Chapter 5: Hydrology of the South Florida Environment

Wossenu Abtew, R. Scott Huebner and Violeta Ciuca

SUMMARY

Given hydrology's significance to the entire South Florida environmental restoration and water management functions of the South Florida Water Management District (SFWMD or District), it is presented in this separate chapter of the *2005 South Florida Environmental Report – Volume I*. This chapter updates hydrologic data and analysis from the 2004 Everglades Consolidated Report (ECR), and expands coverage to address the hydrology of the area within the District's boundaries while providing a more comprehensive overview of the South Florida hydrology. The 2004 ECR covered only the Everglades Protection Area (EPA). Presented in this chapter is the hydrology of the major hydrologic systems from the Upper Kissimmee Chain of Lakes in the north to the Everglades National Park (Park or ENP) in the south. Rainfall, potential evapotranspiration (ETp), water levels, inflows, and outflows are presented for Water Year 2004 (WY2004) (May 1, 2003 to April 30, 2004). Hydrologic conditions in WY2004 were compared with WY2003. Historical hydrologic data also were analyzed and compared with WY2004 and WY2003 hydrology. This chapter does not include comparisons of current hydrology with predevelopment hydrology.

Overall, no extreme hydrologic event (e.g., El Niño, La Niña, hurricanes, or drought) occurred during WY2004 in this area. For the current reporting year, rainfall in the Upper Kissimmee and Lower Kissimmee rainfall areas was close to average, while the Lake Okeechobee, Martin-St. Lucie, and East Everglades Agricultural Area (EAA) rainfall areas had lower than average rainfall. The east coast, excluding Broward County and the ENP, had lower than average rainfall, and the west coast had higher than average rainfall. ETp or evaporation from lakes, wetlands, and impoundments was close to the expected District-wide average of 52.6 inches.

During WY2004, monthly average water levels in most of the lakes in the Upper Kissimmee Chain of Lakes (Lake Alligator, Lake Myrtle, Lake Mary Jane, Lake Gentry, Lake East Tohopekaliga, and Lake Tohopekaliga) were generally close to WY2003 levels and current regulation schedules, except for Lake Tohopekaliga. In WY2004, ecological drawdown was implemented on Lake Tohopekaliga and deviations were made from the regular regulation schedule. A water level decline of 4.5 feet (ft) was observed from December 2003 through April 2004. Lake Kissimmee average water level in WY2004 [50.24 ft National Geodetic Vertical Datum (NGVD)] was lower than that of WY2003, whereas Lake Okeechobee average water level (15.62 ft NGVD) was higher than the WY2003 average water level of 14.76 ft NGVD. Lake Istokpoga average water level in WY2004 (39.06 ft NGVD) was close to the WY2003 average water level.

The average water level in Water Conservation Area 1 (WCA-1) for WY2004 was 16.50 ft NGVD. It was higher than the WY2003 average water level of 16.22 ft NGVD, and higher than the historical average of 15.56 ft NGVD. In the current reporting year, the average water level in WCA-2 was 12.40 ft NGVD. It was higher than the WY2003 average water level of 12.17 ft NGVD, but lower than the historical average of 12.58 ft NGVD. During WY2004, the average water level in WCA-3 was 10.30 ft NGVD. It was higher than the WY2003 water level average of 10.07 ft NGVD, as well as the historical average of 9.50 ft NGVD. In WY2004, the average water level in the Park at site P-33 was 6.68 ft NGVD. It was higher than the WY2003 water level average of 6.35 ft NGVD, as well as the historical average of 5.96 ft NGVD. In WY2004, the average water level in the Park at site P-34 was 3.09 ft NGVD. It was also higher than the WY2003 average water level of 2.53 ft NGVD, as well as the historical average of 2.04 ft NGVD.

During WY2004, surface water outflow through Lake Kissimmee was 1,193,153 acre-feet (ac-ft), and Lake Istokpoga discharge was 401,631 ac-ft. Lake Okeechobee inflows were 2,920,448 ac-ft, and outflows were 2,617,958 ac-ft. Discharge into the Southern Indian River Lagoon and St. Lucie Estuary was 1,103,338 ac-ft, with 688,528 ac-ft discharged through the St. Lucie Canal outflow structure S-80. Discharge into the Caloosahatchee Estuary through the S-79 structure was 2,445,277 ac-ft. Inflows to WCA-1 were 334,957 ac-ft, and outflows were 269,603 ac-ft. In this reporting period, both inflows and outflows were about half as much as the WY2003 flows. WY2004 inflows to WCA-2 were 520,641 ac-ft, and outflows were 749,663 ac-ft. Inflows were lower and outflows were higher in WY2004 than in WY2003. WY2004 inflows to WCA-3 were 1,053,423 ac-ft, and outflows were 1,221,322 ac-ft. These inflows were about the same as WY2003 inflows, but higher than WY2003 outflows. Inflows to the Park were 1,251,807 ac-ft, which were higher than those in WY2003.

INTRODUCTION

The South Florida Water Management District (SFWMD or District) area extends from Orlando in the north to the Florida Keys in the south (**Figure 5-1**). The SFWMD system consists of lakes, impoundments, wetlands, and canals that are managed under a water management schedule based on flood control, water supply, and environmental enhancement. The general surface water direction is from the north to the south, but there are also water supply and coastal discharges to the east and west. The major hydrologic components are comprised of the Upper Kissimmee Chain of Lakes, the Lower Kissimmee River, Lake Okeechobee, Lake Istokpoga Surface Water Management Basin, the Everglades Agricultural Area (EAA), the Caloosahatchee Basin, St. Lucie Basin, and the Everglades Protection Area (EPA).

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

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

Lake Okeechobee is the center of the South Florida hydrologic system, with an area of 730 square miles and a mean depth of 8.86 feet (ft). Since 1931, the average water level elevation has been 14.1 ft National Geodetic Vertical Datum (NGVD), with a maximum 18.77 ft NGVD set on November 2, 1947. The lowest water level in record for the lake was 8.97 ft NGVD, set on May 24, 2001 during the 2000–2001 drought in South Florida. The annual average inflow to Lake Okeechobee (1972–2001) is about 2 million acre-feet (ac-ft), while the average outflow is about 1.3 million ac-ft. Outflows are mainly through the south, southeast, and southwest structures. About 10 percent of the outflow is lakewater flow through the EAA, with most of it reaching the EPA (Abtew and Khanal, 1994; Abtew et al., 2002).

The EAA is the main source of surface water inflow into the EPA. On the average, about 900,000 ac-ft of water is discharged from the EAA to the south and southeast, mostly discharging into the EPA (Abtew and Khanal, 1994; Abtew and Obeysekera, 1996).

The EPA begins at the southern and eastern edges of the EAA, and extends south to Florida Bay. The EPA consists several defined regions: the Arthur R. Marshall Loxahatchee National Wildlife Refuge (Refuge), which contains WCA-1 (221 square miles); WCA-2A and WCA-2B (210 square miles); WCA-3A and WCA-3B (915 square miles); Everglades National Park (ENP or Park) (2,150 square miles); and Florida Bay, as shown in Redfield et al. (2003). The extent and components of the EPA are depicted in **Figure 5-1**. The EPA receives additional surface water inflows from the urban areas in the east, from the southeast, and from northwest sources currently identified as non-Everglades Construction Project (non-ECP) stormwater flows. Surface water flow into and out of the EPA is determined by weather-related factors and multi-objective water management decisions that include fixed regulation schedules, deviations, agreements, obligations, and emergency management. Emergency management includes flood control during high rainfall events, water supply during drought periods, saltwater intrusion, and environmental issues. From north to south, flood control and water supply are managed through systems of canals, stormwater detention ponds, lakes, impoundments, and water control structures. The major hydrologic components of the District are depicted in **Figure 5-1**.

The District has an intensive hydrologic monitoring network and database. The District's hydrometeorologic database DBHYDRO also stores data from other agencies such as the U.S. Geological Survey (USGS), the U.S. Army Corps of Engineers (USACE), National Oceanographic and Atmospheric Administration (NOAA), the ENP, Florida Forestry Service (FFS), Florida Department of Environmental Protection (FDEP), and others. Details of hydrometeorologic monitoring by the SFWMD are presented in Crowell and Mtundu (2000).

HYDROLOGY

RAINFALL

South Florida is a high-rainfall region, with frontal, convective, and tropical system-driven rainfall events. The heaviest rains in South Florida are produced by mesoscale convective systems; extratropical in the dry season and tropical in the rainy season (Rosenthal, 1994). In Central and South Florida (excluding the Florida Keys), 57 percent of total summer rainfall falls on undisturbed sea breeze days, 39 percent on disturbed days, and 4 percent on highly disturbed days (Burpee and Lahiff, 1984). The annual average rainfall on the entire region managed by the SFWMD is 52.8 inches (Ali and Abtew, 1999). The SFWMD area is divided into 14 rainfall areas for operational purposes. **Figure 5-2** depicts these rainfall areas and the ENP. Average annual rainfall for each rainfall area and the ENP is depicted in **Figure 5-3**. The source of annual rainfall statistics (Ali and Abtew, 1999) includes all areas except the Big Cypress Basin and WCA-3, which are from the meteorological analysis section of the District's Operations Control, Engineering and Vegetation Management Department. The annual basin rainfall for the ENP was estimated from an average annual rainfall isohyetal map for Central and South Florida (MacVicar, 1981), and from basin rainfall statistics (Sculley, 1986). The areal rainfall statistics were developed from varying lengths of record for each rainfall station and from a varying number of rainfall stations. The periods of record were 1900–1995 (Ali and Abtew, 1999), 1901–1980 (MacVicar, 1981), 1941–1985 (Sculley, 1986), and 1971–2000 (SFWMD).

In the District area, June is generally the wettest month, and December is the driest month. The wet season runs from June through October, and accounts for 66 percent of annual rainfall (Abtew et al., 2002). The dry season runs from November through May. During El Niño years, high rainfall falls in the dry season, resulting in water level rises and discharge through canals (Huebner, 2000). Extreme hydrometeorological and related events have significant effects on the region. El Niño conditions, hurricanes, and tropical systems are associated with high-rainfall events or seasons, and La Niña conditions and drought events result in dry conditions. El Niño occurs about once every 3 to 4 years (Huebner, 2000). Tropical systems are a frequent occurrence. The general area of the District has been affected by 42 hurricanes, 32 tropical storms, and nine tropical cyclones (a term used before modern hurricane categories were established) from 1871–1999 (Abtew and Huebner, 2000). Other conditions, such as local convective systems and regional frontal systems, have also been associated with high rainfall events.

Historically, the Palm Beach County rainfall area has the highest annual rainfall, followed by the Broward County and Miami-Dade rain areas. The District's east coast receives higher rainfall levels than the inland and west coast areas. Even during drought years, there were cases where the coastal rainfall was close to the average. Because there are no large impoundments in the coastal area, runoff is discharged to the Atlantic Ocean.

Dry periods in Florida result from stable atmospheric conditions that are often associated with high-pressure systems (Winsberg, 1990). These conditions can occur in any season, but are most common in winter and spring. Droughts are characterized by a significant decline in annual rainfall. They also promote the development and spread of wildfires. In Central and South Florida, severe droughts were reported in 1932, 1955–1957, 1961–1963, 1971–1972, 1973–1974, 1980–1982, 1985, 1988–1989, 1990, and 2000–2001 (Abtew et al., 2002). A minimum of one severe drought can be expected every 10 years. Historical droughts are identified by the historical

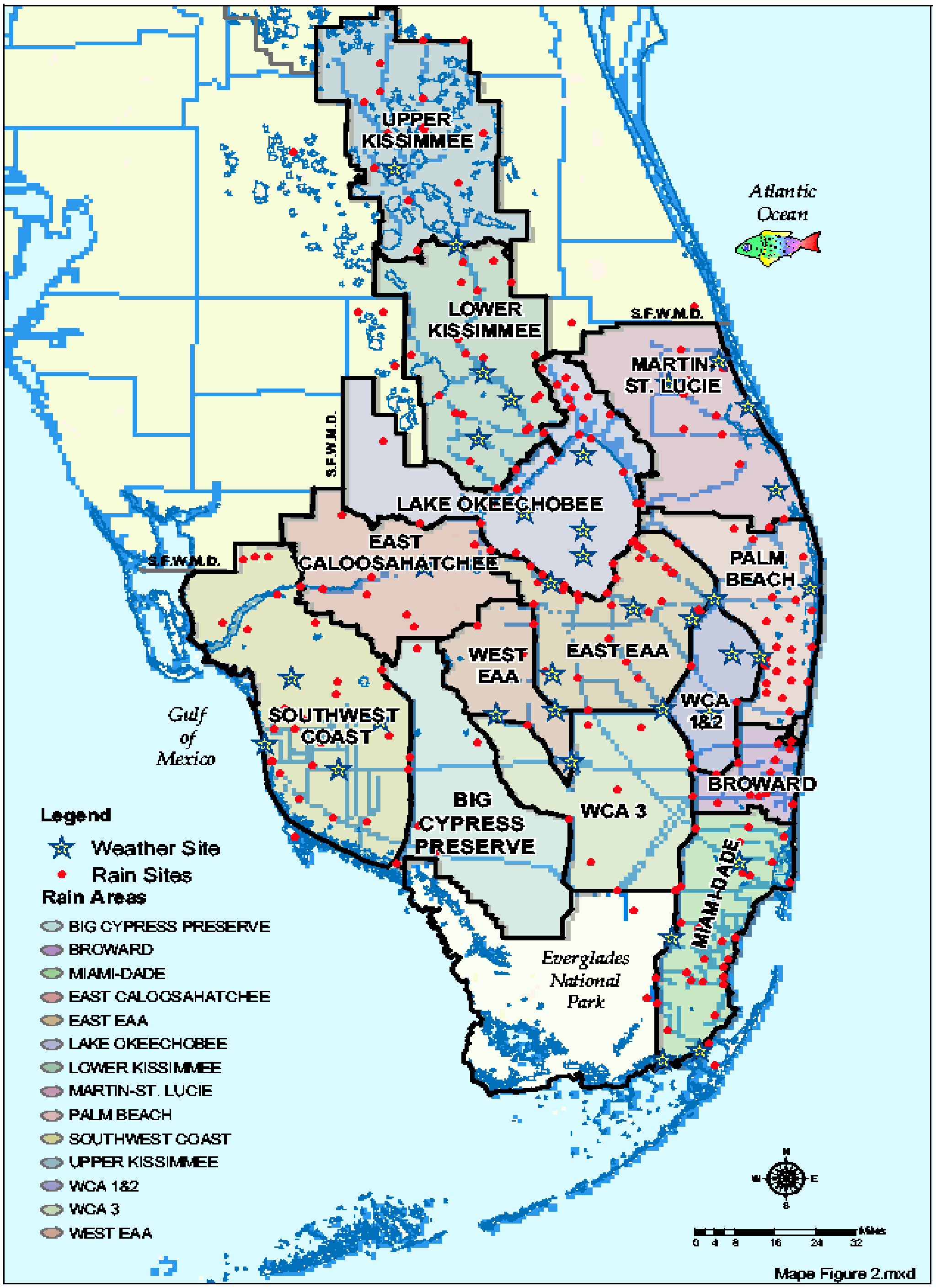

Figure 5-2. Rainfall areas of the South Florida Water Management District (SFWMD or District).

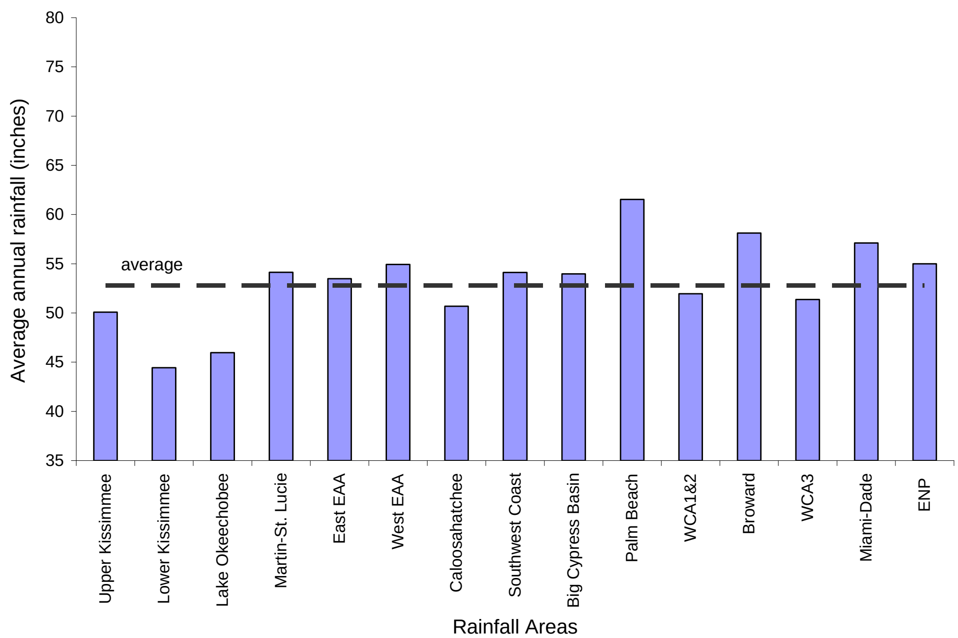

Figure 5-3. Average annual rainfall for the SFWMD and each rainfall area.

Palmer Drought Severity Index, annual rainfall, lake water levels, groundwater levels, stream flow, and wildfire records. Fire is an important ecological process in the Everglades (Wu et al., 1996).

For WY2003 and WY2004, areal rainfall data computed as Thiessen averages of many stations were obtained from the District's Operation and Maintenance Department rainfall report, available online at http://www.sfwmd.gov/org/omd/ops/weather/site_frm.html. The ENP area rainfall was estimated as the simple average of four stations: S174_R, TAMIAMIR_R, S332_R, and Chekika. Generally for WY2004, the east coast had deficit rainfall and the west coast had higher than average rainfall. The West EAA (54.9 inches) and Broward County (57.8 inches) rainfall areas had close to average rainfall. Upper Kissimmee (51.5 inches), Lower Kissimmee (47.3 inches), Caloosahatchee (60.1 inches), Big Cypress Basin (59.1 inches), and the Southwest Coast (67.3 inches) had higher than average rainfall. Lake Okeechobee (43.1 inches), East EAA (43.6 inches), WCA-1 and WCA-2 (44.1 inches), WCA-3 (46.9 inches), Martin-St. Lucie rain area (47.9 inches), Palm Beach County (50.4 inches), Miami-Dade rain area (54.9 inches), and the ENP (47.4 inches) had below-average rainfall. **Figure 5-4** shows the WY2004, WY2003, historical annual average rainfall, the 10-year wet, and the 10-year dry annual rainfall for each rainfall area. **Figures 5-5** through **5-19** show the WY2004, WY2003, historical monthly rainfall, and estimated potential evapotranspiration (ETp) for each rainfall area. For areas such as lakes, WCAs, and wetlands that are wet throughout the year, the ETp approximates the actual ET. The deviation in water year rainfall from the historical average is shown in the legends of **Figures 5-5** through **5-19** for the respective rainfall area. Increase is shown as a "+", and decrease is shown as a "-".

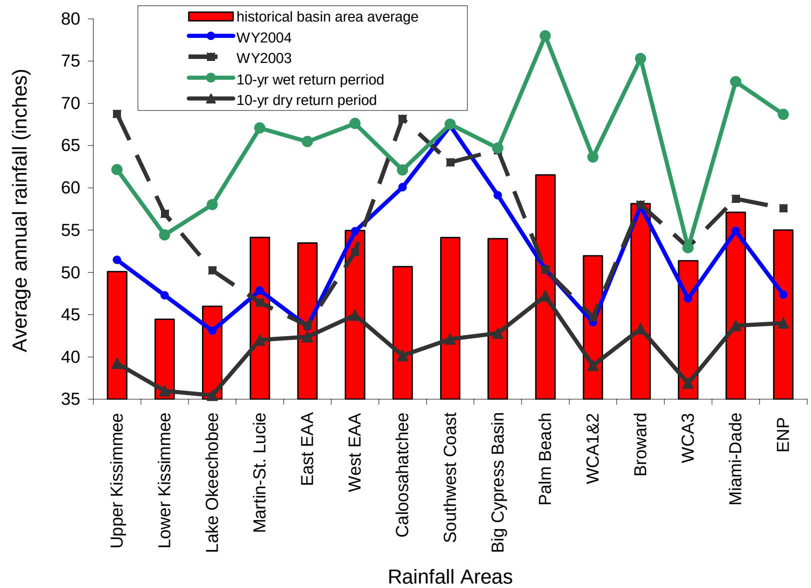

Figure 5-4. WY2004, WY2003, historical average, the 10-year wet, and the 10-year dry return period annual rainfall for each rainfall area.

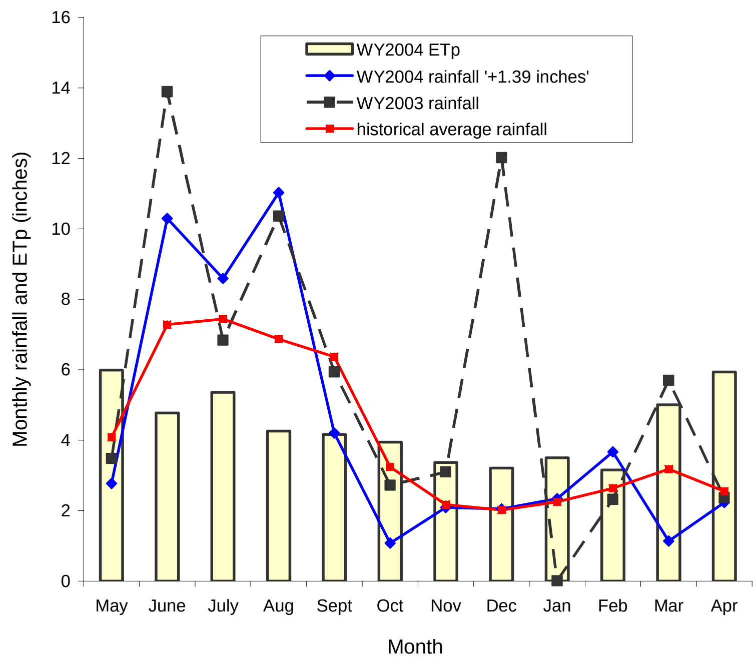

Figure 5-5. Monthly rainfall and potential evapotranspiration (ETp) for Upper Kissimmee rainfall area.

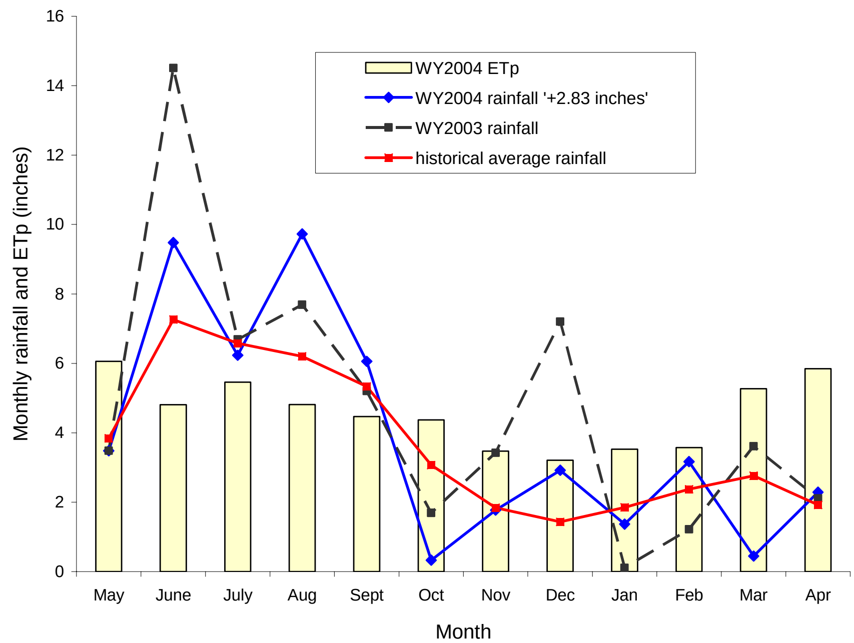

Figure 5-6. Monthly rainfall and ETp for Lower Kissimmee rainfall area.

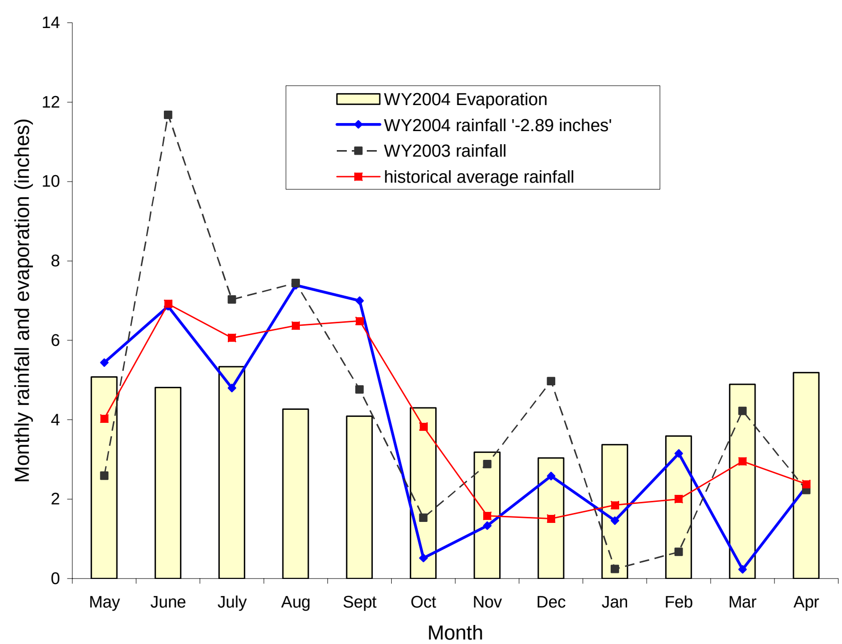

Figure 5-7. Monthly rainfall and ETp for Lake Okeechobee rainfall area.

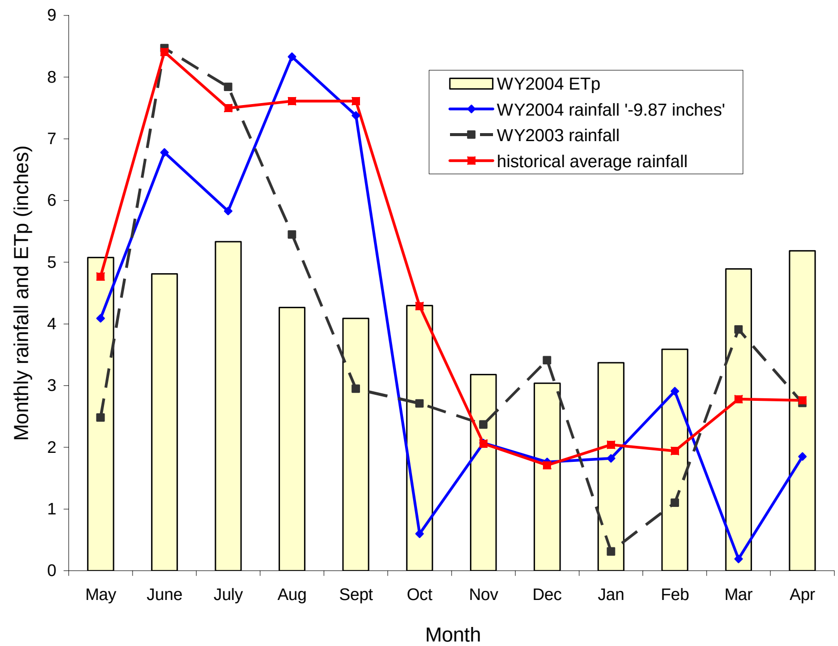

Figure 5-8. Monthly rainfall and ETp for East Everglades Agricultural Area (EAA) rainfall area.

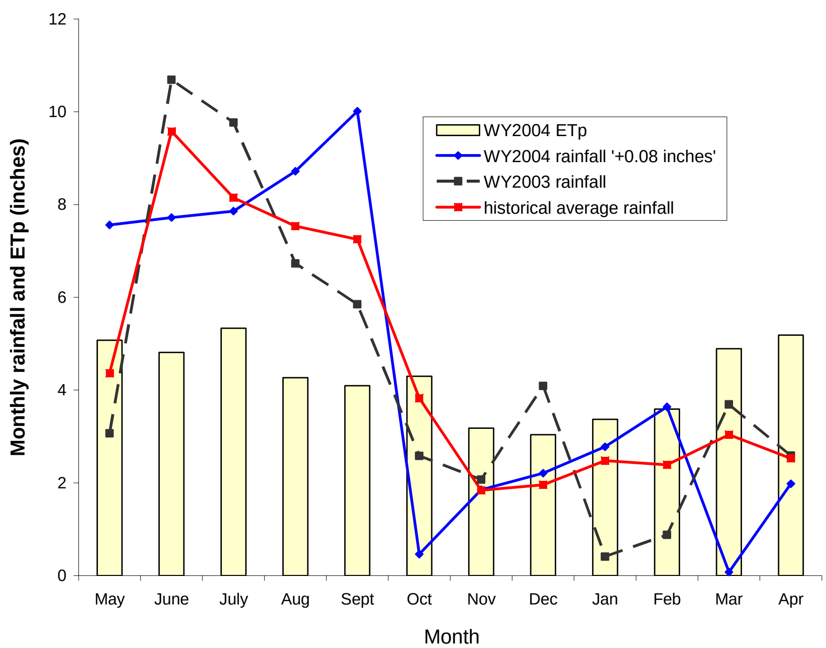

Figure 5-9. Monthly rainfall and ETp for West EAA rainfall area.

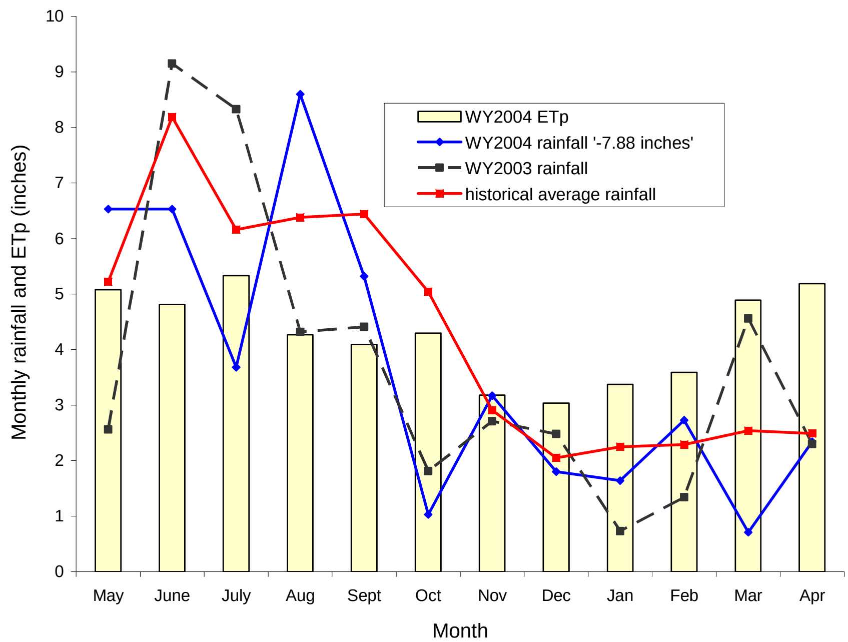

Figure 5-10. Monthly rainfall and ETp for Water Conservation Area 1 and 2 (WCA-1 and WCA-2) rainfall areas.

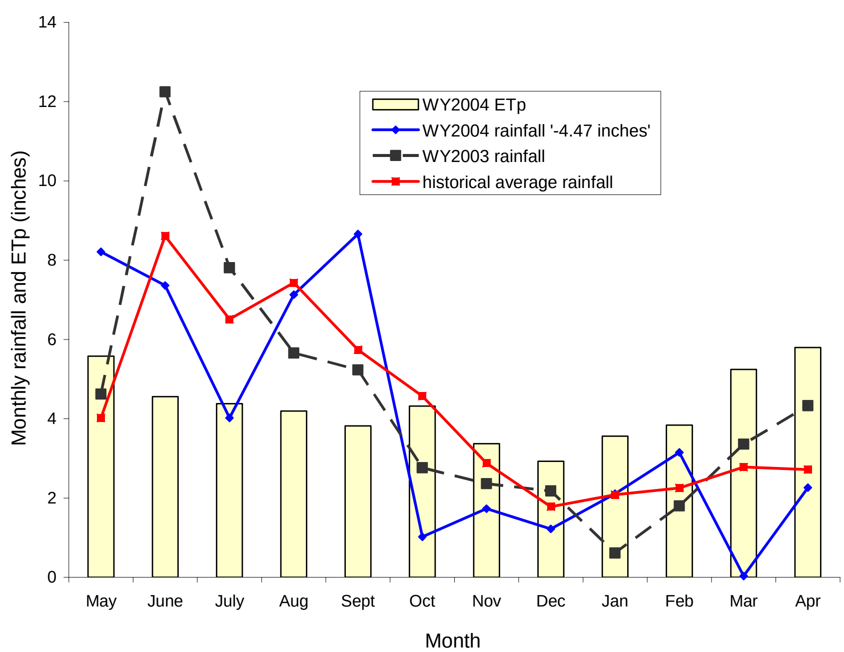

Figure 5-11. Monthly rainfall and ETp for WCA-3 rainfall area.

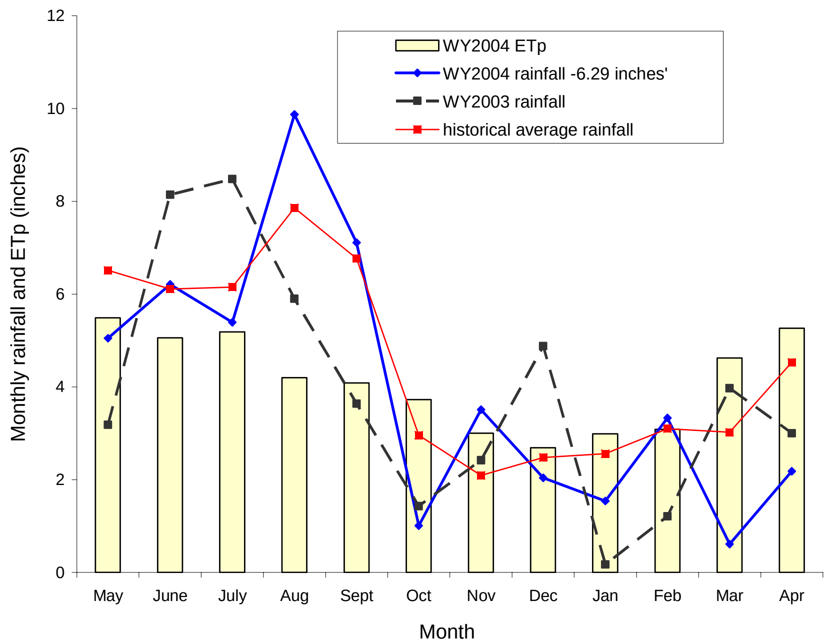

Figure 5-12. Monthly rainfall and ETp for Martin-St. Lucie counties rainfall areas.

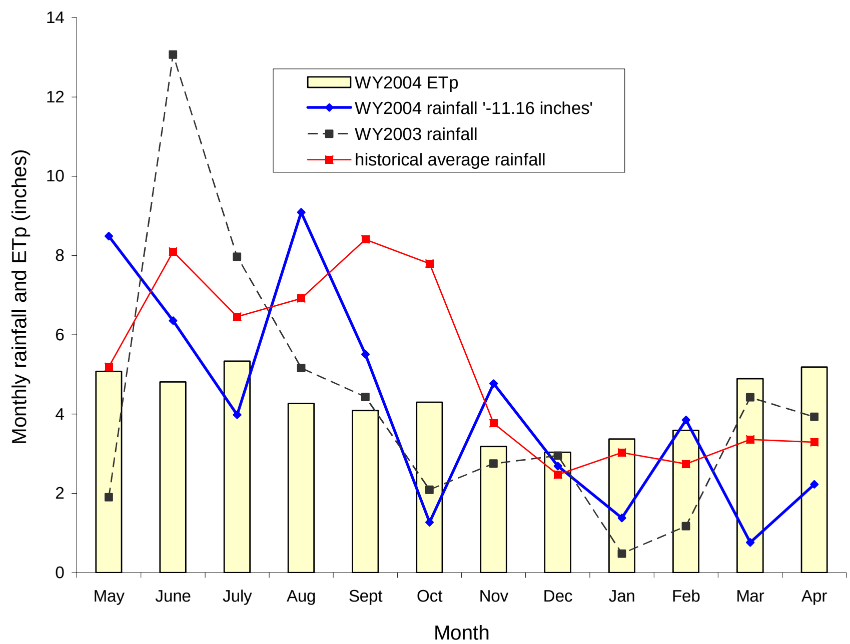

Figure 5-13. Monthly rainfall and ETp for Palm Beach County rainfall area.

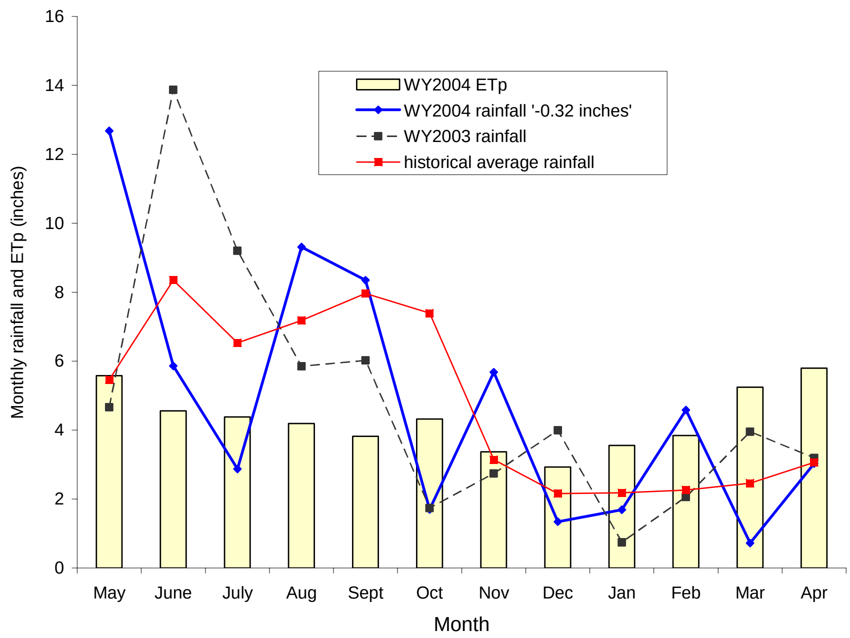

Figure 5-14. Monthly rainfall and ETp for Broward County rainfall area.

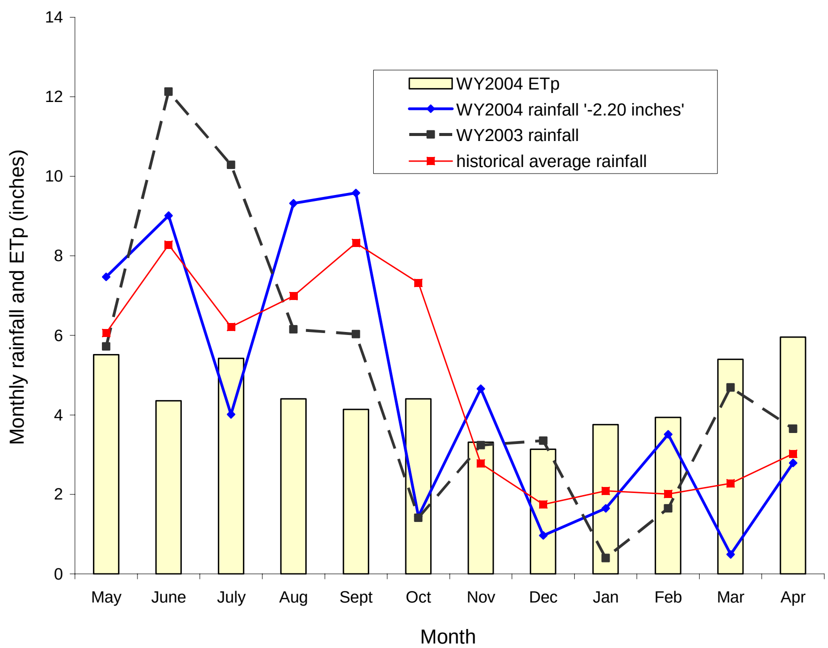

Figure 5-15. Monthly rainfall and ETp for Miami-Dade counties rainfall areas.

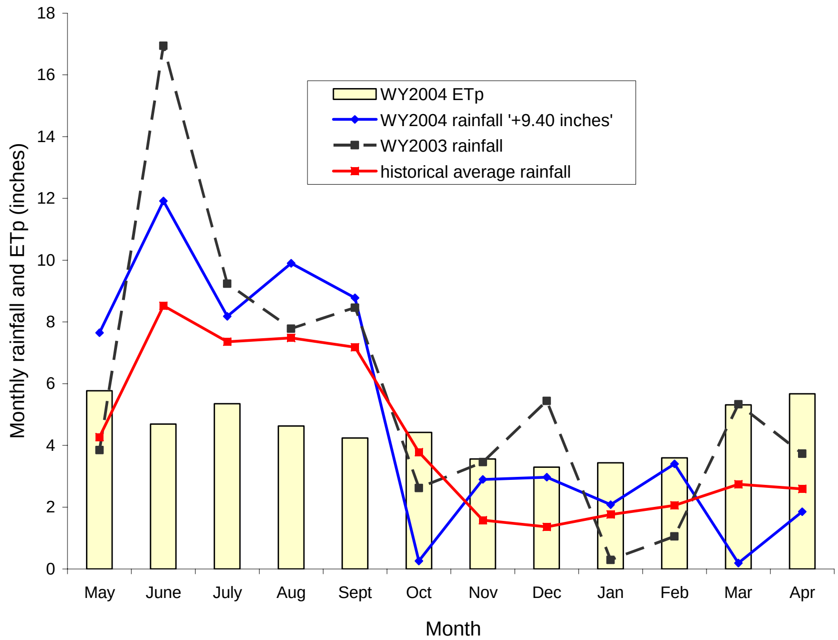

Figure 5-16. Monthly rainfall and ETp for Caloosahatchee rainfall area.

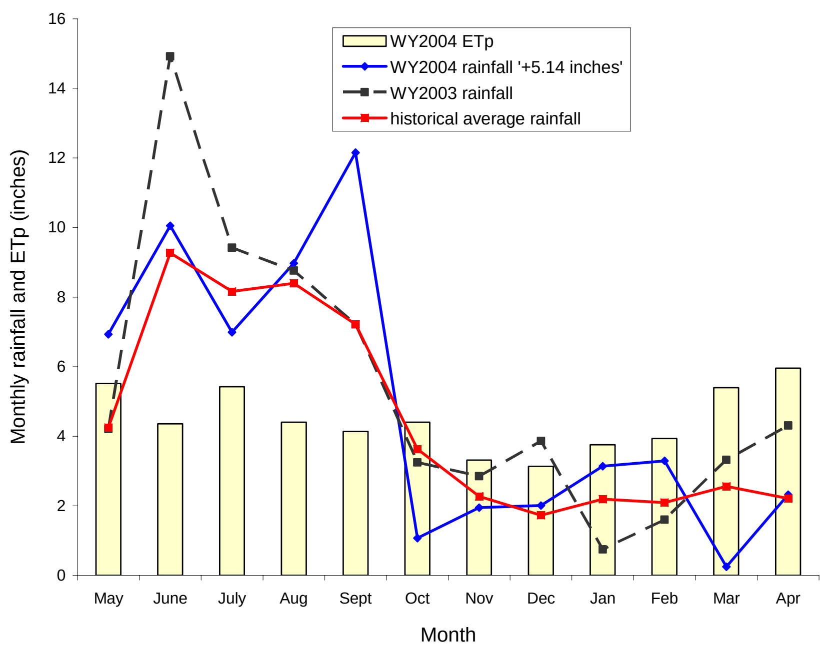

Figure 5-17. Monthly rainfall and ETp for Big Cypress Basin rainfall area.

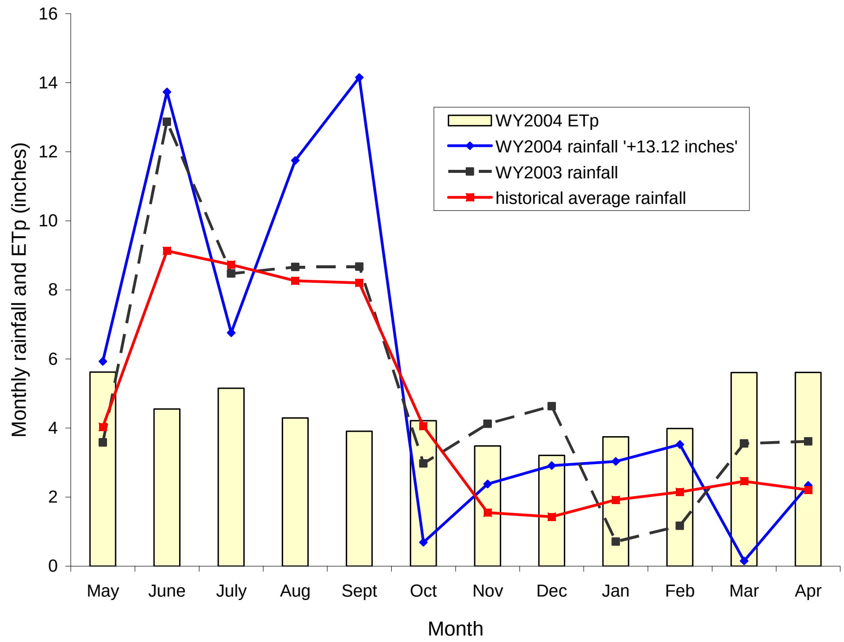

Figure 5-18. Monthly rainfall and ETp for Southwest Coast rainfall area.

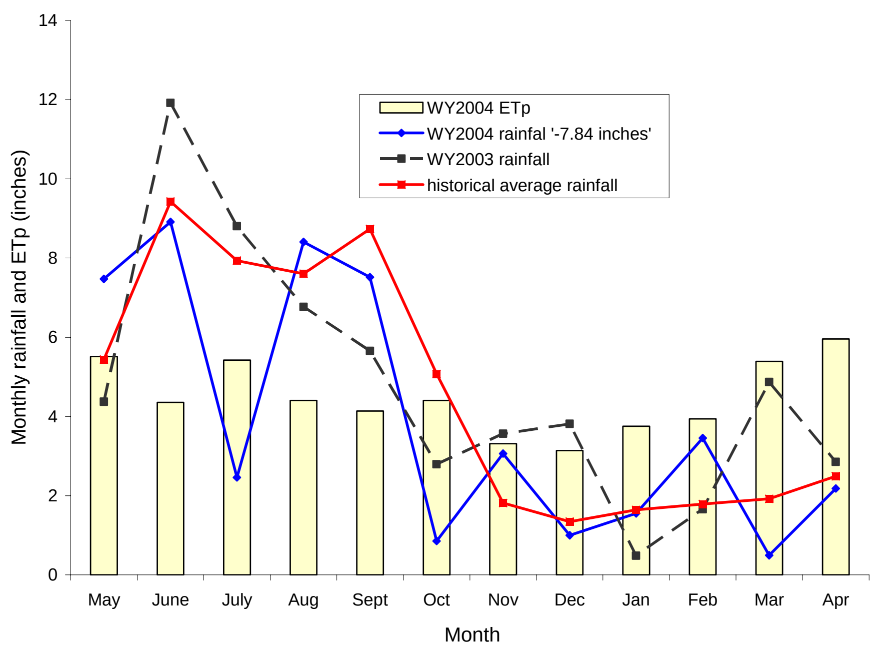

Figure 5-19. Monthly rainfall and ETp for the Everglades National Park (Park or ENP).

EVAPOTRANSPIRATION

Rainfall and evapotranspiration (ET) are the main parameters in the hydrologic balance of the Everglades. The delicate balance between rainfall and ET maintains the hydrology system in either a wet or dry condition. Evaporation from open water and transpiration from vegetation are functions of solar radiation, temperature, wind speed, humidity, atmospheric pressure, characteristics of the surrounding environment, and type and condition of vegetation. In South Florida, most of the variation in ET is explained by solar radiation (Abtew, 1996). Various measurements and estimates of ET have been reported in the literature for various locations in Central and South Florida. Regional estimates of ET from open water and wetlands that do not dry out, range from 48 inches in the northern section of the District, to 54 inches in the Everglades (Abtew et al., 2003). Model estimates of ETp from the SFWMD's database, DBHYDRO, are depicted in **Figures 5-5** through **5-19**. The closest site to a rainfall area with available ETp data was used as estimates of ETp for the area. ETp is actual evaporation for lakes, wetlands, and any feature that is wet year-round. The model that is used to estimate potential or wetland and open water ET is presented as follows (Abtew, 1996; Abtew et al., 2003; Abtew, 2004).

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

Where ET is daily ET from wetland or shallow open water (mm d^{-1}), Rs is solar radiation (MJ m^{-2} d^{-1}), λ is latent heat of vaporization (MJ kg^{-1}), and K1 is a coefficient (0.53). Estimates for WY2004 were as follows: Upper Kissimmee, 52.7 inches; Lower Kissimmee, 54.9 inches; Lake Okeechobee, 51.1 inches; Martin and St. Lucie Counties, 49.4 inches; East EAA, 51.1 inches; West Ag., 51.1 inches; Caloosahatchee, 54 inches; Southwest Coast, 53.4 inches; Big Cypress Basin, 53.7 inches; Palm Beach County, 51.1 inches; WCA-1 and WCA-2, 51.1 inches; Broward, 51.6 inches; WCA-3, 51.6 inches; Miami-Dade County, 53.7 inches; and the ENP, 53.7 inches.

WATER LEVELS

Upper Kissimmee Chain of Lakes Water Levels

Lake Alligator in the Upper Kissimmee Chain of Lakes has an average of 62.34 ft NGVD water level (stage) since 1993 (site S-60 headwater). The maximum daily average water level was 64.17 ft NGVD, and the minimum was 58.13 ft NGVD. The minimum stage was reached during the 2000–2001 drought in South Florida. Daily water level observations for Lake Alligator in the last 10 years show that the most significant change in water levels occurred in 2000 and 2001, during the drought (Appendix 5-1, Figure 1). The daily average stage for WY2004 was 63.08 ft NGVD, compared to 61.24 ft NGVD for WY2003. **Figure 5-20** depicts WY2004, WY2003, historical monthly average water levels, and regulation schedule corresponding to WY2004 water levels, as reported in the SFWMD's Daily System Storage Report, available online at http://www.sfwmd.gov/org/ema/reports/sstorage/sstorage.pdf.

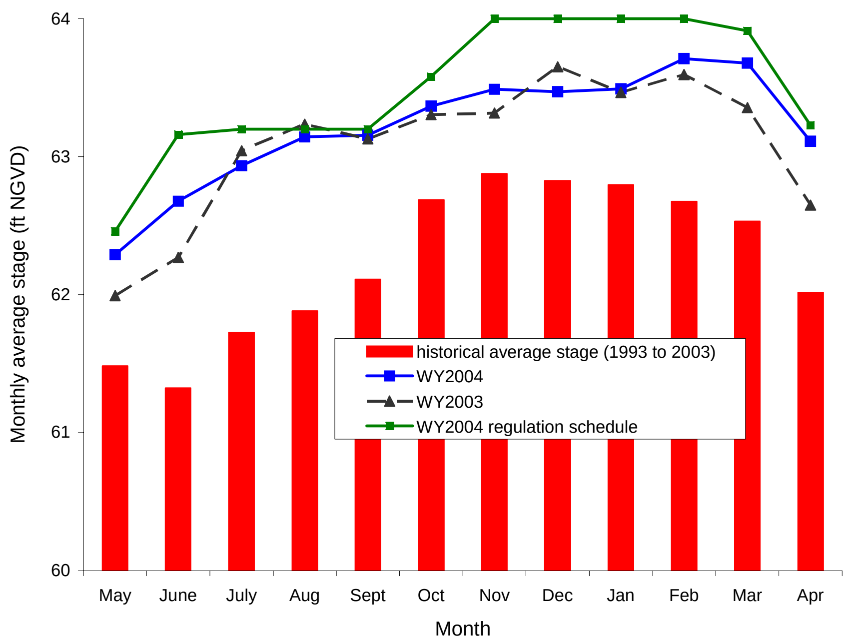

Figure 5-20. Monthly average water levels for Lake Alligator (site S60_H).

Lake Myrtle in the Upper Kissimmee Chain of Lakes has an average of 58.45 ft NGVD water level (stage) since 1993 (site S-57 headwater). The maximum daily average water level was 64.59 ft NGVD, and the minimum was 58.45 ft NGVD. The minimum stage was reached during the 2000–2001 drought in South Florida. Daily water level observations for Lake Myrtle in the last 10 years show that the most significant drop in water level occurred during the 2001 drought (Appendix 5-1, Figure 2). The daily average stage for WY2004 was 61.05 ft NGVD, compared to 61.20 ft NGVD for WY2003. **Figure 5-21** depicts WY2004, WY2003, historical monthly average water levels, and regulation schedules, as reported in the SFWMD's Daily System Storage Report.

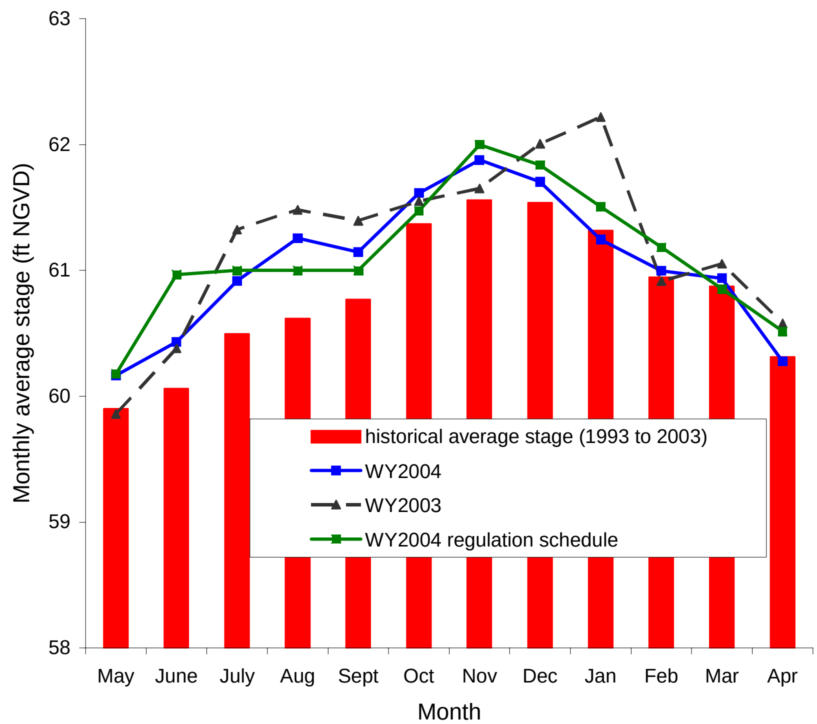

Figure 5-21. Monthly average water levels for Lake Myrtle (site S57_H).

Lake Mary Jane in the Upper Kissimmee Chain of Lakes has an average of 60 ft NGVD water level (stage) since 1993 (site S-62 headwater). The maximum daily average water level was 61.91 ft NGVD and the minimum was 57.19 ft NGVD. The minimum stage was reached during the 2000–2001 drought in South Florida. Daily water level observations for Lake Mary Jane in the last 10 years show that the most significant drop in water level occurred in 2001, during the drought (Appendix 5-1, Figure 3). The daily average stage for WY2004 was 60.36 ft NGVD, compared to 60.30 ft NGVD for WY2003. **Figure 5-22** depicts WY2004, WY2003, historical monthly average water levels, and regulation schedules, as reported in the SFWMD's Daily System Storage Report.

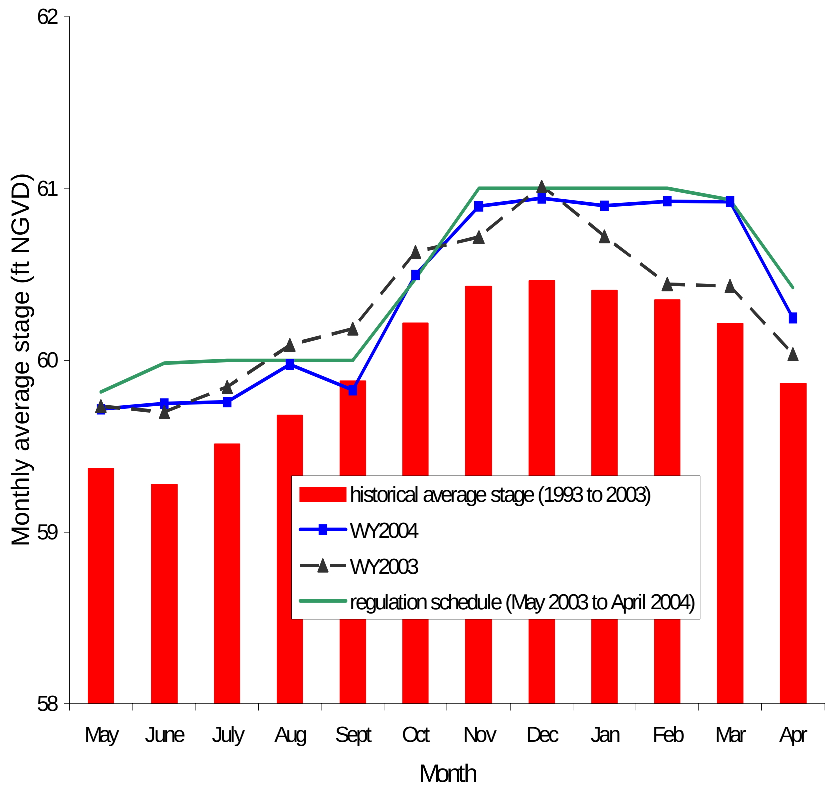

Figure 5-22. Monthly average water levels for Lake Mary Jane (site S62_H).

Lake Gentry in the Upper Kissimmee Chain of Lakes has had an average of 60.59 ft NGVD water level (stage) since 1993 (site S-63 headwater). The maximum daily average water level was 61.91 ft NGVD, and the minimum was 57.31 ft NGVD. The minimum stage was reached during the 2000–2001 drought in South Florida. Daily water level observations for Lake Gentry in the last 10 years show that the most significant drop in water level occurred in 2001 during the drought (Appendix 5-1, Figure 4). The daily average stage for WY2004 was 60.94 ft NGVD, compared to 60.77 ft NGVD for WY2003. **Figure 5-23** depicts WY2004, WY2003, historical monthly average water levels, and regulation schedules, as reported in the SFWMD's Daily System Storage Report.

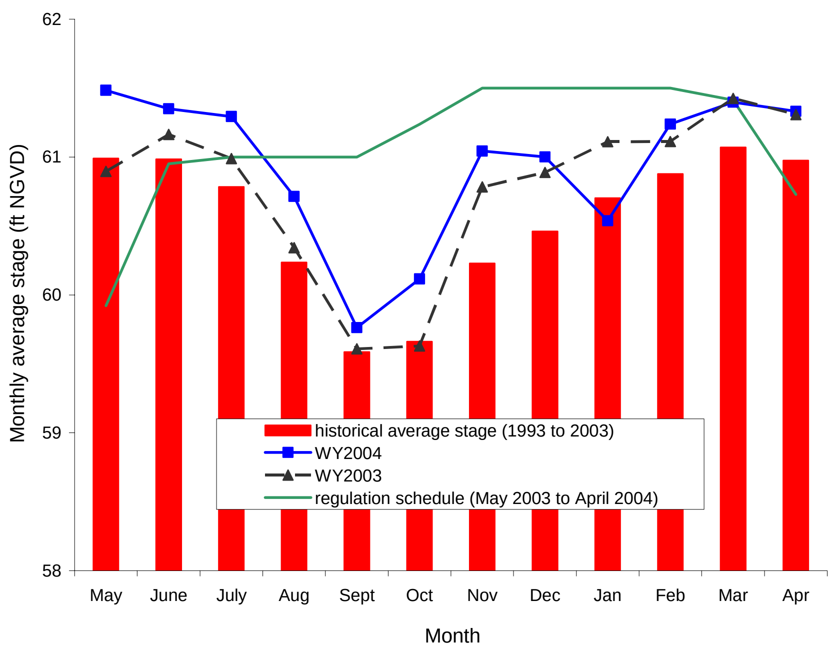

Figure 5-23. Monthly average water levels for Lake Gentry (site S63_H).

Lake East Tohopekaliga in the Upper Kissimmee Chain of Lakes has an average of 56.62 ft NGVD water level (stage) since 1993 (site S-59 headwater). The maximum daily average water level was 59.12 ft NGVD, and the minimum was 54.41 ft NGVD. The minimum stage was reached in 1997. Daily water level observations for Lake East Tohopekaliga in the last 10 years are shown in Appendix 5-1, Figure 5. The daily average stage for WY2004 was 57.13 ft NGVD, compared to 56.98 ft NGVD for WY2003. **Figure 5-24** depicts WY2004, WY2003, historical monthly average water levels, and regulation schedules as reported in the SFWMD's Daily System Storage Report.

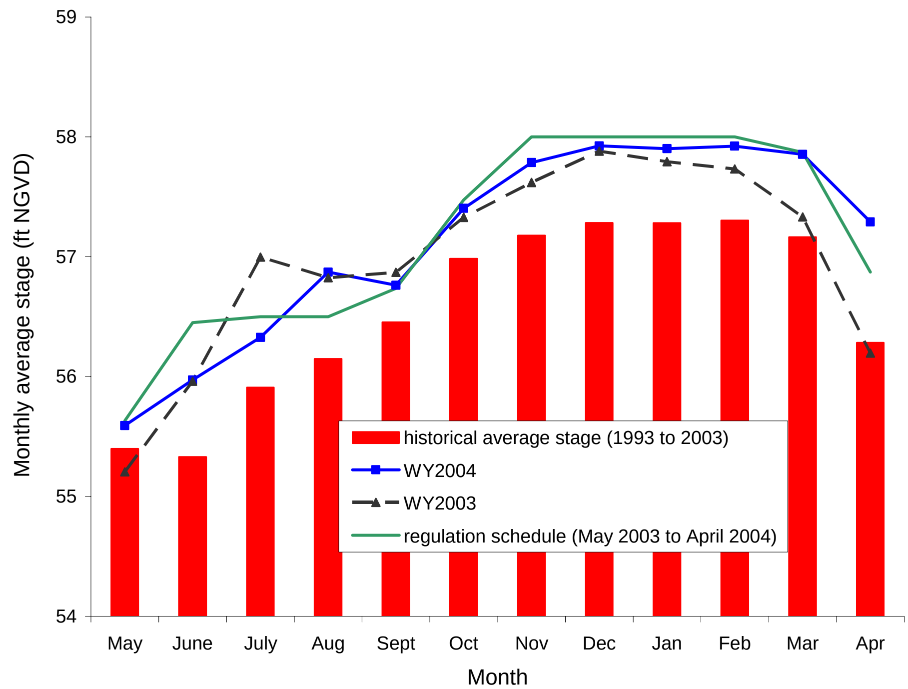

Figure 5-24. Monthly average water levels for East Tohopekaliga (site S59_H).

Lake Tohopekaliga in the Upper Kissimmee Chain of Lakes has an average of 53.66 ft NGVD water level (stage) since 1993 (site S-61 headwater). The maximum daily average water level was 55.77 ft NGVD, and the minimum was 48.49 ft NGVD. The minimum stage was reached in 2004, following the implementation of lake drawdown. In cooperation with the Florida Fish and Wildlife Conservation Commission (FWC), the District began a planned drawdown of water levels in Lake Tohopekaliga in November 2003 to facilitate muck and tussock removal in the lake. The target drawdown water elevation of 49.0 ft NGVD was reached in late February 2004. Daily water level observations for Lake Tohopekaliga in the last 10 years show that the most significant drop in water level occurred in 2004, during the lake drawdown (Appendix 5-1, Figure 6). The daily average stage for WY2004 was 52.16 ft NGVD, compared to 53.79 ft NGVD for WY2003. **Figure 5-25** depicts WY2004, WY2003, historical monthly average water levels and regulation schedules, as reported in the SFWMD's Daily System Storage Report.

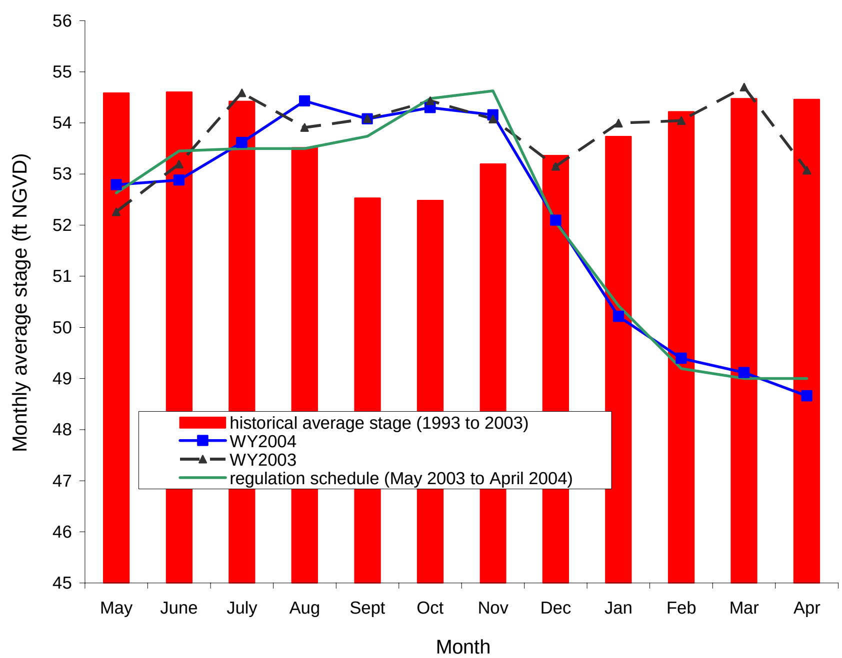

Figure 5-25. Monthly average water levels for Tohopekaliga (site S61_H).

Lake Kissimmee Water Levels

Lake Kissimmee covers an area of approximately 35,500 acres. The lake has an average water level (stage) of 50.38 ft NGVD, based on data starting in 1929 (site S-65 headwater). The maximum daily average water level was 56.64 ft NGVD observed in 1953, and the minimum was 42.87 ft NGVD in 1977. The average daily water level in WY2004 was 50.24 ft NGVD, which is 0.39 ft less than WY2003. **Figure 5-26** depicts monthly average water levels for WY2004, WY2003, and the period of historical record and regulation schedules, as reported in the SFWMD's Daily System Storage Report. Appendix 5-1, Figure 7 shows daily water level for the period of record from 1929–2004.

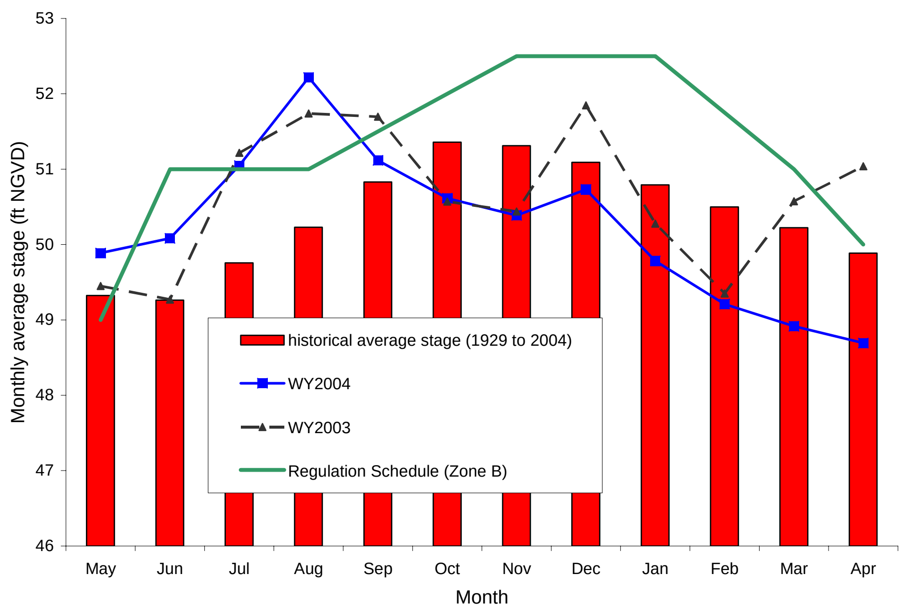

Figure 5-26. Monthly average water levels for Lake Kissimmee (site S65 H).

Lake Istokpoga Water Levels

Lake Istokpoga has a surface area of approximately 27,700 acres. It has an average water level (stage) of 38.78 ft NGVD, based on data collected since 1993 (site S-68 headwater). The maximum daily average water level was 39.74 ft NGVD (observed in 1998 during an El Niño year), and the minimum was 35.84 ft NGVD, observed during the 2001 drought. The low water level observed in 2001 coincided with the environmental enhancement project that removed muck and tussocks from the lake bed. The average daily water level in WY2004 was 39.06 ft NGVD, which is 0.01 ft higher than in WY2003. **Figure 5-27** depicts monthly average water levels for WY2004, WY2003, and the period of historical record and regulation schedule corresponding to WY2004 water levels, as reported in the SFWMD's Daily System Storage Report. Appendix 5-1, Figure 8 shows daily water level for the period of record from 1993–2004.

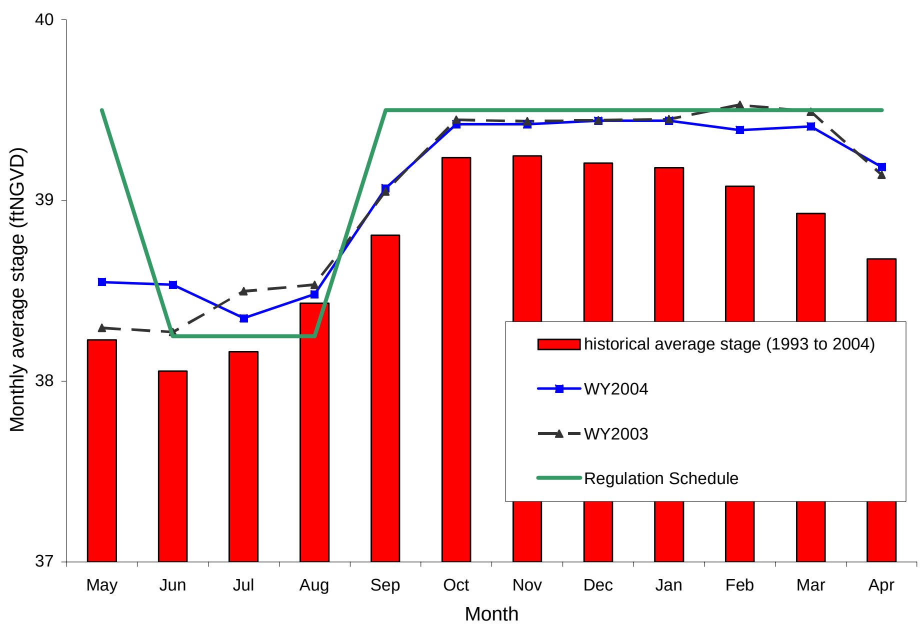

Figure 5-27. Monthly average water levels for Lake Istokpoga (site S68_H).

Lake Okeechobee Water Levels

Lake Okeechobee has an approximate surface area of 428,000 acres and an average water level (stage) of 14.13 ft NGVD, based on a period of record starting in 1931. The maximum daily average water level reached 18.79 ft NGVD, observed in 1947 during a hurricane season, and the minimum was 8.97 ft NGVD, recorded in the 2001 drought in South Florida. The average daily water level in WY2004 was 15.62 ft NGVD, which is 0.86 ft higher than in WY2003. **Figure 5-28** depicts monthly average water levels for WY2004, WY2003, and the period of historical record and regulation schedules. Appendix 5-1, Figure 9 shows daily water level for the period of record from 1931–2004.

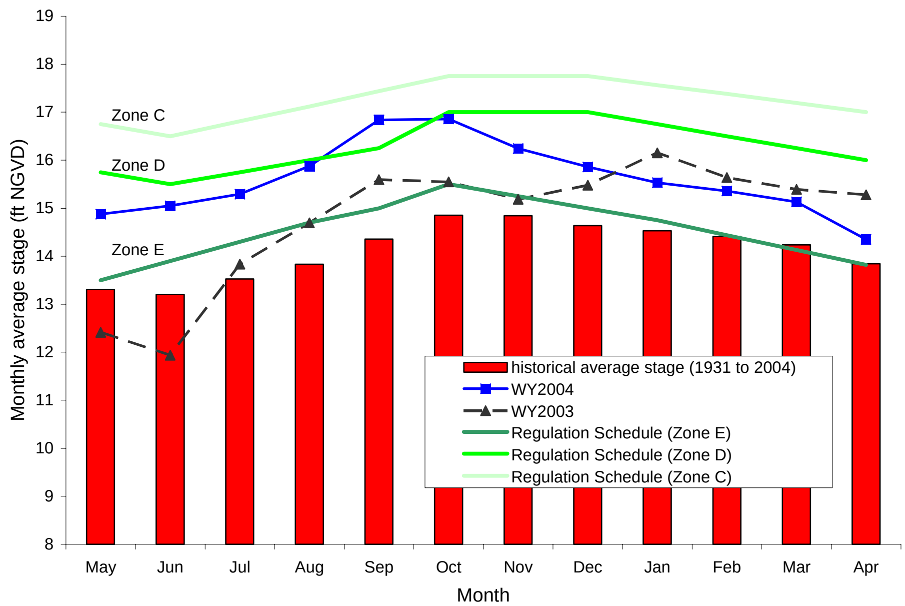

Figure 5-28. Monthly average water levels for Lake Okeechobee.

Everglades Protection Area Water Levels

The WCAs are shallow impoundments, with a total area of approximately 861,440 acres. Water levels in the WCAs change due to drought, rainfall, ET, seepage, and surface water management. Surface water management in the WCAs is based on regulation schedules that vary with the time of year, hydrologic conditions, and other needs. WCA-1 consists of 141,440 acres with a daily average water level of 15.56 ft NGVD. Daily water level was compiled from four sites, based on the regulation schedule uses of the following gauges: 1-8C, 1-7, 1-8T, and 1-9. From January 1–June 30, site 1-8C was used while the rest of the year average water level from sites 1-7, 1-8T, and 1-9 was used if the average was higher than site 1-8C. A maximum daily average water level of 18.16 ft NGVD was attained on October 17, 1999, during Hurricane Irene. A minimum water level of 10 ft NGVD in WCA-1 was reached on June 1, 1962, a drought year. For WY2004, average stage in WCA-1 was 16.50 ft NGVD, which was higher than WY2003 (16.22 ft NGVD). Maximum daily average stage was 17.32 ft NGVD, and minimum was 15.19 ft NGVD. Daily average historical water levels are shown in Appendix 5-1, Figure 10. **Figure 5-29** shows comparisons of historical monthly average water levels, WY2004 average water levels, WY2003 water levels, regulation schedules corresponding to WY2004 water levels, as reported in the SFWMD's Daily System Storage Report, and station elevation (Price et al., 2001).

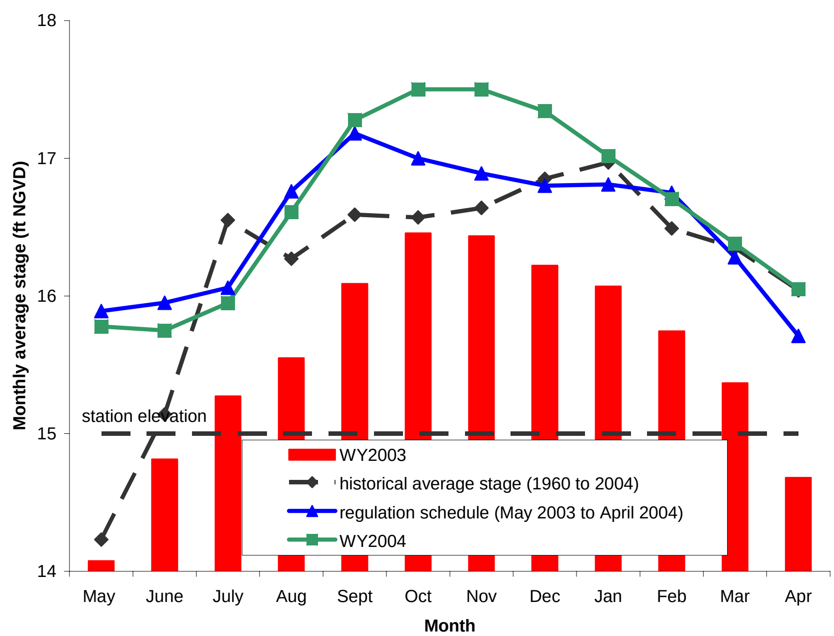

Figure 5-29. Monthly average water levels for WCA-1 (Sites 1-8C, 1-7, 1-8T, and 1-9).

WCA-2A and WCA-2B combined have a total area of 133,400 acres, with 80 percent of the area in WCA-2A. WCA-2A has a historical average water level of 12.58 ft NGVD (site 2-17). A maximum water level of 15.64 ft NGVD was attained on November 18, 1969, and a minimum level of 9.33 ft NGVD was attained on April 29, 1989, during a severe drought year. For WY2004, average stage in WCA-2 was 12.40 ft NGVD, which was higher than WY2003 (12.17 ft NGVD). The maximum daily average stage was 13.58, and the minimum was 11.23 ft NGVD. Daily average historical water levels are shown in Appendix 5-1, Figure 11. **Figure 5-30** shows comparisons of historical monthly average water levels, WY2004 average water levels, WY2003 water levels, regulation schedules corresponding to WY2004 water levels, as reported in the SFWMD's Daily System Storage Report, and station elevations (Price et al., 2001).

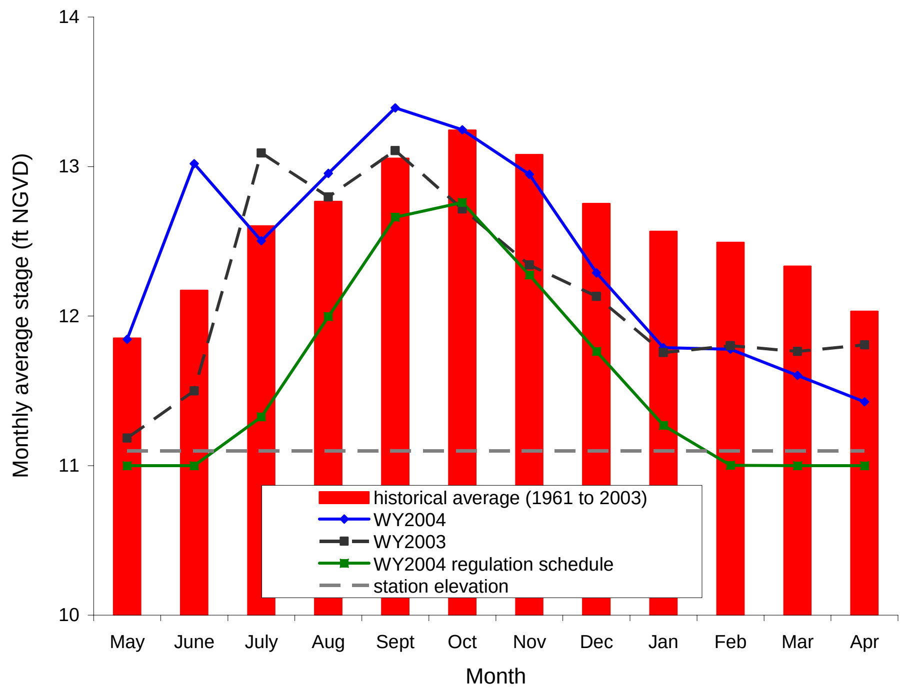

Figure 5-30. Monthly average water levels for WCA-2 (sites 2–17).

WCA-3A and WCA-3B combined have a total area of 585,560 acres, with 83 percent of the area in WCA-3A. WCA-3A has a historical average water level of 9.50 ft NGVD. Maximum water level of 12.79 ft NGVD was attained on January 22, 1995, during an El Niño year, and minimum level of 4.78 ft NGVD was reached on June 6, 1962, during a drought year. For WY2004, average stage in WCA-3 was 10.30 ft NGVD, which was higher than WY2003 (10.07 ft NGVD). The maximum daily average stage was 11.54 and the minimum was 9.11 ft NGVD. Daily average historical water levels are shown in Appendix 5-1, Figure 12. **Figure 5-31** shows comparisons of historical monthly average water level, WY2004 average water levels, WY2003 water levels, regulation schedule corresponding to WY2004 water levels, as reported in the SFWMD's Daily System Storage Report, and station elevations. Site elevation is average for sites 63, 64, and 65 (Price et al., 2001; USGS, personal communication, 2000).

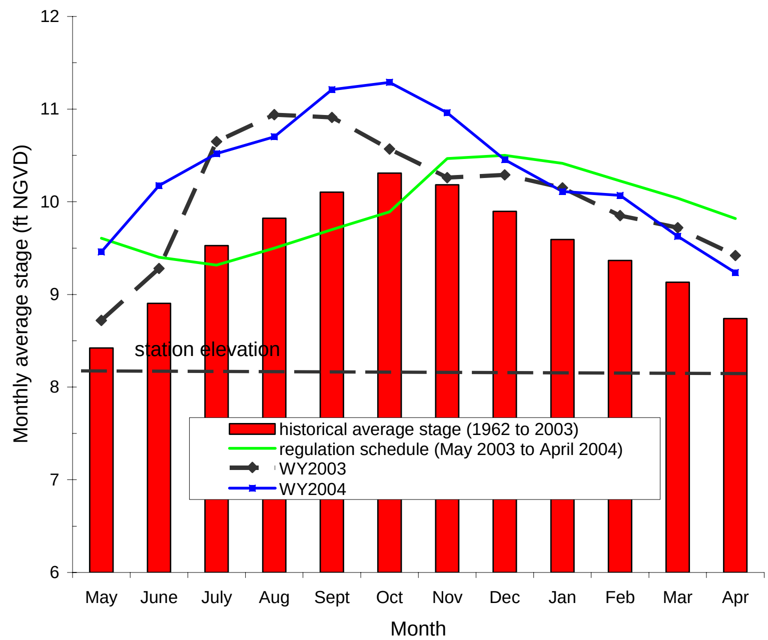

Figure 5-31. Monthly average water levels for WCA-3 (CA3AVG).

The ENP is approximately 1,376,000 acres (Redfield et al., 2003). Water level monitoring at sites P-33 and P-34 has been used in previous Everglades Consolidated Reports as representative of slough and wet prairie, respectively (Sklar et al., 2003). Station elevations for P-33 and P-34 are 5.06 ft NGVD and 2.09 ft NGVD, respectively, as shown in Sklar et al. (2000). Historical water level data for sites P-33 (1952–2004) and P-34 (1953–2004) were obtained from DBHYDRO, and from the ENP's database. For WY2004, the average stage at site P-33 in the ENP was 6.68 ft NGVD, which was higher than WY2003 (6.35 ft NGVD) and the historical average stage (5.96 ft NGVD).

Maximum daily average stage at site P-33 was 7.43, and the minimum was 5.91 ft NGVD. **Figure 5-32** shows comparisons of historical monthly average water level, WY2004 average water levels, WY2003 average water levels, and station elevation at site P-33. For WY2004, the average stage at site P-34 in the ENP was 3.09 ft NGVD, which was higher than WY2003 (2.53 ft NGVD) and the historical average stage (2.04 ft NGVD). Maximum daily average stage was 4.38 ft NGVD, and minimum was 1.79 ft NGVD. **Figure 5-33** depicts the historical monthly average water level, the monthly average water level for WY2004, WY2003, and station elevation for station P-34. WY2004 water levels were higher than WY2003 water levels. Daily average historical water levels for sites P-33 and P-34 are shown in Appendix 5-1, Figures 13 and 14.

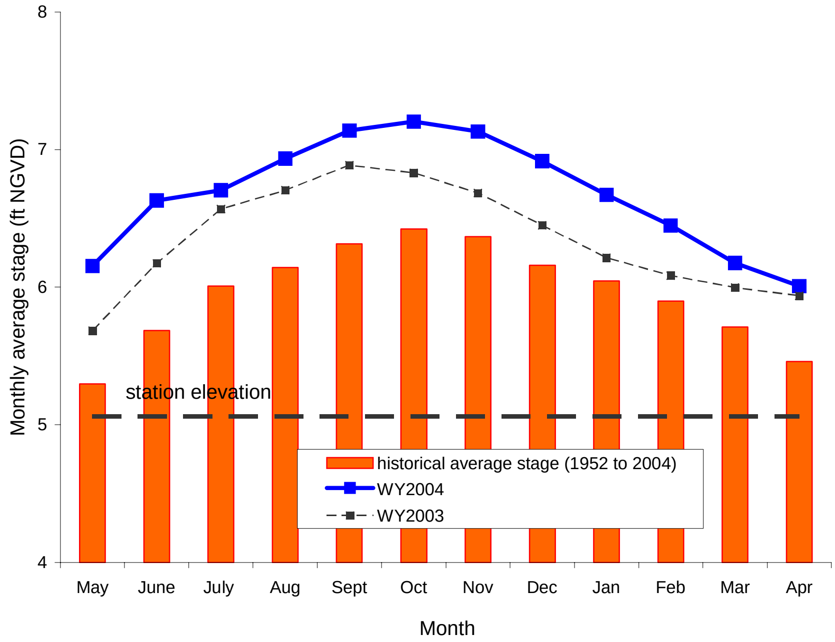

Figure 5-32. Monthly average water levels for site P-33 in the ENP.

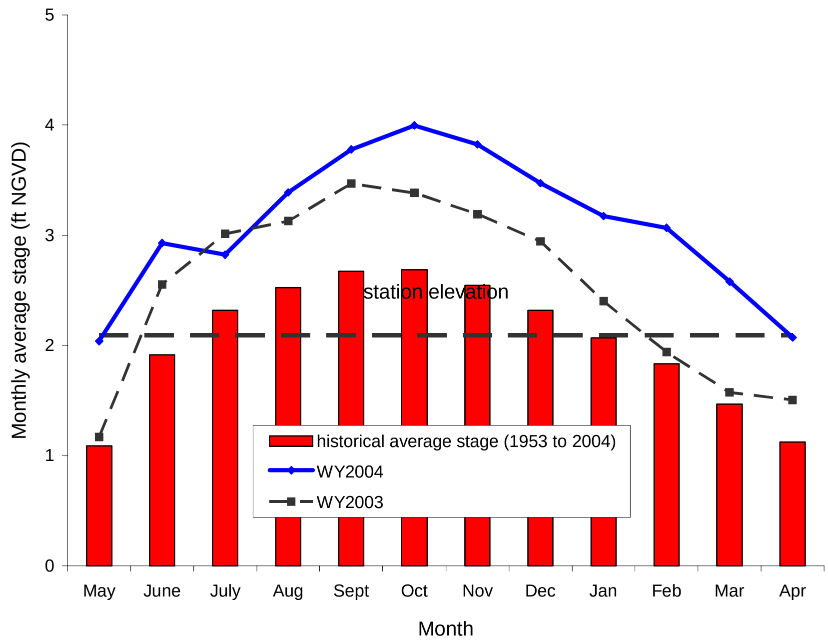

Figure 5-33. Monthly average water levels for site P-34 in the ENP.

SURFACE WATER INFLOWS AND OUTFLOWS

In the District's water management system, surface water flow is generally regulated through water control structures and operational guidelines, such as the different regulation schedules for the major lakes, impoundments, and canals. The water management system is a delicate system that can change from a flooding state to a water shortage, or to situations of environmental impact, in a relatively short period. Water levels and flows are regulated from the Upper Kissimmee Chain of Lakes to the Everglades. Inflows and outflows through the major systems are presented in this chapter.

Lake Kissimmee Flows

Lake Kissimmee outflow is regulated through structure S-65. The lake's regulation schedule varies between 49 ft NGVD and 52.5 ft NGVD. Based on flow data from January 1, 1972–April 30, 2004, the average annual outflow from Lake Kissimmee was 689,821 ac-ft. Minimum annual flow of 7,900 ac-ft occurred during the 1981 drought in South Florida, and the maximum annual outflow of 1,523,275 ac-ft occurred in 2003. During WY2004, the flow volume from Lake Kissimmee was 1,193,153 ac-ft, over 1.7 times the historical average flow, but lower than WY2003 discharges. Total flow volume in WY2003 was 1,571,473 ac-ft. The annual flow volume in WY2004 was augmented by releases from Lake Tohopekaliga during a managed drawdown for an environmental enhancement project. **Figure 5-34** shows the monthly outflow from Lake Kissimmee for WY2004, WY2003, and the historical monthly average outflow. Appendix 5-2, Table 1 depicts monthly flow volumes for WY2004.

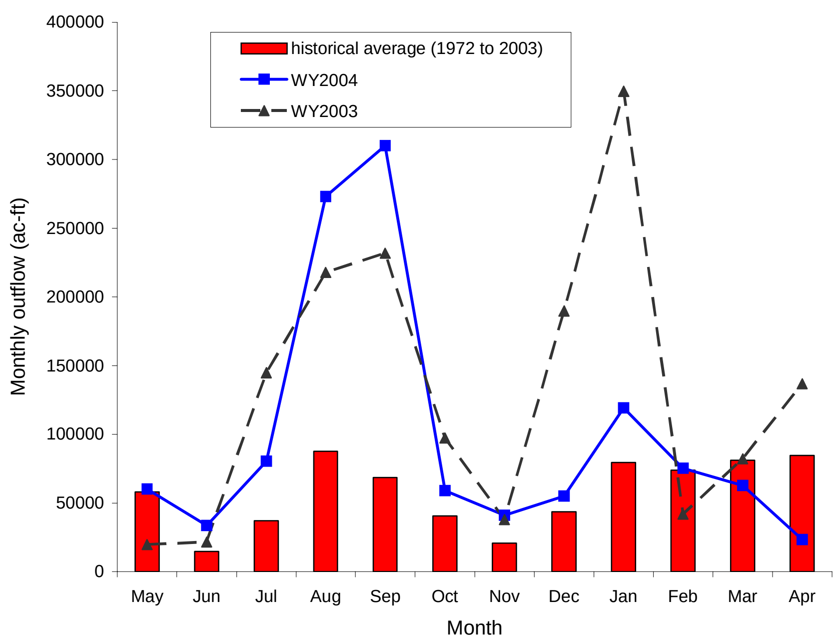

Figure 5-34. Monthly outflow from Lake Kissimmee.

Lake Istokpoga Flows

Lake Istokpoga outflow is regulated through structure S-68. The lake's regulation schedule varies between 37.0 ft NGVD and 39.5 ft NGVD. Based on flow data from January 1, 1972–April 30, 2004, the average annual outflow from Lake Istokpoga was 212,880 ac-ft. The maximum discharge of 562,000 ac-ft occurred during the 1998 El Niño year. Minimum annual flow of 18,000 ac-ft occurred during the 1981 drought in South Florida. During WY2004, the flow volume from Lake Istokpoga was 401,631 ac-ft. This was 1.9 times the average annual outflow, but lower than WY2003 discharges. The outflow volume in WY2003 was 478,670 ac-ft. **Figure 5-35** shows the monthly outflow from Lake Istokpoga for WY2003, WY2004, and the historical monthly average outflow. Appendix 5-2, Table 1 depicts monthly flow volumes for WY2004.

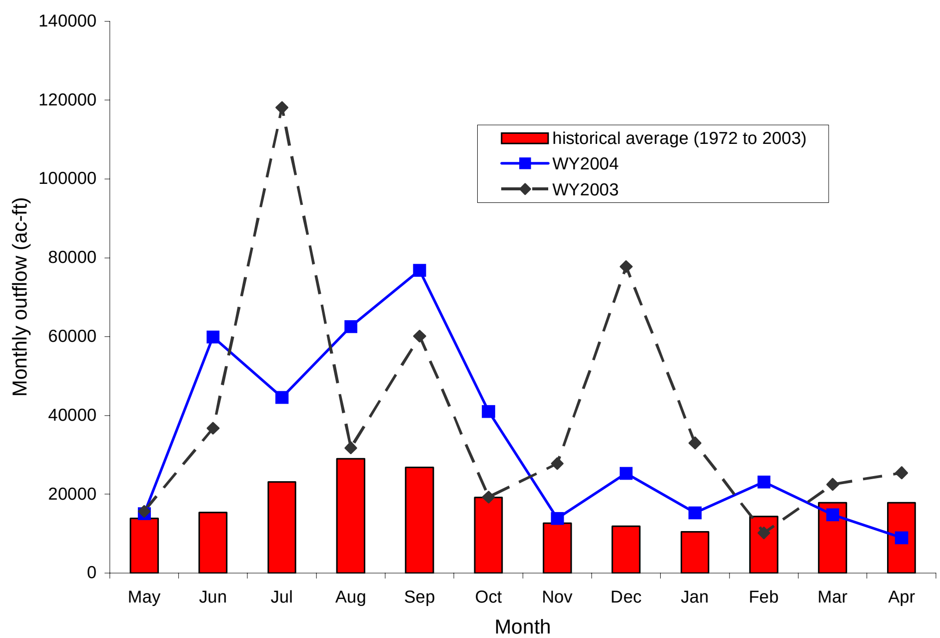

Figure 5-35. Monthly outflow from Lake Istokpoga.

Lake Okeechobee Flows

Based on flow data from January 1, 1972–December 31, 2003 records, annual average inflow into Lake Okeechobee is 2,058,041 ac-ft, with a maximum annual inflow of 3,620,483 ac-ft in 1998 during an El Niño year. A similar volume of inflow also occurred during the 1995 El Niño year. The minimum annual inflow of 664,121 ac-ft occurred in 2000, during the drought. The volume of inflow to Lake Okeechobee in WY2004 was 2,920,448, which was higher than the historical average, and lower than 3,448,689 ac-ft inflows in WY2003.

The volume of outflow from Lake Okeechobee in WY2004 was 2,617,958 ac-ft. During WY2003, 2,078,973 ac-ft of water was released from the lake. Based on data from 1972–2003, the historical annual average discharge from Lake Okeechobee is 1,383,944 ac-ft, with a maximum annual discharge of 3,965,257 ac-ft in 1995, during an El Niño year. The minimum annual discharge of 349,978 ac-ft occurred in 1991. **Figure 5-36** shows the monthly inflow into Lake Okeechobee for WY2003, WY2004, and the historical monthly average inflow. **Figure 5-37** shows the monthly outflow from Lake Okeechobee for WY2004, WY2003, and the historical monthly average outflow. Appendix 5-2, Table 2 depicts monthly inflows, and Appendix 5-2, Table 3 depicts outflows for Lake Okeechobee for WY2004.

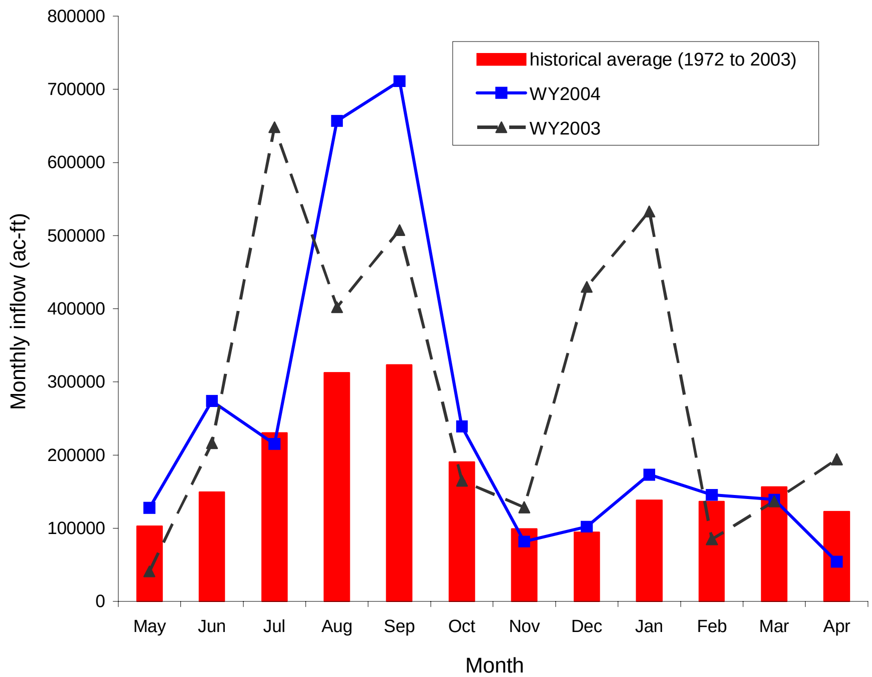

Figure 5-36. Monthly inflow to Lake Okeechobee.

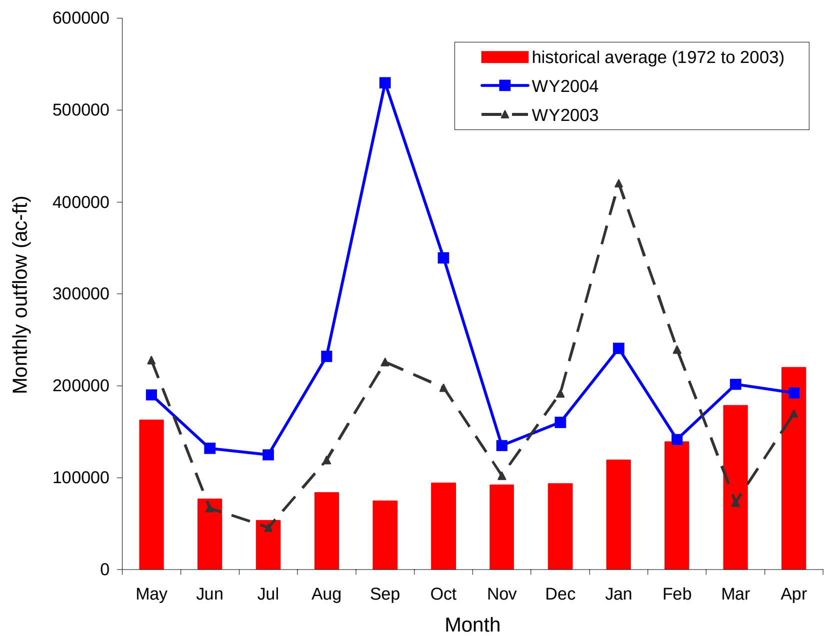

Figure 5-37. Monthly outflow from Lake Okeechobee.

St. Lucie Canal and Estuary Flows

The C-23 canal discharges into the St. Lucie Estuary at structure S-48. During WY2004, 139,689 ac-ft of water was released at S-48, which was 5 percent more than the historical average discharge of 134,016 ac-ft (1995–2004). In WY2003, 125,215 ac-ft of water was discharged at S-48. The C-24 canal discharges into the northern branch of the St. Lucie Estuary at S-49. During WY2004, 155,813 ac-ft of water was discharged at S-49, which was 120 percent of the historical average flow (129,972 ac-ft). The C-25 canal discharges into the southern part of the Indian River Lagoon at structure S-50. In WY2004, 119,307 ac-ft of water was released at this site. This was 90 percent of the historical average discharge at S-50 (132,402 ac-ft), and 78 percent of the flow volume released in WY2003 (157,420 ac-ft).

Structure S-80 discharges through the St. Lucie Canal into the southern part of the St. Lucie Estuary. Flow at this structure comes from the C-44 basin and Lake Okeechobee. Lake Okeechobee discharges into the St. Lucie Canal through structure S-308 were 568,505 ac-ft. In WY2004, 688,528 ac-ft was discharged at S-80. This was 31.4 percent greater than the average historical flow of 534,095 ac-ft. During WY2003, 308,612 ac-ft was discharged at the S-80 structure. **Figures 5-38** through **5-41** show the monthly outflow volumes for WY2004, WY2003, and the period of record monthly average flows at these structures. Appendix 5-2, Table 4 depicts monthly flow volumes for WY2004 for each structure.

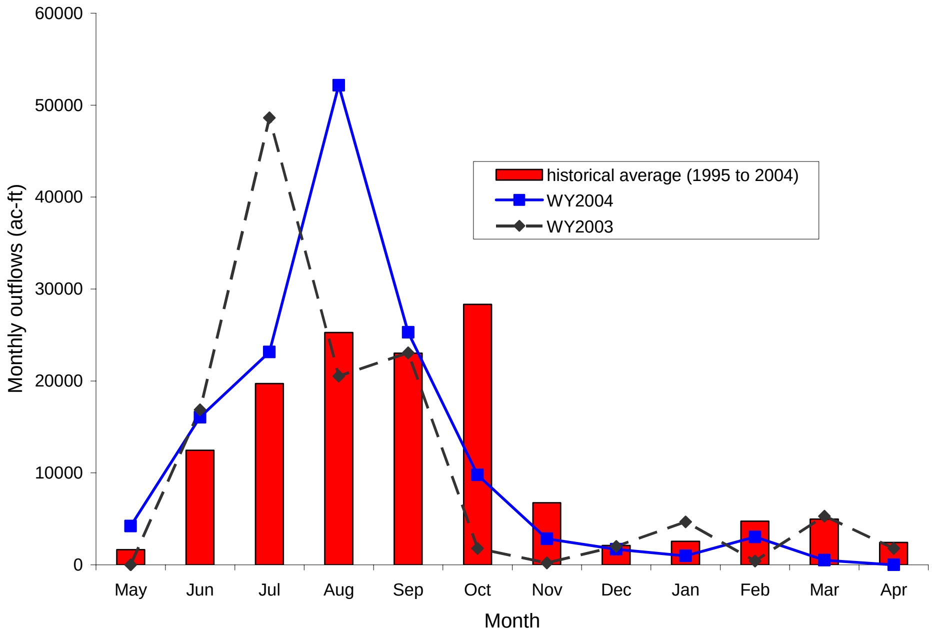

Figure 5-38. Monthly outflow from C-23 (site S-48).

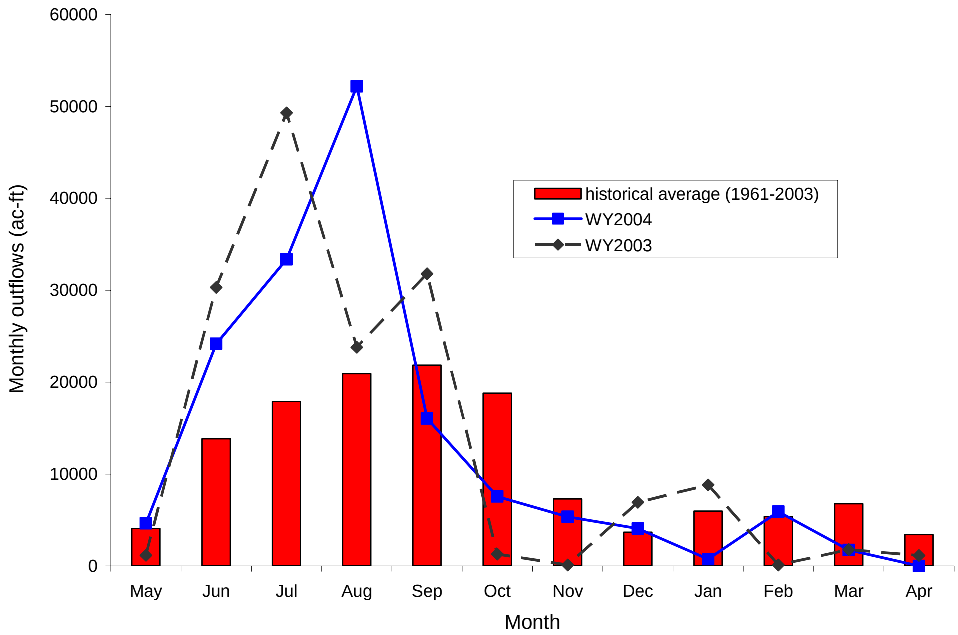

Figure 5-39. Monthly outflow from C-24 (site S-49).

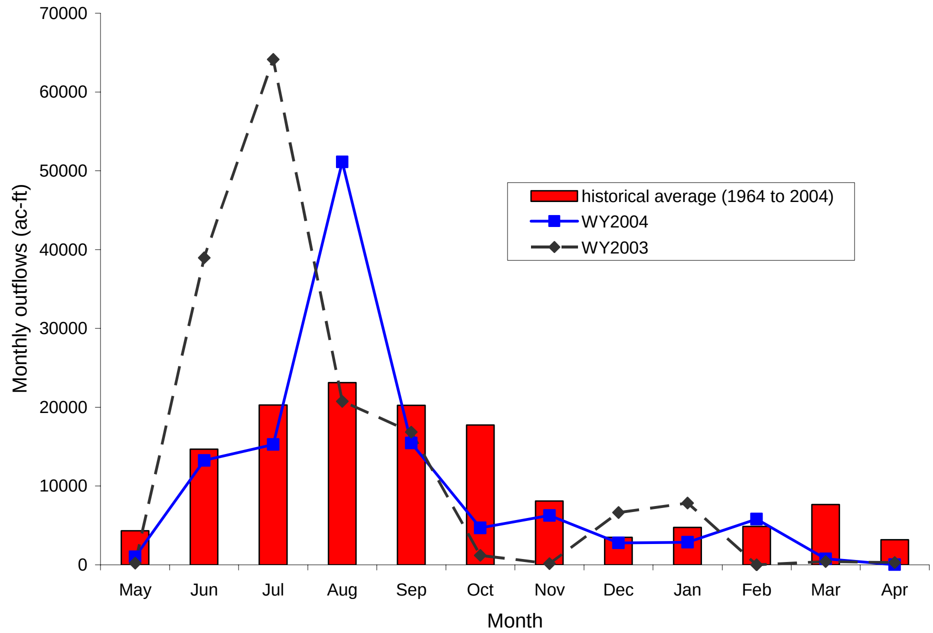

Figure 5-40. Monthly outflow from C-25 (site S-50).

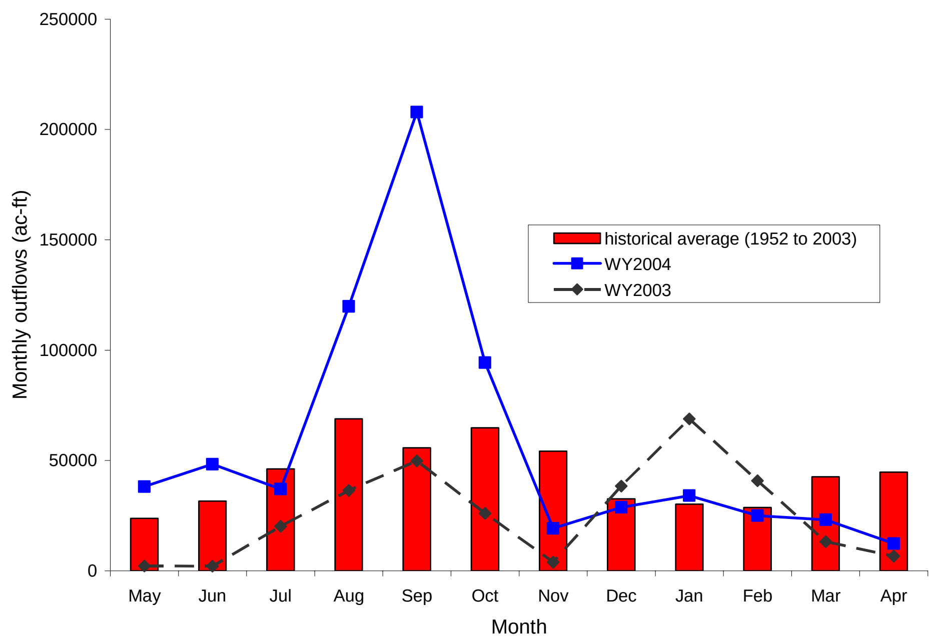

Figure 5-41. Monthly outflow from C-44 (site S-80).

Caloosahatchee River and Estuary Flows

The last structure on the Caloosahatchee River that controls discharges into its estuary is S-79. The average annual flow volume at S-79 is 1,160,378 ac-ft, based on the 1972–2003 record. In WY2004, 2,441,923 ac-ft of water was discharged through the spillway at S-79, and 1,729,106 ac-ft was discharged in WY2003. For WY2004, Lake Okeechobee discharges into the Caloosahatchee River through the S-77 structure were 1,321,711 ac-ft. **Figure 5-42** shows the monthly discharge at S-79 for WY2004, WY2003, and the historical monthly average discharge. Appendix 5-2, Table 5 depicts the monthly flow volumes for WY2004 at this site.

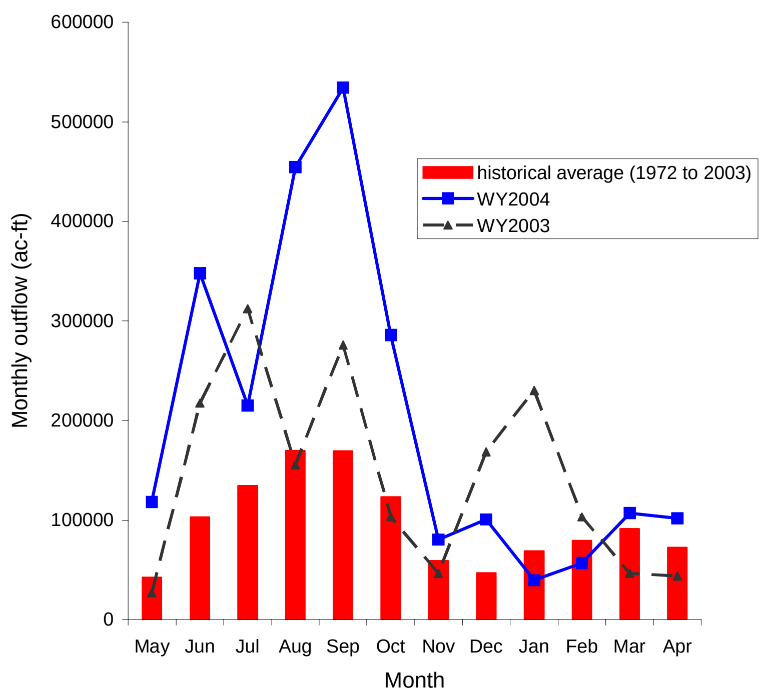

Figure 5-42. Monthly outflow at S-79 in the Caloosahatchee River.

Everglades Protection Area Flows

Inflow and outflow structures throughout the WCAs are operated based on regulation schedules. Historical flows through each structure have varying lengths of period of record, because of new structures coming online or existing structures that no longer contribute to the inflow and outflow of a system. The stormwater treatment structures are relatively recent additions. Time-weighted average historical inflows and outflows were computed for the period from 1978–2003. WCA-1 is regulated from between 14–17.50 ft NGVD. The average historical inflow in WCA-1 was 381,752 ac-ft. The total inflow to WCA-1 for WY2004 was 334,957 ac-ft, which was close to the historical average, and was 54 percent of the WY2003 inflows (620,131 ac-ft). **Figure 5-43** depicts historical monthly average inflows, and WY2004 and WY2003 inflows to WCA-1. The major inflows (89 percent) were from STA-1W through pump stations G-310 and G-251. ACME 1 and ACME 2 sources from Wellington to the east contributed 6 percent of the total inflow. The remaining 5 percent of the flows were mainly through structures G-300 and G-301, which discharge from the inflow and distribution impoundment of STA-1W, where almost all the entire source is the S-5A pump station bypassing STA-1W. Monthly inflows to WCA-1 by water control structures are shown in Appendix 5-2, Table 6. There was no diversion of flow from S-6 to WCA-1 through structure G-338. S-6 pump discharge has been diverted from WCA-1 into STA-2 since May 2001.

Outflows from WCA-1 were mainly into the Hillsboro Canal through structure S-39 (51 percent); into WCA-2A through structures S-10A, C, and D (29 percent); and discharge to the Lake Worth Drainage District through structures G-94A, B, and C (10 percent). The remaining 10 percent of outflows for this reporting year were mostly backflows to the STA-1W inflow and distribution basin through structures G-300 and G-301. The total outflow for WY2004 was 269,603 ac-ft, which is 52 percent of the total outflows in WY2003 (515,099 ac-ft). The average historical monthly outflow is 535,481 ac-ft**. Figure 5-44** depicts historical monthly average outflows, and WY2004 and WY2003 outflows from WCA-1. Monthly outflows from WCA-1 by water control structures are shown in Appendix 5-2, Table 7. There were no flows through structures G-94A and G-94B.

The total inflow to WCA-2 for WY2004 was 520,641 ac-ft, compared to 692,989 ac-ft for WY2003 and 657,929 ac-ft historical averages. The major inflows (55 percent) were from STA-2 through pump station G-335. WCA-1 discharges through the S-10A, C, D, and E structures are inflows to WCA-2A (15 percent). 30 percent of the inflow was from the EAA through the S-7 structure. Inflows through structure G-339, a bypass structure at STA-2, were minimal. **Figure 5-45** depicts historical monthly average inflows, and WY2004 and WY2003 inflows into WCA-2. Monthly inflows to WCA-2 by water control structures are shown in Appendix 5-2, Table 8.

Outflows from WCA-2 are primarily into WCA-3A through structures S-11A, B, and C (54 percent); into the North New River Canal through structure S-34 (20 percent); discharge to the North New River Canal through structure S-143 (6 percent); and discharge to canals 13 and 14 through structure S-38 (19 percent). The remaining one percent of outflow for WY2004 was backflow to the EAA through the S-7 structure, and backflow through the G-339 spillway. The total outflow for WY2004 was 749,663 ac-ft, which is 141 percent of the total outflows in WY2003 (533,400 ac-ft). The average historical monthly outflow is 682,530 ac-ft. **Figure 5-46** depicts historical monthly average outflows, and WY2004 and WY2003 outflows from WCA-2. Monthly outflows from WCA-2 by water control structures are shown in Appendix 5-2, Table 9.

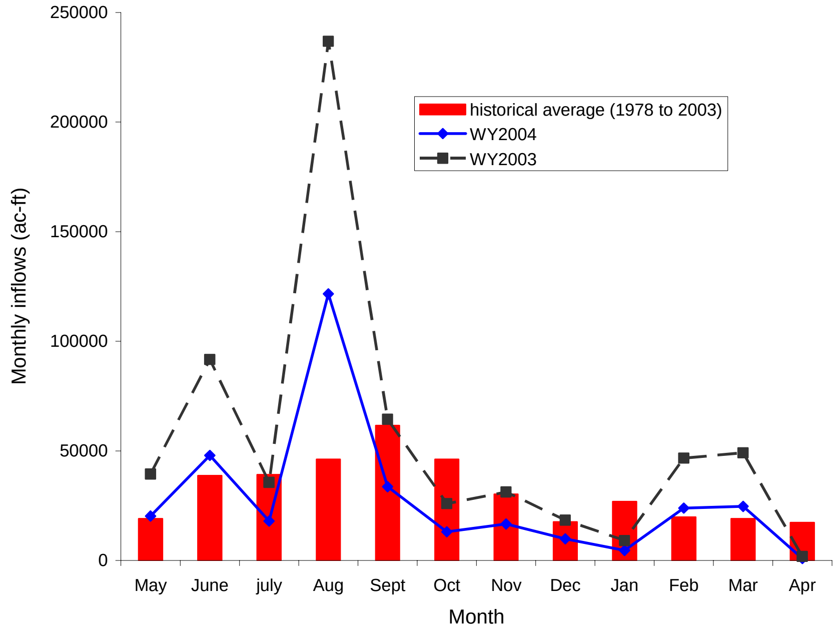

Figure 5-43. Monthly inflows into WCA-1.

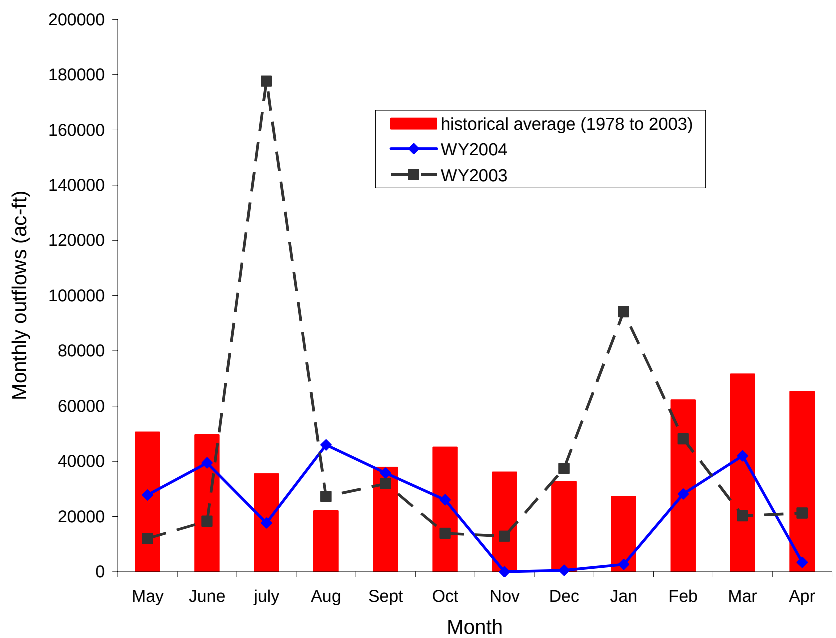

Figure 5-44. Monthly outflows from WCA-1.

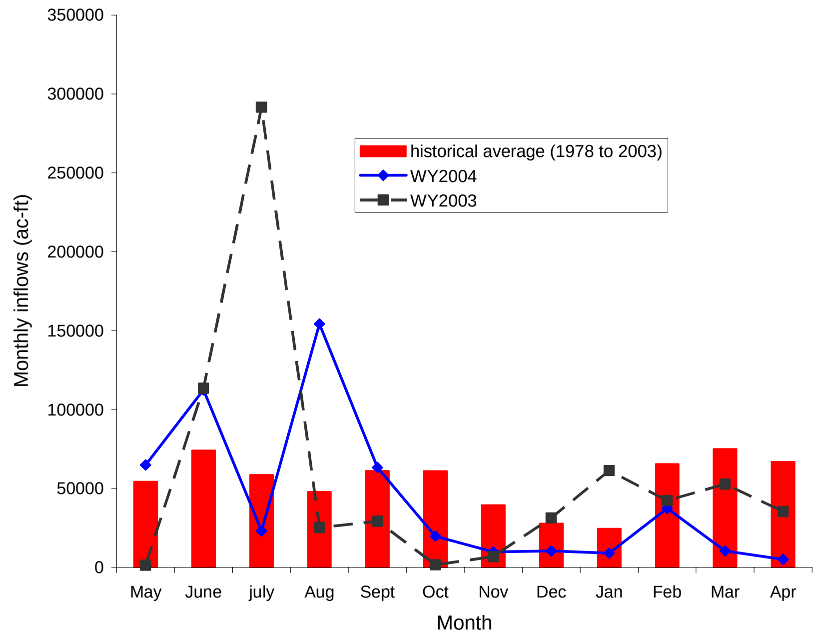

Figure 5-45. Monthly inflows into WCA-2.

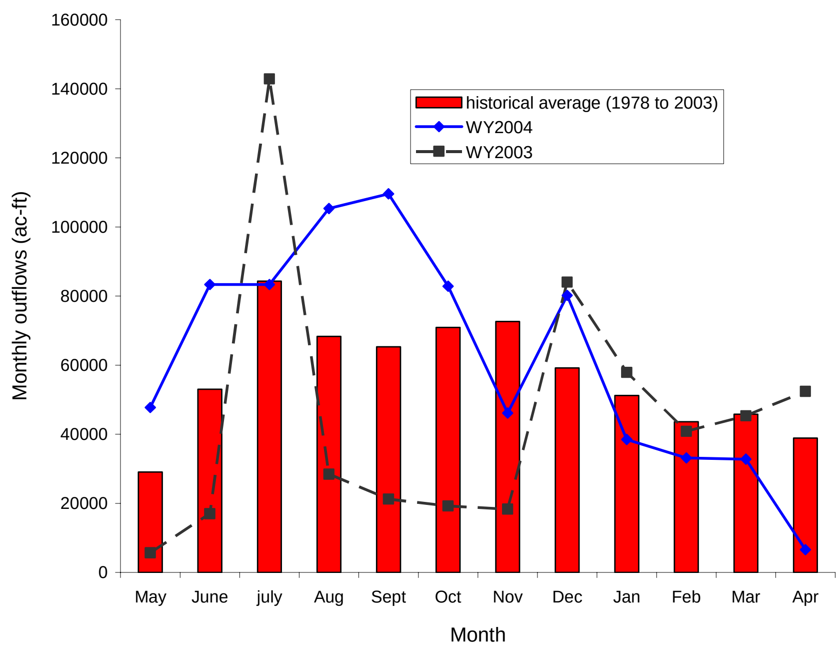

Figure 5-46. Monthly outflows from WCA-2.

Similar to WY2003 inflows (1,073,727 ac-ft), the total inflow to WCA-3 was 1,053,423 ac-ft during WY2004. The historical average inflow is 1,213,727 ac-ft. The major inflows were through S-11A, B, and C (38 percent) from WCA-2, but mostly from the EAA through structures S-8 and S-150 (34 percent). Discharges from the east through structure S-9 accounted for 14 percent. The S-140 structure to the northwest contributed 13 percent of the inflow to WCA-3A. Minor inflows were through structures G-69 and S-142. There are currently ungauged potential inflows to WCA-3A through the L-4 borrow canal breach into the L-3 extension canal. The breach has a bottom of 150 ft, at an elevation of 3.0 ft NGVD (SFWMD, 2002). **Figure 5-47** depicts historical monthly average inflows, and WY2004 and WY2003 inflows into WCA-3. Monthly inflows to WCA-3 by water control structures are shown in Appendix 5-2, Table 10.

Outflows from WCA-3A are mainly into the ENP through structures S-12A, B, C, D, and E (72 percent). S-333 discharged 14 percent, with potential directions of flow to south and east, Shark River Slough, and Taylor Creek of the ENP. Discharges into the North New River Canal through structure S-142 accounted for 8 percent of the total outflow, and S-31 discharge was 4 percent of the total outflow. There are minor outflows through structures S-344, S-30, and G-69. The total outflow for WY2004 was 1,221,322 ac-ft, which is 132 percent of the total outflows in WY2003 (924,089 ac-ft). The average historical monthly outflow is 886,055 ac-ft. **Figure 5-48** depicts historical monthly average outflows, and WY2004 and WY2003 outflows from WCA-3. Monthly outflows from WCA-3 by water control structures are shown in Appendix 5-2, Table 11.

Inflow into the ENP is mainly through structures S-12A, B, C, D, and E; S-18; S-197; S-332; S-174; S-175; S-332D; S-333; and S-334. The major inflow (70 percent) was through the S-12 structures. These structures are operated by the District for the USACE, in accordance with the Rain-Driven Water Deliveries Plan to the ENP and the Regulation Schedule of WCA-3A. This plan discharges through the S-333, with discharges from S-12A, B, C, and D structures estimated a week in advance using a computer program. A weekly report is posted by the SFWMD, and is available online at http://www.sfwmd.gov/org/ema/reports/sharkriver/index.html. The objective of this plan is to restore a more natural hydroperiod and hydropattern in the northeast Shark River Slough. Structural and operational modifications were also incorporated into the delivery plan based on the Interim Operation Plan (IOP) for protection of the Cape Sable seaside sparrow, which is available online at http://hpm.saj.usace.army.mil/i6ssueweb/Sparrow/fiopeis.htm. Flows through S-18 accounted for 13 percent of the total flow. Structure S-332D contributed 10 percent. Structure S-333 and S-334 contributed 7 percent with S-197 and S-174 adding minor inflows. The total surface water inflow to the ENP for WY2004 was 1,251,807 ac-ft, which is 137 percent of WY2003 inflows (913,207 ac-ft). The historical average inflow is 1,168,966 ac-ft. **Figure 5-49** depicts historical monthly average inflows, and WY2004 and WY2003 inflows into the ENP. Monthly inflows to the ENP by water control structures are shown in Appendix 5-2, Table 12. **Figure 5-50** shows total surface water inflows and outflows to major hydrologic components.

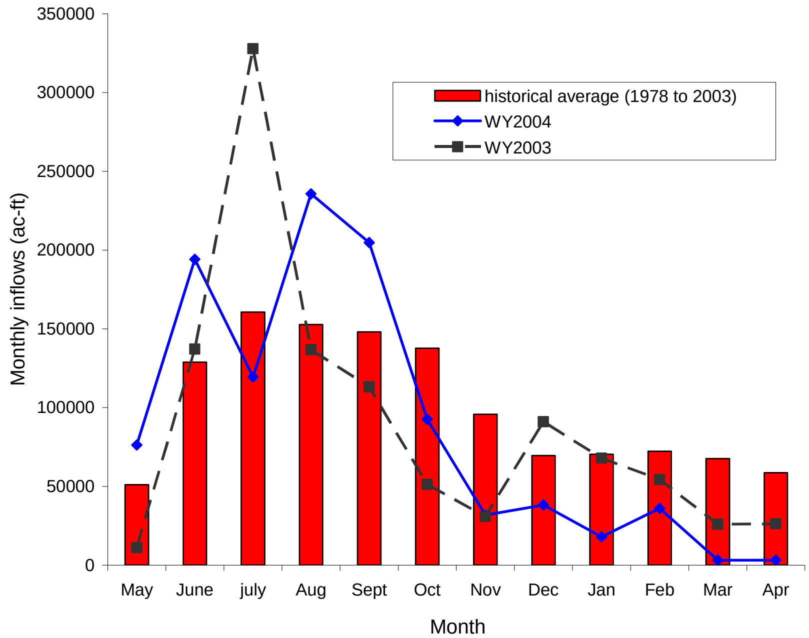

Figure 5-47. Monthly inflows into WCA-3.

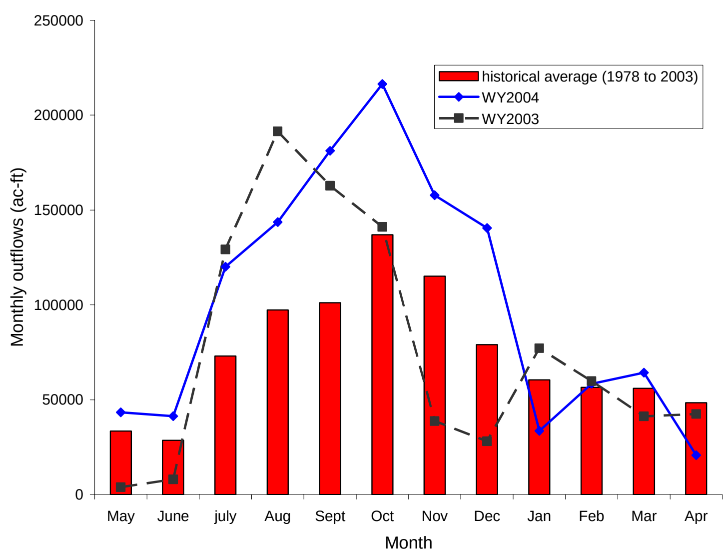

Figure 5-48. Monthly outflows from WCA-3.

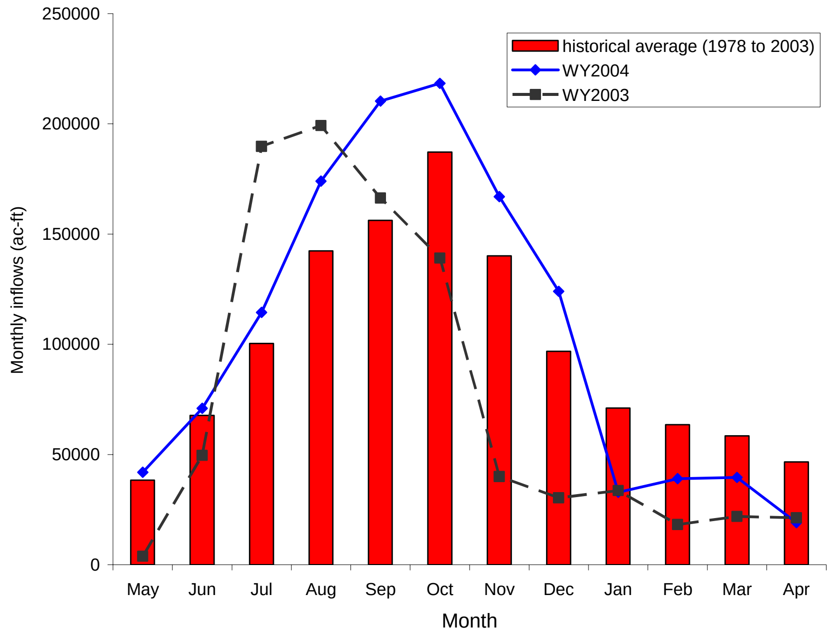

Figure 5-49. Monthly inflows into the ENP.

Figure 5-50. WY2004 inflow and outflows (ac-ft) into major hydrologic components.

CONCLUSIONS

Hydrologic data is essential to the South Florida environmental restoration and water management efforts of the District. Therefore, this information is presented in this separate chapter of the *2005 South Florida Environmental Report – Volume I*. This chapter includes updated hydrologic data and analysis from the 2004 ECR, with expanded coverage to address the hydrology of the entire South Florida area within the District's boundaries. Rainfall, ETp, water levels, inflows, and outflows are presented for WY2004, and hydrologic conditions were compared with WY2003. Historical hydrologic data was also analyzed and compared with WY2004 and WY2003 hydrology. However, it should be noted that given the extensive coverage for this years' report, the extent of data analysis is limited at this time.

During WY2004, rainfall in the Upper Kissimmee and Lower Kissimmee rainfall areas was close to average, while Lake Okeechobee, Martin and St. Lucie Counties, and the East EAA had lower than average rainfall. The east coast, with the exception of Broward County and the ENP, had lower than average rainfall, and the west coast had higher than average rainfall. ETp or evaporation from lakes, wetlands, and impoundments was close to the expected average for the entire District (52.6 in).

Monthly average water levels for WY2004 in most areas within the Upper Kissimmee Chain of Lakes (Lake Alligator, Lake Myrtle, Lake Mary Jane, Lake Gentry, Lake East Tohopekaliga, and Lake Tohopekaliga) were generally close to WY2003 levels and current regulation schedules, except for Lake Tohopekaliga. At Lake Tohopekaliga, ecological drawdown was implemented, and deviations were made from the regular regulation schedule. A water level decline of approximately 4.5 ft resulted by late April 2004, as compared to WY2003. The Lake Istokpoga average water level was similar to that of WY2003. In contrast, the Lake Kissimmee average water level during WY2004 was lower than the WY2003 average stage, while the Lake Okeechobee average water level was higher.

During WY2004, WCA-1 maintained an average stage of 16.50 ft NGVD. This was higher than the WY2003 average of 16.22 ft NGVD, and higher than the historical average water level of 15.56 ft NGVD. The average water level in WCA-2 for WY2004 was 12.40 ft NGVD. This was higher than the WY2003 average of 12.17 ft NGVD, but lower than the historical average water level of 12.58 ft NGVD. The average water level in WCA-3 in WY2004 was 10.30 ft NGVD. This was higher than the WY2003 average of 10.07 ft NGVD and the historical average water level of 9.50 ft NGVD. The average water level in the ENP at site P-33 in WY2004 was 6.68 ft NGVD, which was higher than the WY2003 average of 6.35 ft NGVD, and the historical average water level of 5.96 ft NGVD. The average water level in the ENP at site P-34 in WY2004 was 3.09 ft NGVD, which was also higher than the WY2003 average of 2.53 ft NGVD, and the historical average water level of 2.04 ft NGVD.

During WY2004, surface water outflow through Lake Kissimmee was 1,193,153 ac-ft. Lake Istokpoga discharge was 401,631 ac-ft. Lake Okeechobee inflows totaled 2,920,448 ac-ft, and outflows were 2,617,958 ac-ft. Discharge into the Southern Indian River Lagoon and St. Lucie Estuary was 1,103,338 ac-ft, with 688,528 ac-ft discharged through the St. Lucie Canal outflow structure S-80. Discharge into the Caloosahatchee Estuary through structure S-79 was 2,445,277 ac-ft. For WCA-1, inflows were 334,957 ac-ft, and outflows were 269,603 ac-ft; for WCA-2, inflows were 520,641 ac-ft, and outflows were 749,663 ac-ft; and for WCA-3, inflows were 1,053,423 ac-ft, and outflows were 1,221,322 ac-ft. Inflows to the ENP were 1,251,807 ac-ft. Overall, no extreme hydrologic events such as El Niño, La Niña, hurricanes, or drought occurred in South Florida during WY2004.

LITERATURE CITED

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

Abtew, W. 2004. Evapotranspiration in the Everglades: Comparison of Bowen Ratio Measurements and Model Estimations. Technical Paper EMA-417. South Florida Water Management District, West Palm Beach, FL.

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

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

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

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

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

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

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

Crowell, M.L. and N. D. Mtundu, 2000. Guidelines for Quality Control and Quality Assurance of Hydrologic and Meteorologic Data. Volume 2: Data Management. Prepared by the St. Johns, South Florida, Southwest Florida, and Suwannee River Water Management Districts, FL.

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

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

Price, C., J. Woolverton and K. Overton. 2001. Water Resources Data Florida Water Year 2001. Volume 2A, South Florida Surface Water, Water-Data Report FL-01-2A. United States Geological Survey (USGS).

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

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

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

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

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

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

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

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