The Drought of 1998-2002: Impacts on Florida's Hydrology and Landscape

By Richard Jay Verdi, Stewart A. Tomlinson, and Richard L. Marella

Prepared in cooperation with the
Florida Department of Transportation and the
Florida Department of Environmental Protection

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Foreword

As a leader in the natural sciences and through scientific excellence and responsiveness to society's needs, the U.S. Geological Survey (USGS) serves the Nation by providing reliable scientific information to:

- Describe and understand the Earth;
- Minimize loss of life and property from natural disasters;
- Manage water, biological, energy, and mineral resources; and
- Enhance and protect our quality of life.

The USGS is committed to providing environmental information that is meaningful to policymakers and the public. Collection, archiving, and distribution of data better enable Federal, State, and local agencies to anticipate and respond to natural hazards. The conditions described herein characterize the diverse impacts to the Florida landscape during 1998-2002 caused by drought, and drought-related occurrences such as wildfires and subsidence. The knowledge gained from this report may assist managers in planning for future natural disasters and other catastrophic events.

Robert M. Hirsch
Associate Director for Water
U.S. Geological Survey

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
acre	0.4047	hectare (ha)
	Flow rate	
foot per year (ft/yr)	0.3048	meter per year (m/yr)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Wind speed	
knot (kt)	1.152	mile per hour (mph)
knot (kt)	1.85	kilometer per hour (kph)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to "National Geodetic Vertical Datum of 1929 (NGVD 29)."

Horizontal coordinate information is referenced to the "North American Datum of 1983 (NAD 83)."

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations

mg/L	Milligrams per liter
NWS	National Weather Service
USGS	U.S. Geological Survey
NWISWeb	U.S. Geological Survey National Water Information System Webpage

The Drought of 1998-2002: Impacts on Florida's Hydrology and Landscape

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Introduction

Drought, commonly defined as being a time of less-than-normal or expected rainfall; depending on the effect and cause, may be characterized as agricultural, hydrological, meteorological, or sociological:

- **Agricultural—A shortage of water in the root zone of plants such that plant yield is reduced considerably.**
- **Hydrological—An extended period during which streamflow, lake and reservoir storage, and ground-water levels are below normal.**
- **Meteorological—An extended period during which precipitation is below normal.**
- **Sociological—Meteorologic and hydrologic conditions under which less water is available than is anticipated and relied on for the normal level of social and economic activity of a region.**

Lower than normal **precipitation**[1] caused a severe statewide drought in Florida from 1998 to 2002. Based on precipitation and streamflow records dating to the early 1900s, the drought was one of the worst ever to affect the State. In terms of severity, this drought was comparable to the drought of 1949-1957 in duration and had record-setting low flows in several basins. The drought was particularly severe over the 5-year period in the northwest, northeast, and southwest regions of Florida (fig. 1), where rainfall deficits ranged from 9-10 in. below **normal** (southwest Florida) to 38-40 in. below normal (northwest Florida). Within these regions, the drought caused record-low streamflows in several river basins, increased **freshwater withdrawals**, and created hazardous conditions ripe for wildfires, **sinkhole** development, and even the draining of lakes. South Florida was affected primarily in 2001, when the region experienced below-**average streamflow** conditions; however, cumulative rainfall in south Florida never fell below the 30-year normal. The four regions of Florida (fig. 1), as referred to throughout this report, are defined based upon U.S. Geological Survey (USGS) data collection regions in Florida.

Record-low flows were reported at several **streamflow-gaging stations** throughout the State, including the Withlacoochee River at Trilby, which reached zero flow on June 10-11, 2000, for the first time during the period of record (1928-2004). Streamflow conditions varied across the State from 31 percent of average flow in 2000 in southwest Florida, to 100 percent of average in 1999 in south Florida.

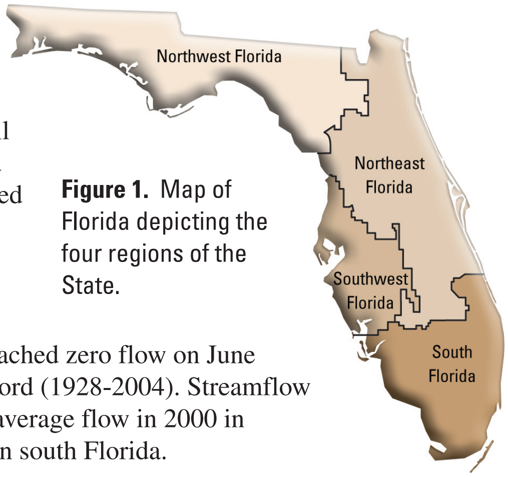

Figure 1. Map of Florida depicting the four regions of the State.

[1]Terms defined in the glossary are in **bold print** where first used in the main body of the report.

Low-flow **recurrence intervals** during the drought ranged from less than 2 years at three locations to greater than 50 years at many locations.

During the 1998-2002 drought, ground-water levels at many wells across the State declined to elevations not seen in many years. At some wells, ground-water levels reached record lows for their period of record. Florida Water Management Districts responded by issuing water-shortage mandates to curb **water use** during the spring months of 2000. Generally, freshwater withdrawals increased 13 percent between 1995 and 2000 as a result of the dry conditions.

Hundreds of new sinkholes developed across the State. Lake Jackson, in northwest Florida near Tallahassee, experienced its eighth and ninth drawdowns of the past 100 years, and became nearly dry. Numerous other lakes in northern and central Florida experienced similar events. Water restrictions were put into effect in urban areas of the northeast, southwest, and south Florida regions. Wildfires periodically raged over parts of Florida throughout the period, when tinder-dry undergrowth caught fire from lightning strikes or manmade causes. Smoke from these fires caused traffic delays as sections of major highways and interstate lanes forced traffic to slow to a crawl or were closed. Wildfire statistics (Florida Division of Forestry, undated(a)) show that 25,137 fires burned 1.5 million acres between 1998 and 2002. Finally, rainfall that occurred in late 2002, in 2003, and from a **tropical storm** and four **hurricanes** in 2004 ended this drought.

Purpose and Scope

The drought of 1998-2002 had a major impact on Florida. This report was prepared to document the surface- and ground-water conditions during the drought, including rainfall quantities over the period of the drought and rainfall variability across the four regions of Florida. Rainfall and other hydrologic conditions are compared with conditions during previous droughts. Climatic conditions leading up to and during the drought are addressed, and the multiple effects of the drought on Florida's landscape and water supply are described and examples provided. Readers will emerge with a better understanding of the causes and characteristics of the drought, the types of ground- and surface-water data that were collected and what they showed, and the impacts that the drought had in Florida. The historical perspective on Florida's drought of 1998-2002, including the frequency of similar occurrences, is valuable to resource managers in planning for such events in the future.

Description of Area

Florida's topography is mostly flat, ranging from **sea level** to the highest known natural point of 345 ft at Britton Hill near Paxton (Walton County in northwest Florida). In north-central and northwest Florida, hills and rolling hills predominate, whereas in the southernmost part of the State, the wetlands of the Everglades prevail (Pride and Crooks, 1962). The water bodies in Florida include thousands of lakes and ponds, more than 50 river systems, 33 first magnitude springs (discharge greater than 100 ft^3/s, more than any other state), and numerous bays and estuaries. The St. Johns River is the longest river in the State, measuring

273 miles in length. Water bodies comprise 4,424 mi^2 of the State's total area (58,560 mi^2) (Florida Office of Cultural and Historical Programs, [undated], accessed August 30, 2005). These water bodies are replenished in multiple ways, mostly from rainfall and stormwater **run-off**. Other sources include **discharge** from the upward movement of ground-water springflow and surface streams, some that originate in Georgia or Alabama. Water loss occurs through evaporation, **transpiration**, water use, and discharge into the Gulf of Mexico or the Atlantic Ocean (Pride and Crooks, 1962).

Definition of Drought

A drought is a period of drier than normal conditions that results in water-related problems, and can be defined by any combination of meteorological, agricultural, hydrological and/or socioeconomic factors (National Oceanic and Atmospheric Administration, undated(b)). In this report, drought is defined in meteorological and hydrological terms as any period in which there is a precipitation deficiency that causes a hydrologic imbalance serious enough to affect the flora, fauna, and human population of an area. Drought severity can be rated based on several dynamics, such as (1) the relation of the deficiency to normal rainfall; (2) land use and coverage; (3) the event location and time; and (4) duration of the deficiency (Pride and Crooks, 1962).

In Florida, a drought can occur any time high-pressure air masses become established over a region for an extended time period. Additionally, the occurrence of a **La Niña** episode can direct winter storm systems toward a more northerly track, reducing precipitation in Florida. According to Hoyt (1938), drought conditions in humid and semiarid states are not considered serious unless the annual rainfall deficit is more than 14 percent. During 1998-2002, Florida experienced multiple high-pressure systems and a La Niña during at least part of the time. Some authors suggest that three droughts occurred during this timeframe, but these events will be considered as one drought in this report because hydrologic conditions never rebounded for an extended period of time until normal rainfall resumed in late 2002.

Acknowledgments

The data used for analyses in this report were collected in cooperation with the following State, Federal, or local agencies: South Florida Water Management District, Southwest Florida Water Management District, Suwannee River Water Management District, Northwest Florida Water Management District, Florida Department of Environmental Protection, Miami-Dade County Environmental Restoration and Management, U.S. Army Corps of Engineers, Walton County, and the City of Tallahassee.

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Climate and Precipitation





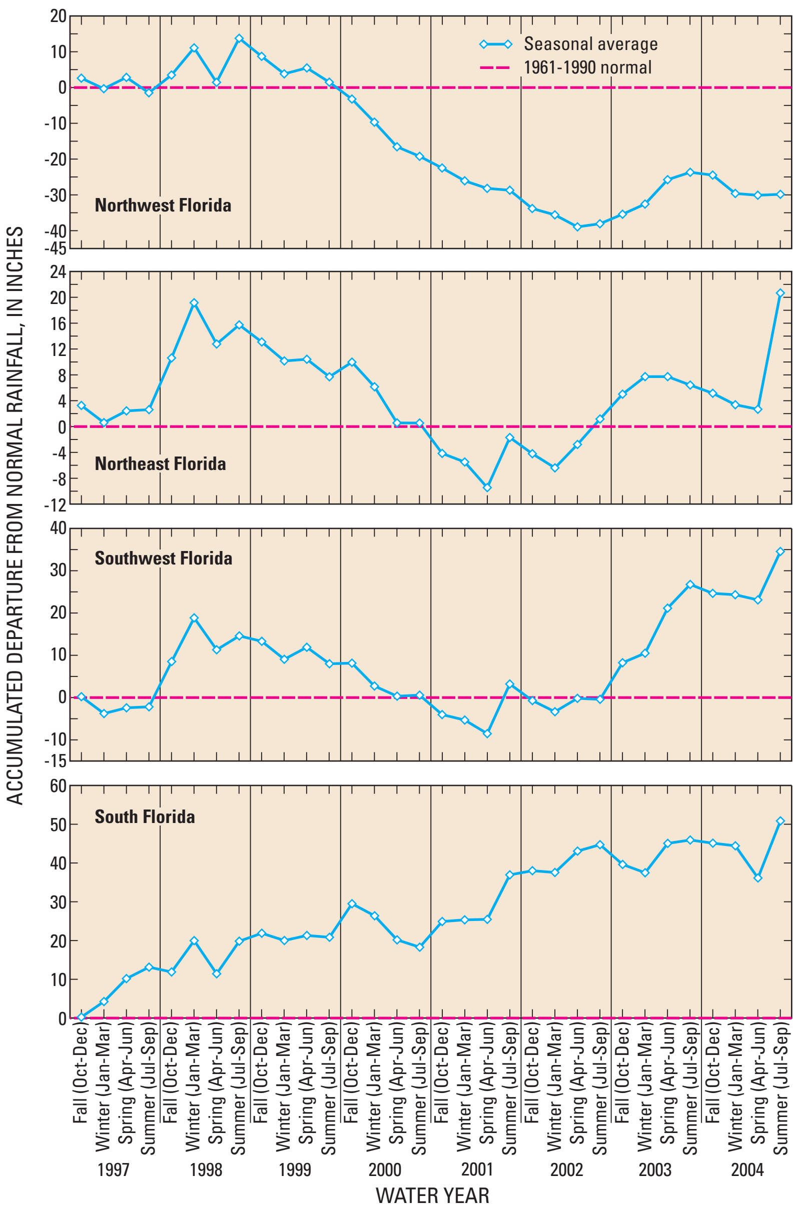


Figure 2. Accumulated departures from normal rainfall for the northwest, northeast, southwest, and the south Florida regions from the 1997 to 2004 water years.

Climatic data, including average weather conditions, factors affecting weather, and precipitation records, were obtained from the National Weather Service (NWS), including the Southeast Regional Climate Center (2005) and the National Climatic Data Center (2001a, b). Precipitation records are discussed here for **water years** 1998 through 2004. The term, "water year," refers to the 12-month USGS hydrologic period from October 1 to September 30. The NWS rainfall data period was adjusted to be concurrent with the USGS water year in this report. **Real-time** USGS data for Florida are accessible to the public through the USGS National Water Information System Webpage (NWISWeb) at http://fl.waterdata.usgs.gov.

Florida is a desired retirement, recreational, and vacation locale for people around the world because of its warm subtropical climate and tourist attractions. During the summer months, average daily temperatures in the State range from 80.5 °F in the north to 82.7 °F in the south. During the winter months, average daily temperatures range from 53.0 °F in the north to 68.5 °F in the south. The highest temperature recorded was 109 °F on June 29, 1931, in Monticello; the lowest temperature recorded was -2 °F on February 13, 1899, in Tallahassee (Southeast Regional Climate Center, 2005).

Seasonal precipitation patterns in Florida vary between summer convective thunderstorms and winter fronts. Summer thunderstorms occur throughout the State, but are most prevalent along the Gulf Coast where they occur an average of 80-95 days per year. The panhandle is the wettest part of the State, averaging 55-65 in. of rainfall annually. The Florida Keys are the driest part of the State, averaging 40-45 in. annually. The panhandle and northern part of the State experience two dry seasons—one in the fall and one in the spring. In peninsular Florida, the dry season occurs primarily during the winter, and the intensity of this dryness progressively increases southward.

The maximum recorded annual rainfall in Florida was 112.4 in. and occurred in 1966 at Wewahitchka in the Florida Panhandle; the minimum recorded annual rainfall was 21.16 in. and occurred in 1989 at Conch Key in the Florida Keys (Southeast Regional Climate Center, 2005). Florida's greatest 24-hour rainfall totaled 38.7 in. and was recorded on September 5, 1950, at Yankeetown, north of St. Petersburg (Southeast Regional Climate Center, 2005). This record rainfall, a result of Hurricane Easy, was also the greatest measured rainfall amount within a 24-hour period in the history of the United States weather records (Intellicast, 2005).

Until 2000, Florida's lowest recorded average annual rainfall was 40.71 in. in 1927 (Hoyt, 1936); this amount is 75 percent of the long-term (1900-2000) average annual rainfall of 53.93 in. (National Climatic Data Center, 2001a). In 2000, however, this record was surpassed when the average annual rainfall for the State was just above 40.00 in. (National Climatic Data Center, 2001b), which is 74 percent of the long-term average.

Statewide impacts of the 1998-2002 drought on precipitation at 18 weather stations are represented in figure 2. The weather stations were selected based on longevity of data, as well as geographic distribution throughout the State. Seasonal rainfall values were calculated by summing the quarterly rainfall and dividing by the number of weather stations within each respective area. Although using more than 18 weather stations could improve the accuracy of the rainfall results, this summary data provides a good representation of rainfall distribution in each of the four regions and throughout the drought period.

The drought began after a strong **El Niño** phenomenon in the fall and winter of 1997-1998 when rainfall was above normal for most of the State and temperatures were cooler. El Niño conditions are characterized by unusually warm ocean temperatures in the Equatorial Pacific, but the effects can be seen globally (fig. 3). By late 1998, a strong La Niña event was in effect, which continued through 2001. The La Niña, characterized by unusually cold ocean temperatures in the Equatorial Pacific, generally causes below-normal rainfall and higher temperatures in Florida (fig. 3). The La Niña, together with a variety of other climatic conditions, brought about the drought of 1998-2002 in Florida.

The following sections describe precipitation patterns in Florida by water year, from 1998 through 2004. The water year, established by the USGS, runs from October of one year through September of the next; USGS water data are collected, processed, and recorded for this time period.

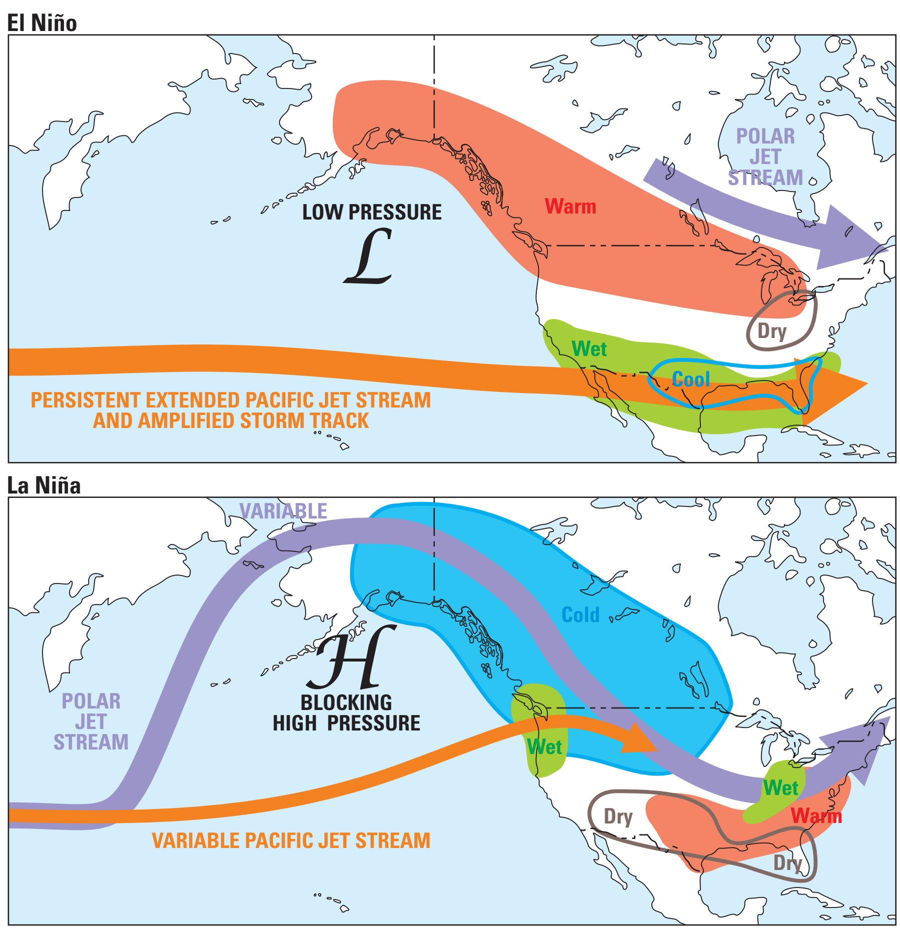


Figure 3. Typical January-March weather anomalies and atmospheric circulation during moderate to strong El Niño and La Niña (National Weather Service, 2005).

1998 Water Year

November 1997 to March 1998 was the wettest period on record for north-central Florida (National Climatic Data Center, 1999) and resulted in lush vegetative growth. Graphs of accumulated departures from normal rainfall show the rainfall trend throughout the State (fig. 2). **Flooding** occurred in March in northwest, northeast, and southwest Florida as a result of persistent rain during most of the winter and early spring. Record-breaking floods occurred in southwest Florida basins. From April to June 1998, however, little precipitation fell throughout the State (fig. 2), which caused drought conditions that were to persist for several years. Dry, warm weather occurred through June 1998. The dry vegetation helped spark wildfires in east and northeast Florida, which on occasion, closed interstate highways. On September 3, 1998, Hurricane Earl came ashore near Panama City, depositing an average of 5-10 in. of rain in northwestern Florida. Then in late September, Hurricane Georges brought an average of 10-20 in. of rainfall to the western panhandle of northwest Florida, with a few locations receiving as much as 27 in. of rain. Hurricane Georges caused record flooding in the Yellow, Shoal, Blackwater, and Escambia River Basins (U.S. Geological Survey, 1999). Following these two events, seasonal rainfall totals in northwest Florida generally declined through the spring of 2002 (fig. 2).

1999 Water Year

Dry conditions predominated in northwest and northeast Florida, and to a lesser extent in southwest Florida, during the fall (October-December) of 1998 and winter (January-March) of 1999. During these periods, some NWS rainfall stations (Tallahassee, Perry, Orlando, and Bartow) received less than half of their normal precipitation (table 1). The spring quarter (April-June) of 1999 brought above-normal rainfall throughout the State, but the summer (July-September) of 1999 rainfall was below normal. Overall, low rainfall totals in most of Florida during the 1999 water year resulted in even drier conditions by the end of the year. An exception occurred in the south Florida region, which recorded near-normal precipitation during the year.

Table 1. Fall and winter 1999 water year rainfall totals and departures from normal.

[Site locations shown on figure 5. NWS, National Weather Service]

Site number (see fig. 5)	NWS rainfall station	Fall total (inches)	Fall departure (inches)	Winter total (inches)	Winter departure (inches)
36	Tallahassee	3.23	-8.59	9.14	-7.40
37	Perry	2.74	-5.97	8.41	-4.87
42	Orlando	2.93	-3.94	3.91	-4.62
48	Bartow	4.48	-2.22	2.75	-5.93

2000 Water Year

During the 2000 water year, this cumulative deficiency in rainfall began to affect streamflow, ground-water conditions, and water supplies across the State. Rainfall during the fall quarter of the 2000 water year varied throughout the State. The northeast and south Florida regions received above-normal rainfall. Rainfall in these two regions was boosted by Hurricane Irene in October. Southwest Florida received near-normal rainfall. The northwest Florida region, however, continued to experience a dry spell with below-normal rainfall. The winter and spring quarters were exceptionally dry when below-normal rainfall conditions persisted throughout the entire State. The following summer quarter brought near- to below-normal rainfall throughout the State, even with the effects of Hurricane Gordon impacting northwest, northeast, and southwest Florida and Tropical Storm Helene impacting northwest Florida in September. The south and northwest Florida regions received below-normal rainfall, whereas rainfall in the southwest and northeast Florida regions was near-normal for the summer quarter (fig. 2). For south Florida, the combined cumulative departure from normal precipitation in the winter, spring, and summer quarters was the largest deficit observed during the period 1998-2002 (fig. 2).

2001 Water Year

Below-normal rainfall persisted throughout most of the 2001 water year (fig. 2). The fall, winter, and spring quarters brought below-normal rainfall throughout most of the State. The exception was in south Florida, which received above normal rainfall during the fall, and near-normal rainfall in the winter and spring quarters. During the 2001 water year, two tropical storms, Allison (in June) and Barry (in August), boosted rainfall in northwest Florida, but only briefly, as dry conditions resumed. During the summer quarter, rainfall averaged well above normal in south, southwest, and northeast Florida and near normal in northwest Florida. In September, Hurricane Gabrielle increased rainfall across the Florida Peninsula, causing record floods in southwest Florida.

2002 Water Year

During the fall and winter quarters of the 2002 water year, dry conditions persisted with below-normal rainfall in most of the State (fig. 2). The exception was in south Florida, which received near-normal rainfall during both quarters. Then, during the spring quarter rainfall averaged well above normal in south, southwest, and northeast Florida, which helped alleviate drought conditions. Rainfall in northwest Florida, however, continued to be below normal. During the summer quarter, rainfall varied from near normal in southwest and northwest Florida to well above normal in the northeast (partially attributed to increased rainfall from Tropical Storm Edouard in September) and in south Florida.

2003 Water Year

The 2003 water year brought much needed above-normal rainfall for most of Florida. Rainfall during the fall and winter quarters averaged above normal for much of the State. The exception was south Florida, which received below-normal rainfall during both quarters. During the spring quarter, rainfall for most of the State was above normal on average. This time, the exception was northeast Florida, which reported near-normal rainfall. During the summer quarter, above-normal rainfall was reported in south, southwest, and northwest Florida. Rainfall in southwest Florida was boosted in part due to Tropical Storm Henri in early September. Northeast Florida received below-normal rainfall during this quarter.

Suwannee River at Dowling Park on August 28, 2002 (discharge, 904 ft^3/s). (Photograph by Stewart Tomlinson, USGS, Tallahassee, Florida.)

The volume of rainfall received during the 2003 water year "unofficially" ended the 5-year drought across Florida. Many basins in northwest and northeast Florida, including the Suwannee River and Santa Fe River Basins, recorded their highest flows since 1998. Figure 4 shows two photographs of the Santa Fe River approximately 1 mile north of U.S. Highway 27, near High Springs. (Note the reference log in each picture.) Ground-water levels also returned to near-average conditions during 2003.

2004 Water Year

After a year of above-normal rainfall during the 2003 water year, the first three quarters of the 2004 water year proved to be comparatively dry. Rainfall during the fall, winter, and spring varied from about normal to well below normal for the entire State. Reductions in streamflow and ground-water levels occurred due to the deficit in precipitation. In August and September, rainfall from Tropical Storm Bonnie, and four hurricanes—Charley, Frances, Ivan, and Jeanne—returned precipitation and hydrologic conditions to near normal throughout most of the State. The only exception was northwest Florida, which still experienced a rainfall deficit, although most streams averaged near normal flow for the year.

At the end of the 2004 water year, the south, southwest, and northeast regions of Florida each registered cumulative rainfall surpluses, ranging from about 20 in. in northeast Florida to about 50 in. in south Florida. Conversely, northwest Florida registered a rainfall deficit of nearly 30 in. for the 1998-2004 period, even after the rainfall surplus associated with the 2004 hurricane season.

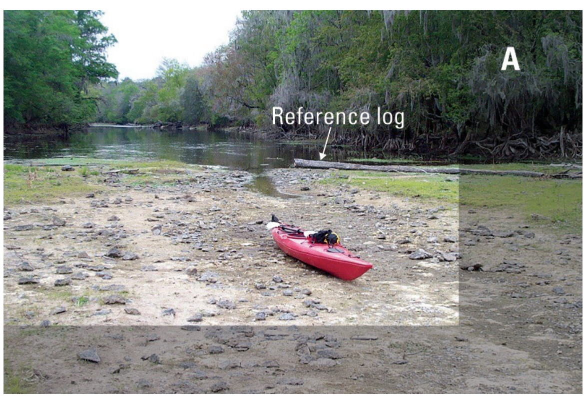


Figure 4. Santa Fe River approximately 1 mile north of U.S. Highway 27 near High Springs. Photograph A was taken in March 2001 after 7 consecutive quarters of below-normal rainfall. Photograph B was taken on December 26, 2002 after above-normal rainfall during the fall quarter of the 2003 water year. (The highlighted area in photograph A is the same area shown in photograph B. Photographs by Craig Fugate at www.seakayakflorida.com.)

Impacts of the Drought on Hydrologic Conditions





In 2004, the USGS operated a network of 405 continuous-record streamflow-gaging stations and 408 continuous-record ground-water observation wells in Florida in cooperation with Federal, State, county, and municipal agencies. Florida's network of streamflow-gaging stations and ground-water wells are operated from five USGS offices: Tallahassee in the northwest, Altamonte Springs in the northeast, Tampa in the southwest, and Fort Lauderdale and Fort Myers in the south. The types of data collected throughout the State may include some or all of the following: **stage**, elevation, **velocity**, temperature, **salinity**, **specific conductance**, and precipitation. Data are recorded at either 60-, 30-, 15-, or 10-minute intervals. Approximately 75 percent of streamflow gages and 40 percent of ground-water observation wells in Florida are equipped with real-time satellite telemetry and transmit data into the USGS database at intervals of 1 to 4 hours. During critical events, such as floods or extremely low flows, data at some satellite telemetry gages and wells are transmitted as often as the recording interval of the data. During periods of high water, these data are essential for flood monitoring, emergency response, and dam and reservoir-system operation. During extreme droughts, which result in low-flow and low ground-water levels, accurate data must be available to efficiently manage Florida's water quantity and quality for public and commercial water supply. Streamflow, ground-water level, rainfall, and lake level data presented in this report were collected from 33 USGS continuous-record streamflow-gaging stations, 4 continuous-record ground-water wells, 18 NWS rainfall gages, and 1 lake-gaging station, respectively (table 2 and fig. 5; see foldin).

Suwannee River at White Springs in April 1932, during the major drought from 1931-1935 (April monthly mean discharge, 22.2 ft^3/s). The Suwannee River at White Springs streamgage is the oldest USGS streamflow-gaging station in Florida with a period of record from 1906 to 1908, and 1927 to 2004. (Photograph by USGS.)

Streamflow

Statewide impacts of the drought on streamflow at 33 gaging stations are represented in tables 3-5 and figure 6. The streamflow-gaging stations used in this study were selected based on longevity of data for each station, as well as geographic distribution throughout the State. Gaging stations were grouped by their location within the State in an effort to quantify the severity of the drought in their respective regions. The average streamflow values for each region (table 4) are only a general indicator, because of the limited number of stations used—especially in southwest and south Florida. A comparison between each year was made by summing the **annual streamflow** and dividing by the number of stations within each region.

As stated previously in this report, the 1998-2002 drought was caused by statewide rainfall deficiencies during the 5-year period. Hydrologic impacts of the 1998-2002 drought and its severity are evident in data collected at many streams throughout Florida. In October 1998, streamflows in northwest and northeast Florida were above average as a result of runoff from Hurricane Georges in late September. Monthly streamflows across Florida, however, only rarely exceeded average conditions after this period. Average annual streamflow remained below average for the 1999-2002 water years of the drought in all four regions, with the exception of south Florida, where annual streamflow was 100 percent of average for the 1999 water year (fig. 6). Even though cumulative departure rainfall never fell below normal in south Florida, streamflow averaged below normal during most of the drought. This condition is likely attributed to the fact that the hydrology in south Florida is controlled through use of canal structures.

During the drought, record low instantaneous streamflows were reported at 18 of the gaging stations included in this study (table 3). On June 10-11, 2000, for example, the Withlacoochee River streamgage at Trilby (site 27) reached zero flow for the only time in its period of record (1928-2004) (table 3). Table 3 lists the lowest instantaneous flow and date for the periods before and during the 1998-2002 drought and the lowest annual streamflow and year of occurrence for the period of record for the streamgage. Photographs of streamflow-gaging stations in figures 7-11 show the extreme low flows caused by the drought.

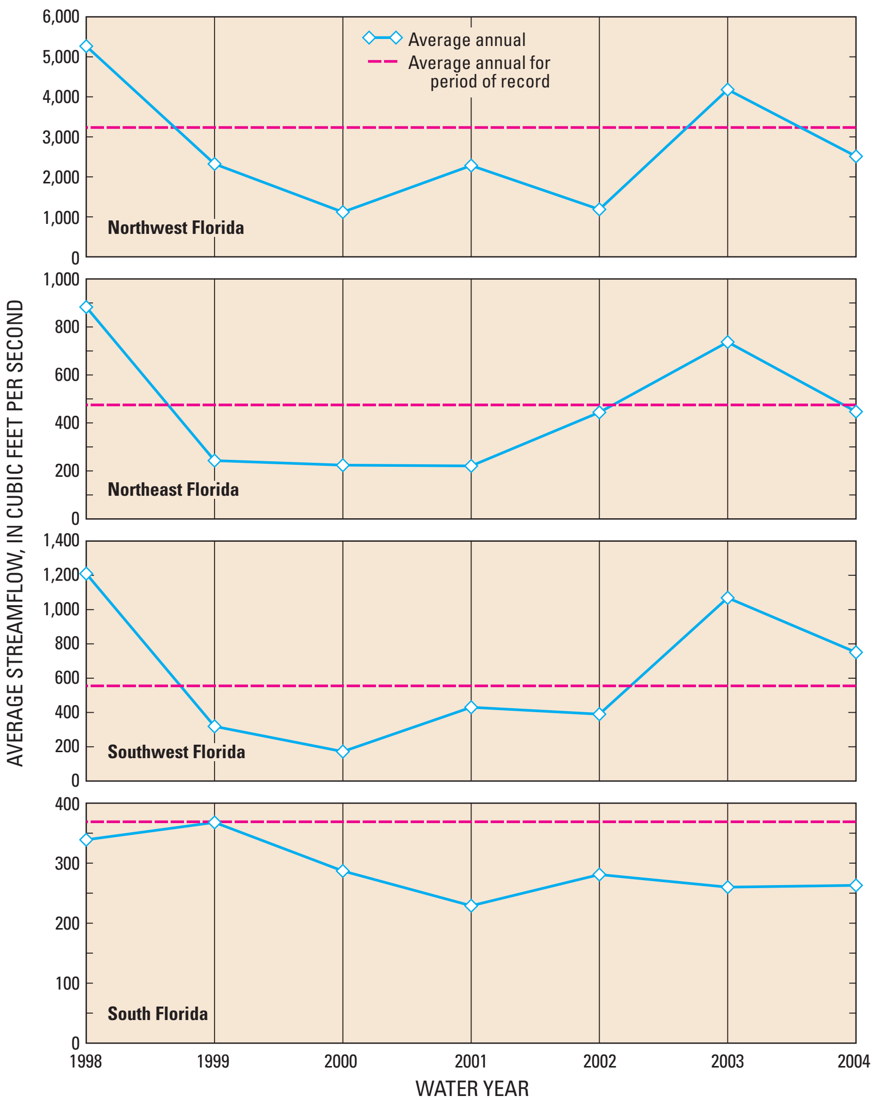


Figure 6. Average annual streamflow for water years 1998-2004 compared to the average annual streamflow for the period of record for the northwest, northeast, southwest, and south Florida regions.

Table 2. U.S. Geological Survey streamflow- and lake-gaging stations, National Weather Service rainfall stations, and observation wells used in this report.

[Site locations shown on figure 5. NWS, National Weather Service]

Geographic region	Site number (fig. 5)	USGS station number or NWS station	Station name
Northwest	1	02315500	Suwannee River at White Springs
	2	02319000	Withlacoochee River near Pinetta
	3	02319500	Suwannee River at Ellaville
	4	02320500	Suwannee River at Branford
	5	02321000	New River near Lake Butler
	6	02321500	Santa Fe River at Worthington Springs
	7	02322500	Santa Fe River near Fort White
	8	02324000	Steinhatchee River near Cross City
	9	02326000	Econfina River near Perry
	10	02329000	Ochlockonee River near Havana
	11	02330000	Ochlockonee River near Bloxham
	12	02330100	Telogia Creek near Bristol
	13	02358000	Apalachicola River at Chattahoochee
	14	02359000	Chipola River near Altha
	15	02366500	Choctawhatchee River near Bruce
	16	02368000	Yellow River at Milligan
	17	02369000	Shoal River near Crestview
	18	02370000	Blackwater River near Baker
	19	02375500	Escambia River near Century
Northeast	20	02231000	St. Mary's River near MacClenny
	21	02231600	Jane Green Creek near Deer Park
	22	02232500	St. John's River near Christmas
	23	02246000	North Fork Black Creek near Middleburg
	24	02248000	Spruce Creek near Samsula
	25	02256500	Fisheating Creek at Palmdale
	26	02270500	Arbuckle Creek near De Soto City
	27	02312000	Withlacoochee River at Trilby
	28	02313000	Withlacoochee River at Holder
Southwest	29	02296750	Peace River at Arcadia
	30	02301500	Alafia River at Lithia
	31	02303000	Hillsborough River near Zephyrhills
South	32	02291000	Barron River near Everglades
	33	02279000	West Palm Beach Canal at West Palm Beach
Northwest	34	NWS	Pensacola
	35	NWS	De Funiak Springs
	36	NWS	Tallahassee
	37	NWS	Perry
	38	NWS	Lake City
Northeast	39	NWS	Jacksonville AP
	40	NWS	Ocala
	41	NWS	Daytona Beach
	42	NWS	Orlando
	43	NWS	Vero Beach
Southwest	44	NWS	Brooksville
	45	NWS	Parrish
	46	NWS	Arcadia
	47	NWS	Punta Gorda
	48	NWS	Bartow
South	49	NWS	West Palm Beach
	50	NWS	Ft. Lauderdale
	51	NWS	Miami
Northwest	52	303025085350501	USGS Observation Well (422A) near Greenhead
Northeast	53	270157081203101	USGS Observation Well (H15A) near Palmdale
Southwest	54	271938082251801	USGS Observation Well (Sarasota Well 9) near Sarasota
South	55	252928080332401	USGS Observation Well (G-789) near Homestead
Northwest	56	2329200	Lake Jackson near Tallahassee

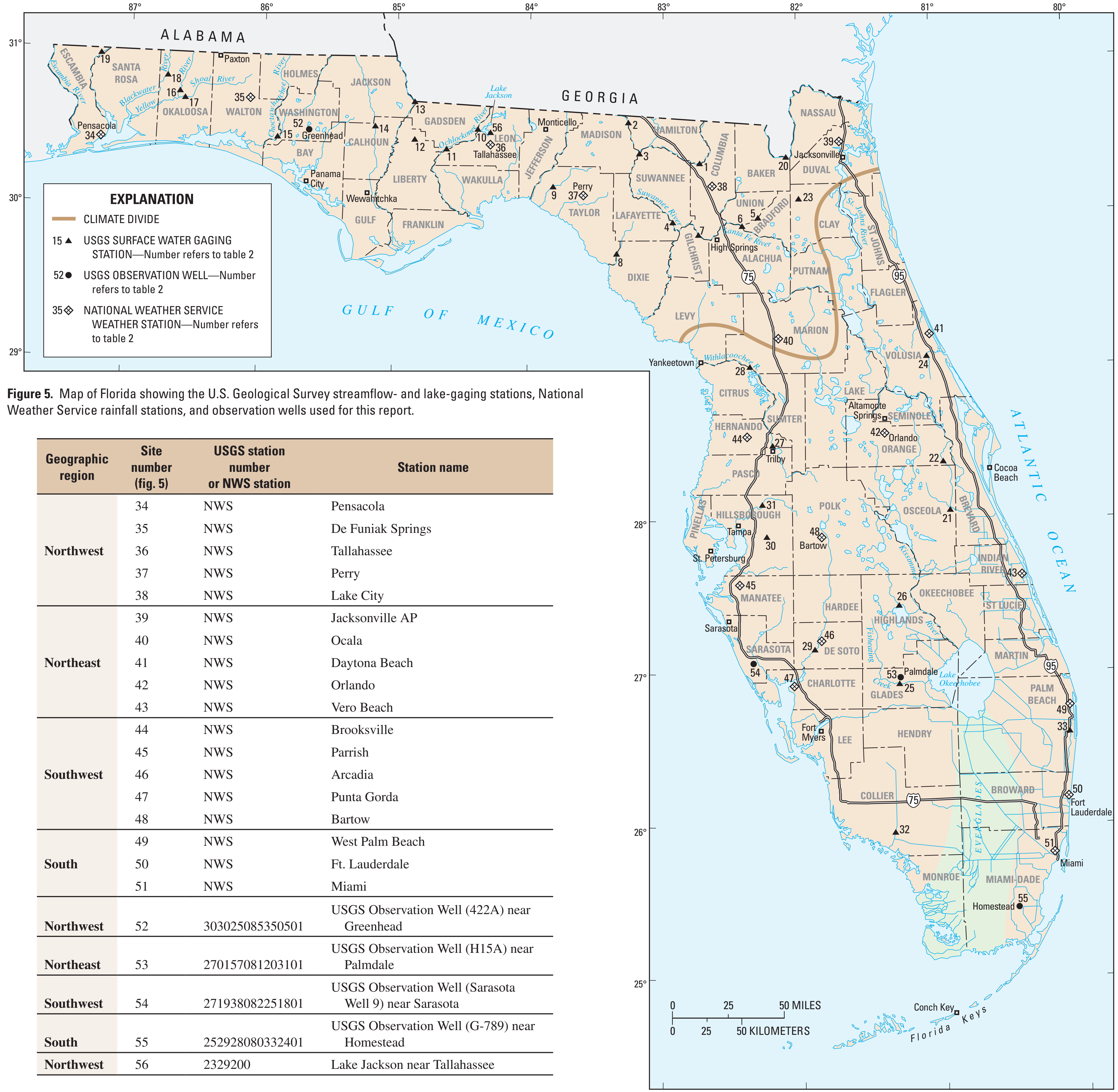


Figure 5. Map of Florida showing the U.S. Geological Survey streamflow- and lake-gaging stations, National Weather Service rainfall stations, and observation wells used for this report.

Streamflow data show that the severity of the drought varied across Florida, ranging from 31 percent of average annual streamflow in southwest Florida during 2000 to 100 percent of average annual streamflow in south Florida during 1999 (table 4). In northwest Florida, the most severe years of the drought were 2000 and 2002, when only 35 and 37 percent of average annual streamflow occurred, respectively, throughout the region. The most severe years in northeast Florida were 2000 and 2001, when only 47 percent of average streamflow occurred each year. The most severe year in southwest Florida was 2000, when only 31 percent of average annual flow occurred through the region. The drought was least severe in south Florida, where the lowest average annual streamflow occurred in 2001 (62 percent); however, precipitation during the 5-year period was lowest in 2000. For each gaging station used in the analyses, table 4 shows the average annual streamflow for the period of record, the annual streamflow for the 1998-2004 water years, and the percent of average flow for that referenced water year.

Two different climatic years were used to determine low-flow **recurrence intervals** north and south of Florida's climatic divide (Rumenik and Grubbs, 1993) (fig. 5) to avoid counting one low-flow event as two low-flow events. In north and northwest Florida, the climatic year begins April 1, because flows are at their lowest during October, November, and December. In central and south Florida, the climatic year begins October 1, because flows generally are at their lowest in April, May, and June. Table 5 lists the **7-day low-flow** and recurrence interval for 23 stations during the climatic years 1999-2002. For sites 21 and 25, 183-day low-flow recurrence intervals are listed, because these two sites often reach zero flow for extended periods of time. Recurrence intervals were not calculated for 1998, because the drought did not have a serious impact on streamflow during the 1998 water year. Low-flow recurrence intervals were not computed for south Florida because the Kissimmee River system above and the drainage system below Lake Okeechobee is almost completely controlled, thus making it difficult to calculate such recurrence intervals (Bridges and Franklin, 1991). Generally, recurrence intervals were greatest during 2000, when the majority of the streamflow-gaging sites analyzed had recurrence intervals of greater than 50 years. For the entire period of the drought, recurrence intervals ranged from less than 2 years at three locations to greater than 50 years at several locations.

Figure 7. Santa Fe River (A) near Hildreth, and (B) streamflow-gaging station on January 3, 2002. (Photograph by Stewart Tomlinson, USGS, Tallahassee, Florida.)

Table 3. Date and lowest instantaneous streamflow for the period of record before the 1998-2002 drought; date and lowest instantaneous streamflow during the 1998-2002 drought; and lowest annual streamflow and year of occurrence for the period of record for the streamflow-gaging station.

[Site locations shown on figure 5. ft³/s, cubic feet per second]

Site no. (fig. 5)	USGS station no.	Station name	Period of record through 2004 (water year)	Lowest instantaneous streamflow before 1998 (ft³/s)	Date	Lowest instantaneous streamflow for 1998-2002 drought (ft³/s)	Date	Lowest annual streamflow for period of record (ft³/s)	Water year
		Northwest Florida							
1	02315500	Suwannee River at White Springs	1906-1908, 1927-2004	2.8	09/26/1990	8.1	06/12/2000	144	2000
2	02319000	Withlacoochee River near Pinetta	1931-2004	70	08/23/1955	14	08/13/2002	236	1955
3	02319500	Suwannee River at Ellaville	1927-2004	835	11/08/1990	703	06/20/2000	1,300	1955
4	02320500	Suwannee River at Branford	1931-2004	1,530	07/01/1955	1,320	08/09/2002	1,950	1955
5	02321000	New River near Lake Butler	1950-1971, 1990-2004	0	Multiple dates	0	Multiple dates	9.7	1962
6	02321500	Santa Fe River at Worthington Springs	1931-2004	0	Multiple dates	0	Multiple dates	33	2000
7	02322500	Santa Fe River near Fort White	1927-1930, 1932-2004	608	01/07/1991	440	06/02/2002	589	2002
8	02324000	Steinhatchee River near Cross City	1950-2004	2.5	07/18/1981	1.4	06/11/2000	35	1956
9	02326000	Econfina River near Perry	1950-2004	2.3	07/08/1955	3.4	07/10/2000	18	1955
10	02329000	Ochlockonee River near Havana	1926-2004	17	10/23/1954	19	08/30/2000	209	1968
11	02330000	Ochlockonee River near Bloxham (Regulated)	1926-2004	1.0	11/01/1957	39	07/15/2000	315	1955
12	02330100	Telogia Creek near Bristol	1950-1971, 1974-1979, 1980-2004	28	10/26/1954	21	06/12/2000	79	2000
13	02358000	Apalachicola River at Chattahoochee (Regulated)	1928-2004	2,570	08/06/1986	3,970	06/22/2000	8,680	2002
14	02359000	Chipola River near Altha	1912-1913, 1921-1927, 1929-1931, 1943-2004	309	11/18/1990	329	08/25/2000	613	1955
15	02366500	Choctawhatchee River near Bruce	1930-1983, 1984-2004	1,290	10/27/1968	1,070	07/23/2000	2,710	2000
16	02368000	Yellow River at Milligan	1928-1993, 1996-2004	131	06/23/1967	120	06/13/2000	374	2000

Table 3. Date and lowest instantaneous streamflow for the period of record before the 1998-2002 drought; date and lowest instantaneous streamflow during the 1998-2002 drought; and lowest annual streamflow and year of occurrence for the period of record for the streamflow-gaging station—Continued.

[Site locations shown on figure 5. ft^3/s, cubic feet per second]

Site no. (fig. 5)	USGS station no.	Station name	Period of record through 2004 (water year)	Lowest instantaneous streamflow before 1998 (ft^3/s)	Date	Lowest instantaneous streamflow for 1998-2002 drought (ft^3/s)	Date	Lowest annual streamflow for period of record (ft^3/s)	Water year
17	02369000	Shoal River near Crestview	1938-2004	240	10/17/1972	183	06/12/2000	470	2000
18	02370000	Blackwater River near Baker	1950-1992, 1996-2004	60	09/07/1954	57	10/29/2000	131	2000
19	02375500	Escambia River near Century	1934-2004	578	10/23/1968	452	10/31/2000	1,820	2000
		Northeast Florida							
20	02231000	St. Mary's River near MacClenny	1926-2004	12	05/22/1932	9.5	06/17/2002	90	1955
21	02231600	Jane Green Creek near Deer Park	1953-2004	0	Multiple dates	0	Multiple dates	39	1981
23	02246000	North Fork Black Creek near Middleburg	1931-2004	3.6	06/08/1935	2.6	06/19/2000	50	1955
24	02248000	Spruce Creek near Samsula	1951-2004	0	Multiple dates	0.21	07/04/1998	2.9	1981
25	02256500	Fisheating Creek at Palmdale	1931-2004	0	Multiple dates	0	Multiple dates	14	1956
26	02270500	Arbuckle Creek near De Soto City	1939-2004	0	Multiple dates	0	Multiple dates	60	1956
27	02312000	Withlacoochee River at Trilby	1928-2004	2.7	07/21/1992	0	06/10-11/2000	16	2000
28	02313000	Withlacoochee River at Holder	1928-1929, 1931-2004	56	06/02/1992	26	07/09/2000	127	2001
		Southwest Florida							
29	02296750	Peace River at Arcadia	1931-2004	14[a]	05/22/1982	5.6[a]	05/06/2000	298	1981
30	02301500	Alafia River at Lithia	1932-2004	6.6[a]	06/06/1945	4.1[a]	05/30/2000	121	2000
31	02303000	Hillsborough River near Zephyrhills	1939-2004	40[a]	05/27/1992	27[a]	06/05/2000	65	2000
		South Florida							
32	02291000	Barron River near Everglades	1952-2004	0	Multiple dates	0	Multiple dates	3.5	1989
33	02279000	West Palm Beach Canal at West Palm Beach	1939-2004	0	Multiple dates	0	Multiple dates	129	1989

[a]Lowest daily mean

Table 4. Average annual streamflow for the period of record, annual streamflow for the 1998-2004 water years, and the percent of average for the referenced water year.

[Site locations shown on figure 5. ft^3/s, cubic feet per second]

Site no. (fig. 5)	Station number	Station name	Period of record through 2004 (water year)	Average annual streamflow (ft^3/s)	1998 Annual streamflow (ft^3/s)	1998 Percent of average	1999 Annual streamflow (ft^3/s)	1999 Percent of average	2000 Annual streamflow (ft^3/s)	2000 Percent of average	2001 Annual streamflow (ft^3/s)	2001 Percent of average	2002 Annual streamflow (ft^3/s)	2002 Percent of average	2003 Annual streamflow (ft^3/s)	2003 Percent of average	2004 Annual streamflow (ft^3/s)	2004 Percent of average
		Northwest Florida																
1	02315500	Suwannee River at White Springs	1906-1908, 1927-2004	1,770	3,850	218	595	34	144	8	429	24	164	9	1,950	110	1,380	78
2	02319000	Withlacoochee River near Pinetta	1931-2004	1,720	3,780	220	899	52	496	29	1,260	73	324	19	2,860	166	1,390	81
3	02319500	Suwannee River at Ellaville	1927-2004	6,350	11,600	183	3,080	49	1,550	24	3,450	54	1,560	25	8,020	126	4,620	73
4	02320500	Suwannee River at Branford	1931-2004	6,870	12,400	180	4,070	59	2,160	31	4,020	59	2,010	29	8,720	127	5,240	76
5	02321000	New River near Lake Butler	1950-1971, 1990-2004	168	317	189	61.5	37	11.4	7	32.7	19	29.6	18	376	224	143	85
6	02321500	Santa Fe River at Worthington Springs	1931-2004	420	824	196	144	34	33.2	8	68.6	16	52.4	12	667	159	333	79
7	02322500	Santa Fe River near Fort White	1927-1930, 1932-2004	1,540	2,360	153	1,070	69	727	47	634	41	589	38	1,400	91	1,210	79
8	02324000	Steinhatchee River near Cross City	1950-2004	311	555	178	135	43	45.7	15	203	65	60.0	19	498	160	234	75
9	02326000	Econfina River near Perry	1950-2004	140	235	168	70.3	50	22.3	16	44.0	31	34.7	25	218	156	148	106
10	02329000	Ochlockonee River near Havana	1926-2004	1,040	1,610	155	628	60	227	22	655	63	245	24	1,720	165	760	73
11	02330000	Ochlockonee River near Bloxham (Regulated)	1926-2004	1,680	2,410	143	972	58	450	27	1,200	71	590	35	2,330	139	1,210	72
12	02330100	Telogia Creek near Bristol	1950-1971, 1974-1979, 1980-2004	216	298	138	131	61	78.9	37	158	73	123	57	245	113	174	81
13	02358000	Apalachicola River at Chattahoochee (Regulated)	1928-2004	21,800	34,600	159	13,500	62	9,110	42	16,300	75	8,680	40	26,900	123	15,600	72
14	02359000	Chipola River near Altha	1912-1913, 1921-1927, 1929-1931, 1943-2004	1,480	2,070	140	1,390	94	702	47	961	65	703	48	2,190	148	1,240	84
15	02366500	Choctawhatchee River near Bruce	1930-1983, 1984-2004	7,050	9,740	138	7,340	104	2,710	38	5,360	76	3,100	44	9,010	128	5,700	81

16	02368000	Yellow River at Milligan	1928-1993, 1996-2004	1,150	1,820	158	1,430	124	374	33	851	74	468	41	1,520	132	1,080	94
17	02369000	Shoal River near Crestview	1938-2004	1,110	1,550	140	1,400	126	470	42	784	71	577	52	1,440	130	1,120	101
18	02370000	Blackwater River near Baker	1950-1992, 1996-2004	348	591	170	375	108	131	38	242	70	144	41	475	136	328	94
19	02375500	Escambia River near Century	1934-2004	6,260	9,490	152	6,820	109	1,820	29	6,700	107	3,100	50	8,910	142	5,840	93
		Average for northwest region		3,233	5,268	163	2,322	72	1,119	35	2,282	71	1,187	37	4,182	129	2,513	78
		Northeast Florida																
20	02231000	St. Mary's River near MacClenny	1926-2004	646	1,100	170	330	51	130	20	114	18	133	21	972	150	743	115
21	02231600	Jane Green Creek near Deer Park	1953-2004	212	326	154	54.2	26	168	79	141	67	196	92	277	131	199	94
22	02232500	St. John's River near Christmas	1933-2004	1,300	2,220	171	621	48	1,170	90	780	60	2,010	155	1,470	113	1,030	79
23	02246000	North Fork Black Creek near Middleburg	1931-2004	190	281	148	68.4	36	84.1	44	118	62	119	63	255	134	207	109
24	02248000	Spruce Creek near Samsula	1951-2004	32	48.9	152	25.9	80	24.5	76	41.0	127	46.0	143	31.4	98	47.2	147
25	02256500	Fisheating Creek at Palmdale	1931-2004	255	493	193	296	116	84.8	33	321	126	264	104	405	159	341	134
26	02270500	Arbuckle Creek near De Soto City	1939-2004	309	736	238	243	79	161	52	233	75	419	136	401	130	304	98
27	02312000	Withlacoochee River at Trilby	1928-2004	332	816	246	48.2	15	15.8	5	115	35	293	88	954	287	307	92
28	02313000	Withlacoochee River at Holder	1928-1929, 1931-2004	995	1,930	194	496	50	177	18	127	13	518	52	1,870	188	845	85
		Average for northeast region		475	883	186	243	51	224	47	221	47	444	94	737	155	447	94
		Southwest Florida																
29	02296750	Peace River at Arcadia	1931-2004	1,080	2,290	212	632	59	328	30	940	87	837	78	2,131	197	1,400	130
30	02301500	Alafia River at Lithia	1932-2004	339	710	209	216	64	121	36	209	62	176	52	614	181	491	145
31	02303000	Hillsborough River near Zephyrhills	1939-2004	246	631	257	110	45	64.9	26	142	58	155	63	462	188	363	148
		Average for southwest region		555	1,210	218	319	58	172	31	430	78	390	70	1,069	193	751	135
		South Florida																
32	02291000	Barron River near Everglades	1952-2004	88.8	64.7	73	83.9	94	49.5	56	48.1	54	58.0	65	68.3	77	65.0	73
33	02279000	West Palm Beach Canal at West Palm Beach	1939-2004	650	613	94	652	100	525	81	409	63	504	78	451	69	460	71
		Average for south region		369	339	92	368	100	287	78	229	62	281	76	260	70	263	71

Table 5. The 7-day low streamflow during the respective climatic year and its recurrence interval.

[Site locations shown on figure 5. ft³/s, cubic feet per second; <, less than; >, greater than]

Site number (fig. 5)	USGS station number	Station name	Period of record through 2004 (water year)	1999 (ft³/s)	Reccurrence interval (years)	2000 (ft³/s)	Reccurrence interval (years)	2001 (ft³/s)	Reccurrence interval (years)	2002 (ft³/s)	Reccurrence interval (years)
		Northwest Florida									
1	02315500	Suwannee River at White Springs	1906-1908, 1927-2004	15.0	>5	8.90	>10	13.6	>5	16.3	>5
2	02319000	Withlacoochee River near Pinetta	1931-2004	82.3	>20	102	>5	89.0	20	26.1	>50
3	02319500	Suwannee River at Ellaville	1927-2004	814	>50	740	>50	767	>50	765	>50
4	02320500	Suwannee River at Branford	1931-2004	1620	>20	1430	>50	1520	50	1340	>50
7	02322500	Santa Fe River near Fort White	1927-1930, 1932-2004	656	>20	471	>50	511	>50	456	>50
8	02324000	Steinhatchee River near Cross City	1950-2004	4.91	>5	1.64	>50	2.63	>20	4.14	>5
9	02326000	Econfina River near Perry	1950-2004	19.3	>2	3.96	>20	14.6	>2	13.0	>2
10	02329000	Ochlockonee River near Havana	1926-2004	51.7	>2	22.0	>20	44.6	>2	40.3	>2
12	02330100	Telogia Creek near Bristol	1950-1971, 1974-1979, 1980-2004	40.7	>5	22.7	>50	23.7	>50	32.7	>20
14	02359000	Chipola River near Altha	1912-1913, 1921-1927, 1929-1931, 1943-2004	620	>2	348	>20	378	>20	464	>5
15	02366500	Choctawhatchee River near Bruce	1930-1983, 1984-2004	2140	>2	1120	>50	1640	>5	1550	>10
16	02368000	Yellow River at Milligan	1928-1993, 1996-2004	243	>2	127	>50	224	>2	165	>20
17	02369000	Shoal River near Crestview	1938-2004	418	<2	190	>50	343	>2	314	>5
18	02370000	Blackwater River near Baker	1950-1992, 1996-2004	107	<2	58.4	>20	78.3	>2	67.1	>5
19	02375500	Escambia River near Century	1934-2004	1190	2	457	>50	1250	<2	947	>2
		Northeast Florida									
20	02231000	St. Mary's River near MacClenny	1926-2004	15.6	>50	13.0	>50	13.7	>50	11.3	>50
21	02231600	Jane Green Creek near Deer Park	1953-2004	10.3	>2*	0.27	>20*	0.36	>20*	15.7	>2*
22	02232500	St. John's River near Christmas	1933-2004	-82.3	>50	-47.9	>50	8.74	>20	51.7	>2
23	02246000	North Fork Black Creek near Middleburg	1931-2004	6.47	>10	3.80	>50	4.79	>20	13.7	>2
25	02256500	Fisheating Creek at Palmdale	1931-2004	14.7	>2*	3.44	>2*	0.42	>10*	12.4	>2*
28	02313000	Withlacoochee River at Holder	1928-1929, 1931-2004	179	>5	48.3	>50	43.4	>50	123	>20
		Southwest Florida									
29	02296750	Peace River at Arcadia	1931-2004	37.1	>20	6.26	>50	8.73	>50	23.9	>50
31	02303000	Hillsborough River near Zephyrhills	1939-2004	52.1	>10	27.7	>50	27.9	>50	36.6	>50

*183-day low-flow recurrence intervals.

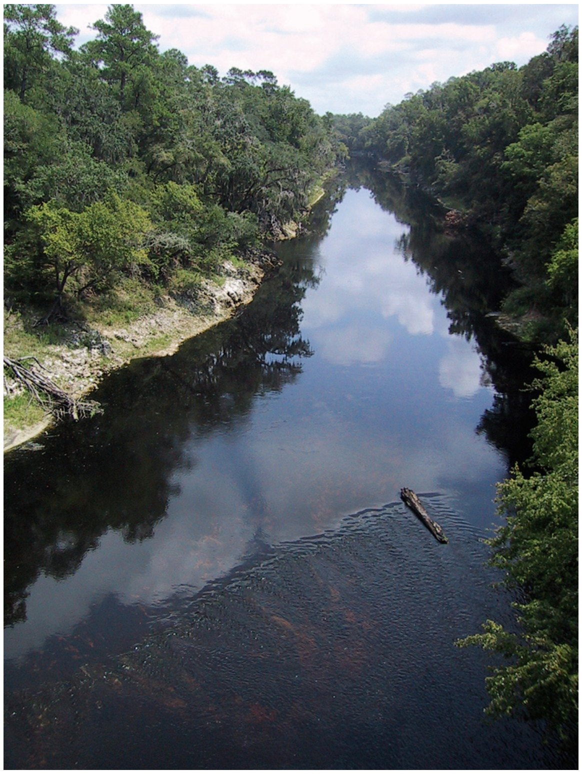


Figure 8. Suwannee River at Ellaville on August 28, 2002. (Photograph by Stewart Tomlinson, USGS, Tallahassee, Florida.)

Figure 9. Stilling well at Suwannee River near Wilcox on January 4, 2002. (Photograph by Stewart Tomlinson, USGS, Tallahassee, Florida.)

Figure 10. Troy Spring near Branford on February 22, 2002. (Photograph by Stewart Tomlinson, USGS, Tallahassee, Florida.)

Figure 11. St. Lucie Canal at Lake Okeechobee (S-308). (Photograph by Mike Oliver, USGS, Ft. Lauderdale, Florida.)

Ground-Water Elevations

Persistent drought conditions cause the water table to decline. This decline is due to reduced rates of percolation, reduced inflows of surface water, and ground-water pumping. During the 1998-2002 drought, ground-water levels at many wells across the State declined to levels not seen in many years. At some wells, ground-water elevations reached record lows for their period of record. For example, USGS Observation Well (Sarasota Well 9, site 54) near Sarasota, in southwest Florida, recorded the lowest daily water elevation for the period of record (1930-2004)—0.31 ft above **mean sea level**—on June 7, 2000. The previous record was 1.19 ft above mean sea level on May 27, 1989. Figure 12 shows **hydrographs** of ground-water elevations in four representative wells in Florida (one in each region). Each hydrograph shows the daily value recorded during the period 1998-2004, and the lowest daily water elevation reached during the 1998-2002 drought. The observation wells shown for the northeast, southwest, and south Florida regions are influenced by pumping.

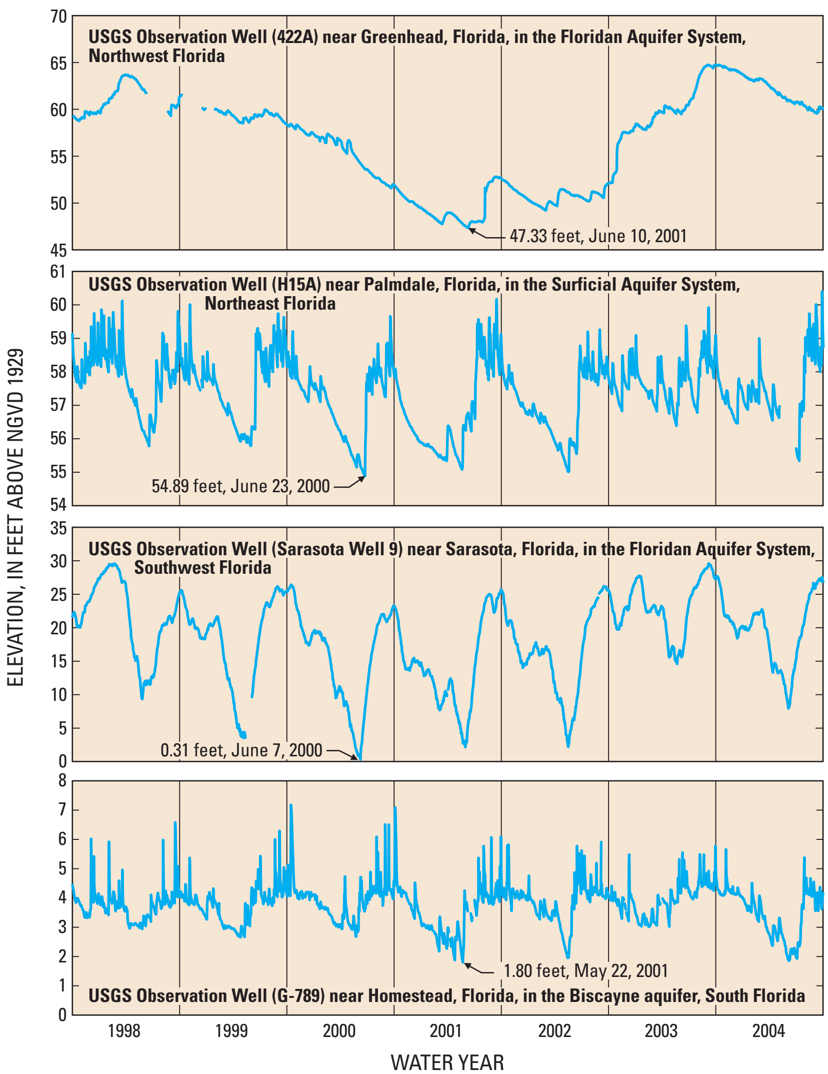


Figure 12. Ground-water elevation hydrographs of four representative wells in Florida for the 1998-2004 water years.

The data from the four representative wells indicate that the drought's impact on ground-water levels varied across the State; the drought was more severe in the northwest region and less severe in the northeast and south regions. Several areas of northwest and southwest Florida had water level declines of greater than 10 ft in the upper Floridan aquifer between 1995 and 2000 (Marella and Sepulveda, 2004). Ground-water elevations rebounded to pre-1998 conditions in the 2003 water year in all four regions. The low ground-water elevations in the northeast, southwest, and south regions recorded during the 2004 water year were comparable to those elevations experienced during the 1998-2002 drought.

An analysis of the period-of-record data shows that the impacts of historical droughts on ground-water elevations varied across Florida. Table 6 shows the lowest water elevation and date during the 1998-2002 drought, the lowest water elevation and date before 1998, and the drought responsible for the lowest water elevation prior to 1998. Data in table 6 indicate that the drought from 1949-1957 was more severe than the most recent drought (1998-2002) for USGS Observation Well (H15A; site 53) near Palmdale (northeast Florida); however, at USGS Observation Well (G-789; site 55) near Homestead (south Florida), the drought from 1970-1977 was most severe (table 6). For both the USGS observation well (422A; site 52) near Greenhead (northwest Florida) and the USGS observation well (Sarasota Well 9, site 53) near Sarasota (southwest Florida), the most severe drought was from 1998-2002.

Table 6. Lowest water elevation and date during the 1998-2002 drought; lowest water elevation and date before 1998; and the drought responsible for the lowest water elevation prior to 1998 for the observation well.

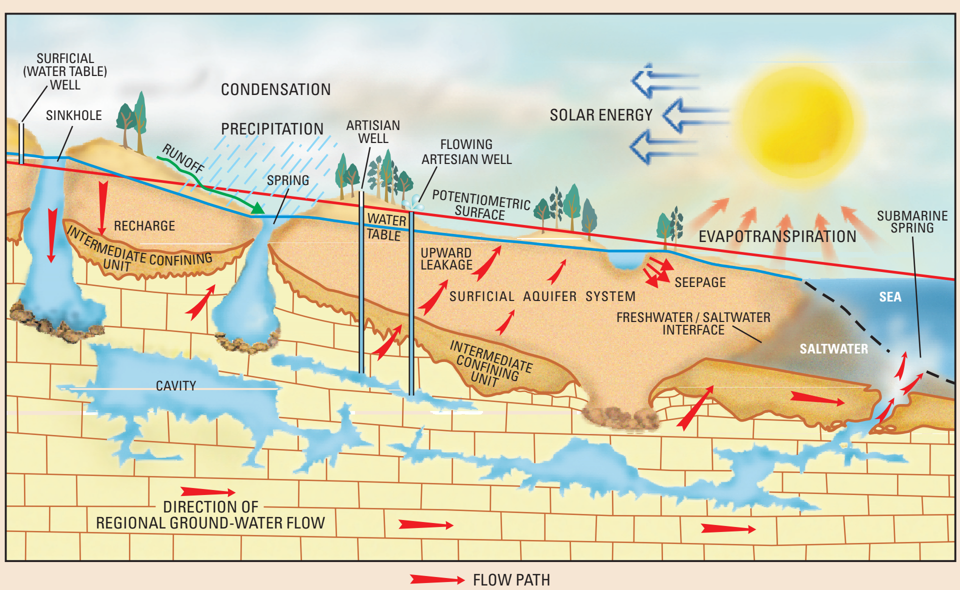
[NGVD 29, National Geodetic Vertical Datum of 1929]

Site number (fig. 5)	USGS station number	Station name	Period of record through 2004 (water year)	Lowest water elevation for 1998-2002 drought NGVD 29 (feet)	Date	Lowest water elevation before 1998 NGVD 29 (feet)	Date	Drought responsible for lowest water elevation prior to 1998
52	303025085350501	USGS Observation Well (422A) near Greenhead	1962-1989; 1998-2004	47.33	06/10/2001	48.19	02/13/ 1969	1967-1969
53	270157081203101	USGS Observation Well (H15A) near Palmdale	1994-2004	54.89	06/23/2000	53.49	06/27/1956	1949-1957
54	271938082251801	USGS Observation Well (Sarasota Well 9) near Sarasota	1930-1931; 1932-1937; 1941-2004	0.31	06/07/2000	1.19	05/27/1989	1989-1992
55	252928080332401	USGS Observation Well (G-789) near Homestead	1956-2004	1.80	05/22/2001	-0.90	05/08/1975	1970-1977

The Hydrologic Cycle

Water in the environment moves from the atmosphere, to the land surface, to the ground-water system, and back to the atmosphere in a cycle called the hydrologic cycle. The primary components of the hydrologic cycle in central Florida are rainfall, runoff, infiltration (including recharge), evaporation, transpiration, and condensation. When rain falls, some of the water infiltrates the ground and recharges the aquifers, some of it is intercepted by plants, and some of it flows over the land surface (surface runoff or overland flow). Beneath the land surface, water moves through the aquifers toward areas of discharge such as the ocean or streams. Water returns to the atmosphere through the process of evaporation and plant transpiration (collectively labeled “evapotranspiration” below). Once in the atmosphere as water vapor, the hydrologic cycle is completed when this vapor condenses and forms rain droplets that subsequently fall on the land surface again. —Excerpt from Schiffer (1998)

In Florida, a drought can occur any time high-pressure air masses become established over the region for an extended period of time. A drought is a period of drier than normal conditions that results in water-related problems. Lower than normal precipitation caused a severe statewide drought in Florida from 1998 to 2002. Record low flows were reported at several stream-gaging stations, hundreds of new sinkholes developed, and wildfires periodically raged over parts of Florida thoughout the period, when tinder-dry undergrowth caught fire.



Hydrologic cycle. (Modified from Fernald and Patton, 1984.)

Impacts of the Drought on Water Use in Florida





Freshwater withdrawals in Florida increased substantially between 1995 and 2000, primarily as a result of higher demands during dry conditions. Between 1995 and 2000, freshwater withdrawals increased 13 percent (Marella, 2004). In contrast, freshwater withdrawals decreased 4 percent between 1990 and 1995. The decrease in freshwater withdrawals between 1990 and 1995, as well as the increase in freshwater withdrawals between 1995 and 2000, in part can be attributed to substantially drier conditions (below-normal rainfall) in 1990 and 2000, coupled with substantially wetter conditions (above-normal rainfall) during 1995. Other factors that contributed to an increase in water demands included increases in population and tourism between 1995-2000. Water conservation and the use of alternative water sources, such as **reclaimed wastewater**, helped offset some of the increasing water demand over those years; however, it is difficult to determine what long-term effects these measures have had on water use and what effect rainfall has had on water demands in Florida.

In 2000, the estimated amount of total water withdrawn in Florida was 20,148 million gallons per day (Mgal/d); 59 percent was **saline water** and 41 percent was freshwater (Marella, 2004). Nearly all of the saline water was withdrawn for cooling purposes at thermoelectric powerplants, whereas agricultural irrigation (48 percent) and **public supply** (30 percent) accounted for the majority of the freshwater withdrawn. **Ground water** accounted for 62 percent of the freshwater withdrawals and surface water accounted for the remaining 38 percent.

The amount of freshwater withdrawn annually and monthly fluctuates because of variations in temperature, precipitation, crop production, population, and tourism. More than one-half (54 percent) of the freshwater withdrawn in 2000 was between February and June (Marella, 2004). Seasonal variation in withdrawals is typical in Florida; however, dry conditions were present throughout most of the State during the first half of 2000 (University of Nebraska, 2004). Three of the five water management districts in Florida—St. Johns River, South Florida, and Southwest Florida Water Management Districts—issued water-shortage mandates to help curb water use during most of 2000 (Marella, 2004).

Because of the lack of sufficient rainfall during these months, water demands for all irrigation purposes (agricultural, recreational, and commercial and residential lawns) were higher than normal. Irrigation withdrawals for agricultural and recreational purposes during 2000 were greatest from March through June and were lowest from July through September (fig. 13). This seasonal fluctuation of more than 5,000 Mgal/d was the result of intense crop production and extreme dry conditions during the spring of 2000 (Marella, 2004). The effects of the drought during the critical agricultural growing season can also be seen when comparing the monthly variation during 2000 with previous 5-year intervals (fig. 13; Marella, 1997). Because a large component of the water used for public supply is for residential and commercial lawn irrigation, the extreme dry conditions in 2000 also affected the amount of water withdrawn seasonally for this category. Peak demand for public supply during 2000 occurred in April, May, and June, when low rainfall caused increased water usage for lawn irrigation (fig. 14). The dry conditions during the spring resulted in water withdrawals for 2000 that were substantially above normal compared with previous 5-year intervals (fig. 14).

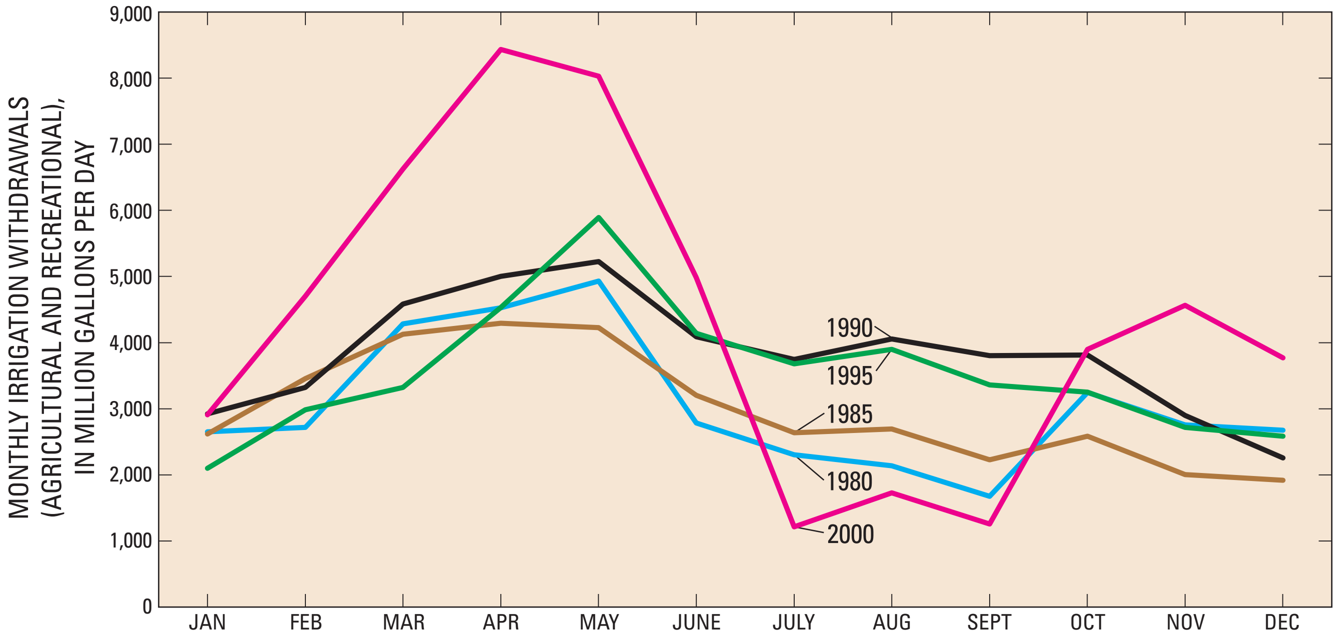


Figure 13. Monthly irrigation withdrawals in Florida for agricultural and recreational use for 1980, 1985, 1990, 1995, and 2000.

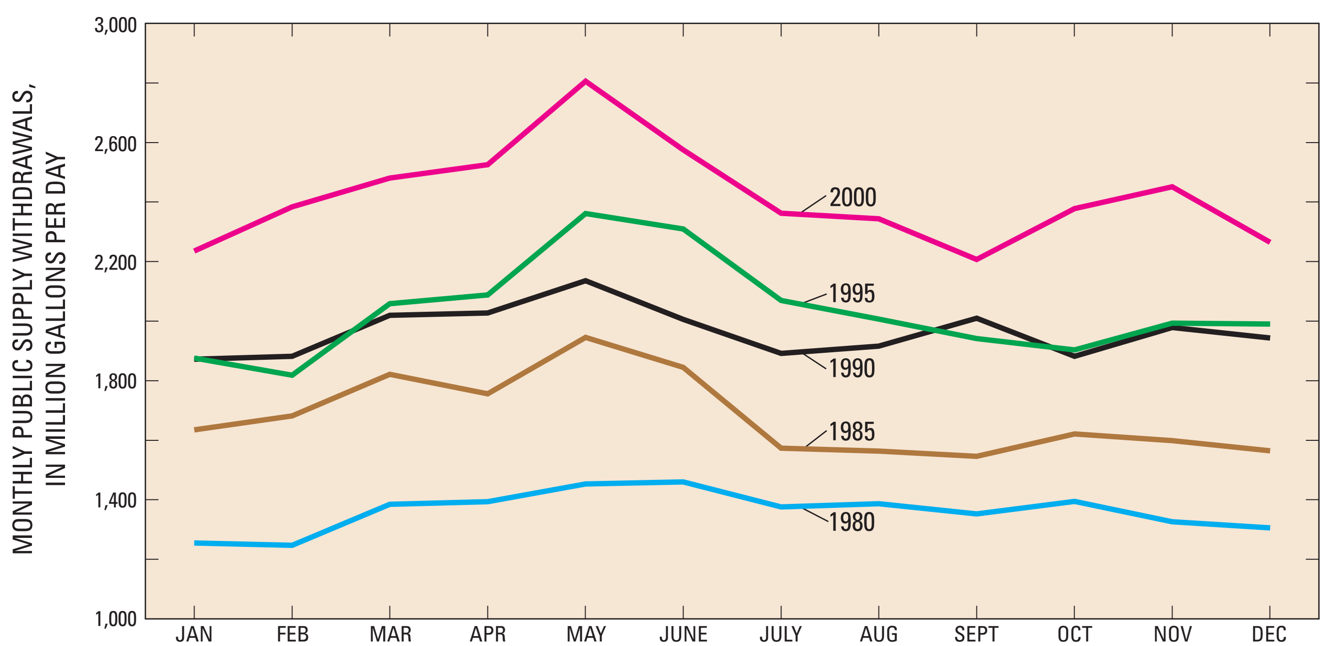


Figure 14. Monthly public-supply withdrawals in Florida for 1980, 1985, 1990, 1995, and 2000.

Impacts of the Drought on Florida's Landscape





In addition to the impact the drought had on Florida's water supply, and the water-use restrictions imposed, other major impacts include the increased development of sinkholes and associated lake water-level drawdowns, and an increase in the number and severity of wildfires.

Sinkholes and Lake Jackson

Florida's karst landscape is highly susceptible to the development of sinkholes, which have the potential to cause substantial damage to property and the natural environment. Sinkholes can cause structural collapse to buildings and roads. They also can draw water from the natural environment by draining streams, lakes, and wetlands into the underlying aquifer systems (Tihansky, 1999). **Limestone** in Florida is very permeable, which means that circulating ground water can easily percolate through the rock, eroding and dissolving away the limestone over time. This is a continual process that can create underground cavities over geologic time. Sinkholes develop when the overlying sediments (or roof) collapse into an underground cavity (fig. 15). Extreme drought conditions lower the ground-water table, which results in less support for the roof of the cavity, thus causing a collapse. Saturation of the roof after a substantial rainfall can also trigger a collapse because of the added weight of the rainwater. During the period from 1998-2002, the Florida Geological Survey reported several hundred newly formed sinkholes throughout the State (Florida Department of Environmental Protection, 2005; accessed on November 23, 2005).

When sinkholes develop beneath lakes, the lake water is drawn downward into the sinkhole and into the ground-water system. Numerous such events occurred during the drought period. One of these, the drawdown of Lack Jackson near Tallahassee, is described in detail here.

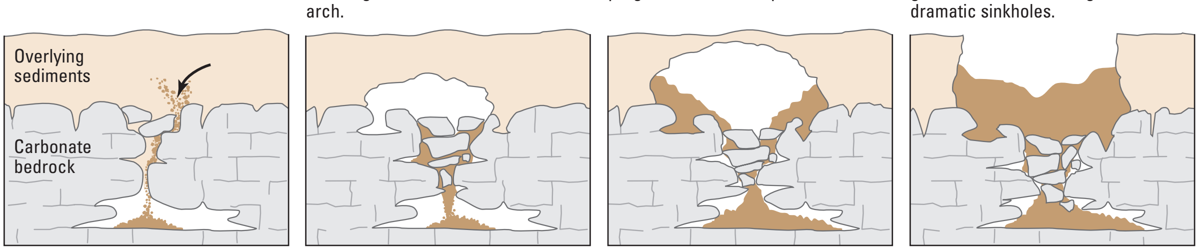


Figure 15. Schematic diagram showing time progression of sinkhole formation (modified from Tihansky, 1999).

Porter Hole Sink and Lime Sink are two large and active sinkholes in Lake Jackson (known by the Native people as Oka Heep Ki, meaning Disappearing Waters). A combination of low ground-water elevations and extreme drought conditions caused the lake to become nearly dry in 1999-2000. On September 16, 1999, a large amount of the lake drained down Porter Hole Sink as a result of the unrelenting dry conditions, which had continued since the drought began in 1998. The persistent dry spell caused the western part of the lake to slowly drain down Lime Sink in May 2000, leaving only a few small areas of standing water in Lake Jackson (Northwest Florida Water Management District, 2002).

Beginning in June 2001, Lake Jackson began refilling due to runoff from Tropical Storm Allison. Runoff associated with Tropical Storm Barry in August of 2001 continued to fill the lake, but water elevations remained well below normal. The lake became nearly dry again in 2002. Finally, after the excessive rainfall experienced during the 2003 water year, and rain from the tropical storm and three hurricanes that impacted northwest Florida during the 2004 water year, the lake began refilling again.

There have been nine natural drawdowns (or drydowns) of Lake Jackson in the last 100 years. These drawdowns occurred in 1907, 1909, 1932, 1935, 1936, 1957, 1982, and the most recent in 1999 to 2000 and 2002 (Northwest Florida Water Management District, 2002). Figure 16 shows areas of Lake Jackson after the drawdown in 2000. Note all the fish on the mud bottom of the lake. A hydrograph of Lake Jackson water elevations from water years 1950 to 2004 (fig. 17) was prepared using USGS and Northwest Florida Water Management District data. The hydrograph shows the lowest water elevations observed or recorded during the droughts of 1949-1957, 1980-1982, and the most recent 1998-2002.



Figure 16. Lake Jackson after the drawdown in 2000. (Photographs by Hal Davis and Ed Oaksford, USGS.)

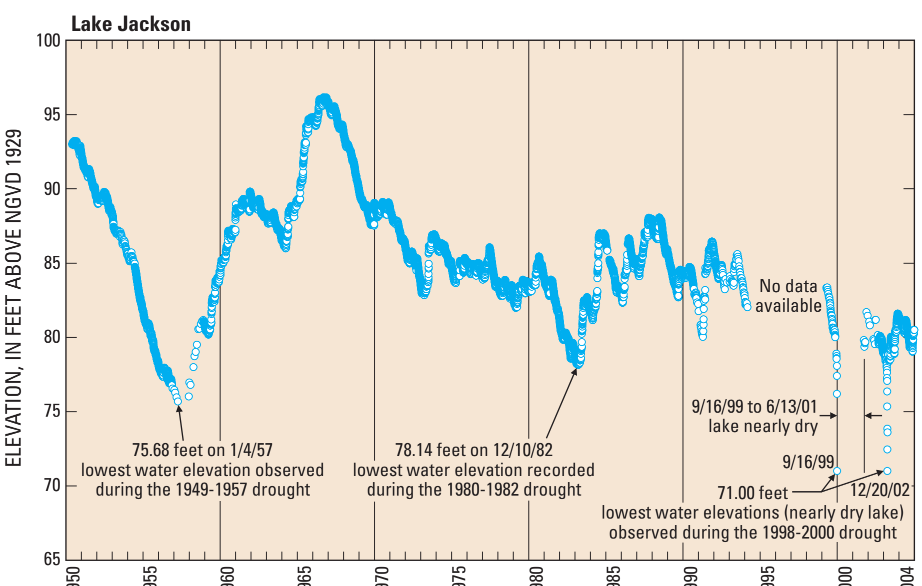


Figure 17. Lake Jackson daily water elevation for the period of record (1950 to 2004 water years).

Wildfires

During the drought of 1998-2002, the Florida Division of Forestry (15 field stations throughout the State) reported that 25,137 wildfires had burned over 1.5 million acres (Florida Division of Forestry, undated(a)). These data do not include statistics from volunteer or local fire departments. The most severe year for wildfires was 1998, when 4,899 fires burned 506,970 acres of land throughout the State; the least severe year was 2002, when 3,065 fires burned 56,835 acres (Florida Division of Forestry, undated(a), accessed August 31, 2005).

The largest fire started April 16, 1999, in the Everglades in Broward County, located in south Florida. The Division of Forestry named the fire "Deceiving" because it continually shifted with the wind direction. Before being contained on April 27, 1999, with the help of nearly 600 firefighters, the fire burned approximately 173,000 acres of dry marsh grass and forced the closure of Interstate 75 (Alligator Alley, a main east-west corridor) for several weeks as a result of dense smoke plumes (Florida Division of Forestry, undated(b), accessed August 31, 2005; Bureau of Land Management, 2000, accessed September 29, 2005) (fig. 18).

In northeast Florida, in Volusia County, several fires raged through the area during late June and early July 1998, causing local authorities to close down approximately 125 miles of Interstate 95 and sections of U.S. Highway 1 between Jacksonville and Cocoa Beach (Cable News Network, 1998, accessed September 2, 2005). Wildfires during 2001 burned USGS water-level monitoring station Site 69 (fig. 19) in south Florida.

Figure 18. Wildfire named "Deceiving," which burned 173,000 acres and forced the closure of Interstate 75 (Alligator Alley) due to heavy smoke plumes in April 1999. (Photographs by the Florida Division of Forestry.)

Figure 19. Site 69 in south Florida after fire in 2001. (Photographs by Mike Oliver, USGS, Ft. Lauderdale, Florida.)

Historical Perspective on Florida's Droughts





Since 1906, Florida has suffered five major droughts: 1931-1935, 1949-1957, 1970-1977, 1980-1982, and 1998-2002. Several less severe droughts also have occurred. Table 7 summarizes the droughts that occurred prior to 1998.

1931-1935 Drought

The 1931-1935 drought impacted northwest Florida, most severely from the Choctawhatchee River east to the Ochlockonee River as well as Fisheating Creek Basin in southwest Florida. Rainfall totals during 1931 averaged 43.97 in. for the State, which

Ochlockonee River near Bloxham in December 1934, during the major drought from 1931-1935 (December monthly mean discharge, 186 ft^3/s). (Photograph by USGS.)

Table 7. Chronology of major and memorable droughts in Florida, 1906-1992.

[Data compiled from Bridges and Franklin (1991); Hoyt (1936); and data on file at the U.S. Geological Survey. >, greater than]

Date	Region affected	Recurrence interval (years)	Remarks
1931-1935	Northwest and southwest	10 to >50	Less than normal runoff for 1-2.5 consecutive years for most streams. Annual rainfall totaled 82 percent of normal in 1931.
1937-1941	Northeast and northwest	10 to 50	Less than normal runoff for 1.5-4.5 consecutive years for most streams.
1949-1957	Statewide	10 to 55	Less than normal runoff for 2-5 consecutive years in southern northeast, southwest, and south Florida and 3-9 years in northern northeast and northwest Florida.
1960-1963	Statewide	5 to 25	Less than normal runoff for 1.5-3 consecutive years for most streams.
1967-1969	Northeast and northwest	10 to 30	Less than normal runoff for 2-4 consecutive years for most streams.
1970-1977	Northeast, southwest and south	10 to 50	Less than normal runoff for 3-8 consecutive years in southern northeast, southwest, and south Florida and 2-4 years in northern northeast and northwest Florida.
1980-1982	Statewide	5 to 55	Less than normal runoff for 2-3 consecutive years.
1989-1992	Statewide	Not available	Less than normal runoff for 2-4 consecutive years for most streams.

Ochlockonee River near Bloxham on January 20, 1955, during the major drought from 1949-1957 (discharge, 212 ft^3/s). (Photograph by USGS.)

is about 82 percent of the long-term (1900-2000) average rainfall of 53.93 in. (National Climatic Data Center, 2001a). This was followed by about 2 consecutive years of below average runoff for most streams in the State. In northwest Florida, recurrence intervals for the drought ranged from 10 to greater than 25 years; recurrence intervals in Fisheating Creek Basin were greater than 50 years (Bridges and Franklin, 1991).

1949-1957 Drought

The regions most impacted by the 1949-1957 drought were the northwest, northeast, and southwest Florida regions, although the south region also was affected to some degree. The most severe period of this 9-year drought was the 4 years from 1954-1957. In 1955, statewide runoff was estimated to be less than half the annual average of 14 in., and wildfires burned more than 300,000 acres of timberland in northwest and northeast Florida in addition to thousands of acres of soil in the Everglades (Pride and Crooks, 1962). During this drought, many record low flows (table 3), ground-water elevations, and lake elevations were recorded in northwest and northeast Florida. In 1954, Tallahassee recorded its all-time lowest annual precipitation of 30.98 in., less than half the long-term annual average. Drought-induced streamflow recurrence intervals for the State ranged from 10 to 20 years in the south and 30 to greater than 50 years in the north (Bridges and Franklin, 1991).

Blackwater River near Baker on November 13, 1973, during the major drought from 1970-1977 (discharge, 115 ft^3/s). Note the sandbar development in the middle of the stream channel. (Photograph by Richard Milner, USGS, Tallahassee, Florida.)

1970-1977 Drought

The 8-year drought of 1970-1977 impacted northeast, southwest, and south Florida, but was most severe in the southwest region and the southern part of the northeast region (fig. 1). Runoff in south Florida, during the dry season of 1971, ranged from 5 to 23 percent of average at several locations according to Benson and Gardner (1974). Drought recurrence intervals of 10 to 50 years occurred throughout the State as a result of less than normal rainfall for the extended period (Bridges and Franklin, 1991). Rainfall totals in south Florida during the 1970-1971 dry season ranged from 37 to 80 percent below normal. The recurrence intervals for dry season rainfall of this magnitude ranged from 100 years to several hundred years (Benson and Gardner, 1974).

1980-1982 Drought

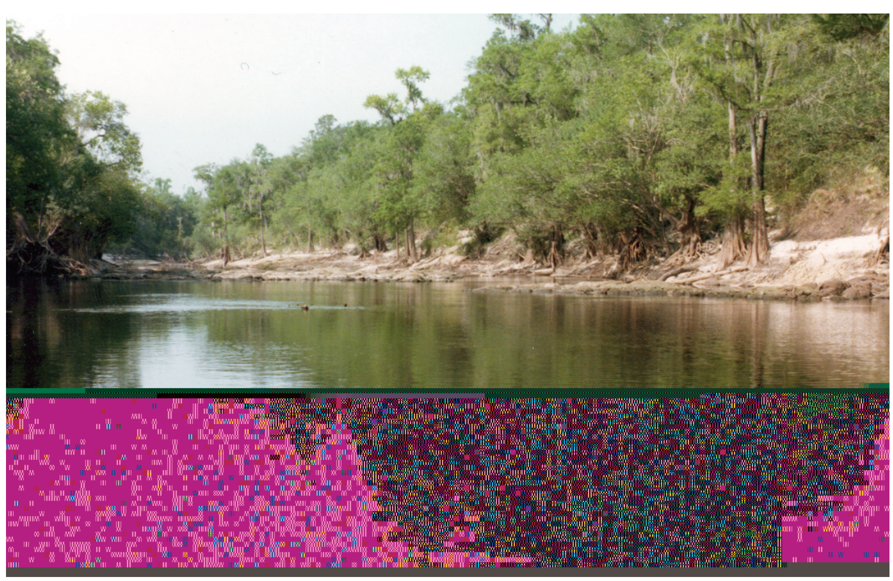
The drought of 1980-1982 impacted nearly all of Florida, except for the northwest region in the extreme westernmost panhandle (Bridges and Franklin, 1991). Rainfall deficits in south Florida ranged from 22.07 to 31.30 in. below normal for the region (Waller, 1985). Recurrence intervals for the drought ranged from 55 years or less in the southwest, the northern part of the south, and the southern two-thirds of the northeast regions of Florida (fig. 1), to 5 to 20 years for the remainder of the impacted areas of the State (Bridges and Franklin, 1991).

Summary

This report provides an overview of the impacts of the 5-year drought of 1998-2002 in Florida, including data analyses for precipitation, streamflow, ground-water levels, water withdrawals, impacts of the drought on Florida's landscape, and historical droughts. The data presented in this report indicate that the drought of 1998-2002 was as severe, if not more so, than the 9-year drought of 1949-1957, which previously had been considered to be the most severe drought of the 20th century. Record-setting instantaneous low streamflows occurred at many sites during the 1998-2002 drought, including the Withlacoochee River streamgage at Trilby, which recorded zero flow on June 10-11, 2000—the only time during its period of continuous record (1928-2004). During the 1998-2002 drought, 14 of the 32 streamflow-gaging stations used in this report registered their lowest annual streamflow for their periods of record. Eleven of the 32 stations registered the lowest annual streamflow during the 1949-1957 drought. Low-flow recurrence intervals ranged from less than 2 years at three site locations, to greater than 50 years at several locations throughout the State. Of the streamflow-gaging stations that were analyzed, 16 of 23 produced greater than 50-year, 7-day (7Q50) low-flow recurrence intervals at least one time during the duration of the 1998-2002 drought—primarily during the 2000 water year.

Ground-water elevations in some wells recorded the lowest daily elevations of their periods of record. Between 1995 and 2000, freshwater withdrawals increased 13 percent. Several hundred new sinkholes developed across Florida, and Lake Jackson near Tallahassee experienced two major natural drawdowns. More than 25,000 wildfires burned over 1.5 million acres across Florida, with the most devastating fire occurring in April 1999 and burning about 173,000 acres.



Suwannee River at White Springs on June 2, 1977, during the major drought of 1970-1977 (discharge, 81 ft^3/s). (Photograph by USGS.)

References

Benson, M.A., and Gardner, R.A., 1974, The 1971 drought in south Florida and its effect on the hydrologic system: U.S. Geological Survey Water-Resources Investigations Report 74-12, 46 p.

Bridges, W.C., and Franklin, M.A., 1991, Florida floods and droughts, in National Water Summary 1988-1989—Floods and droughts: U.S. Geological Survey Water-Supply Paper 2375, p. 231-238.

Bureau of Land Management, 2000, Testimony of Les Rosenkrance, Director Office of Fire and Aviation, Bureau of Land Management, before the Senate Energy Committee, Subcommittee of Forests and Public Land Management, Oversight-fire Preparedness, June 29, 1999, accessed September 29, 2005, at http://www.blm.gov/nhp/news/legislative/pages/1999/te990629.htm.

Cable News Network, 1998, Florida inferno could worsen: Accessed September 2, 2005, at http://www.cnn.com/US/9807/02/florida.fires.02/.

Fernald, E.A., and Patton, D.J., eds., 1984, Water resources atlas of Florida: Tallahassee, Florida State University, 291 p.

Florida Department of Environmental Protection, 2005, Sinkhole Database: Accessed November 23, 2005, at http://www.dep.state.fl.us/geology/gisdatamaps/sinkhole_database.htm.

Florida Division of Forestry, undated(a), Wildfire statistics for Florida: 1981-present: Accessed August 31, 2005, at http://www.fl-dof.com/wildfire/stats_fires_since1981.html.

Florida Division of Forestry, undated(b), Significant fires in Florida since 1981: Accessed August 31, 2005, at http://www.fl-dof.com/wildfire/stats_significant_fires.html.

Florida Office of Cultural and Historical Programs, [undated], Florida Quick Facts: Accessed August 30, 2005, at http://dhr.dos.state.fl.us/facts/stats/quick/.

Hoyt, J.C., 1936, Droughts of 1930-1934: U.S. Geological Survey Water-Supply Paper 680, 106 p.

Hoyt, J.C., 1938, Drought of 1936 with discussion on the significance of drought in relation to climate: U.S. Geological Survey Water-Supply Paper 820, 60 p.

Intellicast, 2005, Weather for Active Lives: Accessed September 2005, at http://www.intellicast.com/Almanac/Southeast/September/content.shtml.

Marella, R.L., 1997, Irrigated crop acreage and water withdrawals in Florida, 1990: Tallahassee, Florida Geological Survey Map Series 143, 1 sheet.

Marella, R.L., 2004, Water withdrawals, use, discharge, and trends in Florida, 2000: U.S. Geological Survey Scientific Investigations Report 2004-5151, 139 p.

Marella, R.L., and Sepulveda, A.A., 2004, Potentiometric surface of the Upper Floridan aquifer in Florida, May 2000: Florida Geological Survey Map Series 149, 1 sheet.

National Climatic Data Center, 1999, Climate of 1998, Florida wild fires and climate extremes: Accessed August 6, 2004, at http://www.ncdc.noaa.gov/oa/climate/research/1998/fla/florida.html.

National Climatic Data Center, 2001a, Climatological Data Annual Summary, Florida 2000, v. 104, no. 13, 23 p.

National Climatic Data Center, 2001b, Climate of 2000—Annual Review, U.S. Summary: Accessed August 30, 2005, at http://www.ncdc.noaa.gov/oa/climate/research/2000/ann/us_summary.html.

National Oceanic and Atmospheric Administration, undated(a), What is meant by drought: Accessed August 6, 2004, at http://nimbo.wrh.noaa.gov/Flagstaff/science/drought.htm.

National Oceanic and Atmospheric Administration, undated(b), National Weather Service Glossary: Accessed December 13, 2005, at http://www.weather.gov/glossary/.

National Weather Service, 2005, Typical January-March weather anomalies and atmospheric circulation during moderate to strong El Niño & La Niña: Accessed January 25, 2006, at http://www.cpc.noaa.gov/products/analysis_monitoring/ensocycle/na winter.shtml.

Northwest Florida Water Management District, 2002, Drydown and Restoration of Lake Jackson, Public Information Bulletin 2002-02.

Pride, R.W., and Crooks, J.W., 1962, The drought of 1954-56, its effect on Florida's surface-water resources: Tallahassee, Florida Geological Survey, Report of Investigations 26, 65 p.

Rumenik, R.P., and Grubbs, J.W., 1993, Low-flow characteristics of Florida streams: U.S. Geological Survey Water-Resources Investigations Report 93-4165, 220 p., 2 pls.

Schiffer, D.M., 1998, Hydrology of central Florida lakes—A primer: U.S. Geological Survey Circular 1137, p. 5-6.

Southeast Regional Climate Center, 2005, Historical climate data for the Southeast: Accessed June 21, 2005, at http://water.dnr.state.sc.us/climate/sercc/climateinfo/historical/historical.html.

Tihanksy, A.B., 1999, Sinkholes, west-central Florida: A link between surface water and ground water, *in* Galloway, Devin, Jones, D.R., and Ingebritsen, S.E., 1999, Land subsidence in the United States: U.S. Geological Survey Circular 1182, p. 121-141.

University of Nebraska, 2004, National drought summaries January 4-December 26, 2000: Accessed February 19, 2004, http://www.drought.unl.edu/dm/archive/2000.

U.S. Geological Survey, 1999, Water resources data, Florida, water year 1999, volume 4, northwest Florida water: U.S. Geological Survey Water-Data Report FL-99-4.

Waller, B.G., 1985, Drought of 1980-1982 in southeast Florida with comparison to the 1961-1962 and 1970-1971 droughts: U.S. Geological Survey Water-Resources Investigations Report 85-4152, 29 p.

Glossary

A

annual streamflow (surface water) The arithmetic average of all the daily mean streamflow for a given water year, calendar year, or climatic year.

average streamflow (surface water) As used by the U.S. Geological Survey, the arithmetic average of all complete water years of record of discharge whether consecutive or not. The term "average" generally is reserved for average of record and "mean" is used for averages of shorter periods, namely, daily, monthly, or annual mean discharges. See also Mean Discharge.

D

discharge (hydraulics) Rate of flow, especially fluid flow; a volume of fluid passing a point per unit time, commonly expressed as cubic feet per second, million gallons per day, or gallons per minute.

drainage basin Land area drained by a river.

drought Commonly defined as being a time of less-than-normal or expected rainfall; depending on the effect and cause, may be characterized as agricultural, hydrological, meteorological, or sociological:

agricultural—A shortage of water in the root zone of plants such that plant yield is reduced considerably.
hydrological—An extended period during which streamflow, lake and reservoir storage, and ground-water levels are below normal.
meteorological—An extended period during which precipitation is below normal.
sociological—Meteorologic and hydrologic conditions under which less water is available than is anticipated and relied on for the normal level of social and economic activity of a region.

E

El Niño A warming of the ocean current along the coasts of Peru and Ecuador that is generally associated with dramatic changes in the weather patterns of the region; a major El Niño event generally occurs every 3 to 7 years and is associated with changes in the weather patterns worldwide.

F

flood Any relatively high streamflow that overflows the natural or artificial banks of a stream.

freshwater Water that contains less than 1,000 milligrams per liter (mg/L) of dissolved solids; generally, more than 500 mg/L is considered undesirable for drinking and many industrial uses. Generally, freshwater is considered potable.

G

gage height *See* Stage.

gaging station A site on a stream, canal, lake, or reservoir where systematic observations of gage height or water discharge are obtained by a gage, recorder, or similar equipment.

ground water Specifically, that part of the subsurface water that is in the saturated zone (a zone in which all voids are filled with water).

H

hurricane A tropical cyclone with surface winds in excess of 64 knots (74 mph) in the Western Hemisphere. There are various regional names for these storms.

Category 1	74-95 mph (64-82 kt or 119-153 km/hr)
Category 2	96-110 mph (83-95 kt or 154-177 km/hr)
Category 3	111-130 mph (96-113 kt or 178-209 km/hr)
Category 4	131-155 mph (114-135 kt or 210-249 km/hr)
Category 5	Greater than 155 mph (135 kt or 249 km/hr)

hydrograph Graph showing variation of stage, discharge, velocity, or other property of water with respect to time.

L

La Niña La Niña is a periodic cooling of surface ocean waters in the wastern tropical Pacific along with a shift in convection in the western Pacific further west than the climatological average.

limestone A sedimentary rock type that is composed of calcium carbonate.

M

mean discharge (mean) is the arithmetic mean of individual daily, monthly, or annual mean discharges during a specific period.

N

N-day, T-year low flow (NQT) A specific frequency characteristic associated with a consecutive-day average period of N days and a recurrence interval of T years.

> **7-day low-flow** For example, the 7-day, 10-year low flow frequency characteristic (7Q10) is the annual minimum average flow for 7 consecutive days that will not be exceeded once in 10 years; or, that there is a 10 percent chance in any given year that the average flow for 7 consecutive days will be less than the 7Q10.

normal As used by the meteorological profession, average (or mean) conditions over a specific period of time; usually the most recent 30-year period, for example 1961 to 1990.

P

precipitation Any or all of the forms of water particles, such as rain, snow, hail, and sleet, that fall from the atmosphere and reach the ground.

public supply Water withdrawn by public or private water suppliers and delivered to users who do not supply their own water. Water suppliers provide water for a variety of uses, such as domestic, commercial, industrial, thermoelectric power (domestic and cooling purposes), and public-water use. According to the Florida Department of Environmental Protection, any water system that serves more than 25 people or has 15 year-round service connections is considered a community public supplier. For this report, public supply includes those systems that serve more than 400 people or use more than 10,000 gallons per day (gal/d).

R

real-time data Data collected by automated instrumentation and telemetered and is analyzed quickly enough to influence a decision that affects the monitored system.

reclaimed wastewater Water that has received at least secondary treatment and is reused after leaving a wastewater treatment facility.

recurrence intervals The average interval of time within which streamflow will be less than or equal to a particular value for low flows, or greater than or equal to a particular value for floods.

runoff That part of the precipitation that appears in surface-water bodies. It is the same as streamflow unaffected by artificial diversions, storage, or other human works in or on the stream channels.

S

saline water Water that contains more than 1,000 milligrams per liter (mg/L) of dissolved solids.

sea level Long-term average position of the sea surface. Sea level varies from place to place and with the time period for which the average is calculated. In this report with respect to the conterminous United States, it refers to the National Geodetic Vertical Datum of 1929.

> **mean sea level** is a local tidal datum. It is the arithmetic mean of hourly heights observed over the National Tidal Datum Epoch. Shorter series are specified in the name; for example, monthly mean sea level and yearly mean sea level. In order that they may be recovered when needed, such datums are referenced to fixed points known as benchmarks.

sinkholes Three types of sinkholes occur within Florida.

> **cover-collapse** sinkholes develop where a solution cavity develops in the limestone to a size such that the overlying material can no longer support its own weight. Collapse is generally abrupt when this occurs and is sometimes catastrophic. Collapse sinkholes provide dramatic local changes in topography.

> **solution sinkholes** develop in areas where limestone is exposed at land surface or is covered by thin layers of soil and permeable sand. Solution is most active at the limestone surface and along joints, fractures, or other openings in the rock that permit water to move easily into the subsurface. Dissolved limestone and some insoluble residue are carried downward by the percolating water along enlarged openings as solution of the limestone progresses. Large voids commonly do not form because subsidence of the soil layer occurs as the limestone surface dissolves. The result is a gradual downward movement of the land surface and development of a depression that collects increasing amounts of surface runoff as its perimeter expands.

> **cover-subsidence** sinkholes develop where the cover material is relatively incohesive and permeable, and individual grains of sand move downward in sequence to replace grains that have themselves moved downward to occupy space formerly held by the dissolved limestone.

spall A fragment removed from a rock or sediment surface by weathering or erosion.

specific conductance A measure of the ability of a sample of water to conduct electricity.

stage Height of the water surface in a river above a predetermined point that may be on or near the channel floor. Used interchangeably with gage height.

streamflow The discharge that occurs in a natural channel. Although the term “discharge” can be applied to the flow of a canal, the word “streamflow” uniquely describes the discharge in a surface stream course. The term “streamflow” is more general than “runoff” as streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

T

transpiration Process by which water passes from the soil through living plants and into the atmosphere as vapor discharged from the plant surface.

tropical storm An organized cyclone in the tropics with wind speed between 39 and 74 mph (35 and 64 kt or 63-118 km/hr).

V

velocity Distance traveled per unit time. For example, feet per second (ft/s).

W

water use (1) In a restrictive sense, the term refers to water that is actually used for a specific purpose such as domestic use, irrigation, or industial processing. (2) More broadly, water use pertains to human's interaction with and influence on the hydrologic cycle, and includes elements such as water withdrawals, deliveries, consumptive use, wastewater releases, reclaimed wastewater, return flow and instream use.

agriculture water use Includes water used for agricultural irrigation and nonirrigation purposes. Irrigation water use includes the artificial application of water on lands to assist in the growing of crops, plants, and pasture. Nonirrigation water use includes water used for livestock, fish farming, and other farm needs. Livestock water use includes water used for stock watering, feedlots, and dairy operations. The water can be obtained from a public supply or be self-supplied.

commercial water use Water for motels, hotels, restaurants, office buildings, commercial facilities and civilian and military institutions. The water may be obtained from a public supply or be self-supplied.

power generation water use Water used in the process of the generation of electric power through a thermoelectric or hydroelectric facility. The majority of water used for this category is for cooling purposes (much of which is used for once-through cooling). Water is also used for boiler makeup or domestic purposes throughout the plant. Boiler makeup water and water used for domestic purposes are generally obtained from public supply, however, for plants located in remote areas, this water can be self-supplied. Cooling water is generally self-supplied, although some smaller plants use public-supply water for cooling purposes.

recreational water use Includes the application of water on lands to assist in the growing of turf grass and landscape vegetation for lawns or recreation purposes, and also includes water used for aesthetic purposes. Turf grass recreation includes the irrigation of golf courses (including all grass and landscape associated with golf courses); turf grass lawns relates to the irrigation of all grass and landscape associated with athletic fields, cemeteries, common public or highway areas, parks, playgrounds, and lawns (primarily nonresidential, but does include some residential). Aesthetic uses include water used to fill or maintain nonagricultural ponds.

water year A continuous 12-month period selected to present data relative to hydrologic or meteorologic phenomena during which a complete annual hydrologic cycle normally occurs. The water year used by the U.S. Geological Survey runs from October 1 through September 30.

withdrawal Water removed from the ground or diverted from a surface-water source. The amount of water withdrawn may not equal the amount of water used due to water transfers or the recirculation or recycling of the same water. For example, a power plant may use the same water multiple times but withdraw a significantly different amount.