Hydrology of Polk County, Florida

By Rick M. Spechler and Sharon E. Kroening

Prepared in cooperation with the
Polk County Board of County Commissioners
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Conversion Factors, Vertical Datum, Abbreviations, and Acronyms

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
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)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
	Leakance	
foot per day per foot [(ft/d)/ft]	1	meter per day per meter

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 the National Geodetic Vertical Datum of 1929 (NGVD 29).

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

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Acronyms and Additional Abbreviations

AMO	Atlantic Multidecadal Oscillation
$CaCO_3$	calcium carbonate
ET	evapotranspiration
FGS	Florida Geological Survey
LOWESS	locally weighted scatterplot
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter at 25 °C
mg/L	milligrams per liter
NOAA	National Oceanic and Atmospheric Administration
NWIS	National Water Data Information System
NO_3^-	nitrate
NO_2^-	nitrite
N	nitrogen
PDO	Pacific Decadal Oscillation
ROMP	Regional Observation and Monitoring-Well Program
SJRWMD	St. Johns River Water Management District
SFWMD	South Florida Water Management District
SWUCA	Southern Water Use Caution Area
SWFWMD	Southwest Florida Water Management District
QS	spring discharge
QO	subsurface outflow
QR	surface-water runoff
USGS	U.S. Geological Survey

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Abstract

Local water managers usually rely on information produced at the State and regional scale to make water-resource management decisions. Current assessments of hydrologic and water-quality conditions in Polk County, Florida, commonly end at the boundaries of two water management districts (South Florida Water Management District and the Southwest Florida Water Management District), which makes it difficult for managers to determine conditions throughout the county. The last comprehensive water-resources assessment of Polk County was published almost 40 years ago. To address the need for current county-wide information, the U.S. Geological Survey began a 3½-year study in 2002 to update information about hydrologic and water-quality conditions in Polk County and identify changes that have occurred.

Ground-water use in Polk County has decreased substantially since 1965. In 1965, total ground-water withdrawals in the county were about 350 million gallons per day. In 2002, withdrawals totaled about 285 million gallons per day, of which nearly 95 percent was from the Floridan aquifer system. Water-conservation practices mainly related to the phosphate-mining industry as well as the decrease in the number of mines in operation in Polk County have reduced total water use by about 65 million gallons per day since 1965.

Polk County is underlain by three principal hydrogeologic units. The uppermost water-bearing unit is the surficial aquifer system, which is unconfined and composed primarily of clastic deposits. The surficial aquifer system is underlain by the intermediate confining unit, which grades into the intermediate aquifer system and consists of up to two water-bearing zones composed of interbedded clastic and carbonate rocks. The lowermost hydrogeologic unit is the Floridan aquifer system. The Floridan aquifer system, a thick sequence of permeable limestone and dolostone, consists of the Upper Floridan aquifer, a middle semiconfining unit, a middle confining unit, and the Lower Floridan aquifer. The Upper Floridan aquifer provides most of the water required to meet demand in Polk County.

Data from about 300 geophysical and geologic logs were used to construct hydrogeologic maps showing the tops and thicknesses of the aquifers and confining units within Polk County. Thickness of the surficial aquifer system ranges from several feet thick or less in the extreme northwestern part of the county and along parts of the Peace River south of Bartow to more than 200 feet along the southern part of the Lake Wales Ridge in eastern Polk County. Thickness of the intermediate aquifer system/intermediate confining unit is highly variable throughout the county because of past erosional processes and sinkhole formation. Thickness of the unit ranges from less than 25 feet in the extreme northwestern part of the county to more than 300 feet in southwestern Polk County. The altitude of the top of the Upper Floridan aquifer in the county ranges from about 50 feet above National Geodetic Vertical Datum of 1929 (NGVD 29) in the northwestern part to more than 250 feet below NGVD 29 in the southern part.

Water levels in the Upper Floridan aquifer fluctuate seasonally, increasing during the wet season (June through September) and decreasing during the rest of the year. Water levels in the Upper Floridan aquifer also can change from year to year, depending on such factors as pumpage and climatic variations. In the southwestern part of the county, fluctuations in water use related to phosphate mining have had a major impact on ground-water levels. Hydrographs of selected wells in southwestern Polk County show a general decline in water levels that ended in the mid-1970s. This water-level decline coincides with an increase in water use associated with

phosphate mining. A substantial increase in water levels that began in the mid-1970s coincides with a period of decreasing water use in the county.

Despite reductions in water use since 1970, however, over the long term, the increase in pumping in and near Polk County has resulted in a decline of the potentiometric surface of the Upper Floridan aquifer across much of the county since predevelopment times. Based on the difference between the estimated predevelopment potentiometric-surface map and water levels in wells measured in May and September and averaged from 2000 to 2004, water-level declines range from zero in the northwestern part of the county to as much as 40 feet in the southwestern part.

Water samples collected from 130 wells were used to characterize ground-water quality in Polk County. Samples from 53 wells and 1 spring in Polk and adjacent counties were collected for this project by the U.S. Geological Survey and analyzed for common inorganic constituents and nutrients. Concentrations of total dissolved solids, sulfate, and chloride in water samples from the surficial and intermediate aquifer systems generally were below State and Federal drinking-water standards. Nitrate concentrations, however, were as high as 26 milligrams per liter (mg/L) in samples from the surficial aquifer system along the Lake Wales Ridge. The application of fertilizers related to citrus farming is a likely source of nitrate to the ground water in this area.

Inorganic constituent concentrations in water from the Floridan aquifer system generally were below State and Federal drinking-water standards. Water from the Upper Floridan aquifer in most of Polk County is hard (hardness ranging from 70 to 290 mg/L), and has a dissolved-solids concentration of less than 500 mg/L. Chloride concentrations in water from the Upper Floridan aquifer range from 4.2 to 61 mg/L, and sulfate concentrations range from about 0.2 to 44 mg/L. In contrast to results from the surficial aquifer system, nitrate concentrations in the Upper Floridan aquifer generally were low (less than 0.02 mg/L) and exceeded 1.0 mg/L in only three wells.

Temporal trends in streamflow in the Peace River were updated in this study using data through 2003. The analyses also were expanded by analyzing trends over a wide range of the hydrologic regime and over several multidecadal periods. Results indicate that annual minimum to 70th percentile streamflows in the Upper Peace River began to decline in the 1950s, and this decline has persisted to 2003. Results also showed a statistically significant decrease in annual minimum streamflows in the Peace River at Bartow from 1974-1993. This decrease may be due to elimination of wastewater discharges to the stream during the mid-1980s.

Temporal trends in lake levels were analyzed to describe long-term trends (1960-2003) and trends of a shorter duration (1990-2003). About 90 percent of the lakes had no change in water levels from 1990-2003. Five of the lakes had an increasing trend in water levels. The increase in water levels likely is not due to increased rainfall. Annual totals at nearby rainfall stations had no significant trends during this period.

Introduction

Increasing demands are being made on the water resources of Polk County, Florida, as a result of rapidly increasing population and a strong agricultural industry. Changes in ground-water levels or water quality that may have resulted from the redistribution of pumping stresses, however, have not been documented on a countywide basis. The last comprehensive hydrogeologic investigation of Polk County was completed in 1966. The U.S. Geological Survey (USGS) and other State and local agencies continue to collect information on the surface-water and ground-water resources of Polk County. Current assessments of hydrologic and water-quality conditions conducted by these agencies commonly end at the water management district boundaries, which makes it difficult for water-resource managers to determine hydrologic and water-quality conditions throughout the county. Three of Florida's water management districts (St. Johns River, South Florida, and Southwest Florida Water Management Districts) have had jurisdiction over parts of the county. An analysis of long-term and current hydrologic data will enable water-resource managers to better evaluate changes in hydrologic conditions. Updated information can be used to redefine baseline conditions against which future changes can be quantified. To address the need for current countywide information, the USGS, in cooperation with Polk County, the South Florida Water Management District (SFWMD), the St. Johns River Water Management District (SJRWMD), and the Southwest Florida Water Management District (SWFWMD) conducted a 3½-year study from 2002 to 2006 to evaluate the hydrogeology and ground-water quality of Polk County and to provide an updated evaluation of surface water including streamflow and lake-level trends and characteristics. The results of the study are summarized in this report.

Purpose and Scope

This report presents the results of a study to describe and update information on the hydrogeology of the surficial, intermediate, and Floridan aquifer systems in Polk County, Florida, characterize water-quality conditions in the three aquifers, and assess long-term trends in the ground-water and surface-water resources. Chapter 1 of the report describes: (1) the lithology, depth, thickness, and extent of the surficial aquifer system, intermediate aquifer system, intermediate confining unit, and the Floridan aquifer system in Polk County; (2) water levels and water-level changes in the aquifer systems; and (3) the water-quality characteristics of the surficial, intermediate and Floridan aquifer systems. Chapter 2 describes trends in lake stage and streamflow by updating flow and lake stage data and duration curves.

Information presented in the report was compiled from data collected during this investigation by the USGS, SWFWMD, SFWMD, and SJRWMD. Additional information also was obtained from published reports by the USGS, SFWMD, Florida Geological Survey (FGS), and private consultants, and from unpublished data by the USGS and FGS. New data collected during this investigation included water-quality samples, ground-water level measurements, and lithologic logs.

Previous Investigations

Numerous reports have described the hydrology, geology, and ground-water resources of Polk County. Discussions of Florida geology with reference to Polk County are included in reports by Cooke (1945) and Stringfield (1966). Miller (1986) describes the hydrogeologic framework of the Floridan aquifer system.

The first comprehensive investigation on the hydrogeology and ground-water resources of Polk County was done by Stewart (1966). A number of studies have described the hydrogeology of selected areas within Polk County. Shaw and Trost (1984) evaluated the regional hydrogeology of the Kissimmee River Basin. Duerr and others (1988) and Knochenmus (2006) described the hydrogeologic framework of the intermediate aquifer system in west-central Florida. O'Reilly and others (2002) described the hydrogeology and water quality of the Lower Floridan aquifer in east-central Florida, which included part of Polk County. Pride and others (1966), Grubb (1978), and Grubb and Rutledge (1979) described the hydrology of the Green Swamp area. Robertson (1971; 1973) discussed the hydrology of the Lakeland Ridge. The hydrogeology of the Lake Wales Ridge was described in several reports, including Barcelo and others (1990) and Yobbi (1996). Hutchinson (1978) described the surficial and intermediate aquifer systems of the upper Peace River and eastern Alafia River Basins. Kaufman (1967) and Robertson and Mills (1974) described the effects of ground-water pumping in the Peace and Alafia River Basins. Basso (2003) discussed the surface-water/ground-water relation in the Upper Peace River Basin. Lewelling and others (1998) assessed the hydraulic connection between ground water and the Peace River.

Several reports evaluated the ground-water quality in Polk County. Swancar and Hutchinson (1995) discussed the chemical and isotopic composition and potential for contamination of water in the Upper Floridan aquifer in west-central Florida. Stewart (1966) presented a general reconnaissance of ground-water quality in Polk County. Barr (1992) evaluated the potential for ground-water contamination of the surficial, intermediate, and Floridan aquifer systems in Polk County. Miller and Sutcliffe (1982), Rutledge (1987), and Lewelling and Wylie (1993) described the quality of water in the surficial aquifer system in parts of the phosphate region of southwestern Polk County. Moore and others (1986) summarized information from the ambient ground-water quality monitoring program for the SWFWMD. Nitrate in shallow ground water in the vicinity of the Lake Wales Ridge was evaluated by Tihansky and Sacks (1997). Pesticides and nitrate concentrations in the surficial aquifer system underlying citrus areas in the northern part of the Lake Wales Ridge were evaluated in a land-use comparison study (German, 1996). Agricultural chemicals in the surficial aquifer system in the Lake Wales Ridge were investigated by Choquette and others (2005).

Several investigators have employed continuous high-resolution seismic-reflection techniques in Polk County lakes and rivers to describe geologic structure at depth—including Evans and others (1994), Tihansky and others (1996), and Lewelling and others (1998).

Ground-water flow modeling studies that include all or part of the study area are presented by Grubb and Rutledge (1979), Wilson and Gerhart (1982), Ryder (1982; 1985), Tibbals (1990), Barcelo and Basso (1993), Yobbi (1996), and Sepúlveda (2002).

Several hydrologic assessments have focused on lakes that lie within Polk County. The hydrology and limnology of Crooked Lake were described by Bradbury and others (1978). Sacks and others (1998) estimated ground-water exchange with lakes in the ridge areas of Polk and Highlands Counties by using water-budget and chemical mass-balance approaches. Swancar and others (2000) estimated ground-water exchange at Lake Starr.

Acknowledgments

The authors gratefully acknowledge the assistance given by many organizations and individuals during the study and especially appreciate the cooperation received from Chris Sweazy, Emily Hopkins Richardson, and Cynthia Gefvert of the South Florida Water Management District; Jeff Spence of the Polk County Board of County Commissioners; Margit Crowell, Eric DeHaven, and Joseph Haber of the Southwest Florida Water Management District; and Nolan Col of the St. Johns River Water Management District. Appreciation also is expressed to the residents and private companies in the area who permitted access to their properties and allowed the sampling of water and measuring of water levels in their wells.

Site-Numbering System

The USGS assigns a unique site identification number to each inventoried well and surface-water site. A 15-digit number based on latitude and longitude is used to identify wells in the USGS National Water Data Information System (NWIS). The first six digits denote the degrees, minutes, and seconds of latitude; the next seven digits denote degrees, minutes, and seconds of longitude; and the last two digits denote a sequential number for a site within a one-second grid. For example, well 280253081235801 is the first well inventoried at latitude 28˚02'53" N, longitude 081˚23'58" W. The latitude and longitude stored in NWIS, however, should be used rather than those defined by the 15-digit site number because the initial measurements may be inaccurate or successive measurements more accurate. Surface-water sites that are part of the long-term data-collection network are assigned an eight-digit downstream order number, such as 02294650 for the Peace River at Bartow, which designates the major river basin (02) and the order in which the tributary joins the main stream. Surface-water sites that are not part of the long-term network usually are given a 15-digit number.

Description of Study Area

Polk County, located in the central part of the Florida peninsula, is Florida's fourth largest county (fig. 1). It is bordered on the north by Lake and Sumter Counties, on the east by Osceola County, on the south by Hardee and Highlands Counties, and on the west by Hillsborough and Pasco Counties. Polk County is approximately 40 miles wide and 50 miles long and has a surface area of about 1,823 square miles (mi^2), of which 187 mi^2 are water (Purdum and others, 1988). Land-surface elevations range from about 50 to 305 feet (ft) above NGVD 29 (Stewart, 1966); however, most of the land lies between 75 and 250 ft above NGVD 29 (Heath, 1961; Southwest Florida Water Management District, 1988). The lowest elevations are found in the eastern part of the county, and the highest elevations are found on the Lake Wales Ridge in the vicinity of the city of Lake Wales and Babson Park (Stewart, 1966). The western part of Polk County is included within the SWFWMD, and the eastern part is included within the SFWMD (fig. 1). A small area in the northern part of the county that corresponded to the Ocklawaha River basin was once part of the SJRWMD, but in 2003 boundary lines were redrawn and this area is now under the jurisdiction of the SWFWMD. All of Polk County that falls under the jurisdiction of the SWFWMD is part of the Southern Water Use Caution Area (SWUCA), which

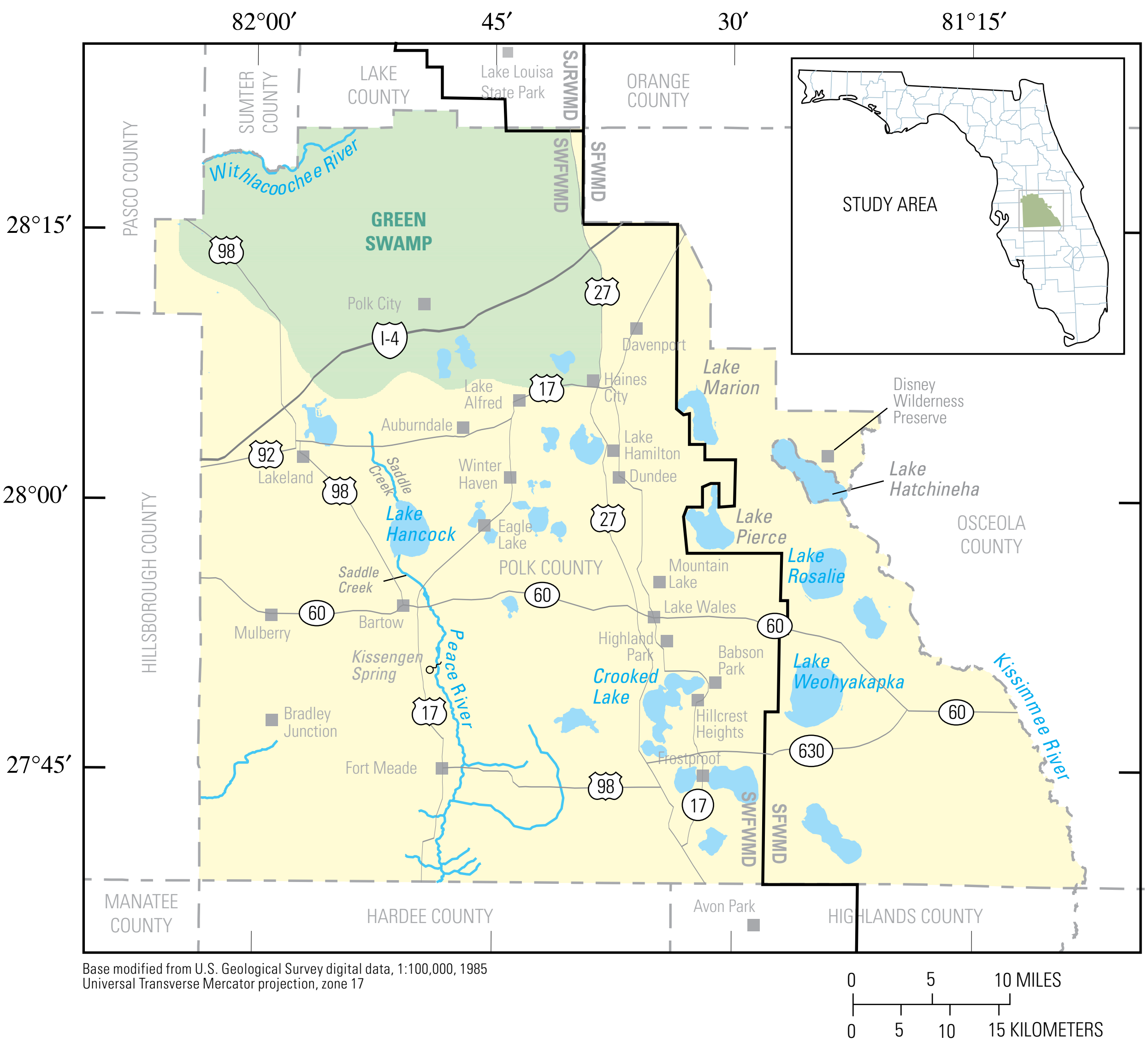


Figure 1. Location of study area in central Florida.

includes all or part of eight counties in southwestern Florida. This water-use caution area was designated in 1992, when it was recognized that increasing ground-water withdrawals (in response to increasing growth) resulted in declines in aquifer heads causing saltwater intrusion in coastal areas, lowered lake levels in the upland areas, and reduced baseflow in some river reaches.

Population, Industry, and Land Use

Since the 1960s, there has been a rapid increase in population and this trend is expected to continue. From 1960 to 2004, the population of Polk County increased from about 195,000 to 528,000 (fig. 2). The population of Polk County is projected to reach about 676,000 by 2020. In 2004, the county was the 10th largest in terms of population in the State (Office of Economic and Demographic Research, 2005). Polk County has 17 municipalities (fig. 1). The largest in population is Lakeland and the second largest is Winter Haven. Other municipalities include Auburndale, Bartow, Davenport, Dundee, Eagle Lake, Fort Meade, Frostproof, Haines City, Highland Park, Hillcrest Heights, Lake Alfred, Lake Hamilton, Lake Wales, Mulberry, and Polk City.

Polk County is one of the leading counties in industrial development in the State, having about 450 manufacturing companies and 3,114 farms in 2002 (U.S. Department of Agriculture, 2005). It ranks first in phosphate production (Polk County Department of Economic Development, 2005) and second in cattle production (U.S. Department of Agriculture, 2005). The county also ranks first in the State in citrus production for 2003-2004, producing nearly 14 percent of Florida's citrus (U.S. Department of Agriculture, 2005).

Agriculture, wetlands, urban land, forests, and mining were the major land-use categories in the county in 1995 (fig. 3). Agricultural land use composed about 40 percent of the county, in which citrus is the primary agricultural product. Agricultural lands are scattered throughout the county, but are concentrated along the ridges. Wetlands composed about 30 percent of the county and generally are found in the Green Swamp area of northern Polk County and east of the Lake Wales Ridge. Urban land composed about 12 percent of the county, and is mostly concentrated around the cities of Lakeland, Bartow, Auburndale, Winter Haven, and Lake Wales. Forest covered about 6 percent of the county, primarily in the eastern one-third of the county. Mining areas composed about 4 percent of the county, and are found primarily in the southwestern part. Phosphate and, to a lesser degree, sand mining are the primary types of mining operations.

A comparison of the extent of urban land use between 1977 and 1995 indicates that the amount of urban area increased from about 10 to 12 percent. Most of the increase in urbanization occurred in an east-west band across the central part of the county, which included the cities of Lakeland, Auburndale, Winter Haven, and Lake Wales. The eastern part of the county (east of the Lake Wales Ridge) has had relatively little increase in urbanization.

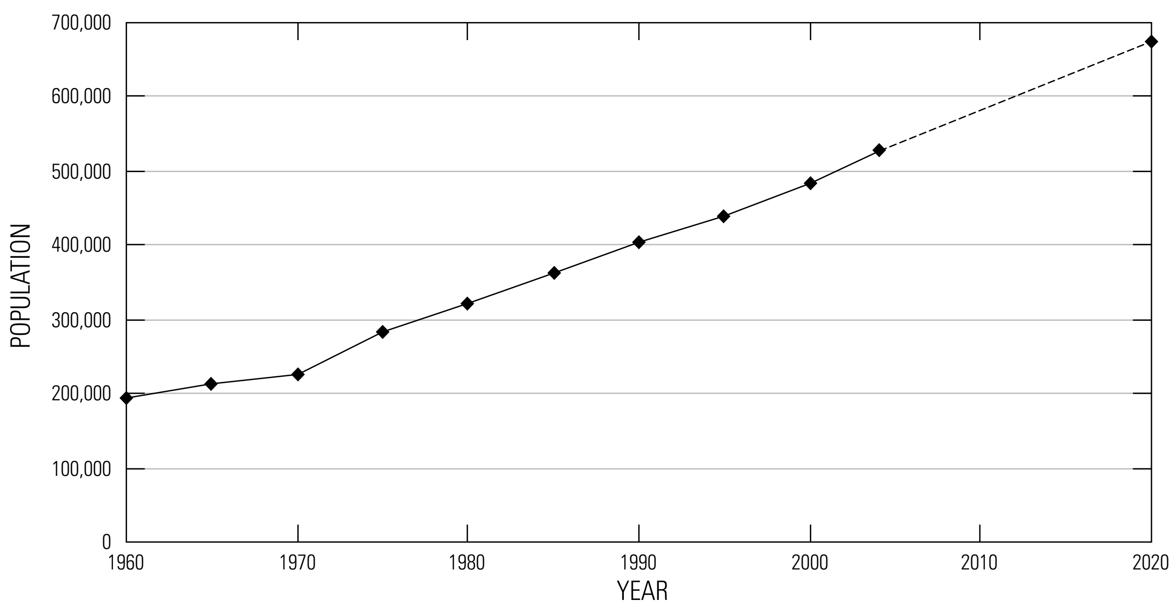


Figure 2. Historical population for Polk County (from the Office of Economic and Demographic Research, 2005).

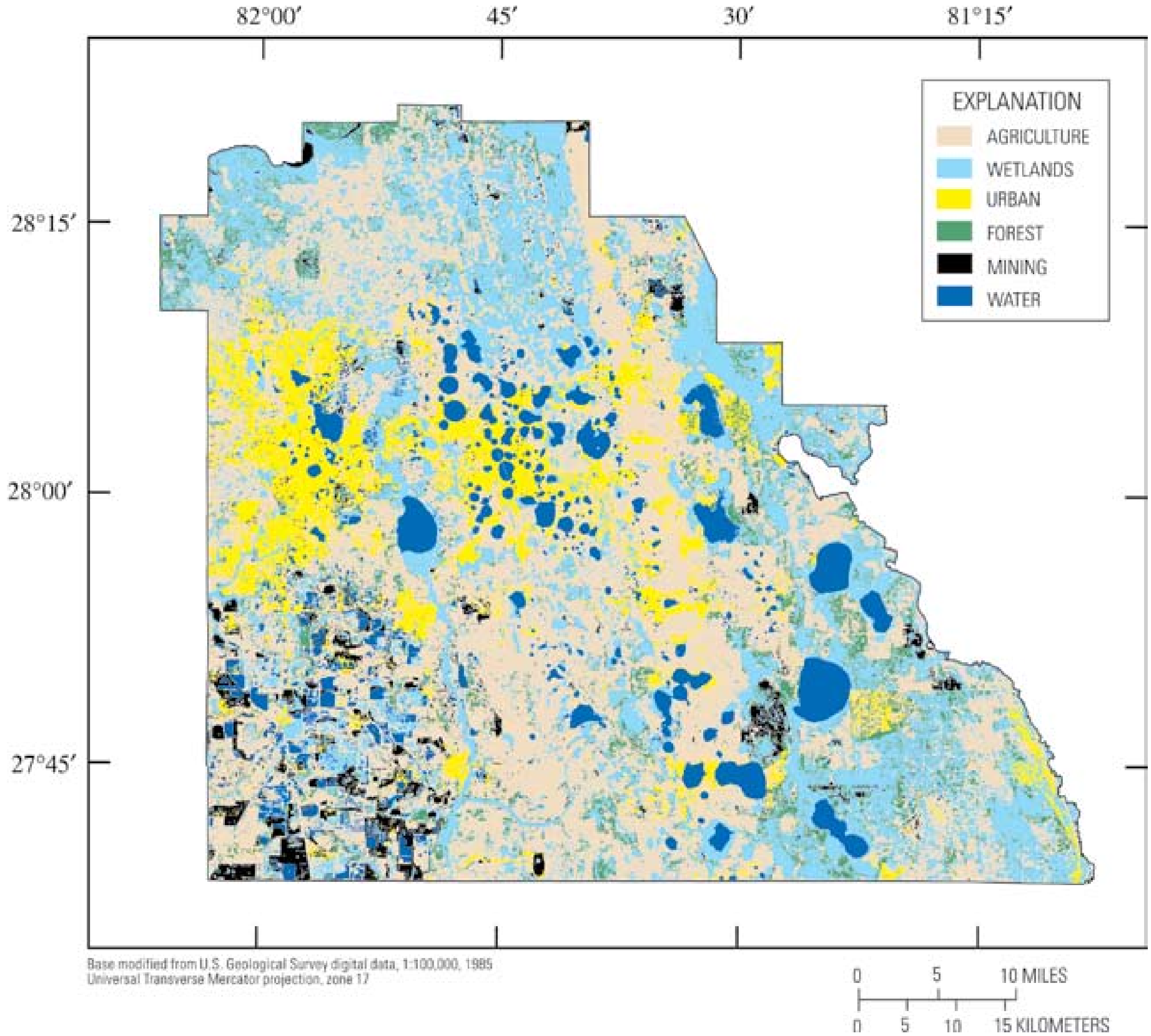


Figure 3. Generalized land use in Polk County, 1995.

Physiography

Polk County is divided into 10 physiographic provinces (White, 1970): the Polk Upland, Lake Upland, Winter Haven Ridge, Lake Henry Ridge, Lakeland Ridge, Lake Wales Ridge, Bombing Range Ridge, Osceola Plain, Western Valley, and Intra Ridge Valley (fig. 4). In general, these physiographic provinces are four basic types: uplands, ridges, valleys, and plains.

Much of the western part of Polk County lies in the Polk and Lake Uplands. These uplands are characterized by moderate relief, shallow lakes, and moderate water-table depths. The Polk Upland is a broad sandy area that ranges in altitude from about 65 ft above NGVD 29 along parts of the Peace River to about 150 ft above NGVD 29. In the northern part of the county, the Polk Upland merges with the Lake Upland. The boundary between the Polk and Lake Uplands is inferred because there is not a distinct topographic break between the two uplands (White, 1970). The part of the Lake Upland that is in Polk County ranges in altitude from 100 to 135 ft above NGVD 29. In much of the Lake Upland lies the Green Swamp. The Green Swamp is a composite of many swamps that are distributed fairly uniformly over the area. Interspersed among the swamps are low ridges, hills, and flatlands. In the extreme northwestern part of the county lies the Western Valley physiographic province. The Western Valley is a low, irregular valley produced by the erosion of soluble sediments (Campbell, 1986). Elevations of the Western Valley that lie within Polk County range from 75 to about 120 ft above NGVD 29.

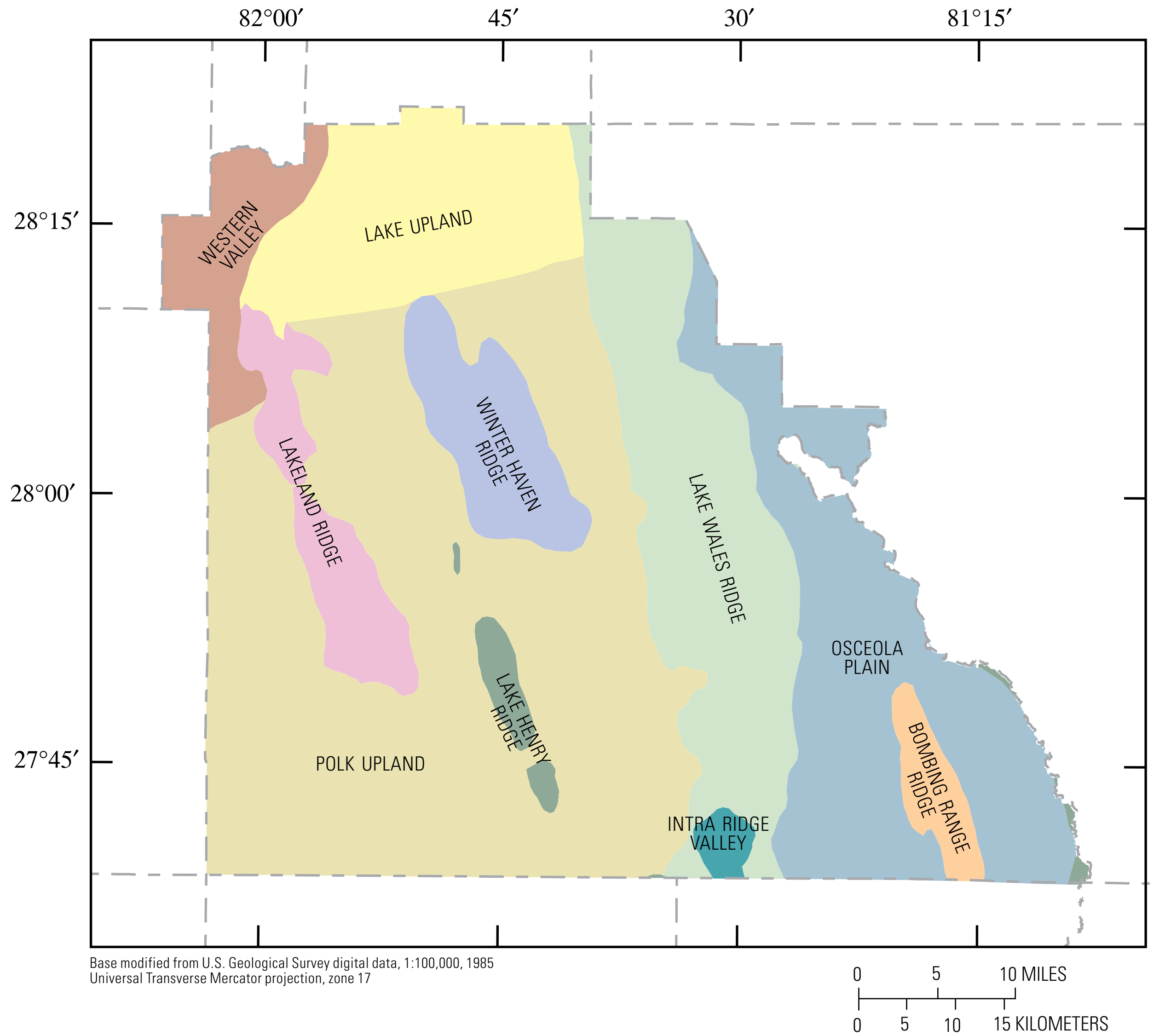


Figure 4. Generalized physiography of Polk County (from White, 1970).

Three north-northwest to south-southeast trending ridges rise from the surface of the Polk Upland. These ridges have the highest land-surface elevations in the county and are characterized by closed basin lakes and sinkholes, deep water tables, and subsurface drainage. Surface drainage features generally are absent. The easternmost ridge within the Polk Upland (the Winter Haven Ridge) consists mostly of small ridge remnants, reaching altitudes of about 200 ft above NGVD 29. The southern extension of the Winter Haven Ridge is referred to as the Lake Henry Ridge. Maximum altitudes along this ridge are 230 ft above NGVD 29. The westernmost ridge, the Lakeland Ridge, begins about 10 miles north of Lakeland and extends to the south of Bartow, reaching altitudes of about 270 ft above NGVD 29.

The most prominent ridge in Polk County is the Lake Wales Ridge (fig. 4). The Lake Wales Ridge, located east of the Winter Haven Ridge, borders the eastern edge of the Polk Upland and extends southward from Lake County, through Polk County and into Highlands County. The Lake Wales Ridge is the highest and longest of the ridges, with maximum altitudes of 305 ft above NGVD 29. This long, narrow, sandy ridge contains numerous sinkhole lakes and depressions, many of which do not have any surface-water outlets. In the southern part of the county, the Lake Wales Ridge is divided into two secondary ridges by the Intra Ridge Valley. This valley was formed by the dissolution of the underlying limestone and contains numerous karst features.

The Osceola Plain is a broad marine terrace that lies east of the Lake Wales Ridge. It is characterized by large lakes, little relief, and altitudes that range from about 50 to 75 ft above NGVD 29. Water levels in the surficial aquifer system are at, or only a few feet below, land surface in much of the plain. In southeastern Polk County, the Bombing Range Ridge rises above the level of the Osceola Plain. Reaching altitudes of about 135 ft above NGVD 29 in Polk County, this ridge is probably the result of a former marine sand bar (White, 1970).

Climate

The climate of Polk County is classified as humid subtropical and is characterized by hot, wet summers and mild, relatively dry winters. The mean annual temperature at Lakeland is 73 ˚F, and the mean monthly temperature ranges from a low of about 61 ˚F in January to 83 ˚F in August. Temperatures commonly exceed 90 ˚F from June to September, and may fall below freezing for a few days in the winter months.

Rainfall is unevenly distributed throughout the year. About 55 percent of the annual rainfall total is derived from thunderstorms that occur frequently during the months of June through September. During the summer, thunderstorms can produce heavy but localized rainfall, resulting in several inches of precipitation falling in one location and little or none falling a few miles away. During the summer months and early fall, occasional tropical storms and hurricanes also can bring heavy precipitation into the area. During the winter, rainfall is associated with frontal system activity, which is usually of a longer duration and areally more uniform than summer convectional precipitation. April and November typically are the driest months.

The National Oceanic and Atmospheric Administration (NOAA) records indicate that long-term average annual rainfall totals are similar throughout the county. Rainfall data for a 73-year period from 1931 to 2003 at the Lakeland, Mountain Lake, and Avon Park (Highlands County) stations are shown in figure 5. The mean annual rainfall was about 51 inches (in.) at the Lakeland and Mountain Lake stations and about 53 in. at the Avon Park station.

Drought conditions prevailed throughout much of Florida during 2000. The lowest annual rainfall totals recorded at the Avon Park and Mountain Lake stations occurred in 2000: 26.10 and 29.53 in., respectively. At the Lakeland site, however, the lowest annual rainfall total was 35.83 in. measured in 1961. Annual rainfall totals of more than 74 in. were measured at both the Avon Park and Mountain Lake stations in 1953, and an annual rainfall total of 70.24 in. was measured at Lakeland in 1959.

A considerable amount of variation in annual rainfall occurs from year to year, sometimes making it difficult to determine whether annual rainfall totals changed substantially over time. Patterns are apparent at some of the rainfall stations (fig. 5). From 1931 to 1960, the average annual rainfall was 53.9 and 55.3 in. at Mountain Lake and Avon Park, respectively. At Lakeland, the average rainfall was 51.3 in. during this period. In contrast, average annual rainfall from 1961 to 2003 was lower, 48.5 and 50.9 in. at Mountain Lake and Avon Park, respectively. At Lakeland, however, the average annual rainfall during this period was not much different at 50.1 in.

Several investigators (Barcelo and others, 1990; Flannery and Barcelo, 1998; Basso and Schultz, 2003) reported lower rainfall amounts in the county from 1960-2000 compared to earlier decades. These multidecadal variations in rainfall may result from alternating cycles of warmer and cooler sea-surface temperatures in the North Atlantic and Pacific Oceans. Sea-surface temperatures in the North Atlantic Ocean vary by about 0.4 °C, which is referred to as the Atlantic Multidecadal Oscillation (AMO) (Enfield and others, 2001). These variations in temperature likely are caused by natural internal variations in the strength of the ocean thermohaline circulations and the associated meridional heat transport. Warm phases of the AMO have occurred from 1930-1960 and 1995-2004, and cool phases have occurred from 1905-1925 and 1970-1990 (McCabe and others, 2004). Enfield and others (2001) have shown the AMO has a strong influence on rainfall in the conterminous United States. Warm phases of the AMO are correlated with dry conditions in most of the conterminous United States; however, in Florida it is generally correlated with wet conditions. Sea-surface temperatures in a large part of the northern Pacific Ocean also vary on multidecadal cycles, which is referred to as the Pacific Decadal Oscillation (PDO) (Mantau and others, 1997). These variations also may affect rainfall in Florida. When sea-surface temperatures along the coast of North America are unusually warm, there is a strong tendency for temperatures in the central Pacific Ocean to be anomalously cool. This is referred to as a cool phase of the PDO. Cool phases of the PDO generally are associated with below-average precipitation from March through October in the southern United States and have occurred from 1890-1924 and 1947-76 (Mantau and others, 1997).

McCabe and others (2004) decomposed the drought frequency in the Nation into the primary factors affecting variability; most of the variability was attributed to the AMO, PDO, and a factor related to increasing North American temperatures. The effect that both AMO and PDO conditions have on droughts in the Nation was analyzed by McCabe and others (2004). Under cool AMO conditions and the combination of warm AMO and cool PDO conditions, there is a tendency for above-normal drought frequency in most of Florida. McCabe and Wolock (2002) reported a change in precipitation across the eastern Unites States around 1970 that may be related to a shift in climatic conditions.

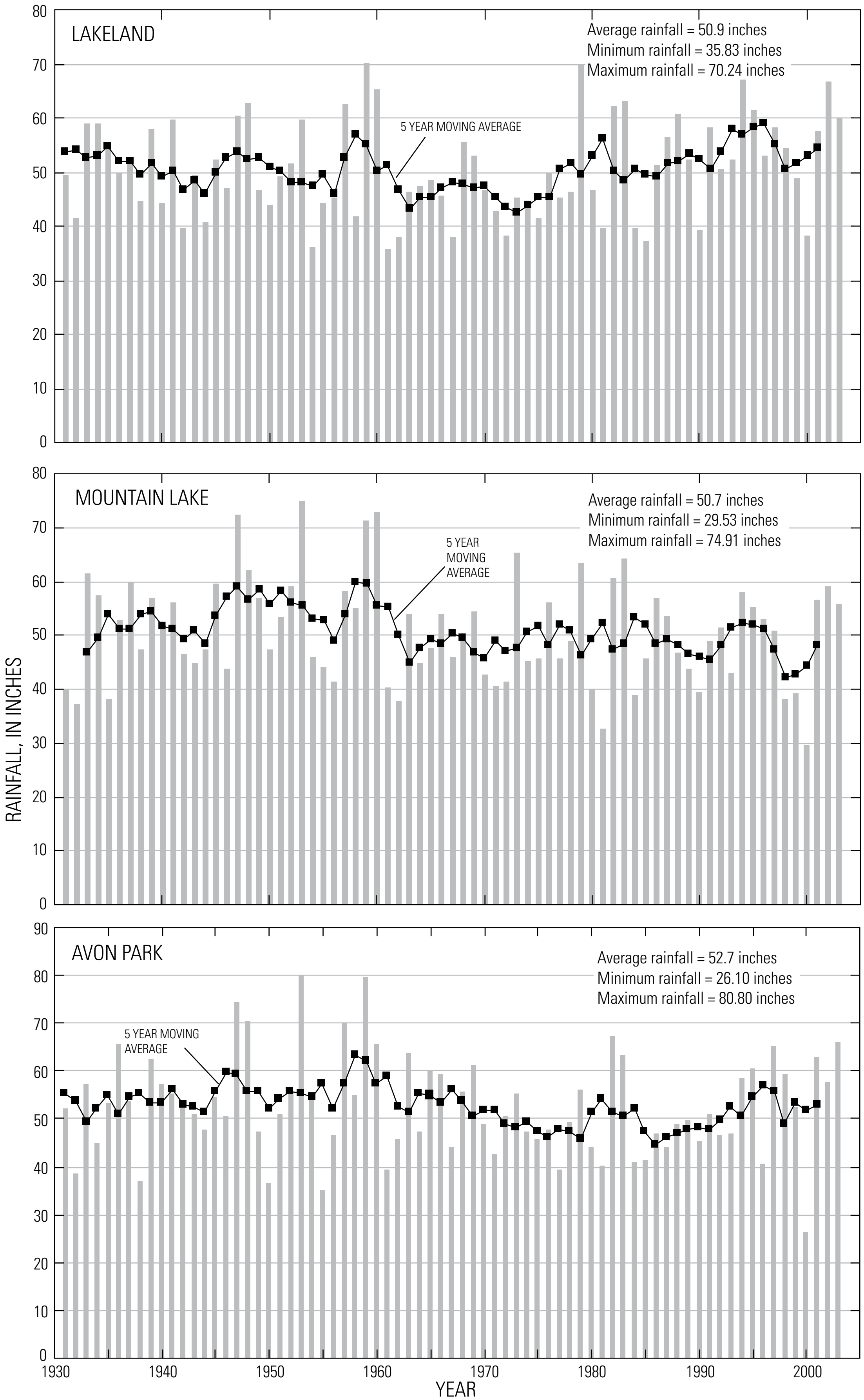


Figure 5. Annual rainfall at Lakeland, Mountain Lake, and Avon Park, Florida, 1931-2003.

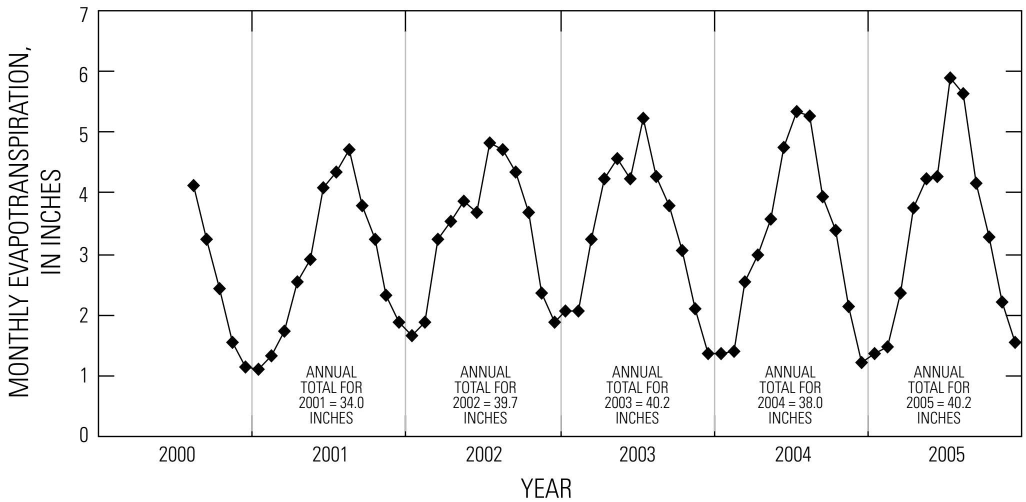


Figure 6. Monthly evapotranspiration at the Disney Wilderness Preserve in eastern Polk County, August 2000 to December 2005 (D.M. Sumner, U.S. Geological Survey, written commun., 2006).

Most of the rainfall returns to the atmosphere by evapotranspiration, which is defined as the evaporation of water from soil and water surfaces and transpiration of plants. About 60 percent of the annual evapotranspiration occurs from May to October (Southwest Florida Water Management District, 1988). Locally, evapotranspiration varies with the evaporative demand of the atmosphere and the availability of water. The upper limit of evapotranspiration is approximately equal to the rate at which water can evaporate from a free-water surface under natural conditions (Tibbals, 1990). Evapotranspiration rates are highest in the lakes, swamps, and marshes, where water is near or above land surface much of the time. Lake evaporation rates measured at Lake Starr in Polk County for a 2-year period (August 1996 to July 1998) were 57.08 and 55.88 inches per year (in/yr), respectively (Swancar and others, 2000).

During 2001-2005, annual evapotranspiration rates ranged from 34.0 to 40.2 in/yr (D.M. Sumner, U.S. Geological Survey, written commun., 2006) at a Bahia grass/palmetto site in eastern Polk County where the water table is shallow (fig. 6). The lowest rates of evapotranspiration in Polk County occur along the ridges where the surficial sediments are permeable and the depth to the water table is greater. Tibbals (1990) estimated the relation of evapotranspiration to water-table depth and determined that the minimum rate of evapotranspiration in east-central Florida occurred where the water table was greater than 13 ft below land surface. In a study along the Lake Wales Ridge in Orange County, Sumner (1996) determined an annual evapotranspiration rate of about 27 in. at a site with a deep water table. This rate is probably close to a minimum evapotranspiration value for central Florida.

Ground-Water Use

The Upper Floridan aquifer is the principal source of water supply in Polk County. The aquifer supplies nearly all the ground water used for commercial-industrial self-supplied, public-supply, domestic self-supplied, agricultural irrigation uses, and recreational irrigation. In 2000, about 4 percent of the total amount of ground-water withdrawn was from the surficial or intermediate aquifer systems in Polk County (Marella, 2004). At present (2005), no water is withdrawn from the Lower Floridan aquifer in Polk County. Ground-water withdrawals vary from season to season and from year to year, primarily as a function of the amount and distribution of rainfall. Of the total water withdrawn in 2000, 48 percent was used for agricultural irrigation, 23 percent for public supply, 21 percent for commercial/industrial self-supplies, 4 percent for domestic self-supplied, 3 percent for recreational irrigation, and 1 percent for thermoelectric power generation (fig. 7).

Ground-water use has decreased substantially in Polk County since 1965. In 1965, total ground-water withdrawals in Polk County were about 350 million gallons per day (Mgal/d) (fig. 8). In 2002, withdrawals totaled about 285 Mgal/d. The large declines in water use are the result of water-conservation practices related to the mining and processing of phosphate ore, as well as the decrease in the number of mines operating in Polk County. Water use from the commercial/industrial self-supplied category, which includes mining, decreased from 270 Mgal/d in 1965 to 56 Mgal/d in 2002. Some of this decline in water use, however, was partially offset by increases in water use for public supply and agriculture. From 1965 to 2002, water use for public supply increased from 26 to about 74 Mgal/d. During the same period, agricultural water use increased from 52 to 127 Mgal/d.

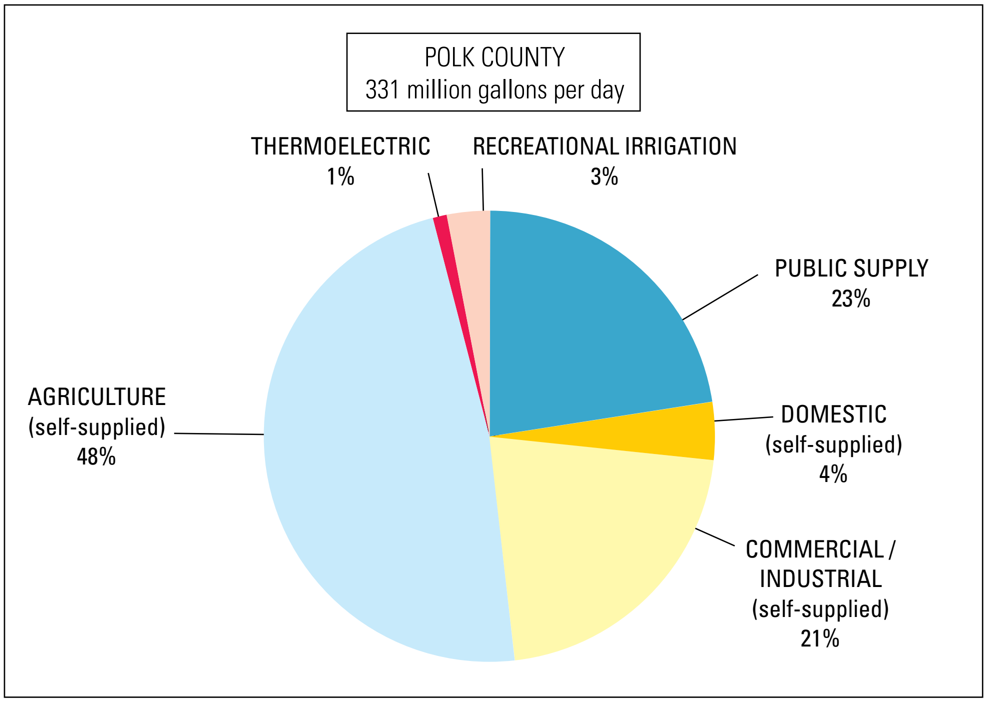


Figure 7. Total ground-water use, by category, for 2000 (from Marella, 2004).

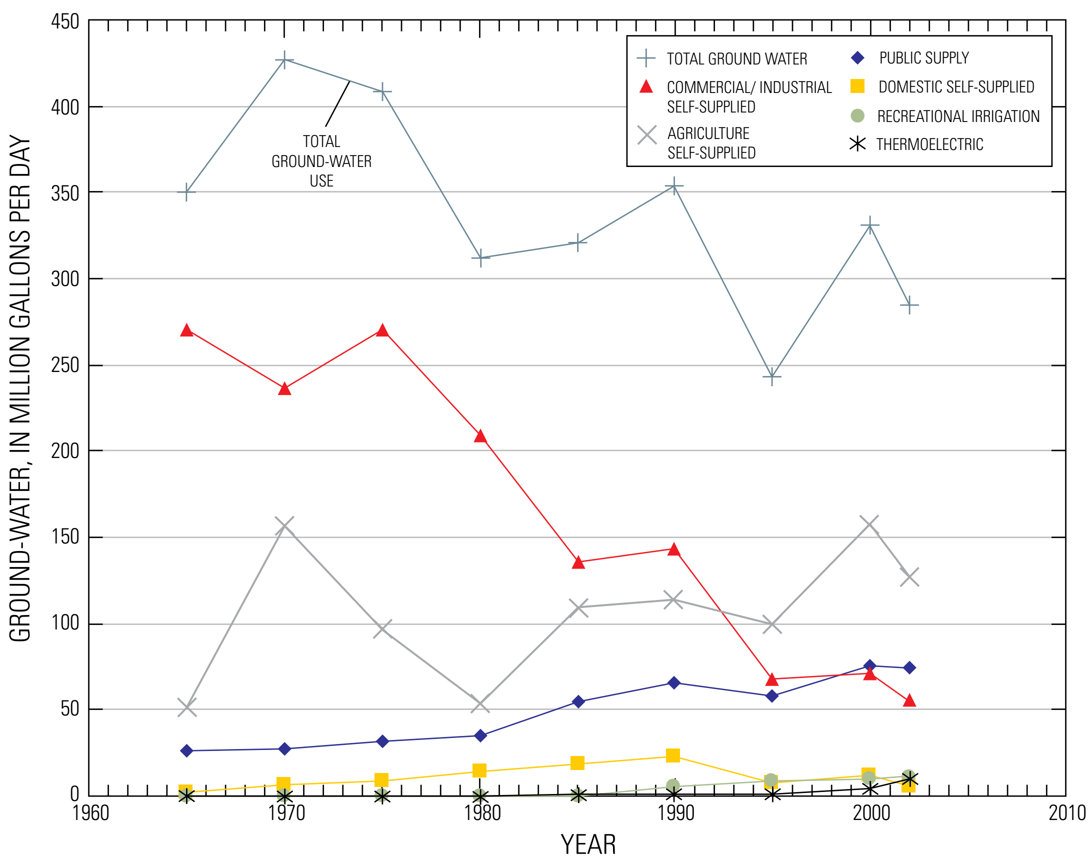


Figure 8. Historical total ground-water use in Polk County, 1965-2002 (from Marella, 2004; and Southwest Florida Water Management District, 2004a, 2004b).

CHAPTER 1—Ground-Water Resources of Polk County

Data Collection

The hydrology of Polk County was described by using existing data and new geologic, water-level, and water-quality data. Data were obtained from published reports and from Federal, State, and County agencies. A network of monitoring wells was established for the collection of water levels and ground-water samples from the surficial, intermediate, and Floridan aquifer systems. Data-collection sites were inventoried based on a review of existing wells and available water-level and water-quality data in the study area. The locations of wells and springs used for the collection of water-level and water-quality data are shown in figures 9 and 10, respectively. Well construction information is presented in appendix 1.

Geologic and geophysical information from more than 300 wells was used to construct hydrogeologic maps and cross sections of the surficial aquifer system, the intermediate aquifer system/intermediate confining unit, and the Floridan aquifer system in Polk County. This information was obtained from the files of the USGS, FGS, SWFWMD, SFWMD, and from published reports. The data that were analyzed include borehole geophysical logs and lithologic descriptions of well cuttings by geologists and drillers.

Three surficial aquifer system monitor wells were constructed in areas where data were not available. These wells were installed near existing wells that tap the Upper Floridan aquifer to provide a comparison of water levels and water quality between the two aquifers. Split-spoon samples were collected every 5 ft and were used to provide additional data on surficial aquifer system lithology. The altitude of the measuring points of monitoring wells was determined by instrument leveling.

Water samples collected by the USGS and State agencies from 130 wells between 1998 and 2003 were used to characterize ground-water quality in Polk County (fig. 10). Water-quality samples from 53 wells and 1 spring in Polk and adjacent counties were collected specifically for this project by the USGS and analyzed for common inorganic constituents and nutrients, mostly in 2003. Sampled wells include public supply, domestic, irrigation, and dedicated monitoring wells.

Geologic Framework

The study area is underlain by a thick sequence of sedimentary rocks that has a minimum thickness of about 5,300 ft, as shown by a deep oil test well at Mulberry (Davis and Associates, 1981). These sediments are predominantly of shallow-water marine origin and are composed of limestone, dolostone, evaporite, clay, and sand that range in age from Late Cretaceous to Holocene. The major stratigraphic units of interest in Polk County, from oldest to youngest, are: the Cedar Keys Formation of late Paleocene age, the Oldsmar Formation of early Eocene age, the Avon Park Formation of middle Eocene age, the Ocala Limestone of late Eocene age, the Suwannee Limestone of early Oligocene age, the Hawthorn Group of late Oligocene to Miocene age, and the undifferentiated surficial deposits of Pliocene to Holocene ages (fig. 11). Most geologic units cropping out within Polk County (fig. 12) are composed of unconsolidated siliciclastic sediments. The exceptions, however, are in the extreme northwestern part of the county and along the Peace River, where some of the sediments are composed of carbonates.

There are some differences in the geologic nomenclature used in earlier water-resource assessments of Polk County (Stewart, 1966; Pride and others, 1966) and those used in this report (fig. 11). Miller (1986) determined that the Avon Park Limestone and the Lake City Limestone could not be distinguished from each other on the basis of either lithology or fauna; therefore, all of the lithologic units within the Lake City Limestone were reclassified as Avon Park Limestone. Miller (1986) also recognized that the Avon Park Limestone contained a considerable amount of dolostone and should be called a formation (Avon Park Formation), rather than a limestone. The Ocala Group is now referred to as the Ocala Limestone, and the unit previously referred to as the Hawthorn Formation is now recognized as the Hawthorn Group (Scott, 1988). Similarly, the Tampa Member of the Arcadia Formation was formerly referred to as the Tampa Limestone or Tampa Formation.

Stratigraphy

The basal Tertiary unit within the study area is the Cedar Keys Formation of late Paleocene age (fig. 11). The Cedar Keys Formation generally has extremely low permeability, and thus, functions as the sub-Floridan confining unit at the base of the Floridan aquifer system. Conformably overlying the Cedar Keys Formation is the Oldsmar Limestone of Eocene age. It is composed mostly of limestone and dolostone that in places contains inclusions of gypsum and anhydrite. These evaporites were deposited in shallow, restricted marine basins on emergent areas of the Florida Platform during lower sea-level stands. The Avon Park Formation, a thick sequence of marine limestone and dolostone, overlies the Oldsmar Formation and is characterized by alternating layers of soft to well-indurated, fossiliferous, tan to light-brown limestone

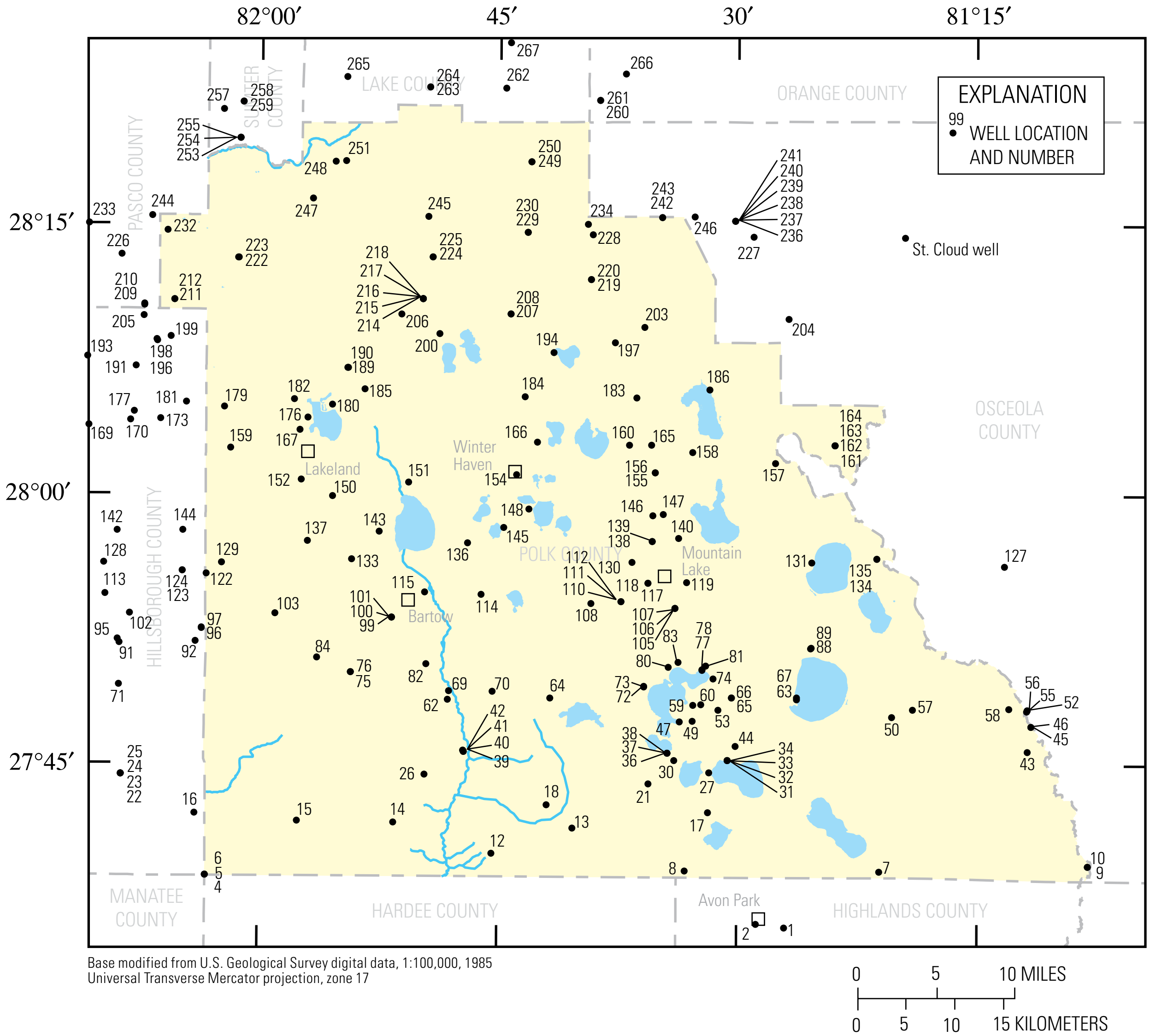
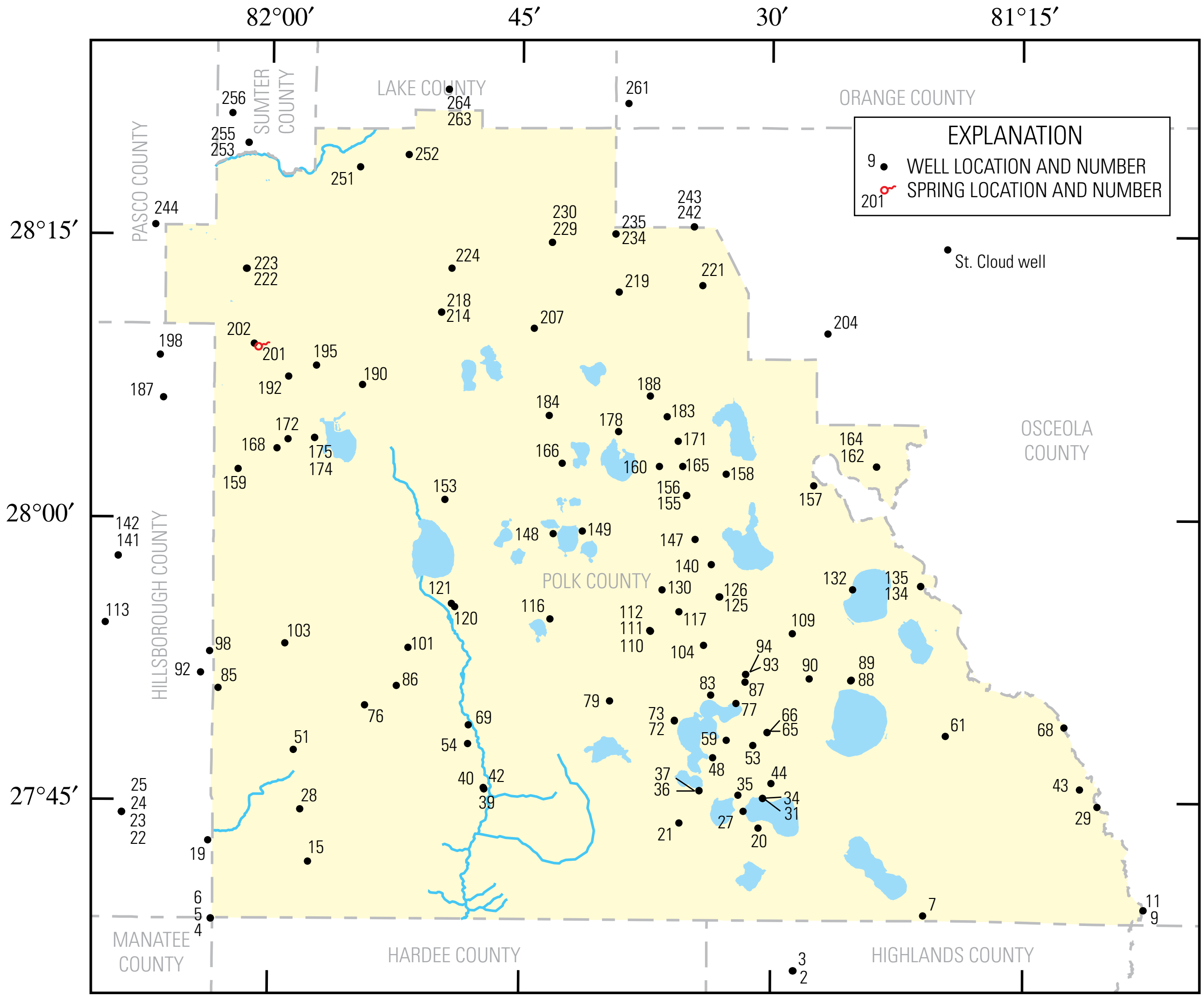


Figure 9. Location of wells with periodic or continuous water-level data (well numbers and information in appendix 1).

and brown, crystalline dolostone. The Avon Park Formation typically is highly fractured and cavernous. Inclusions of gypsum and anhydrite nodules also occur within the lower part of the Avon Park Formation (Navoy, 1986). The formation is distinguished from overlying formations by the abundance of cone-shaped foraminifera of the genus Dictyoconus. The top of the Avon Park Formation ranges from about 0 ft NGVD 29 in northeastern Polk County to about 700 ft below NGVD 29 in the extreme southwestern part of the county (Arthur and others, 2007).

An erosional unconformity separates the Avon Park Formation from the overlying Ocala Limestone of late Eocene age (Stewart, 1966). The Ocala Limestone can contain two distinct lithologic units. The lower unit consists of a white-to-cream to dark-brown, granular, fossiliferous, well-indurated, dense, limestone and dolostone. The upper unit is described as a white-to-cream or tan, fossiliferous, generally poorly indurated, pure limestone. The Ocala Limestone is recognized by the disc-shaped foraminifera of the genus Lepidocyclina. The top of the Ocala Limestone ranges from about 75 ft above NGVD 29 in the extreme northwestern part of the county to about 450 ft below NGVD 29 in the extreme southwestern part of the county (Arthur and others, 2007). In the extreme northwestern part of the county, the Ocala Limestone is at or near land surface (Stewart, 1966).

Overlying the Ocala Limestone is the Suwannee Limestone of early Oligocene age. The Suwannee Limestone has undergone extensive erosion and is absent in much of the northern and extreme eastern part of the county (Arthur and others, 2007). The limestone is white, cream, or tan, fossiliferous,



Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Universal Transverse Mercator projection, zone 17

Figure 10. Location of wells and spring where water-quality data were collected from 1998-2003 (well numbers and information in appendix 1).

poorly to well-indurated and variably recrystallized. The limestone can be interbedded with calcilutite (calcareous mud, greater than 50 percent silt or clay-size carbonate particles) and calcarenite (calcareous sand, greater than 50 percent sand-size carbonate particles) units. The top of the Suwannee Limestone ranges from about 75 ft above to about 250 ft below NGVD 29 (Arthur and others, 2007). The Suwannee Limestone generally is distinguished from the overlying Hawthorn Group by the lack of phosphatic sand.

Unconformably overlying the Suwannee Limestone is the Hawthorn Group of late Oligocene to Miocene age. Although originally believed to be Miocene in age, more recently the Hawthorn Group has been interpreted to include late Oligocene-aged sediments as well (Scott and others, 2001). Scott (1988) reclassified the sediments of the Hawthorn to group status because of its areally extensive and mapable lithologic units. In southern peninsula Florida, the Hawthorn Group includes, in ascending order, the Arcadia and Peace River Formations. The Arcadia Formation may contain up to two named members, in ascending order, the Nocatee and Tampa Members. Where both of these members cannot be identified, the section is referred to as the Arcadia Formation (Scott, 1988). The Arcadia Formation is composed of lime-stone and dolostone containing varying amounts of quartz sand, clay, and phosphate grains. Thin beds of quartz sand and clay are scattered throughout the section and generally are calcareous or dolomitic and phosphatic (Scott, 1988). The top of the Arcadia Formation ranges from about 100 ft above to more than 100 ft below NGVD 29 (Scott, 1988). The unit is absent in the northern part of the study area.

SERIES	STRATIGRAPHIC UNIT		GEOLOGY AND LITHOLOGY	HYDROGEOLOGIC UNIT		
Holocene and Pleistocene	Undifferentiated surficial deposits		Sand	Surficial aquifer system		
Pliocene	Undifferentiated surficial deposits	Cypresshead Formation	Sand, clay	Surficial aquifer system		
				Intermediate aquifer system or Intermediate confining unit	Confining unit	
Miocene	Hawthorn Group	Bone Valley Member	Phosphate, clay, sand, limestone, and dolostone	Intermediate aquifer system or Intermediate confining unit	Confining unit	
		Peace River Formation			Zone 2	
		Arcadia Formation			Confining unit	
		Tampa Member			Zone 3	
		Nocatee Member			Confining unit	
Oligocene	Suwannee Limestone		Limestone and dolostone	Floridan aquifer system	Upper Floridan aquifer	Upper permeable zone
Eocene	Ocala Limestone					Semi-confining unit
	Avon Park Formation					Lower permeable zone
			Limestone and dolostone with some intervals containing inclusions of gypsum and anhydrite		Middle confining unit	Middle semiconfining unit
	Oldsmar Formation				Lower Floridan aquifer	
Paleocene	Cedar Keys Formation		Limestone and dolostone with beds of gypsum and anhydrite	Sub-Floridan confining unit		

Figure 11. Relation of stratigraphic and hydrogeologic units (modified from Barr, 1992; Tihansky and others, 1996; O'Reilly and others, 2002; Sepúlveda, 2002; and Basso and Hood, 2005).

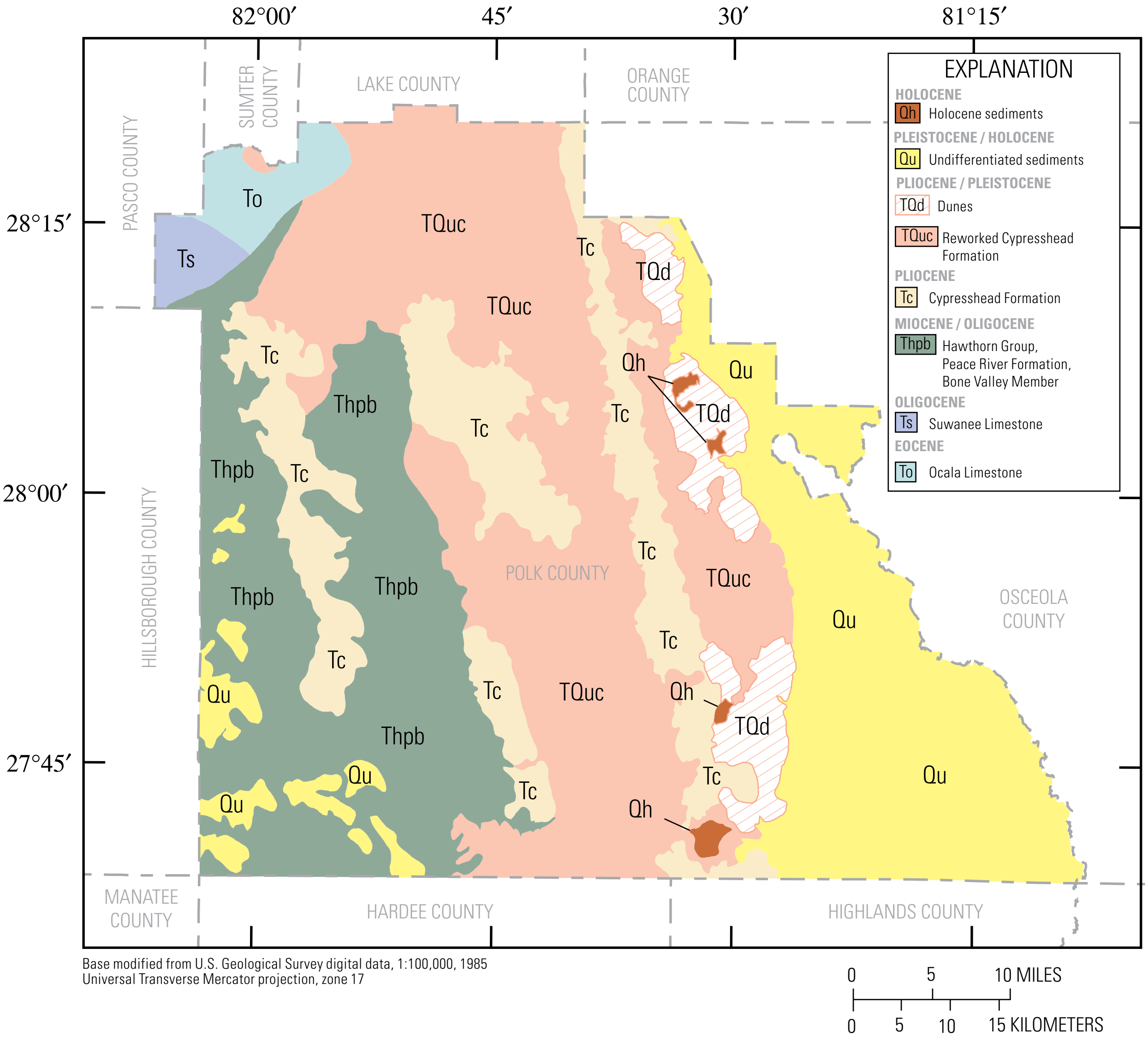


Figure 12. Geologic map of Polk County (from Scott and others, 2001).

The lowermost sediments of the Arcadia Formation form the Nocatee Member. The Nocatee Member consists of a complexly interbedded sequence of variably phosphatic quartz sands, clays, and carbonates (Scott, 1988). Previously, this unit was called the “sand and clay unit” of the Tampa Limestone by Wilson (1977). In Polk County, the top of the Nocatee Member ranges from about 0 to more than 200 ft below NGVD 29 (Arthur and others, 2007). The unit is absent in all but the southwestern part of the county.

The Tampa Member of the Arcadia Formation consists predominantly of limestone and subordinate dolostone, sand, and clay. Phosphate concentrations are low, generally less than 3 percent (Scott, 1988). The top of the unit ranges from about 50 ft above to 150 ft below NGVD 29 and is present only in southwestern Polk County (Arthur and others, 2007).

Unconformably overlying the Arcadia Formation is the Peace River Formation. The Peace River Formation is composed of interbedded quartz sand, clay, and carbonates, with variable amounts of phosphate. Siliciclastics, however, are the predominant lithology, comprising more than two-thirds of the formation (Scott, 1988). The Peace River Formation is present throughout most of Polk County. The top of the unit generally ranges from about 125 ft above to 125 ft below NGVD 29 (Arthur and others, 2007).

The unit formerly called the Bone Valley Formation was reclassified by Scott (1988) to member status within the Peace River Formation. The Bone Valley Member is a clastic unit consisting of pebble or gravel-sized phosphate fragments and sand-sized phosphate grains in a matrix of quartz sand and clay (Scott, 1988). The presence of phosphate gravels in the

Bone Valley Member is the most important lithologic factor in the differentiation of this member from the remainder of the Peace River Formation. The unit extends over much of the southwestern part of Polk County, where it attains a maximum thickness of about 50 ft (Scott, 1988). Because of its thickness and high concentration of phosphate, the Bone Valley Member has been extensively mined in Polk County. The top of the unit ranges from more than 120 ft to about 60 ft above NGVD 29 (Arthur and others, 2007).

Overlying the Hawthorn Group are the undifferentiated clastic (surficial) deposits of Pliocene to Holocene age, which includes the Cypresshead Formation. The undifferentiated surficial deposits consist primarily of sands, clayey sands, and clay. These deposits are present throughout most of Polk County, except in the extreme northwestern part of the county and along parts of the upper Peace River, where at a few locations, limestone is exposed at land surface. The quartz sands, which make up the upper part of the unit, are fine-to-coarse grained and reach their maximum thickness under the Lake Wales Ridge.

Karst Features

The soluble limestones and dolostones that underlie Polk County have been sculptured by dissolution and weathering processes to form what is known as karst terrain. Characteristic features of karst terrains that are directly related to carbonate dissolution and ground-water flow include sinkholes, springs, caves, disappearing streams, internally drained basins, and subsurface drainage networks. Water percolating through the upper soil zone combines with carbon dioxide, forming a slightly acidic solution. This water passes through insoluble sediments until it reaches the underlying carbonates. These carbonate rocks may be fractured, jointed, and have many voids and cavities that provide conduits for water flow. The voids or fractures can range in size from small vugs to large caverns. Acidic water passing through these openings slowly dissolves the carbonate rocks, and, over a long period of time, results in the formation of enlarged conduits and cavities. As the solution caverns become larger, in some instances, the roofs may not be able to support the overlying sediment. Collapse of the cavity roofs is evident today as sinkholes and sinkhole depressions.

Sinkholes most commonly develop in areas where ground-water recharge rates are rapid and where the overlying siliciclastic sediments are relatively thin or very permeable. Although sinkholes in all stages of development are common throughout Polk County, most occur along the ridges and range from small depressions to large lakes (fig. 13). These sinkholes, which often are filled with permeable surficial sands, provide more direct avenues for water from the surficial aquifer system to recharge the underlying Upper Floridan aquifer. The locations of sinkholes and depressions in Polk County are shown in figure 14. The features presented, which range from about 10 ft to several hundred feet in diameter, were delineated from USGS topographic maps. Also included may be some man-made features, which can be indistinguishable from the natural features on the topographic maps. Many of the natural lakes, ponds, and topographic depressions in the county were formed by sinkholes. Larger lakes often were formed by the coalescence of several sinkholes. Continuous high-resolution seismic-reflection surveys of lakes on the Lake Wales Ridge indicate that many of these lakes likely were formed by subsidence activity (Lee and others, 1991; Sacks and others, 1992; Evans and others, 1994; Tihansky and others, 1996).

The existence of karstic features along the upper Peace River and adjacent floodplains between Bartow and Fort Meade (fig. 1) provide a direct hydraulic connection between the river and aquifers at some locations (Lewelling and others, 1998). The Peace River in this area is characterized by shallow, sometimes exposed carbonate units, with karst features that vary in type and size and include sinkholes, subsidence depressions, dissolution pipes, and enlarged fractures. Patton (1981) and Patton and Klein (1989) mapped more than 90 sinkholes in the upper Peace River floodplain. Along this stretch of the river, the water level in the river often is higher than water levels in the underlying aquifers. The downward head gradient allows the Peace River to lose water to the ground-water system through sinkholes and conduits (fig. 15).

Ground-Water Resources

The hydrogeologic system in the study area consists of a series of clastic deposits underlain by a thick sequence of carbonate rocks. The stratigraphic units underlying the county form a layered sequence of aquifers and confining units. Each aquifer system has unique hydraulic characteristics that determine its potential for water supply.

The uppermost water-bearing unit is the surficial aquifer system. This aquifer system is underlain by and separated from the Floridan aquifer system by the intermediate confining unit or the intermediate aquifer system, both of which restrict the movement of water between the overlying and underlying aquifers. The lowermost hydrogeologic unit underlying the county is the Floridan aquifer system (fig. 11). The Floridan aquifer system has two major water-bearing zones (Upper Floridan aquifer and Lower Floridan aquifer), which are separated by a less-permeable middle semiconfining unit and/or a middle confining unit. Underlying the Floridan aquifer system are low-permeability limestone and dolostone that contain considerable gypsum and anhydrite, and define the base of the Floridan aquifer system. Generalized hydrogeologic sections (locations shown in fig. 16), based on geophysical and geologic logs, are shown in figures 17 and 18. The sections show the relative positions of the surficial, intermediate, and Floridan aquifer systems. Stratigraphic units, general lithology, and corresponding hydrogeologic units underlying Polk County are given in figure 11.

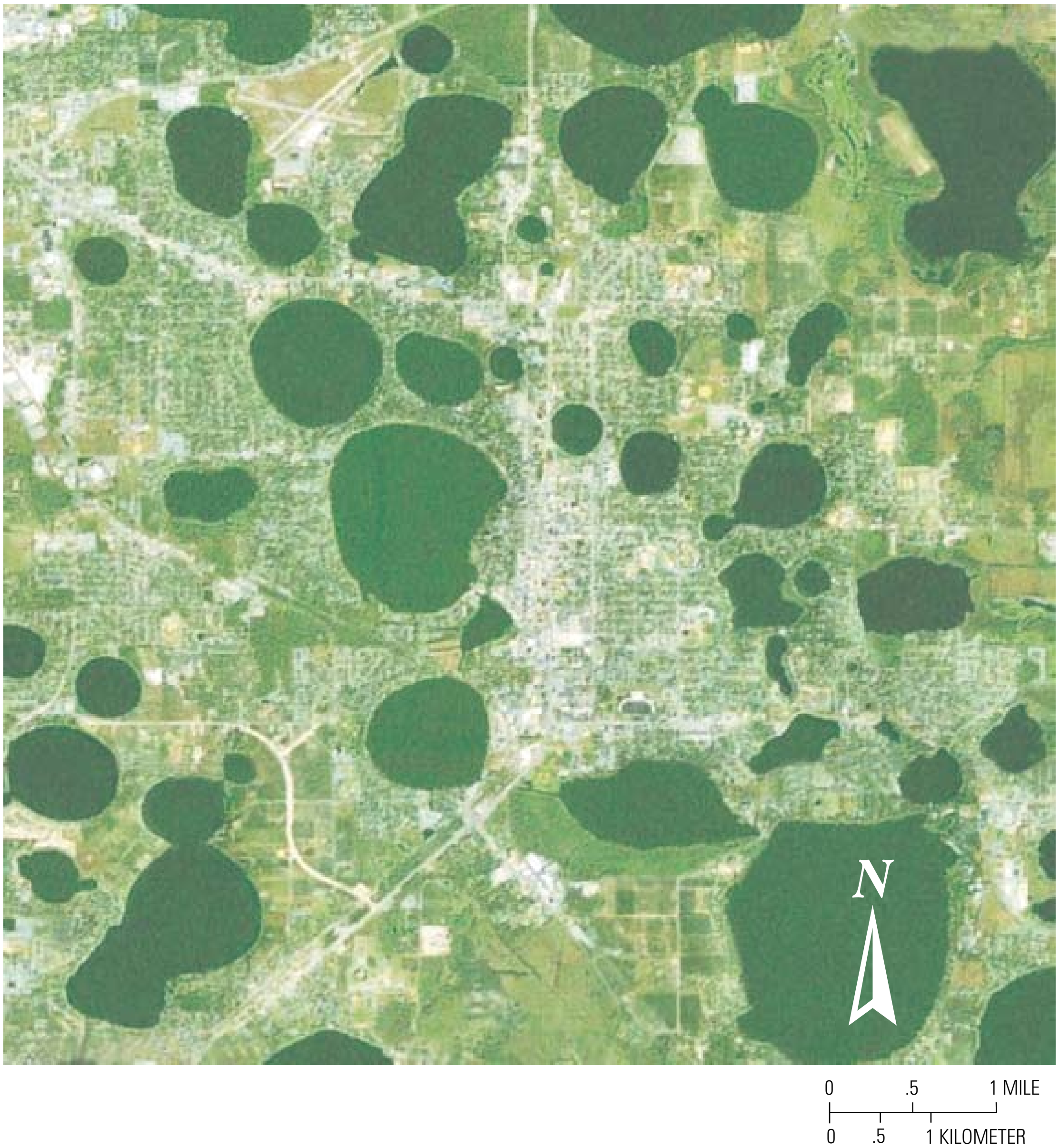


Figure 13. Sinkhole-formed lakes near Winter Haven, Florida (source: Land Voyage 15-meter satellite).

Surficial Aquifer System

The surficial aquifer system is unconfined and consists of unconsolidated clastic deposits that range in age from Pliocene to Holocene. The unit is composed primarily of fine- to medium-grained quartz sand near land surface that grades with depth to silty and clayey sands. The lithology and texture of the sediments within the surficial aquifer system can vary considerably both vertically and laterally. The base of the surficial aquifer system is defined by the first persistent beds of Miocene or Pliocene age sediments containing a substantial increase in clay or silt.

Thickness of the surficial aquifer system in Polk County is variable. A generalized contour map of the thickness of the surficial aquifer system is shown in figure 19. The thicknesses shown in figures 17 to 19 represent the thickness of both saturated and unsaturated undifferentiated sediments. In much of the western one-third of the county, thicknesses generally are less than 50 ft. In the Green Swamp area where the Upper Floridan aquifer is near land surface, deposits from the surficial aquifer system may be only a few feet thick or less. Along parts of the Peace River south of Bartow, the surficial aquifer system exists as thin sand units within the streambed and exposed cut banks that may be several feet or less in

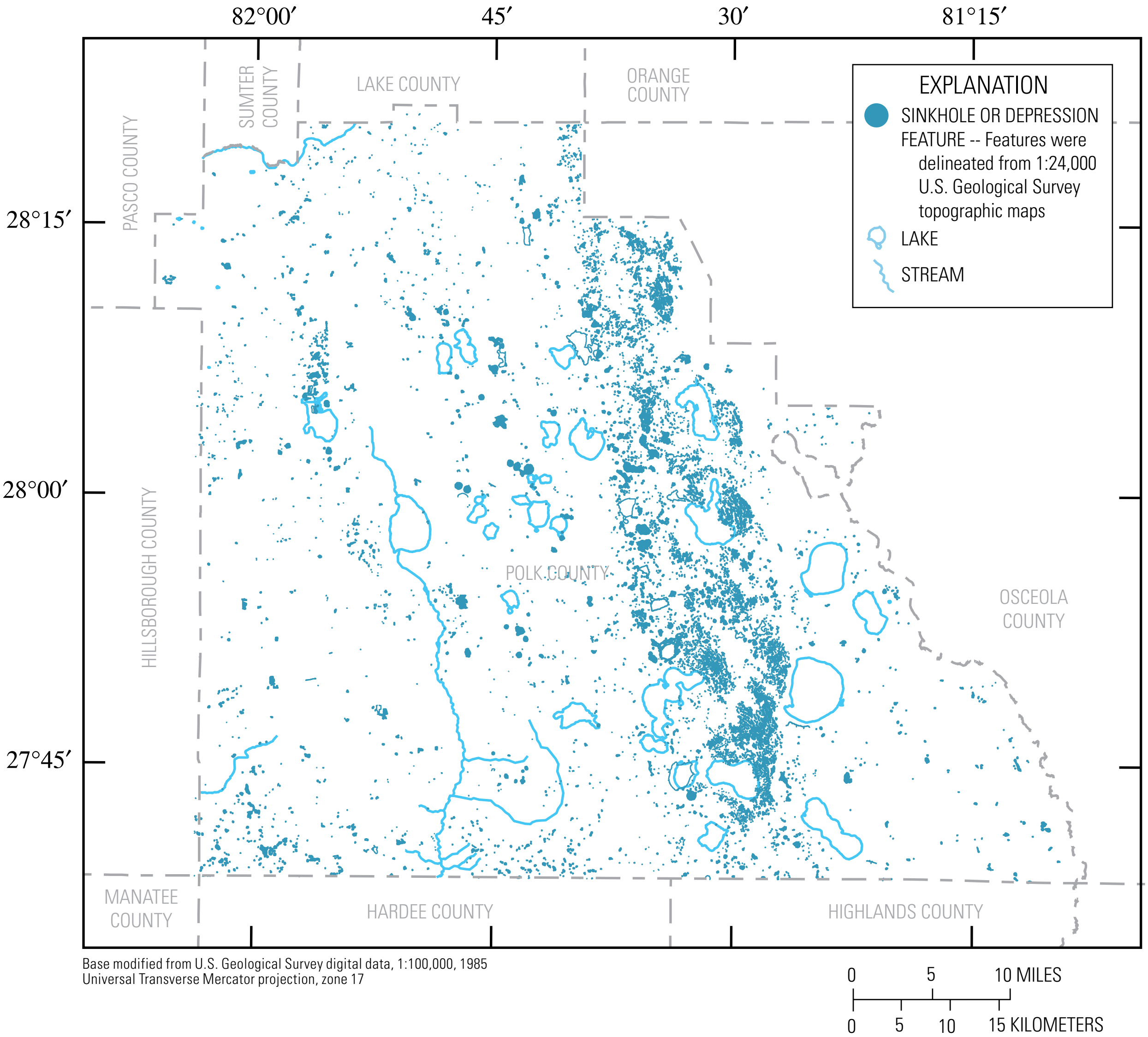


Figure 14. Location of sinkholes and depressions in Polk County.

thickness (Lewelling and others, 1998). The surficial aquifer system generally thickens toward the east, especially along the southern part of the Lake Wales Ridge where the thickness can exceed 200 ft.

The surficial aquifer system is recharged primarily by the infiltration of rainfall. Much of the rain that falls in the study area, however, drains into streams or lakes or is lost to evapotranspiration. The remaining rainfall percolates into the unsaturated surficial deposits and recharges the surficial aquifer system. In extreme eastern Polk County, the surficial aquifer system also is recharged by the upward leakage of water from the Upper Floridan aquifer where heads in the underlying Upper Floridan aquifer are higher than in the surficial aquifer system. Other sources of recharge include the land application of wastewater and reclaimed water, septic-tank effluent, irrigation of agricultural land or residential areas, and lateral ground-water inflow from adjacent areas. Water is discharged from the surficial aquifer system by evapotranspiration; by seepage into lakes, wetlands, and streams; by downward leakage to the Floridan aquifer system in areas where the potentiometric surface of the Upper Floridan aquifer is below the water table; and by pumpage.

Even though most water in the surficial aquifer system flows vertically to recharge the Upper Floridan aquifer, there is also a lateral component of flow. The lateral direction in which the water flows in the surficial aquifer generally is governed by the topography. Water in the surficial aquifer system usually flows laterally from areas of higher altitude and discharges into lakes, streams, and wetlands in areas of lower altitude. The altitude of the water table varies from one

Figure 15. Loss of water from the Peace River through underlying conduit during low-flow period, May 2004.

physiographic region to another. In low, flat, poorly drained areas, such as in the Green Swamp area in northern Polk County, the water table generally is at or near land surface throughout most of the year. The stage of the streams and lakes also represents the altitude of the water table. In areas of relatively high land-surface altitude, the water table generally is a subdued reflection of land-surface topography, but can be as much as 100 ft below land surface in some areas along the Lake Wales Ridge (Yobbi, 1996). In addition to the influence of topography, the slope of the water table varies depending on the hydrologic conditions, such as antecedent rainfall and evapotranspiration rates (Knochenmus, 1976). During wet periods when rainfall exceeds evapotranspiration, the slope of the water table steepens as the storage of water in the surficial aquifer system increases. During dry periods, the slope flattens as water drains from storage or is lost to evapotranspiration.

The altitude of the water table in the surficial aquifer system fluctuates in response to seasonal changes in precipitation and evapotranspiration. Water levels also may fluctuate in response to pumpage and may be affected by the manipulation of streamflows. Hydrographs for selected wells completed in the surficial aquifer system (fig. 20) show that water levels generally are highest in September or October, which is at or near the end of the wet season. Water levels gradually decrease to their lowest levels in April or May, which is the end of the dry season.

Although the range of water-level fluctuation in wells from the surficial aquifer system varies over the county, seasonal fluctuations of water levels average about 1 to 5 ft. The magnitude of seasonal water-table highs and lows are controlled mostly by local variations in rainfall. Rainfall events can cause sharp rises in water level in the surficial aquifer system, whereas lack of rainfall causes a gradual decline. Extended periods of drought also can affect water levels. Water levels in some wells from the surficial aquifer system declined to record or near-record lows in 2000 and 2001, when annual rainfall averaged about 21 and 27 in. below normal at the Mountain Lake and Avon Park stations, respectively. For the same amount of rainfall, however, the magnitude of water-level fluctuations may differ spatially depending on variations in permeability and porosity of the sediments, and on the depth to the water table. For example,

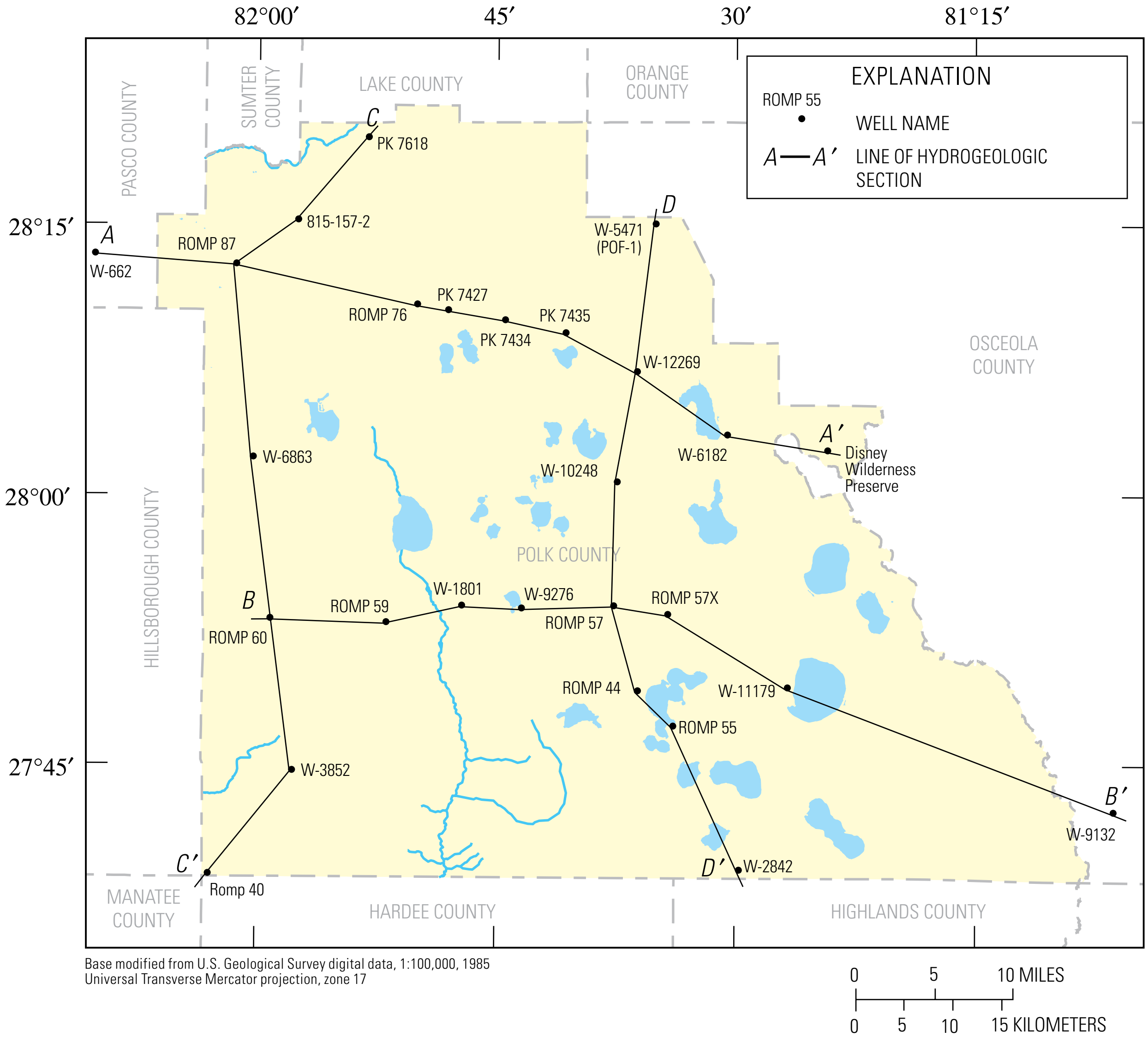


Figure 16. Location of hydrogeologic sections.

in areas where the unsaturated zone is relatively thin, water levels respond quickly to rainfall, generally peaking within 1 or 2 days following the event. In areas where the unsaturated zone is thick, water levels in the surficial aquifer system wells can take weeks before responding to rainfall (O'Reilly, 1998; Swancar and others, 2000; Knowles and others, 2002).

Hydraulic properties of the surficial aquifer system vary considerably across the county and are dependent largely upon aquifer thickness, grain-size distribution, sorting, packing, and cementation of the sediments within the aquifer. These properties are reflected in values of transmissivity, storage coefficient, hydraulic conductivity, and specific capacity that indicate the ability of an aquifer to yield water to wells. Few data are available on the hydraulic characteristics of the surficial aquifer system in Polk County. Horizontal hydraulic conductivity values determined for the surficial aquifer system from six wells in Polk County ranged from 0.3 to 55 feet per day (ft/d) (Southwest Florida Water Management District, 2000). Field horizontal hydraulic conductivity determined from slug tests performed on 30 surficial aquifer system monitoring wells in adjacent Lake County and the Ocala National Forest ranged from 0.2 to 35 ft/d (Knowles and other, 2002). Adamski and German (2004) reported field horizontal hydraulic conductivity values that ranged from 0.05 to 30 ft/d, which were determined from slug tests performed on 21 surficial aquifer system wells in adjacent Orange County. Additional hydraulic conductivity values reported in wells in adjacent southeastern Hillsborough and northwestern Hardee Counties ranged from 18 to 102 ft/d. CH2MHill (1989) reported horizontal hydraulic conductivity of the surficial

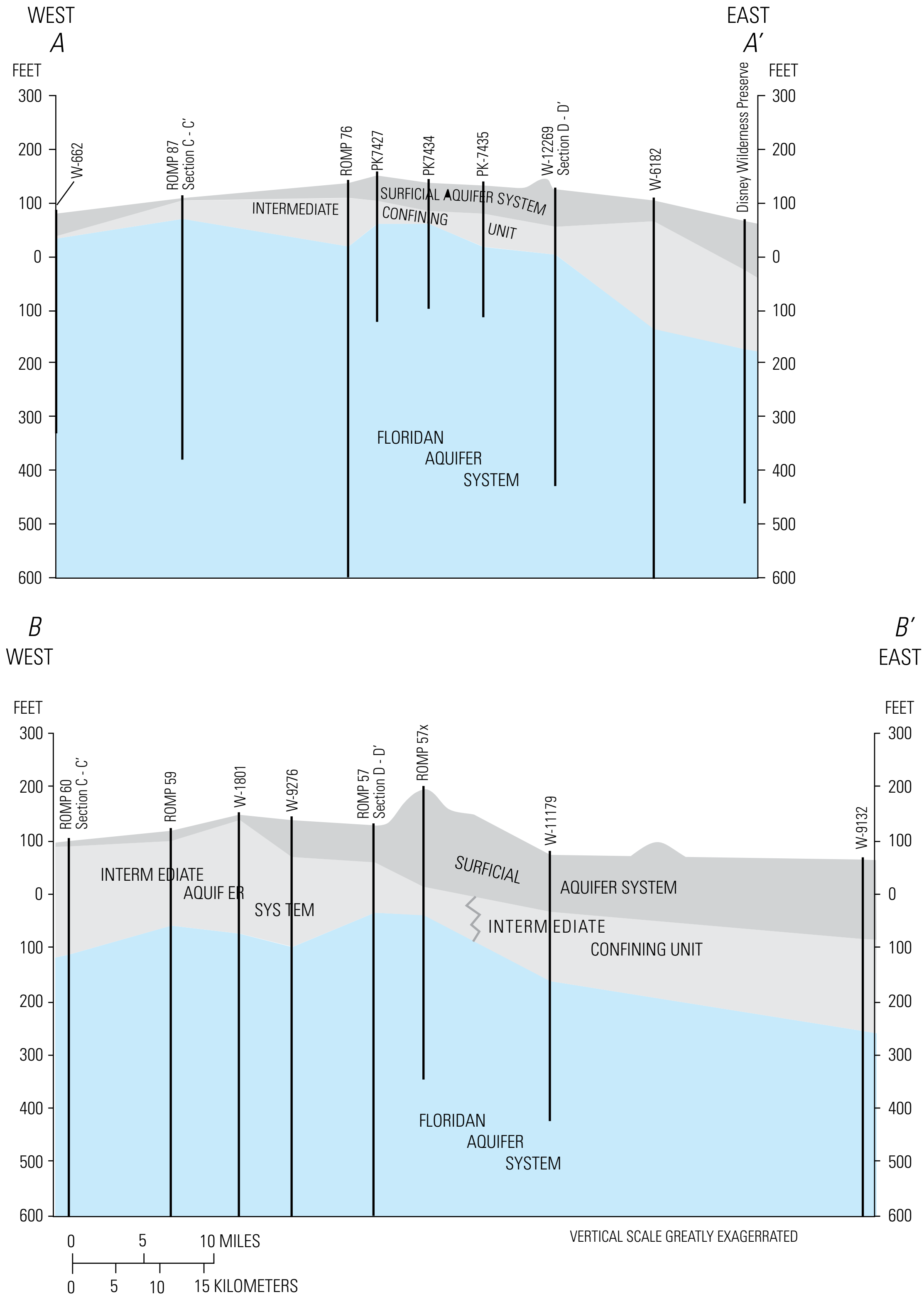


Figure 17. Generalized hydrogeologic sections *A-A′* and *B-B′* (section lines shown in fig. 16).

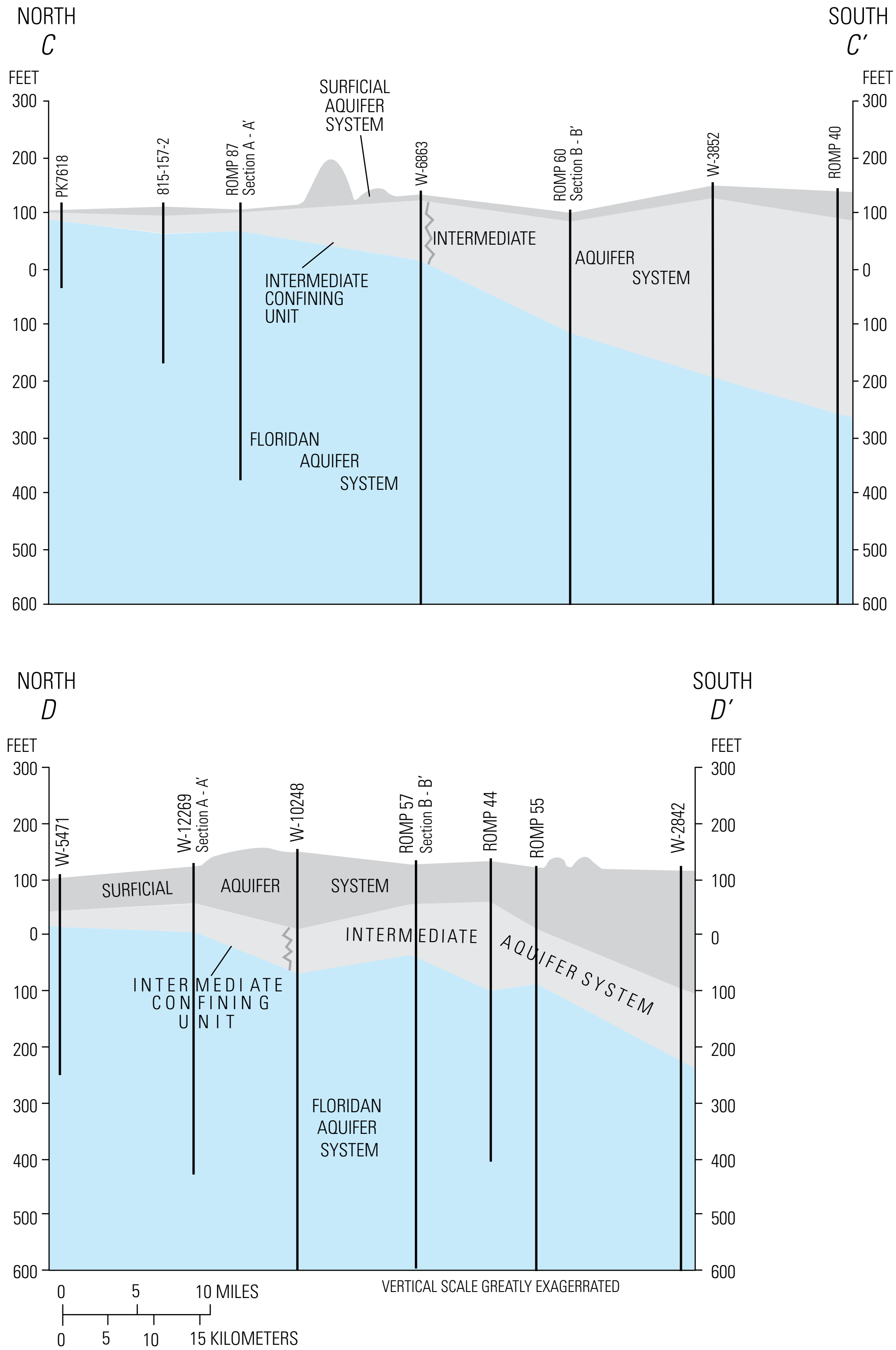


Figure 18. Generalized hydrogeologic sections *C-C′* and *D-D′* (section lines shown in fig. 16).

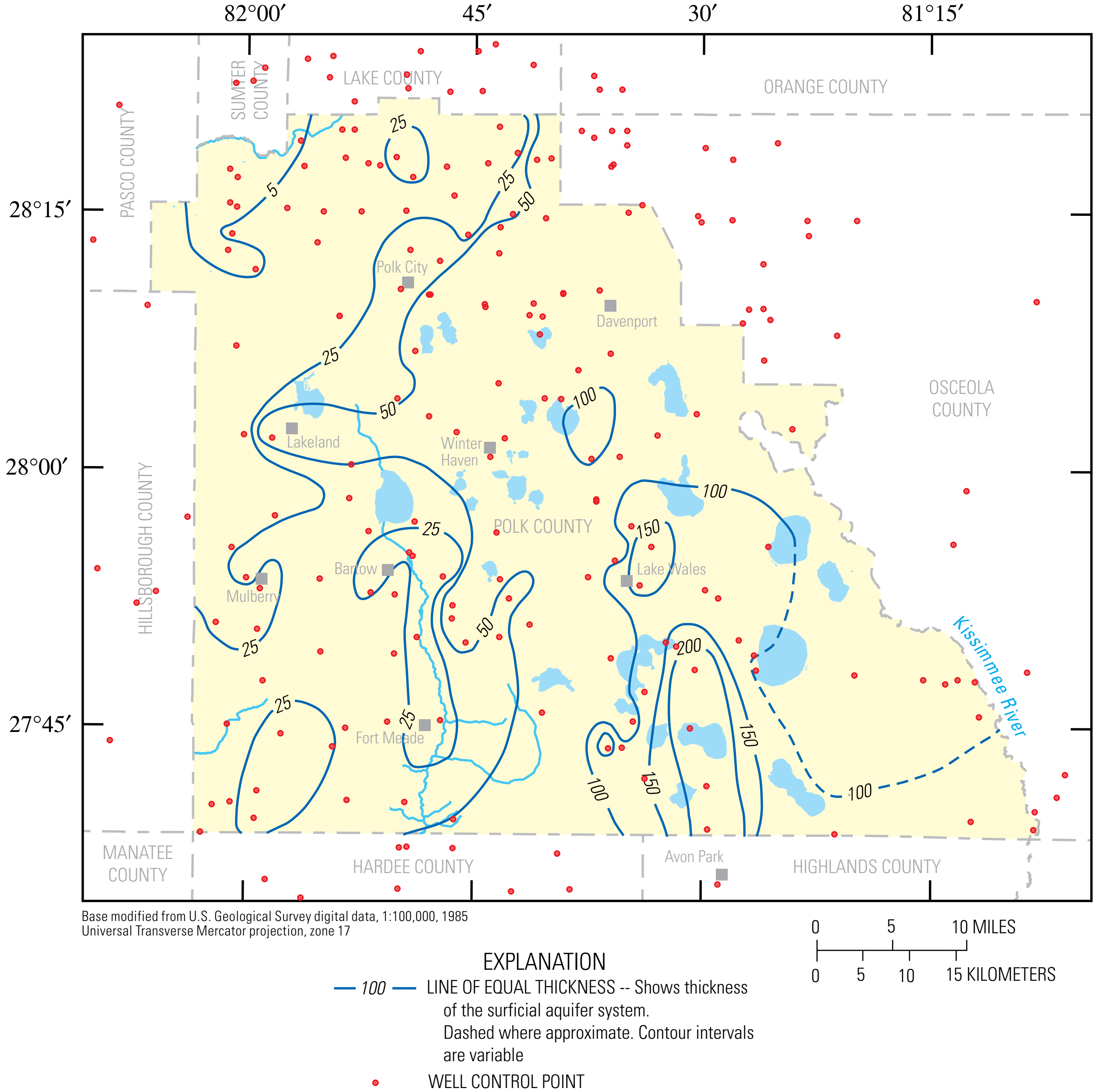


Figure 19. Generalized thickness of the surficial aquifer system.

aquifer system ranging from 25 to 160 ft/d, based on slug tests conducted in the Lake Wales Ridge in extreme southwestern Orange County. Transmissivity estimates from surficial aquifer system wells ranged from 8 to 2,400 feet squared per day (ft^2/d) in Polk County to 535 to 5,300 ft^2/d in nearby wells in southeastern Hillsborough and northwestern Hardee Counties (fig. 21). Barr (1992) determined an average specific yield of 0.25 for the surficial aquifer system in Polk County.

The surficial aquifer system is not widely used as a source of water supply because, relative to the underlying aquifers, its permeability is low, resulting in low yields. In addition, water from the surficial aquifer system often contains high concentrations of dissolved iron or can contain substantially higher concentrations of nutrients, pesticides, or bacteria than water from underlying aquifers. According to Marella (2004), less than 1 percent of the total ground water used in Polk County comes from the surficial aquifer system. Lawn irrigation and domestic supply are the main uses of water from this aquifer. Well yields depend on the thickness and permeability of the aquifer system and generally range from 10 to 50 gallons per minute (gal/min) (Barr, 1992).

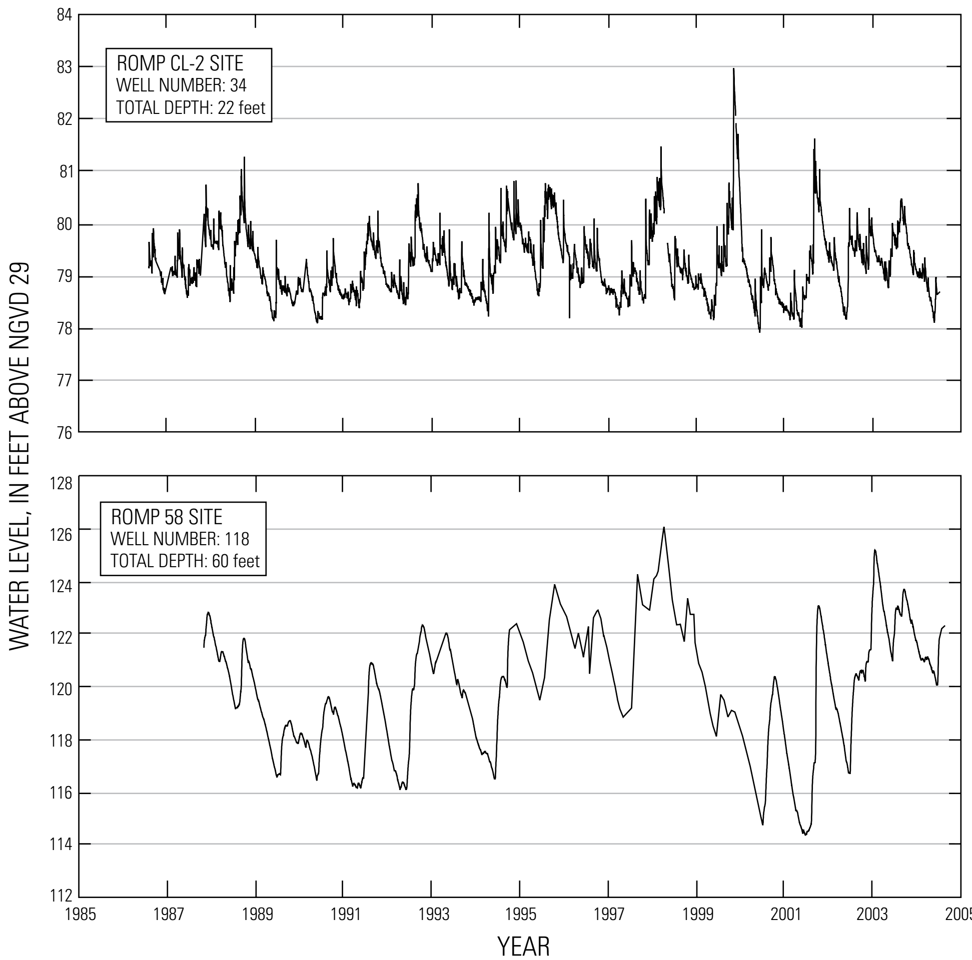


Figure 20. Water levels at selected wells tapping the surficial aquifer system (well locations shown in fig. 9).

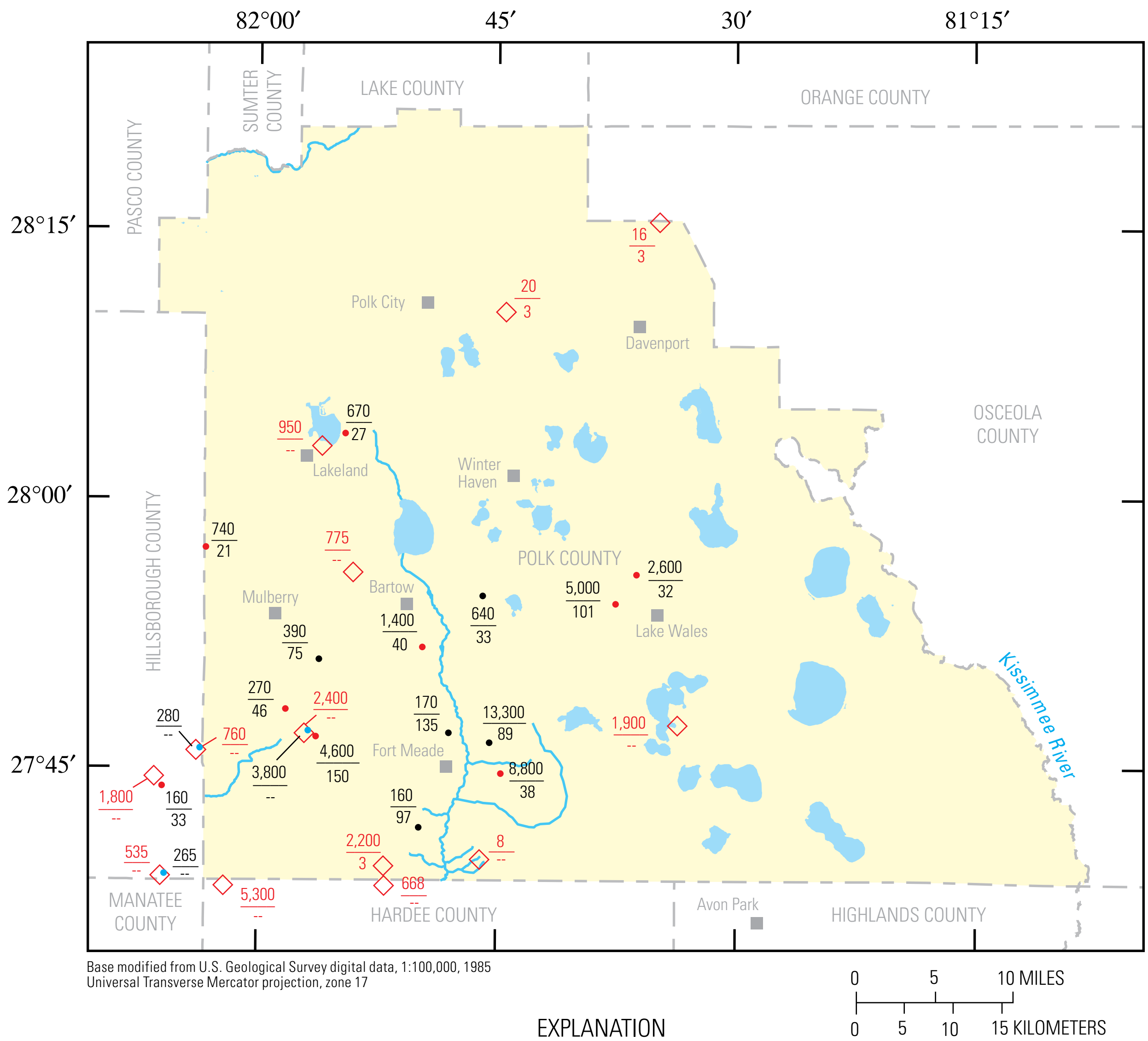
Intermediate Confining Unit and Intermediate Aquifer System

The surficial aquifer system underlies the intermediate confining unit or intermediate aquifer system of late Oligocene to Pliocene age. These deposits have varying degrees of permeability, consisting of permeable sands or carbonates, or relatively impermeable layers of clay, sandy clay, or clayey carbonates.

The intermediate confining unit is present throughout much of northern and eastern Polk County (fig. 22). The intermediate confining unit serves as a confining layer (except where breached by sinkholes) that restricts the vertical movement of water between the surficial aquifer system and the underlying Upper Floridan aquifer. The unit consists mostly of interbedded clay, silt, phosphate, and sand, but includes some limestone and dolostone of the Hawthorn Group. In many areas, the intermediate confining unit also can include low-permeability clay and silt layers of early Pliocene age.

Data from geologic and geophysical logs and from published reports were used to construct generalized maps of the top and thickness of the intermediate confining unit and intermediate aquifer system (figs. 22 and 23, respectively). The top of the intermediate confining unit (defined as the first persistent clays of Pliocene or Miocene age) ranges from about 100 ft above NGVD 29 in the northwestern part of the county to more than 50 ft below NGVD 29 in the southeastern part of the county. Thickness of the intermediate confining unit generally ranges from less than 25 ft in the northern part of the county to more than 200 ft in the southeastern part of the county. The unit is locally thin or absent in the extreme northwestern part of Polk County. Thickness of the unit is variable throughout Polk County due to past erosional processes and sinkhole formation.

The intermediate aquifer system is present in southwestern Polk County, where the intermediate confining unit grades into more permeable sediments of the Peace River and Arcadia Formations. These deposits are a source of water supply and have sufficient permeability to warrant being referred to as



EXPLANATION

20/3 ◇ TRANSMISSIVITY OF THE SURFICIAL AQUIFER SYSTEM -- Top number is transmissivity, in feet squared per day. Bottom number is open hole interval of well, in feet; -- data not available

160/33 • TRANSMISSIVITY OF ZONE 2 OF THE INTERMEDIATE AQUIFER SYSTEM -- Top number is transmissivity, in feet squared per day. Bottom number is open hole interval of well, in feet

640/33 • TRANSMISSIVITY OF ZONE 3 OF THE INTERMEDIATE AQUIFER SYSTEM -- Top number is transmissivity, in feet squared per day. Bottom number is open hole interval of well, in feet

3,800/-- • TRANSMISSIVITY OF THE INTERMEDIATE AQUIFER SYSTEM, ZONE UNKNOWN -- Top number is transmissivity, in feet squared per day. Bottom number is open hole interval of well, in feet; -- data not available

Figure 21. Transmissivity of the surficial and intermediate aquifer systems (from Pride and others, 1966; Hutchinson, 1978; and Southwest Florida Water Management District, 2000).

an aquifer system. The intermediate aquifer system includes all water-bearing and confining units between the base of the surficial aquifer system to the top of the Floridan aquifer system. Generally, the intermediate aquifer system includes an upper confining unit of clayey sand, clay, shell, and marl, and a lower confining unit of sandy clay and clayey sand (Yobbi, 1996). These confining units are highly variable both spatially and vertically. Lying between these confining units in Polk County are one or two water-producing zones, which also are separated by another confining unit. The water-producing zones are composed primarily of clastic sediments interbedded with carbonate rocks (Yobbi, 1996; Basso, 2003). As a whole, however, the entire system, including the water-bearing units, restricts vertical movement of ground water between the overlying surficial aquifer system and underlying Upper Floridan aquifer.

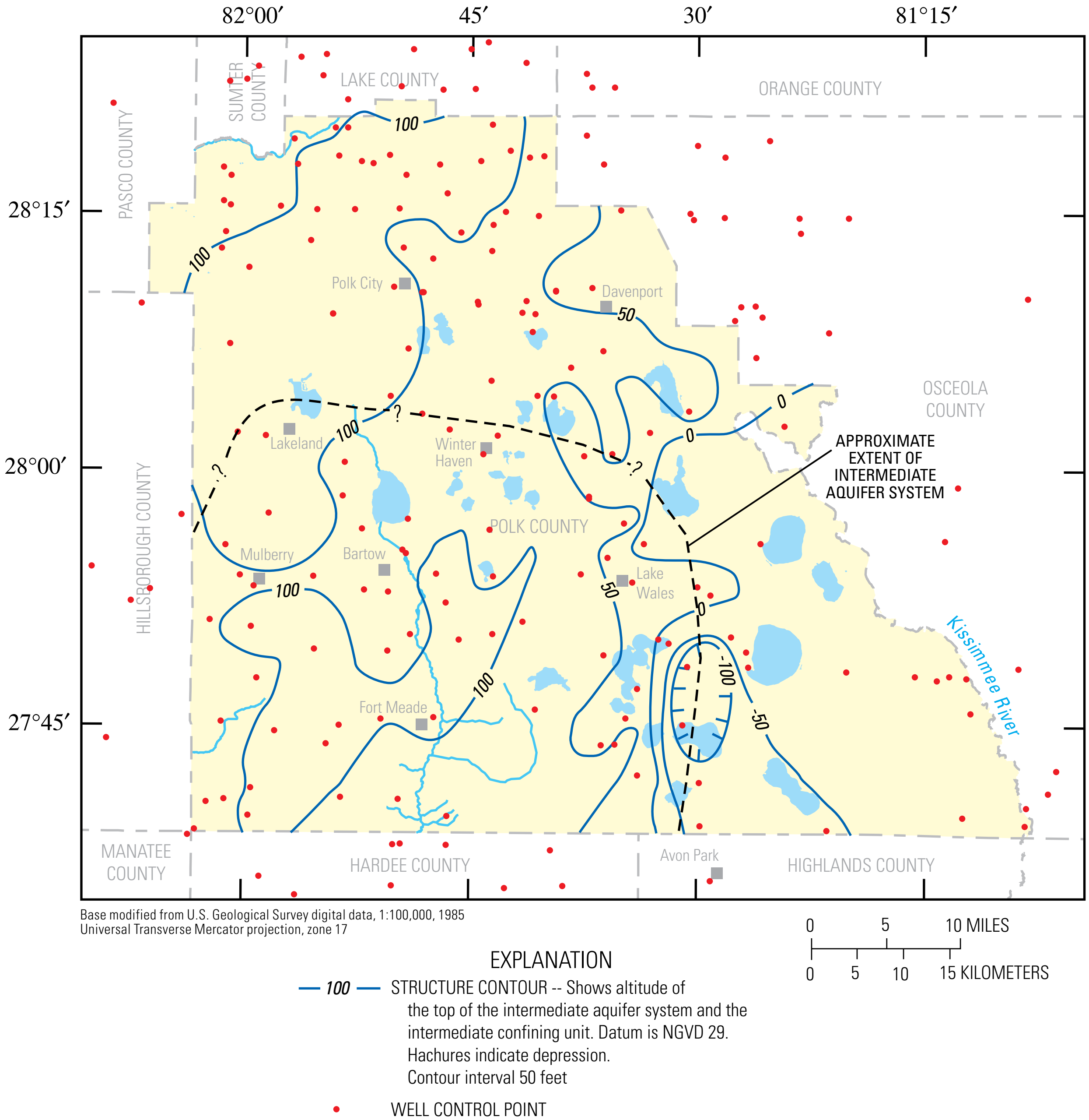


Figure 22. Generalized altitude of the top of the intermediate confining unit and intermediate aquifer system.

Basso (2003) determined that the transitional boundary where these sediments change from a confining unit to an aquifer system (with associated confining units) begins in western Polk County, extending north to Auburndale, then south to the western side of the Lake Wales Ridge (fig. 22). The lateral extent and water-bearing potential of the various zones within the intermediate aquifer system can be highly variable because the water-bearing zones can be thin in places and contain a mixture of shell, sand, and carbonate beds that are interbedded within a clay matrix. This heterogeneous sequence often results in low overall permeability of the water-bearing zones and complicates mapping the lateral extent of each zone (Basso and Hood, 2005). The line defining the extent of the aquifer is approximate, however, and only defines the area where the aquifer is most productive. Minor water-bearing units of lower transmissivity may exist outside of the boundary, but these are not shown.

The top of the intermediate aquifer system ranges from about 100 ft above to more than 100 ft below NGVD 29 (fig. 22). Thickness of the intermediate aquifer system generally ranges from nearly zero, where the permeable zones pinch out in central Polk County, to more than 300 ft in the

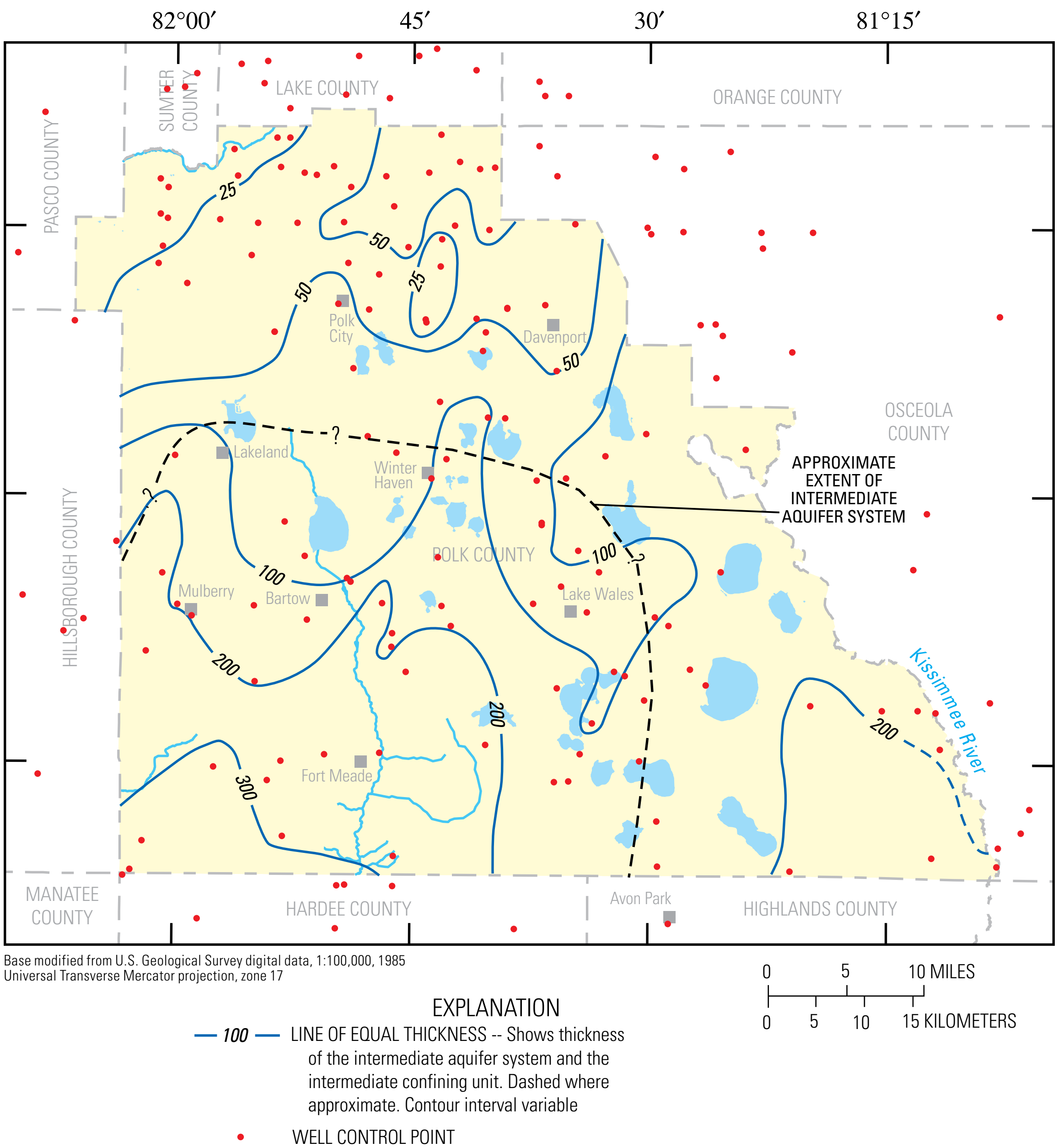


Figure 23. Generalized thickness of the intermediate confining unit and the intermediate aquifer system.

southwestern part of the county (fig. 23). The intermediate aquifer system is absent in the northern and eastern part of the county, where less-permeable sediments (intermediate confining unit) overlie the Floridan aquifer system.

Previous investigators (Barr, 1992; Torres and others, 2001; Basso, 2003) describe three water-bearing zones within the intermediate aquifer system in southwestern Florida, which were designated in descending order as PZ1, PZ2, and PZ3. Differentiation of these zones was based predominantly on visual inspection of rock cores, and was corroborated by water-level and water-quality changes and specific-capacity data collected during test drilling. Knochenmus (2006), however, renamed these vertically stratified permeable units in the intermediate aquifer system (in descending order) as Zone 1, Zone 2, and Zone 3. This report uses the nomenclature of Knochenmus (2006).

In Polk County, only two water-bearing zones are present in the intermediate aquifer system—Zones 2 and 3 (fig. 11). Investigations of these zones indicated that they are limited in vertical extent and are present at variable depths (Knochenmus, 2006). The uppermost hydrogeologic zone (Zone 2) is the most extensive aquifer within the intermediate

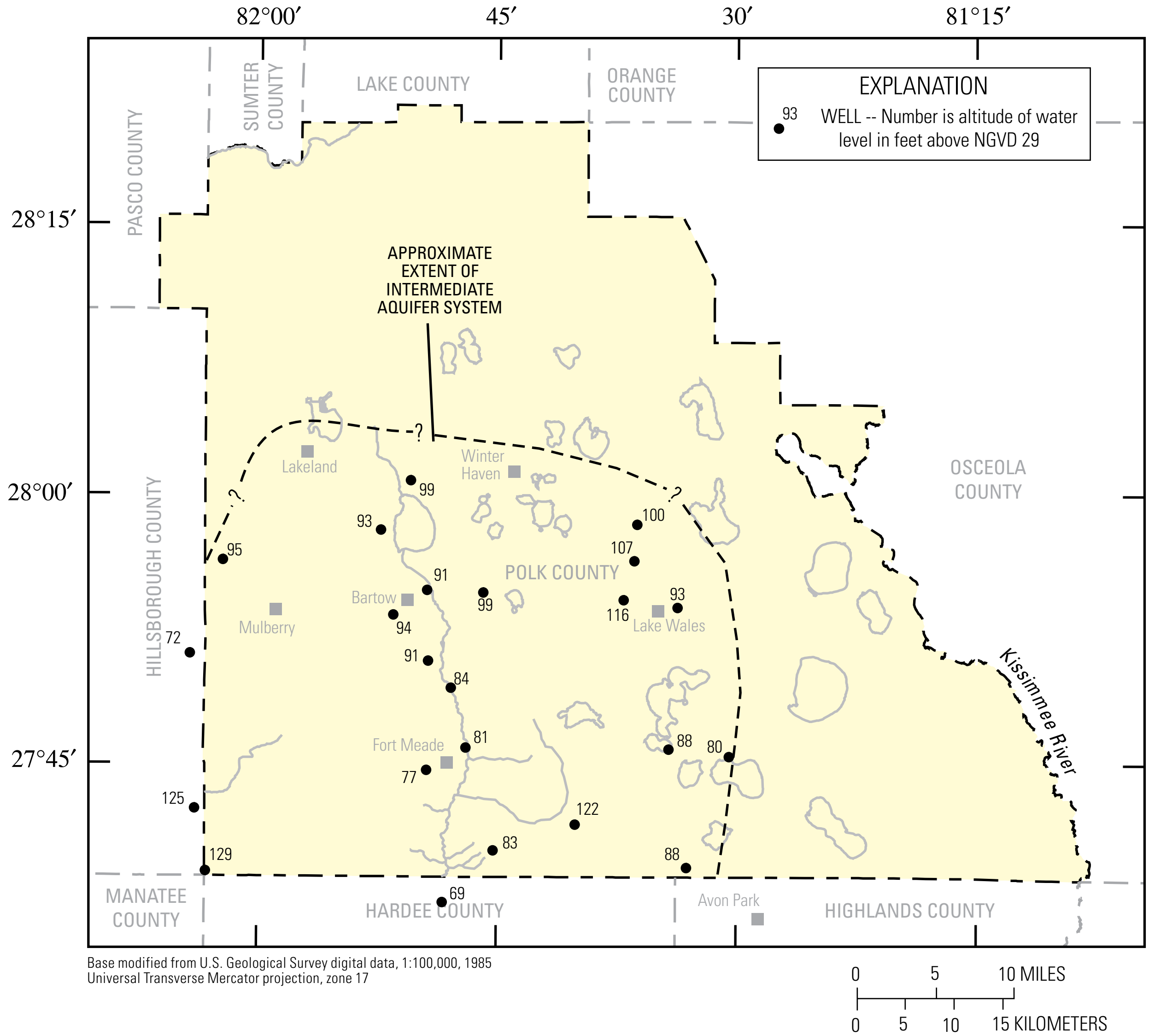


Figure 24. Water levels of the intermediate aquifer system (Zone 2), September 2003.

aquifer system in Polk County, occurring throughout much of the southwestern part of the county. This water-bearing zone is composed primarily of dolostone and limestone units within the Peace River Formation and the upper parts of the Arcadia Formation (Torres and others, 2001; Basso, 2003; Basso and Hood, 2005). Based on limited data, thickness of Zone 2 in Polk County ranges from about 24 to 104 ft (Basso and Hood, 2005). The lowermost water-bearing zone (Zone 3) is found only in the extreme south-central part of Polk County. Zone 3 consists of limestone and dolostone with varying amounts of interbedded siliciclastics within the Tampa or Nocatee Members of the Arcadia Formation (Torres and others, 2001; Basso, 2003; Basso and Hood, 2005).

Recharge to the intermediate aquifer system/intermediate confining unit primarily occurs as downward leakage from the overlying surficial aquifer system, and more directly, through sinkholes, mines, or quarries that breach the confining units. Discharge from the intermediate aquifer system occurs as pumpage; upward leakage to the surficial aquifer system, rivers, and streams; and downward leakage to the Upper Floridan aquifer.

Ground-water flow in the intermediate aquifer system in Polk County is not well understood. Little is known about the continuity of flow zones within the intermediate aquifer system. In Polk County, and in much of southwestern Florida, the lateral continuity of Zone 2, and to a lesser degree Zone 3, is highly variable because the producing zones are thin, can be poorly productive, and contain considerable clay.

Water levels for Zone 2 of the intermediate aquifer system are shown in figures 24 and 25. Because Zone 2 is made up of localized, discontinuous lenses of permeable materials that are not laterally connected, potentiometric

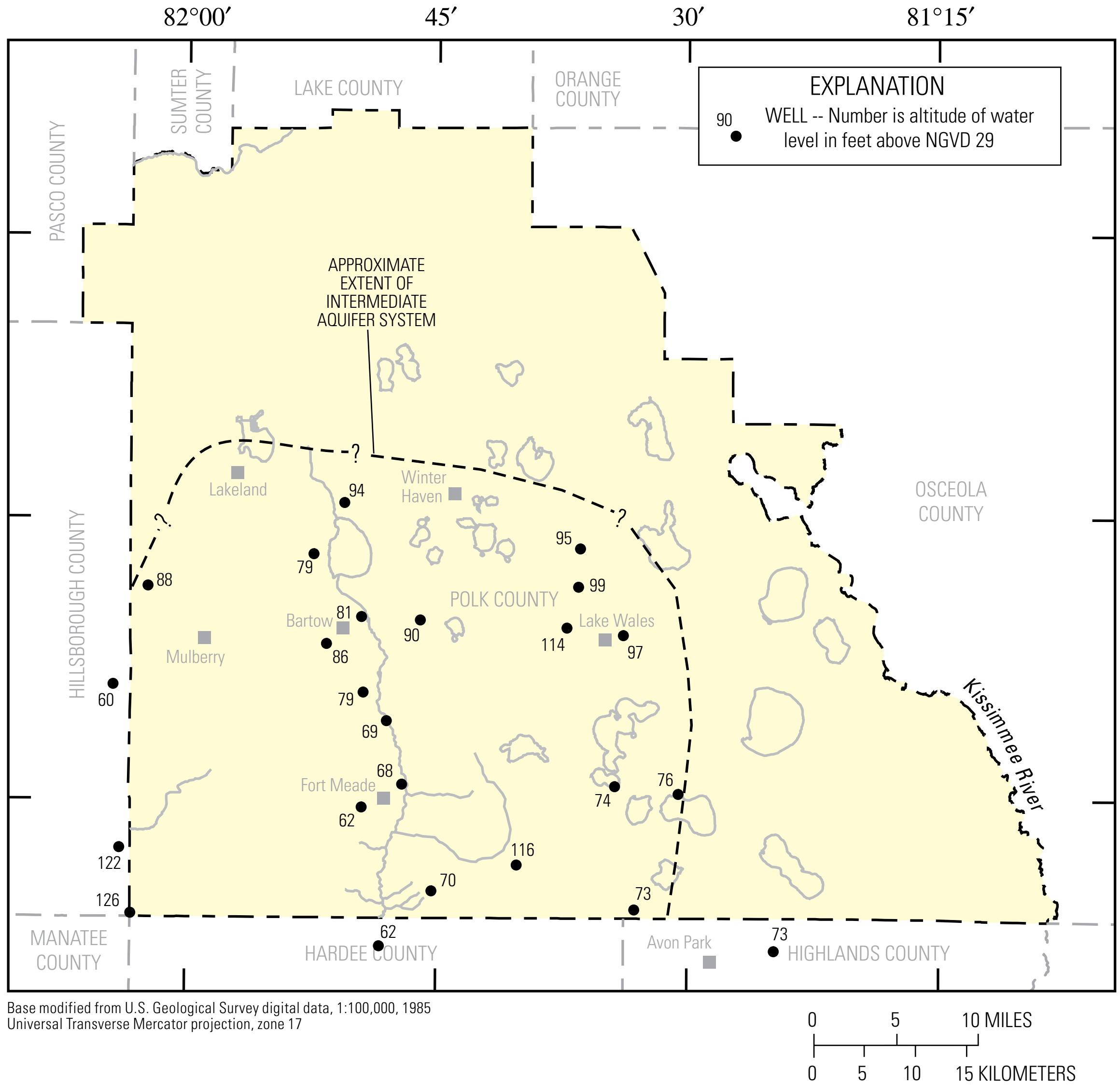


Figure 25. Water levels of the intermediate aquifer system (Zone 2), May 2004.

surface contours were not constructed. The construction of potentiometric maps implies a regional flow system, and in southern Polk County, this likely does not occur.

The water-level map of Zone 2 of the intermediate aquifer system for September 2003 (fig. 24) represents conditions near the end of the wet season, when withdrawals from the Upper Floridan aquifer for agricultural irrigation and public supply are near minimum, and water levels generally are at their highest. Water in the intermediate aquifer system is under confined conditions in most areas where the aquifer system occurs. Water levels ranged from about 129 ft above NGVD 29 in the southwestern part of the county to less than 70 ft above NGVD 29 along the Peace River near the Polk County-Hardee County line. The May 2004 water-level map (fig. 25) represents conditions when ground-water withdrawals are at their greatest and water levels are near seasonal lows. Water levels ranged from 126 ft above NGVD 29 to about 62 ft above NGVD 29. Comparison of the September and May maps shows a change in water levels that ranges from about 2 to 14 ft from one season to another. Both maps show that the highest water levels occur in the south-central and southwestern parts of the county. The lowest water levels occur in the extreme western part of the county and along the southern part of the Peace River. A hydrograph for a well open to Zone 2 is shown in figure 26.

Water-level maps were not constructed for hydrologic unit Zone 3 because of the lack of wells drilled into this zone. Because the aquifer is present in only a small part of southern Polk County, few wells are available for measurement. A hydrograph for a well open to Zone 3 is shown in figure 26.

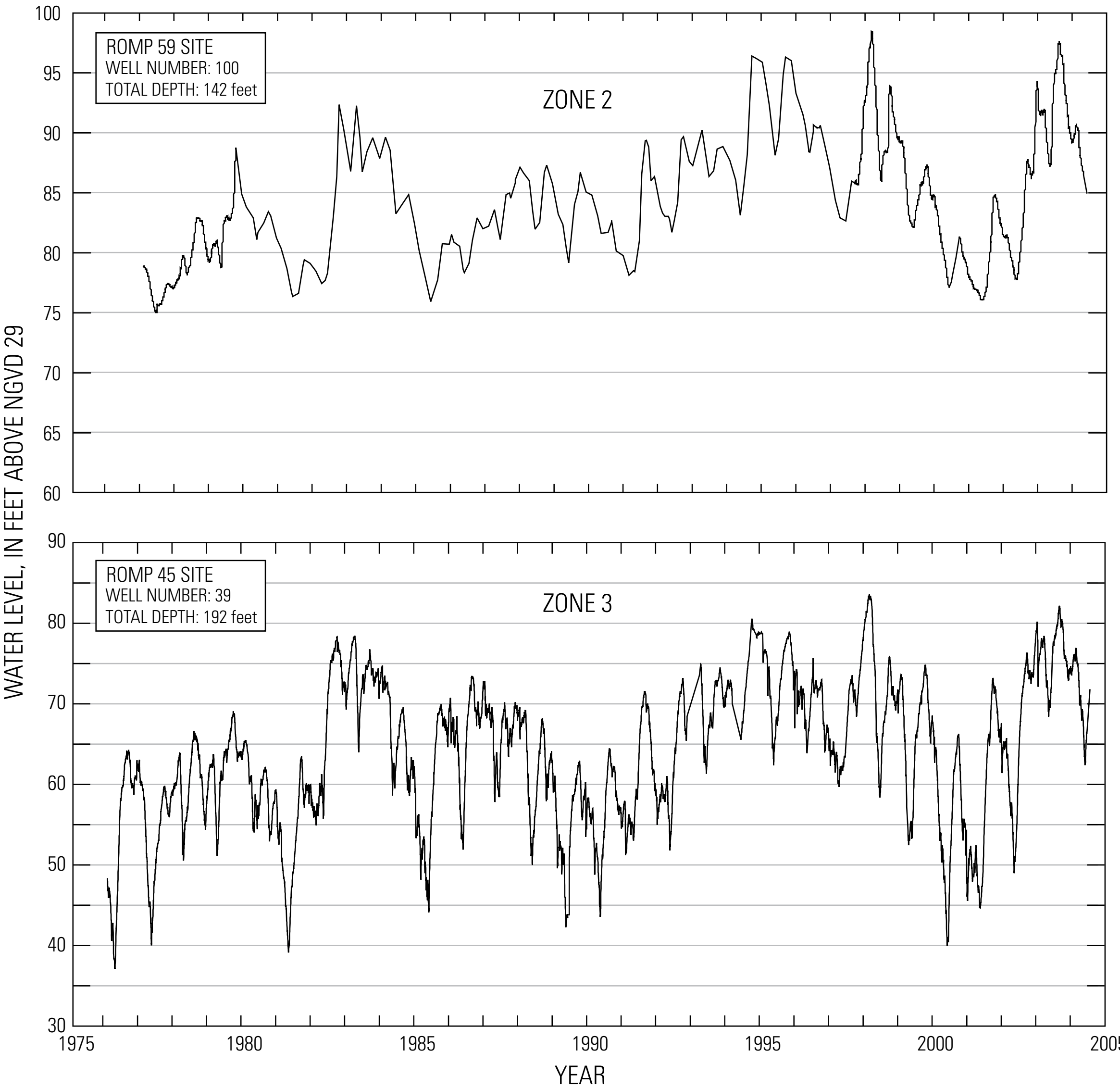


Figure 26. Water levels at selected wells tapping the intermediate aquifer system (well locations shown in fig. 9).

Data on the hydraulic properties of the intermediate aquifer system in Polk County are limited and values vary considerably because of the variable nature of the lithology (Basso, 2003). Transmissivity is variable over short distances, which is indicative of lithologic heterogeneity within the aquifer system (Yobbi, 1996). Transmissivity estimates for the permeable zones of the intermediate aquifer system in Polk County, derived from aquifer tests, ranged from 160 to 13,330 ft^2/d (fig. 21). Model-derived transmissivity values for the intermediate aquifer system in Polk County ranged from about 100 to 5,000 ft^2/d (Sepúlveda, 2002). Reported transmissivity values ranged from 1 to 8,800 ft^2/d at 43 sites (Zone 2) and from 20 to about 43,000 ft^2/d at 36 sites (Zone 3) in southwestern Florida (Knochenmus, 2006).

The intermediate aquifer system is a minor source of water supply west of the Lake Wales Ridge and south of Lakeland, where it is thicker and more permeable than in other areas of the county. Marella (2004) reported that in 2000 about 11.6 Mgal/d, or about 3 percent of the total ground water used in Polk County, was withdrawn from the intermediate aquifer system for domestic, industrial, and irrigation uses.

The confining units that occur within the intermediate aquifer system have low hydraulic conductivity values and restrict the vertical movement of water. Depending on the hydraulic gradients, however, these confining units may transmit water or allow water to leak from one water-bearing unit to another. Leakage between the intermediate aquifer system and adjacent aquifers may be upward or downward.

Field hydraulic data for the confining units are limited, and estimates of the hydraulic properties are mainly available from regional flow-model simulations. The leakance of the intermediate aquifer system is highly variable across the study area and depends on the vertical hydraulic conductivity and thickness of the confining unit. Leakance values calibrated in a regional flow model for the upper confining unit of the intermediate aquifer system ranged from $1x10^{-5}$ per day (d^{-1}) to $3x10^{-4}$ d^{-1}, and from $7x10^{-6}$ d^{-1} to more than $1x10^{-4}$ d^{-1} for the lower confining unit (Ryder, 1985). In another model, simulated leakance of the upper confining unit of the intermediate aquifer system ranged from $1x10^{-6}$ d^{-1} to $6x10^{-4}$ d^{-1} and from $1x10^{-6}$ d^{-1} to $1x10^{-3}$ d^{-1} for the lower confining unit (Sepúlveda, 2002). Calibrated leakance for the upper confining unit along the Lake Wales Ridge in Polk County ranged from $1x10^{-5}$ d^{-1} to $1x10^{-3}$ d^{-1} and from $1x10^{-5}$ d^{-1} to $5x10^{-4}$ d^{-1} for the lower confining unit (Yobbi, 1996). Model-derived leakance for the entire intermediate confining unit in Polk County ranged from about $1x10^{-5}$ d^{-1} to $3x10^{-4}$ d^{-1} (Tibbals, 1990). Leakance values are highest along the ridges and the northern part of the county where the confining beds are relatively thin, permeable, or breached by karst features. The lowest values occur in the southern part of the county where karst features are less numerous and confining units are relatively thick or have lower permeability.

Floridan Aquifer System

The Floridan aquifer system, which is the principal source of ground water in Polk County, underlies all of Florida and parts of Alabama, Georgia, and South Carolina. The Floridan aquifer system, as defined by Miller (1986), is a vertically continuous sequence of carbonate rocks of generally high permeability that are mostly of Tertiary age. The rocks are hydraulically connected in varying degrees, and their permeability generally is one order to several orders of magnitude greater than that of the units bounding the system above and below. The top of the Floridan aquifer system usually coincides with the top of the Suwannee Limestone, which is present throughout Polk County except in the northern and extreme eastern parts of the county. Where the Suwannee Limestone is absent, the top of the aquifer is the Ocala Limestone. The base of the system is defined by the first occurrence of relatively impermeable, persistent beds of gypsum or anhydrite found in the upper part of the Paleocene-age Cedar Keys Formation. Thickness of the Floridan aquifer system ranges from about 2,400 to 3,100 ft in Polk County (Miller, 1986). The aquifer system includes the following stratigraphic units in descending order: the Suwannee Limestone, the Ocala Limestone, the Avon Park Formation, the Oldsmar Formation, and the upper part of the Cedar Keys Formation (fig. 11).

The Floridan aquifer system is divided into two aquifers of relatively high permeability—the Upper Floridan and Lower Floridan aquifers (fig. 11). In Polk County, the Upper Floridan aquifer contains freshwater, and the Lower Floridan aquifer contains more mineralized water. These aquifers are separated by less-permeable units called the middle semiconfining and middle confining units, both of which restrict the vertical movement of water.

Upper Floridan Aquifer

The geologic units that compose the Upper Floridan aquifer include the Suwannee Limestone, the Ocala Limestone, and the upper part of the Avon Park Formation (fig. 11). A generalized structure contour map of the altitude of the top of the Upper Floridan aquifer (top of the Floridan aquifer system) is shown in figure 27. The altitude of the top of the Upper Floridan aquifer is highest in the northwestern part of the county, where it is more than 50 ft above NGVD 29. In a few areas of the Green Swamp in extreme northwestern Polk County, the aquifer is at or within a few feet of land surface (Pride and others, 1966; Stewart, 1966). The top of the aquifer dips toward the south, to more than 250 ft below NGVD 29 in both the extreme southeastern and southwestern parts of the county. The surface of the Upper Floridan aquifer is the remnant of an ancient karst plain, and generally exhibits considerable irregularity throughout the county. Sinkhole-type depressions on the surface of the aquifer are common. Thickness of the Upper Floridan aquifer ranges from about 300 ft in eastern Polk County to more than 1,200 ft in the southwestern part of the county (Ryder, 1985; Miller, 1986; Basso, 2003). The base of the aquifer is considered to be the first occurrence of vertically persistent intergranular evaporites in the Avon Park Formation.

Permeability of the Upper Floridan aquifer is not uniform with depth. Reports describing well drilling and testing indicate the presence of two important water-bearing zones separated by a less-permeable zone. In the northern and eastern parts of Polk County, where the Suwannee Limestone has been removed by erosion, the lower part of the Ocala Limestone generally is the uppermost permeable zone of the Upper Floridan aquifer. Permeable intervals in this area are more dolomitic; may be granular in texture; contain solution features such as caverns, cavities, and pipes; and yield moderate amounts of water to wells (Pride and other, 1966; Stewart, 1966). In much of the county where the Suwannee Limestone is present, the uppermost permeable zone of the Upper Floridan aquifer generally coincides with the Suwannee Limestone (Stewart, 1966; Basso, 2003). The permeability of the Suwannee Limestone appears to be primarily intergranular, with some minor contribution due from moldic porosity (Basso, 2003). In parts of the county, the Suwannee Limestone may contain solution cavities and conduits due to the thinning of the overlying confining unit (Basso, 2003). Wells drilled into the Suwannee Limestone generally yield more water than those wells drilled into the Ocala Limestone; therefore, many domestic and small irrigation wells tap this zone for water supply.

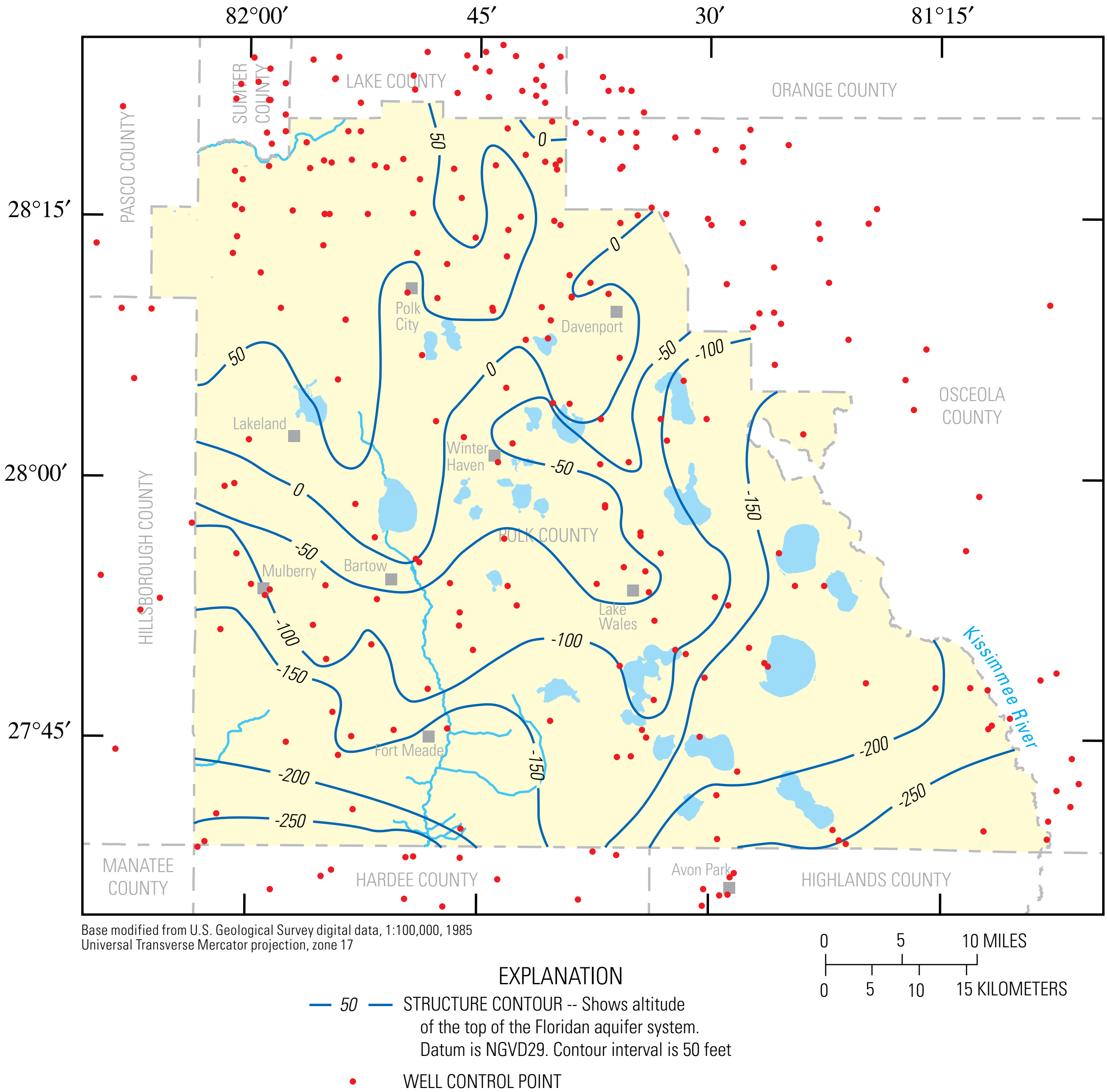


Figure 27. Altitude of the top of the Floridan aquifer system (modified from Shaw and Trost, 1984; Schiner, 1993; Knowles and others, 2002; Arthur and others, 2007).

Underlying the Suwannee Limestone is a semiconfining unit that generally corresponds stratigraphically to all or parts (mostly the upper part) of the Ocala Limestone, but in some areas, also may include the extreme upper part of the Avon Park Formation (Basso, 2003). The unit is composed of a soft, chalky, fine-grained foraminiferal calcilutite and calcarenitic limestone (Basso, 2003).

The lowermost permeable zone of the Upper Floridan aquifer occurs in the hard, fractured dolostone within the Avon Park Formation, and is the major source of water in the Upper Floridan aquifer. Yields from large diameter wells completed into this zone can range from 2,000 to 3,000 gal/min (Basso, 2003). The permeability of the upper Avon Park Formation is due primarily to fractures and interconnecting solution cavities. The top of the lowermost permeable zone generally is marked by an increase in formation resistivity due to the increasing presence of dolostone, and by an increase in the occurrence of fractures and solution cavities within the carbonates, as indicated by caliper logs (O'Reilly and others, 2002; Basso, 2003).

Spechler and Halford (2001) also showed that two water-bearing zones exist in the Upper Floridan aquifer in east-central Florida. Flow logs from wells indicate that two distinct zones of different permeabilities (referred to in their report as Zones A and B) exist in the Upper Floridan aquifer. Zone A, which corresponds to about the upper two-thirds of the aquifer, generally coincides with the Ocala Limestone. The Suwannee Limestone is not present in most of east-central Florida. Zone B is equivalent to about the lower one-third of the Upper Floridan aquifer and generally coincides with the upper part of the Avon Park Formation. The upper part of the Avon Park Formation in east-central Florida, like in Polk County, generally consists of hard, dense dolostone with abundant fractures and other secondary porosity features and is a major source of water in the Upper Floridan aquifer. Hydraulic conductivities in Zone B range from 3 to more than 10 times greater than the hydraulic conductivities in Zone A (Spechler and Halford, 2001).

Transmissivity estimates for the Upper Floridan aquifer vary widely across Polk County. Variations from one aquifer test to another can be attributed to differences in open-hole intervals and well depths, and to the heterogeneous and anisotropic nature of the carbonate aquifer system. Variations in the hydraulic characteristics of the rock strata within the Floridan aquifer system are complex and are closely related to the geologic framework of the system. The porosity and permeability of the rock strata result from a combination of: (1) the original texture of the rock; (2) processes that have acted on the rock, such as dolomization and recrystalization; (3) joints, fractures, and other structural deformities; and (4) mineral dissolution and precipitation (Schiner, 1993). Water moves through porous limestone and dolostone, and the movement is enhanced by fractures and solution features.

Transmissivity estimates for the Upper Floridan aquifer in Polk County, as determined from aquifer and specific capacity tests, range from about 1,200 to 179,000 ft^2/d (fig. 28). Model-derived transmissivity values range from 10,000 to 500,000 ft^2/d (Sepúlveda, 2002). Model-derived transmissivity values determined by Yobbi (1996) in the vicinity of the Lake Wales Ridge in Polk County range from 12,000 to 130,000 ft^2/d. Even though these ranges of values are similar, model-derived transmissivity values generally are higher than those obtained from aquifer tests. This is due to the highly heterogeneous and anisotropic nature of the cavernous limestone and dolostone and because the wells used in aquifer tests generally tap less than the full thickness of the Upper Floridan aquifer (Yobbi, 1996).

Transmissivity values generally are lowest in the northeastern part of the county and highest in the central and southwestern part of the county. According to Pride and others (1966) and Yobbi (1996), the lower transmissivity values in the northern part of the county and in some areas along the Lake Wales Ridge can be attributed to the infilling of fractures and cavities in the carbonate units of the Upper Floridan aquifer by siliciclastic materials.

Middle Semiconfining Unit and Middle Confining Unit

In much of Polk County, the Upper and Lower Floridan aquifers are separated by the middle semiconfining unit and a middle confining unit. The middle semiconfining unit is a sequence of softer, relatively less-permeable limestone and dolomitic limestone of variable thickness. This unit is considered semiconfining because it has lower porosity and lacks abundant secondary solution features. The middle semiconfining unit (equivalent to the middle confining unit I as mapped by Miller, 1986) generally is present in the middle one-third of the Avon Park Formation. It is present in the eastern part of the county and is believed to extend into much of the western part (Miller, 1986). Although individual zones can yield moderate amounts of water, flowmeter logs of wells located to the northeast in Orange County indicate that this unit is considerably less transmissive than either the Upper or Lower Floridan aquifers (O’Reilly and others, 2002). Data points for estimating the extent and thickness of the middle semiconfining unit are nearly non-existent in Polk County. Thickness of this unit in extreme northeastern Polk County was estimated to be less than 400 ft, based on data collected in adjacent Osceola and Orange Counties (O’Reilly and others, 2002). Thickness of the unit was estimated to be 507 ft at the Polk City test well (well 217) (O’Reilly and others, 2002) and about 360 ft at the Regional Observation and Monitoring-Well Program (ROMP) well (ROMP 74X, well 203) (Gates, 2003). O’Reilly and others (2002) observed from geophysical logs in east-central Florida that the top of the unit generally is recognized by a sharp decrease in formation resistivity compared to the overlying fractured dolostone, and by a sharp decrease in flow as observed on flowmeter logs. Caliper logs also show an enlarged borehole when penetrating this zone, indicating that the rock is soft and contains few fractures or cavities.

In west-central Florida, including all of Polk County, there is a separate and distinct second confining unit underlying the middle semiconfining unit. The unit, called the middle confining unit (middle confining unit II of Miller, 1986), is composed primarily of anhydritic and gypsiferous dolostone and dolomitic limestone. This unit generally corresponds to the lower part of the Avon Park Formation and is considerably less permeable than the overlying middle semiconfining unit. It forms an essentially non-leaky confining bed that separates freshwater in the Upper Floridan aquifer from the more mineralized water in the underlying rocks. The top of the middle confining unit, generally defined as the first occurrence of evaporites, ranges from less than 900 ft below NGVD 29 in parts of northern Polk County to more than 1,300 ft below NGVD 29 in the southern part of the county (fig. 29).

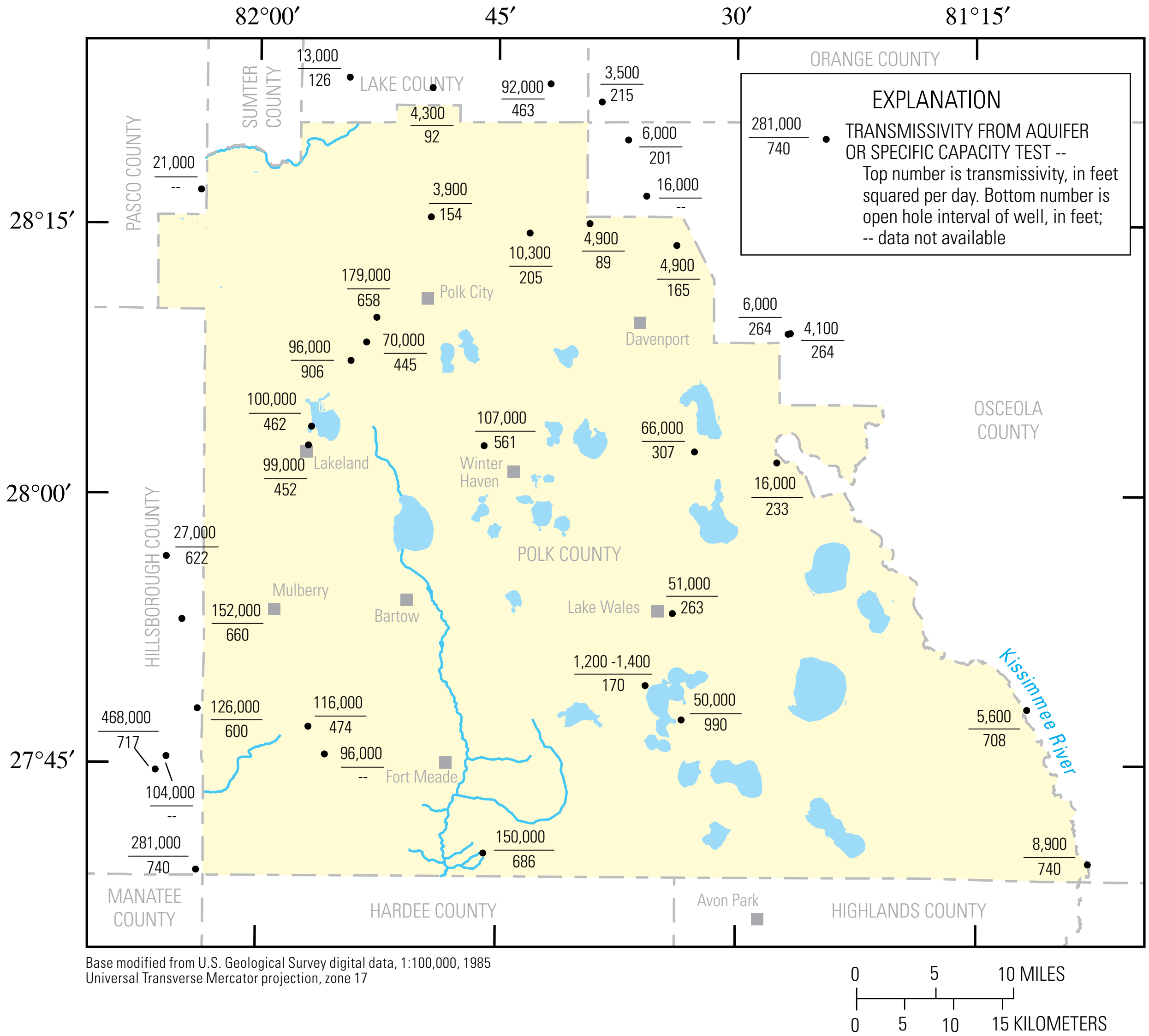


Figure 28. Transmissivity of the Upper Floridan aquifer (from Pride and others, 1966; Shaw and Trost, 1984; Szell, 1993; and Southwest Florida Water Management District, 2000).

The thickness of the middle confining unit ranges from about 100 to 200 ft in much of southern Polk County to as much as 762 ft at Polk City in northern Polk County (Miller, 1986; O'Reilly and others, 2002). The anomalously thick area occurring in northern Polk County is thought to have been caused by incomplete dissolution of evaporites where the deep flow system is very sluggish (Miller, 1986). Areas where the evaporites are thinner represent areas where more vigorously circulating waters have dissolved much of the unit's interstitial evaporitic material, thereby increasing porosity and permeability.

Little information is available on the hydraulic properties of the middle confining unit in Polk County. Hydraulic testing of the carbonate rocks containing evaporites in the intergranular pore spaces indicates that they are extremely low in permeability (Wolansky and others, 1979). Horizontal hydraulic conductivities from cores taken at different depths within the middle confining unit at the Polk City test well generally ranged from about 0.000024 to 0.90 ft/d (Navoy, 1986). Two samples taken from this interval, however, had hydraulic conductivities of 6.6 and 19.0 ft/d, indicating that isolated zones of higher hydraulic conductivity exist within this confining unit. Horizontal hydraulic conductivity values range from 0.002 to 0.04 ft/d, based on packer tests conducted on this zone in Hillsborough, Manatee, and Sarasota Counties (Basso, 2003). No hydraulic data are available for the middle semiconfining unit in Polk County.

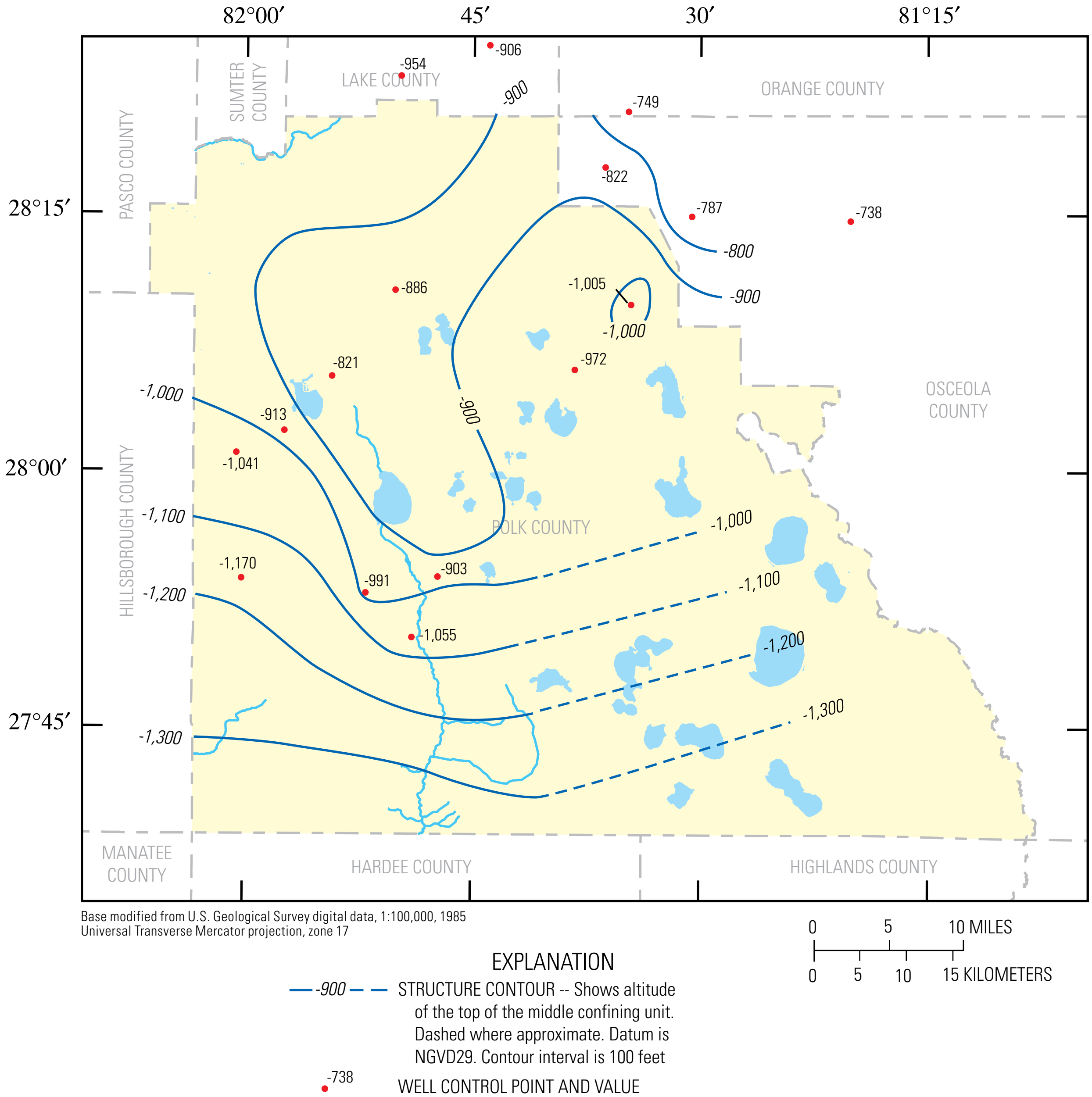


Figure 29. Altitude of the top of the middle confining unit (modified from Wolansky and others, 1979; Miller, 1986; O'Reilly and others, 2002; and Basso, 2003).

Lower Floridan Aquifer

The Lower Floridan aquifer is present throughout Polk County and underlies the middle confining unit. Because the water within the Lower Floridan aquifer is thought to be very mineralized throughout much of the county, and sufficient amounts of water can be obtained from the Upper Floridan aquifer, few wells have been drilled into the Lower Floridan aquifer. Consequently, little is known of the hydrologic properties or the chemical quality of water of the Lower Floridan aquifer within Polk County.

The Lower Floridan aquifer generally is present within the lower part of the Avon Park Formation, the Oldsmar Formation, and the upper part of the Cedar Keys Formation (fig. 11). In east-central Florida, the Lower Floridan aquifer is highly productive and is composed of alternating beds of limestone and fractured dolostone (O'Reilly and others, 2002). Permeability within this zone mostly is related to secondary porosity developed along bedding planes, joints, and fractures. In much of Polk County, the Lower Floridan is composed of alternating beds of limestone and dolostone containing intergranular evaporites and generally is not as productive.

Altitudes of the top of the Lower Floridan aquifer are estimated to range from 1,000 ft to more than 1,600 ft below NGVD 29 (Miller, 1986). At well 203 (ROMP 74X), located in Davenport, a permeable unit delineated as part of the Lower Floridan aquifer was encountered at 1,165 ft below NGVD 29 (Gates, 2003). The permeable zone consists of hard, fractured dolostone without the presence of gypsum. At Polk City, a test well penetrated the Lower Floridan aquifer at a depth of 1,648 ft below NGVD 29 (O'Reilly and others, 2002). In a test well completed in 2005 in Lake County near the four corner region of northeastern Polk County, CH2MHILL (2005) determined that the top of the Lower Floridan aquifer was at about 1,030 ft below NGVD 29. Thickness of the aquifer was estimated to range from about 1,100 to 1,800 ft across the study area (Miller, 1986).

In east-central Florida, the top of the Lower Floridan aquifer generally is marked on geophysical logs by an increase in formational resistivity due to the increased presence of dolostone (O'Reilly and others, 2002). A noticeable increase in flow to a well due to the presence of fractures and solution cavities also commonly marks the contact between the Lower Floridan aquifer and overlying unit (O'Reilly and others, 2002).

Few data are available to describe the hydraulic properties of the Lower Floridan aquifer in Polk County. In southwestern Orange County, where the transmissivity of the aquifer has been enhanced by secondary porosity features, transmissivity estimates exceeding 500,000 ft^2/d were reported from several aquifer tests (Lichtler and others, 1968; Szell, 1993). In west-central Florida, the unit is of relatively low permeability because of the presence of intergranular gypsum.

Sub-Floridan Confining Unit

Underlying the Lower Floridan aquifer are low-permeability dolostone and limestone containing abundant evaporite minerals that form the sub-Floridan confining unit. The top of this unit is defined as the uppermost stratigraphic occurrence of persistent evaporite deposits in the upper part of the Cedar Keys Formation (Miller, 1986). These beds of very low permeability serve as the hydraulic base of the Floridan aquifer system and range in altitude from about 2,200 ft below NGVD 29 in northern Polk County to about 3,400 ft below NGVD 29 in southwestern Polk County (O'Reilly and others, 2002; Sepúlveda, 2002). Test drilling, however, indicates that, based on hydraulic properties, the sub-Floridan confining unit may be considerably shallower than mapped by Miller (1986). At a site in south-central Orange County, a gypsiferous dolostone was first encountered at 2,150 ft below NGVD 29 and substantial amounts at 2,240 ft below NGVD 29 (McGurk and Sego, 1999). Packer tests completed in the test hole indicated the presence of low-permeability rocks below a depth of 1,990 ft (McGurk and Sego, 1999). Another test well drilled in south-central Orange County found gypsiferous dolostone at about 2,160 ft below NGVD 29 (Boyle Engineering Corporation, 1995). Decreasing permeability, however, was reported in the dolostone and limestone below a depth of 1,960 ft below NGVD 29.

Ground-Water Flow System

The recharge and discharge areas of Polk County and ground-water flow patterns in the Upper Floridan aquifer (based on potentiometric surface maps) are discussed herein.

Recharge and Discharge

Recharge areas of the Upper Floridan aquifer cover much of Polk County. These areas include well-drained and poorly drained soils, swamps, closed-basin lakes, and sinkholes. The Upper Floridan aquifer is recharged by the downward movement of water through the surficial aquifer system and intermediate confining unit or intermediate aquifer system. The rate of recharge varies with the vertical hydraulic conductivity, the thickness of the surficial aquifer system and underlying units, and the magnitude of the downward head gradient.

Estimated rates of recharge from the surficial aquifer system to the Upper Floridan aquifer range from 0 to greater than 10 in/yr in Polk County (Stewart, 1980; Ryder, 1985; Tibbals, 1990; Yobbi, 1996). Highest rates of recharge occur on the Lake Wales Ridge with somewhat lower rates along adjacent ridges. These karst ridge areas are characterized by deep water tables, an intermediate confining unit that is relatively thin or permeable, and a downward hydraulic gradient. These areas also include numerous closed basins where the intermediate confining unit has been breached by sinkholes and the infiltration rate of ground water to the underlying Upper Florida aquifer is high. Very low to moderate recharge rates occur in areas where the underlying confining unit is thicker or less permeable, such as in southwestern Polk County. Very low to moderate recharge rates also occur in areas where the confining unit may be thin or absent, but where the water table and the potentiometric surface of the Floridan aquifer are similar, such as in the Green Swamp area.

Areas of discharge from the Upper Floridan aquifer occur where the altitude of the potentiometric surface is normally above the water table in the surficial aquifer system. In some areas, the Upper Floridan aquifer potentiometric surface is above land surface. Areas of discharge occur primarily east of the Lake Wales Ridge and along parts of the Kissimmee River (fig. 30). Estimated discharge by diffuse upward leakage from the Upper Floridan to the surficial aquifer system ranges from about 0.5 to 6 in/yr (Tibbals, 1990).

Potentiometric Surface

The potentiometric surface maps used to evaluate ground-water flow patterns in the Upper Florida aquifer were constructed from water-level data from a network of wells distributed across Polk County. The potentiometric surface of the Upper Floridan aquifer represents the altitude to which water levels will rise in tightly cased wells. The surface is mapped by measuring the altitude of water levels in a network of wells and is represented on maps by contours that connect points of equal water-level altitudes. Potentiometric surface

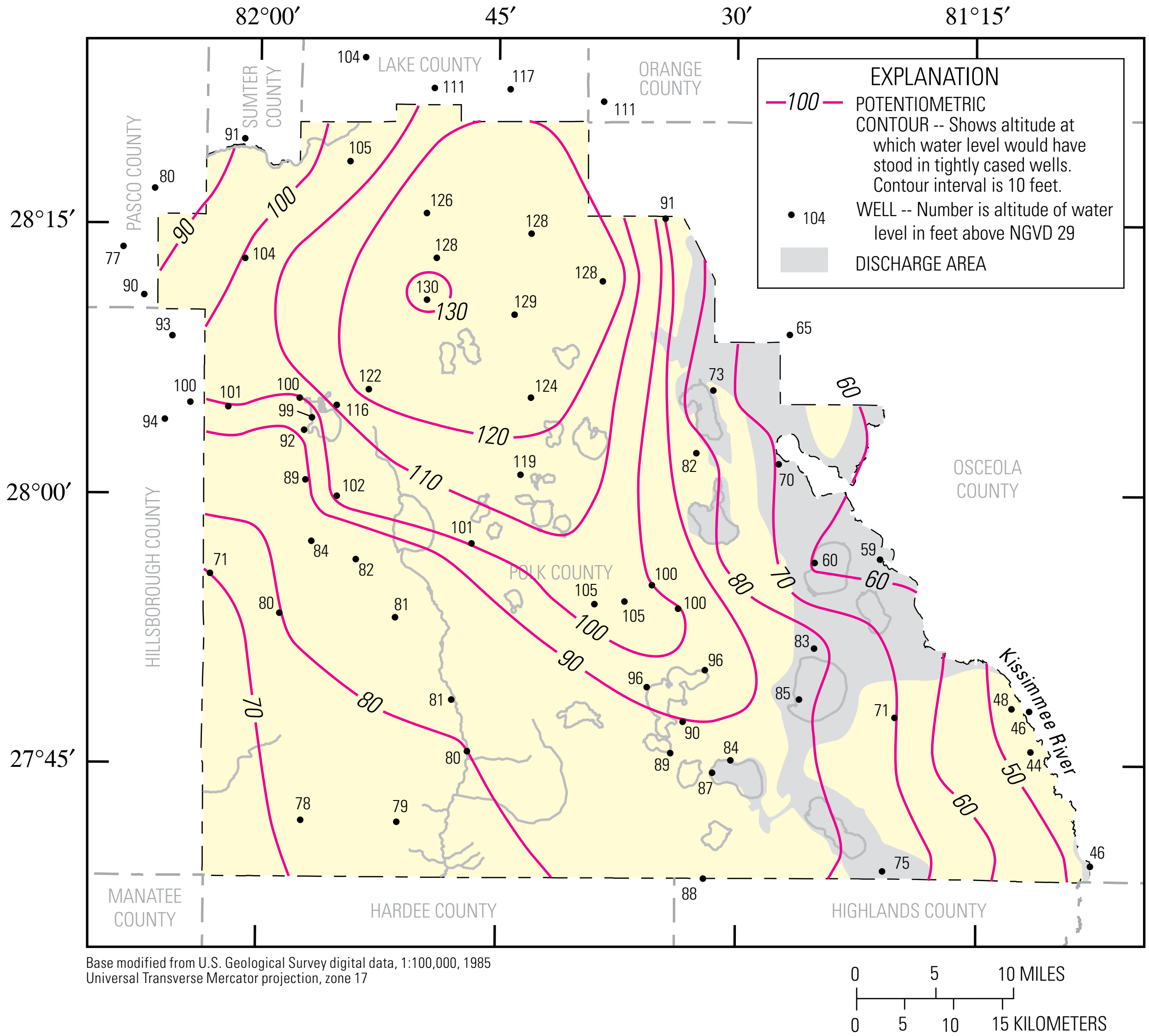


Figure 30. Potentiometric surface of the Upper Floridan aquifer, September 2003 (from Kinnaman and Knowles, 2004a).

maps of the Upper Floridan aquifer in northern and central Florida are published semiannually by the USGS in cooperation with the SFWMD, SWFWMD, SJRWMD, and other local agencies. The configuration of the potentiometric surface of the Upper Floridan aquifer for September 2003 is shown in figure 30. The September 2003 potentiometric surface represents conditions near the end of the wet season, when withdrawals from the aquifer for agricultural irrigation and public supply are near minimum, and water levels generally are at their highest. Ground water in the Upper Floridan aquifer moves downgradient from potentiometric highs toward potentiometric lows, in directions perpendicular to the lines of equal head. The potentiometric surface ranges from about 130 ft above NGVD 29 in northern Polk County to about 44 ft above NGVD 29 in the extreme southeastern part of the county along the Kissimmee River.

During May 2004, which represented conditions when ground-water withdrawals are greatest and water levels are near seasonal lows, the potentiometric surface ranged from 127 ft above NGVD 29 to about 30 ft above NGVD 29 (fig. 31). Comparison of the September and May maps shows little change in the configuration of the surface from one seasonal extreme to another, even though the potentiometric surface is considerably lower during the dry season. The potentiometric surface was about 1.5 to 17 ft lower in May 2004 as compared to September 2003. The decline in the potentiometric surface was greatest in the southwestern part of the county and least in the northern and extreme eastern part of the county. Comparison of the maps also shows that the potentiometric contours are shifted slightly to the west in September relative to May because of recharge from the summer rains and the associated reduction of pumping.

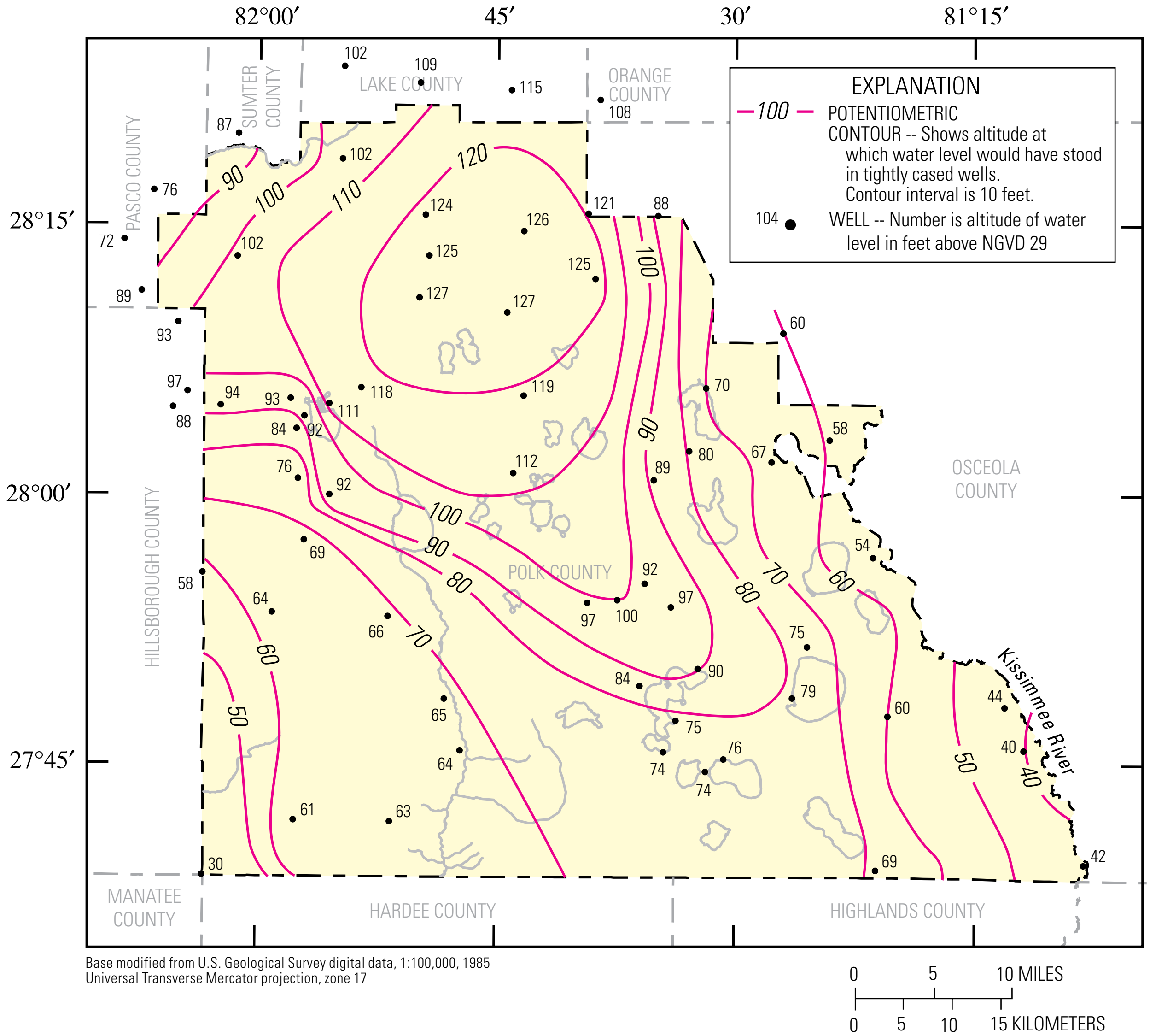


Figure 31. Potentiometric surface of the Upper Floridan aquifer, May 2004 (from Kinnaman and Knowles, 2004b).

The potentiometric surface of the Upper Floridan aquifer is constantly fluctuating, mainly in response to seasonal variations in rainfall and ground-water withdrawals. Seasonal and year-to-year fluctuations of water levels in two wells open to the Upper Floridan aquifer in Polk County are shown in figure 32. Hydrographs show that the water levels generally are at or near their minimums during May and then begin to rise rapidly through September or October in response to summer rains and the cessation of irrigation pumpage. The range of water-level fluctuations in the Upper Floridan aquifer varies to some extent with geographical location. Fluctuations are greatest where the aquifer is well confined and is heavily pumped for irrigation, or near areas of major industrial pumping, such as in southwestern Polk County (well 4). In areas where withdrawals from the Upper Floridan aquifer are less and the overlying confining beds are thin or leaky, such as in the Green Swamp area, seasonal variations in water levels generally range from about 1 to 5 ft (well 263). Variations in water levels generally are similar to those in the surficial aquifer system, but usually are of greater magnitude. Fluctuations that more closely mimic those in the water table generally indicate a better hydraulic connection between the surficial and Upper Floridan aquifers.

Prior to large withdrawals from the Upper Floridan aquifer, the level of the potentiometric surface was mainly controlled by the hydraulic characteristics of the aquifer and the overlying confining units, the topography and altitude of the recharge areas, and by natural recharge and discharge. Predevelopment hydrologic conditions are considered to be conditions that existed prior to man’s influence on the system.

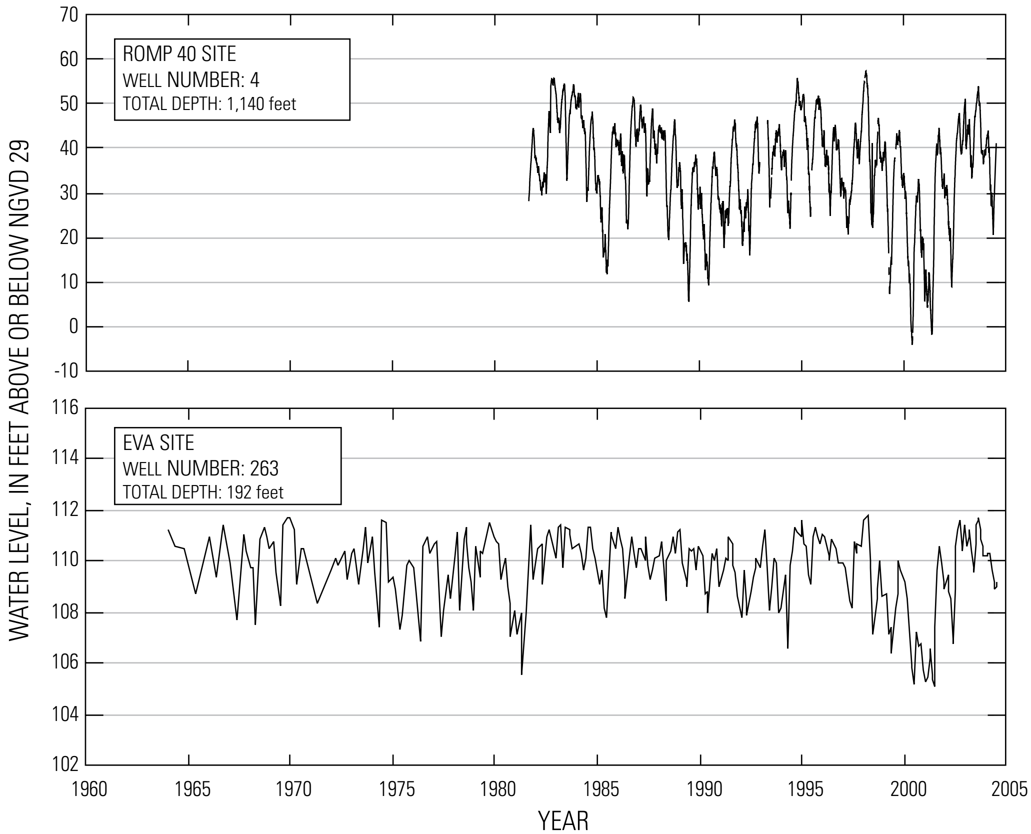


Figure 32. Water levels in selected wells tapping the Upper Floridan aquifer (well locations shown in fig. 9).

Johnston and others (1980) estimated the predevelopment potentiometric surface of the Upper Floridan aquifer in the southeastern United States. A map showing the average potentiometric surface of the Upper Floridan aquifer prior to development in Polk County is shown in figure 33. Altitude of the potentiometric surface ranged from more than 130 ft above NGVD 29 in the north-central part of the county to less than 60 ft above NGVD 29 along the Kissimmee River.

Since predevelopment times, the increase in ground-water withdrawals in Polk and adjacent counties resulted in a decline of the potentiometric surface of the Upper Floridan aquifer across much of the county (fig. 34). The approximate decline in the potentiometric surface of the Upper Floridan aquifer was based on the difference between the estimated predevelopment potentiometric-surface map and water levels in wells measured in May and September, and averaged from 2000 to 2004. Even though in many locations throughout Polk County water levels have risen or remained constant over the past 20-40 years, water levels, for the most part, are still considerably lower than during predevelopment times. For example, in southwestern Polk County where substantial rises in water levels have been observed, present water levels range from about 15 ft to as much as 40 ft below predevelopment times. In the eastern and west-central parts of the county, water levels have declined from about 0 to 15 ft. In a few areas that were not impacted much by pumping, such as in northwestern Polk County and along the Kissimmee River, little or no change in the potentiometric surface has occurred.

Associated with the long-term decline in the potentiometric surface of the Upper Floridan aquifer has been the cessation of flow from Kissengen Spring and other minor springs in southern Polk County (fig. 35). Kissengen Spring, located along the Peace River in south-central Polk County (fig. 1), was the first known major spring to cease flowing in Florida due to ground-water withdrawals from wells (Rosenau and others, 1977). The two initial discharge measurements made of the spring in 1898 and 1917 were 31 cubic feet per second (ft^3/s) and 21 ft^3/s, respectively (Peek, 1951). A record high discharge measurement of 44 ft^3/s was made in 1933. Discharge from the spring declined progressively from 1933 until it ceased flowing in February 1950. Sporadic spring discharges were measured in 1955, 1959, and 1960. A discharge of 0.3 ft^3/s was measured in April 1960, and the spring has not flowed since that time.

Vertical ground-water head gradients along the Peace River have reversed as a result of the long-term reduction in ground-water levels. Areas of the upper Peace River basin exhibited artesian flow conditions prior to the regional

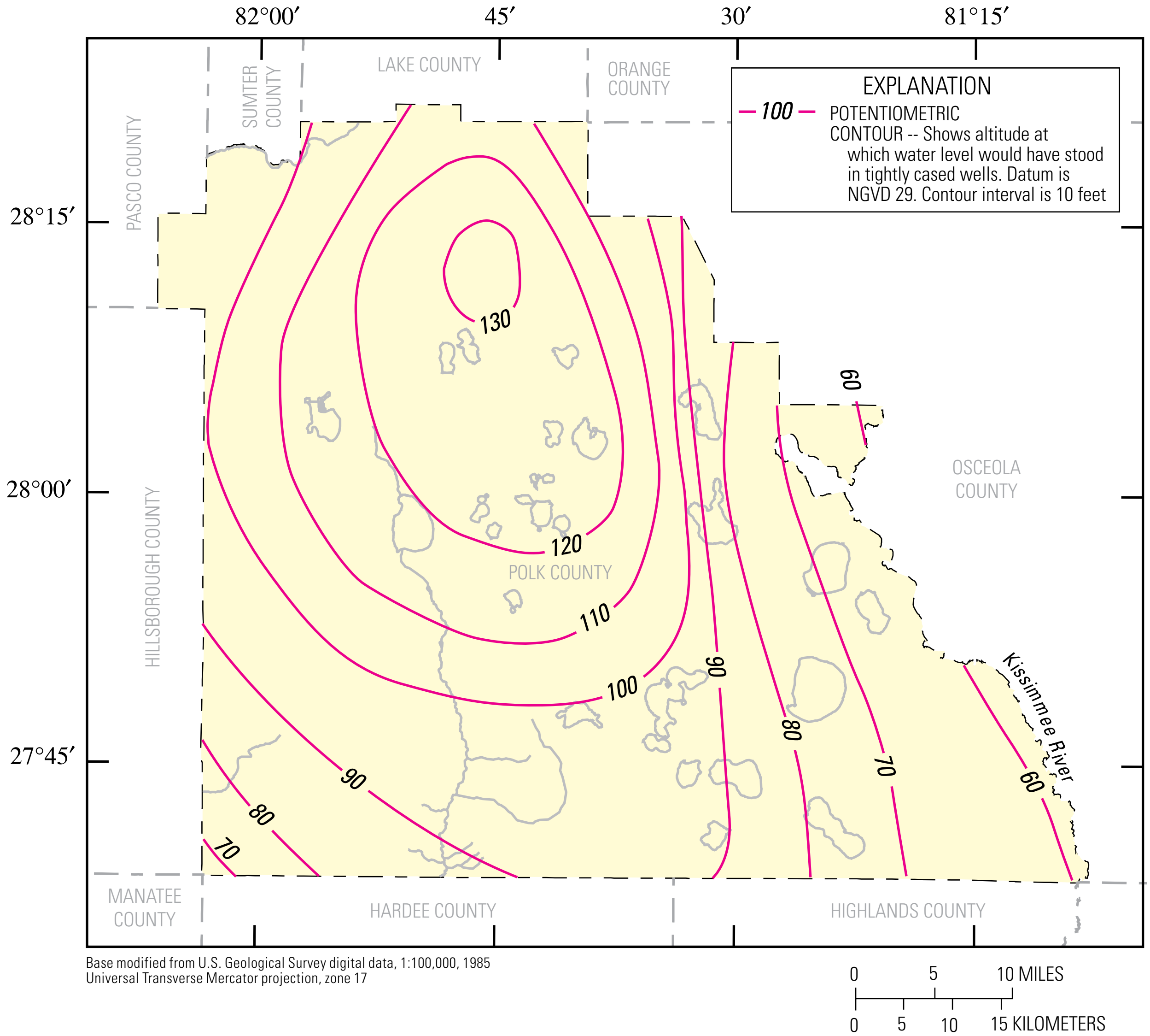


Figure 33. Predevelopment potentiometric surface of the Upper Floridan aquifer (from Johnston and others, 1980).

lowering of the Upper Florida aquifer potentiometric surface in the area (Stewart, 1966). At the headwaters of the Peace River, flowing wells were reported by Stewart (1966) in 1948 near Saddle Creek. Stewart (1966) also reported ground-water discharge from limestone outcrops of the Hawthorn Group from a quarry in this same area. The most upstream parts of the Peace River in Polk County are presently a ground-water recharge area. During the dry season, ground-water levels in both the intermediate aquifer system and Upper Floridan aquifer are below the river stage from upstream of Bartow to downstream from Fort Meade (Lewelling and others, 1998). During the wetter periods, heads in the intermediate aquifer system can be higher than the river stage for short periods.

In the future, water levels in the Floridan aquifer system in southwestern Polk County may continue to rise because of the continuing decrease in water use by the phosphate industry as active mining moves farther south. The potential rise in water levels, however, may be offset by increases in water use for residential and possibly agricultural developments.

Long-Term Trends in Ground-Water Levels

As a result of an increasing population and strong agricultural industry, ground-water withdrawals for public supply and agricultural purposes in Polk County have increased considerably since 1965. In contrast, withdrawals for phosphate mining have declined almost 80 percent as the industry implemented water-conservation practices and as production decreased in the 1980s. Long-term changes in ground-water levels have resulted from this redistribution of pumping stresses.

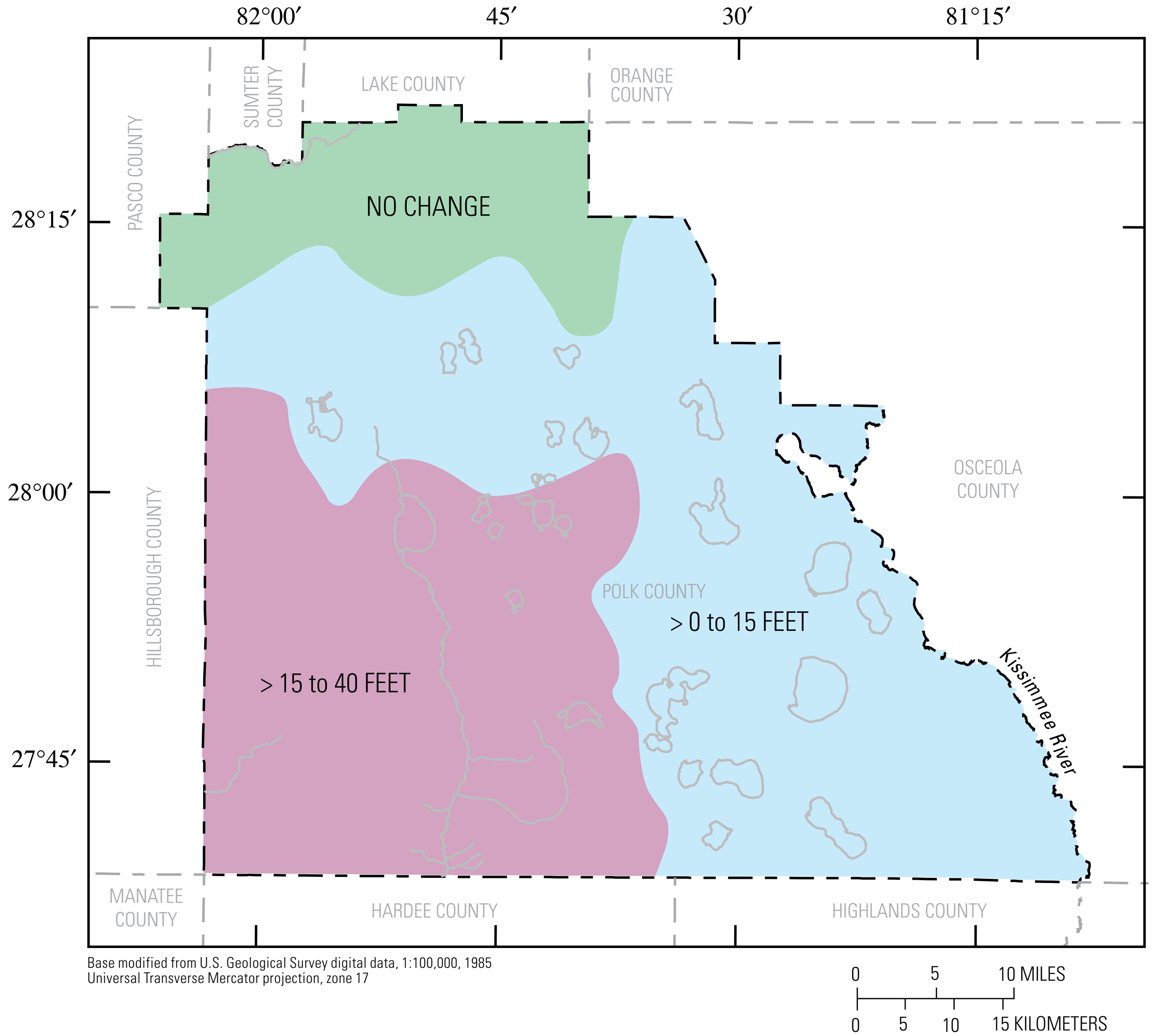


Figure 34. Change in the potentiometric surface of the Upper Floridan aquifer from predevelopment to average 2000-2004 conditions.

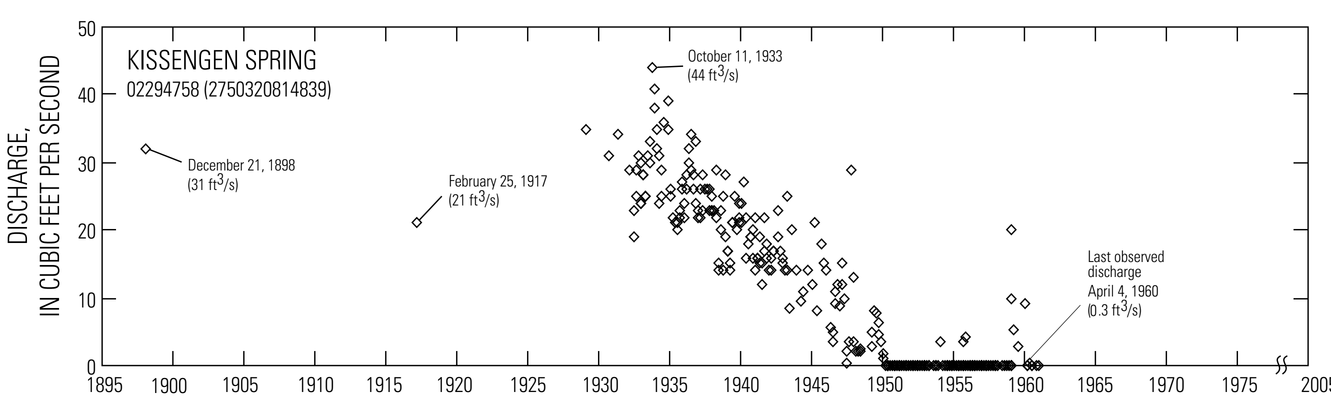


Figure 35. Discharge at Kissengen Spring, 1898-1960.

Long-term water level-data from observation wells tapping the surficial, intermediate, and Floridan aquifer systems were analyzed statistically for significant trends (table 1) using the nonparametric Kendall's tau (Helsel and Hirsch, 1992). A 0.05 significance level was used as the criterion for statistical significance. The test is a ranked-base procedure that examines whether data values tend to increase or decrease with time. No assumption of normality is required and the test is resistant to the influence of extremes, but there can be no serial correlation for the resulting probability values to be correct (Helsel and Hirsch, 1992). Hydrologic data tend to be serially correlated on measurement scales of less than 1 year, whereas annual data typically do not have a serial correlation problem. Therefore, trend analysis was conducted using annual sets of data. Locally weighted scatterplot (LOWESS) smoothing, a robust smoothing technique (Helsel and Hirsch, 1992), also provided information on significant trends in ground-water levels.

For the surficial aquifer system, the test was conducted at three monitoring wells with water-level data that began in the mid-1960s and three that began in the mid-1970s. Results of the Kendall's tau trend analysis show that for the period of record analyzed, two of the six wells showed significant declines in water levels and two wells showed a significant rise in water levels (table 1, p-values less than 0.05). The remaining two wells had no significant trends (p-values greater than 0.05). Although the Kendall's tau showed significant trends for the entire period of record at some wells, these long-term trends may not be continuous and may vary somewhat over time. The use of LOWESS for trend analysis for the period of record shows these short-term rises and declines in water levels (fig. 36). For example, at well 189, which was one of the wells where the Kendall's tau trend indicated a decline in water levels for the period of record (fig. 36), the LOWESS line indicates that the decline was not constant over the period of record. The water levels in the well increased from

Table 1. Results of trend analysis for long-term observation wells and for rainfall stations.

[Locations of wells and rainfall stations shown in figure 9. SAS, surficial aquifer system; IAS, intermediate aquifer system; UFA, Upper Floridan aquifer]

Well number	USGS site identification number	Station name	County	Aquifer	Bottom of casing (feet)	Depth of well (feet)	Period of record analyzed	p-value	Kendall's tau
264	282245081492602	Eva SAS	Lake	SAS	18	23	1963-2004	0.0450	-0.2160
243	281532081345002	Loughman shallow	Polk	SAS	29	32	1964-2004	.3512	-.1024
145	275815081444201	Lake McLeod shallow	Polk	SAS	24	26	1965-2004	.0000	.5539
208	281008081441802	Lake Alfred SAS	Polk	SAS	6	9	1973-2003	.1261	.1957
189	280719081543301	Combee Road SAS near Lakeland	Polk	SAS	8	9	1974-2004	.0381	-.2645
17	274225081315201	USGS shallow well P-48	Polk	SAS	59	62	1977-2004	.0108	.3439
39	274547081470901	Romp 45 Htrn	Polk	IAS	110	192	1976-2004	.0190	.3104
101	275314081514203	Romp 59 Upper Htrn	Polk	IAS	50	60	1977-2004	.0022	.4127
27	274440081314801	Coley UFA	Polk	UFA	208	319	1949-2004	.0000	-.5364
103	275326081585801	ROMP 60 UFA	Polk	UFA	237	710	1955-2004	.2553	-.1118
207	281008081441801	Lake Alfred 6" UFA PO0006	Polk	UFA	102	425	1959-2004	.9396	.0087
242	281532081345001	Loughman UFA (POF-1)	Polk	UFA	85	247	1960-2004	.0001	-.4146
144	275802082044701	Fletcher Lett UFA	Hillsborough	UFA	100	530	1963-2004	.8369	-.0232
158	280229081325201	Lake Hatchinea Rd 8" UFA (POF-4)	Polk	UFA	146	453	1963-2004	.0829	-.1870
210	281037082071801	J.O. Alston 2" UFA	Pasco	UFA	47	55	1964-2003	.2172	-.1390
263	282245081492601	Eva UFA (L-0057)	Lake	UFA	100	192	1964-2004	.1888	-.1439
63	274846081262001	USGS Well at Lake Weohyakapka (POF-0008)	Polk	IAS/UFA	149	197	1969-2004	.1957	-.1524
150	275959081552501	Sanlon Ranch 24" UFA	Polk	UFA	293	1220	1970-2004	.0002	.4387
184	280531081431601	Lake Alfred 12" UFA	Polk	UFA	282	555	1971-2004	.0012	.3977
58	274815081130301	River Ranch UFA (POF-5)	Polk	UFA	185	300	1974-2004	.7597	.0409
		Avon Park rainfall station	Highlands				1931-2003	.5548	-.0476
		Lakeland rainfall station	Polk				1931-2003	.3104	.0814
		Mountain Lake rainfall station	Polk				1931-2003	.2776	-.0871
		Winter Haven rainfall station	Polk				1949-2003	.1274	.1421

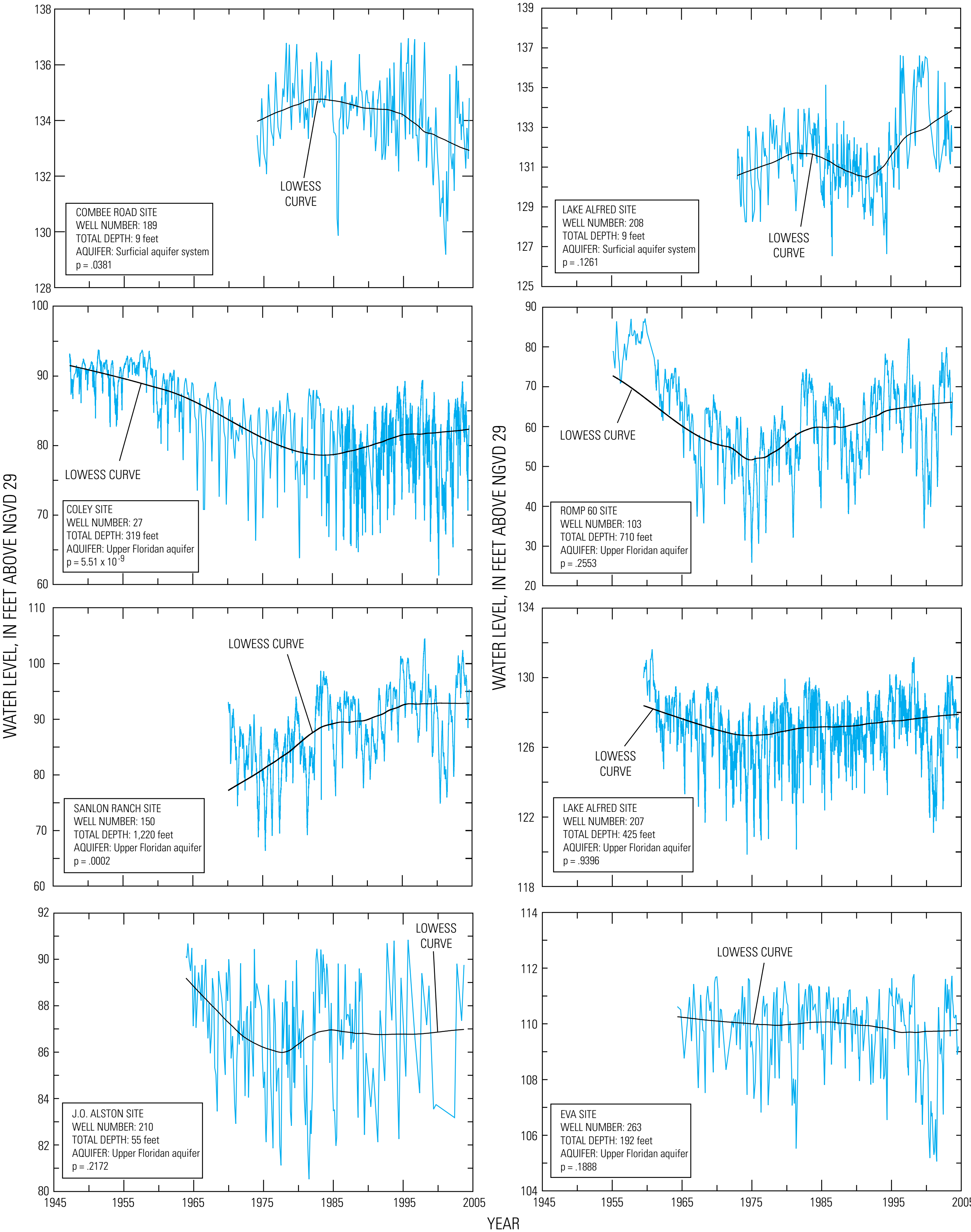


Figure 36. Long-term water levels in observation wells tapping the surficial aquifer system and the Upper Floridan aquifer (well locations shown in fig. 9).

the beginning of the record until the early 1980s, and then declined to 2004. The LOWESS lines for some of the other surficial aquifer wells also indicate periods of declining or rising water levels. These oscillations probably are the result of the cyclic variations in rainfall over time.

Long-term water-level data from 14 observation wells tapping the intermediate aquifer system and the Upper Floridan aquifer also were statistically analyzed for trends (table 1). The period of record used for data analysis ranged from 31 to 56 years. Two of the intermediate aquifer monitoring wells analyzed had water levels that began in the 1970s. Three of the Upper Floridan aquifer monitoring wells had water-level data that began prior to 1960. Six of the wells had water-level data that began in the 1960s, and three monitoring wells had water-level data that began in the 1970s.

Eight wells (of 14) had no significant trends in water-level (p-values greater than 0.05). Two intermediate aquifer wells and two Upper Floridan aquifer wells showed significant increases in water levels in (p-values less than 0.05). Two Upper Floridan aquifer wells had significant declines in water levels (p-values less than 0.05).

As previously mentioned, the long-term trends identified in these wells may not be continuous throughout the period of record. For example, at well 103, there was no significant trend in water levels for the period of record; however, water levels clearly declined from the beginning of record until the early 1970s, and then began to rise (fig. 36). Water-level trends in southwestern Polk County, similar to those at well 103 (ROMP 60), illustrate that industrial pumpage has had a major impact on ground-water levels in the county. Water-level declines prior to the mid-1970s coincide with an increase in water use associated with phosphate mining in Polk and Hillsborough Counties that had been occurring for several decades. Mining in Polk County, for the most part, had been concentrated south of Lakeland and west of the Peace River. At the peak of phosphate production in the mid-1970s, ground-water pumpage for phosphate mining was estimated to be about 270 Mgal/d. The rise in water levels that began in the mid-1970s at some well locations (and several years later at others) coincides with a period when ground-water use associated with the phosphate industry declined. In addition to a decrease in ground-water pumpage, an increase in rainfall during part of the period at some of the rainfall stations (fig. 5) also may be responsible for some of the increase in water level.

Changes in the distribution of pumpage also could account for some of the variation in water-level trends. At well 27 (located in southeastern Polk County), which had a significant water-level decline for the period of record, water levels declined until the early 1980s (fig. 36). Water levels then stabilized and rose slowly for the next 20 years. The water-level declines observed until the early 1980s were partially the result of water use associated with the phosphate industry as well as water use associated with agricultural irrigation along the Lake Wales Ridge. The water-level stabilization that began in this well in the 1980s is somewhat muted compared to other wells like well 103 (ROMP 60) in southern Polk County that rose more in response to the reduced mining water use. Possibly, the recovery in water levels was offset by an increase in agricultural water use as the citrus industry grew along the Lake Wales Ridge.

Head Relations

Water levels within the aquifer systems in Polk County vary with depth. Heads decrease with depth in recharge areas and increase with depth in discharge areas. The magnitude of head differences between the surficial, intermediate, and Floridan aquifer systems is directly related to the character of the confining units separating the aquifers. In areas not affected by pumpage, greater head differences between the aquifers generally are found where the confining unit is thicker and less permeable. In contrast, small head differences between hydrogeologic units indicate a better hydraulic connection.

Water-level data show a wide variation in the magnitude of head differences between the surficial, intermediate, and Floridan aquifer systems (fig. 37). Hydrographs at wells 242 and 243 in northern Polk County show a small (0 to 4 ft) head difference between wells in the surficial aquifer system and wells in the Upper Floridan aquifer. Water-level trends in the surficial aquifer system also generally mimic the trends observed in the Upper Floridan aquifer at this site. This similarity in trends indicates that leaky, fairly permeable or thin confining beds at this location allow relatively good connection between the aquifers. Small head differences and similar trends are also observed at ROMP 45 between wells in Zone 3 of the intermediate aquifer system (well 39) and wells tapping the Upper Floridan aquifer (well 40). Hydrographs at wells 4 and 6 (ROMP 40) and wells 72 and 73 (ROMP 44) in southern Polk County show large head differences between the surficial and Upper Floridan aquifers. At ROMP 40, water levels are about 75 to 135 ft higher in the surficial aquifer system than in the underlying Upper Floridan aquifer. Little similarity in trends is observed between the water levels of the two aquifers, indicating that the confining beds between aquifers are thicker and relatively impermeable.

Head differences between the surficial aquifer system and the Upper Floridan aquifer in May 2004 varied considerably at 27 well pairs in Polk and adjacent counties (fig. 38). The magnitude of the downward head gradient between the two aquifers increases toward the southwest, mostly as the result of increased ground-water withdrawals for industrial use and tighter confinement between the two aquifers. In southwestern Polk County, water levels in the surficial aquifer system ranged from about 18 to 104 ft higher than water levels in the Upper Floridan. Ground-water withdrawals are high along the Lake Wales Ridge, but the head difference is smaller due to the fact that some drawdown is attenuated by vertical leakage from above. In northern Polk County, surficial aquifer system heads generally were about 0 to 8 ft higher than heads in

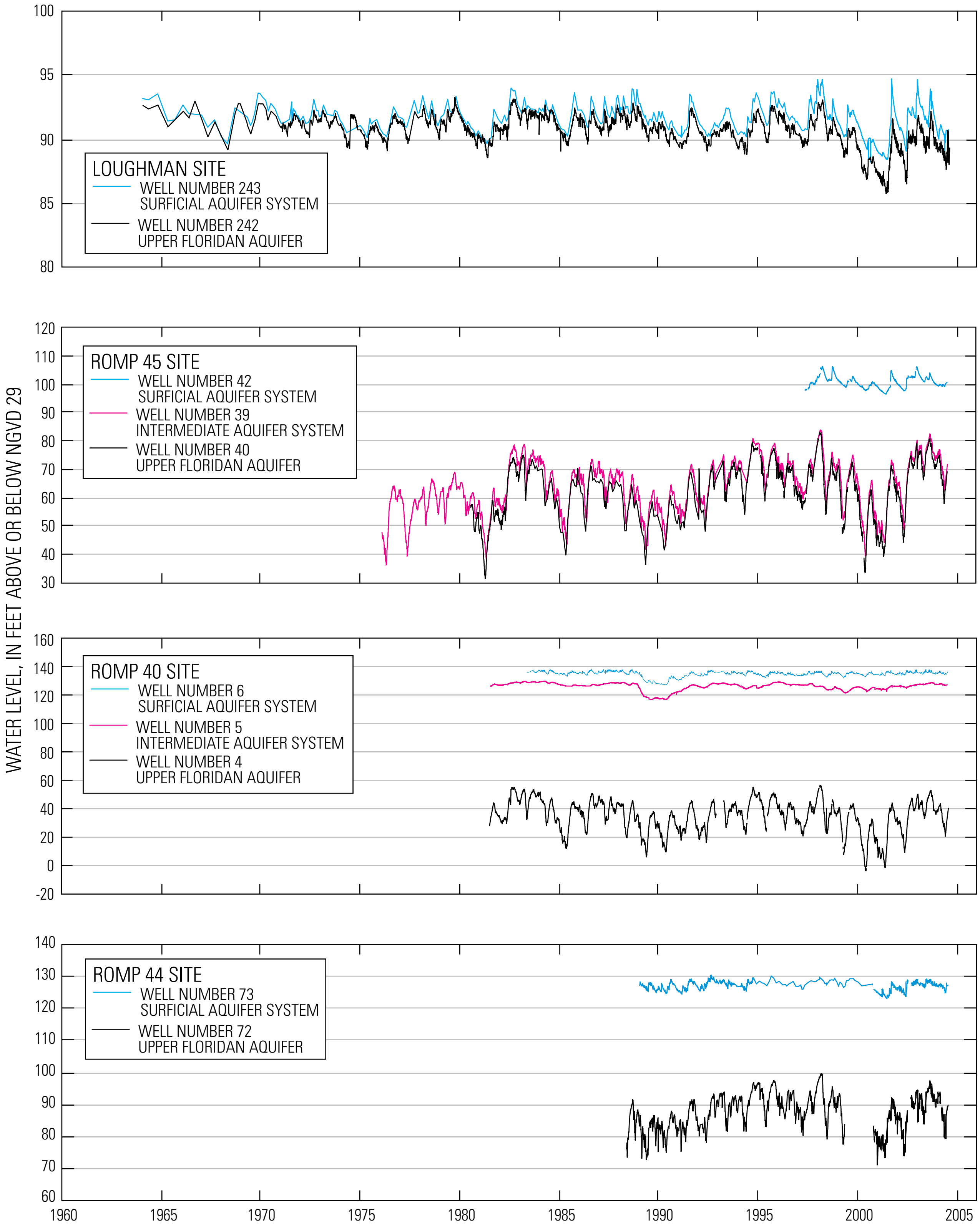


Figure 37. Water levels in selected wells open to the surficial aquifer system, the intermediate aquifer system, and the Upper Floridan aquifer (well locations shown in fig. 9).

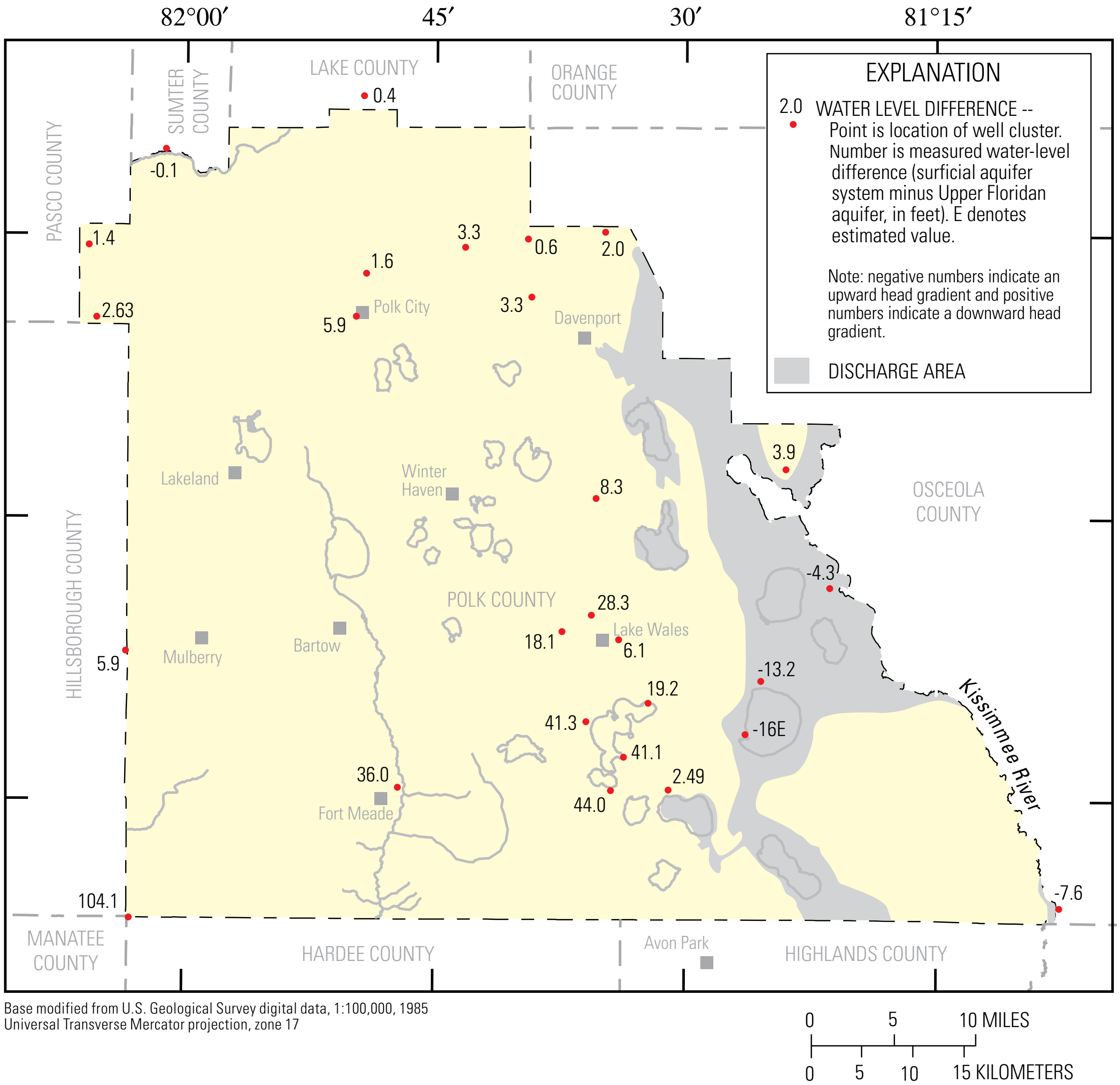
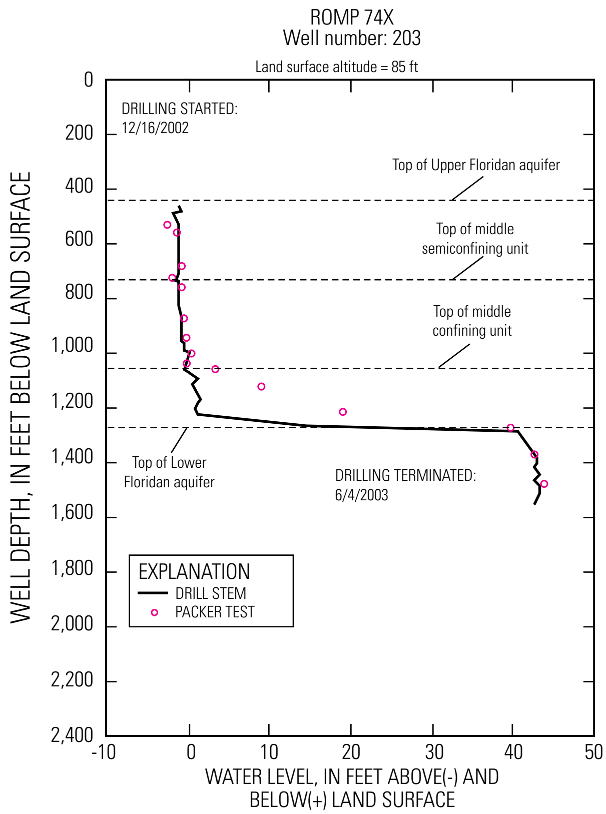


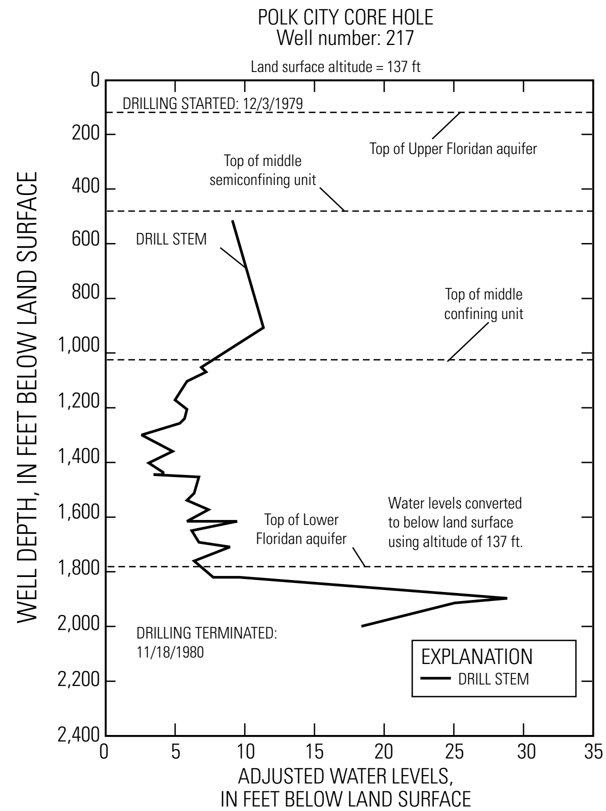
Figure 38. Head differences between the surficial aquifer system and the Upper Floridan aquifer, May 2004 (well numbers shown in fig. 9).

the Upper Floridan aquifer. The head gradient is reversed in the extreme eastern part of the county, where the underlying Upper Floridan aquifer has a higher head than the surficial aquifer system. In this area, water levels in the Upper Floridan aquifer ranged from about 0 to 16 ft higher than water levels in the surficial aquifer system.

Little data are available on water-level variations with depth in the Floridan aquifer system in Polk County. To investigate the potential of obtaining potable water supplies from the Lower Floridan aquifer, however, several test wells were drilled in Polk and adjacent Lake and Osceola Counties. The variations in water levels with depth during the construction of three test wells (drilled to depths ranging from 1,560 to 2,400 ft) are shown in figure 39.

During drilling of the Lake Louisa State Park well (well 267), water levels measured in the drill stem decreased about 32 ft over the interval from 435 to 2,366 ft below land surface (fig. 39). At ROMP 74X (well 203), water levels measured in the drill stem decreased about 41 ft over the interval from 461 to 1,556 ft. During the drilling of the Polk City core hole (well 217), water levels decreased about 9 ft over the interval from 512 to 1,996 ft. Substantial declines in water levels occurred from 1,200 to 1,300 ft below land surface at Lake Louisa State Park and from 1,226 to 1,286 ft below land surface at ROMP 74X. The head changes appear to mark the base of the middle confining unit (the top of the Lower Floridan aquifer) and indicate good hydraulic separation between the Upper and Lower Floridan aquifers.





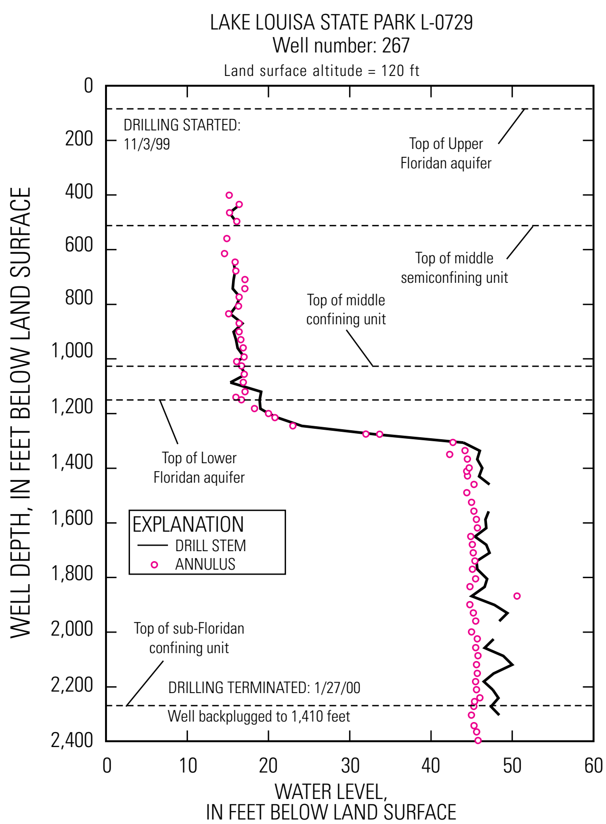


Figure 39. Water levels during drilling of monitoring wells (modified from Navoy, 1986; O'Reilly and others, 2002; and Gates, 2003). (Well numbers refer to fig. 9.)

At the Polk City well, a slight rise in water levels seems to occur to a depth of 1,300 ft (fig. 39). According to Navoy (1986), the rise is probably due to an inaccurate adjustment made to head measurements in the deeper part of the aquifer, rather than to an actual increase in water levels with depth. During the drilling of the well which took about 11 months, prevailing dry conditions caused a regional lowering of the potentiometric surface. To determine the true head-depth relation, an adjustment was made by Navoy (1986) to filter out the effects of the regional potentiometric surface decline. Navoy (1986) concluded that the most reasonable interpretation of the data is that the water levels remained at a rather constant level as depth increased, until a marked decline of about 16 ft occurred at the 1,800- to 1,900-ft interval.

Water levels at two well sites (fig. 39, wells 203 and 267) were not adjusted for changes with time. Additionally, water-level data in all wells presented in figure 39 were not adjusted for density differences between freshwater and mineralized water in various zones within the wells.

Water Budget

A water budget evaluates the quantities of water that enter and leave an area during a given time period, and equates their net sum to the change in the quantity of water stored in the area during that period. A generalized steady-state water budget for Polk County was made by using measured or estimated values for rainfall, lateral subsurface outflow, runoff and surface-water discharge, spring discharge, and evapotranspiration. Assuming there is no change in storage, inputs are balanced by outputs. An average estimate of evapotranspiration was calculated as the residual of the water budget. A generalized water budget can be described by the following equation:

$$ET = P - Q_0 - Q_R - Q_S, \quad (1)$$

where

ET is evapotranspiration, in inches per year;

P is precipitation, in inches per year;

Q_0 is net lateral subsurface outflow, in inches per year;

Q_R is runoff (sum of overland runoff and ground-water seepage to streams), in inches per year; and

Q_S is spring discharge, in inches per year.

A generalized water budget was computed for Polk County over a 10-year period from 1994 to 2003 (fig. 40). A water budget averaged over a 10-year period is more representative of long-term conditions than a 1-year water budget. Additionally, when long-term average annual values

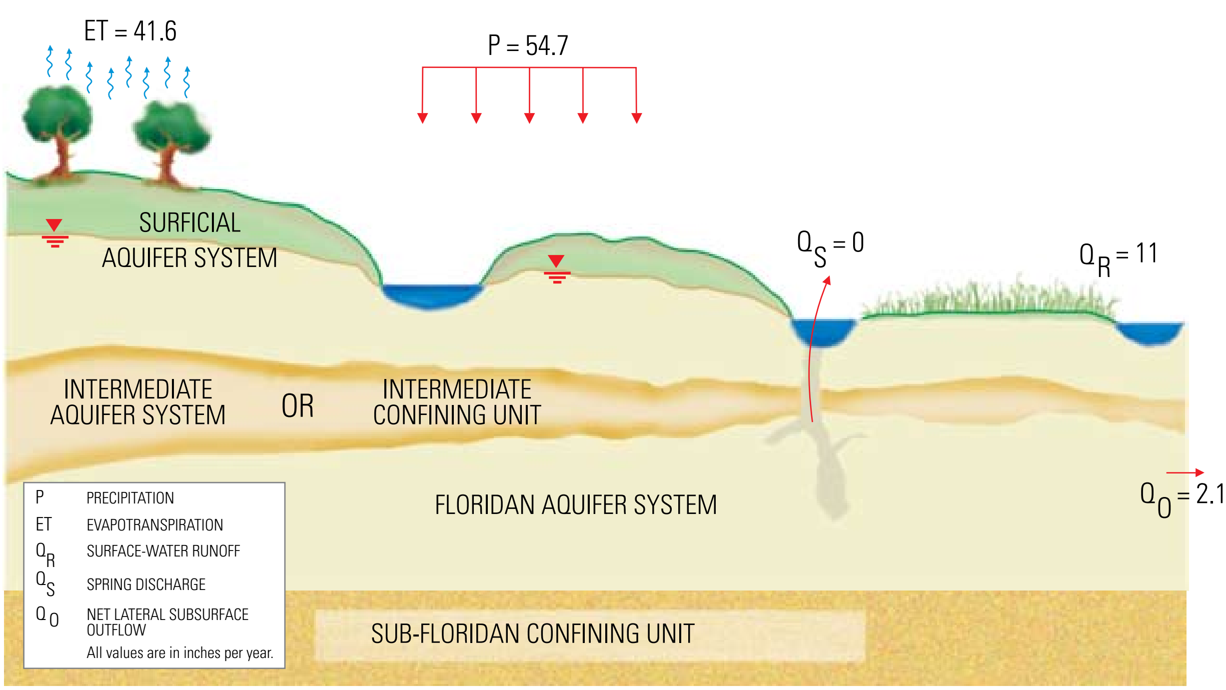


Figure 40. Water budget for Polk County, Florida, 1994-2003.

of the various water-budget items are used, it is more valid to assume that the change in storage is negligible and can be disregarded without significant error. It was also assumed that all ground water pumped out was returned to the system as wastewater or irrigation return flow and that no substantial amount of ground water was piped into or out of the county.

The major input to the system is precipitation, which averaged about 54.7 in/yr from 1994 to 2003 at five NOAA stations (Avon Park, Bartow, Lakeland, Mountain Lake, and Winter Haven). Ten-year rainfall averages varied across the area during this period, ranging from about 49.6 in/yr at Mountain Lake to nearly 57.4 in/yr at Winter Haven.

Net lateral subsurface outflow (Q_0) from Polk County was determined by using a USGS modular ground-water flow model (Nicasio Sepúlveda, U.S. Geological Survey, written commun., 2005). Net lateral outflow was determined for the surficial aquifer system (0.03 in/yr), the intermediate aquifer system (0.02 in/yr), the Upper Floridan aquifer (1.35 in/yr), and the Lower Floridan aquifer (0.70 in/yr). Net lateral subsurface outflow from all aquifers was about 2.1 in/yr.

Water leaving the county as surface-water runoff (Q_R) averaged about 11 in/yr from 1994 to 2003, based on the analysis of streamflow records at nine USGS gaging sites in basins that lie entirely or partially within Polk County. These gaged surface-water sites include the: Kissimmee River at S-65; Peace River at Fort Meade; Peace River at Zolfo Springs; North Prong Alafia River near Keysville; South Prong Alafia River near Lithia; Hillsborough River near Crystal Springs; Withlacoochee River near Cumpressco; Green Swamp Run near Eva; and Blackwater Creek near Knights. Runoff at sites not located in the vicinity of the Polk County line was estimated using drainage area proration. Runoff was not prorated from the Withlachoochee River and Green Swamp Run, because the former site is located near the Polk County line and the drainage basin is not well defined for the latter site. It was assumed in the water budget that one-half of the runoff from the Kissimmee River Basin was from Polk County and the other half from Osceola County.

Spring discharge (Q_S) was estimated to be 0 in/yr. Due to the lowering of the potentiometric surface of the Upper Floridan aquifer, Kissengen Spring (the largest spring in Polk County) ceased flowing in the early 1960s.

Evapotranspiration is the largest output component in the water budget and is the most difficult to measure. Few accurate estimates of evapotranspiration were available; therefore, a value of 41.6 in. was determined by solving equation 1 for evapotranspiration. This back-calculated value of evapotranspiration is a reasonable estimate for Polk County and falls within the range of evapotranspiration values determined for the area—27 in/yr reported for a well-drained, deep water-table site along the Lake Wales Ridge in southwestern Orange County (Sumner, 1996) and about 56.5 in/yr reported at Lake Starr in east-central Polk County (Swancar and others, 2000).

Ground-Water Quality

The chemical and physical characteristics of water in aquifers are affected by the initial chemical composition of water entering the aquifer, the mineralogy and solubility of rocks with which it comes in contact, and the residence time of water in contact with the aquifer matrix. Atmospheric precipitation also can contribute to mineralization of water. The nature and extent of interconnection of sinkholes, rivers, and lakes, as well as anthropogenic sources, can affect the chemical composition of ground water.

The chemical characteristics of water can determine its suitability for various uses. The Florida Department of State (1989) established primary regulations and secondary standards for drinking water distributed by public water-supply systems. The primary drinking-water regulations establish mandatory limits and apply to the physical and chemical characteristics of water that may affect the health of the consumer. The secondary drinking-water standards establish recommended limits on certain chemical constituents that pertain to the aesthetic qualities of drinking water—which are not enforceable and are intended as guidelines. Concentrations of nitrate greater than 10 milligrams per liter (mg/L) as nitrogen exceed the national and State primary drinking-water regulations (U.S. Environmental Protection Agency, 2000). Secondary drinking-water standards set maximum limits of 500 mg/L for dissolved-solids concentration, 250 mg/L for chloride and sulfate concentrations, 1.4 mg/L for fluoride concentration, and 0.3 mg/L for iron concentration. The principal chemical constituents in ground water that affect potability are chloride, sulfate, nitrate, and the amount of dissolved ions in the water (specific conductance). Hardness, due primarily to calcium and magnesium ions, may also be important for public and domestic water use.

Water-chemistry data collected by the USGS and State agencies were compiled for this study (fig. 10 and app. 2). Water samples from 53 wells and 1 spring were collected and analyzed by the USGS for major chemical constituents in 2002-2003. Samples were collected from 9 wells and 1 spring tapping the surficial aquifer system, 5 wells tapping the intermediate aquifer system, and 39 wells tapping the Upper Floridan aquifer. Additionally, water-quality data (primarily field measurements and concentrations of major ions and nutrients) collected by the SFWMD, SWFWMD, and SJRWMD were compiled for the 1998-2003 period to further evaluate ground-water quality conditions. These data included 37 samples from the surficial aquifer system, 10 samples from the intermediate aquifer system/intermediate confining unit, and 29 samples from the Upper Floridan aquifer.

Water samples collected by the USGS for this study were obtained from monitoring, public supply, and privately owned wells. Purging methods varied depending upon the type of well. For monitoring wells, water samples were collected using a centrifugal or submersible electric pump. These wells were sampled after at least three casing volumes of water were pumped and temperature, specific conductance, and pH had stabilized. Public supply and privately owned wells have pumps installed that are used routinely. These wells were sampled after field parameters stabilized. A water sample for the spring was collected at the spring vent. Field measurements were made at this site by inserting the instrument probes directly into the spring orifice.

Specific conductance, temperature, pH, and dissolved oxygen were determined in the field. Water samples were collected for laboratory analysis of major ions, selected trace metals, alkalinity, total organic carbon, and nutrients. Nutrients included nitrite as nitrogen (nitrite), nitrite plus nitrate as nitrogen (nitrate), ammonia as nitrogen (ammonia), ammonia plus organic nitrogen as nitrogen, phosphorus, and orthophosphate as phosphorus (hereafter referred to as phosphate) (app. 2). Nitrogen (N) occurs as anions in water as nitrite (NO_2^-) or nitrate (NO_3^-). Both species are mobile and NO_3^- is stable over a wide range of conditions (Hem, 1985). The NO_2^- ion is unstable in aerated water and generally is present in negligible concentrations compared to NO_3^-. In this report, the combined concentration of nitrite plus nitrate reported by the laboratory is referred to as nitrate. Water samples were processed at the time of collection using standard USGS procedures (U.S. Geological Survey, 1998). Samples collected to determine major ion, trace-element, and nutrient analyses were filtered through a 0.45-micron pore-size disposable encapsulated filter. Samples for major cation and trace-element analyses were acidified with 2 milliliters of 7.7N nitric acid to adjust the sample pH to less than 2. All water samples were analyzed by USGS laboratories in Ocala, Florida, and Denver, Colorado.

Surficial Aquifer System

Major factors that control the quality of water in the surficial aquifer system are: (1) the quality and quantity of rainfall that infiltrates the aquifer system, and (2) the aquifer system properties, such as permeability and sediment type (Schiner, 1993). The concentrations of inorganic constituents in water from the surficial aquifer are related to the quality of the recharge water. Recharge water that moves through the soil zone or sediments may be chemically altered through mineral dissolution, mineral precipitation, cation or anion exchange, oxidation-reduction reactions, and sorption of organic molecules (Crandall and Berndt, 1996).

The concentrations of most chemical constituents in ground water from the surficial aquifer are somewhat variable (app. 2). The surficial aquifer system is primarily composed of insoluble quartz sand, which generally results in ground water with low mineral content and hardness. Water type is variable from location to location, but generally is a mixed water type, meaning that no one or two cations or anions were dominant in the ground water (fig. 41).

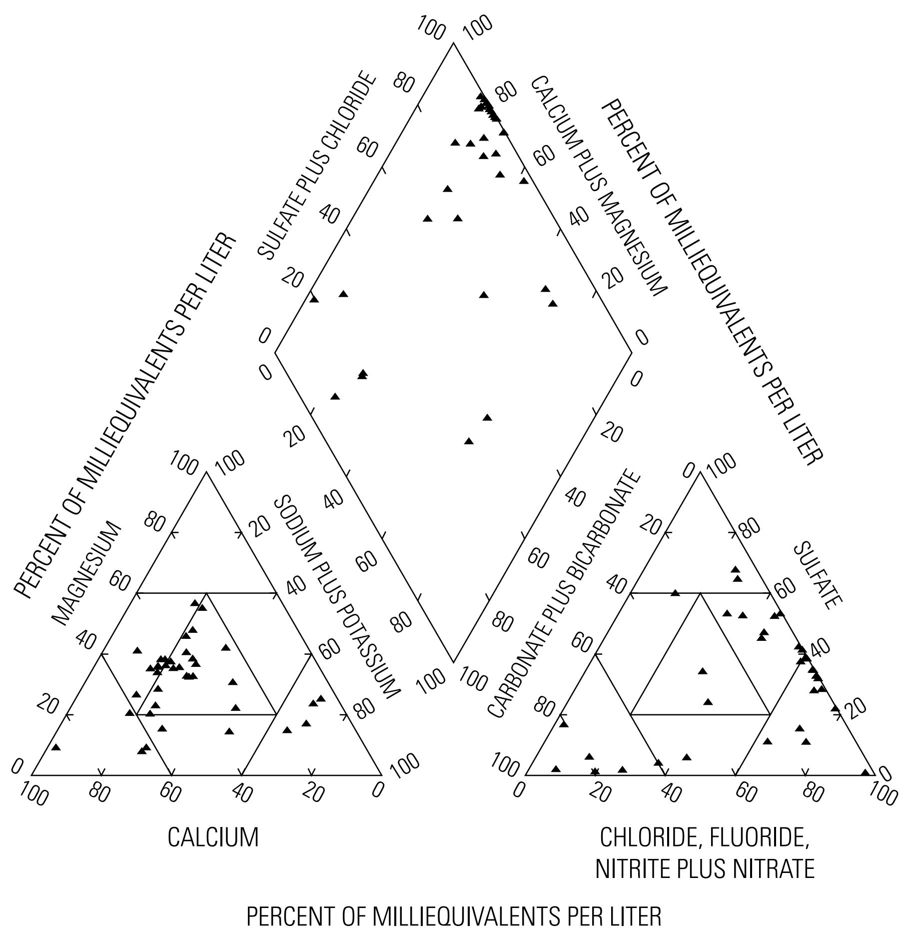


Figure 41. Trilinear diagram for water from wells tapping the surficial aquifer system.

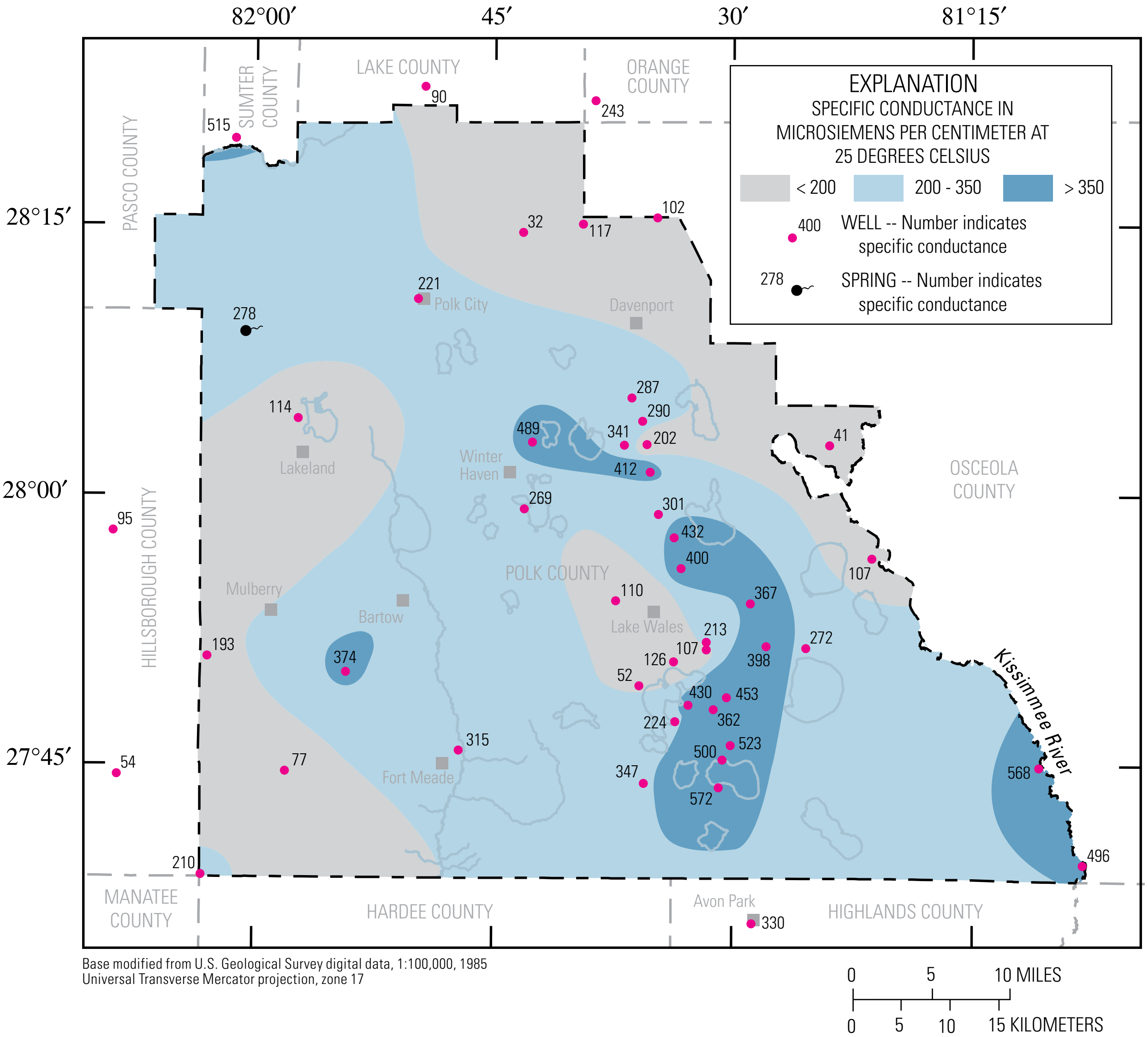


Figure 42. Generalized distribution of specific conductance in water from the surficial aquifer system.

The areal variability of specific conductance, chloride, sulfate, and nitrate in water from the surficial aquifer system is shown in figures 42-45. Although 47 surficial aquifer wells were sampled from 1998 to 2003, the distribution is somewhat skewed because nearly two dozen wells were sampled along the Lake Wales Ridge. Many of the surficial aquifer wells incorporated into the water-quality network were drilled for a pesticide and nutrient monitoring network along the Lake Wales Ridge (Choquette and Sepúlveda, 2000).

Specific conductance, the ability of water to conduct an electrical current, is related to the presence of charged ionic species in water, thus providing an indication of the ion concentration of water. In the sampled wells, specific conductance ranged from 32 to 572 microsiemens per centimeter (µS/cm) (fig. 42 and app. 2). Specific conductance in the surficial aquifer system is variable over the county. Water having specific conductance of less than 200 µS/cm generally occurred in parts of northeastern and southwestern Polk County. Values ranging from 200 to 350 µS/cm occurred in a wide diagonal band beginning in the northwestern part of the county and extending to the southeastern part. Specific conductance values exceeding 350 µS/cm generally occurred along the Lake Wales Ridge area in the southern part of the county and along the Kissimmee River in the extreme south-eastern part of the county.

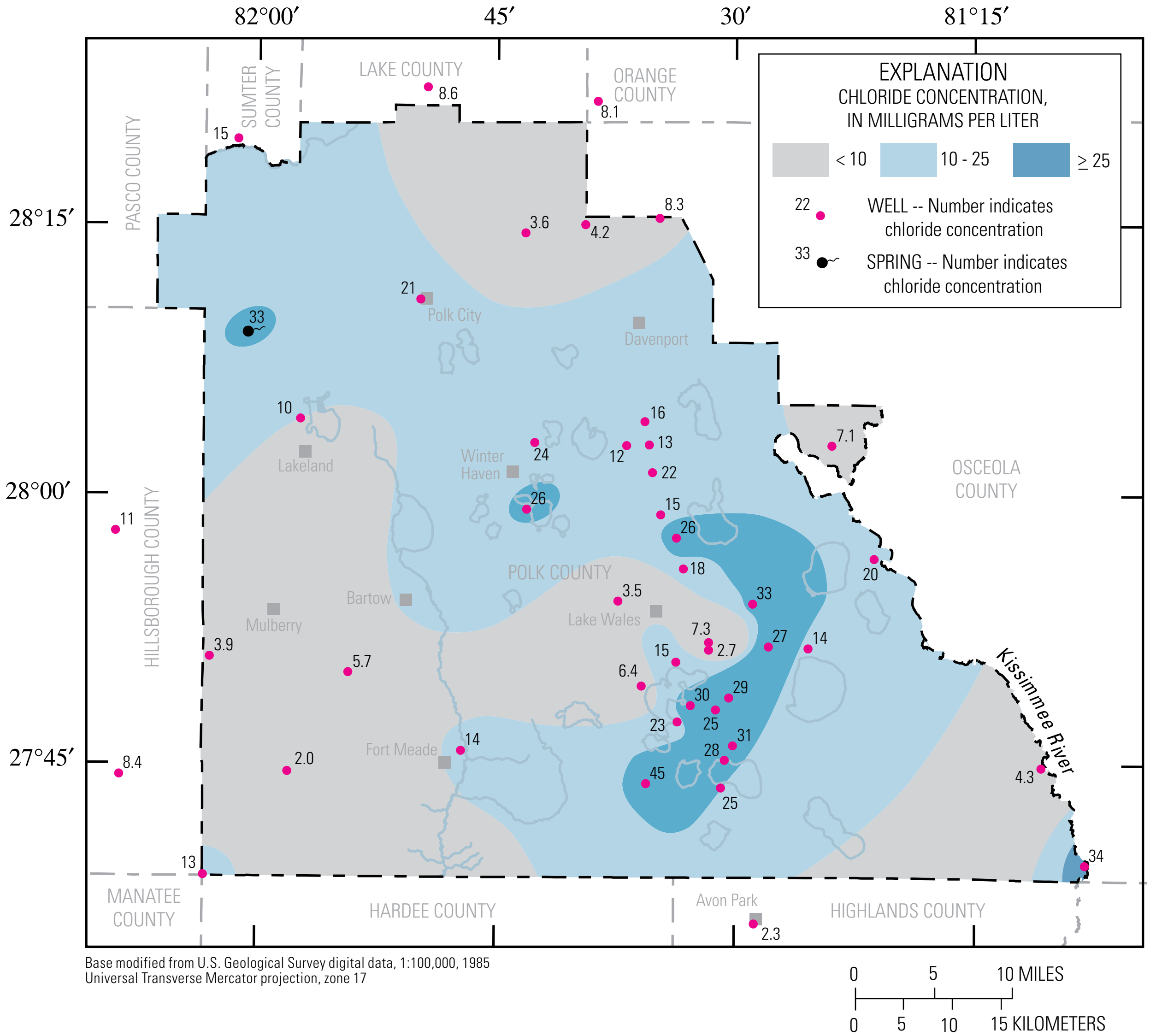


Figure 43. Generalized distribution of chloride concentrations in water from the surficial aquifer system.

Chloride concentrations in water from the surficial aquifer system ranged from 2.0 to 45 mg/L (fig. 43 and app. 2). Over most of the county, concentrations were less than 25 mg/L. Lowest concentrations (less than 10 mg/L) were in the southwestern part, and in parts of northern and southeastern Polk County. Highest chloride concentrations (exceeding 25 mg/L) occurred primarily along the areas that generally coincide with the southern part of the Lake Wales Ridge. Chloride is a major constituent of dissolved solids in ground water in coastal Florida. Chloride concentration often is used as an indicator of the extent of saltwater intrusion or amount of remnant seawater in an aquifer. In Polk County, the source of chloride in ground water from the surficial aquifer system is likely from agricultural activities, septic tank effluent, and small amounts contributed by rainfall.

Sulfate concentrations in water sampled from the surficial aquifer system ranged from 0.25 to 99 mg/L (fig. 44 and app. 2). Sulfate concentrations were generally less than 10 mg/L throughout much of the eastern and some of the northwestern and southwestern parts of Polk County. Sulfate concentrations ranging from 10 to 30 mg/L occurred in much of west-central Polk County. Sulfate concentrations greater than 30 mg/L were mostly along the Lake Wales Ridge. In Polk County, sulfate in the surficial aquifer system is likely derived from inorganic sulfates found in fertilizers or from organic sulfides that undergo oxidation in the soil or in organic waste treatment (Hem, 1985).

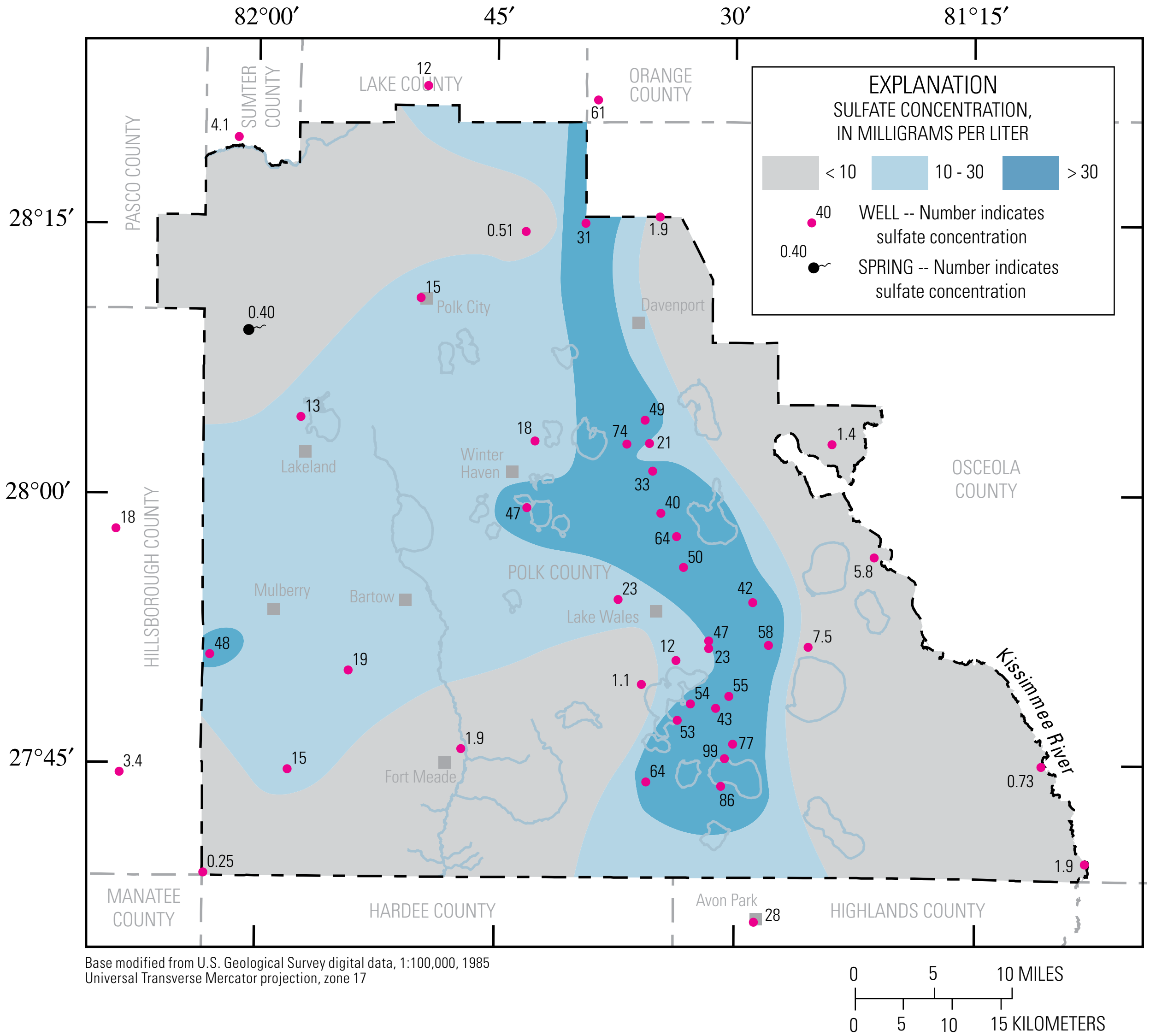


Figure 44. Generalized distribution of sulfate concentrations in water from the surficial aquifer system.

Nitrate concentrations in water from the surficial aquifer system ranged from less than 0.004 to 26 mg/L (fig. 45 and app. 2). Lowest concentrations were generally east and west of the Lake Wales Ridge. Highest concentration generally were along the Lake Wales Ridge. Fourteen wells along the Lake Wales Ridge had nitrate concentrations of 10 mg/L or greater. Additionally, a small spring discharging from a hill in northwestern Polk County had a nitrate concentration of 17 mg/L.

Nitrate concentrations are an important limiting factor for domestic water use. Excessive concentrations of nitrate in drinking water may cause methemoglobinemia in small children (Hem, 1985). The presence of elevated nitrate levels in surficial aquifer water could be an indication of contamination from fertilizers, animal waste associated with livestock management, and/or septic tank leachate. Along the Lake Wales Ridge, citrus groves are ubiquitous and fertilization is common practice. Tihansky and Sacks (1997) determined that water samples collected from wells in citrus land-use areas in Polk and Highlands Counties had the highest nitrate concentrations, ranging from 4.9 to 57 mg/L. Fertilizers also can contain additional chloride and sulfate, which could account for the increases in chloride and sulfate concentrations found

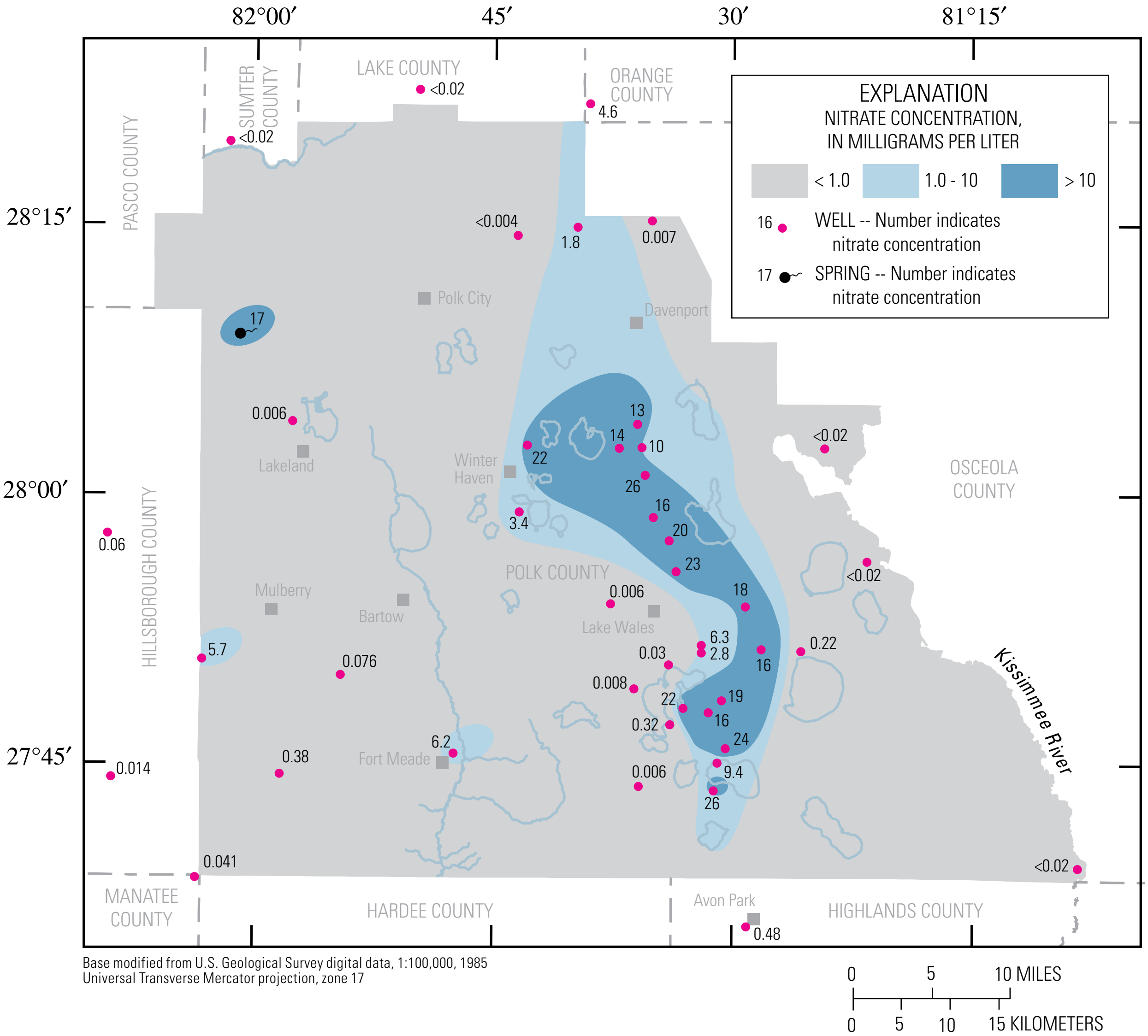


Figure 45. Generalized distribution of nitrate concentrations in water from the surficial aquifer system.

along the Lake Wales Ridge, as well the increases in specific conductance. Nitrates are readily transported in water and are stable over a considerable range of conditions (Hem, 1985). In east-central Florida, concentrations of nitrates in ground water underlying pristine areas were generally low, indicating that natural sources of nitrate do not contribute substantially to concentrations in ground water (Adamski and German, 2004). Water samples collected from the surficial aquifer system beneath undeveloped land in Polk and Highlands Counties also had low nitrate concentrations of less than 0.002 mg/L (Tihansky and Sacks, 1997).

Concentrations of iron in water from the surficial aquifer system ranged from less than 2.0 to 11,300 micrograms per liter (μg/L) (app. 2). Although most water samples yielded concentrations below 300 μg/L (the secondary drinking-water standard), concentrations greater than 300 μg/L were found in some places throughout the county. Iron in ground water is derived from the dissolution of rocks and soils in the aquifer. Concentrations exceeding 300 μg/L may stain laundry and plumbing fixtures. Large quantities of iron cause an unpleasant taste and favor growth of iron bacteria. Repeated use of such water for lawn irrigation can cause staining of sidewalks and buildings.

Intermediate Aquifer System

Concentrations of major ions and nutrients in ground water of the intermediate aquifer system are somewhat variable because of the variability in the lithology of the sediments composing the intermediate aquifer system, and mixtures with water from the underlying Upper Floridan aquifer and overlying surficial aquifer system. Differences in composition result from the abundance of quartz sand, limestone, dolostone, clay, and phosphorite.

Water samples were collected from water-bearing zones from 15 wells tapping the intermediate aquifer system in Polk and adjacent counties. Seven wells tapped Zone 2 and one well tapped Zone 3. The water-bearing zones for seven wells were not determined because geologic or hydrologic information was not available for those sites.

The results of chemical analyses of water from the intermediate aquifer system in Polk and adjacent counties are given in appendix 2. In general, water quality of the intermediate aquifer system in Polk County is within the Florida Department of Environmental Protection primary and secondary drinking-water standards. Water type, as identified by a trilinear diagram, is of a calcium bicarbonate type (fig. 46). Specific conductance, chloride, sulfate, and nitrate concentrations of water from the intermediate aquifer system are shown in figure 47. Specific conductance ranged from 257 to 601 µS/cm. Chloride concentrations in water ranged from 4.1 to 51 mg/L, and sulfate concentrations ranged from less than 0.2 to 17 mg/L. Nitrate concentrations ranged from less than 0.02 to 9.7 mg/L.

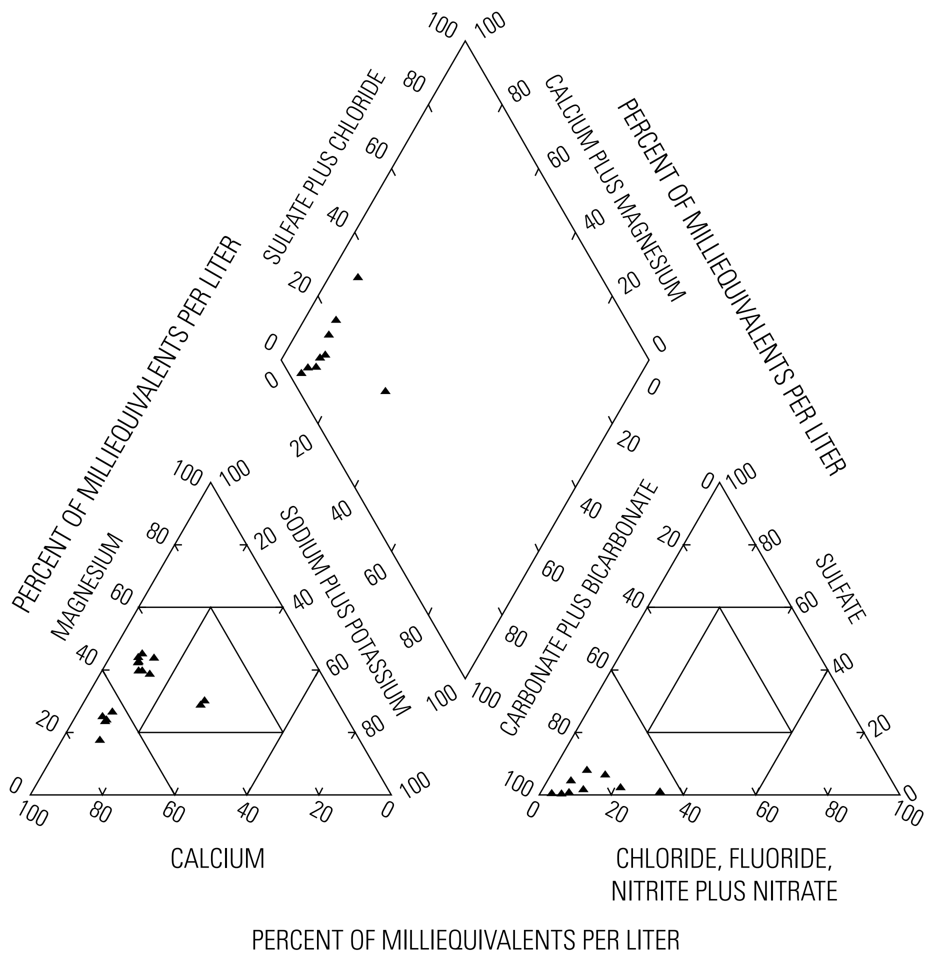


Figure 46. Trilinear diagram for water from wells tapping the intermediate aquifer system.

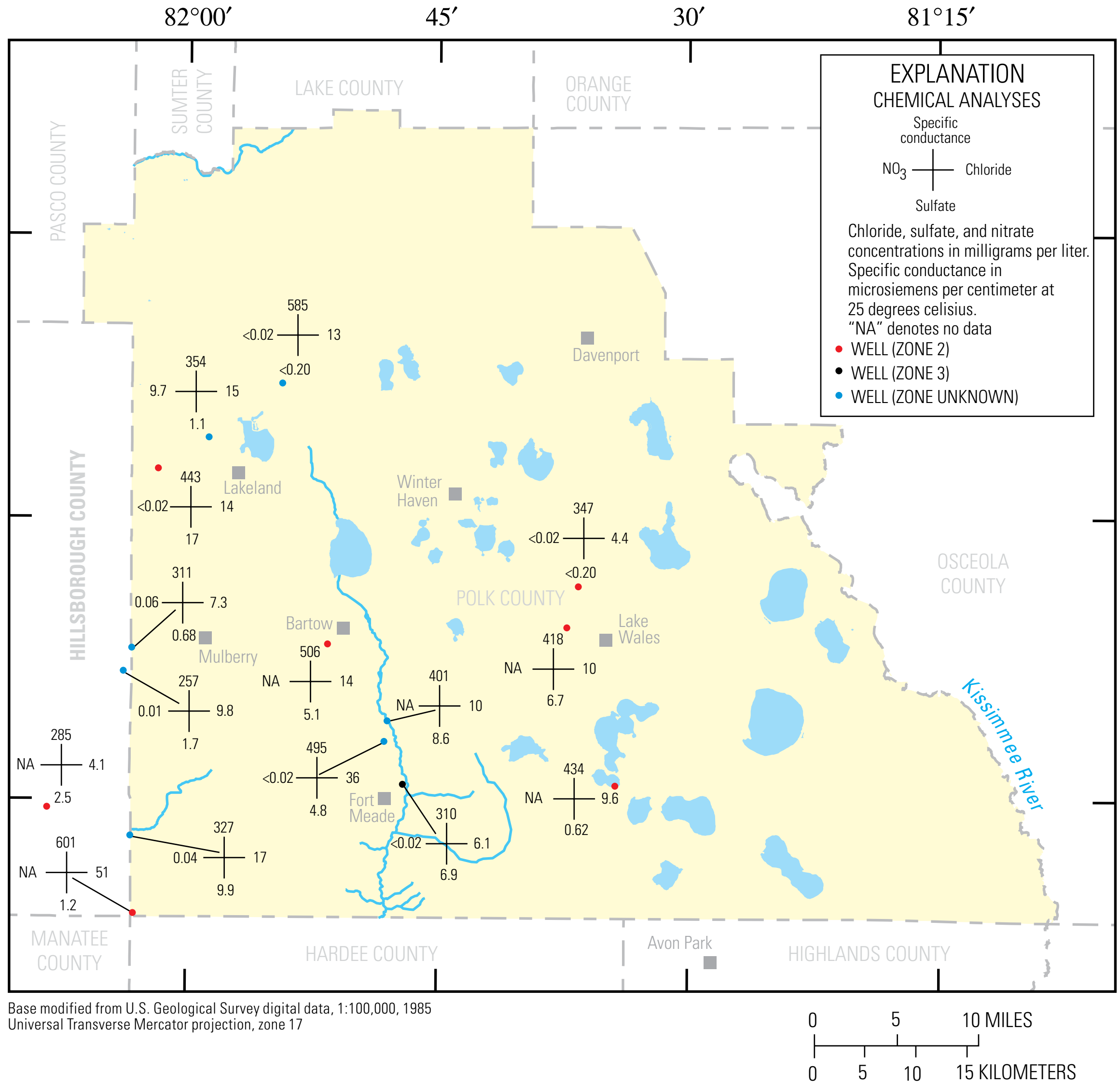


Figure 47. Generalized distribution of selected constituents in water from the intermediate aquifer system.

Floridan Aquifer System

The Upper Floridan aquifer is the major source of potable water to Polk County residents. The aquifer is composed of limestone and dolostone, which generally results in ground water that typically is hard. The quality of water in the Upper Floridan aquifer in Polk County generally meets Florida Department of Environmental Protection primary and secondary drinking-water standards. Water type, as identified by a trilinear diagram, is a calcium bicarbonate type (fig. 48).

Maps of specific conductance, chloride, sulfate, hardness, and nitrate in water from the Upper Floridan aquifer were constructed to delineate areas of different water quality (figs. 49-53). Because all water samples were collected at the wellhead, they represent a composite from the various producing zones penetrated by the open borehole. Major constituent concentrations in water from the Floridan aquifer system vary areally and with depth.

The extent of mineralization of water in the Upper Floridan aquifer is indicated by specific conductance. The areal distribution of specific conductance values from the Upper Floridan aquifer is shown in figure 49. Specific conductance ranged from 104 to 577 µS/cm. The lowest specific conductance (less than 250 µS/cm) generally occurred in eastern Polk County. In much of the western two-thirds of the county, specific conductance ranged from about 250 to

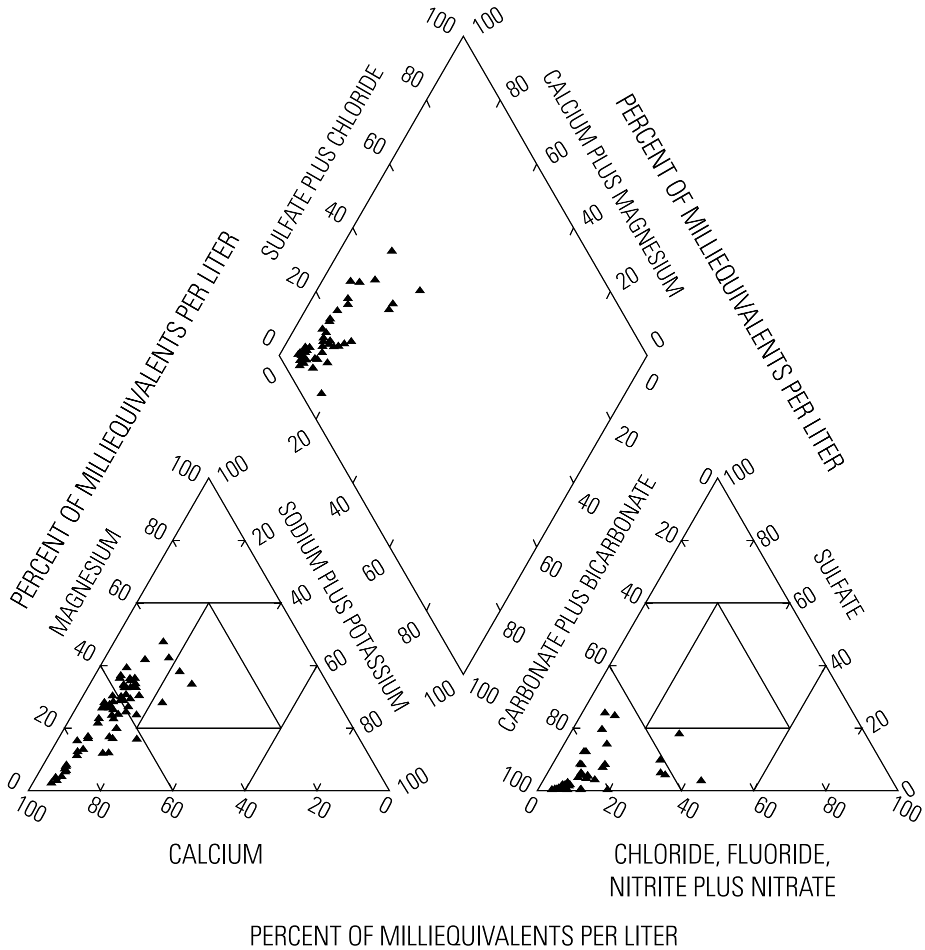


Figure 48. Trilinear diagram for water from wells tapping the Upper Floridan aquifer.

500 µS/cm. Highest specific conductance values were in the Green Swamp area of northwestern Polk County and in parts of the discharge areas near the Kissimmee River.

Another indicator of mineralization is total dissolved-solids concentration. The U.S. Environmental Protection Agency (2000) established a secondary drinking water regulation of 500 mg/L for dissolved-solids concentrations. Because water from many of the wells sampled in the past was not analyzed for dissolved-solids concentration, these values in ground water from the Upper Floridan aquifer were estimated from values of specific conductance. For the range of specific conductance values found in Polk County, multiplying specific conductance by 0.55 to 0.65 gives a reasonable approximation of the dissolved-solids concentration. Thus, specific conductance values shown in figure 49 (as well as existing dissolved-solids concentrations) indicate that water in the entire county is below the 500-mg/L recommended limit for dissolved solids (U.S. Environmental Protection Agency, 2000).

The distribution of chloride concentrations in the Upper Floridan aquifer is shown in figure 50. Concentrations are below the 250-mg/L recommended limit for drinking water throughout the entire county. Chloride concentrations in water from the Upper Floridan aquifer ranged from 4.2 to 61 mg/L (app. 2). The lowest concentrations, generally less than 10 mg/L, occurred in much of eastern and west-central Polk County. Chloride concentrations exceeding 25 mg/L occur at only three sites—one in the southwestern and two in the southeastern parts of the county.

The somewhat higher chloride concentrations (greater than 50 mg/L) that occur in the Upper Floridan aquifer along the Kissimmee River in the extreme southeastern part of the county are probably a mixture of freshwater and relict seawater that entered the aquifer system during a higher stand of sea level in the geologic past. The mineralized water, which has not been completely flushed from the Upper Floridan aquifer, extends east into southern Osceola County (Schiner, 1993).

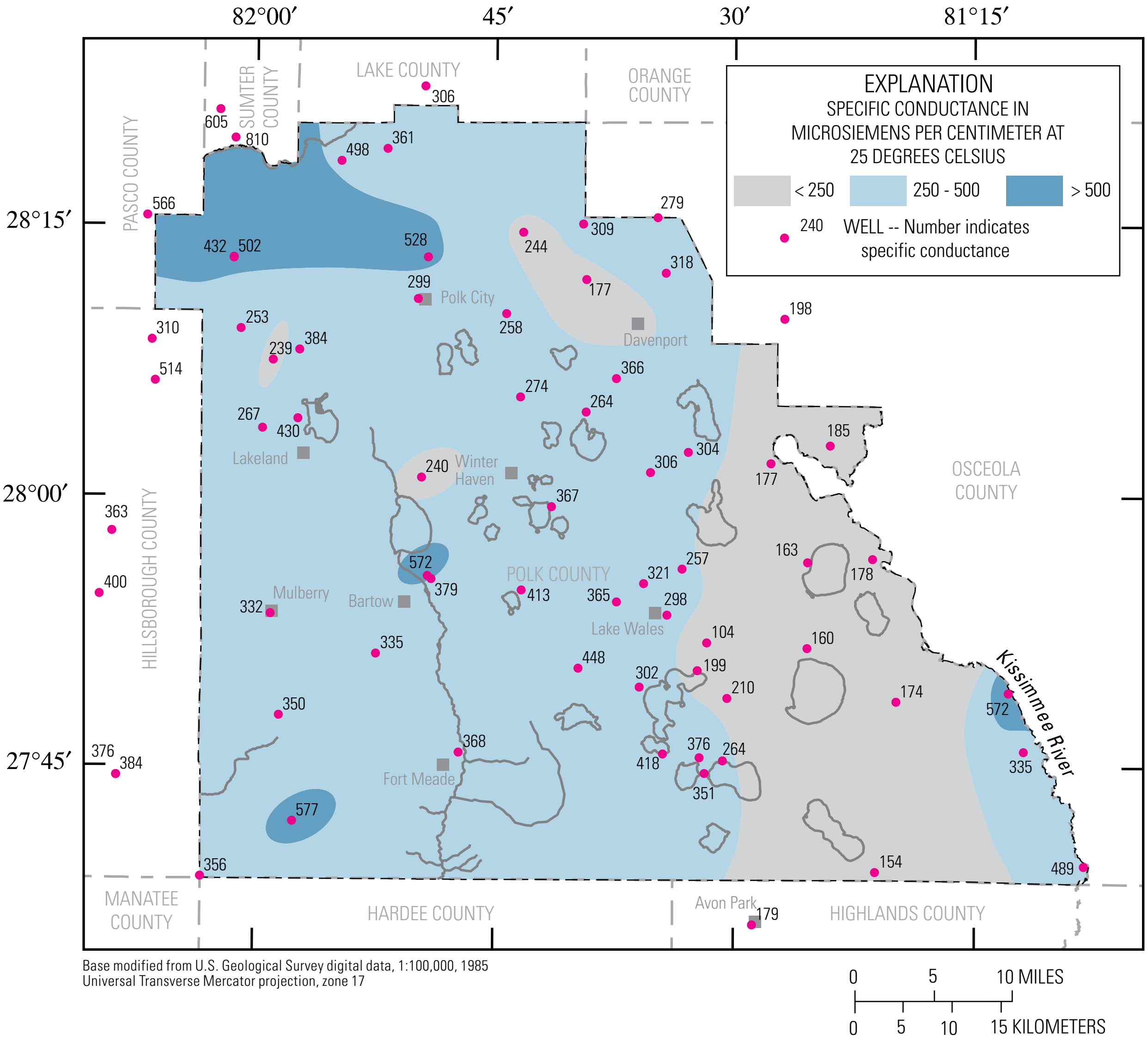


Figure 49. Generalized distribution of specific conductance in water from the Upper Floridan aquifer.

The distribution of sulfate concentrations in the Upper Floridan aquifer is shown in figure 51. Sulfate concentrations ranged from less than 0.20 to 44 mg/L. Sulfate concentrations of less than 10 mg/L occurred in nearly all of the county. Sulfate concentrations exceeding 30 mg/L were primarily in a small area in southwestern and southeastern Polk County.

Hardness concentrations in water sampled from the Upper Floridan aquifer ranged from 70 to 290 mg/L (fig. 52). Concentrations of less than 120 mg/L occurred primarily in eastern Polk County. Concentrations ranging from 120 to 180 mg/L were in much of the western two-thirds of the county. Highest concentrations (greater than 180 mg/L) were in the northwestern part and in a small area in south-central Polk County.

Hardness is principally due to calcium and magnesium ions, and can be an important water-quality criterion for public supply and domestic water use. Hard water may have detrimental effects, such as causing excessive soap consumption and the formation of encrustations or boiler scale. Hardness is expressed as milligrams per liter of calcium carbonate ($CaCO_3$). A classification by Hem (1985) considers water soft if its hardness concentration lies between 0 and 60 mg/L, moderately hard between 61 and 120 mg/L, hard between 121 and 180 mg/L, and very hard for concentrations greater than 180 mg/L of $CaCO_3$. Hardness of water from the Upper Floridan aquifer in Polk County, therefore, ranges from moderately hard to very hard.

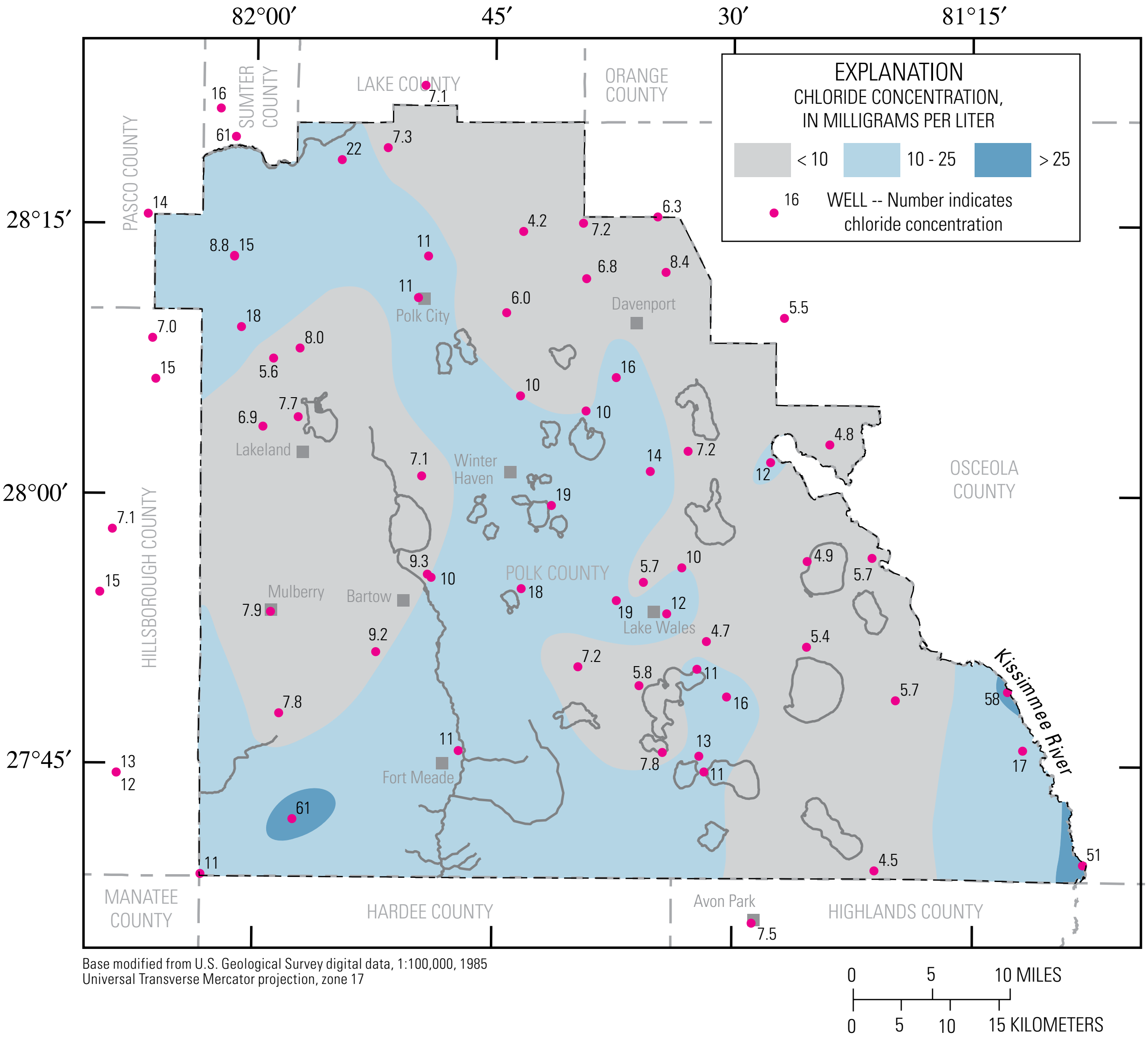


Figure 50. Generalized distribution of chloride concentrations in water from the Upper Floridan aquifer.

Nitrate concentrations in water from the Upper Floridan aquifer range from less than 0.02 to 7.8 mg/L (fig. 53). Most of the water samples collected throughout Polk County had nitrate concentrations less than 0.02 mg/L, and only at three locations did concentrations exceed 1.0 mg/L. Nitrate may enter the Upper Floridan aquifer through breaches in the intermediate confining unit caused by sinkholes or where the intermediate confining unit is thin or absent. Where such features do not exist, nitrate concentrations typically decrease with depth below land surface due to denitrification, a process in which nitrate is reduced into gaseous nitrogen. In general, denitrification occurs when oxygen is depleted, and bacteria turn to nitrate in order to respire organic matter. Four conditions must be present for denitrification to occur: (1) nitrate must be present, (2) anaerobic conditions must be present in the aquifer, (3) a sufficient source of reduced organic carbon must be present, and (4) the bacteria capable of reducing nitrate must be present. Some evidence supporting the occurrence of denitrification is seen by comparing nitrate concentration in water of the surficial aquifer system to that in the Upper Floridan aquifer. At four locations where a comparison could be made (wells 31 and 34, 40 and 42, 93 and 94, 234 and 235), nitrate concentrations observed in Upper Floridan aquifer waters were substantially lower than in the surficial aquifer system. For example, nitrate concentrations were 9.4 mg/L at well 34 (surficial aquifer system) and

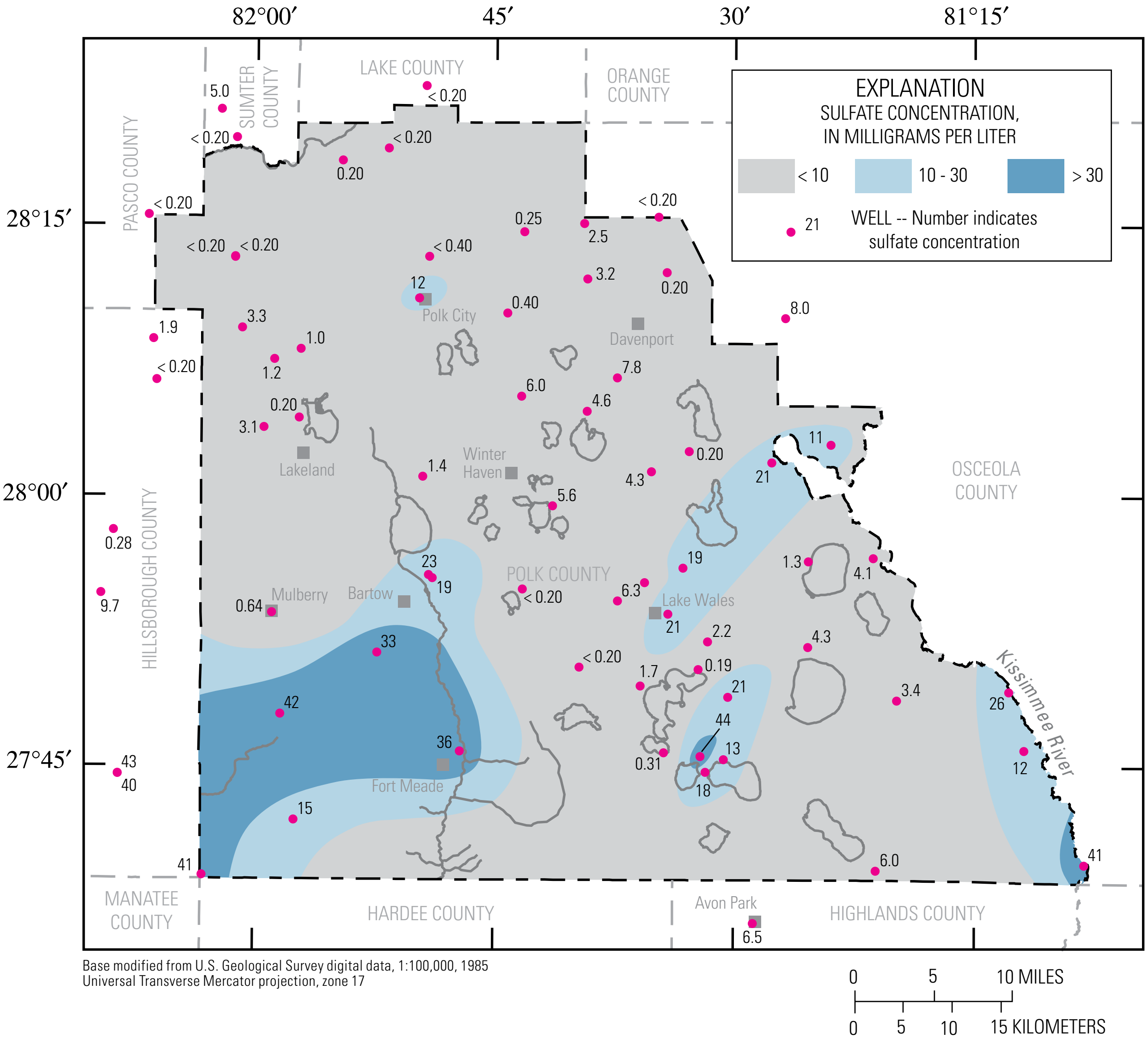


Figure 51. Generalized distribution of sulfate concentrations in water from the Upper Floridan aquifer.

0.01 mg/L at well 31 (Upper Floridan aquifer). Lower nitrate concentrations in the Upper Floridan aquifer compared to the surficial aquifer system, however, do not necessarily indicate that denitrification has occurred. Lower nitrate concentrations in the Upper Floridan aquifer may have resulted from dilution of high nitrate water with low nitrate water present in the Upper Floridan aquifer, or high concentrations found in the surficial aquifer water may not have reached the Upper Floridan aquifer.

Vertical Distribution of Chloride and Sulfate Concentrations

Little data are available on the quality of water underlying the Upper Floridan aquifer in Polk County. Several monitoring wells have been drilled into the Lower Floridan aquifer in northern Polk and adjacent counties to acquire information about variations in water quality within the Floridan aquifer system. Chloride and sulfate concentrations in water samples collected during the drilling of three monitoring wells are shown in figure 54. Water samples were collected through the drill stem as the wells were drilled. Differences in trends in chloride and sulfate profiles are indicators of differences

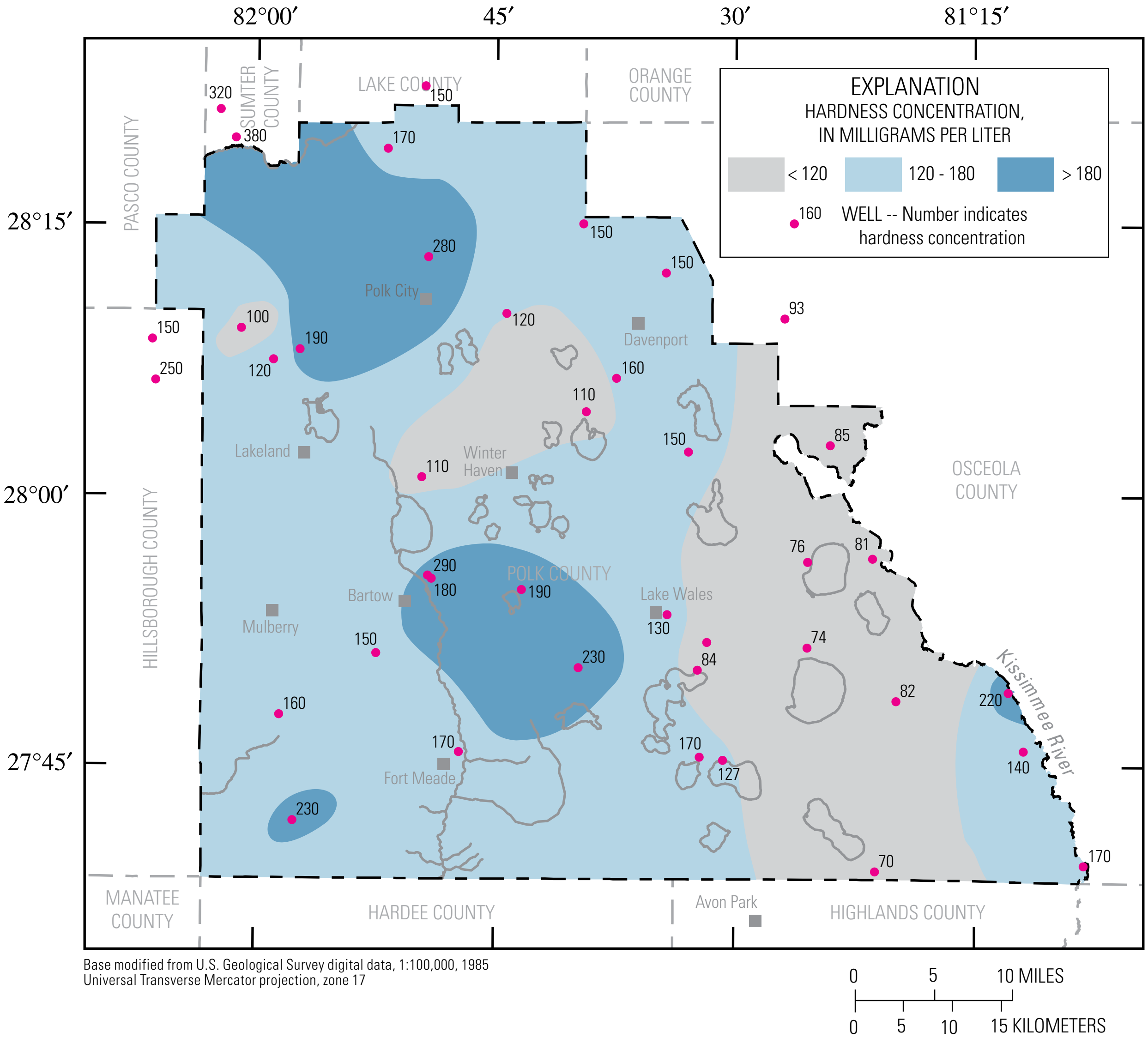


Figure 52. Generalized distribution of hardness concentrations in water from the Upper Floridan aquifer.

in mixing of recharge water, relict seawater, and sulfate-rich water. In general, chloride and sulfate concentrations increased with depth, and water in the Lower Floridan aquifer was more mineralized than in the Upper Floridan aquifer.

The data shown in figure 54 assume that these water samples originate from the formation at or near the drill bit. Under certain conditions, when using the reverse air-rotary method, a change in water quality with depth may not be detected, or may be detected at a somewhat greater depth where the change in water quality occurs. This condition results if the permeability of the rock being drilled is low so that little of the return flow originates from the formation at or near the drill bit. Rather, most of the flow comes from a permeable zone higher in the hole.

The limited water-quality data show that, at least in northern Polk County, ground water having chloride concentrations less than 25 mg/L extends to considerable depths in the Floridan aquifer system. At ROMP 74X (well 203), chloride concentration was less than 25 mg/L to a depth of 1,486 ft below land surface. At the Polk City test well (well 217), chloride concentration was less than 11 mg/L to a depth of about 1,895 ft. At the St. Cloud well (located in northwestern Osceola County), chloride concentration remained below 25 mg/L from about 500 ft to a depth of 1,180 ft. At the interval between 1,180 to 1,220 ft, chloride concentration increased sharply from 25 to 240 mg/L. The increase in chloride concentration occurred near the contact between the middle confining unit and the Lower Floridan aquifer.

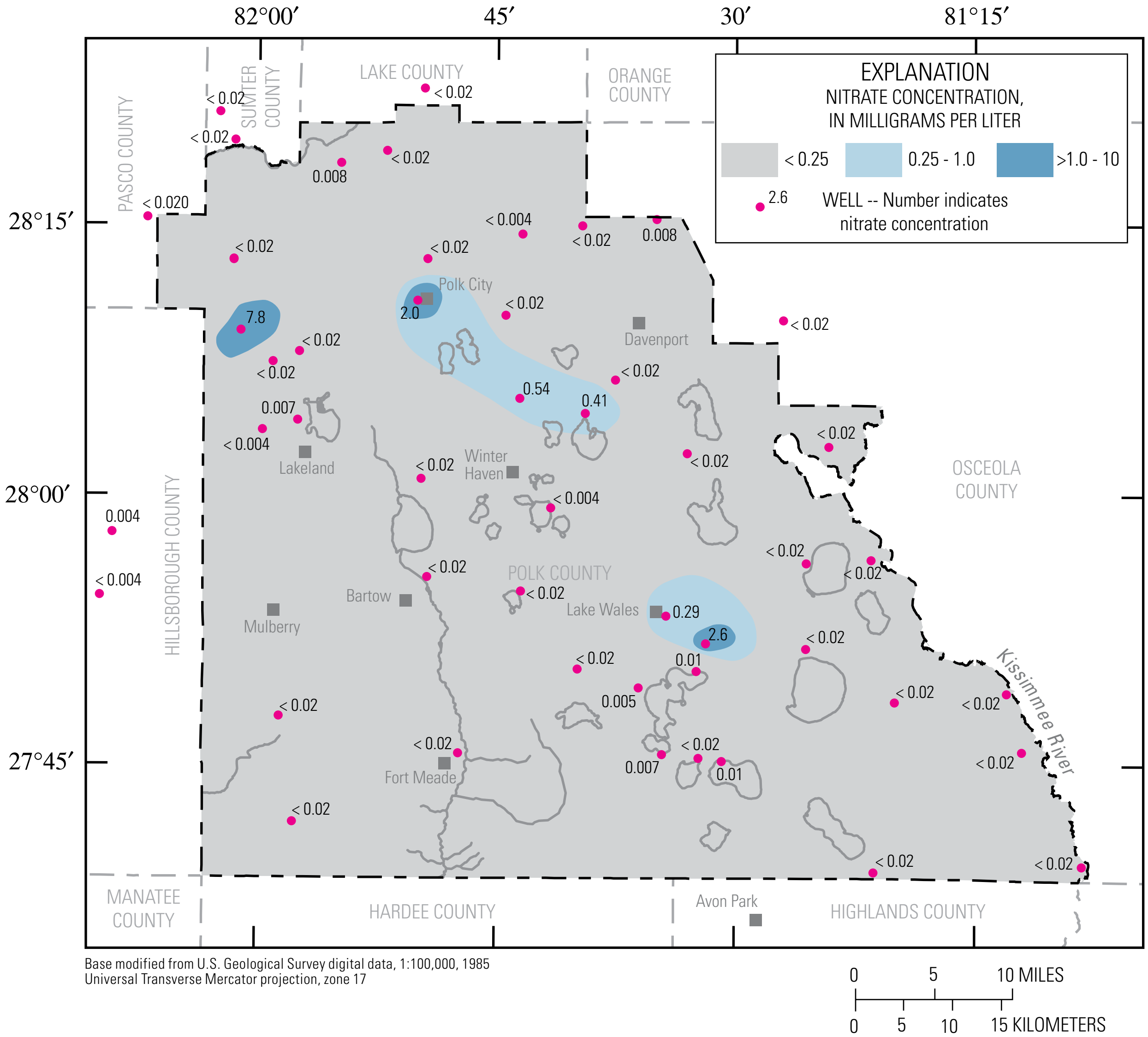


Figure 53. Generalized distribution of nitrate concentrations in water from the Upper Floridan aquifer.

In the interval between 1,220 to 1,480 ft, chloride concentrations increased gradually with depth and ranged from 240 to 660 mg/L. At the interval between 2,020 to 2,140 ft, chloride concentrations increased sharply again from 740 to 3,600 mg/L (O'Reilly and others 2002).

Vertical changes in sulfate concentrations coincide well with the different hydrogeologic units. Sulfate concentrations in the Upper Floridan aquifer and much of the middle semiconfining unit at the three monitoring wells (fig. 54) were generally less than 100 mg/L, but increased substantially when the middle confining unit was penetrated. For example, during the drilling of ROMP 74X (well 203), an increase in sulfate concentration from 66 to 314 mg/L was observed between 1,051 and 1,071 ft below land surface (Gates, 2003). This increase marked the approximate contact where evaporites were first found, which is also considered to be the top of the middle confining unit. Sulfate concentrations remained constant throughout the middle confining unit but increased to 2,210 mg/L after the Lower Floridan aquifer was penetrated. During the drilling of the St. Cloud well, sulfate concentrations increased from 72 to 420 mg/L in the interval between 760 to 800 ft (O'Reilly and others, 2002). The top of the middle confining unit is estimated at 800 ft. Between 1,180 and 1,220 ft below land surface, a moderate decrease in sulfate concentration was observed, along with a sharp increase in chloride concentration. This change in water quality corresponds with a change in head difference and apparently marks the base of the middle confining unit (the top of the Lower

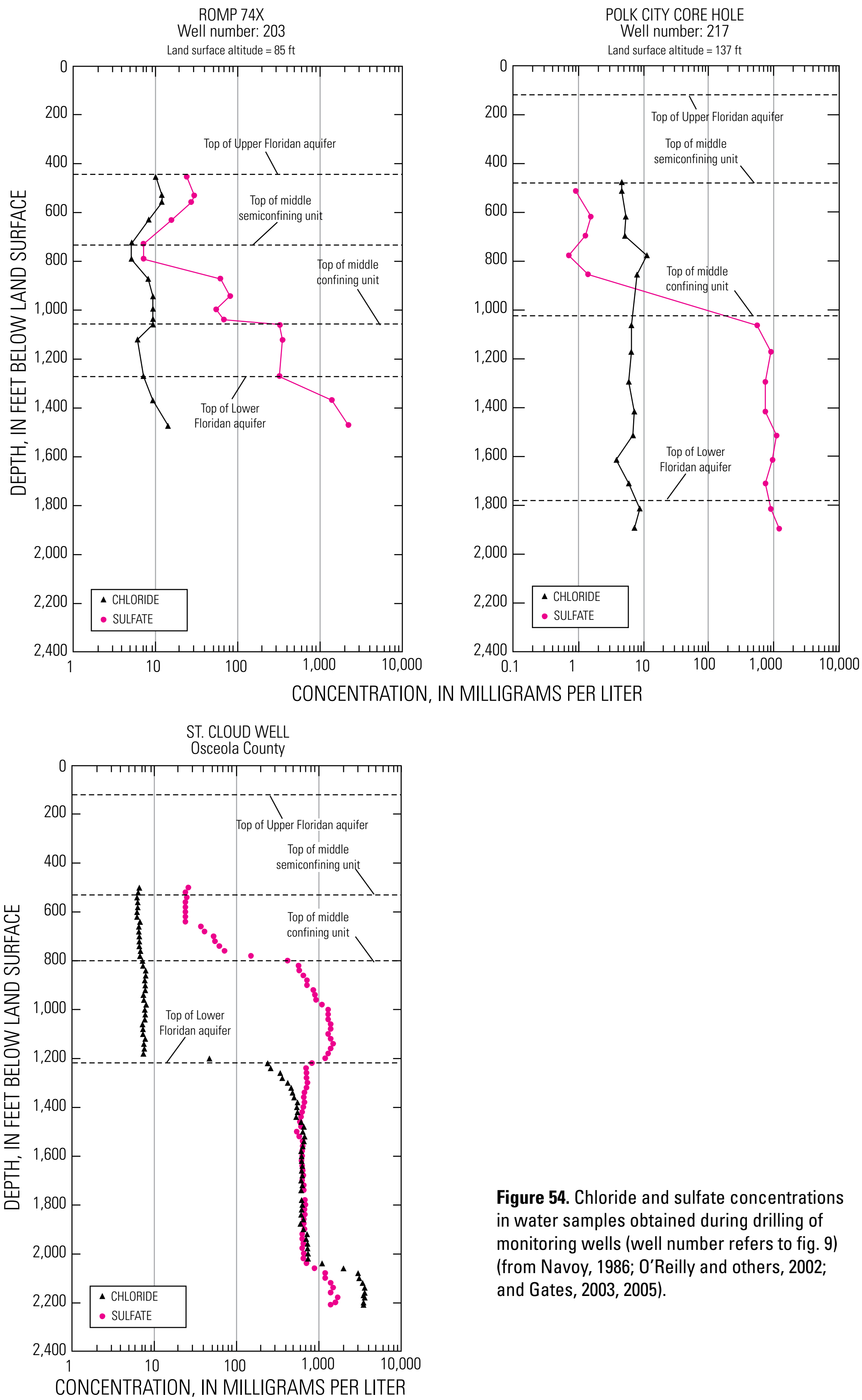


Figure 54. Chloride and sulfate concentrations in water samples obtained during drilling of monitoring wells (well number refers to fig. 9) (from Navoy, 1986; O'Reilly and others, 2002; and Gates, 2003, 2005).

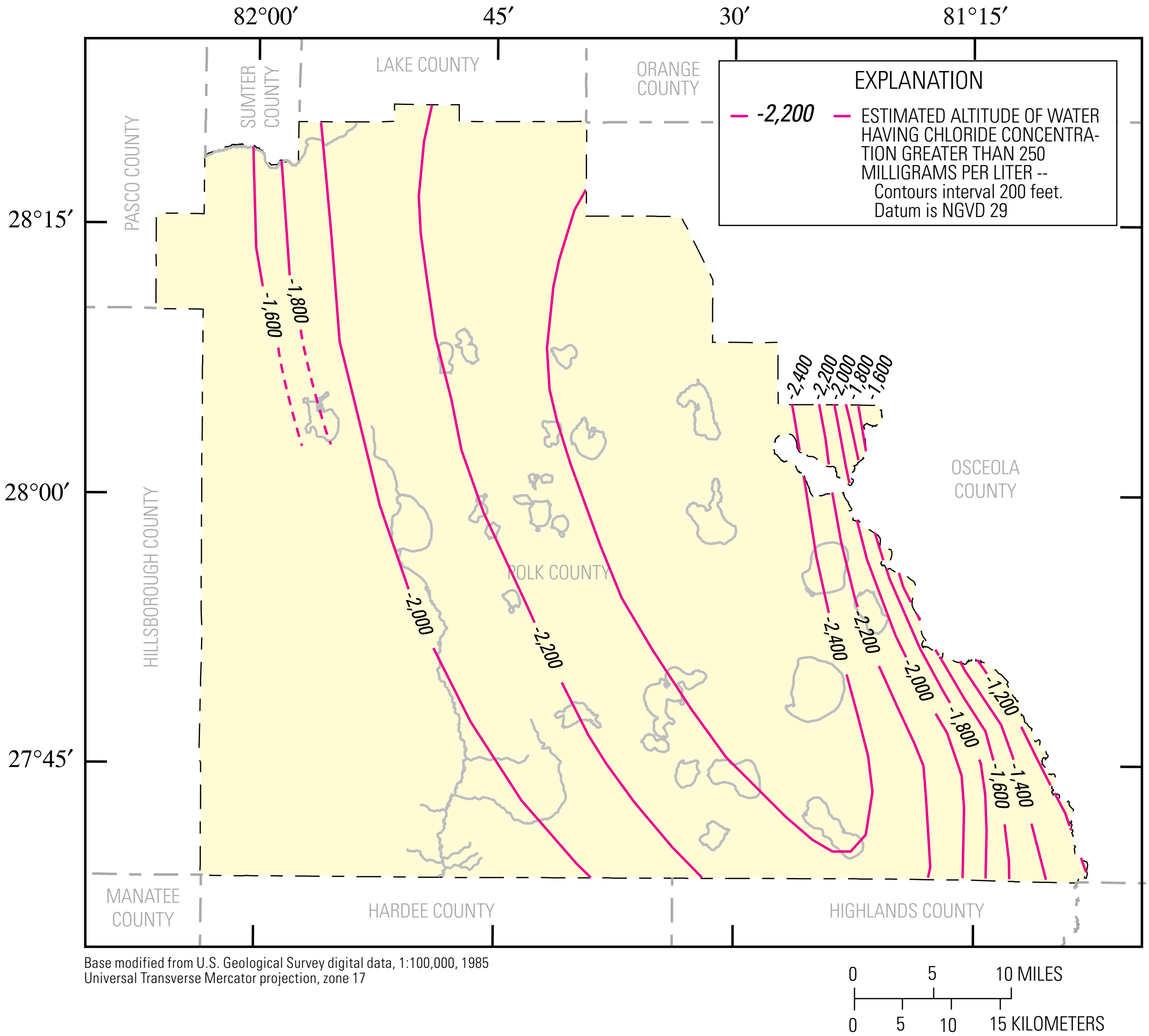


Figure 55. Estimated altitude of water in the Florida aquifer system having chloride concentrations greater than 250 milligrams per liter (from McGurk and others, 2003).

Floridan aquifer) (O'Reilly and others, 2002). At the Polk City test well, sulfate concentration increased from 1.4 mg/L at 856 ft to about 560 mg/L at 1,065 ft below land surface.

A generalized map of the altitude of water with chloride concentrations greater than 250 mg/L is shown in figure 55. The map, taken from a larger map covering the 19 counties of the SJRWMD, was based primarily on water-quality samples collected from monitoring and test wells, and on surface- and borehole-geophysical data (McGurk and others, 2003). The altitude of the top of the 250-mg/L isochlor is variable throughout Polk County, and the estimated position of the top of the 250-mg/L isochlor surface is less than 1,200 ft below NGVD 29 in the extreme southeastern part of the county. The thickest section where chloride concentrations are less than 250 mg/L is along the Lake Wales Ridge. In this area, the altitude of the top of the 250-mg/L isochlor is estimated to be about 2,400 ft below NGVD 29. In the western half of the county, the isochlor surface appears to rise gradually. Because few deep wells were drilled in western Polk County, little is known about the vertical distribution of chloride concentrations in the Floridan aquifer system. Thus, the estimated altitudes of the 250-mg/L isochlor were not drawn in parts of western Polk County. Figure 55, however, may not accurately portray the thickness of the freshwater zone in the county. The limited data indicate that beneath the top of the middle confining unit, dissolved-solids concentrations could be too high (due primarily to the high concentrations of sulfate) to consider the ground water in this part of the aquifer as fresh.

CHAPTER 2—Streamflow and Lake-Level Characteristics in Polk County

Purpose and Scope

This chapter describes the streams and lakes of Polk County, emphasizing trends in streamflow and lake levels. No information on water quality is presented. Substantial changes in the county that may affect streamflows and lake levels are described. Streamflow and lake locations summarized in this study are shown in figure 56 and appendix 3. Temporal trends in streamflows were updated using data through the year 2003. Streamflow duration curves and low- and flood-flow frequency statistics also were updated through 2003. Seasonal fluctuations and temporal trends in lake levels are presented using data from 1960-2003. The factors that control lake levels in the county are summarized based upon the existing literature. Temporal trends in streamflow and flow-frequency statistics were determined using USGS data. Lake-level trends were determined using data collected by the SFWMD, SWFWMD, and USGS.

Methods

Several statistical methods were used in this study. Temporal trends in streamflow and lake levels were determined using Kendall's tau (Helsel and Hirsch, 1992). Strong linear correlations correspond to tau levels of 0.7 and greater (Helsel and Hirsch, 1992). The criterion for statistical significance used was the 0.05 significance level. The annual minimum, maximum, 10th, 30th, 50th, 70th, and 90th percentiles of streamflow were tested for trends to gain information about how different parts of the streamflow regime have changed over time. Temporal trends in streamflow also were analyzed over 15 multidecadal periods, ranging from 20 to 60 years, to gain insight into the short-term temporal trends and the persistence of any temporal trends over time. Long-term temporal trends in lake levels in Polk County were updated during this study using data from 1960-2003. Temporal trends also were determined for 1990-2003, using a larger set of lakes, to quantify recent trends that may have occurred.

Kendall's tau and the resulting p-values were corrected for ties in the time series according to Helsel and Hirsch (1992). A large number of ties (values with the same sign and magnitude) can cause misleading results when calculating and interpreting Kendall's tau. The variance of the test statistic is used to calculate the p-values associated with Kendall's tau. As the number of ties in the time series increases, the variance of the test statistic decreases, which results in a more significant value of Kendall's tau.

Low-flow frequency statistics were determined by fitting time series of annual minimum streamflows over 1, 2, 3, 7, 10, 30, 60, 90, 183, and 365 consecutive-day periods, commonly referred to as N-day annual minimum low-flow values, to a log Pearson Type III distribution (Riggs, 1972). In this study, N-day annual minimum flows were computed using a climatic year beginning on October 1 to ensure that all low-flow data related to a particular drought are contained in the same climatic year because the lowest streamflows in Polk County typically occur from April through June. Flood-frequency statistics were determined using the method described by the U.S. Interagency Advisory Committee on Water Data (1982).

The accuracy of low-flow and flood-frequency statistics is dependent upon the period of record used in the analysis, the variability and skewness of the data, and the recurrence interval. Standard error was calculated according to Kite (1977) for selected low-flow and flood-frequency statistics. This procedure assumes the error in the estimation of frequency statistics is a function of the uncertainty in estimating the mean, standard deviation, and skewness of the data.

Streamflow and Lake-Level Characteristics

Polk County contains the headwaters of five river basins—the Alafia, Hillsborough, Peace, Ocklawaha, and Withlacoochee Rivers. The county also contains numerous lakes and part of the Kissimmee River Basin (fig. 57). Surface-water drainage from the county primarily occurs through the Peace and Kissimmee Rivers. Many changes to surface-water drainage patterns have occurred since the late 1800s. For flood-control purposes, the Kissimmee River downstream from Lake Kissimmee was channelized and many other lake outlets were modified (Barcelo and others, 1990), either by constructing structures to regulate lake levels or constructing canals to connect previously unconnected lakes.

Streamflow and lake level characteristics and trends were assessed in this study because the changes in the ground-water resources that have occurred in Polk County also have been expressed in the surface-water resources. Prior to human development, the Peace River was considered to be a gaining stream, which continuously received inflow from the ground-water system (Southwest Florida Water Management District, 2002). The river now (2005) loses water to the ground-water system in parts of Polk County because the hydraulic gradient in the vicinity of the river has been reversed because of the lowering of the potentiometric surface of the Upper Floridan

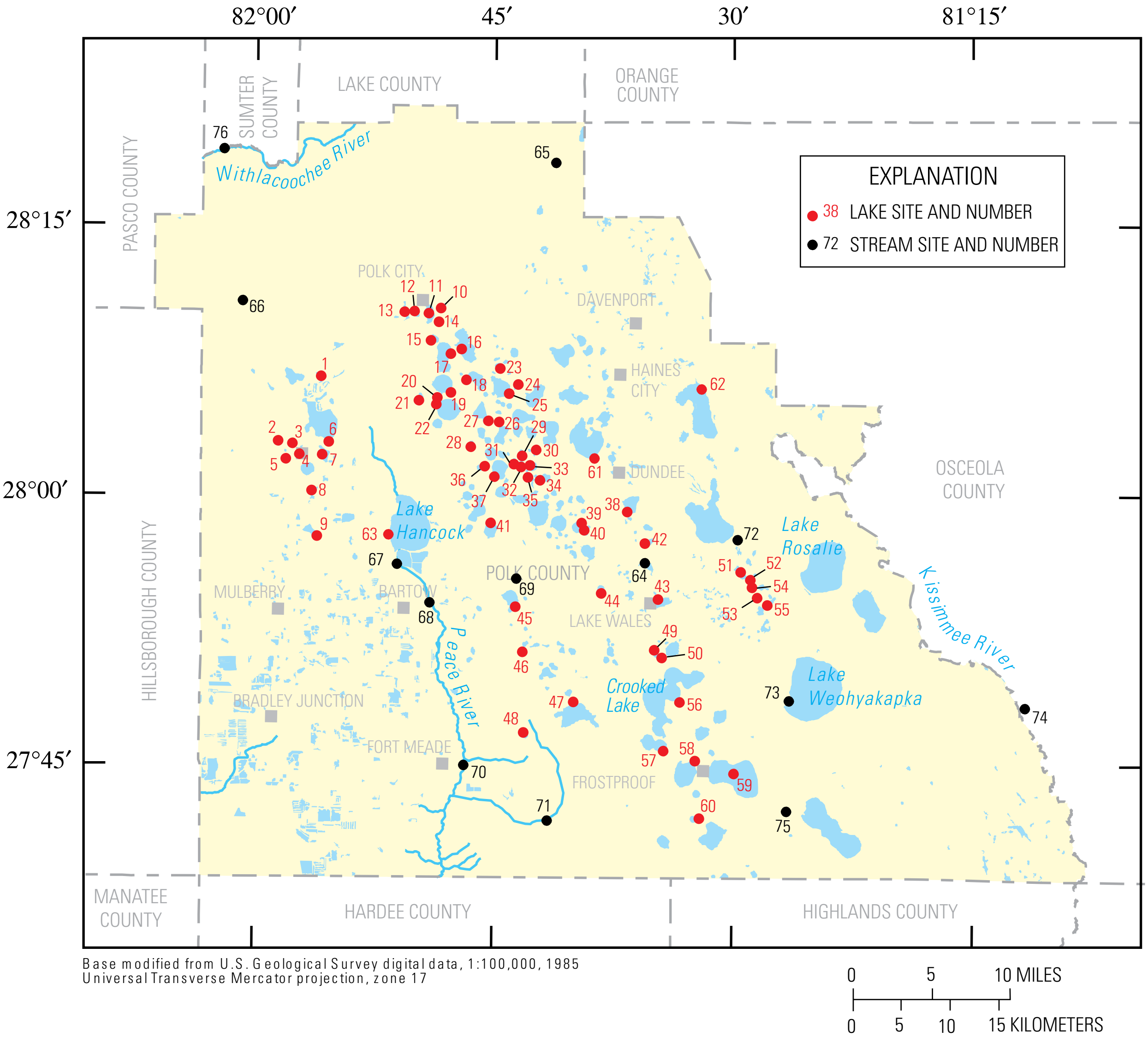


Figure 56. Location of lakes and streams analyzed in this report (site names in appendix 3).

aquifer system (Lewelling and others, 1998). Several investigators (Geraghty and Miller, Inc., 1980; Barcelo and others, 1990) also reported declining water levels over time in several of the lakes in Polk County, most notably in Crooked Lake, Lake Clinch, and Lake Buffum. Other lakes, such as Reedy Lake, have had no substantial declines in lake levels (Barcelo and others, 1990) despite being in the immediate vicinity of lakes that do.

Streamflow Characteristics

Mean annual runoff for individual basins in the county ranges from 6.6 to 16.1 in. (table 2). Runoff was calculated by dividing the mean annual streamflow by the basin area and is given in inches of water over the entire basin area. Streamflow generally has a seasonal distribution, which is similar to the Peace River at Bartow (fig. 58). Streamflow generally is greatest in September and October, which is near the end of the wet season. The lowest streamflow usually occurs in May or June.

Several investigators (Enfield and others, 2001; McCabe and Wolock, 2002; Basso and Schultz, 2003; Kelly, 2004) have related streamflow conditions in Florida and elsewhere in the United States to shifts in climatic conditions or multidecadal cycles in precipitation. Enfield and others (2001) reported Mississippi River outflow varied by 10 percent between warm and cool AMO phases, and the estimated unregulated inflow to Lake Okeechobee varied by 40 percent. Kelly (2004) reported significantly higher streamflows in west-central Florida during 1940-1969 compared to 1970-1999, which roughly coincides with the warm and cool phases of the AMO.

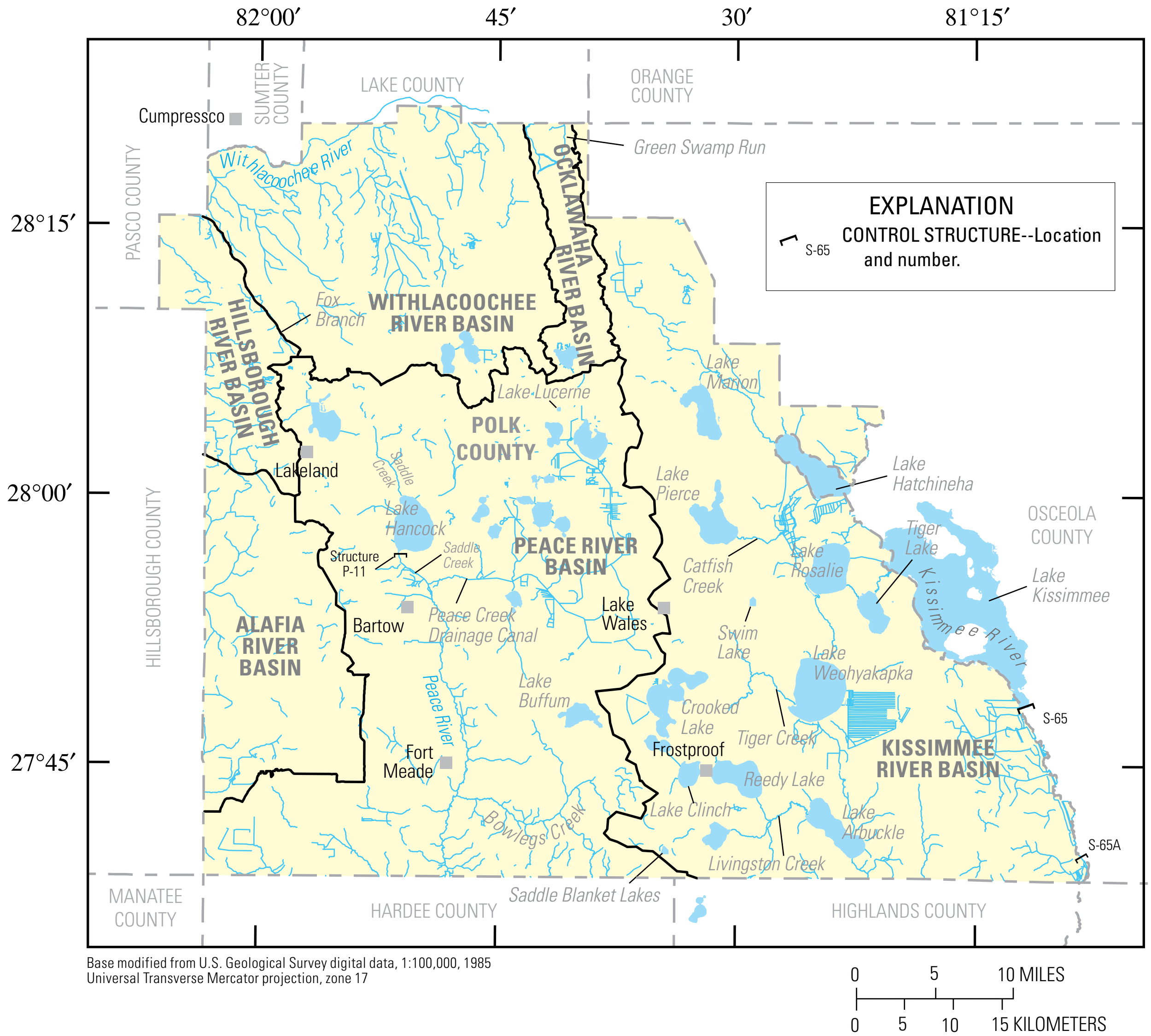


Figure 57. Major surface-water drainage basins, tributaries, and lakes.

Table 2. Mean annual flow and runoff for selected streams in Polk County, water years 1991-2003.

[Locations of site numbers shown in figure 56]

Site number	Location name	Drainage basin	Drainage area, in square miles	Mean annual flow, in cubic feet per second	Mean annual runoff, in inches
76	Withlacoochee River near Cumpressco	Withlacoochee	280	144	7.0
65	Green Swamp Run near Eva	Withlacoochee	43	29.1	9.2
72	Catfish Creek near Lake Wales	Kissimmee	58.9	35.5	8.2
73	Tiger Creek near Babson Park	Kissimmee	52.8	37.9	9.8
74	Kissimmee River at S-65, near Lake Wales	Kissimmee	1,607	1,274	10.8
75	Livingston Creek near Frostproof	Kissimmee	120	58	6.6
66	Fox Branch near Socrum	Hillsborough	9.5	11.3	16.1
67	Saddle Creek near Structure P-11 near Bartow	Peace	135	83.1	8.4
68	Peace River at Bartow	Peace	390	215	7.5
69	Peace Creek Drainage Canal near Wahneta	Peace	162	97	8.1
70	Peace River at Fort Meade	Peace	480	259	7.3
71	Bowlegs Creek near Fort Meade	Peace	47.2	29.1	8.4

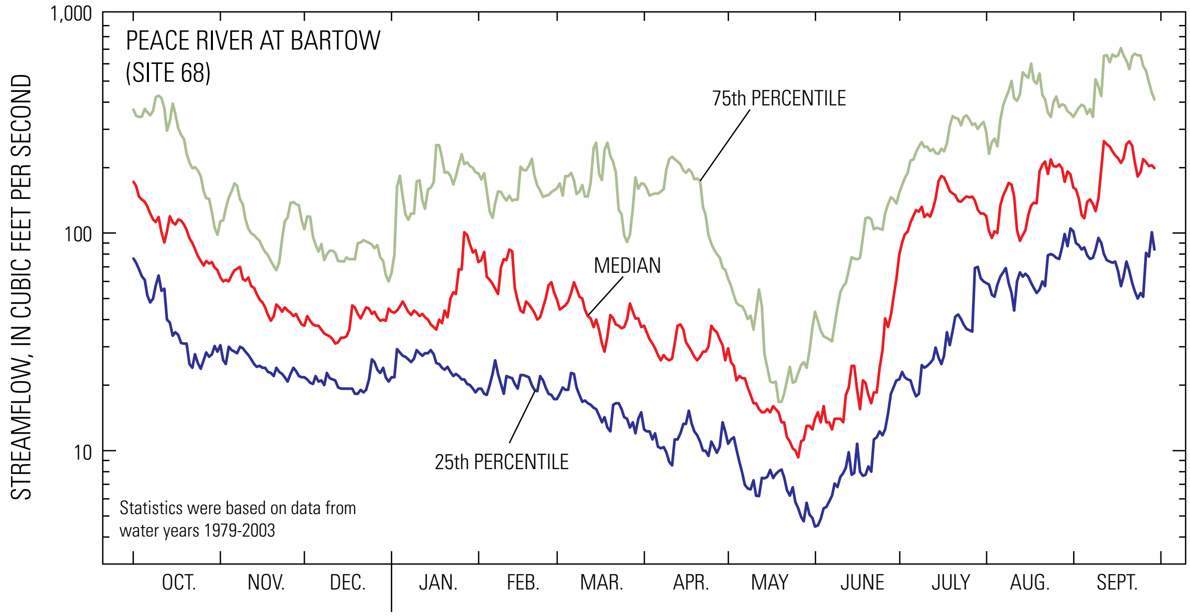


Figure 58. Flow-duration hydrographs for Peace River at Bartow, water years 1979-2003.

Peace River Basin

The confluence of Saddle Creek and the Peace Creek Drainage Canal form the headwaters of the Peace River (fig. 57). Saddle Creek originates from lakes north of the city of Lakeland, and is regulated by structure P-11, which is near the outlet of Lake Hancock. As its name implies, the Peace Creek Drainage Canal is not a natural stream. Peace Creek was dredged in the 1930s and in places was channelized to drain the land, forming the Peace Creek Drainage Canal (Southwest Florida Water Management District, 2002).

The natural hydrography of the part of the Peace River Basin north of Fort Meade was altered by the surface mining of phosphate ore (T. King, Florida Fish and Wildlife Conservation Commission, written commun., 1995; University of South Florida, 2003; Basso, 2003). Reclamation of surface-mined land prior to July 1, 1975, was voluntary (Florida Institute of Phosphate Research, 2006a), and the post-mining topography was generally characterized by mine pit lakes, clay settling areas, sand tailings, and tracts of homogenized overburden (University of South Florida, 2003). Since 1975, the State of Florida required reclamation of all surface-mined areas (Florida Statutes, chapter 378), which generally consists of reshaping the land to resemble the premining topography and hydrography and replanting the landscape (Florida Institute of Phosphate Research, 2006b). Clay settling areas are former mine pits where fine particles of waste sand, clay, and phosphate from the beneficiation process are allowed to settle and consolidate. Beneficiation refers to the process used to separate the sand and clay from the phosphate rock. The waste products from phosphate mining typically consist of a slurry of about 3- to 5-percent solids. This slurry takes years to settle and eventually consolidates into a relatively impermeable layer. Lewelling and Wylie (1993) determined the hydraulic conductivity of materials redeposited in areas reclaimed with waste clay ranged from 0.01 to 1.2 ft/d, which is lower compared to values in areas reclaimed using other methods.

Surface-water drainage to the Peace River within Polk County is limited. Most of the surface-water drainage to the river between Bartow and Fort Meade is water released from five phosphate-mine outfalls and reclaimed stream channels (Lewelling and others, 1998; Basso, 2003). Bowlegs Creek is the largest tributary to the Peace River within Polk County (fig. 57), and provides a minor amount of flow to the river. The mean annual streamflow in Bowlegs Creek near Fort Meade (site 71) was 29.1 ft^3/s, compared to 215 ft^3/s in the Peace River at Bartow (site 68), based on data from water years 1991-2003 (table 2). The water year is the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which it ends. Thus, the year ending September 30, 2002, is called the 2002 water year.

Flow-duration curves constructed from data collected at the Bartow and Fort Meade stream gages illustrate the loss of water from the Peace River to the ground-water system during low-flow conditions along this reach (fig. 59). During low-flow conditions, streamflow per square mile at Bartow is greater compared to the downstream Fort Meade site. Furthermore, the entire flow of the river has been observed disappearing into karstic features in the streambed during dry

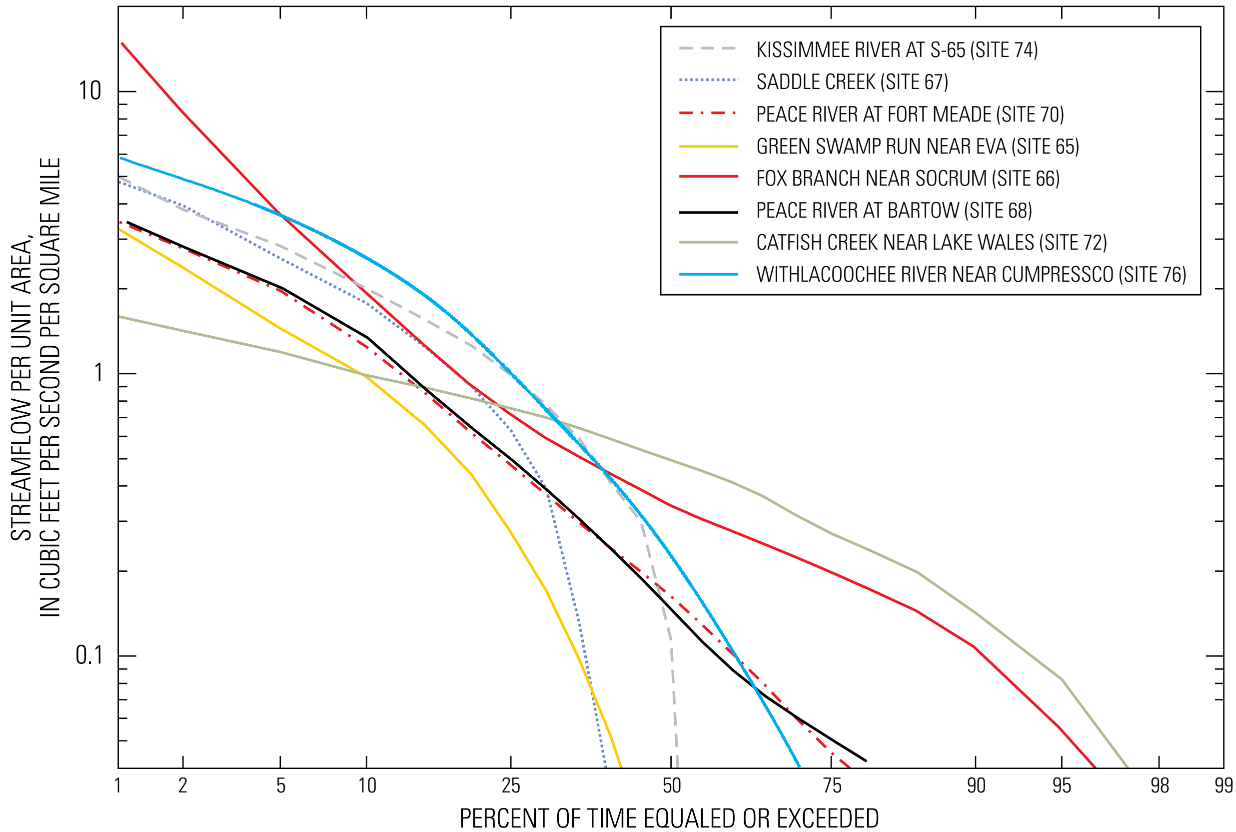


Figure 59. Flow-duration curves for selected stream sites in Polk County, water years 1979-2003.

periods (Hammett, 1990; Barr, 1992; Lewelling and others, 1998). Seepage runs have been conducted along the Peace River during low- and high-flow conditions to quantify the amount of water lost to the ground-water system. Seepage runs consist of a series of streamflow measurements along a stream reach during stable flow conditions to quantify streamflow gains and losses. Between Bartow and Fort Meade, the Peace River lost 16 to 30 ft^3/s of water during low-flow conditions (Lewelling and others, 1998; R. Basso, Southwest Florida Water Management District, written commun., 2006). Some water also may be lost to the ground-water system during high-flow conditions. Lewelling and others (1998) reported a loss of 118 ft^3/s during high-flow conditions, although this loss of water may be an artifact of the measurement technique, which had an estimated error of 5 to 8 percent.

Previous studies reported statistically significant declining streamflows in the Peace River at Bartow from 1940-2002 (Hammett, 1990; Flannery and Barcelo, 1998; Lewelling and others, 1998; Southwest Florida Water Management District, 2002). This decrease has been attributed to rainfall deficits, which have occurred since about 1960, and the lowering of the potentiometric surface of the Upper Floridan aquifer in the area (fig. 34). Previous analyses of the data from the Bartow and Fort Meade stream gages have indicated that most of these decreases occurred prior to 1965. Most investigators have reported no significant trends in annual mean or mean monthly streamflows from 1965-2000 (Flannery and Barcelo, 1998; Lewelling and others, 1998). These stationary trends were attributed to improved water-conservation practices implemented by the phosphate-mining industry. One study (Southwest Florida Water Management District, 2002) reported a significant reduction in low streamflows (10th percentile) at the Peace River at Bartow from 1970-1990. This decrease was attributed to reductions in point-source discharges to the river during the 1980s.

Temporal trend analyses conducted over several multidecadal periods in this report indicate annual minimum to 70th percentile streamflows have declined in the upper part of the Peace River. The analyses also indicate these declines began in the 1950s and have persisted to 2003. An analysis of the data over a series of 20-year periods showed that annual minimum and 10th percentile streamflows from the Peace River at Bartow significantly increased from water years 1944-1963 (table 3), which is consistent with the trend analyses reported by the Southwest Florida Water Management District (2002). Annual minimum to 70th percentile streamflows at the Bartow site, however, significantly decreased from 1954-1973. These decreases persisted when data over 30-, 40-, 50-, and 60-year periods were analyzed (tables 4 and 5). In contrast to the results from other studies that reported stabilized annual

Table 3. Temporal trends in streamflow over 20-year periods for Peace River at Bartow.

[Top value, Kendall's tau; bottom value, p-value; values significant at the 0.05 significance level are shown in bold]

Flow statistic	Period analyzed				
	1944-1963	1954-1973	1964-1983	1974-1993	1984-2003
Annual minimum flow	**0.5579** **.0006**	**-0.5158** **.0016**	-0.1579 .3457	-0.3789 .0211	-0.2368 .1522
Annual 10th percentile	**.5474** **.0008**	**-.4947** **.0026**	-.3158 .0556	-.2684 .1046	-.1579 .3462
Annual 30th percentile	.3105 .0597	**-.4474** **.0064**	-.2842 .0852	-.2105 .2048	-.0316 .8710
Annual 50th percentile	.2316 .1630	**-.3632** **.0273**	-.2000 .2300	-.1263 .4556	.0789 .6495
Annual 70th percentile	.0316 .8711	**-.3263** **.0478**	-.0211 .09225	-.1474 .3810	.1368 .4173
Annual 90th percentile	-.0632 .7211	-.2526 .1273	.0000 1.0000	.0316 .8711	.1368 .4173
Annual maximum flow	-.1000 .5590	-.2211 .1834	.0211 .9225	-.0158 .9482	**.3263** **.0478**

Table 4. Temporal trends in streamflow over 30-year periods for Peace River at Bartow.

[Top value, Kendall's tau; bottom value, p-value; values significant at the 0.05 significance level are shown in bold]

Flow statistic	Period analyzed			
	1944-1973	1954-1983	1964-1993	1974-2003
Annual minimum flow	-0.0115 .9431	**-0.4989** **.0001**	**-0.4598** **.0004**	**-0.3724** **.0040**
Annual 10th percentile	.0161 .9147	**-.5310** **.0000**	**-.4920** **.0001**	**-.2598** **.0455**
Annual 30th percentile	-.1609 .2181	**-.4712** **.0003**	**-.4207** **.0012**	-.1172 .3719
Annual 50th percentile	-.1471 .2609	**-.3862** **.0029**	**-.3241** **.0125**	.0069 .9715
Annual 70th percentile	-.2368 .0688	-.2368 .0688	-.2230 .0868	.0253 .8584
Annual 90th percentile	**-.2920** **.0246**	-.1494 .2535	-.0943 .4754	.0805 .5441
Annual maximum flow	**-.3126** **.0160**	-.0989 .4537	-.1149 .3819	.2046 .1163

Table 5. Temporal trends in streamflow over 40-, 50-, and 60-year periods for Peace River at Bartow.

[Top value, Kendall's tau; bottom value, p-value; values significant at the 0.05 significance level are shown in bold]

Flow statistic	40-year period			50-year period		60-year period
	1944-1983	1954-1993	1964-2003	1944-1993	1954-2003	1944-2003
Annual minimum flow	**-0.2205** **.0461**	**-0.6244** **.0000**	**-0.4705** **.0000**	**-0.4237** **.0000**	**-0.6155** **.0000**	**-0.4876** **.0000**
Annual 10th percentile	**-.2308** **.0370**	**-.6167** **.0000**	**-.4410** **.0001**	**-.4147** **.0000**	**-.5755** **.0000**	**-.4497** **.0000**
Annual 30th percentile	**-.3359** **.0023**	**-.5487** **.0000**	**-.2897** **.0087**	**-.4661** **.0000**	**-.4416** **.0000**	**-.4181** **.0000**
Annual 50th percentile	**-.2949** **.0076**	**-.4551** **.0000**	-.1808 .1028	**-.4073** **.0000**	**-.3355** **.0006**	**-.3362** **.0002**
Annual 70th percentile	**-.2641** **.0169**	**-.3538** **.0014**	-.0718 .5216	**-.3829** **.0001**	**-.2229** **.0229**	**-.2791** **.0017**
Annual 90th percentile	**-.2590** **.0192**	-.2051 .0640	-.2590 .0192	**-.3061** **.0018**	-.1135 .2483	**-.2192** **.0136**
Annual maximum flow	**-.2551** **.0210**	-.1756 .1130	.1102 .3219	**-.2996** **.0022**	.0008 1.000	-.1475 .0972

mean and mean monthly streamflows from the 1970s to the 1990s, there were significant decreases in the annual minimum streamflows at the Bartow (tau = -0.3789, p = 0.0211) and Fort Meade (tau = -0.2709, p = 0.0407) sites from 1974-1993 and 1975-1993, respectively.

Annual 90th percentile and maximum streamflows in the Peace River at Bartow significantly decreased from 1944-1993. Significant decreases in 90th percentile and annual maximum streamflows were determined using Kendall's tau from 1944-1973, 1944-1983, and 1944-1993 (tables 4 and 5).

Several factors have been attributed to the reduced streamflow in the Peace River within Polk County, including the increased pumpage of ground water, lower rainfall amounts from about 1960-2000, which may be associated with the cool phase of the AMO, and elimination of point-source discharges. The increased pumpage of ground water in the Peace River Basin over time and the corresponding effect on Upper Floridan aquifer levels was discussed previously in this report. Reducing Upper Floridan aquifer levels may increase the potential for leakage from the surficial and intermediate aquifer systems to the Upper Floridan aquifer, thus reducing the amount of water available to contribute baseflow to the Peace River. Declines in streamflow from about 1940-2000 also have been attributed by several investigators to deficient rainfall associated with the cool phase of the AMO in Florida (Enfield and others, 2001; Basso and Schultz, 2003; Kelly, 2004). Nationally, step changes in streamflow around 1970 were documented and attributed to changes in precipitation (McCabe and Wolock, 2002). Multidecadal variations in rainfall may be especially important to understand the variations in high streamflows in the Peace River (R. Basso, Southwest Florida Water Management District, written commun., 2006). Annual 90th percentile and maximum streamflow in the Peace River at Bartow were determined in this study to be significantly greater from 1940-1960 compared to 1970-90 (p = 0.0001 and p = 0.0023, respectively), which is consistent with the phases of the AMO. Decreases in annual minimum streamflows at the Bartow and Fort Meade sites from 1974-1993 likely resulted from the elimination or reduction of point-source discharges to the river. A number of point-source discharges to the Peace River or its tributaries were reduced or eliminated around 1995 (Southwest Florida Water Management District, 2002).

In contrast to the streamflow declines that have been documented in the Peace River, there were significant increases in the 90th percentile to maximum annual streamflows at the Fort Meade site from 1975-2003. There was a significant increase in annual maximum streamflows at the Fort Meade site from 1975-2003 (tau = 0.2808, p = 0.0340) and 1984-2003 (tau = 0.3789, p = 0.0212). There also was a significant increase in annual maximum streamflows at the Bartow site from 1984-2003 (table 3).

The effect of reducing pumpage in the Peace River Basin on restoring the potential for upward flow from the Upper Floridan aquifer and springflow from Kissengen Spring was evaluated by Basso (2003) using a ground-water flow model calibrated to 1989 conditions and a graphical analysis. The study concluded that ground-water withdrawals would need to be reduced by 60 to 80 percent for the Upper Floridan aquifer to contribute baseflow to the section of the Peace River from Bartow to Fort Meade and to return flow to Kissengen Spring.

There were no significant temporal trends in streamflows in Saddle Creek, and there were insufficient data from the Bowlegs Creek and the Peace Creek Drainage Canal tributaries to quantify temporal trends. The lack of temporal trends in Saddle Creek was in contrast with other investigations that reported a significant decline in streamflow (T. King, Florida Fish and Wildlife Conservation Commission, written commun., 1994; University of South Florida, 2003). These declines were partly attributed to changes in basin hydrography, which occurred after the area was surface mined. Approximately 70 percent of the northern part of the Saddle Creek Basin was surface mined prior to 1960 and left unreclaimed by the original owners of the mine (T. King, Florida Fish and Wildlife Conservation Commission, written commun., 1994; BCI, 2000). This resulted in surface runoff being diverted into canals or impounded in mine pit lakes or clay settling areas. Lewelling and Wylie (1993) compared the hydrologic characteristics of small unimpacted basins in the vicinity of southwestern Polk County to those with substantial amounts of reclaimed mined land. There was no sustained baseflow to streams in basins where the mined lands were backfilled with clay. The declining streamflows noted in the previous studies likely resulted from more water being stored in these features. The lack of temporal trends in Saddle Creek determined in this report likely resulted from the period of record of the analyzed data. Data were analyzed in this report from 1963-2003, which is subsequent to the hydrography changes that likely affected streamflows in Saddle Creek.

Kissimmee River Basin

The Kissimmee River Basin includes about 700 mi^2 of the eastern part of Polk County and is the largest watershed providing water to Lake Okeechobee. Water-resource managers typically subdivide the Kissimmee River Basin into the upper and lower basins. The southern boundary of the Upper Kissimmee River Basin generally corresponds to State Road 60 (U.S. Army Corps of Engineers, 1996). Polk County contains parts of both the Upper and Lower Kissimmee River Basins (fig. 57). The Upper Kissimmee River Basin generally does not contain a well-defined stream channel for the Kissimmee River (which begins at the outlet of Lake Kissimmee) and is characterized by many lakes connected by a series of canals. The Lower Kissimmee River Basin is characterized by the channelized Kissimmee River and tributary streams.

Most of the Kissimmee River Basin is regulated for flood-control purposes as part of the comprehensive Central and South Florida Flood Control Project. Nine water-control structures constructed between 1964 and 1970, located on streams, lakes, and canals upstream of Polk County in Osceola and Orange Counties, currently (2005) are operated to lower water levels from January through May to provide storage for wet-season precipitation (U.S. Army Corps of Engineers, 1996). The entire Kissimmee River was channelized from 1962 to 1971, resulting in a reduction in the total length of the river from 103 to 56 miles (U.S. Army Corps of Engineers, 1991). The channelized Kissimmee River is often referred to as Canal 38 or C-38 (U.S. Army Corps of Engineers, 1996). The channelized river is about 30 ft deep (U.S. Army Corps of Engineers, 1991). Six water-control structures and locks originally were located on C-38 to step the canal down in 6-ft increments, which segmented the canal into five navigation pools. Two of these water-control structures (S-65 and S-65A) are located on the border of Polk County. These structures historically were managed to maintain a constant water level in the navigation pools (U.S. Army Corps of Engineers, 1991).

The streams draining the large lakes in eastern Polk County provide minor amounts of streamflow to the Kissimmee River. Three of these streams are instrumented by the USGS to continuously measure streamflow—Catfish Creek (site 72), Tiger Creek (site 73), and Livingston Creek (site 75) (figs. 56 and 57). Streamflow has been monitored on Catfish Creek since 1947, and has been monitored on Tiger and Livingston Creeks since 1991. The average streamflow in the Kissimmee River at S-65 is 1,274 ft^3/s based on data from water years 1991-2003 (table 2). The average streamflow in Catfish Creek, Livingston Creek, and Tiger Creek for the same period is 35.5, 58, and 38 ft^3/s, respectively. Streamflow per square mile in Catfish Creek is less variable (resulting in a flatter slope on the flow-duration curve) compared to other streams in Polk County (fig. 59) due to the large amount of storage available in Lake Pierce.

Prior to regulation, the Kissimmee River was described as resembling a large lake during major flood events (U.S. Army Corps of Engineers, 1991). Lakes in the upper part of the basin formerly contributed inflow to the Kissimmee River most of the time; flow in the river generally was greater than 100 ft^3/s about 95 percent of the time (fig. 60). Streamflows had a seasonal variation similar to the other streams in the county. Prior to regulation, the highest median streamflows generally occurred in September and October and the lowest occurred in June and July (fig. 61). Over one-half of the time, 94 percent (about 42,000 acres) of the floodplain of the Kissimmee River historically was inundated with water (Koebel, 1995). Overbank flow generally occurred in the upper part of the river when streamflows exceeded 1,400 ft^3/s (Koebel, 1995). Hydroperiods generally were longest near the river channel and the part of the basin within Polk County (Toth and others, 1995). Water in the lakes in the Upper Kissimmee Basin also would overflow the banks for about 3 to 5 months during the wet season and inundate the surrounding wetland areas (U.S. Army Corps of Engineers, 1996). During wet years, inundation of the wetlands surrounding the lakes could last as long as 10 months (U.S. Army Corps of Engineers, 1996).

The hydrologic characteristics of much of the Kissimmee River were altered due to regulation of lake levels and channelization in the basin. The regulation schedule implemented in the Upper Kissimmee River lakes results in frequent periods of no discharge to C-38 (Obeysekera and Loftin, 1990). The median streamflow in the Kissimmee River at S-65 was near zero about one-half of the time, primarily during the months of June-July and October-December based on data from water years 1979-2003 (figs. 60 and 61). The seasonal variation in streamflows has changed dramatically as well. Streamflows

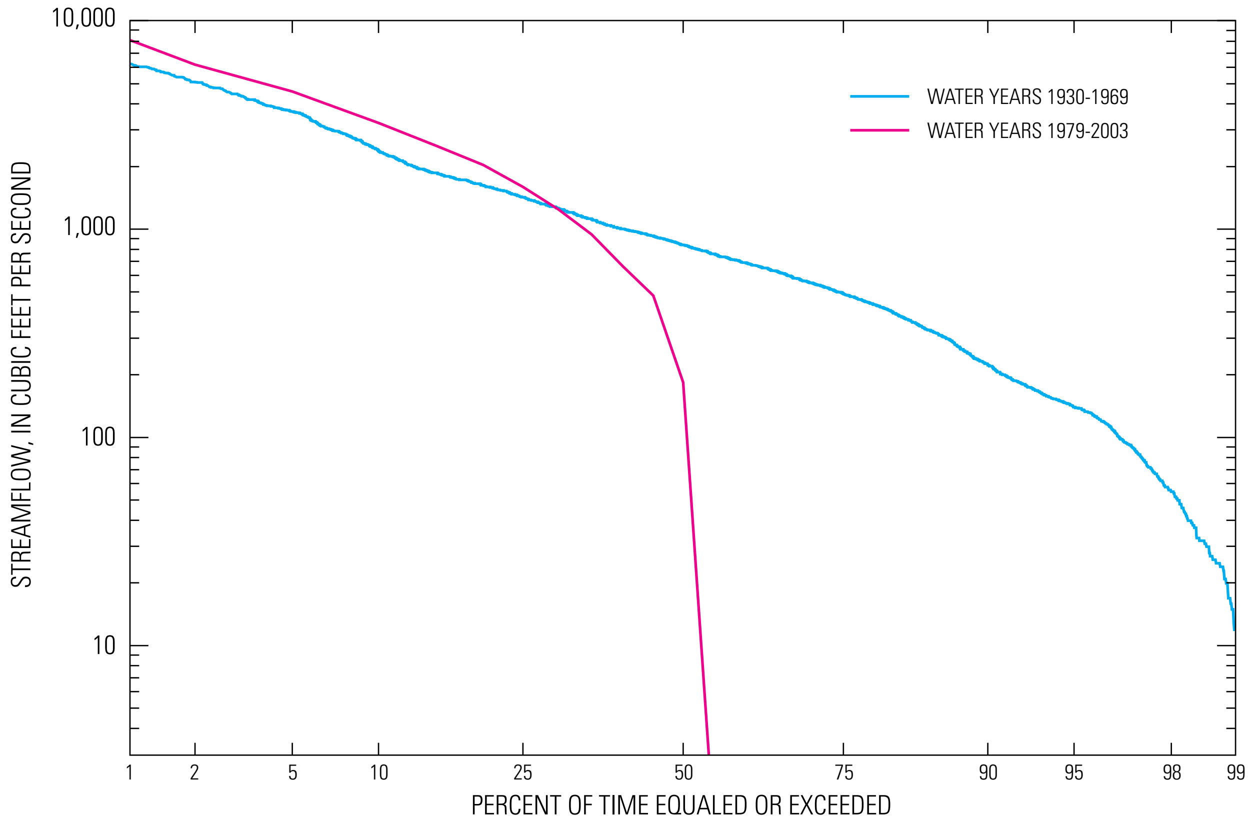


Figure 60. Flow-duration curves for Kissimmee River at S-65, water years 1930-1969 and water years 1979-2003.

generally were greatest from January-May and in August compared to other times of the year based on data from water years 1979-2003 (fig. 61). Streamflow also was greater during high-flow events from water years 1979-2003 compared to water years 1930-1969 due to less storage in the basin (fig. 60). Many of the original river meanders are now stagnant and have filled in with vegetation and sediment (U.S. Army Corps of Engineers, 1991). The only original river meanders with flowing water receive tributary inflow (U.S. Army Corps of Engineers, 1991).

Regulation of the Kissimmee River Basin has resulted in adverse ecological impacts to the watershed. The floodplain of the river historically was dominated by wetlands. Forty-four percent of these wetlands were drained and replaced with improved and unimproved pasture (Toth and others, 1995). The lack of flow to most of the remaining meanders in the Kissimmee River has drastically changed habitat conditions and has allowed aquatic macrophytes (plants) to encroach upon the center of these channels (Toth and others, 1995). Water-level fluctuations in the wetlands that existed prior to channelization have been largely eliminated, which has resulted in less diverse wetland plant communities (Koebel, 1995; Toth and others, 1995). Water fowl usage of the Kissimmee River floodplain decreased 92 percent by the 1970s (Perrin and others, 1982), and waterfowl were replaced with species generally associated with upland, terrestrial habitats (Koebel, 1995). Dissolved-oxygen concentrations in C-38 and the remnant river channels were lower than the 5-mg/L criterion recommended for the protection of aquatic life. Concentrations typically range from 2 to 3 mg/L near the surface of the channel and less than 1 mg/L at depths greater than 3 to 6 ft (Toth and others, 1995). Low dissolved-oxygen conditions have resulted in sport fish, such as largemouth bass, being replaced with species tolerant of poorer water-quality conditions, such as gar and bowfin (Koebel, 1995).

The flood-control project in the Kissimmee River Basin currently (2005) is being modified by the State of Florida and the Federal Government to restore the ecosystem by: (1) re-establishing the historical hydrologic conditions; (2) recreating the historic river/floodplain connectivity; (3) recreating the historical mosaic of wetland plant communities; and (4) restoring the historical biological diversity (South Florida Water Management District, 2005b). Restoring the ecosystem of the Lower Kissimmee River Basin is to be

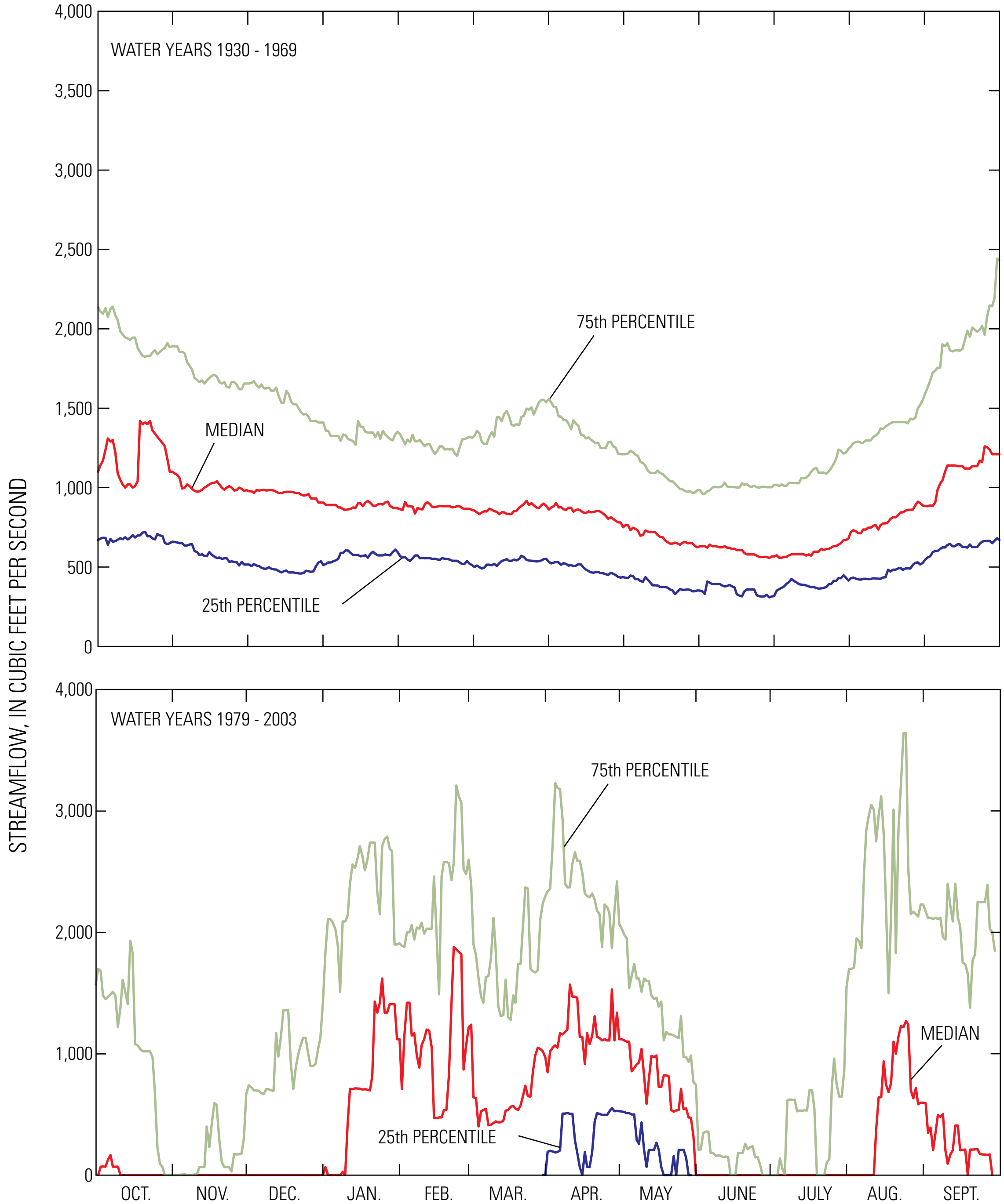


Figure 61. Flow-duration hydrographs for Kissimmee River at S-65 (site 74), water years 1930-1969 and 1979-2003.

accomplished through two major projects: (1) the Headwaters Revitalization project in the upper basin and (2) the Modified Level II Backfilling plan in the lower basin (Koebel, 1995). The Headwaters Revitalization project will modify the regulation schedules for the headwaters lakes to provide greater and more natural fluctuations of water levels in the lakes. The S-65 structure was modified in 2001 to provide a higher discharge capacity (Koebel, 1995; South Florida Water Management District, 2005a). The Modified Level II Backfilling plan includes the backfilling of 22 miles of canal, removal of two water-control structures, and the recarving of 9 miles of former river channel (South Florida Water Management District, 2005b). The project area for most of the Modified Level II Backfilling plan is located downstream from Polk County.

Alafia, Hillsborough, Ocklawaha, and Withlacoochee River Basins

The Alafia, Hillsborough, Ocklawaha, and Withlacoochee River Basins make up about 600 mi^2 of Polk County (fig. 57). The Alafia and Hillsborough River Basins are characterized by land that is flat and relatively high; the Ocklawaha River Basin is characterized by high, sandy ground (Heath, 1961). Drainage from this basin is to the north through poorly defined stream channels (Heath, 1961). Within Polk County, the Withlacoochee River Basin is characterized by innumerable low hammocks and shallow cypress ponds (Heath, 1961).

The only streams gaged in these basins in or in near Polk County are the Withlacoochee River and two streams in the Ocklawaha and Hillsborough Rivers—Green Swamp Run and Fox Branch, respectively. No streams within the Alafia Basin are gaged in or near the county. The Withlacoochee River is the largest of these streams, with a mean annual streamflow of 144 ft^3/s (table 2). The Fox Branch and Green Swamp Run sites periodically have no flow. Fox Branch has no flow less than 5 percent of the time (fig. 59). In contrast, Green Swamp Run near Eva has no flow more than one-half of the time. Flow-duration curves for the Withlacoochee River near Cumpressco and Green Swamp Run flatten out during high streamflows because of storage of water in wetlands.

Low-Flow and Flood-Frequency Statistics

Low-flow frequency statistics may aid in determining requirements for: (1) the amount of water that may be withdrawn from a stream, or (2) disposal of treated wastes to streams. Low-flow frequency statistics are presented in tables 6 through 14, and flood-flow frequency statistics are presented in table 15. Low-flow and flood-flow frequency statistics were not computed for the Kissimmee River at S-65 due to the regulated nature of this stream. There were insufficient non-zero data from Green Swamp Run near Eva to compute low-flow frequency statistics for 1-, 2-, 3-, 7-, 10-, 30-, 60-, and 90-day annual minimum flows. The Peace River at Bartow, Peace River at Fort Meade, and Catfish Creek near Lake Wales sites had significant temporal trends in the low-flow data over the entire period of record. Frequency analysis assumes the data were homogeneous and were not affected by temporal trends associated with either watershed or climatic changes. For this reason, data from water years 1985-2003 were analyzed to determine low-flow frequency statistics for the Bartow and Fort Meade sites. The period of record from 1965-2003 was analyzed to determine low-flow frequency statistics at the Catfish Creek site. Flood-flow frequency estimates at the Peace River at Bartow, Peace River at Fort Meade, and Fox Branch sites were similar to estimates reported by Hammett and DelCharco (2005) who analyzed data through 2001. Flood-flow frequencies listed in this report and those reported by Hammett and DelCharco (2005) generally were within the standard error of the estimates.

Lake Characteristics

Polk County ranks fourth in the State of Florida in the number of lakes per county (Gant, 1993). There are about 900 lakes or open-water features with a surface area greater than 10 acres (fig. 56). Ninety-four percent of the lakes or open-water features in the county are located within the Alafia, Kissimmee, and Peace River Basins. Lakes located on the ridge areas are thought to occupy depressions formed by sinkholes (Sinclair and others, 1985; Barcelo and others, 1990; Yobbi, 1996), and generally lack surface-water inflows or outflows. The large lakes located in eastern Polk County, such as Lake Marion and Lake Pierce (fig. 62), originally were deeper parts of a vast wetland that occupied the area prior to human development (U.S. Army Corps of Engineers, 1996). Water from most of these large lakes, with the exception of Lake Arbuckle, flows to Lake Kissimmee by streams and canals. Water from Lake Arbuckle flows southward and eventually discharges into Lake Istokpoga in Highlands County (not shown). The numerous small open-water features in southwestern Polk County are not natural lakes but are former mine pits and bermed clay-settling areas formed during phosphate-mining operations (Southwest Florida Water Management District, 2003). A few of the named lakes within the vicinity of Lakeland (fig. 62) originated from phosphate-mining activities, including Lake Bentley, Lake Crago, and Lake John (City of Lakeland, 2001). Most of these lakes were created in the 1950s and 1960s.

Most of the lakes in Polk County exchange water with the ground-water system. Direct runoff from the land surface into these lakes, with the exception of stormwater runoff in urban areas, is considered to be minimal because of the high permeability of the sandy soils in the area. Lakes can be classified as seepage and drainage lakes. Seepage lakes have no surface-water inflow or outflow, and primarily lose water through the ground-water system or evaporation. Drainage lakes primarily lose water through a surface-water outlet. Seepage lakes receive ground-water inflow from the surficial aquifer

Table 6. Low-flow frequency statistics for Catfish Creek near Lake Wales.

[Site 72, figure 56. Period of record analyzed was water years 1965-2003. $SE_{x,y}$, standard error of the x-day annual minimum flow with a y-year recurrence interval. Accuracy, $SE_{7,2}$=2.1 ft^3/s, $SE_{7,10}$=0.4 ft^3/s, $SE_{30,2}$=2.5 ft^3/s, $SE_{30,10}$=0.7 ft^3/s]

Recurrence interval (in years)	Annual minimum low flow, in cubic feet per second, for the indicated number of consecutive days									
	1	2	3	7	10	30	60	90	183	365 (annual mean)
2	8.8	8.8	8.8	9.1	11	11	13	16	23	34
5	2.2	2.3	2.4	2.6	2.7	3.7	5.6	7.9	13	22
10	.7	.8	.9	1.0	.9	1.8	3.2	4.8	9.4	17
20	.2	.2	.3	.4	.3	.9	1.9	3.1	6.9	14
50	0	0	0	0	.1	.4	1.0	1.7	4.7	10

Table 7. Low-flow frequency statistics for Fox Branch near Socrum.

[Site 66, figure 56. Period of record analyzed was water years 1966-2003. $SE_{x,y}$, standard error of the x-day annual minimum flow with a y-year recurrence interval. Accuracy, $SE_{30,2}$=0.1 ft^3/s, $SE_{30,10}$=0.03 ft^3/s]

Recurrence interval (in years)	Annual minimum low flow, in cubic feet per second, for the indicated number of consecutive days									
	1	2	3	7	10	30	60	90	183	365 (annual mean)
2	0.3	0.3	0.3	0.4	0.4	0.8	1.2	1.7	3.3	8.3
5	0	0	0	.01	.04	.3	.5	.8	1.9	5.5
10	0	0	0	0	0	.1	.3	.5	1.4	4.5
20	0	0	0	0	0	0	.2	.4	1.1	3.7
50	0	0	0	0	0	0	0	.2	.8	3.1

Table 8. Low-flow frequency statistics for Green Swamp Run near Eva.

[Site 65, figure 56. Period of record analyzed was water years 1979-2003. $SE_{x,y}$, standard error of the x-day annual minimum flow with a y-year recurrence interval. Accuracy, $SE_{365,2}$=1.9 ft^3/s, $SE_{365,10}$=0.3 ft^3/s. NC, not computed]

Recurrence interval (in years)	Annual minimum low flow, in cubic feet per second, for the indicated number of consecutive days									
	1	2	3	7	10	30	60	90	183	365 (annual mean)
2	NC	NC	NC	NC	NC	NC	NC	NC	0.2	5.4
5	NC	NC	NC	NC	NC	NC	NC	NC	0	1.3
10	NC	NC	NC	NC	NC	NC	NC	NC	0	.6
20	NC	NC	NC	NC	NC	NC	NC	NC	0	.3
50	NC	NC	NC	NC	NC	NC	NC	NC	0	.1

Table 9. Low-flow frequency statistics for Bowlegs Creek near Fort Meade.

[Site 71, figure 56. Period of record analyzed was water years 1965-68, 1992-2003. $SE_{x,y}$, standard error of the x-day annual minimum flow with a y-year recurrence interval. Accuracy, $SE_{7,2}$=0.2 ft^3/s, $SE_{7,10}$=0.1 ft^3/s, $SE_{30,2}$=0.3 ft^3/s, $SE_{30,10}$=0.2 ft^3/s]

Recurrence interval (in years)	Annual minimum low flow, in cubic feet per second, for the indicated number of consecutive days									
	1	2	3	7	10	30	60	90	183	365 (annual mean)
2	1.2	1.2	1.3	1.3	1.4	1.7	2.2	3.3	6.7	12
5	.7	.7	.7	.8	.8	1.0	1.3	1.8	3.2	14
10	.5	.5	.5	.6	.6	.7	1.0	1.3	2.2	18
20	.4	.4	.4	.4	.5	.6	.8	1.0	1.6	26
50	.3	.3	.3	.3	.3	.4	.6	.8	1.1	10

Table 10. Low-flow frequency statistics for Livingston Creek near Frostproof.

[Site 75, figure 56. Period of record analyzed was water years 1992-2003. $SE_{x,y}$, standard error of the x-day annual minimum flow with a y-year recurrence interval. Accuracy, $SE_{7,2}$=1.6 ft^3/s, $SE_{7,10}$=0.9 ft^3/s, $SE_{30,2}$=2.2 ft^3/s, $SE_{30,10}$=1.3 ft^3/s]

Recurrence interval (in years)	Annual minimum low flow, in cubic feet per second, for the indicated number of consecutive days									
	1	2	3	7	10	30	60	90	183	365 (annual mean)
2	8.7	8.8	8.9	9.4	9.9	12	16	18	27	48
5	5.9	5.9	6.0	6.2	6.4	7.6	9.6	11	16	33
10	4.9	4.9	4.9	5.1	5.2	6.0	7.4	8.9	12	28
20	4.2	4.3	4.3	4.3	4.4	4.9	5.9	7.3	10	24
50	3.6	3.7	3.7	3.7	3.7	3.9	4.6	5.9	8.0	21

Table 11. Low-flow frequency statistics for Peace Creek Drainage Canal near Wahneta.

[Site 69, figure 56. Period of record analyzed was water years 1992-2003. $SE_{x,y}$, standard error of the x-day annual minimum flow with a y-year recurrence interval. Accuracy, $SE_{7,2}$=1.6 ft^3/s, $SE_{7,10}$=0.5 ft^3/s, $SE_{30,2}$=2.0 ft^3/s, $SE_{30,10}$=0.8 ft^3/s]

Recurrence interval (in years)	Annual minimum low flow, in cubic feet per second, for the indicated number of consecutive days									
	1	2	3	7	10	30	60	90	183	365 (annual mean)
2	3.3	3.4	3.7	4.1	4.5	5.9	7.9	12	25	77
5	1.1	1.1	1.3	1.5	1.7	2.3	3.6	5.0	9.8	46
10	.5	.5	.7	.8	.9	1.3	2.3	3.2	6.1	36
20	.2	.3	.4	.4	.5	.8	1.7	2.3	4.2	29
50	.1	.1	.2	.2	.2	.4	1.1	1.6	2.8	24

Table 12. Low-flow frequency statistics for Tiger Creek near Babson Park.

[Site 73, figure 56. Period of record analyzed was water years 1992-2003. $SE_{x,y}$, standard error of the x-day annual minimum flow with a y-year recurrence interval. Accuracy, $SE_{7,2}$=1.5 ft^3/s, $SE_{7,10}$=1.3 ft^3/s, $SE_{30,2}$=1.8 ft^3/s, $SE_{30,10}$=1.6 ft^3/s]

Recurrence interval (in years)	Annual minimum low flow, in cubic feet per second, for the indicated number of consecutive days									
	1	2	3	7	10	30	60	90	183	365 (annual mean)
2	11	11	11	12	13	15	18	21	27	38
5	7.8	7.8	8.0	8.5	8.8	11	13	15	20	31
10	6.4	6.4	6.6	6.9	7.2	9.0	11	13	17	28
20	5.3	5.4	5.5	5.9	6.1	7.7	9.7	11	15	25
50	4.3	4.4	4.5	4.8	5.0	6.4	8.1	9.3	13	22

Table 13. Low-flow frequency statistics for Peace River at Bartow.

[Period of record analyzed: water years 1984-2003. $SE_{x,y}$, standard error of the x-day annual minimum flow with a y-year recurrence interval. Accuracy, $SE_{30,2}$=4.5 ft^3/s, $SE_{30,10}$=0.8 ft^3/s]

Recurrence interval (in years)	Annual minimum low flow, in cubic feet per second, for the indicated number of consecutive days									
	1	2	3	7	10	30	60	90	183	365 (annual mean)
2	3.6	3.7	3.8	5.5	6.2	7.5	11	14	31	108
5	1.8	1.8	1.9	.7	.8	2.1	3.7	5.3	12	60
10	.0	0	0	0	0	.7	1.8	3.1	7.6	46
20	0	0	0	0	0	0	1.0	2.0	5.2	37
50	0	0	0	0	0	0	.4	1.2	3.4	29

Table 14. Low-flow frequency statistics for Peace River at Fort Meade.

[Period of record analyzed: water years 1985-2003. $SE_{x,y}$, standard error of the x-day annual minimum flow with a y-year recurrence interval. Accuracy, $SE_{7,2}$=1.4 ft^3/s, $SE_{7,10}$=0.2 ft^3/s, $SE_{30,2}$=3.7 ft^3/s, $SE_{30,10}$=0.7 ft^3/s]

Recurrence interval (in years)	Annual minimum low flow, in cubic feet per second, for the indicated number of consecutive days									
	1	2	3	7	10	30	60	90	183	365 (annual mean)
2	2.2	2.4	2.5	3.2	3.7	7.5	14	21	41	132
5	.5	.6	.6	.8	.9	1.9	4.3	6.3	13	76
10	.2	.2	.2	.3	.4	.8	2.0	3.1	7.0	59
20	.1	.1	.1	.1	.2	.3	1.0	1.6	4.0	48
50	.04	.04	.04	.1	.1	.1	.4	.7	2.1	39

Table 15. Flood-flow frequency statistics for selected sites in Polk County.

[Locations of site numbers shown in figure 56. Units are cubic feet per second]

Site number	Site	Recurrence interval, in years				
		2	5	10	25	50
72	Catfish Creek near Lake Wales	77 ± 5	112 ± 8	136 ± 11	168 ± 17	193 ± 26
66	Fox Branch near Socrum	256 ± 42	568 ± 101	862 ± 182	1 ,349 ± 363	1,803 ± 620
65	Green Swamp Run near Eva	52 ± 12	102 ± 23	142 ± 36	197 ± 61	242 ± 97
73	Tiger Creek near Babson Park	126 ± 10	157 ± 13	175 ± 16	195 ± 22	209 ± 30
75	Livingston Creek near Frostproof	244 ± 36	374 ± 63	471 ± 97	606 ± 161	716 ± 246
69	Peace Creek Drainage Canal near Wahneta	385 ± 66	658 ± 104	846 ± 145	1,083 ± 227	1,256 ± 345
68	Peace River at Bartow	913 ± 83	1,608 ± 159	2,168 ± 255	2,989 ± 447	3,683 ± 701
70	Peace River at Fort Meade	857 ± 96	1,375 ± 166	1,759 ± 249	2,286 ± 408	2,706 ± 614
71	Bowlegs Creek near Fort Meade	378 ± 46	557 ± 69	676 ± 96	827 ± 145	939 ± 209

system (Sacks and others, 1998; Lee and Swancar, 1997); most of the inflow occurs near the shoreline (Lee, 2000). Most seepage lakes can be further classified as flow-through lakes, where ground water flows in along part of the lake perimeter, and lake water leaks to the ground water laterally along the remainder of the lake perimeter. The percentage of the lake perimeter that exhibits ground-water inflow or outflow varies between lakes and by season (Sacks and others, 1998). The direction of lateral ground-water outflow from lakes does not necessarily parallel the basin topography. For example, lateral ground-water outflow from Lake Starr (site 42, fig. 56, app. 3) occurred in topographically higher parts of the lake basin, which was attributed to preferential flow toward karstic features (Swancar and others, 2000). In the deeper parts of the lake bottom, water typically flows vertically to recharge the Upper Floridan aquifer.

Transient water-table mounding was observed near the shoreline of seepage lakes in Polk County and also may affect lake levels. Lee and others (1991) and Swancar and others (2000) observed transient water-table mounds near Lake Lucerne and Lake Starr. Transient water-table mounding generally was short in duration, and generally lasted less than 1 day at Lake Starr (Swancar and others, 2000). Lee (1996) used a ground-water flow model combined with an independent water budget to document the effects of transient ground-water mounds on ground-water inflow to Lake Barco, a seepage lake in a ridge setting in Putnam County—located about 80 miles north of Polk County. Transient water-table mounds sometimes reversed ground-water flow directions on outflow sides of lakes, resulting in greater ground-water inflow and less lateral ground-water outflow. The generation of net ground-water inflow (defined as ground-water inflow minus ground-water outflow) to the lake that originated from transient water-table mounding was usually the result of a single large rainfall event, rather than a succession of small events.

The ground-water catchment areas for seepage lakes in Polk County are probably substantially smaller than the topographic drainage basins (Sacks and others, 1998; Lee, 2002). For example, Swancar and Lee (2003) simulated a catchment area for Lake Starr that was only 16 percent of the topographic drainage. At Lake Barco, the simulated catchment area was determined to be 2.4 hectares compared to the topographic basin of 81 hectares (Lee, 1996).

Regulation of Lake Levels

Water levels of some lakes in Polk County are controlled by flood-control structures or are influenced by other lakes connected to them. Forty-two of the 262 named lakes (16 percent) in Polk County inventoried by Gant (2001) were reported to have a control structure on the outlet. There are two large chains of lakes connected by canals in the vicinity of Winter Haven—the Lake Hamilton and Winter Haven Chain of Lakes (fig. 62). The Lake Hamilton Chain of Lakes consists of seven interconnected lakes—Lake Haines, Lake Rochelle, Lake Conine, Lake Smart, Lake Fannie, Lake Henry, and Lake Hamilton. Four control structures regulate the flow of water between lakes in this system—P-5 (located on Lake Henry), P-6 (located on Lake Smart), P-7 (located on Lake Fannie), and P-8 (located on Lake Hamilton) (Southwest Florida Water Management District, 2002). The Winter Haven Chain of Lakes consists of 13 interconnected lakes—Lake Mariana, Lake Jessie, Lake Idylwild, Lake Hartridge, Lake Cannon, Lake Mirror, Lake Deer, Lake Howard, Lake May, Lake Shipp, Lake Eloise, Lake Winterset, and Lake Lulu. An outlet structure on Lake Lulu regulates the water levels in the lakes. Lakes Hartridge and Conine are connected by a canal. Locks in the canal permit the flow of water from Lake Hartridge to Conine during high water levels (U.S. Environmental Protection Agency, 2005). These lakes historically were not

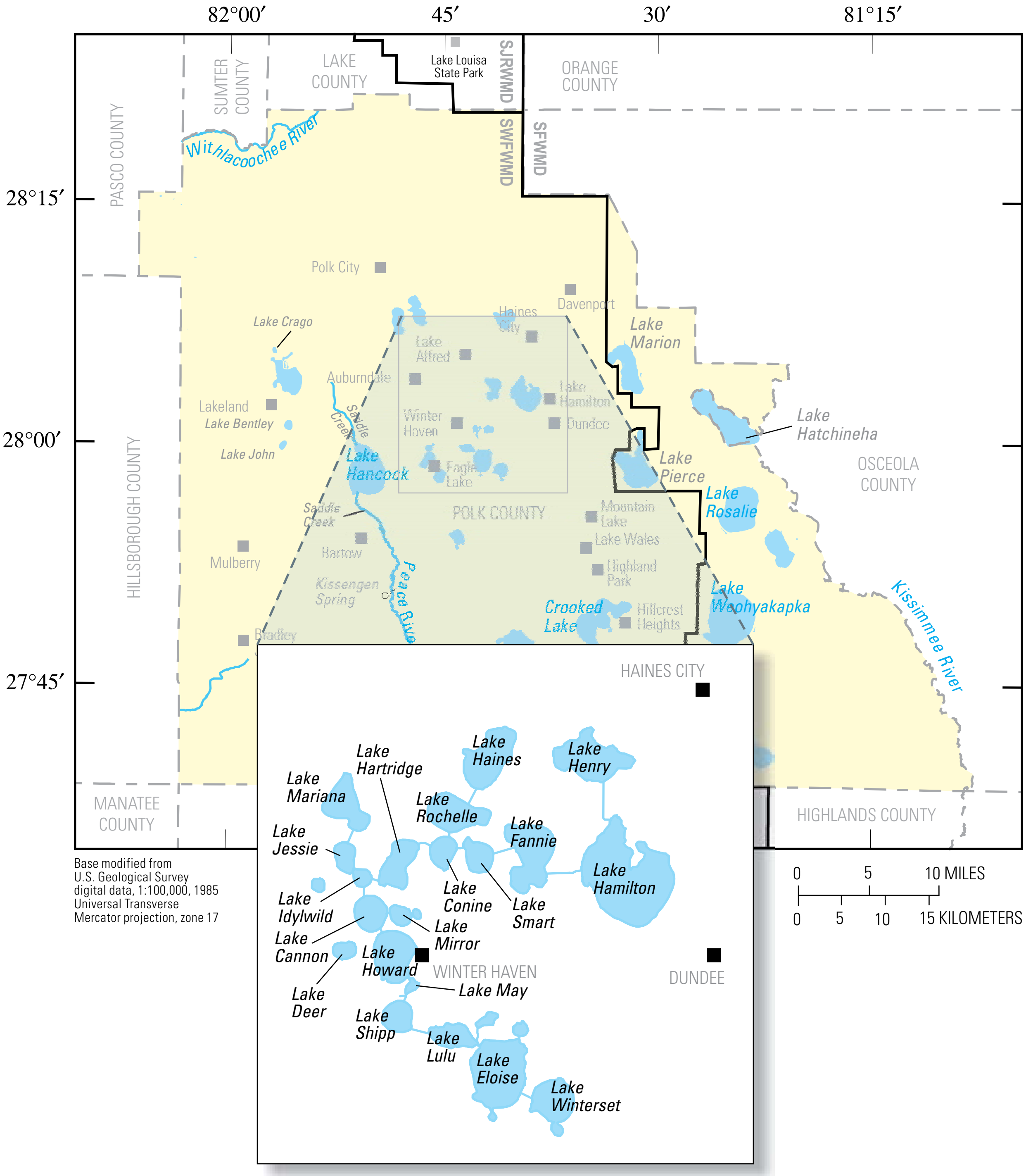


Figure 62. Location of Lake Hamilton and Winter Haven Chain of Lakes.

connected and occupied individual basins before construction of the canals. Within the Kissimmee River Basin, Lakes Hatchineha and Kissimmee have been regulated to maintain their stages between 48.5 and 54.0 ft NGVD 29, and Tiger Lake has been regulated to maintain the stage between 49.0 and 52.5 ft NGVD 29 (U.S. Army Corps of Engineers, 1996). Lake levels in these three lakes historically were lowered from January through May to provide storage for wet-season precipitation (U.S. Army Corps of Engineers, 1996).

Lake levels vary seasonally in response to rainfall, evaporation, surface-water inflow and outflow, ground-water inflow and outflow, and ground-water pumpage. Water levels in most lakes in Polk County have seasonal variations similar to those in Lake Deeson (site 1, figs. 56 and 63). In Lake Deeson, lake levels generally were lowest from May through July and highest in September and October. Seasonal variations in lake levels, however, have deviated from this general pattern in any given year due to variations in rainfall or pumpage. For example, Sacks and others (1998) reported a steady decline in water levels in Saddle Blanket Lake (from January through December 1996) due to below normal rainfall during this period (fig. 64). Decreases in lake levels

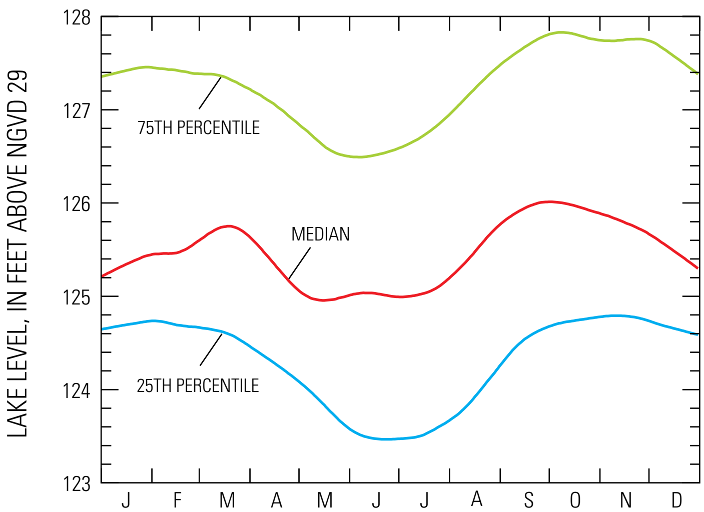


Figure 63. Generalized seasonal variations in Lake Deeson, 1954-2003.

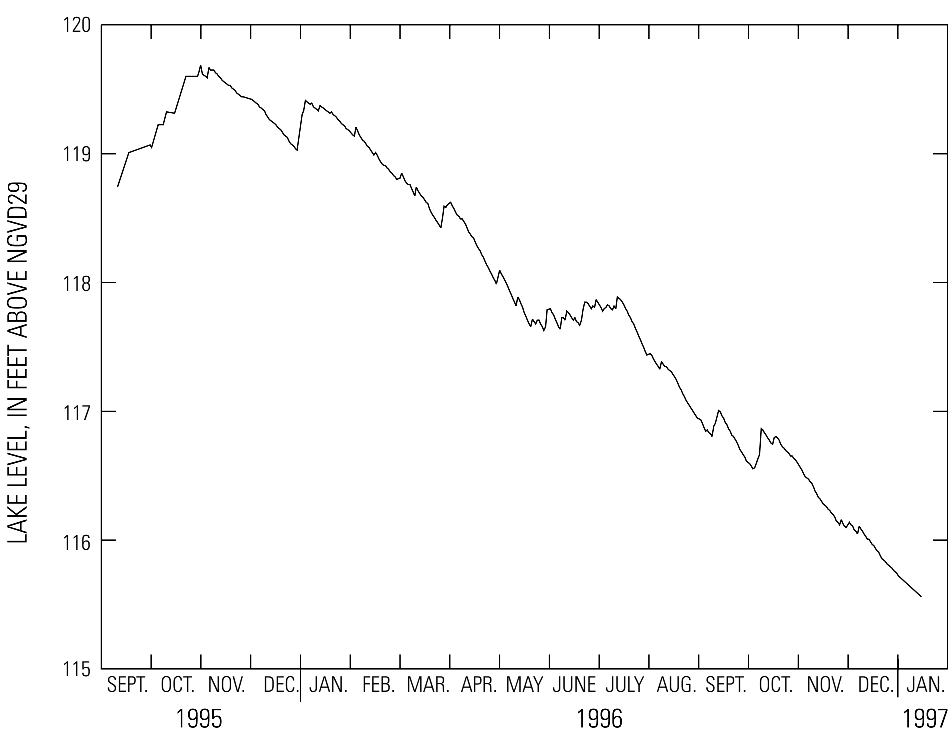


Figure 64. Seasonal variations in lake levels in Saddle Blanket Lake during a period of below normal rainfall.

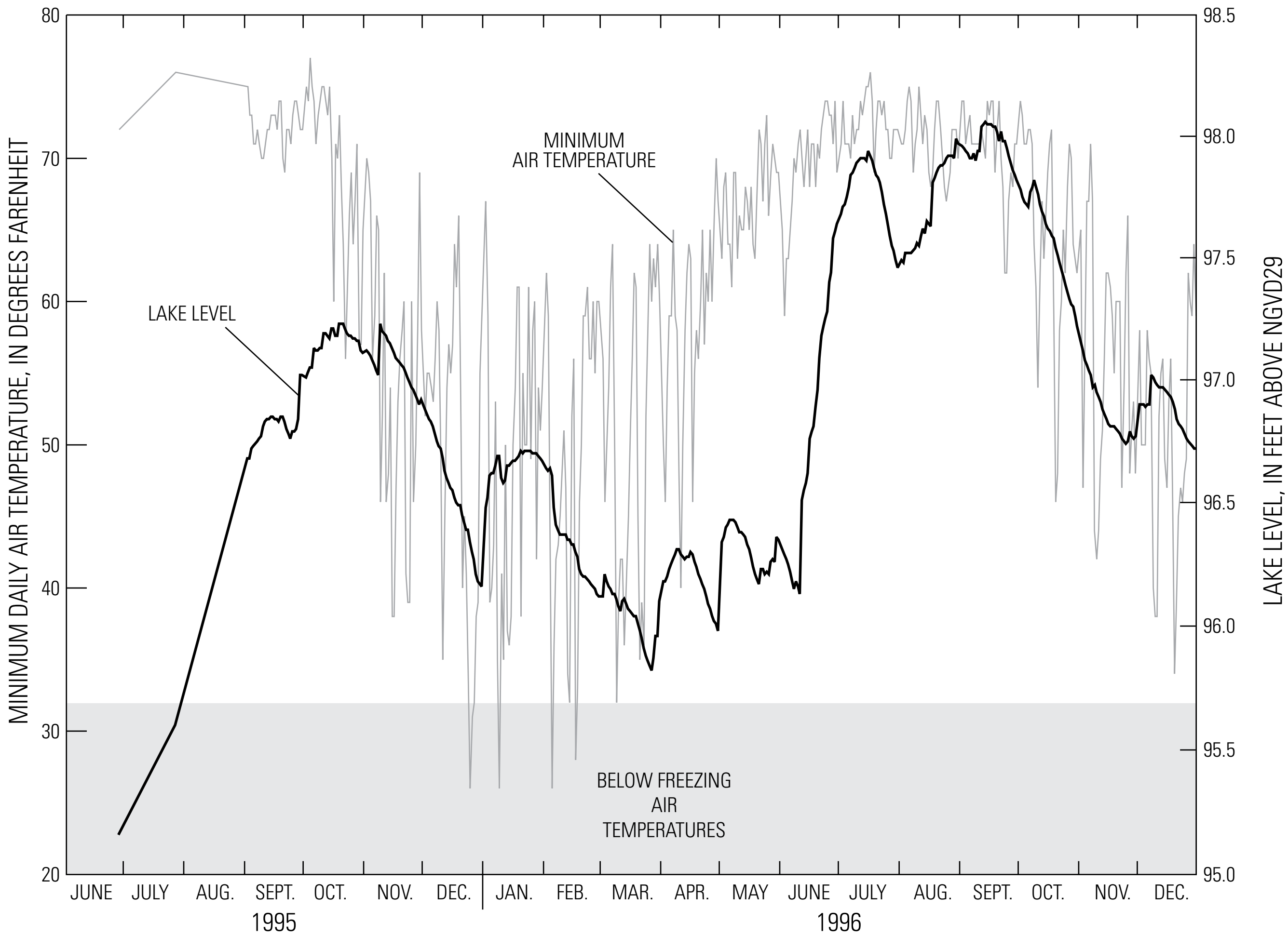


Figure 65. Seasonal variations in lake levels and the minimum daily air temperatures at a lake (Swim Lake) affected by ground-water pumpage.

measured in December 1995 during cold periods at Swim Lake (fig. 65), a 5-acre lake located within a citrus area on the Lake Wales Ridge, were attributed to increased pumpage from the Upper Floridan aquifer to protect citrus crops from frost damage (Sacks and others, 1998). Increased pumpage from the Upper Floridan aquifer results in an increased head difference between the lake and the aquifer, which induces more downward ground-water outflow from the lake.

Physical alteration of lakes in the county resulted in attenuated lake-level fluctuations in some lakes. Lake-level fluctuations were reduced in some lakes in the Kissimmee River Basin due to regulation by structure S-65. The lakes that compose the Winter Haven Chain of Lakes historically differed in surface-water elevations over a range of several feet; with the construction of the interconnecting canals in the 1920s, however, these lakes now fluctuate at approximately the same elevation as Lake Lulu (Southwest Florida Water Management District, 2002). Reduced or eliminated water-level fluctuations were suggested by some investigators as a major cause of undesirable changes in lake and wetland communities in the Kissimmee River Basin (Perrin and others, 1982) because of accelerated accumulation of bottom sediments, declines in dissolved oxygen, nutrient enrichment, vegetation changes in the littoral zone, and the reduction of fish and wildlife populations.

Temporal Trends in Lake Levels

Temporal trends of lake levels in Polk County were examined to: (1) update previously published information on long-term temporal trends, and (2) quantify recent trends that may have occurred. Trends were computed for all lakes having sufficient data. Long-term temporal trends from generally the 1960-2003 period were computed for 14 lakes (sites 1, 9, 27,

Table 16. Temporal trends in mean annual water levels for selected lakes in Polk County, 1960-2003.

[Locations of site numbers shown in figure 56. Bolded values indicate a statistically significant trend]

Site number	Lake name	Period of record analyzed	Kendall's tau	p-value
58	Lake Clinch	1960-2003	**-0.2812**	**0.0071**
44	Lake Parker	1960-2003	.1501	.1509
56	Crooked Lake	1960-2003	**-.4017**	**.0001**
61	Lake Hamilton	1960-2002	.0122	.9084
9	Scott Lake	1960-2002	**.2918**	**.0052**
64	Mountain Lake	1960-1986, 1989-1999, 2000-2003	**-.5282**	**.0000**
63	Lake Hancock	1960-2002	.0808	.4449
37	Lake Howard	1960-2003	.1067	.3070
27	Lake Mariana	1960-2003	**.9784**	**.0003**
1	Lake Deeson	1960, 1965-2003	.1667	.1299
35	Lake Otis	1960-2003	-.0761	.4665
59	Reedy Lake	1960-2003	.0878	.4187
62	Lake Marion	1960-1993, 1998, 2001-2003	**-.2319**	**.0404**
43	Lake Wales	1960-2003	**-.2902**	**.0075**

35, 37, 43-44, 56, 58-59, 61-64; fig. 56). These were the only lakes with sufficient data to compute temporal trends during this period. Temporal trends were computed for the 1960-2003 period to facilitate comparisons of trends among the lakes. Recent trends were quantified for 71 lakes during the 1990-2003 period. Three of the lakes (Scott Lake, Lake Hamilton, and Lake Hancock, sites 9, 61, and 63, respectively) had data only from 1960-2002. These sites were included in the analyses because there were few lakes that had data extending back to 1960.

Lake levels during 1960-2003 declined in 5 of the 14 lakes (table 16, fig. 66). Most of these lakes are located along the Lake Wales Ridge. One-half of the 14 lakes had no trend in lake levels during this period; water levels in most of these lakes are regulated by a control structure or by a connection to another lake. Two of the lakes, Lake Mariana and Scott Lake (sites 27 and 9, fig. 56, app. 3), had increases in lake levels. It is unknown whether increasing water levels in Lake Mariana are related to changes in the regulation of the control structure on the lake's outlet or some other factor. The increasing trend in Scott Lake seems to be related to the fact that low water levels were reported in the late 1960s and early 1970s, although the cause of the low levels is unknown. Decreases in water levels at selected lakes along the Lake Wales Ridge have been reported by other investigators (Geraghy and Miller, 1980; Barcelo and others, 1990) and were attributed to below-normal rainfall and ground-water pumpage.

Temporal trend analyses using data from 1990-2003 show that almost 90 percent of the lakes had no significant change in water levels (fig. 67). Five of the lakes (Blue Lake, Crooked Lake, Lake Buffum, Lake Clinch, and Little Crooked Lake), located in the vicinity of Frostproof, had an increasing trend in water levels during this period. Most of these lakes were identified as having long-term declines in water levels, which indicate that a reversal in lake-level trends may be occurring. Possible reasons for the increase in water levels include a reduction in ground-water pumpage in the area or increased rainfall during 1990-2003. The increase in water levels likely is not due to increased rainfall. Annual totals at the Avon Park, Lakeland, and Mountain Lake rainfall stations maintained by NOAA and the West Frostproof station maintained by the SWFWMD had no significant trends during this period (tau = 0.3407, p = 0.1005; tau = 0.3077, p = 0.1388; tau = 0.1429, p = 0.5112; and tau = 0.2747, p = 0.1889; respectively).

Factors Controlling Lake Levels

Reported declines in lake levels have resulted in several investigations of the factors that control lake levels in Polk County and in other parts of Florida (Lee and others, 1991; Lee and Swancar, 1997; Sacks and others, 1998; Lee, 2000; Swancar and others, 2000; Lee, 2002; Metz and

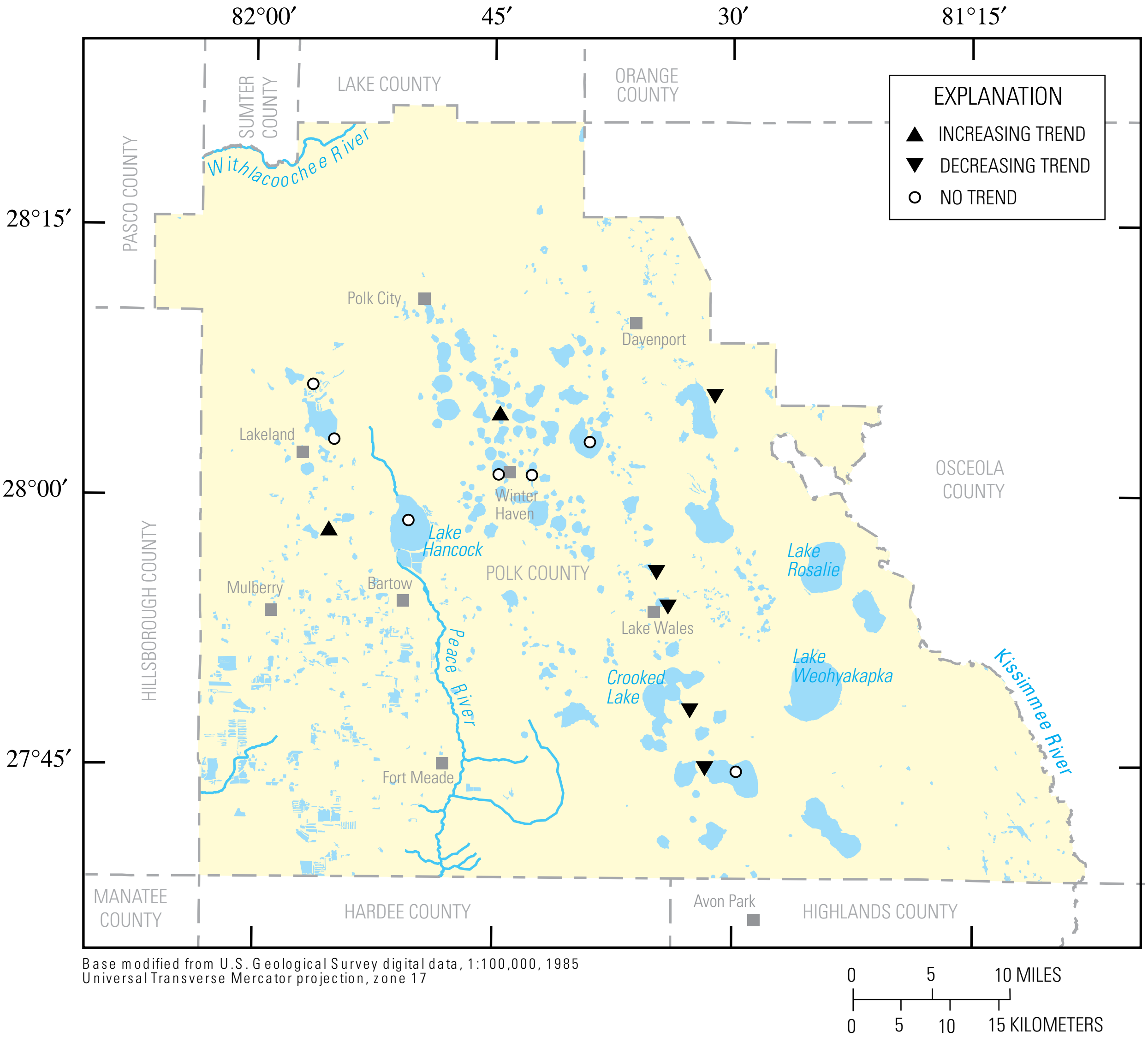


Figure 66. Temporal trends in lake levels in Polk County, Florida, 1960-2003.

Sacks, 2002; Sacks, 2002). Water budgets were developed for eight lakes in Polk County to determine the relative importance of precipitation, evaporation, and ground-water inflow and outflow on lake stage (Lee and others, 1991; Lee and Swancar, 1997; Sacks and others, 1998; and Swancar and others, 2000). Ground-water inflow was quantified at about 40 seepage lakes on the Winter Haven and Lake Wales Ridges (Sacks and others, 1998; Sacks, 2002). Three modeling studies (Lee and Swancar, 1997; Lee, 2002; and Swancar and Lee, 2003) examined the relative importance of the factors controlling ground-water exchange with lakes.

Rainfall and evaporation generally accounted for more than one-half of either the total annual inflow or outflow in most of the studied lakes. Ground-water inflow and outflow, however, generally were not negligible components of the annual water budget. Ground-water inflow accounted for 47 percent, on average, of the total annual inflow in 32 lakes studied by Sacks (2002). Ground-water outflow accounted for 39 percent, on average, of the total outflow from Lake Lucerne (Lee and Swancar, 1997) and the seven lakes studied by Sacks (2002).

Ground-water inflow varied substantially among lakes and also seasonally in Polk County. Sacks (2002) reported that ground-water inflow to lakes located in Polk County ranged from 7 percent of the annual total inflows to Grassy Lake (site 23, fig. 56, app. 3) to 83 percent in Lake Josephine. Most of the lakes studied in Polk County were rated as receiving

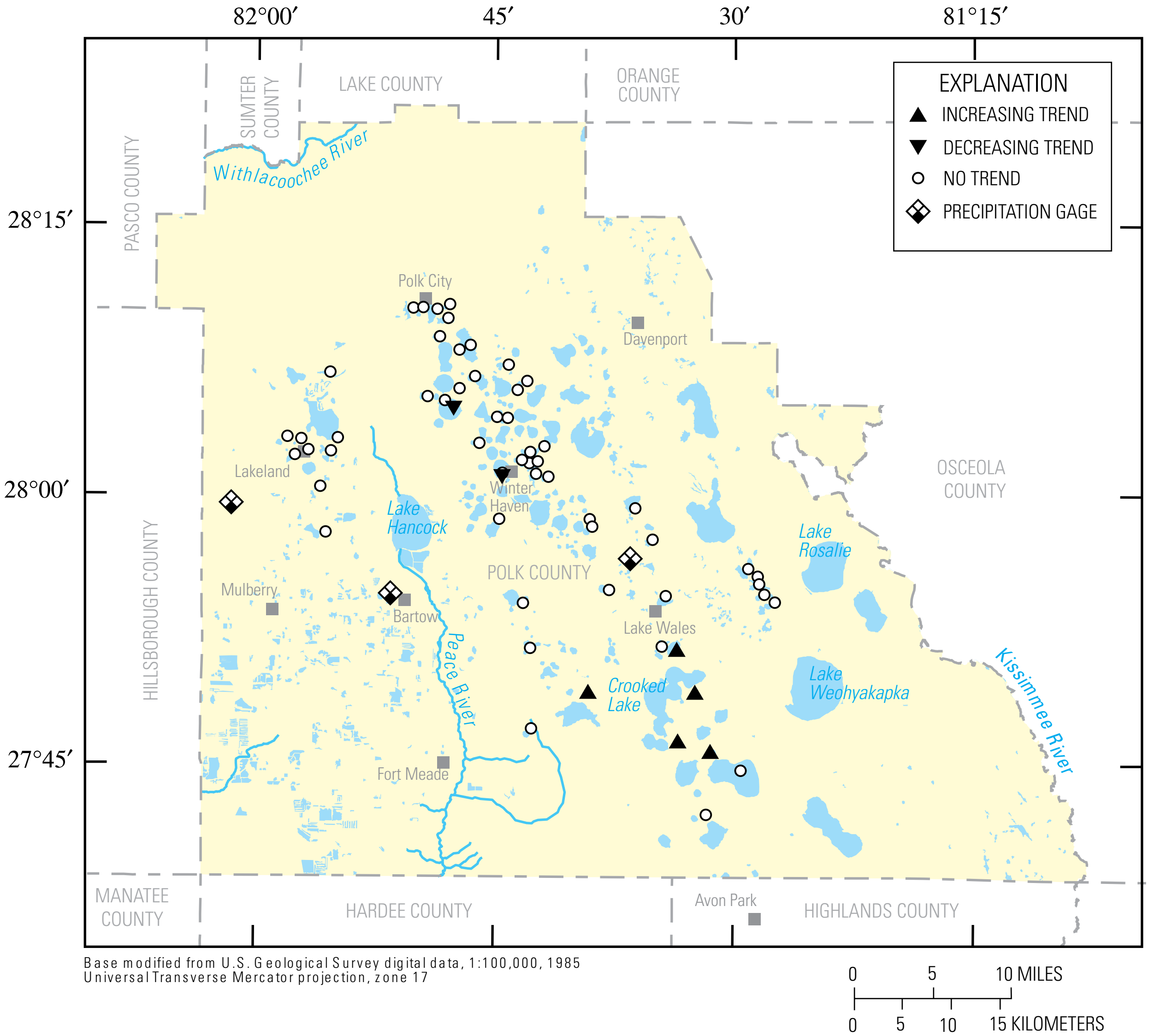


Figure 67. Temporal trends in lake levels in Polk County, Florida, 1990-2003.

medium to high amounts of ground-water inflow compared to other regions of west-central Florida (Sacks, 2002). Sacks and others (1998) and Swancar and others (2000) reported that net ground-water inflow varied seasonally in seepage lakes. The lakes generally had positive net ground-water flow during months with higher rainfall (typically June-September), and negative net ground-water flow during drier months.

Several factors affect ground-water exchange with lakes. Lateral ground-water inflow and outflow to the lake is affected by the head gradients between the surficial aquifer system and the lake. Additional ground-water inflow into a lake may be induced by temporary increases in the head gradient due to water-table mounding or artificially lowering the lake level by pumpage. Ground-water inflow to a lake also may be affected by the amount of recharge to the surficial aquifer system. The potential for a lake to receive ground-water inflow also may be affected by the depth of a lake. A deeper lake potentially receives more ground-water inflow compared to a shallower lake because the deeper lake intercepts a larger portion of the surficial aquifer system. More lateral ground-water inflow, however, may be received by a smaller lake relative to its surface area, compared to a large lake, because the smaller lake has a larger ratio of lake perimeter to surface area.

Summary

The hydrogeology, ground-water quality, and streamflow and lake level trends and characteristics of Polk County, Florida, were evaluated during a 3½-year study from 2002 to 2006. The study area encompasses about 1,823 square miles in central Florida. Rapid increases in population have occurred in Polk County since the 1960s and this trend is expected to continue. From 1960 to 2004, the population increased from about 195,000 to 528,000, making it the tenth largest county in terms of population in the State. The population in Polk County is projected to reach about 676,000 by 2020.

Ground-water use has decreased substantially since 1965. In 1965, total ground-water withdrawals in Polk County were about 350 million gallons per day. In 2002, withdrawals totaled about 285 million gallons per day, of which nearly 95 percent was from the Floridan aquifer system. Water-conservation practices related to the phosphate-mining industry have helped reduce total water use by about 65 million gallons per day since 1965. Of the total ground-water use in 2000, 48 percent was for agricultural irrigation, 23 percent for public supply, 21 percent for commercial/industrial self-supplied, 4 percent for domestic self-supplied, 3 percent for recreation, and 1 percent for thermoelectric power generation.

Three principal water-bearing units underlie Polk County. The uppermost water-bearing unit is the surficial aquifer system. The surficial aquifer system is underlain by the intermediate confining unit or by the intermediate aquifer system. The lowermost hydrogeologic unit is the Floridan aquifer system.

The surficial aquifer system is unconfined and consists of unconsolidated clastic deposits that range in age from Pliocene to Holocene. The unit is composed primarily of fine- to medium-grained quartz sand near the land surface that grades with depth to silty and clayey sands. The lithology and texture of the sediments within the surficial aquifer system can vary considerably both vertically and laterally. Thickness of the surficial aquifer system is highly variable, ranging from several feet or less in extreme northwestern Polk County and along parts of the Peace River south of Bartow, to more than 200 feet along the southern part of the Lake Wales Ridge in eastern Polk County. The water table in the surficial aquifer system fluctuates about 1 to 5 feet seasonally. The hydraulic properties of the surficial aquifer system vary considerably across the county and are dependent largely upon aquifer thickness, grain-size distribution, sorting, packing, and cementation of the sediments within the aquifer. Transmissivity estimates from surficial aquifer wells ranged from 8 to 2,400 foot squared per day. Ground water in the surficial aquifer system is recharged primarily by the infiltration of rainfall. The surficial aquifer provides small amounts of water for lawn irrigation and domestic use.

The intermediate confining unit is present throughout much of the northern and eastern parts of Polk County. The intermediate confining unit serves as a confining layer (except where breached by sinkholes) that restricts the vertical movement of water between the surficial aquifer system and the underlying Upper Floridan aquifer. The unit consists mostly of interbedded clay, silt, phosphate, and sand, but includes some limestone and dolostone of the Hawthorn Group. In many areas, the intermediate confining unit also can include low-permeability clay and silt layers of early Pliocene age. Thickness of the intermediate confining unit generally ranges from less than 25 feet in northern Polk County to more than 200 feet in southeastern Polk County. The unit is locally thin or absent in extreme northwestern Polk County.

The intermediate aquifer system is present in southwestern Polk County, where the intermediate confining unit grades into more permeable sediments of the Peace River and Arcadia Formations. These deposits are a source of water supply and have sufficient permeability to warrant being referred to as an aquifer system. The intermediate aquifer system includes all water-bearing and confining units between the base of the surficial aquifer system to the top of the Floridan aquifer system. As a whole, however, the entire system, including the water-bearing units, restricts vertical movement of ground water between the overlying surficial aquifer system and underlying Upper Floridan aquifer. Thickness of the intermediate aquifer system generally ranges from nearly zero, where the permeable zones pinch out in central Polk County, to more than 300 feet in southwestern Polk County.

In Polk County, two water-bearing zones are present in the intermediate aquifer system. Investigations of these zones indicated that they are limited in vertical extent and are present at variable depths. The uppermost hydrogeologic zone (Zone 2) is the most extensive aquifer within the intermediate aquifer system in Polk County, and is present throughout much of the southwestern part of the county. The lowermost water-bearing zone (Zone 3) is found only in the extreme south-central part of Polk County. Data on the hydraulic properties of the intermediate aquifer system in Polk County are limited, and values vary considerably because of the variable nature of the lithology. Transmissivity estimates for the permeable zones of the intermediate aquifer system in Polk County ranged from 160 to 13,330 feet squared per day. The intermediate aquifer system is a minor source of water supply. About 3 percent of the total ground water used in Polk County is withdrawn from the intermediate aquifer system for domestic, industrial, and irrigation uses.

The Floridan aquifer system is subdivided into two aquifers, the Upper Floridan aquifer and Lower Floridan aquifer. In Polk County, the Upper Floridan aquifer contains freshwater and the Lower Floridan aquifer contains more mineralized water. These aquifers are separated by a less-permeable middle semiconfining unit and middle confining unit, both of which restrict the vertical movement of water. The Upper Floridan aquifer can be further subdivided into two separate zones of different permeabilities. The Upper Floridan aquifer system consists primarily of limestone and dolostone of Eocene to Oligocene age. The altitude of the top of the Upper Floridan aquifer ranges from about 50 feet above NGVD 29 in the northwestern part of the county to more

than 250 feet below NGVD 29 in the southern part. In a few areas in extreme northwestern Polk County, the aquifer is at or within a few feet of land surface. Transmissivity estimates for the Upper Floridan aquifer in the Polk County area range from about 3,500 to 468,000 feet squared per day. The Upper Floridan aquifer provides most of the water-supply demands in Polk County.

The potentiometric surface of the Upper Floridan aquifer system fluctuates, mainly in response to seasonal variations in rainfall and ground-water withdrawals. In September 2003, the altitude of the potentiometric surface of the Upper Floridan aquifer ranged from about 44 to 130 feet above NGVD 29. Potentiometric surface altitudes in May 2004 were about 1.5 to 17 feet lower than those measured in September 2003.

Water levels in the Upper Floridan aquifer also can change from year to year, depending on such factors as pumpage and climatic variations. Long-term trends of water levels in the southwestern part of the county show that fluctuations in water use related to phosphate mining have had a major impact on water levels in the area. Hydrographs of selected wells in southwestern Polk County show a general decline in water levels that ended in the mid-1970s. This water-level decline coincided with an increase in water use associated with phosphate mining. A significant rise in water levels that began in the mid-1970s coincided with a period when pumping associated with the phosphate industry declined. In addition to a decrease in pumping, an increase in rainfall during this same period also may be responsible for some of the increase in water levels.

Since predevelopment times, the increase in pumping in and near the study area has resulted in a decline of the potentiometric surface of the Upper Floridan aquifer across much of the county. The approximate decline in the potentiometric surface of the Upper Floridan aquifer is based on the difference between the estimated predevelopment potentiometric surface map and the water levels of wells measured in May and September and averaged from 2000 to 2004. In the southwestern part of the county, where large withdrawals for industrial use have occurred, declines in water levels ranged from about 15 to as much as 40 feet. In the eastern and west-central parts of the county, water levels have declined from greater than 0 to 15 feet. In the northwestern part of the county, an area that has not been impacted by pumping, little or no change in water levels has occurred.

Ground-water quality was assessed by sampling 53 wells and one spring and by compiling data collected from 76 additional wells by State and other Federal agencies. Inorganic constituents were the focus of water-quality analysis. Concentrations of dissolved solids, sulfate, and chloride in water samples from the surficial and intermediate aquifer systems generally were below State and Federal drinking-water standards. Nitrate concentrations, however, were elevated (as high as 26 milligrams per liter (mg/L)) in the surficial aquifer system along the Lake Wales Ridge. The application of fertilizers related to citrus farming is a likely source of nitrate to the ground water in this area.

Water in the Upper Floridan aquifer is typically a calcium bicarbonate water type, resulting from the dissolution of the carbonate rock. Inorganic constituent concentrations in water from the Floridan aquifer system generally were below State and Federal drinking-water standards. Water from the Upper Floridan aquifer in most of the county is hard and has a dissolved-solids concentration of less than 500 mg/L. Chloride concentrations in water from the Upper Floridan aquifer range from 4.2 to 61 mg/L, and sulfate concentrations range from about 0.2 to 44 mg/L. In contrast to results from the surficial aquifer system, nitrate concentrations in the Upper Floridan aquifer generally were low and exceeded 1.0 mg/L in only three wells. Lower nitrate concentrations in the Upper Floridan aquifer suggest that denitrification may be occurring as ground water moves downward, but also may be due to dilution.

Chloride concentrations less than 250 mg/L extend to considerable depths in the Floridan aquifer system. The thickest section where chloride concentrations are less than 250 mg/L is along the Lake Wales Ridge. The altitude of the top of the 250-mg/L isochlor surface in this area is estimated to be about 2,400 feet below NGVD 29. The estimated position of the 250-mg/L isochlor surface is less than 1,200 feet below NGVD 29 in the extreme southeastern part of the county. The depth of the chloride isochlor surface, however, may not accurately portray the thickness of the freshwater zone. The limited data available indicate that within and beneath the middle confining unit, dissolved-solids concentrations may be high not because of chloride, but because of high sulfate concentrations.

Low-flow and flood-flow frequency statistics were updated in this study based on data collected by the USGS through 2003. A shorter period of record was used to compute frequency statistics for the Peace River at Bartow, Peace River at Fort Meade, and Catfish Creek near Lake Wales due to temporal trends in the streamflow data. Frequency statistics at these sites were computed to represent 2003 conditions.

The Kissimmee River within Polk County has been regulated for flood-control purposes as part of the Central and South Florida Flood Control Project. The entire stream was channelized from 1962 to 1971. These changes have resulted in alteration of the hydrologic characteristics of the stream. The seasonal variation in streamflows has changed substantially. Based on data from water years 1979-2003, the greatest streamflows for the Kissimmee River generally occurred from January through May and in August. In contrast, streamflows generally are greatest in September and October and least in May and June in all other streams in the county. Further changes in the hydrology of the Kissimmee River in Polk County may occur in the future because the flood-control project in the Kissimmee Basin is being modified by the State of Florida and the Federal Government, in part to re-establish the historic hydrologic conditions in the basin.

The declines measured in the potentiometric surface of the Upper Floridan aquifer also have been expressed in some of the surface-water resources of the county as well. The section of the Peace River within the county formerly was a gaining stream, which received springflow from Kissengen Spring and ground-water inflow from the Floridan aquifer system. This part of the Peace River is now classified as a losing stream. Kissengen Spring has not flowed since 1960, and the Floridan aquifer system no longer contributes ground-water inflow to the river. Several studies also have been published documenting long-term declines in streamflow in the Peace River and in the water levels of selected lakes.

Temporal trends in streamflow in the Peace River were updated in this study using data through 2003. The analyses also were expanded by analyzing trends over a wider range of the hydrologic regime and over 15 multidecadal periods. The results indicated that annual minimum to 70th percentile streamflows in the Upper Peace River began to decline in the 1950s, and that this decline in streamflows has persisted to 2003. Results also showed a statistically significant decrease in annual minimum streamflows in the Peace River at Bartow from 1974 to 1993. This decrease may be due to elimination of wastewater discharges to the river during the mid-1980s.

The lakes in Polk County exchange water with the ground-water system. Direct runoff from the land surface, with the exception of stormwater runoff in urban areas, is considered to be minimal because of the high permeability of the sandy soils in the area. Most of the seepage lakes are classified as flow-through lakes, where ground-water inflows along part of the lake perimeter and outflows laterally along the remainder. The percentage of the lake perimeter receiving ground-water inflow varies among lakes and from season to season.

Water levels in lakes in the county vary seasonally. Water levels generally are lowest in May and greatest in September and October. There may, however, be deviations from this general pattern due to variations in rainfall or pumpage. Transient water-table mounding also has been observed near the shoreline of seepage lakes in the county and may affect lake levels. Observed water-table mounding generally was short in duration. At Lake Starr, water-table mounds generally lasted less than 1 day.

Temporal trends in lake levels were analyzed to describe long-term trends (1960-2003) and trends that occurred from 1990-2003. About 90 percent of the lakes had no change in water levels from 1990-2003. Five of the lakes had an increasing trend in water levels. The increase in water levels likely is not due to increased rainfall. Annual totals at nearby rainfall stations had no significant trends during this period.

Selected References

Adamski, J.C., and German, E.R., 2004, Hydrology and quality of ground water in Orange County, Florida: U.S. Geological Survey Water-Resources Investigations Report 03-4257, 113 p.

Aucott, W.R., 1988, Areal variation in recharge to and discharge from the Floridan aquifer system in Florida: U.S. Geological Survey Water-Resources Investigations Report 88-4057, 1 sheet.

Anderson, Warren, and Simonds, E.P., 1983, Hydrology of Hamilton Lake and vicinity, Polk County, Central Florida: U.S. Geological Survey Open-File Report 82-630, 1 sheet.

Arthur, J., Fischler, C., Kromhout, C., Clayton, J., Kelley, M., Lee, R., Li, L., O'Sullivan, M., Green, R., and Werner C., 2007, Hydrogeologic framework of the Southwest Florida Water Management District: Tallahassee, Florida Geological Survey Bulletin 68.

BCI, 2000, Reclamation and mitigation of the Upper Peace River watershed at the Tenoroc Fish Management Area—Task 1, restoration approach and identification of work elements: Prepared for the Florida Department of Environmental Protection, the U.S. Army Corps of Engineers, and the Southwest Florida Water Management District, 95 p.

Barcelo, Mark, and Basso, Ron, 1993, Computer model of ground-water flow in the Eastern Tampa Bay Water Use Caution Area: Brooksville, Southwest Florida Water Management District, 102 p.

Barcelo, M.D., Slonena, D.L., Camp, S.C., and Watson, J.D., 1990, Ridge II: A hydrogeologic investigation of the Lake Wales Ridge: Brooksville, Southwest Florida Water Management District Technical Report, 130 p.

Barr, G.L., 1992, Ground-water contamination potential and quality in Polk County, Florida: U.S. Geological Survey Water-Resources Investigations Report 92-4086, 92 p.

Basso, Ron, 2003, Predicted change in hydrologic conditions along the Upper Peace River Basin due to a reduction in ground-water withdrawals: Brooksville, Southwest Florida Water Management District, 53 p.

Basso, Ron, and Hood, Jill, 2005, Assessment of minimum levels for the intermediate aquifer system in the Southwest Florida Water Management District: Brooksville, Southwest Florida Water Management District, 217 p.

Basso, Ron, and Schultz, Richard, 2003, Long-term variation in rainfall and its effect on Peace River flow in west-central Florida: Brooksville, Southwest Florida Water Management District, 33 p.

Blanchard, R.A., Seidenfeld, A.V., and McCulloch, D.S., 2004, Potentiometric surface of the Upper Floridan aquifer, west-central Florida, September 2003: U.S. Geological Survey Open-File Report 2004-1314, 1 sheet.

Blanchard, R.A., Seidenfeld, A.V., and McCulloch, D.S., 2004, Potentiometric surface of the Upper Floridan aquifer, west-central Florida, May 2004: U.S. Geological Survey Open-File Report 2004-1399, 1 sheet.

Boyle Engineering Corporation, 1995, Hydrogeologic report—Orange County southern regional wellfield: Consultant's report prepared for Orange County Public Utilities Commission, Orange County, Florida, Report OR-003-305-01.

Bradbury, K.R., Bartos, L.F., and Richters, D.F., 1978, Hydrology and limnology of Crooked Lake near Babson Park, Florida: Brooksville, Southwest Florida Water Management District Environmental Section Technical Report 1978-1, 47 p.

Bush, P.W., and Johnston, R.H., 1988, Ground-water hydraulics, regional flow, and ground-water development of the Floridan aquifer system in Florida and in parts of Georgia, South Carolina, and Alabama: U.S. Geological Survey Professional Paper 1403-C, 80 p.

Campbell, K.M., 1986, Geology of Polk County, Florida: Tallahassee, Florida Geological Survey Open-File Report 13, 18 p.

Carr, W.J., and Alverson, D.C., 1959, Stratigraphy of middle Tertiary rocks in parts of west-central Florida: U.S. Geological Survey Bulletin 1092, 111 p.

CH2MHILL, 1989, Wastewater management program for the 1,000-acre site: Consultant's report prepared for Reedy Creek Improvement District, Lake Buena Vista, Florida.

CH2MHILL, 2005, Construction and testing of well F at the Southlake Utilities water treatment facility site: Consultant's report prepared for Southlake Utilities, Lake County, Florida.

Charlotte Harbor National Estuary Program, 2000, Committing to the future—A comprehensive conservation and management plan for the greater Charlotte Harbor watershed, v. 1: Charlotte Harbor National Estuary Program, North Fort Myers, Florida, 272 p.

Choquette, A.F, and Sepúlveda, A.A., 2000, Design of a shallow ground-water network to monitor agricultural chemicals, Lake Wales Ridge, Central Florida: U.S. Geological Survey Water-Resources Investigations Report 00-4134, 35 p.

Choquette, A.F, Turner, R.D., Haber, J.D., Lucas, P.A., and Daiker, D.H., 2005, Temporal variability of agricultural chemicals in ground water and implications for water-quality sampling, *in* Proceedings of the Annual Tennessee Water Resources Symposium, April 2005, Burns, Tennessee: American Water Resources Association, p. 2B6-2B14.

City of Lakeland, 2001, City of Lakeland lakes water quality report, 1988-2000: Public Works Department, Florida, 37 p.

Cooke, W.C., 1945, Geology of Florida: Tallahassee, Florida Geological Survey Bulletin 29, 339 p.

Crandall, C.A., and Berndt, M.P., 1996, Water quality of surficial aquifers in the Georgia-Florida Coastal Plain: U.S. Geological Survey Water-Resources Investigations Report 95-4269, 28 p.

Davis and Associates, 1981, Application and technical report for disposal well no. 2: Consultant's report prepared for the Kaiser Aluminum and Chemical Corporation, Mulberry Plant, Polk County, Florida, 32 p.

Dietrich, T.S., 1978, The urbanization of Florida's population: An historical perspective of county growth 1830-1970: Gainesville, University of Florida, Bureau of Economic and Business Research.

Duerr, A.D., and Enos, G.M., 1991, Hydrogeology of the intermediate aquifer system and Upper Floridan aquifer, Hardee and DeSoto Counties, Florida: U.S. Geological Survey Water-Resources Investigations Report 90-4104, 46 p.

Duerr, A.D., Hunn, J.D., Lewelling, B.R., and Trommer, J.T., 1988, Geohydrology and 1985 water withdrawals of the aquifer systems in southwest Florida with emphasis on the intermediate aquifer system: U.S. Geological Survey Water-Resources Investigations Report 87-4259, 115 p.

Enfield, D.B., Mestas-Nunez, A.M., and Trimble, P.J., 2001, The Atlantic multidecadal oscillation and its relation to rainfall and river flows in the continental U.S.: Geophysical Research Letters, v. 28, no. 10, p. 2077-2080.

Evans, M.W., Snyder, S.W., and Hine, A.C., 1994, High-resolution seismic expression of karst evolution within the Upper Floridan aquifer system, Crooked Lake, Polk County, Florida: Journal of Sedimentary Research, v. B64, p. 232-244.

Flannery, M.S., and Barcelo, M., 1998, Spatial and temporal patterns of streamflow trends in the Upper Charlotte Harbor watershed, *in* Proceedings of the Charlotte Harbor Public Conference and Technical Symposium: Charlotte Harbor National Estuary Program, Florida, Technical Report 98-02.

Florida Department of State, 1989, Rules of the Department of Environmental Regulation, public drinking water systems: Tallahassee, *in* Florida Administrative Code, chap. 17-550.

Florida Institute of Phosphate Research, 2006a, History of phosphate land reclamation in Florida [accessed 9/5/2006] *http://www.fipr.state.fl.us/research-area-reclamation.htm#History*

Florida Institute of Phosphate Research, 2006b, Reclamation— Strategies and stages [accessed 9/5/2006] *http://www1.fipr.state.fl.us/PhosphatePrimer/0/764E773481EAD02A85256F790058D446*

Gant, R.D., 1993, Directory of lakes within the Southwest Florida Water Management District—Lake levels program: Brooksville, Southwest Florida Water Management District, 58 p.

Gant, R.D., 2001, Directory of lakes within the Southwest Florida Water Management District: Brooksville, Southwest Florida Water Management District, 61 p.

Gates, M.T., 2003, Hydrogeology of the ROMP 74x Davenport monitor well site, Polk County, Florida, phase 1 core drilling and testing: Brooksville, Southwest Florida Water Management District, 58 p.

Gates, M.T., 2005, ROMP 74x Davenport, Polk County, Florida: Brooksville, Southwest Florida Water Management District, 28 p.

Geraghty and Miller, Inc., 1980, Highlands Ridge hydrologic investigation: Consultant's report prepared for the Peace River Basin Board, Brooksville, Southwest Florida Water Management District, 142 p.

German, E.R., 1996, Analysis of nonpoint-source ground-water contamination in relation to land use: Assessment of nonpoint-source contamination in central Florida: U.S. Geological Survey Water-Supply Paper 2381-F, 60 p.

Grubb, H.F., 1978, Potential for downward leakage to the Floridan aquifer, Green Swamp area, central Florida: U.S. Geological Survey Water-Resources Investigations Report 77-71, 1 sheet.

Grubb, H.F., Chappelear, J.W., and Miller, J.A., 1978, Lithologic and borehole geophysical data, Green Swamp area, Florida: U.S. Geological Survey Open-File Report 78-574, 270 p.

Grubb, H.F., and Rutledge, A.T., 1979, Long-term water supply potential, Green Swamp area, Florida: U.S. Geological Survey Water-Resources Investigations Report 78-99, 76 p.

Grubbs, J.W., 1995, Evaluations of ground-water flow and hydrologic budget for Lake Five-O, a seepage lake in northwestern Florida: U.S. Geological Survey Water-Resources Investigations Report 94-4145, 42 p.

Hammett, K.M., 1990, Land use, water use, streamflow characteristics, and water-quality characteristics of the Charlotte Harbor inflow area, Florida: U.S. Geological Survey Water-Supply Paper 2359-A, 64 p.

Hammett, K.M., and DelCharco, M.J., 2005, Estimating the magnitude and frequency of floods for streams in west-central Florida, 2001: U.S. Geological Survey Scientific Investigations Report 2005-5080, 15 p.

Heath, R.C., 1961, Surface-water resources of Polk County, Florida: Tallahassee, Florida Geological Survey Information Circular 25, 123 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Techniques of Water-Resources Investigations of the United States Geological Survey, book 4, Hydrologic Analysis and Interpretation, chap. A3, 510 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hickey, J.J., 1990, An assessment of the flow of variable-salinity ground water in the middle confining unit of the Floridan aquifer system, west-central Florida: U.S. Geological Survey Water-Resources Investigations Report 89-4142, 13 p.

Hutchinson, C.B., 1978, Appraisal of shallow ground-water resources and management alternatives in the upper Peace and eastern Alafia River basins, Florida: U.S. Geological Survey Water-Resources Investigations Report 77-124, 57 p.

Irwin, G.A., and Hutchinson, C.B., 1976, Reconnaissance water sampling for radium-226 in central and northern Florida, December 1974-March 1976: U.S. Geological Survey Water-Resources Investigations Report 76-103, 16 p.

Jackson, T.E., 2000, Report on the Kissengen Spring site near Bartow, Florida, and the potential for restoration of the spring flow: Brooksville, Southwest Florida Water Management District Technical Memorandum, 9 p.

Johnston, R.H., Krause, R.E., Meyer, F.W., Ryder, P.D., Tibbals, C.H., and Hunn, J.D., 1980, Estimated potentiometric surface for the Tertiary limestone aquifer system, southeastern United States, prior to development: U.S. Geological Survey Open-File Report 80-406, 1 sheet.

Kaufman, M.I., 1967, Hydrologic effects of ground-water pumpage in the Peace and Alafia River basins, Florida, 1934-1965: Tallahassee, Florida Geologic Survey Report of Investigations 49, 32 p.

Kelly, Martin, 2004, Florida river flow patterns and the Atlantic multidecadal oscillation: Brooksville, Southwest Florida Water Management District, Ecologic Evaluation Section, 80 p.

Kinnaman, S.L., and Knowles, Leel, Jr., 2004a, Potentiometric surface of the Upper Floridan aquifer in the St. Johns River Water Management District and vicinity, Florida, September 2003: U.S. Geological Survey Open-File Report 2004-1288, 1 sheet.

Kinnaman, S.L., and Knowles, Leel, Jr., 2004b, Potentiometric surface of the Upper Floridan aquifer in the St. Johns River Water Management District and vicinity, Florida, May 2004: U.S. Geological Survey Open-File Report 2004-1377, 1 sheet.

Kite, G.W, 1977, Frequency and risk analyses in hydrology: Water Resources Publication, Fort Collins, Colorado, 224 p.

Knochenmus, D.D., 1976, Hydrology of Lake County: U.S. Geological Survey Water-Resources Investigations Report 76-72, 99 p.

Knochenmus, L.A., 2006, Regional evaluation of the hydrogeologic framework, hydraulic properties, and chemical characteristics of the intermediate aquifer system underlying southern west-central Florida: U.S. Geological Survey Scientific Investigations Report 2006-5013, 52 p.

Knowles, Leel, Jr., O'Reilly, A.M., and Adamski, J.C., 2002, Hydrogeology and simulated effects of ground-water withdrawals from the Floridan aquifer system in Lake County and in the Ocala National Forest and vicinity, north-central Florida: U.S. Geological Survey Water-Resources Investigations Report 02-4207, 140 p.

Koebel, J.W., Jr., 1995, A historical prospective on the Kissimmee River restoration project: Restoration Ecology, v. 3, p. 149-159.

LaMoreaux, P. E., and Associates, 1975a, Water resources evaluation for W.R. Grace and Company's Hookers Prairie tract, Polk County, Florida.

LaMoreaux, P. E., and Associates, 1975b, Four corners mine, Hillsborough and Manatee Counties, Florida, application for development approval.

Leach, S.D., 1977, Estimated water-use inventory in Florida, 1975: U.S. Geological Survey Open-File Report 77-577, 57 p.

Lee, T.M., 1996, Hydrogeologic controls on the ground-water interactions with an acidic lake in karst terrain, Lake Barco, Florida: Water Resources Research, v. 32, no. 4, p. 831-844.

Lee, T.M., 2000, Effects of near-shore recharge on ground-water interactions with a lake in mantled karst terrain: Water Resources Research, v. 36, p. 2167-2182.

Lee, T.M., 2002, Factors affecting ground-water exchange and catchment size for Florida lakes in mantled karst terrain: U.S. Geological Survey Water-Resources Investigations Report 02-4033, 54 p.

Lee, T.M., Adams, D.B., Tihansky, A.B., and Swancar, Amy, 1991, Methods, instrumentation, and preliminary evaluation of data for the hydrologic budget assessment of Lake Lucerne, Polk County, Florida: U.S. Geological Survey Water-Resources Investigations Report 90-4111, 42 p.

Lee, T.M., and Swancar, Amy, 1997, Influence of evaporation, ground water, and uncertainty in the hydrologic budget of Lake Lucerne, a seepage lake in Polk County, Florida: U.S. Geological Survey Water-Supply Paper 2439, 61 p.

Lewelling, B.R., 1987, Potentiometric surface of the intermediate aquifer system, west-central Florida, May 1987: U.S. Geological Survey Open-File Report 87-705, 1 sheet.

Lewelling, B.R., Tihansky, A.B., and Kindinger, J.L., 1998, Assessment of the hydraulic connection between ground water and the Peace River, west-central Florida: U.S. Geological Survey Water-Resources Investigations Report 97-4211, 96 p.

Lewelling, B.R., and Wylie, R.W., 1993, Hydrology and water quality of unmined and reclaimed basins in phosphate-mining areas, west-central Florida: U.S. Geological Survey Water-Resources Investigations Report 93-4002, 93 p.

Lichtler, W.F., Anderson, Warren, and Joyner, B.F., 1968, Water resources of Orange County, Florida: Tallahassee, Florida Geological Survey Report of Investigations 50, 150 p.

Long, H.W., Jr., and Orne, D.P., 1990, Regional study of land use planning and reclamation: Central Florida Planning Council, p. 77.

Mantau, N.J., Hare, S.R., Zhang, Yuan, Wallace, J.M., and Francis, R.C., 1997, A Pacific interdecadal climate oscillation with impacts on salmon production: Bulletin of the American Meteorological Society, v. 78, p. 1069-1079.

Marella, R.L., 1988, Water withdrawals, use, and trends in Florida, 1985: U.S. Geological Survey Water-Resources Investigations Report 88-4103, 43 p.

Marella, R.L., 2004, Water withdrawals, use, discharge, and trends in Florida, 2000: U.S. Geological Survey Scientific Investigations Report 2004-5151, 136 p.

McCabe, G.J., Palecki, M.A., and Betancourt, J.L., 2004, Pacific and Atlantic Ocean influences on multidecadal drought frequency in the United States: Proceedings of the National Academy of Sciences, USA, v. 101, p. 4136-4141.

McCabe, G.J., and Wolock, D.M., 2002, A step increase in streamflow in the conterminous United States: Geophysical Research Letters, v. 29, no. 24, p. 2185-2188.

McGurk, B., and Sego, J., 1999, Hydrologic data from a Lower Floridan test well, central Orange County, Florida: Palatka, St. Johns River Water Management District Technical Publication SJ99-SP8, 133 p.

McGurk, Brian, Burger, Patrick, and Toth, David, 2003, Three-dimensional mapping of salinity zones within the Floridan aquifer system in the St. Johns River Water Management District and adjoining areas, northeast Florida: National Ground Water Association National Ground Water Expo, Association of Ground Water Scientists and Engineers Symposium, Technical Interactive Presentation, Orlando, Florida, December 2003.

Menke, C.G., Meredith, E.W., and Wetterhall, W.S., 1961, Water resources of Hillsborough County, Florida: Tallahassee, Florida Geological Survey Report of Investigations 25, 101 p.

Menke, C.G., Meredith, E.W., and Wetterhall, W.S., 1964, Water-resources records of Hillsborough County, Florida: Tallahassee, Florida Geological Survey Information Circular 44, 95 p.

Metz, P.A., 1995, Hydrogeology and simulated effects of ground-water withdrawals for citrus irrigation, Hardee and DeSoto Counties, Florida: U.S. Geological Survey Water-Resources Investigations Report 93-4158, 83 p.

Metz, P.A., and Brendle, D.L., 1996, Potential for water-quality degradation of interconnected aquifers in west-central Florida: U.S. Geological Survey Water-Resources Investigations Report 96-4030, 54 p.

Metz, P.A., and Sacks, L.A., 2002, Comparison of the hydrogeology and water quality of a ground-water augmented lake with two non-augmented lakes in northwest Hillsborough County, Florida: U.S. Geological Survey Water-Resources Investigations Report 02-4032, 74 p.

Miller, J.A., 1986, Hydrogeologic framework of the Floridan aquifer system in Florida and in parts of Georgia, South Carolina, and Alabama: U.S. Geological Survey Professional Paper 1403-B, 91 p., 33 plates.

Miller, R.L., and Sutcliffe, Horace, Jr., 1982, Water-quality and hydrogeologic data for three phosphate industry waste-disposal sites in central Florida, 1979-80: U.S. Geological Survey Water-Resources Investigations Report 81-84, 77 p.

Miller, R.L., and Sutcliffe, Horace, Jr., 1984, Effects of three phosphate industrial sites on ground-water quality in central Florida, 1974 to 1980: U.S. Geological Survey Water-Resources Investigations Report 83-4256, 184 p.

Mills, L.R., and Laughlin, C.P., 1976, Potentiometric surface of Floridan aquifer, Southwest Florida Water Management District, May 1975: U.S. Geological Survey Open-File Report FL 76002, 1 sheet.

Mills, L.R., Laughlin, C.P., and Parsons, D.C., 1976, Potentiometric surface of Floridan aquifer, Southwest Florida Water Management District, September 1975: U.S. Geological Survey Open-File Report FL 76003, 1 sheet.

Moore, D.L., Martin, D.W., Walker, S.T., Rauch, J.T., and Jones, G.W., 1986, Initial sampling results of an ambient background ground-water quality monitor network in the Southwest Florida Water Management District: Brooksville, Southwest Florida Water Management District, 393 p.

National Oceanic and Atmospheric Administration, 1965-75, Climatological data, Florida: v. 68-79.

Navoy, A.S., 1986, Hydrogeologic data from a 2,000-foot deep core hole at Polk City, Green Swamp area, central Florida: U.S. Geological Survey Water-Resources Investigations Report 84-4257, 89 p.

Obeysekera, J., and Loftin, M.K., 1990, Hydrology of the Kissimmee River basin, influence of man-made and natural changes, *in* Loftin, M.K., Toth, L.A., and Obeysekera, J., eds., Proceedings of the Kissimmee River Restoration Symposium, October 1988, Orlando, Florida: West Palm Beach, South Florida Water Management District, p. 211-222.

Office of Economic and Demographic Research, 2005, Total county population: April 1, 1970-2030: Tallahassee, The Florida Legislature, Excel file [accessed 8/2005] *http:www.state.fl.us/population.htm*

O'Reilly, A.M., 1998, Hydrogeology and simulation of the effects of reclaimed-water application in west Orange and southeast Lake Counties, Florida: U.S. Geological Survey Water-Resources Investigations Report 97-4199, 91 p.

O'Reilly, A.M., Spechler, R.M., and McGurk, B.E., 2002, Hydrogeology and water-quality characteristics of the Lower Floridan aquifer in east-central Florida: U.S. Geological Survey Water-Resources Investigations Report 02-4193, 60 p.

Parizek, R.R., 1976, On the nature and significance of fracture traces and lineaments in carbonate and other terranes, *in* Karst Hydrology and Water Resources: Proceedings of the U.S.-Yugoslavia Symposium, Dubrovnik, Croatia, June 2-7, 1974, v. 1, p. 47-108.

Patton, T.H., 1981, Geologic investigations of the ordinary high water line along the upper Peace River, Polk County, Florida: Patton and Associates, Inc., prepared for Beckham, McAliley, and Proenza, P.A., 141 p.

Patton, T.H., and Klein, Jean-Georges, 1989, Sinkhole formation and its effect on Peace River hydrology, *in* Beck, B.F., ed., Engineering and environmental impacts of sinkholes and karst: Proceedings of the third multidisciplinary conference on sinkholes, St. Petersburg Beach, Florida, October 2-4, 1989: Rotterdam, Balkema Publishers, p. 25-31.

Peek, H.M., 1951, Cessation of flow of Kissengen Spring in Polk County, Florida: Tallahassee, Florida Geological Survey Report of Investigations 7, p. 73-82.

Perrin, L.S., Allen, M.J., Rowse, L.A., Montalbano, F., III, Foote, K.J., and Olinde, M.W., 1982, A report on fish and wildlife studies in the Kissimmee River Basin and recommendations for restoration: Okeechobee, Florida Game and Fresh Water Fish Commission, Office of Environmental Services, 260 p.

Polk County Department of Economic Development, 2005, Demographics [accessed 8/2005] *http://www.cfdc.org*

Pride, R.W., Meyer, F.W., and Cherry, R.N., 1966, Hydrology of Green Swamp area in central Florida: Tallahassee, Florida Geological Survey Report of Investigations 42, 137 p.

Purdum, E.D., Krafft, P.A., and Fernald, E.A., 1988, Florida county atlas and municipal fact book: Tallahassee, Florida State University, Institute of Science and Public Affairs, 45 p.

Riggs, H.C., 1972, Frequency curves: U.S. Geological Survey Techniques of Water-Resources Investigations, chap. A2, book 4, 15 p.

Robertson, A.F., 1971, A preliminary evaluation of hydrologic conditions of the Lakeland Ridge area of Polk County, Florida: U.S. Geological Survey Open-File Report FL-71007, 37 p.

Robertson, A.F., 1973, Hydrologic conditions in the Lakeland Ridge area of Polk County, Florida: Tallahassee, Florida Geological Survey Report of Investigations 64, 54 p.

Robertson, A.F., and Mills, L.R., 1974, Ground-water withdrawals in the upper Peace and upper Alafia River basins, Florida: Tallahassee, Florida Geological Survey Map Series 67, 1 sheet.

Rosenau, J.C., Faulkner, G.L., Hendry, C.W., Jr., and Hull, R.W., 1977, Springs of Florida (2d ed.): Tallahassee, Florida Geological Survey Bulletin 31, 461 p.

Rutledge, A.T., 1987, Effects of land use on ground-water quality in central Florida—Preliminary results: U.S. Geological Survey Water-Resources Investigations Report 86-4163, 49 p.

Ryder, P.D., 1982, Digital model of predevelopment flow in the Tertiary limestone (Floridan) aquifer system in west-central Florida: U.S. Geological Survey Water-Resources Investigations Report 81-54, 61 p.

Ryder, P.D., 1985, Hydrology of the Floridan aquifer system in west-central Florida: U.S. Geological Survey Professional Paper 1403-F, 63 p.

Sacks, L.A., 2002, Estimating ground-water inflow to lakes in central Florida using the isotope mass-balance approach: U.S. Geological Survey Water-Resources Investigations Report 02-4192, 59 p.

Sacks, L.A., Lee, T.M., and Tihansky, A.B., 1992, Hydrogeologic setting and preliminary data analysis for the hydrologic-budget assessment of Lake Barco, an acid seepage lake in Putnam County, Florida: U.S. Geological Survey Water Resources Investigations Report 91-4180, 28 p.

Sacks, L.A., Swancar, Amy, and Lee, T.M., 1998, Estimated ground-water exchange with lakes using water-budget and chemical mass-balance approaches for ten lakes in ridge areas of Polk and Highlands Counties, Florida: U.S. Geological Survey Water-Resources Investigations Report 98-4133, 52 p.

Sacks, L.A., and Tihansky, A.B., 1996, Geochemical and isotopic composition of ground water, with emphasis on sources of sulfate, in the Upper Floridan aquifer and intermediate aquifer system in southwest Florida: U.S. Geological Survey Water-Resources Investigations Report 96-4146, 54 p.

Schiner, G.R., 1993, Geohydrology of Osceola County, Florida: U.S. Geological Survey Water-Resources Investigations Report 92-4076, 68 p.

Scott, T.M., 1988, The lithostratigraphy of the Hawthorn Group (Miocene) of Florida: Tallahassee, Florida Geological Survey Bulletin 59, 148 p.

Scott, T.M., Campbell, K.M., Rupert, F.R., Arthur, J.D., Missimer, T.M., Lloyd, J.M., Yon, J.W., and Duncan, J.G., 2001, Geologic map of Florida: Tallahassee, Florida Geological Survey Map Series 146, 1 sheet.

Sepúlveda, Nicasio, 2002, Simulation of ground-water flow in the Intermediate and Floridan aquifer systems in peninsular Florida: U.S. Geological Survey Water-Resources Investigations Report 02-4009, 130 p.

Shaw, J.E., and Trost, S.M., 1984, Hydrogeology of the Kissimmee planning area: West Palm Beach, South Florida Water Management District Technical Publication 84-1, 235 p.

Sinclair, W.C., and Reichenbaugh, R.C., 1981, Hydrology of the Winter Haven Chain of Lakes, Polk County, Florida: U.S. Geological Survey Open-File Report 81-212, 1 plate.

Sinclair, W.C., Stewart, J.W., Knutilla, R.L., Gilboy, A.E., and Miller, R.L., 1985, Types, features, and occurrence of sinkholes in the karst of west-central Florida: U.S. Geological Survey Water-Resources Investigations Report 85-4126, 81 p.

Snyder, S.W., Evans, M.W., Hine, A.C., and Compton, J.S., 1989, Seismic expression of solution collapse features from the Florida platform, *in* Beck, B.F., ed., Engineering and environmental impacts of sinkholes and karst: Proceedings of the Third Multidisciplinary Conference on Sinkholes, St. Petersburg Beach, Florida: Orlando, Florida Sinkhole Research Institute, p. 281-298.

South Florida Water Management District, 2005a, Headwaters projects [accessed 8/1/2005] *http://www.sfwmd.gov/org/erf/krr/construct/headwaters/s65_mods.html*

South Florida Water Management District, 2005b, Kissimmee River restoration [accessed 8/1/2005] *http:// www.sfwmd.gov/org/erd/krr/pubs/3_krrpub.html*

Southwest Florida Water Management District, 1988, Ground-water resources availability inventory, Polk County, Florida: Brooksville, 220 p.

Southwest Florida Water Management District, 2000, Aquifer characteristics within the Southwest Florida Water Management District: Brooksville, 123 p.

Southwest Florida Water Management District, 2002, Upper Peace River—An analysis of minimum flows and levels: Brooksville, 244 p.

Southwest Florida Water Management District, 2003, Florida forever work plan—Annual update: Brooksville, 84 p.

Southwest Florida Water Management District, 2004a, 2002 estimated water use in the Southwest Florida Water Management District: Brooksville, 178 p.

Southwest Florida Water Management District, 2004b, Estimated water use, 1998 to 2002, in the Southwest Florida Water Management District: Brooksville, 5 p.

Spechler, R.M., and Halford, K.J., 2001, Hydrogeology, water quality, and simulated effects of ground-water withdrawals from the Floridan aquifer system, Seminole County and vicinity, Florida: U.S. Geological Survey Water-Resources Investigations Report 01-4182, 116 p.

Sprinkle, C.L., 1989, Geochemistry of the Floridan aquifer system in Florida and in parts of Georgia, South Carolina, and Alabama: U.S. Geological Survey Professional Paper 1403-I, 105 p.

Stewart, H.G., Jr., 1963, Records of wells and other water-resources data in Polk County, Florida: Tallahassee, Florida Geological Survey Information Circular 38, 144 p.

Stewart, H.G., Jr., 1966, Ground-water resources of Polk County, Florida: Tallahassee, Florida Geological Survey Report of Investigations 44, 170 p.

Stewart, J.W., 1980, Areas of natural recharge to the Floridan aquifer in Florida: Tallahassee, Florida Bureau of Geology Map Series 98, 1 sheet.

Stringfield, V.T., 1936, Artesian water in the Florida Peninsula: U.S. Geological Survey Water-Supply Paper 773-C, p. 115-195.

Stringfield, V.T., 1966, Artesian water in Tertiary limestone in the southeastern States: U.S. Geological Survey Professional Paper 517, 226 p.

Sumner, D.M., 1996, Evapotranspiration from successional vegetation in a deforested area of the Lake Wales Ridge, Florida: U.S. Geological Survey Water-Resources Investigations Report 96-4244, 37 p.

Swancar, Amy, and Hutchinson, C.B., 1995, Chemical and isotopic composition and potential for contamination of water in the Upper Floridan aquifer, west-central Florida, 1986-89: U.S. Geological Survey Water-Supply Paper 2409, 68 p.

Swancar, Amy, and Lee, T.M., 2003, Effects of recharge, Upper Floridan aquifer heads, and time scale on simulated ground-water exchange with Lake Starr, a seepage lake in central Florida: U.S. Geological Survey Water-Resources Investigations Report 02-4295, 53 p.

Swancar, Amy, Lee, T.M., and O'Hare, T.M., 2000, Hydrogeologic setting, water budget, and preliminary analysis of ground-water exchange at Lake Starr, a seepage lake in Polk County, Florida: U.S. Geological Survey Water-Resources Investigations Report 00-4030, 66 p.

Szell, G.P., 1993, Aquifer characteristics in the St. Johns River Water Management District: Palatka, St. Johns River Water Management District Technical Publication SJ 93-1, 495 p.

Tibbals, C.H., 1990, Hydrology of the Floridan aquifer system in east-central Florida: U.S. Geological Survey Professional Paper 1403-E, 98 p.

Tibbals, C.H., and Grubb, H.F., 1982, Aquifer test results, Green Swamp area, Florida: U.S. Geological Survey Water-Resources Investigations Report 82-35, 29 p.

Tihansky, A.B., Arthur, J.D., and DeWitt, D.W., 1996, Sublake geologic structure from high-resolution seismic-reflection data from four sinkhole lakes in the Lake Wales Ridge, central Florida: U.S. Geological Survey Open-File Report 96-224, 72 p.

Tihansky, A.B., and Sacks, L.A., 1997, Evaluation of nitrate sources using nitrogen-isotope techniques in shallow ground water within selected lake basins in the Central Lakes District, Polk and Highlands Counties, Florida: U.S. Geological Survey Water-Resources Investigations Report 97-4207, 28 p.

Torres, A.E., Sacks, L.A., Yobbi, D.K., Knochenmus, L.A., and Katz, B.G., 2001, Hydrogeologic framework and geochemistry of the intermediate aquifer system in parts of Charlotte, De Soto, and Sarasota Counties, Florida: U.S. Geological Survey Water-Resources Investigations Report 01-4015, 74 p.

Toth, L.A., Arrington, D.A., Brady, M.A., and Muszick, D.A., 1995, Conceptual evaluation of factors potentially affecting restoration of habitat structure within the channelized Kissimmee River Ecosystem: Restoration Ecology, v. 3, p. 160-180.

U.S. Army Corps of Engineers, 1991, Central and southern Florida project environmental restoration of the Kissimmee River, Florida—Final integrated feasibility report and environmental impact statement: U.S. Army Corps of Engineers, Jacksonville District, 699 p.

U.S. Army Corps of Engineers, 1992, Central and southern Florida project environmental restoration of the Kissimmee River, Florida—Final integrated feasibility report and environmental impact statement: U.S. Government House Document 102-286, 716 p.

U.S. Army Corps of Engineers, 1996, Central and southern Florida project Kissimmee River headwaters revitalization project—Integrated project modification report and supplement to the final environmental impact statement: U.S. Army Corps of Engineers, Jacksonville District, 888 p.

U.S. Department of Agriculture, 2005, National agricultural statistics service [accessed 8/05] *http://www.nass.usda.gov/fl*

U.S. Environmental Protection Agency, 2000, Drinking water standards and health advisories: Washington D.C., Office of Water, Publication EPA 822-B-00-001, 12 p.

U.S. Environmental Protection Agency, 2005, Proposed TMDL report—Nutrient TMDL for Winter Haven Chain of Lakes: Atlanta, Ga., 47 p.

U.S. Environmental Protection Agency, 2006, TMDL report—Dissolved oxygen and nutrient TMDLs for Lake Hancock and Lower Saddle Creek: Atlanta, Ga., 110 p.

U.S. Geological Survey, 1998, National field manual for the collection of water quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1-A9, 2 v., variously paged. Also available at *http://pubs.water.usgs.gov/twri9A*

U.S. Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency, Bulletin 17-B of the Hydrology Subcommittee: Reston, Virginia, U.S. Geological Survey, Office of Data Coordination, 183 p.

University of Florida, 1985, Florida statistical abstract: Gainesville, Bureau of Economic and Business Research, 722 p.

University of South Florida, 2003, Hydrologic investigation of the phosphate-mined upper Saddle Creek watershed, West-Central Florida: Tampa, 166 p.

White, W.A., 1970, The geomorphology of the Florida Peninsula: Tallahassee, Florida Bureau of Geology Bulletin 51, 164 p.

Wilson, W.E., 1977, Hydrologic data for a subsurface waste-injection site at Mulberry, Florida, 1972-76: U.S. Geological Survey Open-File Report 77-511, 24 p.

Wilson, W.E., and Gerhart, J.M., 1982, Simulated effects of ground-water development on the potentiometric surface of the Floridan aquifer, west-central Florida: U.S. Geological Survey Professional Paper 1217, 83 p.

Wolansky, R.M., Barr, G.L., and Spechler, R.M., 1979, Generalized configuration of the bottom of the Floridan aquifer, Southwest Florida Water Management District: U.S. Geological Survey Water-Resources Investigations Open-File Report 79-1490, 1 sheet.

Wolansky, R.M., and Corral, M.A., 1985, Aquifer tests in west-central Florida, 1952-76: U.S. Geological Survey Water-Resources Investigations Report 84-4044, 127 p.

Wood, W.W., 1976, Guidelines for collection and field analysis of ground-water supplies for selected unstable constituents: U.S. Geological Survey Techniques of Water-Resources Investigations, book 1, chap. D2, 24 p.

Yobbi, D.K., 1996, Analysis and simulation of ground-water flow in Lake Wales Ridge and adjacent areas of central Florida: U.S. Geological Survey Water-Resources Investigations Report 94-4254, 82 p.

Appendix 1. Well and spring data-collection sites.

[–, no data. Abbreviations for aquifer: SAS, surficial aquifer system; ICU, intermediate confining unit; IAS, intermediate aquifer system; UFA, Upper Floridan aquifer; MCU, middle confining unit; LFA, Lower Floridan aquifer. Abbreviations for data type: qw, water-quality sample; wl, ground-water level. Abbreviations for source of data: SF, South Florida Water Management District; SWF, Southwest Florida Water Management District, SJR, St. Johns River Water Management District; USGS, U.S. Geological Survey. Well locations shown in figures 9 and 10]

Well number	USGS site identification number	Station name	Aquifer	Bottom of casing (feet)	Depth of well (feet)	Primary data type	County	Source of data
1	273603081270501	Dressler Dairy	UFA	–	350	wl	Highlands	SWF, USGS
2	273615081284901	ROMP 43XX UFA	UFA	409	1,363	wl, qw	Highlands	SWF, USGS
3	273615081284902	ROMP 43XX SAS	SAS	32	83	qw	Highlands	SWF, USGS
4	273851082031501	ROMP 40-1 UFA	UFA	408	1,140	wl, qw	Polk	SWF, USGS
5	273851082031502	ROMP 40 Htrn	IAS	76	180	wl, qw	Polk	SWF, USGS
6	273851082031503	ROMP 40 shallow	SAS	38	43	wl, qw	Polk	SWF, USGS
7	273903081185201	Avon Park Prison #1 (POF-9)	UFA	–	1,035	wl, qw	Polk	USGS
8	273913081331801	Wegvar Htrn well	IAS	170	240	wl	Polk	USGS
9	273929081080601	S-65A, POF-20	UFA	260	1,000	wl, qw	Polk	SF, USGS
10	273929081080602	S-65A, OSS-74	SAS	45	90	wl	Polk	SF
11	273929081080603	S-65A, OSS-75	SAS	17	32	qw	Polk	SF, USGS
12	274009081452202	Mobil UF-5 Htrn	IAS	–	217	wl	Polk	USGS
13	274134081401801	Lastinger Rd Htrn	IAS	94	135	wl	Polk	USGS
14	274151081513201	Gardinier UFA	UFA	410	908	wl	Polk	USGS, SWF
15	274155081573201	Ft. Green Springs Rd.	IAS/UFA	280	302	wl, qw	Polk	USGS, SWF
16	274218082035701	Barber Htrn	IAS	11	191	wl	Hillsborough	USGS
17	274225081315201	USGS shallow well P-48	SAS	59	62	wl	Polk	SWF, USGS
18	274238081415801	Mobil UFA-1	UFA	221	243	wl	Polk	SWF, USGS
19	274259082032801	C.L. Harlow	IAS	165	290	qw	Hillsborough	SWF, USGS
20	274347081305201	Turkey Hill Road surf	SAS	54	64	qw	Polk	SWF, USGS
21	274402081353401	P-10 Frostproof fire twr	SAS	20	42	wl, qw	Polk	SWF, USGS
22	274427082083701	ROMP 48 Tpa/Suw	UFA	215	541	wl, qw	Hillsborough	SWF, USGS
23	274427082083702	ROMP 48 Htrn	IAS	46	61	wl, qw	Hillsborough	SWF, USGS
24	274427082083703	ROMP 48 Avon Park	UFA	780	815	wl, qw	Hillsborough	SWF, USGS
25	274427082083704	ROMP 48 WT	SAS	10	14	wl, qw	Hillsborough	SWF, USGS
26	274432081493401	Barnette Htrn	IAS	–	229	wl	Polk	USGS
27	274440081314801	Coley UFA	UFA	208	319	wl, qw	Polk	SWF, USGS
28	274434081575201	CR 630 surficial	SAS	18	38	qw	Polk	SWF, USGS
29		KREFFS, site E	SAS	10	15	qw	Polk	SF
30		Ridge Wrap CLP-9	SAS	25	35	wl	Polk	SWF
31	274522081303901	ROMP CL-2 UFA	UFA	412	442	wl, qw	Polk	SWF, USGS
32	274522081303902	ROMP CL-2 Htrn	IAS	330	346	wl	Polk	SWF, USGS
33	274522081303903	ROMP CL-2 deep SAS	SAS	200	220	wl, qw	Polk	SWF, USGS
34	274522081303904	ROMP CL-2 SAS	SAS	17	22	wl, qw	Polk	SWF, USGS
35	274532081320601	City of Frostproof, plant 2, well 4	UFA	207	1,082	qw	Polk	USGS
36	274545081342501	ROMP CL-3 UFA	UFA	228	440	wl, qw	Polk	SWF, USGS
37	274545081342502	ROMP CL-3 Htrn	IAS	140	197	wl, qw	Polk	SWF, USGS
38	274545081342503	ROMP CL-3 surficial	SAS	20	49	wl	Polk	SWF, USGS
39	274547081470901	ROMP 45 Htrn	IAS	110	192	wl, qw	Polk	SWF, USGS
40	274547081470902	ROMP 45 Suwannee	UFA	330	440	wl, qw	Polk	SWF, USGS

Appendix 1. (Continued) Well and spring data-collection sites.

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Well number	USGS site identification number	Station name	Aquifer	Bottom of casing (feet)	Depth of well (feet)	Primary data type	County	Source of data
41	274547081470903	ROMP 45 Avon Park	UFA	680	757	wl, qw	Polk	SWF, USGS
42	274547081470904	ROMP 45 shallow	SAS	38	58	wl, qw	Polk	SWF, USGS
43	274552081115201	River Ranch replacement	UFA	–	–	wl, qw	Polk	USGS
44	274605081301001	Wardlaw Road SAS	SAS	19	37	wl, qw	Polk	SWF
45		KRFFFS, site F	SAS	10	15	wl	Polk	SF
46		KRFFFM, site F	SAS	15	30	wl	Polk	SF
47	274730081333801	ROMP 55 UFA	UFA	212	1,200	wl	Polk	SWF, USGS
48	274730081333802	ROMP 55 surficial	SAS	23	73	qw	Polk	SWF, USGS
49		Ridge Wrap VC-4	SAS	85	105	wl	Polk	SWF
50	274746081202201	Indian Lake Estates golf course	UFA	–	800	wl	Polk	USGS
51	274749081582501	Polk Co. (Bradley Junction #2)	UFA	300	550	qw	Polk	USGS
52	274807081115501	S-65 (OSF-52) UFA	UFA	172	850	wl	Osceola	USGS, SF
53	274806081311401	North Lake Patrick Road	SAS	35	55	wl, qw	Polk	SWF
54	274810081480601	T. Winkler	IAS	112	320	qw	Polk	USGS
55		S-65, OSS-73	SAS	12	15	wl	Osceola	SF
56		S-65, OSS-72	SAS	105	120	wl	Osceola	SF
57	274812081190301	P49	SAS	14	17	wl	Polk	USGS
58	274815081130301	River Ranch UFA (POF-5)	UFA	185	300	wl	Polk	USGS
59	274820081324501	West Cody Villa Rd.	SAS	130	150	wl, qw	Polk	SWF
60		Ridge Wrap CLP-7	SAS	180	200	wl	Polk	SWF
61	274840081195001	Indian Lakes Utilities	UFA	295	976	qw	Polk	USGS
62	274841081480901	Homeland #9 UFA	UFA	–	746	wl	Polk	USGS
63	274846081262001	USGS Well at Lake Weohyakapka (POF-0008)	IAS	149	197	wl	Polk	USGS
64	274847081414501	Cloninger Htrn	UFA	–	–	wl	Polk	USGS
65	274848081302201	Murray Road UFA	UFA	245	263	wl, qw	Polk	SWF
66	274848081302202	Murray Road SAS	SAS	10	21	wl, qw	Polk	SWF
67	274851081262001	Lake Weohyakapka SAS	SAS	5	20	wl	Polk	SF
68	274907081124801	Grape Hammock RV Park	UFA	–	465	qw	Polk	USGS
69	274908081480901	Homeland DEP #4	IAS	56	202	wl, qw	Polk	SWF, USGS
70	274910081452201	Lake Garfield Nursery UFA	UFA	317	817	wl	Polk	USGS, SWF
71	274925082084301	WCRWSA SCHM-6 UFA	UFA	231	910	wl	Hillsborough	USGS,SWF
72	274926081355301	ROMP 44 UFA	UFA	235	402	wl, qw	Polk	SWF, USGS
73	274926081355302	ROMP 44 surficial	SAS	25	75	wl, qw	Polk	SWF, USGS
74		Ridge Wrap CLP-5	SAS	48	58	wl	Polk	SWF
75	275009081540901	Pebbledale Rd. well	UFA	288	303	wl, qw	Polk	SWF, USGS
76	275009081540902	Pebbledale shallow	SAS	56	58	wl, qw	Polk	SWF, USGS
77	275023081321501	ROMP CL-1 UFA	UFA	220	315	wl, qw	Polk	SWF, USGS
78	275023081321602	ROMP CL-1 SAS	SAS	29	49	wl	Polk	SWF
79	275028081394301	Orange Acres Ranch	UFA	80	850	qw	Polk	USGS
80	275031081342100	Ridge Wrap CLP-1	SAS	60	70	wl	Polk	SWF

Appendix 1. (Continued) Well and spring data-collection sites.

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Well number	USGS site identification number	Station name	Aquifer	Bottom of casing (feet)	Depth of well (feet)	Primary data type	County	Source of data
81		Ridge Wrap CLP-3	SAS	30	60	wl	Polk	SWF
82	275040081493001	Homeland Flrd Well 8	IAS	68	227	wl	Polk	USGS
83	275040081335801	Muncie Rd. surficial	SAS	70	90	wl, qw	Polk	SWF
84	275059081562201	Commercial Carrier Htrn	IAC	92	167	wl	Polk	USGS
85	275101082025501	USGS surficial	SAS	12	17	qw	Polk	SWF, USGS
86	275115081522101	City of Bartow, Chamber Drive	UFA	252	740	qw	Polk	USGS
87	275128081314201	Golfview Road	SAS	45	65	qw	Polk	SWF
88	275135081252601	East Lake Wales Utility SAS (PO0027)	SAS	12	22	wl, qw	Polk	USGS
89	275137081252501	East Lake Wales Utility UFA (POF-19)	UFA	–	837	wl, qw	Polk	USGS
90	275158081275601	Glenn St. Mary Rd. SAS	SAS	25	35	qw	Polk	SWF
91	275146082084301	WCRWSA SCHM-4 UFA	UFA	222	915	wl	Hillsborough	USGS
92	275152082035801	Edison Junction WCRWSA 8	IAS	65	211	wl, qw	Hillsborough	SWF, USGS
93	275154081314001	Polk Co. LF #203 D-1 (ROMP 14)	SAS	68	78	qw	Polk	SWF, USGS
94	275154081314002	Polk Co. LF #203 AW-1 (ROMP 14)	UFA	155	245	qw	Polk	SWF, USGS
95	275158082085101	WCRWSA Grassy Gulch UFA	UFA	220	900	wl	Hillsborough	SWF, USGS
96	275235082033601	WCRWSA SCHM-4 UFA	UFA	209	900	wl	Hillsborough	SWF, USGS
97	275235082033603	WCRWSA SCHM-4 NRSD	SAS	–	17	wl	Hillsborough	USGS
98	275259082032501	W.E. Bugg	IAS	55	300	qw	Hillsborough	SWF, USGS
99	275314081514201	ROMP 59 UFA	UFA	200	1,050	wl	Polk	SWF, USGS
100	275314081514202	ROMP 59 Htrn	IAS	122	142	wl	Polk	SWF, USGS
101	275314081514203	ROMP 59 Upper Htrn	IAS	50	60	wl, qw	Polk	SWF, USGS
102	275323082080601	WCRWSA SCHM-11 UFA	UFA	220	918	wl	Hillsborough	USGS
103	275326081585801	ROMP 60 UFA	UFA	237	710	wl, qw	Polk	SWF, USGS
104	275327081341001	City of Lake Wales, Grove Ave.	UFA	745	1,063	qw	Polk	USGS
105	275348081335701	ROMP 57X UFA	UFA	274	315	wl	Polk	SWF, USGS
106	275348081335702	ROMP 57X Htrn	IAS	192	210	wl	Polk	SWF, USGS
107	275348081335703	ROMP 57X surficial	SAS	114	135	wl	Polk	SWF, USGS
108	275403081391301	St. Joe, SR60	–	–	1,500	wl	Polk	USGS
109	275406081285501	Mammoth Grove Road surficial	SAS	11	21	qw	Polk	SWF, USGS
110	275411081372001	ROMP 57 UFA	UFA	160	634	wl, qw	Polk	SWF, USGS
111	275411081372002	ROMP 57 Htrn	IAS	95	140	wl, qw	Polk	SWF, USGS
112	275411081372003	ROMP 57-3 SAS	SAS	15	40	wl, qw	Polk	SWF, USGS
113	275429082093901	ROMP 61 UFA	UFA	360	1,000	wl, qw	Hillsborough	SWF, USGS
114	275433081460501	Thompson Htrn	IAS	68	101	wl	Polk	USGS
115	275440081493701	Central Fla. Truss Htrn	IAS	47	60	wl	Polk	USGS
116	275448081431601	Polk County, Lake Garfield	UFA	130	410	qw	Polk	USGS
117	275507081353701	ROMP 58 UFA	UFA	155	330	wl, qw	Polk	SWF, USGS
118	275507081353702	ROMP 58 surficial	SAS	45	60	wl	Polk	SWF, USGS
119		Ridge Wrap VC-7	SAS	67	87	wl	Polk	SWF
120	275524081485601	City of Bartow #4	UFA	183	750	qw	Polk	USGS

Appendix 1. (Continued) Well and spring data-collection sites.

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Well number	USGS site identification number	Station name	Aquifer	Bottom of casing (feet)	Depth of well (feet)	Primary data type	County	Source of data
121	275536081490901	City of Bartow #2	UFA	180	750	qw	Polk	USGS
122	275538082031901	Knox UFA	UFA	240	300	wl	Polk	SWF, USGS
123	275547082044801	WCRWSA SCHM-3 UFA	UFA	218	880	wl	Hillsborough	SWF, USGS
124	275547082044802	WCRWSA SCHM-3	IAS	65	90	wl	Hillsborough	USGS
125	275600081331501	Mountain Lake Corp. SAS	SAS	40	60	qw	Polk	SWF
126	275600081331502	Mountain Lake Corp.	UFA	162	260	qw	Polk	SWF
127	275609081132001	Joe Overstreet 4” UFA	UFA	–	401	wl	Osceola	USGS
128	275613082094401	WCRWSA SCHM-2 UFA	UFA	115	910	wl	Hillsborough	USGS
129	275615082022001	Warren Htrn	IAS	89	127	wl	Polk	USGS
130	275545081362701	Tower Wood Htrn	IAS	118	150	wl, qw	Polk	USGS
131	275622081252301	Lake Rosalie (POF-0015)	UFA	–	575	wl	Polk	USGS
132	275624081252201	Harbor Camp Ground, Lake Rosalie #2	UFA	365	575	qw	Polk	USGS
133	275628081541201	Tillery Rd UFA	UFA	231	542	wl	Polk	USGS
134	275634081211801	Kissimmee St Pk (POF-0013)	UFA	226	560	wl, qw	Polk	USGS
135	275634081211901	Kissimmee St Pk SAS (PO0028)	SAS	18	28	wl, qw	Polk	USGS
136	275723081465701	Cumberland Farms UFA	UFA	200	300	wl	Polk	USGS
137	275728081570001	ROMP 60X UFA	UFA	212	806	wl	Polk	SWF, USGS
138	275732081352402	Lake Starr 1PNS-25 SAS	SAS	22	25	wl	Polk	USGS
139	275732081352406	Lake Starr 1PNS-125 UFA	UFA	122	125	wl	Polk	USGS
140	275745081333501	St. Helena Rd. SAS	SAS	50	70	wl, qw	Polk	SWF
141	275759082085401	ROMP DV-2 SAS	SAS	15	35	qw	Hillsborough	SWF, USGS
142	275759082085402	ROMP DV-2 UFA	UFA	108	130	wl, qw	Hillsborough	SWF, USGS
143	275800081523001	Central St. Htrn	IAS	77	100	wl	Polk	USGS
144	275802082044701	Fletcher Lett UFA	UFA	100	530	wl	Hillsborough	USGS
145	275815081444201	Lake Mcleod shallow	SAS	24	26	wl	Polk	USGS
146	275857081352201	P-8 Tindel Camp Rd	SAS	90	110	wl	Polk	SWF
147	275903081342801	Lake Mable Loop Rd south	SAS	59	79	wl, qw	Polk	SWF
148	275918081430601	P-3 Lake Eloise Terrace	SAS	41	61	wl, qw	Polk	SWF
149	275941081413001	Cypress Gdns # 5 PRO	UFA	143	737	qw	Polk	SWF
150	275959081552501	Sanlon Ranch 24” UFA	UFA	293	1,220	wl	Polk	SWF, USGS
151	280045081504001	Polk Co. Landfill Htrn	IAS	90	120	wl	Polk	USGS
152	280053081572301	Orleans St. UFA	UFA	219	773	wl	Polk	SWF, USGS
153	280103081493301	Polk County, Donald Lane	UFA	81	610	qw	Polk	USGS
154	280113081435301	ROMP 73 UFA	UFA	161	389	wl	Polk	SWF, USGS
155	280115081352001	Swann Rd. surficial	SAS	77	97	wl, qw	Polk	SWF
156	280115081352002	Swann Rd.	UFA	178	200	wl, qw	Polk	SWF
157	280153081274101	Lake Hatchineha near Haines City (POF-6)	UFA	178	411	wl, qw	Polk	USGS
158	280229081325201	Lake Hatchinea Rd. 8” UFA (POF-4)	UFA	146	453	wl, qw	Polk	USGS
159	280247082015301	D.J. Trusses Co. Htrn	ICU	80	140	wl, qw	Polk	USGS
160	280252081365001	Watertank Rd. west	SAS	125	145	wl, qw	Polk	SWF

Appendix 1. (Continued) Well and spring data-collection sites.

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Well number	USGS site identification number	Station name	Aquifer	Bottom of casing (feet)	Depth of well (feet)	Primary data type	County	Source of data
161	280253081235801	Disney Preserve mid-Htrn 122 ft	ICU	108	122	wl	Polk	SF
162	280253081235802	Disney Preserve SAS 36 ft	SAS	26	36	wl, qw	Polk	USGS, SF
163	280253081235803	Disney Preserve SAS 10 ft	SAS	5	10	wl	Polk	SF
164	280253081235804	Disney Preserve UFA 460 ft	UFA	200	460	wl, qw	Polk	USGS, SF
165	280255081354201	Watertank Road	SAS	69	89	wl, qw	Polk	SWF
166	280301081423701	P-2 11th St. NE	SAS	66	86	wl, qw	Polk	SWF
167	280338081572901	North Fla. Ave. UFA	UFA	203	865	wl	Polk	SWF, USGS
168	280318081593201	Lakeland 10th St. PRO	UFA	273	790	qw	Polk	SWF
169	280350082104401	Fisher UFA #60	UFA	–	–	wl	Hillsborough	SWF, USGS
170	280408082080801	McIntosh Ellap UFA	UFA	99	155	wl	Hillsborough	SWF, USGS
171	280413081353801	Polk Co. LF #204 B-3	SAS	49	59	qw	Polk	SWF
172	280415081590301	Lakeland Util. MW # 1	ICU	98	127	qw	Polk	SWF
173	280413082061401	M. Quagliani UFA	UFA	80	216	wl	Hillsborough	SWF, USGS
174	280416081572001	ROMP 70 surficial	SAS	22	35	qw	Polk	SWF
175	280416081572002	ROMP 70 Floridan	UFA	185	645	qw	Polk	SWF
176	280420081570101	Lakeland Stadium UFA	UFA	660	920	wl	Polk	SWF, USGS
177	280438082075301	Griffin UFA	UFA	127	469	wl	Hillsborough	SWF, USGS
178	280443081391701	City of Winter Haven Ridge Vo-Tech School	UFA	182	445	qw	Polk	USGS
179	280455082021501	J.B. Sergeant UFA	UFA	–	144	wl	Polk	SWF, USGS
180	280503081552801	Fish Lake deep	UFA	82	311	wl	Polk	USGS
181	280510082043801	T-2 UFA	UFA	130	585	wl	Hillsborough	SWF, USGS
182	280520081575201	Cresent Dr. UFA	UFA	224	827	wl	Polk	SWF, USGS
183	280530081362301	Ridge Wrap P-6	SAS	85	105	wl, qw	Polk	SWF
184	280531081431601	Lake Alfred 12” UFA	UFA	282	555	wl, qw	Polk	SWF, USGS
185	280556081532601	Tennorock Road	UFA	45	72	wl	Polk	USGS
186	280558081314801	Kimbell (POF-14)	UFA	149	396	wl	Polk	USGS
187	280622082061701	ROMP 86.5 Cone Ranch UFA	UFA	128	177	qw	Hillsborough	USGS
188	280635081372301	City of Haines #3	UFA	170	570	qw	Polk	USGS
189	280719081543301	Combee Road SAS	SAS	8	9	wl	Polk	SWF, USGS
190	280715081543501	Combee Road DP	ICU	31	55	wl, qw	Polk	SWF, USGS
191	280708082074801	T-1 UFA	UFA	140	579	wl	Hillsborough	SWF, USGS
192	280732081585301	Polk County (Palmore well)	UFA	150	562	qw	Polk	USGS
193	280740082105201	Black Water Creek UFA	UFA	94	154	wl	Hillsborough	SWF, USGS
194		PO0024 Lake Lowery UC	SAS	–	7	wl	Polk	SJR
195	280807081571401	Polk Co., Lake Gibsonia High School	UFA	145	618	qw	Polk	USGS
196	280834082062901	Blackwater Creek transect well 4	ICU	6.4	8.9	wl	Hillsborough	USGS
197		Ridge Wrap P-5	SAS	95	115	wl	Polk	SWF
198	280837082063101	Blackwater Creek transect deep	UFA	43	91	wl, qw	Hillsborough	USGS
199	280849082053701	T-3 UFA	UFA	144	700	wl	Hillsborough	SWF, USGS
200		Ridge Wrap P-1	SAS	55	75	wl	Polk	SWF

Appendix 1. (Continued) Well and spring data-collection sites.

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Well number	USGS site identification number	Station name	Aquifer	Bottom of casing (feet)	Depth of well (feet)	Primary data type	County	Source of data
201	280906082004001	Socrum Spring	SAS	–	–	qw	Polk	USGS
202	280916082005501	Costine	UFA	101	139	qw	Polk	USGS
203		ROMP 74x Davenport test well		–	1,560	wl	Polk	SWF
204	280905081270101	Reedy Creek overlook (OSF-11)	UFA	134	398	wl, qw	Osceola	USGS
205	280957082072001	LS-01 UFA	UFA	40	65	wl	Hillsborough	
206	281007081511001	Zimmerman	UFA	67	118	wl	Polk	SWF
207	281008081441801	PO0006 Lake Alfred 6" UFA	UFA	102	425	wl, qw	Polk	SWF, USGS
208	281008081441802	Lake Alfred SAS	SAS	6	9	wl	Polk	SWF, USGS
209	281031082071801	Alston Track deep	UFA	59	98	wl	Pasco	SWF, USGS
210	281037082071801	J.O. Alston 2" UFA	UFA	47	55	wl	Pasco	SWF, USGS
211		Alston Tract SAS	SAS	1	9	wl	Polk	SWF
212		Alston Tract SAS	SAS	1	9	wl	Polk	SWF
213	281052082052601	Alston deep UFA	UFA	50	112	wl	Polk	USGS
214	281057081495002	ROMP 76 6" UFA, Polk City	UFA	264	315	wl, qw	Polk	SWF, USGS
215	281058081495002	USGS 1.75" drill pipe at Polk City	UFA	840	908	wl	Polk	USGS
216	281058081495003	USGS 4" annular monitor	UFA	590	908	wl	Polk	USGS
217	281058081495004	USGS core hole 2 at Polk City	MCU, LFA	1,000	1,996	wl, qw	Polk	USGS
218	281058081495005	ROMP 76 SAS (PO0026)	SAS	25	35	wl, qw	Polk	SWF
219	281202081391701	PO-0001 Thornhill UFA	UFA	108	151	wl, qw	Polk	SJR
220	281202081391702	PO0002 Thornhill SAS	SAS	10	15	wl	Polk	SJR
221	281226081341901	Three Worlds RV Park	UFA	118	310	qw	Polk	USGS
222	281312082011601	ROMP 87 UFA	UFA	300	380	wl, qw	Polk	SWF, USGS
223	281312082011602	ROMP 87 shallow UFA	UFA	28	38	wl, qw	Polk	SWF, USGS
224	281317081491301	Fussell Road UFA	UFA	78	217	wl, qw	Polk	USGS
225	281317081491302	Fussell Road SAS	SAS	19	27	wl	Polk	USGS
226	281322082084501	Chancey Rd. UFA	UFA	50	87	wl	Pasco	SWF, USGS
227	281429081290501	Mercantile Ln. (OSF-254)	UFA	–	–	wl	Osceola	USGS, SF
228		Ridge Wrap P-4	SAS	90	110	wl	Polk	SWF
229	281440081431701	Spread Eagle Ranch deep	UFA	80	285	wl, qw	Polk	SWF, USGS
230	281440081431702	Spread Eagle Ranch shallow	SAS	15	20	wl, qw	Polk	SWF, USGS
231	281443082055501	Howard Blvd. UFA	UFA	134	172	wl	Polk	SWF, USGS
232		Howard Street SAS	SAS	4	24	wl	Polk/ Hillsborough	SWF
233	281504082104801	ROMP 86 UFA	UFA	425	434	wl	Pasco	SWF, USGS
234	281511081393101	USGS deep observation on US 27 (POF-2)	UFA	358	453	wl, qw	Polk	SWF, USGS
235	281511081393102	USGS shallow observation on US 27	SAS	89	92	qw	Polk	SWF, USGS
236		Intercession City IC-SAS	SAS	15	20	wl, qw	Osceola	SF
237		Intercession City IC-HCU	ICU	45	55	wl, qw	Osceola	SF
238		Intercession City OSF-100	UFA	110	280	wl, qw	Osceola	SF
239		Intercession City OSF-99	UFA	355	675	wl	Osceola	SF
240		Intercession City OSF-98	–	1,220	1,490	wl	Osceola	SF

Appendix 1. (Continued) Well and spring data-collection sites.

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Well number	USGS site identification number	Station name	Aquifer	Bottom of casing (feet)	Depth of well (feet)	Primary data type	County	Source of data
241		Intercession City OSF-97	–	2,000	2,130	wl	Osceola	SF
242	281532081345001	Loughman UFA (POF-1)	UFA	85	247	wl, qw	Polk	SWF, USGS
243	281532081345002	Loughman shallow	SAS	29	32	wl, qw	Polk	SWF, USGS
244	281532082065001	54-East UFA	UFA	45	98	wl, qw	Pasco	USGS
245	281532081493001	USGS shallow well W5470	UFA	78	231	wl	Polk	USGS
246	281536081324801	FPC 6" UFA	UFA	63	261	wl	Osceola	USGS
247	281631081564501	Spears	UFA	90	290	wl	Polk	USGS
248	281835081552201	Green Swamp Check Station	UFA	–	–	wl	Polk	USGS
249	281836081430401	Green Bay Ranch Cabin deep	UFA	–	–	wl	Polk	USGS
250	281836081430402	Green Bay Ranch Cabin shallow	SAS	30	35	wl	Polk	USGS
251	281837081544101	ROMP 88 Avon Park	UFA	195	385	wl, qw	Polk	SWF, USGS
252	281917081514801	Van Fleet Trail	UFA	–	–	qw	Polk	USGS
253	281951082012001	Green Swamp L11MD	UFA	–	49	wl, qw	Sumter	USGS
254	281951082012002	Green Swamp L11MM	–	–	18	wl	Sumter	USGS
255	281951082012003	Green Swamp SAS L11MS	SAS	–	9	wl, qw	Sumter	USGS
256	282125082021901	Green Swamp check station	UFA	–	20	qw	Sumter	USGS
257	282127082022501	ROMP 89 Cumpressco Ranch	UFA	20	142	wl	Sumter	SWF, USGS
258	282152082011201	Green Swamp L-11K deep	UFA	0	36	wl	Sumter	SWF
259	282152082011202	Green Swamp L-11K shallow	SAS	0	17	wl	Sumter	SWF
260	282202081384601	OR0064 Lake Oliver UFA	UFA	103	318	wl	Orange	USGS, SJR
261	282202081384602	Lake Oliver SAS replacement	SAS	–	38	wl, qw	Orange	USGS, SJR
262	282241081443901	L-0051 Sand Mine UFA	UFA	85	115	wl	Lake	USGS, SJR
263	282245081492601	Eva UFA (L-0057)	UFA	100	192	wl, qw	Lake	SWF, USGS
264	282245081492602	Eva SAS	SAS	18	23	wl, qw	Lake	SWF, USGS
265	282318081544003	L-0555 Green Swamp test	UFA	64	190	wl	Lake	USGS, SJR
266	282331081370801	USGS well Hartzog Rd.	UFA	92	117	wl	Orange	USGS
267		Lake Louisa test well L-0729	–	–	2,400	wl, qw	Lake	SJR

Appendix 2. Chemical and physical data for water from the surficial aquifer system, intermediate aquifer system, and Upper Floridan aquifer wells in Polk and parts of adjacent Highlands, Hillsborough, Lake, Orange, and Osceola Counties.

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Well No.	Latitude	Longitude	Data source	Aquifer	Date	Temperature, °C	Specific conductance, field, µS/cm	Total dissolved solids, mg/L	pH	Hardness total, mg/L as $CaCO_3$	Silica, mg/L	Nitrate, mg/L	Calcium, mg/L	Magnesium, mg/L	Potassium, mg/L	Sodium, mg/L	Iron, µg/L	Chloride, mg/L	Fluoride, mg/L	Sulfate, mg/L	Alkalinity, mg/L as $CaCO_3$
2	273615	812849	SWF	UFA	7/2/2003	26.1	179	–	8.3	–	11	–	22	7.4	1.4	6.4	<30	7.5	0.11	6.5	73
3	273616	812848	SWF	SAS	7/2/2003		330	–	–	–	3.0	.48	64	3.9	1.9	1.0	<3.0	2.3	<.1	28	145
4	273851	820315	SWF	UFA	3/12/2002	26.4	356	217	7.8	–	17	–	40	14	1.2	7.9	100	11	–	41	131
5	273851	820315	SWF	IAS	4/29/2003	25.1	601	–	7.4	–	47	–	52	23	1.7	50	<30	51	1.3	1.2	264
6	273852	820315	SWF	SAS	12/1/1998	24.9	210	–	6.0	–	18	.041	19	6.9	.83	5.9	11,300	13	.60	.25	88
7	273911	812108	USGS	UFA	7/15/2003	25.7	154	104	8.2	70	11	<.02	17	6.1	.50	3.0	5.0	4.5	.10	6.0	65
9	273929	810806	USGS	UFA	8/5/2003	24.6	489	285	7.5	170	26	<.02	35	19	1.9	29	<2.0	51	.50	41	123
11	273929	810806	USGS	SAS	8/5/2003	24.0	496	292	7.3	180	28	<.02	63	5.4	1.3	32	293	34	.50	1.9	201
15	274155	815732	USGS	IAS/ UFA	8/6/2003	25.2	577	351	7.3	230	43	<.02	46	27	1.8	30	92	61	2.3	15	182
19	274259	820328	SWF	IAS	3/16/2000	24.5	327	180	7.4	–	–	.04	33	17	.52	6.5	–	17	.47	9.9	134
20	274348	813053	SWF	SAS	7/15/2003	26.8	572	–	4.3	–	8.1	26	38	19	25	5.7	55	25	.05	86	<1.0
21	274403	813534	SWF	SAS	5/13/1999	24.4	347	–	5.0	–	14	.006	14	15	28	7.1	202	45	<.10	64	12
22	274427	820833	SWF	UFA	6/25/2003	25.8	384	–	7.7	–	21	–	46	17	1.8	12	<30	13	.48	43	133
23	274427	820833	SWF	IAS	6/25/2003	28.3	285	–	7.4	–	16	–	31	15	1.6	9.5	520	4.1	.64	2.5	137
24	274427	820833	SWF	UFA	6/25/2003	27.0	376	–	7.7	–	20	–	44	17	1.7	11	<30	12	.44	40	133
25	274427	820833	SWF	SAS	11/30/1998	27.2	54	–	5.0	–	3.5	.014	2.1	1.1	.07	4.8	16	8.4	.12	3.4	3.1
27	274440	813148	SWF	UFA	4/24/2003	25.8	351	–	7.7	–	20	–	40	14	1.9	7.6	<30	11	.29	18	147
28	274440	815801	SWF	SAS	11/11/1998		77	–	–	–	4.5	.38	15	1.6	.09	1.5	<20	2.0	.33	15	25
29	274456	811051	SF	SAS	10/24/2000	25.2	568	–	6.8	–	–	–	100*	55*	1.6*	4.7*	72	4.3*	–	.73*	270*
31	274522	813039	SWF	UFA	2/10/2000	26.4	264	–	8.1	127	23	.01	23	17	2.2	8.0	<25	8.2	–	13	106
34	274522	813039	SWF	SAS	2/10/2000	24.6	500	–	6.3	197	2.8	9.4	45	21	23	7.3	<25	28	–	99	52
35	274532	813206	USGS	UFA	7/17/2003	25.7	376	272	7.2	170	22	<.02	46	14	2.4	8.1	20	13	.20	44	128
36	274545	813425	SWF	UFA	5/19/1999	24.7	418	–	7.4	–	23	.007	52	13	11	12	5.8	7.8	.22	.31	194
37	274545	813425	SWF	IAS	4/25/2003	24.3	434	–	7.3	–	28	–	61	15	3.5	8.5	106	9.6	.16	.62	236
39	274547	814709	USGS	IAS	8/6/2003	24.4	310	199	7.3	150	39	<.02	34	16	.90	7.5	<7.0	6.1	.80	6.9	151

Appendix 2. (Continued) Chemical and physical data for water from the surficial aquifer system, intermediate aquifer system, and Upper Floridan aquifer wells in Polk and parts of adjacent Highlands, Hillsborough, Lake, Orange, and Osceola Counties.

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Well No.	Latitude	Longitude	Data source	Aquifer	Date	Temperature, °C	Specific conductance, field, µS/cm	Total dissolved solids, mg/L	pH	Hardness total, mg/L as $CaCO_3$	Silica, mg/L	Nitrate, mg/L	Calcium, mg/L	Magnesium, mg/L	Potassium, mg/L	Sodium, mg/L	Iron, µg/L	Chloride, mg/L	Fluoride, mg/L	Sulfate, mg/L	Alkalinity, mg/L as $CaCO_3$
40	274547	814709	USGS	UFA	8/6/2003	27.2	368	229	7.6	170	18	<.02	43	15	1.6	7.9	<2.0	11	.40	36	140
42	274551	814710	USGS	SAS	8/6/2003	26.7	315	181	7.6	140	20	6.2	30	15	.50	6.6	<2.0	14	.30	1.9	113
43	274552	811152	USGS	UFA	9/9/2003	25.0	335	204	7.7	140	28	<.02	25	16	1.3	12	8.0	17	.60	12	135
44	274610	813008	SWF	SAS	7/15/2003	25.2	523	–	4.2	–	6.5	24	30	16	22	8.2	74	31	.04	77	<1.0
48	274730	813337	SWF	SAS	2/16/2000	24.9	224	–	5.0	57	9.8	.32	11	7.1	.82	17	1,110	23	–	53	–
51	274749	815825	USGS	UFA	7/16/2003	25.1	350	223	7.3	160	16	<.02	44	13	.70	6.3	31	7.8	.30	42	122
53	274809	813113	SWF	SAS	7/15/2003	26.2	362	–	4.7	–	11	16	24	13	13	6.4	55	25	.06	43	<1.0
54	274810	814806	USGS	IAS	8/12/2003	24.5	495	295	7.0	170	35	<.02	37	18	.90	38	3.0	36	1.0	4.8	193
59	274825	813249	SWF	SAS	7/14/2003	27.4	430	–	4.1	–	8.2	22	28	15	17	4.4	57	30	.09	54	<1.0
61	274840	811950	USGS	UFA	7/17/2003	25.6	174	106	8.0	82	12	<.02	19	7.4	.80	3.9	6.0	5.7	.20	3.4	78
65	274851	813023	SWF	UFA	4/24/2003	25.3	210	–	8.7	–	6.1	–	24	3.8	2.3	8.4	<30	16	.05	21	42
66	274851	813023	SWF	SAS	7/7/2003	25.7	453	–	4.3	–	6.9	19	24	12	23	6.9	130	29	.13	55	<1.0
68	274907	811248	USGS	UFA	9/9/2003	24.1	572	345	7.3	220	27	<.02	55	19	1.4	29	10	58	.90	26	173
69	274910	814804	SWF	IAS	4/28/2003	22.8	401	–	7.3	–	33	–	46	24	1.0	9.1	<30	10	.53	8.6	210
72	274926	813553	SWF	UFA	5/17/1999	24.0	302	–	7.6	–	28	.005	34	14	2.4	7.2	4.2	5.8	.60	1.7	142
73	274928	813553	SWF	SAS	5/17/1999	25.2	52	–	5.0	–	3.6	.008	.85	.66	2.6	3.7	94	6.4	<.10	1.1	11
76	275011	815415	SWF	SAS	11/9/1998	25.1	374	–	7.0	–	43	.076	38	19	1.1	7.5	601	5.7	.83	19	163
77	275023	813215	SWF	UFA	2/16/2000	24.3	199	–	8.4	84	–	.01	19	9.2	1.4	11	<25	11	–	.19	–
79	275028	813943	USGS	UFA	9/9/2003	24.9	448	289	6.8	230	46	<.02	54	24	3.4	6.9	55	7.2	.30	<.20	250
83	275049	813343	SWF	SAS	7/7/2003	28.6	126	–	5.6	–	6.8	.03	5.0	7.0	2.8	3.5	1,900	15	.03	12	19
85	275102	820254	SWF	SAS	11/4/1998	25.0	193	–	4.9	–	3.8	5.7	22	4.3	.28	3.5	9.0	3.9	.59	48	3.0
86	275115	815221	USGS	UFA	9/16/2003	24.1	335	208	7.6	150	17	–	39	12	1.1	10	197	9.2	.50	33	123
87	275129	813141	SWF	SAS	7/14/2003	27.0	107	–	5.6	–	6.2	2.8	10	2.9	4.2	1.1	47	2.7	.06	23	7.2
88	275135	812526	USGS	SAS	11/18/2003	26.5	272	155	7.1	100	12	.22	22	11	1.7	17	13	14	.50	7.5	111
89	275137	812525	USGS	UFA	7/15/2003	25.8	160	111	8.1	74	9.6	<.02	18	6.4	.60	3.2	18	5.4	.10	4.3	70

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Well No.	Latitude	Longitude	Data source	Aquifer	Date	Temperature, °C	Specific conductance, field, µS/cm	Total dissolved solids, mg/L	pH	Hardness total, mg/L as $CaCO_3$	Silica, mg/L	Nitrate, mg/L	Calcium, mg/L	Magnesium, mg/L	Potassium, mg/L	Sodium, mg/L	Iron, µg/L	Chloride, mg/L	Fluoride, mg/L	Sulfate, mg/L	Alkalinity, mg/L as $CaCO_3$
90	275140	812755	SWF	SAS	7/8/2003	27.3	398	–	4.1	–	6.7	16	19	12	23	4.5	75	27	.19	58	<1.0
92	275152	820358	SWF	IAS	1/14/1999	23.8	257	–	7.4	–	25	.01	25	12	.70	6.2	796	9.8	.20	1.7	112
93	275155	813139	SWF	SAS	9/14/1999	25.2	213	–	4.6	–	12	6.3	11	9.2	8.8	3.0	24	7.3	.32	47	11
94	275155	813139	SWF	UFA	9/14/1999	24.8	104	–	8.8	–	8.5	2.6	12	3.0	.70	2.9	20	4.7	<.10	2.2	30
98	275259	820325	SWF	IAS	4/3/2000	24.2	311	–	7.5	–	–	.061	46	6.6	.45	7.6	–	7.3	.61	.68	144
101	275314	815142	SWF	IAS	4/25/2003	24.9	506	–	7.2	–	30	–	47	28	.61	15	465	14	.48	5.1	254
103	275326	815858	SWF	UFA	4/29/2003	26.4	332	–	7.6	–	19	–	44	12	.96	7.0	<30	7.9	.33	.64	168
104	275327	813410	USGS	UFA	7/17/2003	25.9	298	193	7.4	130	11	.29	39	8.7	2.1	6.4	<2.0	12	.10	21	109
109	275405	812855	SWF	SAS	4/3/2002	25.2	367	–	5.4	–	3.9	18	38	7.5	7.6	8.2	25	33	.01	42	6.0
110	275411	813720	SWF	UFA	4/24/2003	24.5	365	–	6.8	–	22	–	44	12	3.9	10	413	19	.28	6.3	158
111	275411	813720	SWF	IAS	4/24/2003	25.4	418	–	7.2	–	30	–	61	13	4.3	7.2	612	10	.23	6.7	214
112	275413	813721	SWF	SAS	5/27/1999	26.0	110	–	5.2	–	4.0	.006	10	1.7	1.9	5.3	238	3.5	.10	23	11
113	275429	820939	SWF	UFA	4/4/2000	25.9	400	182	7.6	–	–	<.004	45	15	.94	–	–	15	.12	9.7	177
116	275448	814316	USGS	UFA	7/16/2003	24.4	413	245	7.2	190	28	<.02	50	16	3.5	9.6	379	18	.40	<.20	188
117	275511	813538	SWF	UFA	4/28/2003	24.9	321	–	7.5	–	33	–	39	14	3.3	7.7	94	5.7	.16	.14	198
120	275524	814856	USGS	UFA	8/13/2003	23.8	572	324	6.8	290	20	–	71	28	.90	10	541	10	.40	19	279
121	275536	814909	USGS	UFA	8/13/2003	26.4	379	232	7.3	180	17	<.02	50	13	1.0	7.3	19	9.3	.30	23	159
125	275600	813315	SWF	SAS	7/10/2003	28.0	400	–	4.6	–	6.8	23	32	6.9	21	3.3	56	18	.13	50	<1.0
126	275600	813315	SWF	UFA	4/24/2003	25.4	257	–	8.1	–	11	–	31	7.2	3.4	5.2	<30	10	.07	19	66
130	275621	813639	USGS	IAS	8/5/2003	23.6	347	207	7.0	170	31	<.02	50	11	3.8	4.3	1,030	4.4	.40	<.20	228
132	275624	812522	USGS	UFA	7/17/2003	24.6	163	106	8.0	76	11	<.02	15	8.1	1.0	3.6	7.0	4.9	.10	1.3	77
134	275634	812118	USGS	UFA	7/15/2003	24.0	178	106	7.5	81	12	<.02	19	7.6	1.1	3.5	22	5.7	.30	4.1	78
135	275634	812119	USGS	SAS	11/19/2003	23.6	107	60	5.0	13	7.1	<.02	2.9	1.3	.20	11	3,580	20	.10	5.8	5.7
140	275743	813343	SWF	SAS	7/10/2003		432	–	5.7	–	9.5	20	34	16	16	6.1	69	26	.03	64	5.1
141	275800	820853	SWF	SAS	1/12/1999	26.0	95	–	4.8	–	5.1	.06	3.4	2.3	1.6	5.1	546	11	.20	18	1.0

Appendix 2. (Continued) Chemical and physical data for water from the surficial aquifer system, intermediate aquifer system, and Upper Floridan aquifer wells in Polk and parts of adjacent Highlands, Hillsborough, Lake, Orange, and Osceola Counties.

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Well No.	Latitude	Longitude	Data source	Aquifer	Date	Temperature, °C	Specific conductance, field, µS/cm	Total dissolved solids, mg/L	pH	Hardness total, mg/L as $CaCO_3$	Silica, mg/L	Nitrate, mg/L	Calcium, mg/L	Magnesium, mg/L	Potassium, mg/L	Sodium, mg/L	Iron, µg/L	Chloride, mg/L	Fluoride, mg/L	Sulfate, mg/L	Alkalinity, mg/L as $CaCO_3$
142	275759	820854	SWF	UFA	3/21/2000	25.1	363	207	7.6	–	–	.004	42	16	1.8	5.2	–	7.1	.60	.28	182
147	275901	813443	SWF	SAS	7/10/2003	27.0	301	–	4.2	–	7.4	16	19	9.6	11	5.5	54	15	.11	40	<1.0
148	275918	814306	SWF	SAS	5/25/1999	25.6	269	–	4.3	–	6.8	3.4	14	9.3	7.2	8.2	15	26	<.10	47	11
149	275927	814124	SWF	UFA	5/24/1999	25.5	367	–	7.6	–	11	<.004	55	8.0	1.4	13	29	19	<.10	5.6	152
153	280103	814933	USGS	UFA	7/16/2003	25.4	240	136	7.5	110	15	<.02	32	7.8	1.1	5.5	4.0	7.1	.20	1.4	114
155	280121	813513	SWF	SAS	7/8/2003	28.3	412	–	4.6	–	8.9	26	32	11	19	5.1	56	22	.11	33	<1.0
156	280121	813514	SWF	UFA	4/24/2003	25.4	306	–	8.6	–	14	–	31	8.9	1.4	5.7	<30	14	.03	4.3	20
157	280153	812741	USGS	UFA	9/16/2003	26.7	177	–	–	–	–	–	–	–	–	–	–	12	–	21	–
158	280229	813252	USGS	UFA	8/5/2003	24.0	304	175	7.3	150	15	<.02	42	10	1.0	4.7	358	7.2	<.10	.20	149
159	280237	820149	USGS	ICU	7/16/2003	23.6	443	294	7.2	210	38	<.02	63	13	.60	9.5	335	14	.50	17	193
160	280253	813650	SWF	SAS	7/9/2003		341	–	4.8	–	8.8	14	23	12	13	3.2	53	12	.19	74	<1.0
162	280253	812358	USGS	SAS	8/7/2003	23.8	41	30	4.4	4.0	4.7	<.02	.25	.78	<.10	4.1	652	7.1	<.10	1.4	2.0
164	280253	812358	USGS	UFA	8/7/2003	24.1	185	115	7.8	85	11	<.02	26	4.8	.70	3.2	12	4.8	.10	11	75
165	280253	813527	SWF	SAS	7/9/2003	26.7	202	–	5.1	–	12	10	14	6.1	4.4	2.9	46	13	.04	21	1.0
166	280301	814237	SWF	SAS	5/24/1999	25.9	489	–	4.1	–	8.7	22	23	22	11	13	45	24	.10	18	45
168	280345	815933	SWF	UFA	3/21/2000	26.7	267	–	7.8	–	–	<.004	35	8.4	.52	4.2	–	6.9	.29	3.1	126
171	280412	813543	SWF	SAS	9/1/1999	25.3	290	–	4.2	–	7.2	13	22	9.5	8.1	5.5	15	16	<.10	49	1.0
172	280412	815853	SWF	ICU	3/21/2000	25.5	354	–	7.6	–	–	9.7	33	18	.34	6.2	190	15	.32	1.1	114
174	280417	815720	SWF	SAS	11/11/1998	25.8	114	–	5.5	–	7.9	.006	7.9	1.1	.36	11	2,230	10	.15	13	21
175	280417	815720	SWF	UFA	11/11/1998	27.3	430	–	7.4	–	16	.007	65	11	1.1	5.5	450	7.7	.28	.20	225
178	280443	813917	USGS	UFA	9/15/2003	26.4	264	152	7.4	110	14	.41	34	7.2	1.2	6.6	4.0	10	.20	4.6	113
183	280530	813623	SWF	SAS	4/7/1999		287	–	7.2	–	–	–	–	–	–	–	–	–	–	–	–
184	280532	814323	SWF	UFA	5/20/1999	25.9	274	–	7.7	–	15	.54	35	10	1.9	7.0	52	10	.13	6.0	115
187	280622	820617	USGS	UFA	5/24/2002	23.4	514	294	7.5	250	15	–	93	4.3	.40	8.0	1,710	15	.20	<.20	246
188	280635	813723	USGS	UFA	9/8/2003	25.6	366	209	7.3	160	13	<.02	51	7.6	1.3	11	10	16	.10	7.8	158

Appendix 2. (Continued) Chemical and physical data for water from the surficial aquifer system, intermediate aquifer system, and Upper Floridan aquifer wells in Polk and parts of adjacent Highlands, Hillsborough, Lake, Orange, and Osceola Counties.

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Well No.	Latitude	Longitude	Data source	Aquifer	Date	Temperature, °C	Specific conductance, field, µS/cm	Total dissolved solids, mg/L	pH	Hardness total, mg/L as $CaCO_3$	Silica, mg/L	Nitrate, mg/L	Calcium, mg/L	Magnesium, mg/L	Potassium, mg/L	Sodium, mg/L	Iron, µg/L	Chloride, mg/L	Fluoride, mg/L	Sulfate, mg/L	Alkalinity, mg/L as $CaCO_3$
190	280707	815430	USGS	ICU	8/6/2003	23.8	585	356	6.3	300	23	<.02	62	36	.30	13	10,800	13	.20	<.20	307
192	280732	815853	USGS	UFA	7/15/2003	24.0	239	145	7.8	120	15	<.02	33	8.6	.50	3.8	4.0	5.6	.30	1.2	117
195	280807	815714	USGS	UFA	7/15/2003	25.5	384	216	7.7	190	12	<.02	63	7.6	.70	4.8	15	8.0	.20	1.0	188
198	280838	820630	USGS	UFA	9/24/2002	23.3	310	175	7.9	150	16	–	48	6.6	.80	5.4	8.0	7.0	.20	1.9	151
201	280906	820040	USGS	SAS	9/8/2003	25.3	278	171	4.6	89	7.2	17	11	15	.60	9.0	8.0	33	.40	.40	3.0
202	280916	820055	USGS	UFA	9/8/2003	24.0	253	176	6.4	100	14	7.8	31	5.6	.60	7.5	10	18	.20	3.3	64
204	280955	812651	USGS	UFA	8/14/2003	22.5	198	115	7.8	93	9.9	<.02	28	5.6	.60	3.4	8.0	5.5	.10	8.0	85
207	281008	814418	USGS	UFA	8/14/2003	24.2	258	177	7.5	120	17	<.02	42	4.2	1.5	4.4	252	6.0	.20	.40	125
214	281057	814950	SWF	UFA	5/25/1999	24.1	299	–	7.7	–	13	2.0	40	9.8	1.2	5.8	6.3	11	.21	12	119
218	281058	814950	SJR	SAS	11/17/2003	24.8	221	166	5.7	–	4.2	–	12	5.2	2.2	20	165	21	.10	15	20
219	281204	813916	SJR	UFA	12/14/2001	22.0	177	116	8.0	–	–	–	25*	6.0*	.51*	4.6*	–	6.8*	.12	3.2*	83
221	281226	813419	USGS	UFA	9/8/2003	24.0	318	181	7.1	150	11	–	52	4.8	.60	5.2	134	8.4	<.10	.20	154
222	281312	820125	SWF	UFA	3/15/2000	24.7	432	–	7.3	–	–	<.02	73	6.0	.77	7.7	–	8.8	<.10	<.20	215
223	281313	820124	SWF	UFA	5/5/1999	23.6	502	–	7.0	–	19	.017	91	3.9	.35	8.6	1,420	15	.25	<.20	235
224	281317	814913	USGS	UFA	8/12/2003	23.7	528	304	6.8	280	14	<.02	108	2.8	1.9	6.4	83	11	<.10	<.40	267
229	281441	814316	SWF	UFA	5/3/1999	23.9	244	–	7.3	–	11	<.004	45	1.3	1.6	3.1	74	4.2	<.10	.25	117
230	281441	814316	SWF	SAS	5/3/1999	23.9	32	–	4.9	–	2.8	<.004	.23	.42	.24	2.2	8,310	3.6	<.10	.51	8.9
234	281509	813929	USGS	UFA	8/7/2003	25.3	309	173	7.4	150	13	<.02	55	3.1	.70	4.4	64	7.2	<.10	2.5	148
235	281509	813929	USGS	SAS	8/7/2003	25.5	117	79	4.9	31	6.1	1.8	6.7	3.5	7.2	1.9	13	4.2	<.10	31	3.0
242	281532	813450	SWF	UFA	5/12/1999	24.5	279	–	7.4	–	11	.008	51	2.7	.80	4.0	120	6.3	<.10	<.20	136
243	281532	813450	SWF	SAS	5/12/1999	24.5	102	–	5.7	–	7.7	.007	10	1.2	1.1	4.3	9,950	8.3	<.10	1.9	–
244	281532	820650	USGS	UFA	9/19/2002	22.4	566	327	7.2	–	12	<.020	108	1.5	.20	6.8	4,260	14	<.10	<.20	275
251	281837	815441	SWF	UFA	5/5/1999	23.7	498	–	7.2	–	17	.008	77	7.4	1.1	17	59	22	.18	.20	228
252	281917	815148	USGS	UFA	11/19/2003	23.3	361	205	7.2	170	15	<.02	56	7.4	.80	6.6	330	7.3	.10	<.20	180
253	281951	820120	USGS	UFA	8/13/2003	23.0	810	541	6.3	380	16	<.02	131	13	.20	34	7,200	61	.40	<.20	354

Appendix 2. (Continued) Chemical and physical data for water from the surficial aquifer system, intermediate aquifer system, and Upper Floridan aquifer wells in Polk and parts of adjacent Highlands, Hillsborough, Lake, Orange, and Osceola Counties.

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Well No.	Latitude	Longitude	Data source	Aquifer	Date	Temperature, °C	Specific conductance, field, µS/cm	Total dissolved solids, mg/L	pH	Hardness total, mg/L as $CaCO_3$	Silica, mg/L	Nitrate, mg/L	Calcium, mg/L	Magnesium, mg/L	Potassium, mg/L	Sodium, mg/L	Iron, µg/L	Chloride, mg/L	Fluoride, mg/L	Sulfate, mg/L	Alkalinity, mg/L as $CaCO_3$
255	281951	820120	USGS	SAS	8/13/2003	25.1	515	352	6.3	210	9.7	<.02	58	15	.20	30	10,000	15	.60	4.1	258
256	282125	820219	USGS	UFA	8/8/2003	22.0	605	350	6.7	320	12	<.02	123	2.4	<.10	9.7	921	16	.10	5.0	294
261	282202	813846	USGS	SAS	3/6/2001	23.9	243	163	5.0	69	5.7	4.6	13	8.9	14	1.9	405	8.1	<.10	61	7.0
263	282245	814926	USGS	UFA	8/12/2003	23.3	306	176	7.2	150	14	<.02	55	2.2	1.6	4.3	307	7.1	<.10	<.20	148
264	282245	814926	USGS	SAS	8/12/2003	22.7	90	50	5.3	18	3.5	<.02	5.1	1.2	2.3	6.6	969	8.6	<.10	12	12

Appendix 3. Lake and stream data-collection sites.

[Site number in figure 56]

Site number	Site name	Latitude	Longitude
1	Lake Deeson	28º06’38”	81º55’50”
2	Lake Bonny	28º03’01”	81º58’29”
3	Lake Wire	28º02’51”	81º57’34”
4	Lake Morton	28º02’16”	81º57’09”
5	Lake Hunter	28º02’01”	81º57’59”
6	Lake Parker	28º03’00”	81º55’21”
7	Lake Bonny	28º02’16”	81º55’44”
8	Lake John	28º00’16”	81º56’24”
9	Scott Lake	27º57’45”	81º56’03”
10	Lake Helene	28º10’26”	81º48’20”
11	Lake Agnes	28º10’07”	81º49’05”
12	Clearwater Lake	28º10’13”	81º49’59”
13	Mud Lake	28º10’11”	81º50’37”
14	Little Lake Agnes	28º09’41”	81º48’27”
15	Lake Tennessee	28º08’38”	81º48’56”
16	Lake Mattie	28º08’11”	81º47’02”
17	Lake Juliana	28º07’52”	81º47’44”
18	Lake Van	28º06’26”	81º46’45”
19	Lake Arietta	28º05’44”	81º47’42”
20	Lake Whistler	28º05’29”	81º48’34”
21	Lake Myrtle	28º05’16”	81º49’40”
22	Lake Ariana	28º05’04”	81º48’37”
23	Grassy Lake	28º07’04”	81º44’34”
24	Lake Swoope	28º06’11”	81º43’30”
25	Lake Alfred	28º05’42”	81º44’05”
26	Lake Pansy	28º04’06”	81º44’39”
27	Lake Mariana	28º04’11”	81º45’19”
28	Blue Lake	28º02’43”	81º46’24”
29	Lake Buckeye	28º02’31”	81º42’19”
30	Lake Maude	28º02’11”	81º43’14”
31	Lake Silver	28º01’16”	81º43’44”
32	Lake Martha	28º01’36”	81º43’19”
33	Lake Elbe	28º01’41”	81º42’44”
34	Lake Mariam	28º00’51”	81º42’04”
35	Lake Otis	28º01’01”	81º42’51”
36	Deer Lake	28º01’38”	81º45’34”
37	Lake Howard	28º01’03”	81º44’57”
38	Lake Annie	27º59’06”	81º36’39”
39	Lake Ruby	27º58’28”	81º39’29”
40	Lake Bess	27º58’04”	81º39’20”

Appendix 3. (Continued) Lake and stream data-collection sites.

[Site number in figure 56]

Site number	Site name	Latitude	Longitude
41	Lake McLeod	27º58’29”	81º45’09”
42	Lake Starr	27º57’23”	81º35’32”
43	Lake Wales	27º54’14”	81º34’43”
44	Lake Parker	27º54’34”	81º38’14”
45	Lake Garfield	27º53’49”	81º43’37”
46	Lake Walker	27º51’16”	81º43’11”
47	Lake Buffum	27º48’31”	81º40’00”
48	Lake Henry	27º46’50”	81º43’08”
49	Blue Lake	27º51’23”	81º34’55”
50	Blue Lake	27º51’01”	81º34’26”
51	Big Gum Lake	27º55’45”	81º29’32”
52	Little Gum Lake	27º55’19”	81º28’55”
53	Cypress Lake	27º54’55”	81º28’48”
54	Thomas Lake	27º54’19”	81º28’30”
55	Saddlebag Lake	27º53’53”	81º27’52”
56	Crooked Lake	27º48’29”	81º33’18”
57	Little Crooked Lake	27º45’46”	81º34’21”
58	Lake Clinch	27º45’16”	81º32’24”
59	Reedy Lake	27º44’32”	81º29’57”
60	Lake Hickory	27º42’01”	81º32’09”
61	Lake Hamilton	28º2’1”	81º38’39”
62	Lake Marion	25º5’57”	81º31’57”
63	Lake Hancock	27º57’49”	81º51’28”
64	Mountain Lake	27º56’9”	81º35’27”
65	Green Swamp Run near Eva	28º18’39”	81º41’08”
66	Fox Branch near Socrum	28º10’55”	82º00’45”
67	Saddle Creek near Structure P-11 near Bartow	27º56’17”	81º51’05”
68	Peace River at Bartow	27º54’07”	81º49’03”
69	Peace Creek Drainage Canal near Wahneta	27º55’28”	81º43’37”
70	Peace River at Fort Meade	27º45’04”	81º46’56”
71	Bowlegs Creek near Fort Meade	27º41’59”	81º41’44”
72	Catfish Creek near Lake Wales	27º57’40”	81º29’48”
73	Tiger Creek near Babson Park	27º48’40”	81º26’38”
74	Kissimmee River at S-65 near Lake Wales	27º48’14”	81º11’53”
75	Livingston Creek near Frostproof	27º42’30”	81º26’48”
76	Withlacoochee River near Compressco	28º18’42”	82º03’22”