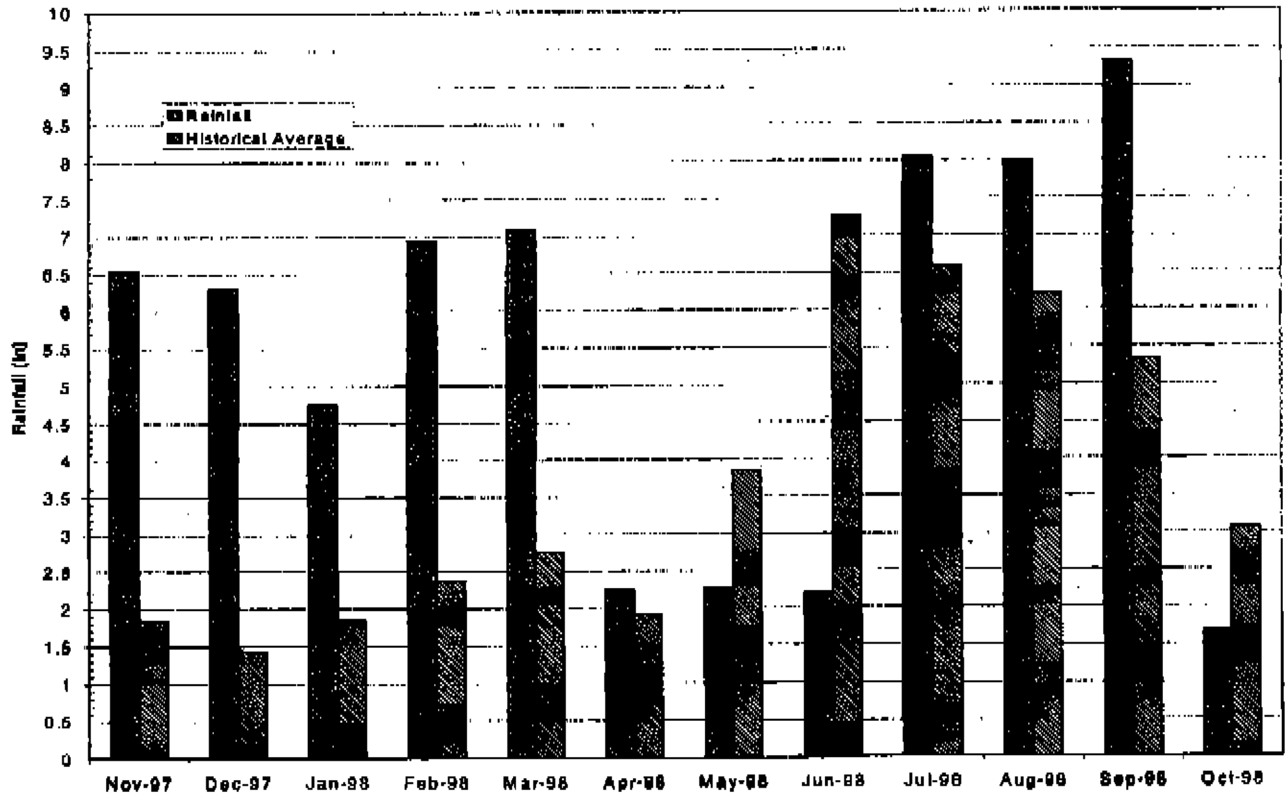

Figure B15. *Lower Kissimmee Rain Area Monthly Rainfall November 1997 through October 1998 vs. Historic Monthly Average Rainfall*

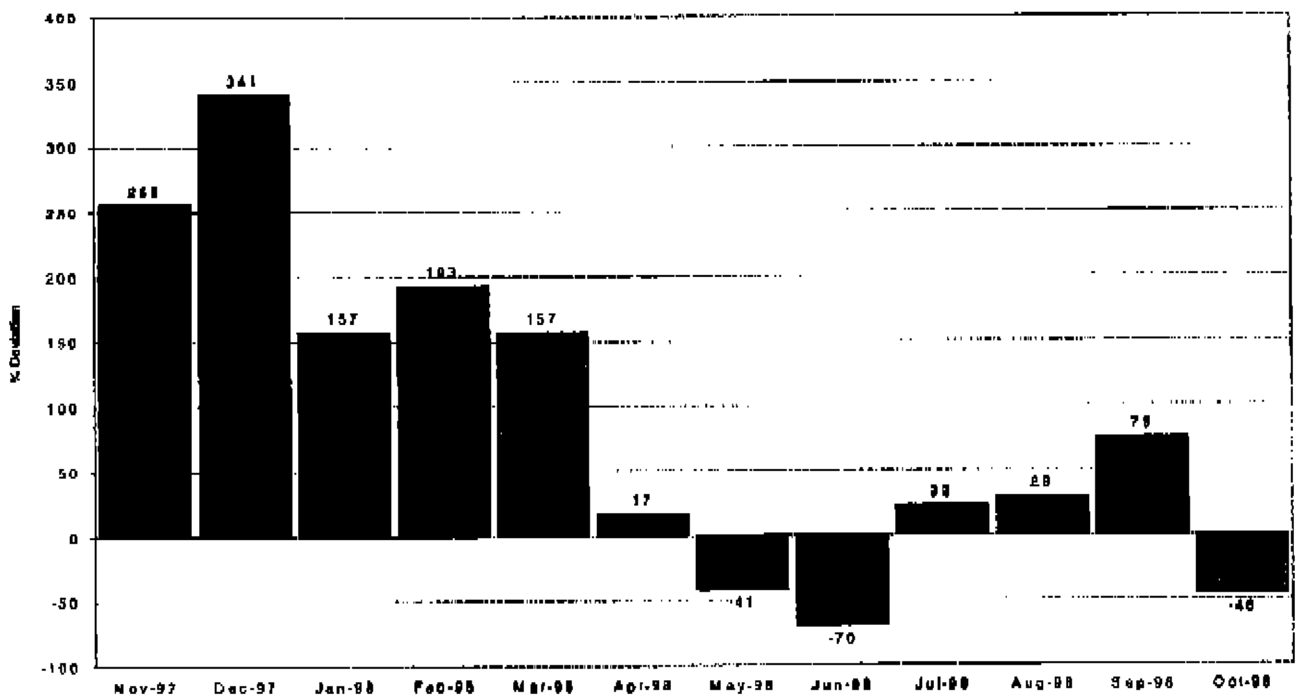

Figure B16. *Lower Kissimmee Rain Area Percent Deviation from Historic Monthly Average Rainfall November 1997 through October 1998*

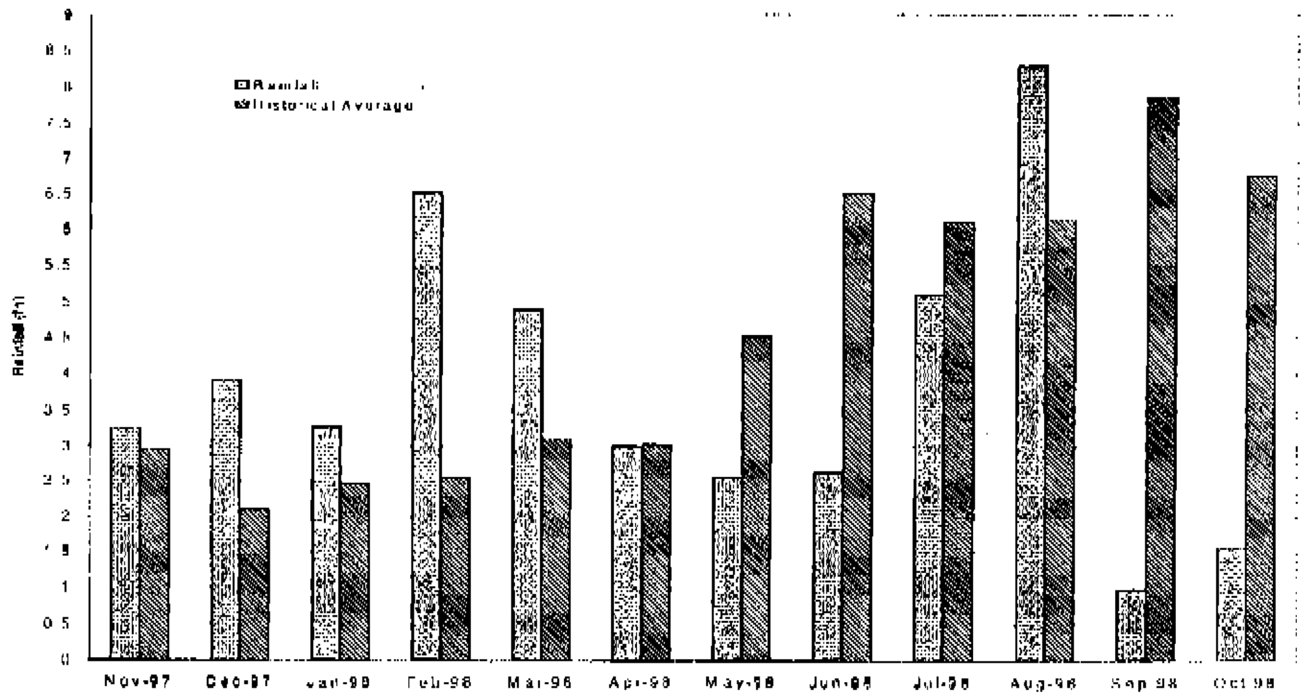

***Figure B17.** Martin/St. Lucie Rain Area Monthly Rainfall November 1997 through October 1998 vs. Historic Monthly Average Rainfall*

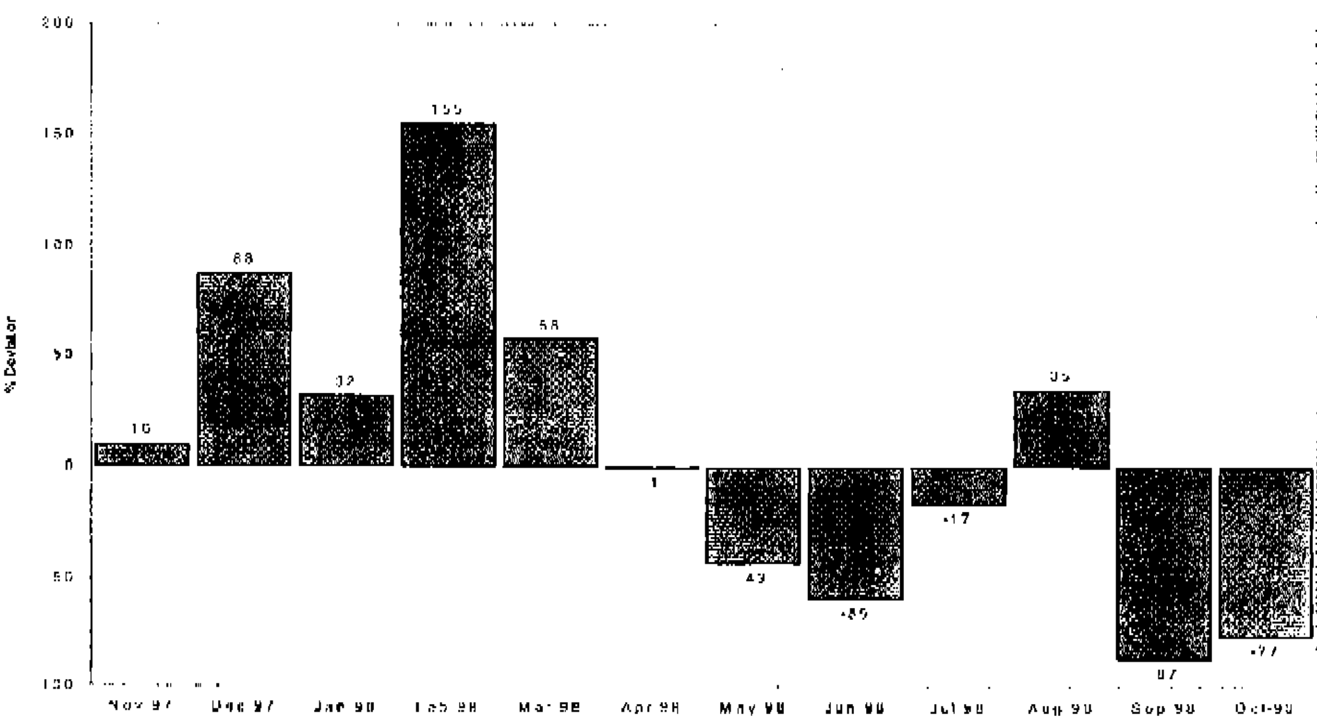

***Figure B18.** Martin/St. Lucie Rain Area Percent Deviation from Historic Monthly Average Rainfall November 1997 through October 1998*

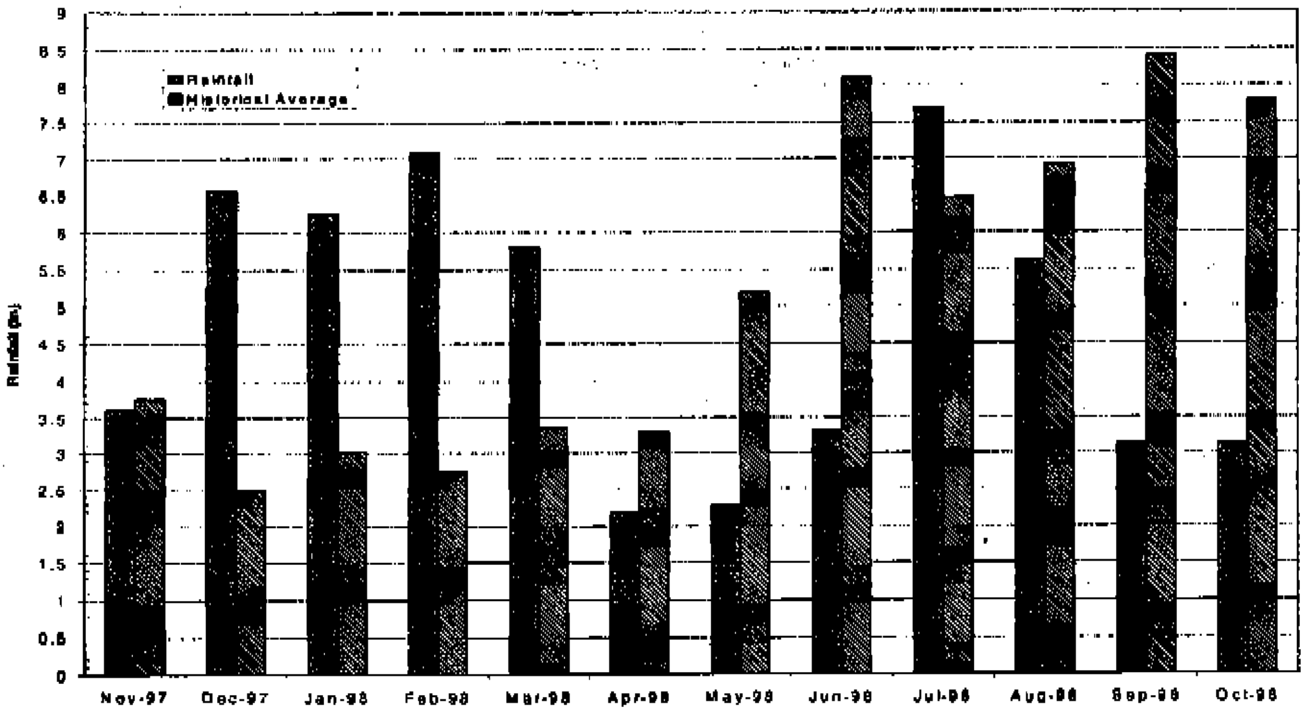

Figure B19.* *Palm Beach Rain Area Monthly Rainfall November 1997 through October 1998 vs. Historic Monthly Average Rainfall

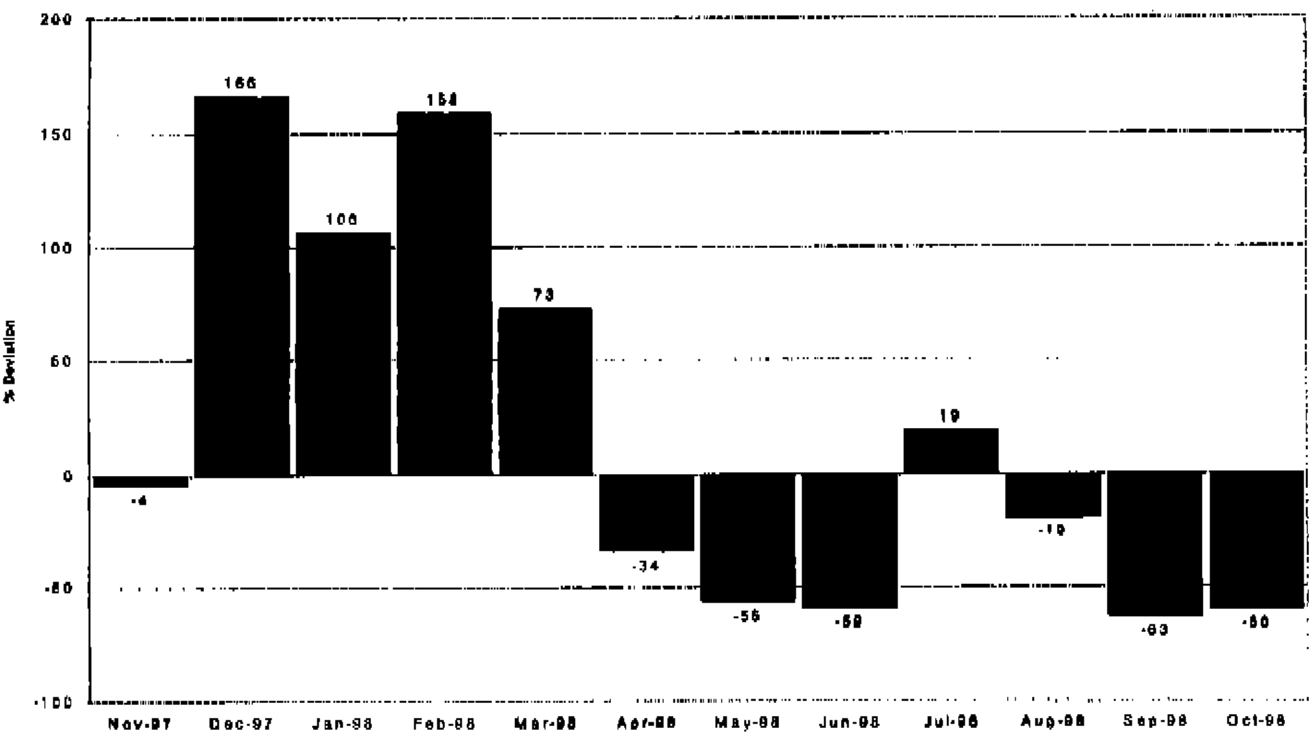

Figure B20.* *Palm Beach Rain Area Deviation from Historic Monthly Average Rainfall November 1997 through October 1998

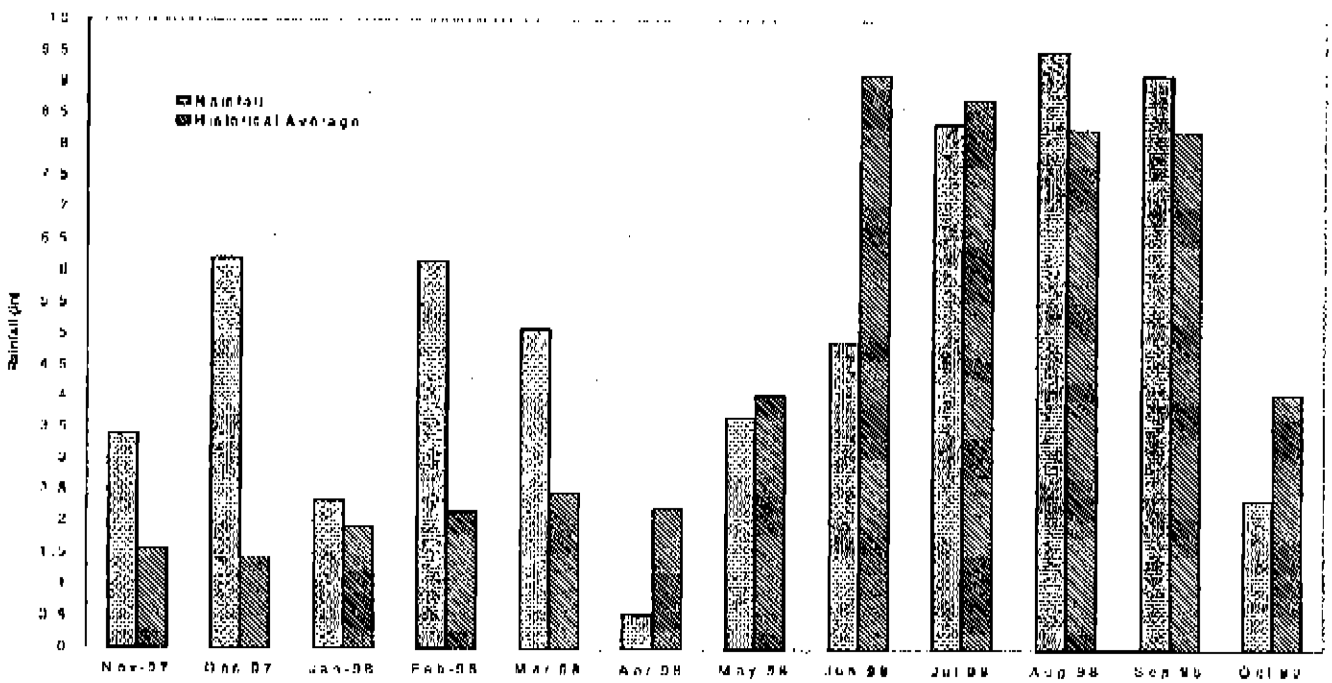

Figure B21. *Southwest Coast Rain Area Monthly Rainfall November 1997 through October 1998 vs. Historic Monthly Average Rainfall*

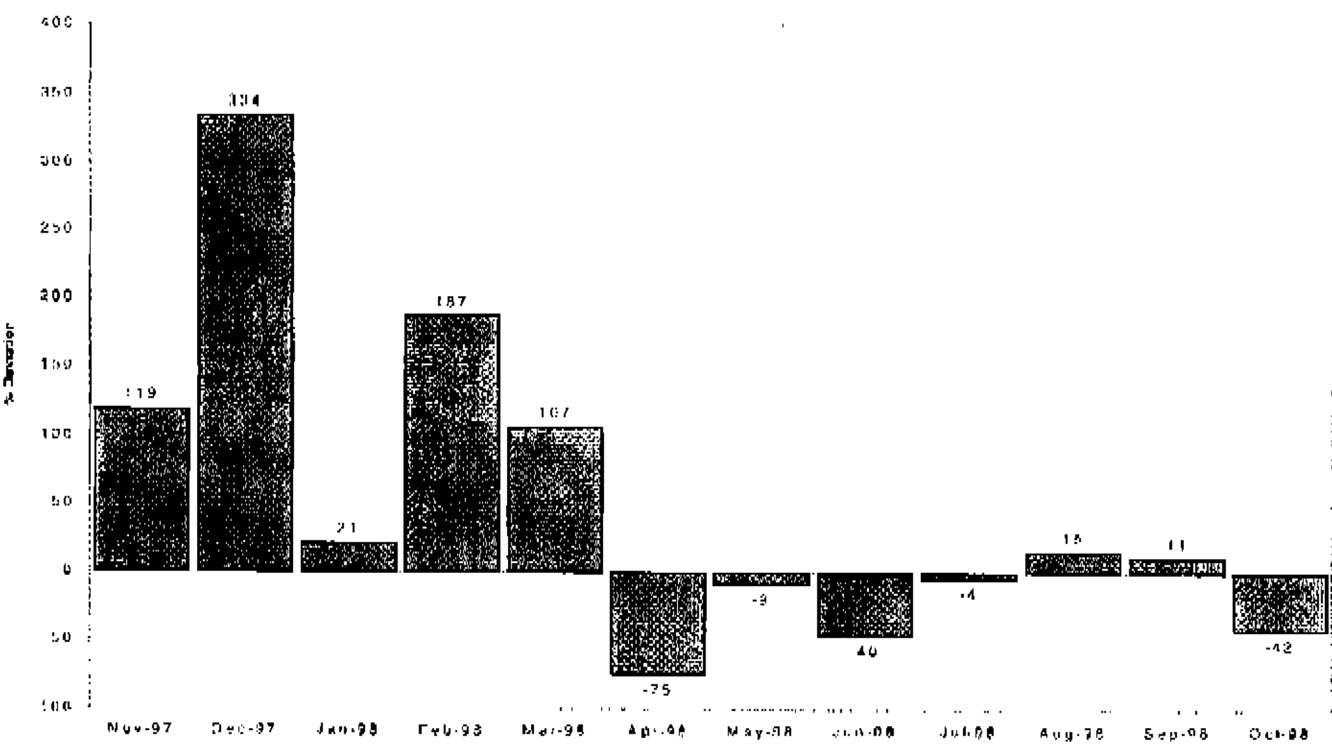

Figure B22. *Southwest Coast Rain Area Percent Deviation from Historic Monthly Average Rainfall November 1997 through October 1998*

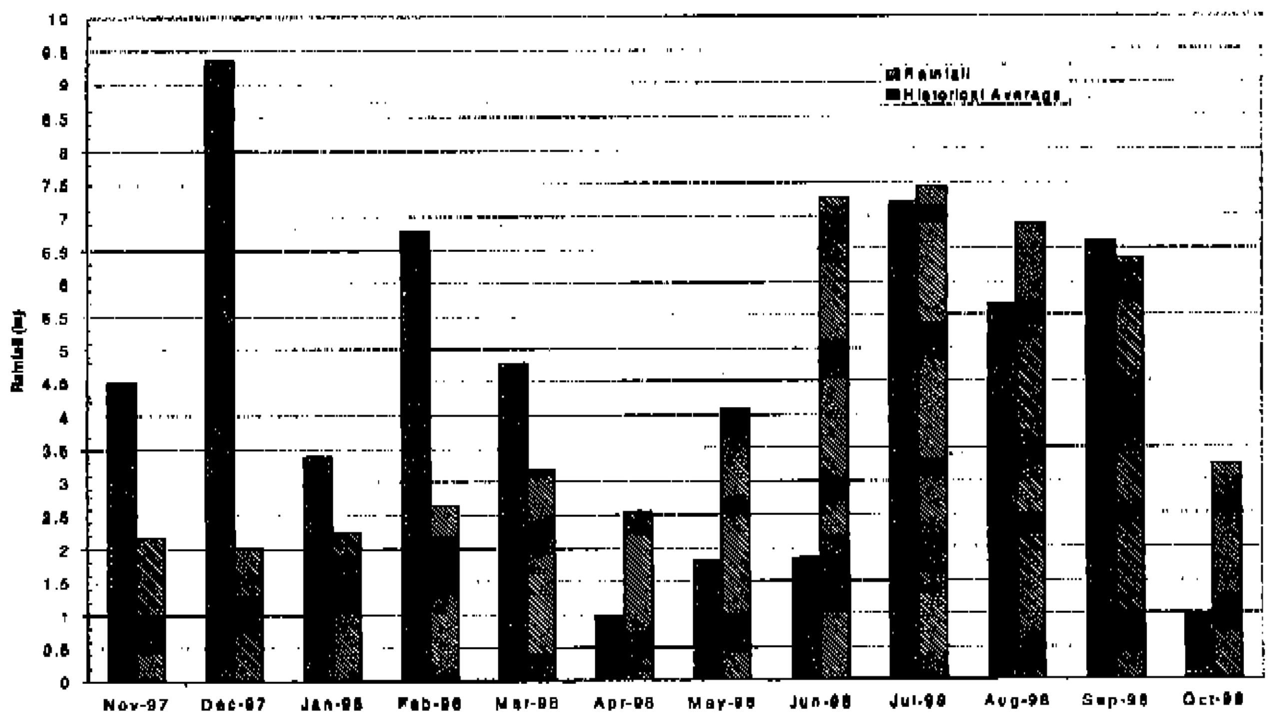

Figure B23. *Upper Kissimmee Rain Area Monthly Rainfall November 1997 through October 1998 vs. Historic Monthly Average Rainfall*

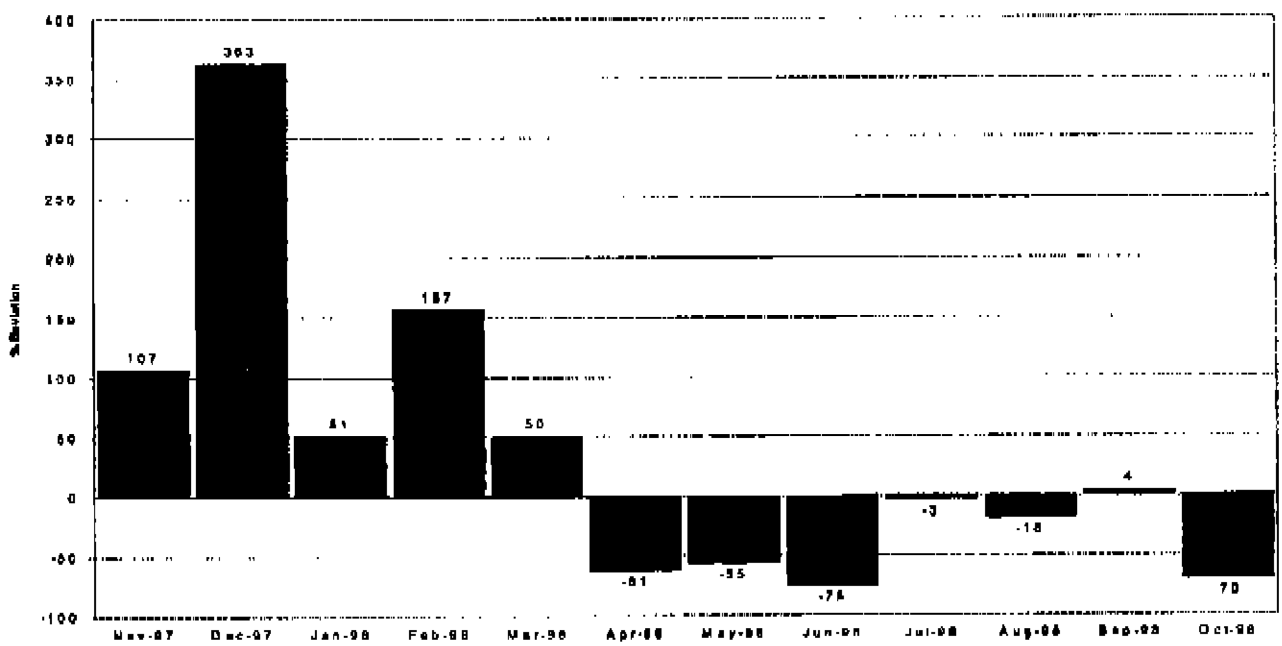

Figure B24. *Upper Kissimmee Rain Area Percent Deviation from Historic Monthly Average Rainfall November 1997 through October 1998*

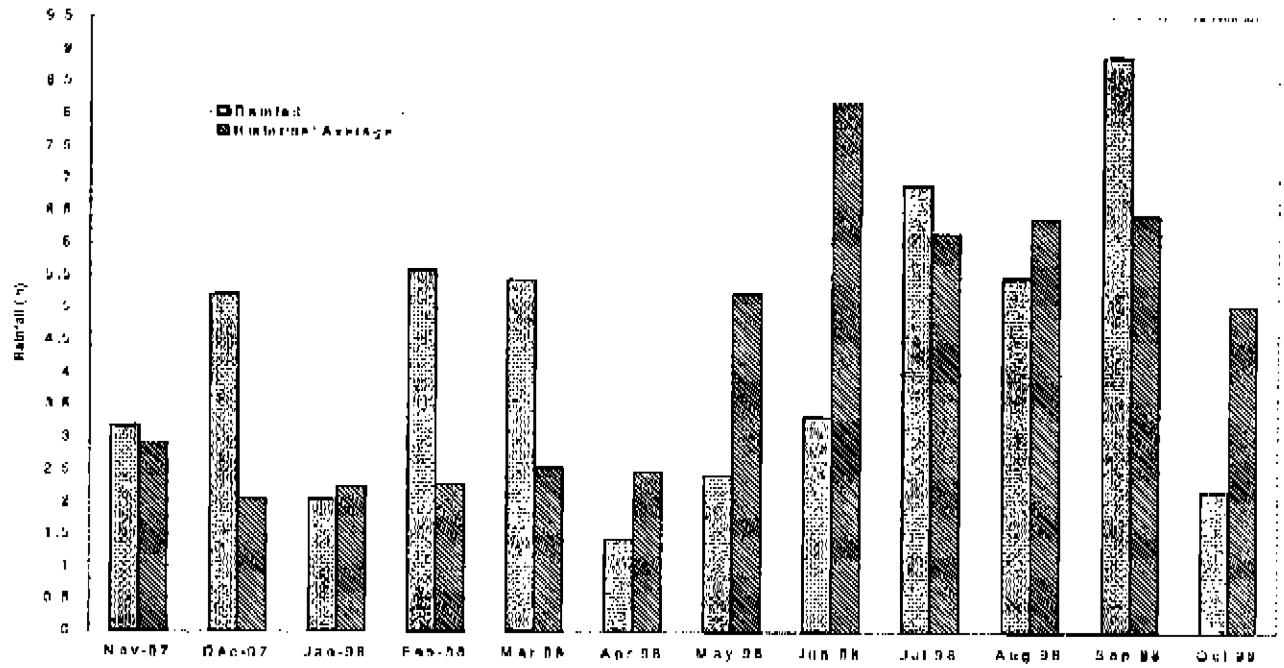

***Figure B25.** WCA 1&2 Rain Area Monthly Rainfall November 1997 through October 1998 vs. Historic Monthly Average Rainfall*

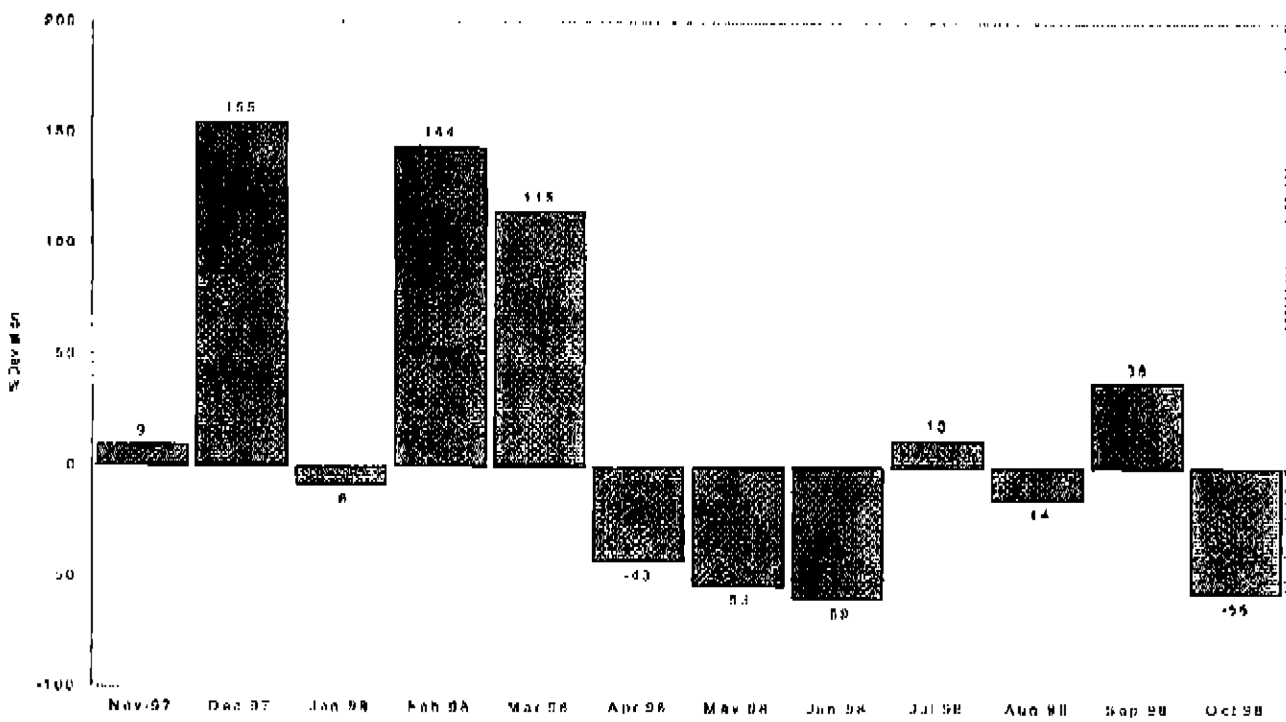

***Figure B26.** WCA 1&2 Rain Area Percent Deviation from Historic Monthly Average Rainfall November 1997 through October 1998*

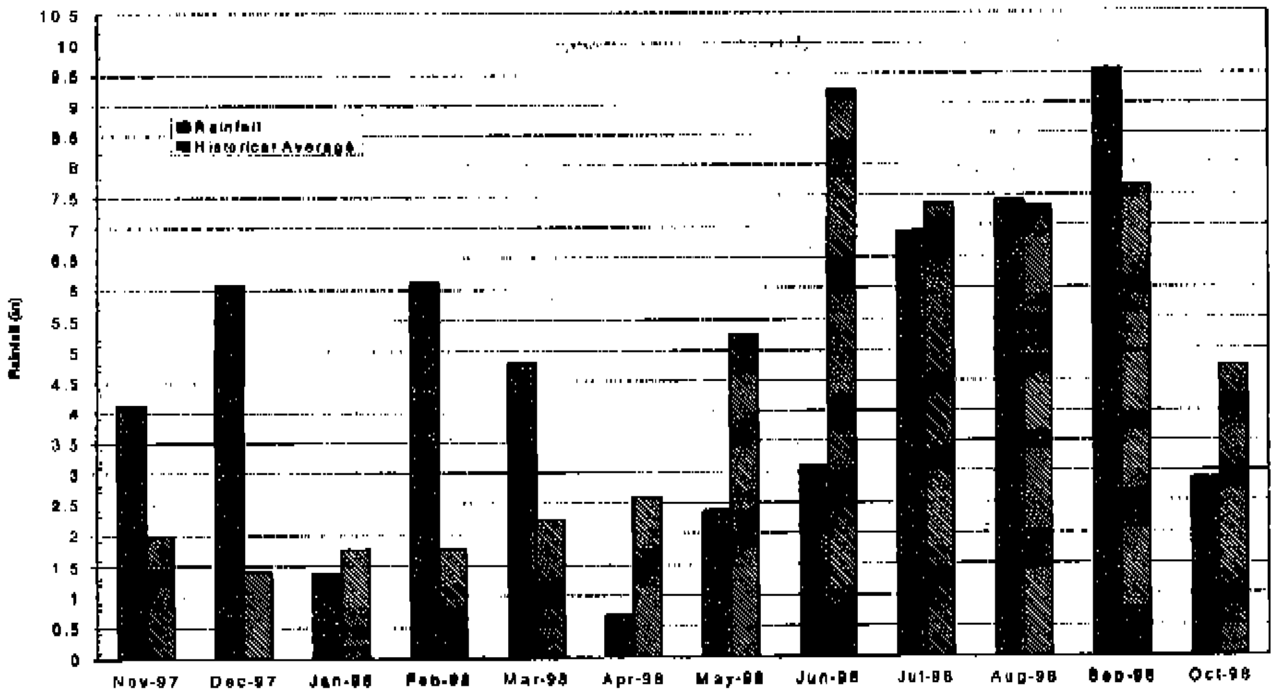

Figure B27. *WCA 3 Rain Area Monthly Rainfall November 1997 through October 1998 vs. Historic Monthly Average Rainfall*

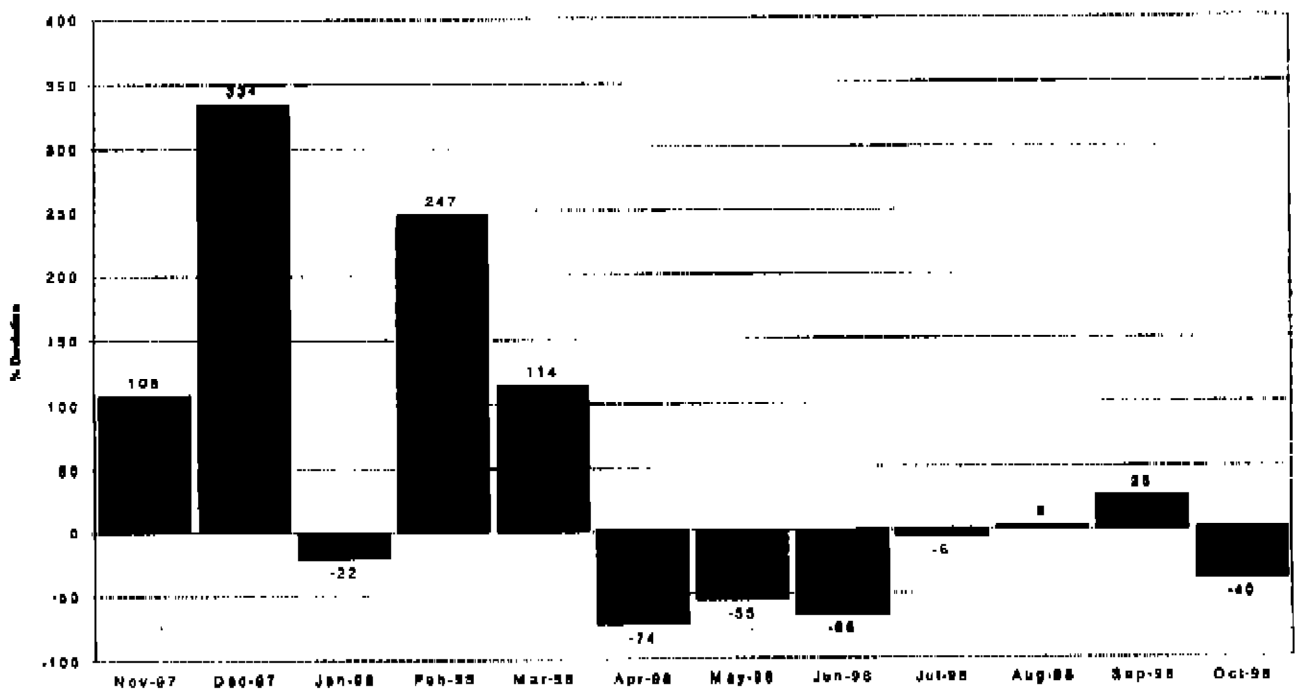

Figure B28. *WCA 3 Rain Area Percent Deviation from Historic Monthly Average Rainfall November 1997 through October 1998*

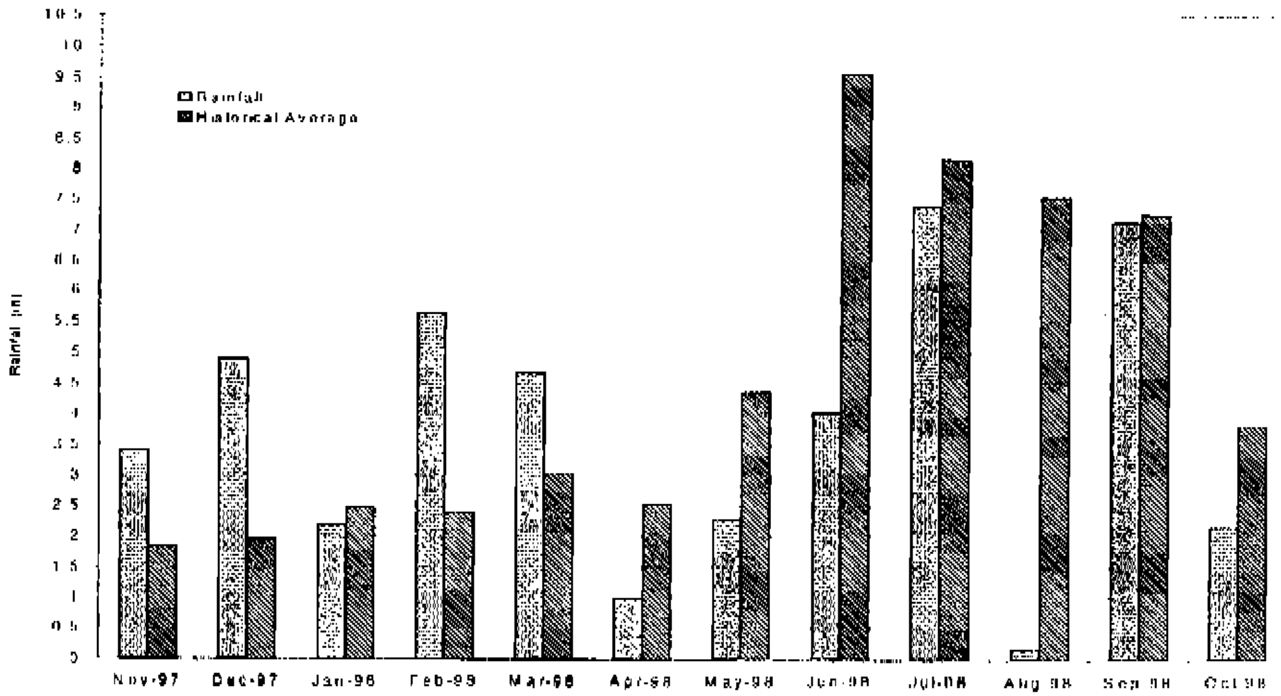

***Figure B29.** West Ag Rain Area Monthly Rainfall November 1997 through October 1998 vs. Historic Monthly Average Rainfall*

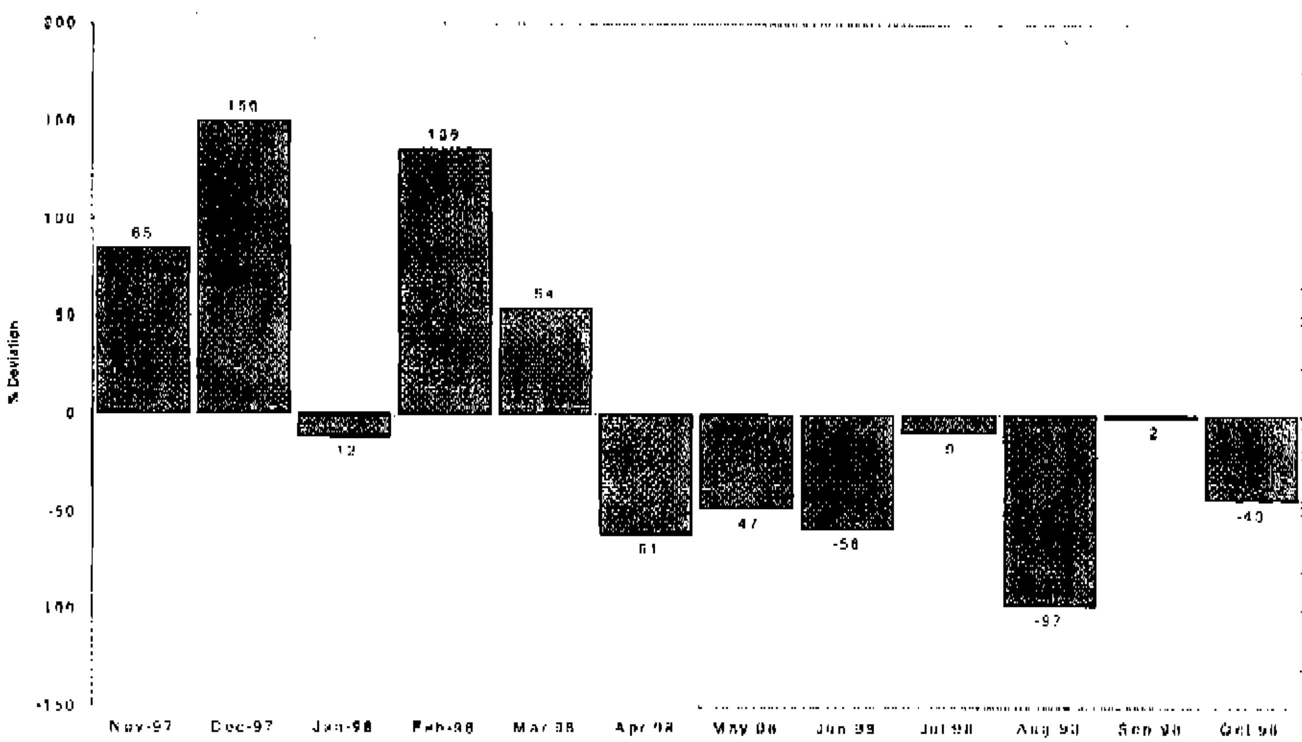

***Figure B30.** West Ag Rain Area Percent Deviation from Historic Monthly Average Rainfall November 1997 through October 1998*

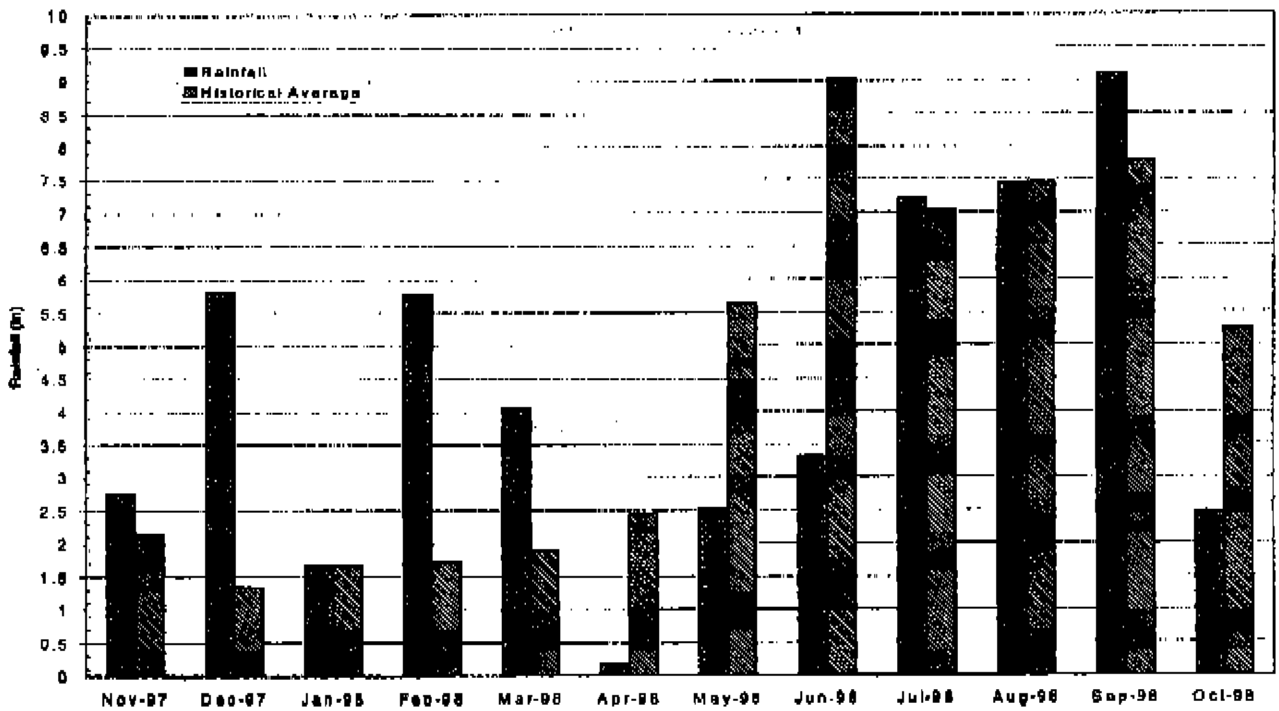

Figure B31. Everglades National Park (ENP) Rain Area Monthly Rainfall November 1997 through October 1998 vs. Historic Monthly Average Rainfall

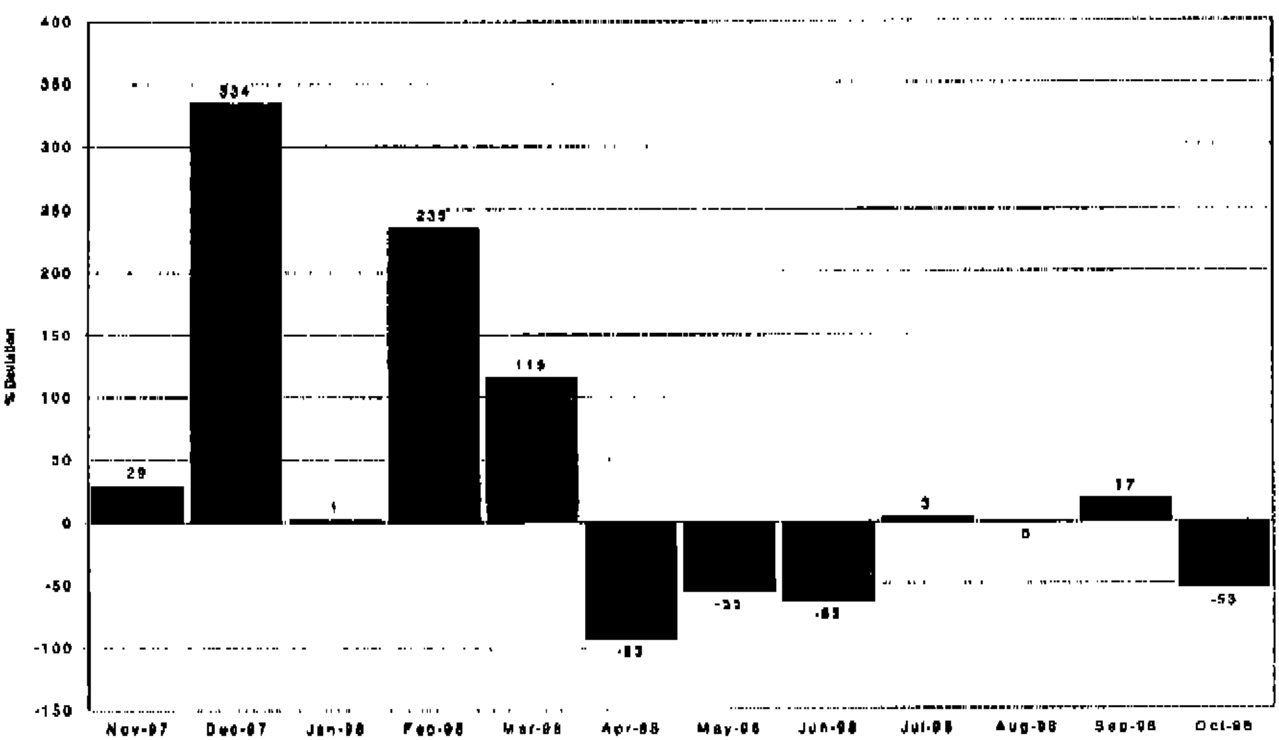

Figure B32. Everglades National Park (ENP) Rain Area Percent Deviation from Historic Monthly Average Rainfall November 1997 through October 1998

Appendix C

Deviation in Monthly Average Estimated Potential Evapotranspiration Niño/La Niña vs. Monthly Historic Averages at Four Meteorological Stations

Table C1. Computed Evapotranspiration November 1997 through October 1998

Station	Station Description	Deviation From Hist. Average
L006	LAKE OKEECHOBEE TOWER SOUTH (#6)	-2.84
S65CW	WEATHER STATION NEAR S-65C SPILLWAY ON CANAL C-38	-2.21
BIG CY SIR	BIG CYPRESS @ SEMINOLE INDIAN RESERVATION	0.00
ENR308	WEATHER STATION NEAR INTERIOR LEVEE IN CELL3	-1.11
S331W	S-331 WEATHER STATION ON L-31N	-0.84

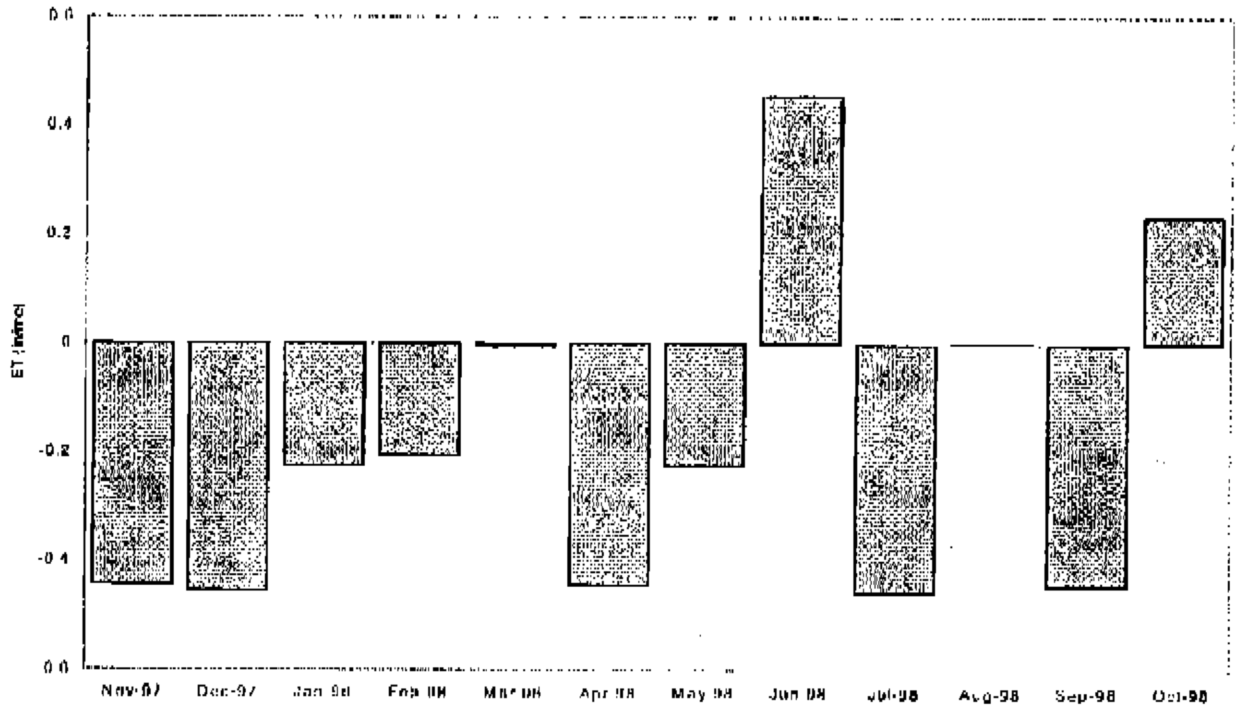

Figure C1. Deviation in Monthly Average Estimated Evapotranspiration from Monthly Historic Averages at Station S65CW November 1997 through October 1998

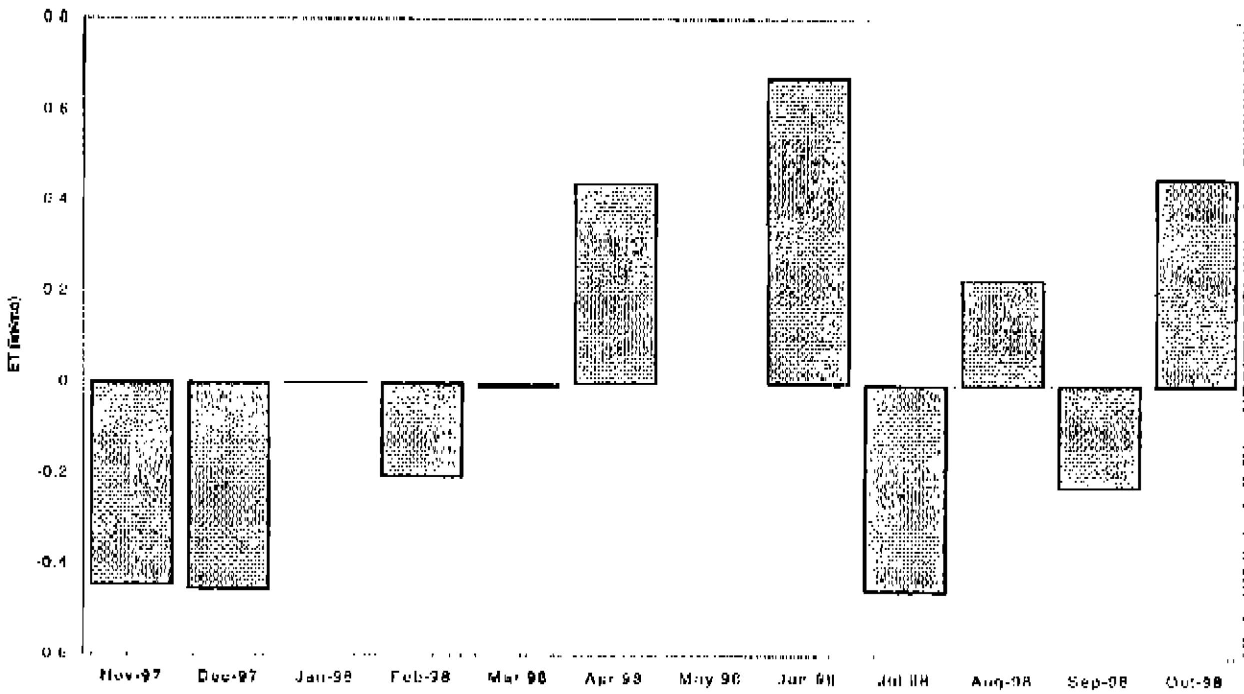

Figure C2. Deviation in Monthly Average Estimated Evapotranspiration from Monthly Historic Averages at Station BIG_CY_SIR November 1997 through October 1998

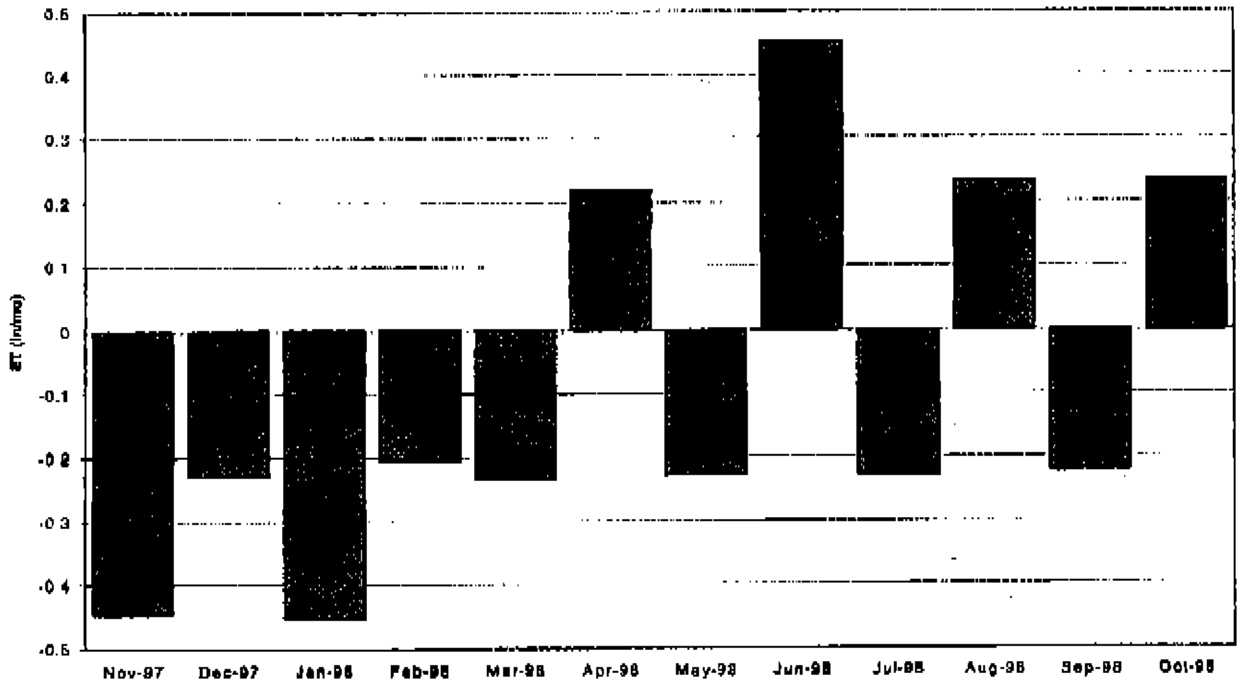

Figure C3.* *Deviation in Monthly Average Estimated Evapotranspiration from Monthly Historic Averages at Station ENR308 November 1997 through October 1998

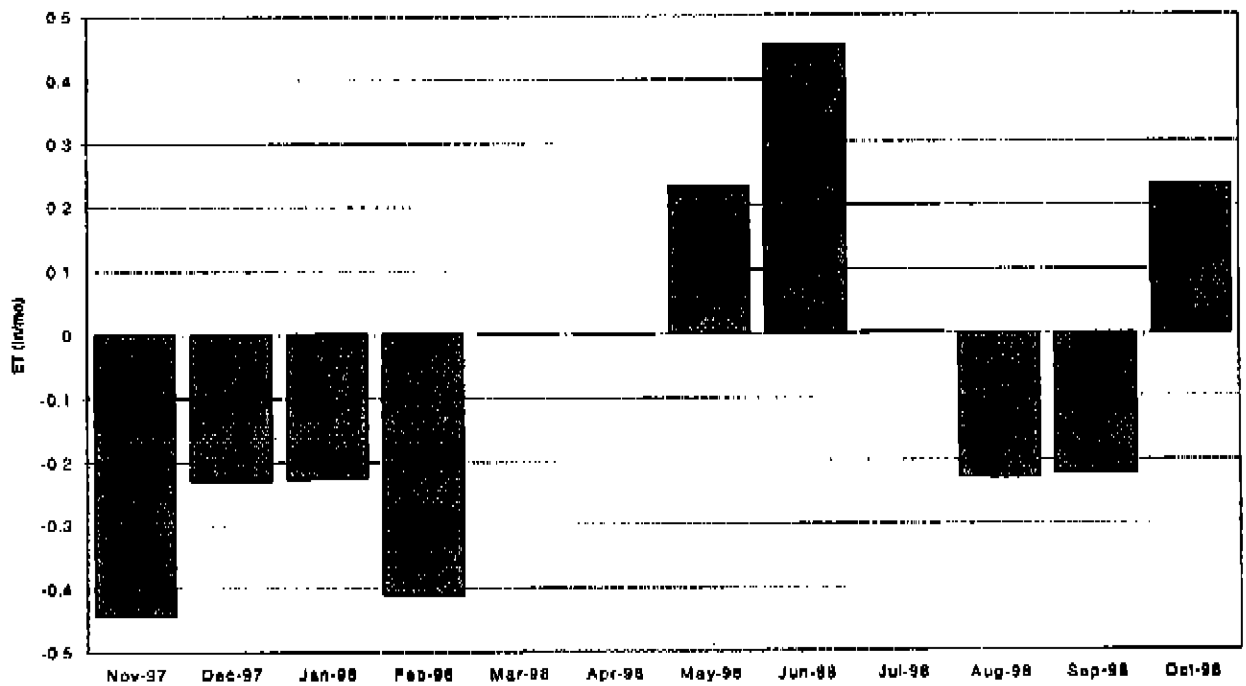

Figure C4.* *Deviation in Monthly Average Estimated Evapotranspiration from Monthly Historic Averages at Station S331W November 1997 through October 1998

Appendix D

Deviation in Monthly Average Ground Water Table Levels Niño/La Niña vs. Monthly Historic Averages at Twelve Key Indicator Wells

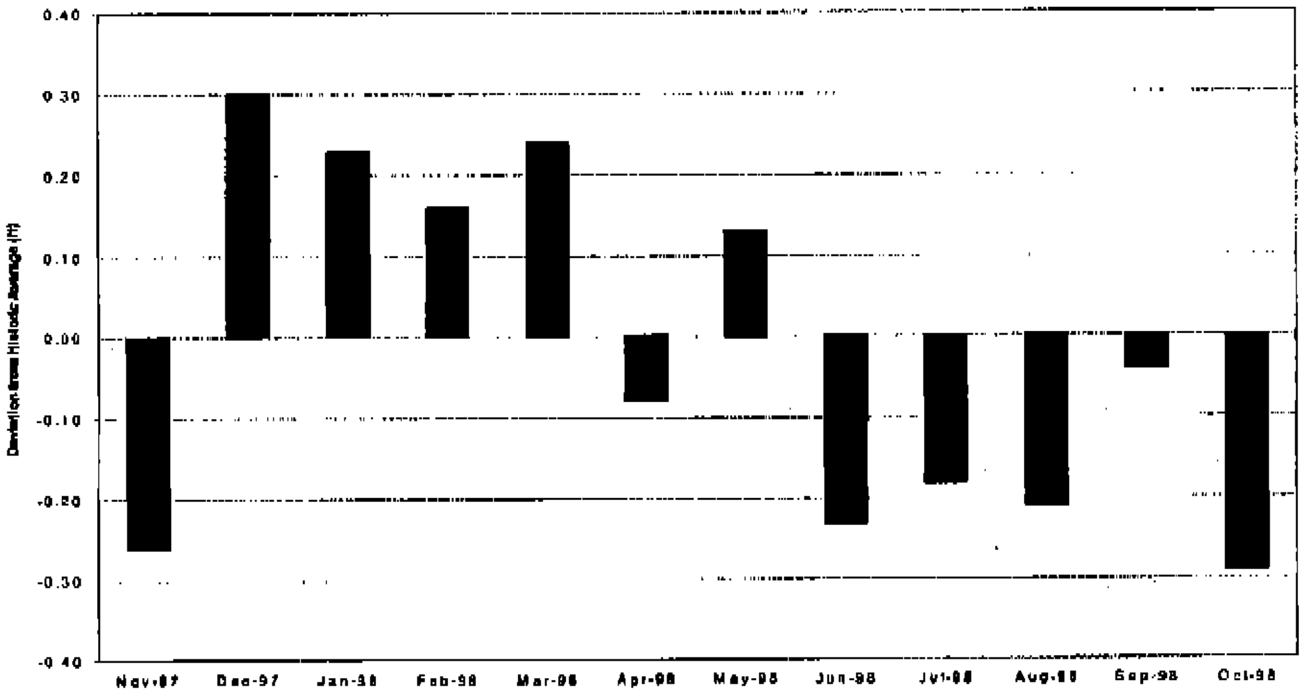

Figure D1. *Deviation in Monthly Average Ground Water Table Levels from Monthly Historic Averages at Well G-1183 in Dade County November 1997 through October 1998*

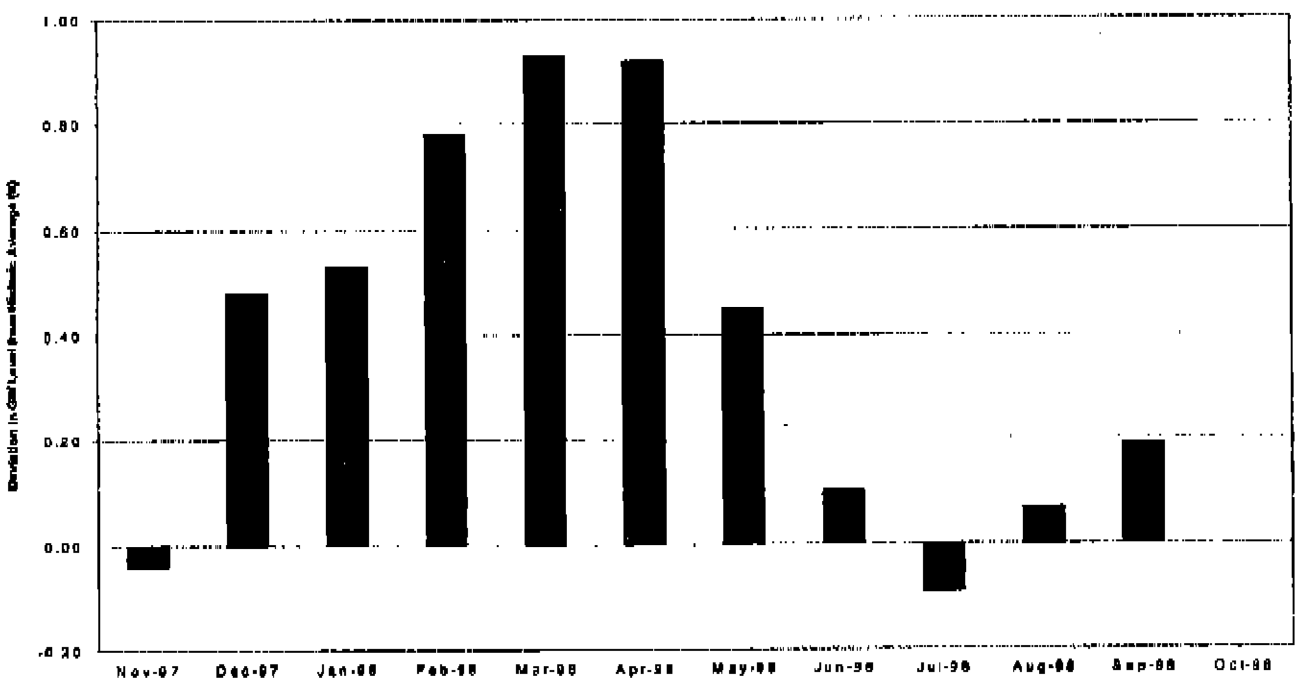

Figure D2. *Deviation in Monthly Average Ground Water Table Levels from Monthly Historic Averages at Well G-1251 in Everglades National Park November 1997 through October 1998*

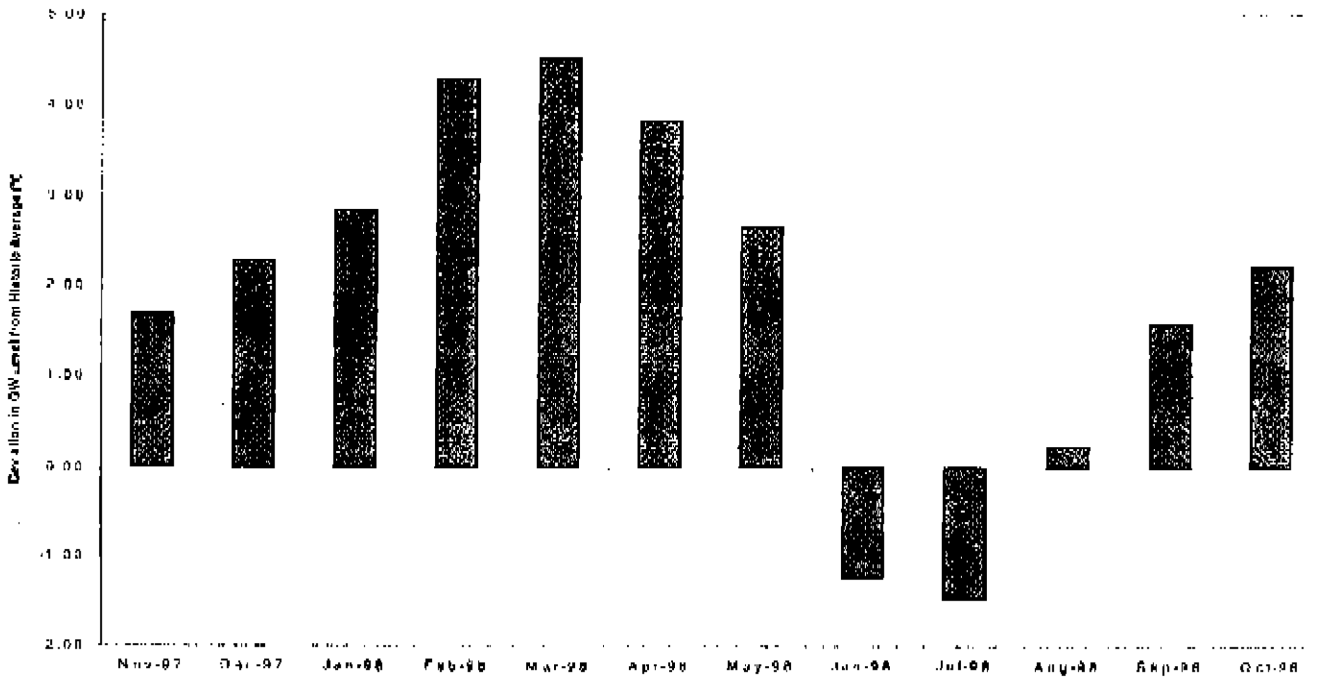

Figure D3. *Deviation in Monthly Average Ground Water Table Levels from Monthly Historic Averages at Well G 853 in Broward County November 1997 through October 1998*

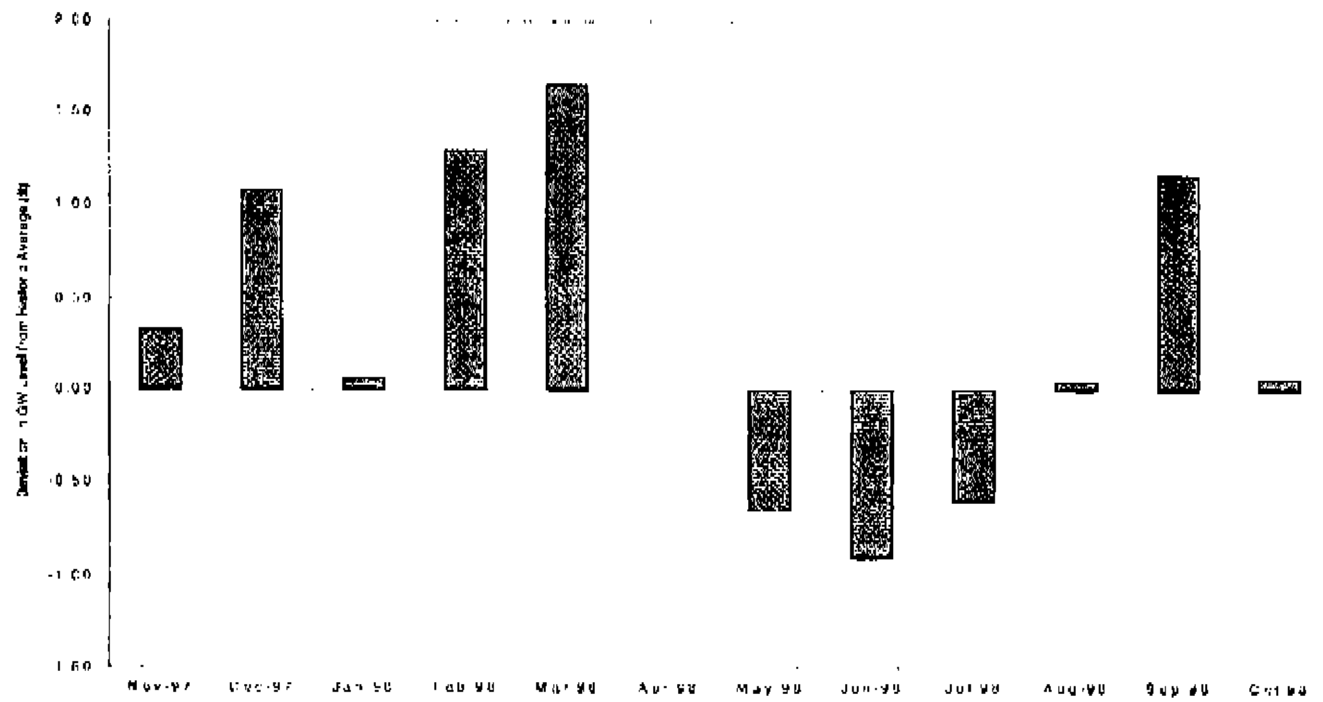

Figure D4. *Deviation in Monthly Average Ground Water Table Levels from Monthly Historic Averages at Well M-1090 in Martin County November 1997 through October 1998*

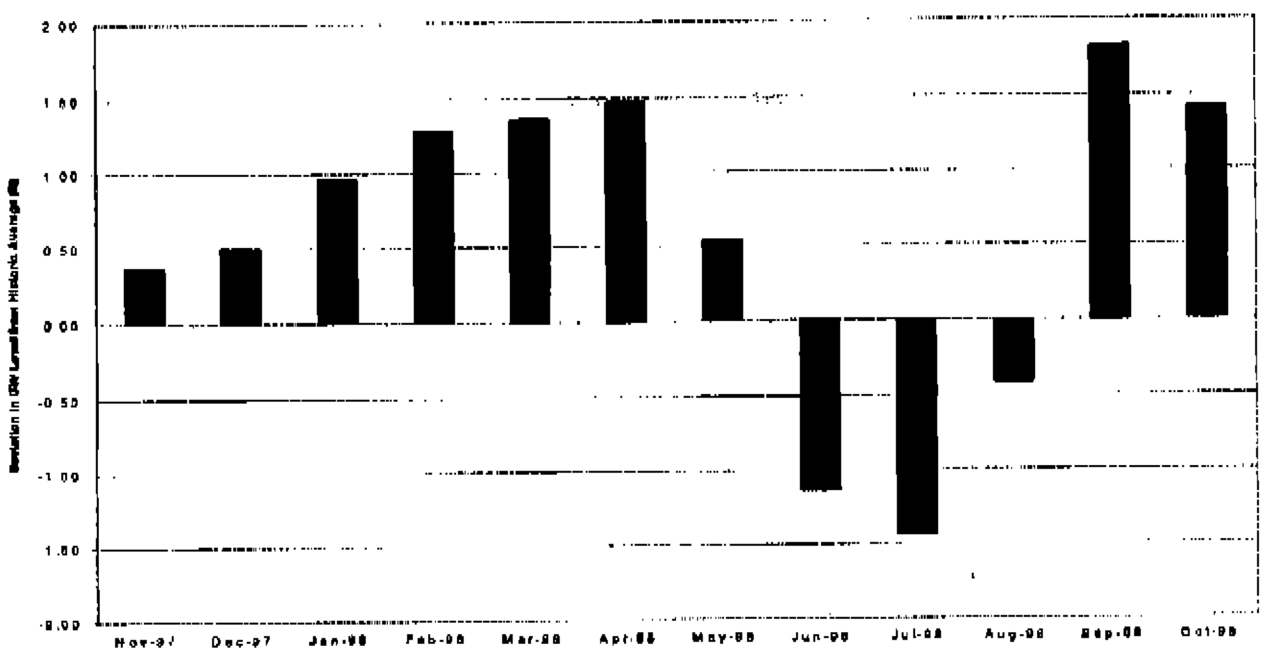

***Figure D5.* Deviation in Monthly Average Ground Water Table Levels from Monthly Historic Averages at Well STL-125 in St. Lucie County November 1997 through October 1998**

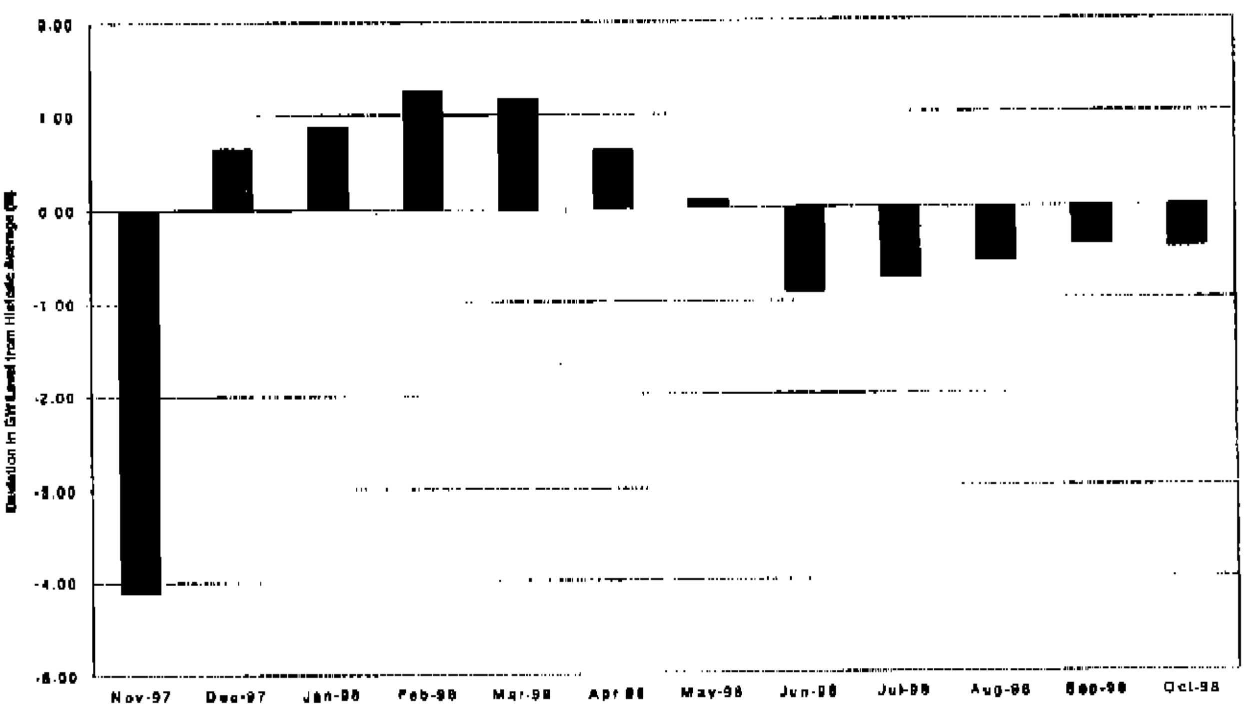

***Figure D6.* Deviation in Monthly Average Ground Water Table Levels from Monthly Historic Averages at Well L-730 in the Lower West Coast November 1997 through October 1998**

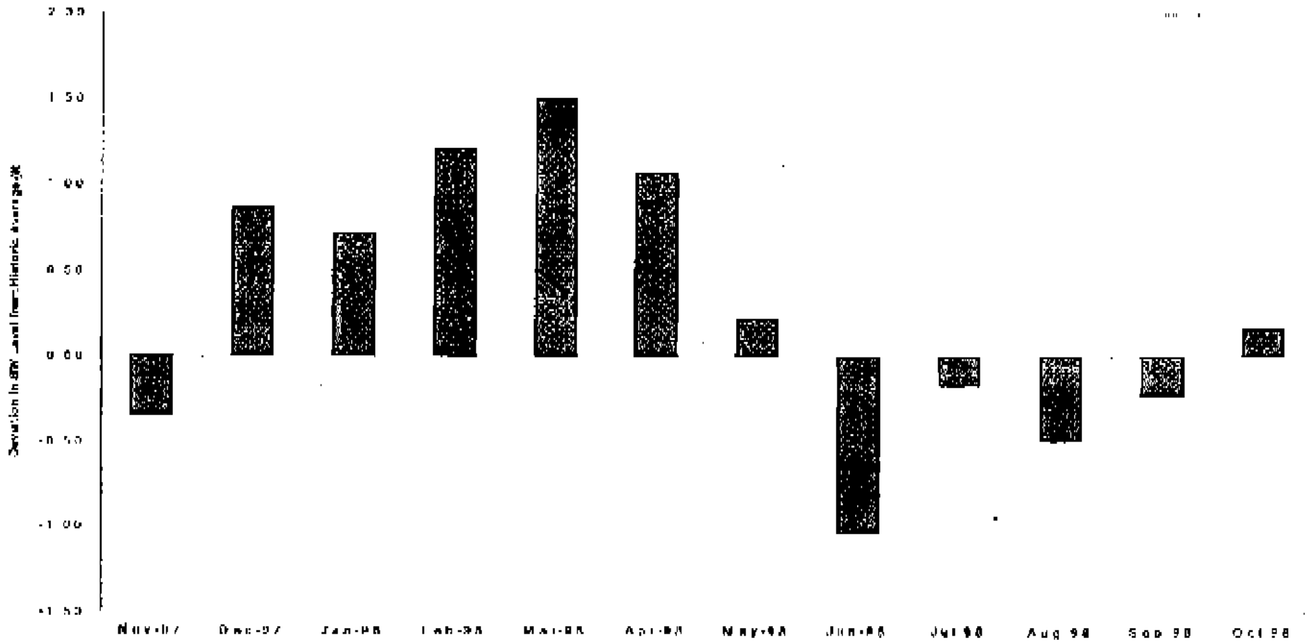

Figure D7. *Deviation in Monthly Average Ground Water Table Levels from Monthly Historic Averages at Well C-492 in the Lower West Coast November 1997 through October 1998*

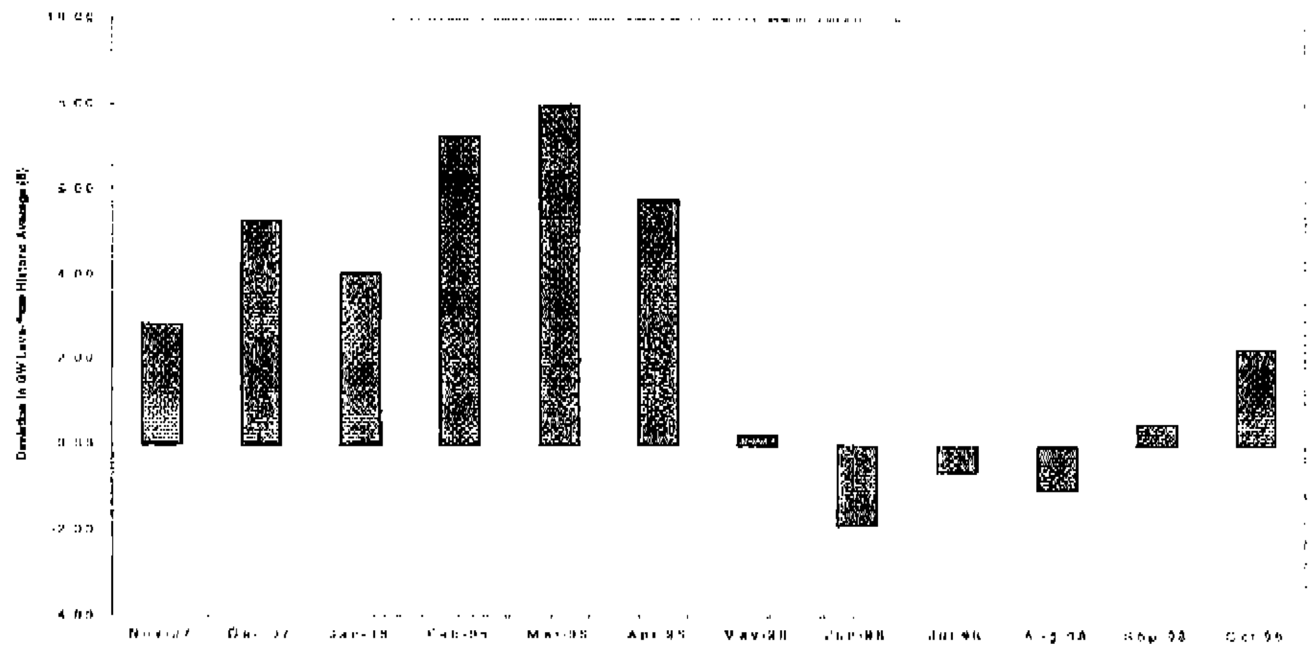

Figure D8. *Deviation in Monthly Average Ground Water Table Levels from Monthly Historic Averages at Well L-731 in the Lower West Coast November 1997 through October 1998*

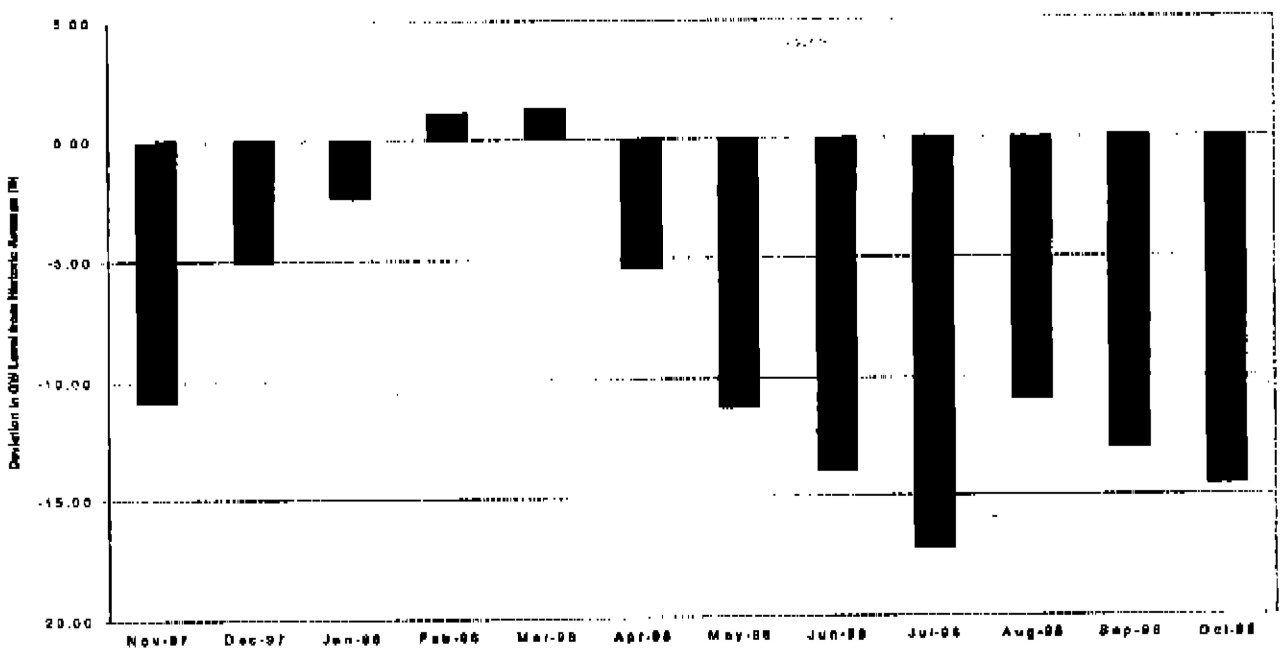

Figure D9. *Deviation in Monthly Average Ground Water Table Levels from Monthly Historic Averages at Well L-581 in the Lower West Coast November 1997 through October 1998*

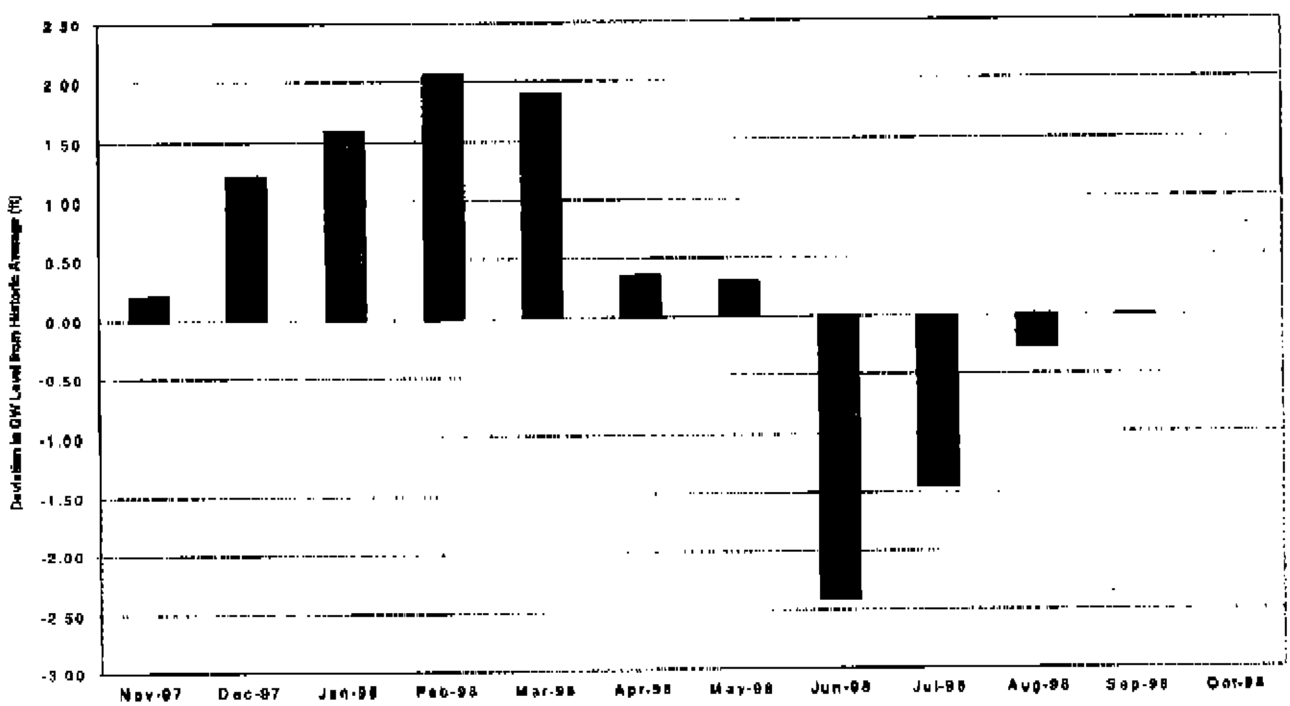

Figure D10. *Deviation in Monthly Average Ground Water Table Levels from Monthly Historic Averages at Well OK-1 in Okeechobee County November 1997 through October 1998*

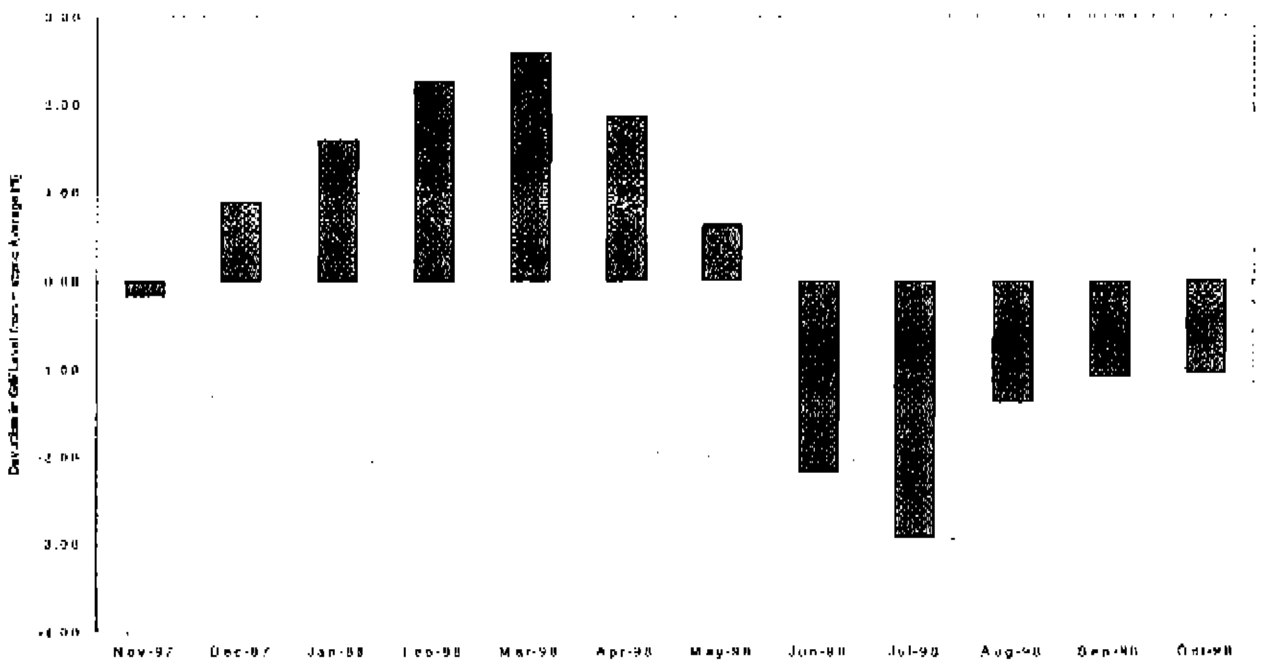

***Figure D11.** Deviation in Monthly Average Ground Water Table Levels from Monthly Historic Averages - Well at Lake Joel in Osceola County November 1997 through October 1998*

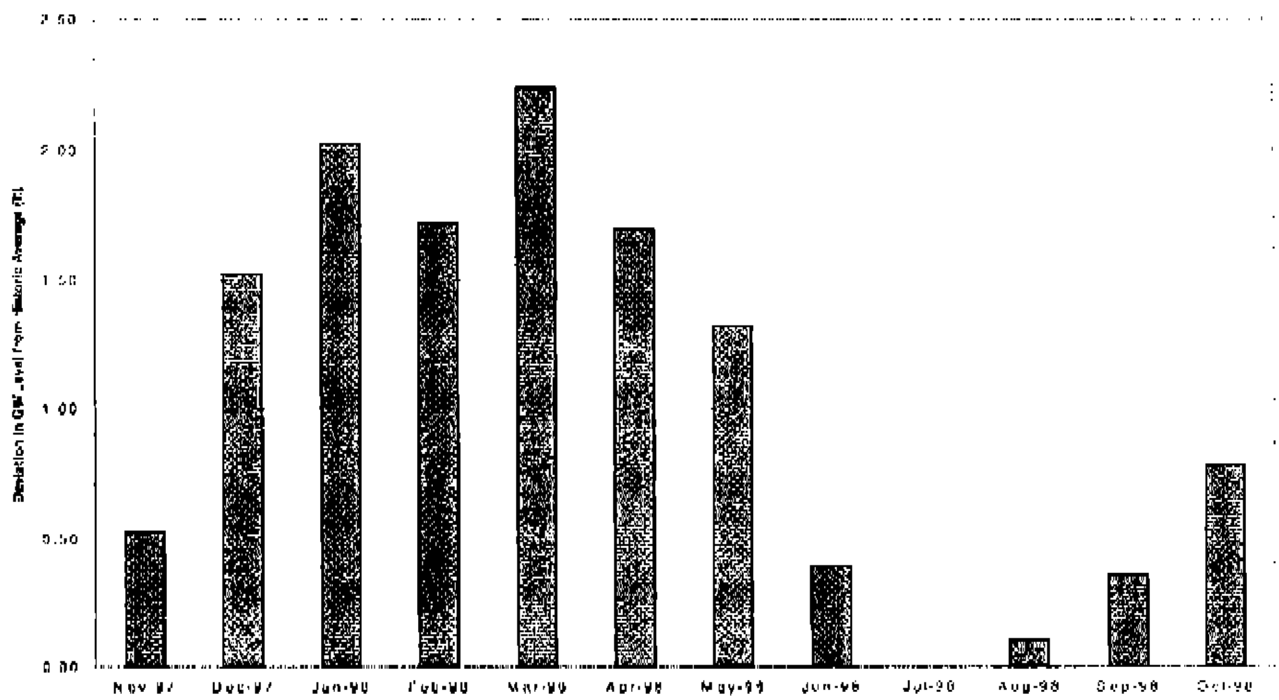

***Figure D12.** Deviation in Monthly Average Ground Water Table Levels from Monthly Historic Averages - Well at Lake Oliver in Orange County November 1997 through October 1998*

Appendix E

Monthly Average Inflows for the Caloosahatchee River at S79 and and St. Lucie Estuary at S49, S80 and S97

Table E1. Caloosahatchee River at S79 - Monthly Inflow

(DB Key)	El Niño / La Niña Flow (cfs) (DJ237)	Historic Average Flow (cfs) (00865)
NOV-97	360.03	987.46
Dec-97	2639.29	663.24
Jan-98	5296.35	1231.41
Feb-98	8308.29	1518.15
Mar 98	10143.61	1852.63
Apr 98	6114	1296.33
May 98	1947.81	721.36
Jun 98	432.5	1949.96
Jul-98	725.16	2393.37
Aug 98	2928.39	2812
Sep 98	2586.27	2330.93
Oct-98	928.23	2007.32

Table E2. St. Lucie Estuary at S49 – Monthly Inflow

(DB Key)	El Niño / La Niña Flow (cfs) (15777)	Historic Average Flow (cfs) (04790)
Nov 97	60.85	114.7
Dec 97	215.31	49.57
Jan-98	292.41	92.78
Feb-98	531.06	82.58
Mar-98	395.76	94.74
Apr-98	4.64	47.78
May-98	190.47	77.51
Jun 98	6.2	214.8
Jul-98	98.43	230.93
Aug-98	287.06	266.74
Sep-98	689.09	343.71
Oct-98	147.66	234.88

Table E3. St. Lucie Estuary at S80 – Monthly Inflow

(DB Key)	El Niño / La Niña Flow (cfs) (DJ238)	Historic Average Flow (cfs) (00286)
Nov-97	6.37	957.79
Dec-97	616	555.05
Jan-98	2298.68	500.96
Feb-98	4063.5	553.86
Mar-98	7152.42	761.84
Apr-98	4450.83	811.84
May-98	888.74	382.85
Jun-98	41.73	576.29
Jul-98	11.13	838.49
Aug-98	109.97	1224.11
Sep-98	577.33	939.8
Oct-98	148.74	1101.72

Table E4. St. Lucie Estuary at S97 – Monthly Inflow

(DB Key)	El Niño / La Niña Flow (cfs) (15780)	Historic Average Flow (cfs) (04850)
Nov-97	460.39	253.88
Dec-97	0.15	180.28
Jan-98	198.11	232.23
Feb-98	586.4	250.56
Mar-98	265.34	194.01
Apr-98	0.07	138.79
May-98	0.16	72.67
Jun-98	0	223.43
Jul-98	0.1	306.25
Aug-98	209.99	338.11
Sep-98	340.86	306.94
Oct-98	49.34	311.1