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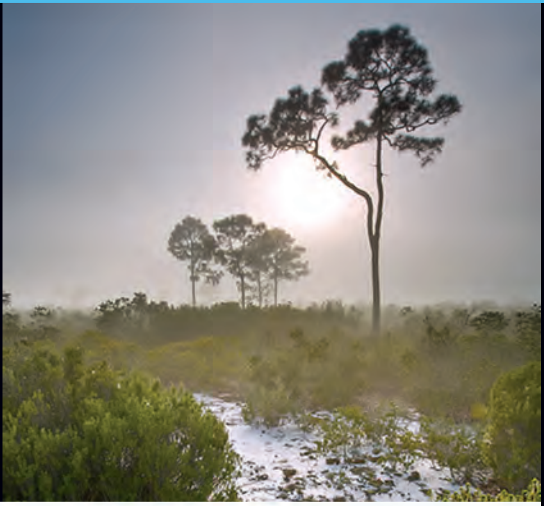
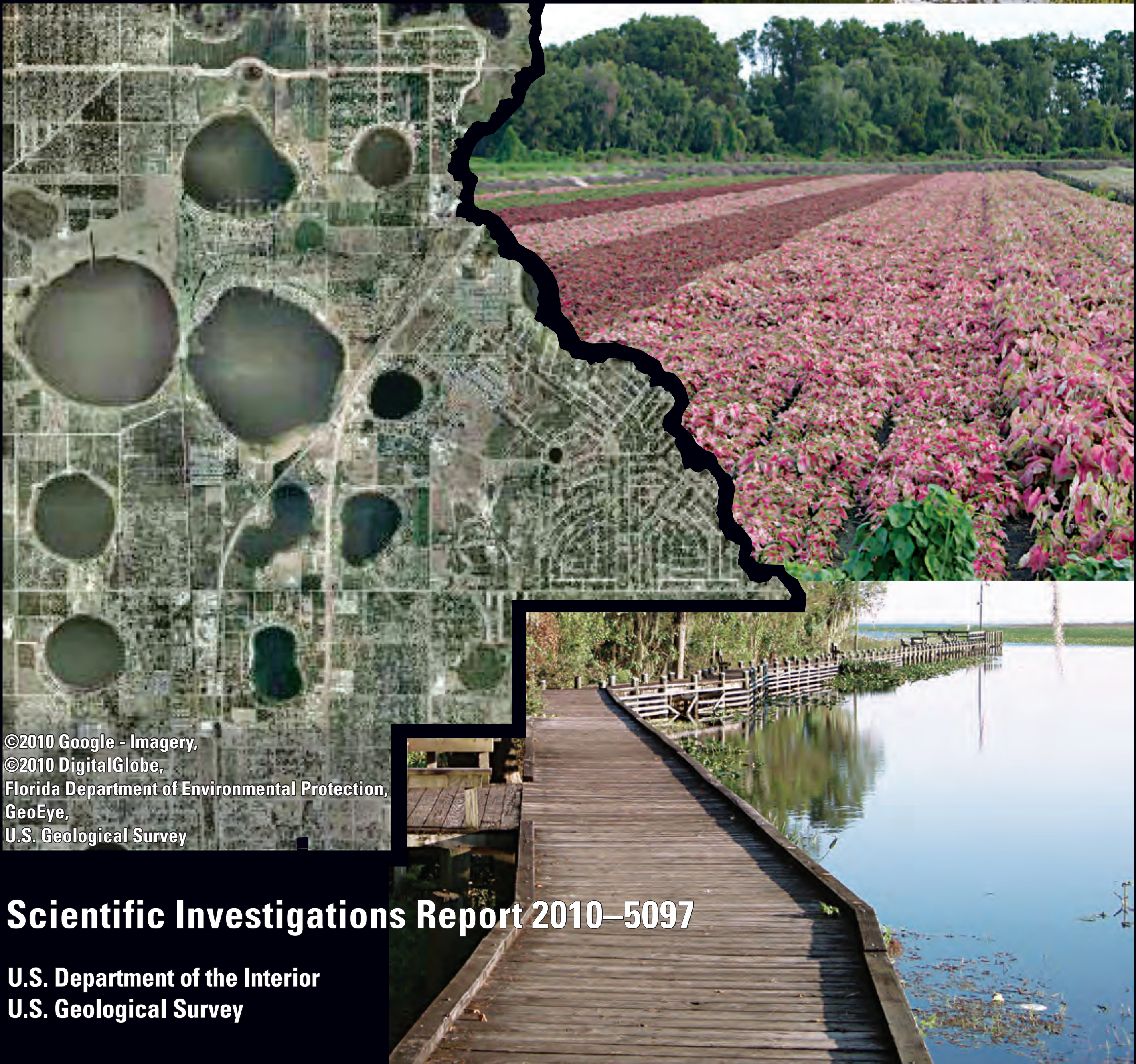


Hydrogeology and Groundwater Quality of Highlands County, Florida



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Scientific Investigations Report 2010–5097

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Clockwise from top:

- Rosemary scrub—photograph by Reed Bowman
- Caladiums—photograph by Rick Spechler
- Lake Istokpoga—photograph by Rick Spechler
- Areal photo of lakes and sinkholes—
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Hydrogeology and Groundwater Quality of Highlands County, Florida

By Rick M. Spechler

Prepared in cooperation with
Highlands County
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Southwest Florida Water Management District

Scientific Investigations Report 2010–5097

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch per year (in/yr)	2.54	centimeter per year (cm/yr)
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 meters 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 (m/d)/m
	Temperature	
Fahrenheit (°F)	°C = (°F-32)/1.8	Celsius (°C)

*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.

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.

Additional Abbreviations

μ = micron
μS/cm = microsiemen per centimeter
mL = milliliter
mg/L = milligrams per liter

Hydrogeology and Groundwater Quality of Highlands County, Florida

By Rick M. Spechler

Abstract

Groundwater is the main source of water supply in Highlands County, Florida. As the demand for water in the county increases, additional information about local groundwater resources is needed to manage and develop the water supply effectively. To address the need for additional data, a study was conducted to evaluate the hydrogeology and groundwater quality of Highlands County.

Total groundwater use in Highlands County has increased steadily since 1965. Total groundwater withdrawals increased from about 37 million gallons per day in 1965 to about 107 million gallons per day in 2005. Much of this increase in water use is related to agricultural activities, especially citrus cultivation, which increased more than 300 percent from 1965 to 2005

Highlands County is underlain by three principal hydrogeologic units. The uppermost water-bearing unit is the surficial aquifer, which is underlain by the intermediate aquifer system/intermediate confining unit. The lowermost hydrogeologic unit is the Floridan aquifer system, which consists of the Upper Floridan aquifer, as many as three middle confining units, and the Lower Floridan aquifer.

The surficial aquifer consists primarily of fine-to-medium grained quartz sand with varying amounts of clay and silt. The aquifer system is unconfined and underlies the entire county. The thickness of the surficial aquifer is highly variable, ranging from less than 50 to more than 300 feet. Groundwater in the surficial aquifer is recharged primarily by precipitation, but also by septic tanks, irrigation from wells, seepage from lakes and streams, and the lateral groundwater inflow from adjacent areas.

The intermediate aquifer system/intermediate confining unit acts as a confining layer (except where breached by sinkholes) that restricts the vertical movement of water between the surficial aquifer and the underlying Upper Floridan aquifer. The sediments have varying degrees of permeability and consist of permeable limestone, dolostone, or sand, or relatively impermeable layers of clay, clayey sand, or clayey carbonates. The thickness of the intermediate aquifer system/intermediate confining unit ranges from about 200 feet in northwestern Highlands County to more than 600 feet in the southwestern part. Although the intermediate aquifer system is present in the county, it is unclear where the aquifer system grades into a confining unit in the eastern part of the county. Up to two water-bearing units are present in the intermediate aquifer system within the county. The lateral continuity and water-bearing potential of the various aquifers within the intermediate aquifer system are highly variable.

The Floridan aquifer system is composed of a thick sequence of limestone and dolostone of Upper Paleocene to Oligocene age. The top of the aquifer system ranges from less than 200 feet below NGVD 29 in extreme northwestern Highlands County to more than 600 feet below NGVD 29 in the southwestern part. The principal source of groundwater supply in the county is the Upper Floridan aquifer. As of 2005, about 89 percent of the groundwater withdrawn from the county was obtained from this aquifer, mostly for agricultural irrigation and public supply. Over most of Highlands County, the Upper Floridan aquifer generally contains freshwater, and the Lower Floridan aquifer contains more mineralized water. The potentiometric surface of the Upper Floridan aquifer is constantly fluctuating, mainly in response to seasonal variations in rainfall and groundwater withdrawals.

The potentiometric surface of the Upper Floridan aquifer in May 2007, which represents the hydrologic conditions near the end of the dry season when water levels generally are near their lowest, ranged from about 79 feet above NGVD 29 in northwestern Highlands County to about 40 feet above NGVD 29 in the southeastern part of the county. The potentiometric surface of the Upper Floridan aquifer in September 2007 was about 3 to 10 feet higher than that measured in May 2007.

Groundwater samples collected from 129 wells by the U.S. Geological Survey, State, and County agencies between 2000 and 2008 were used to characterize groundwater quality in Highlands County. Water-quality samples from 58 wells were collected specifically for this study by the U.S. Geological Survey and analyzed for common inorganic constituents and nutrients.

Water quality in the surficial aquifer can be highly variable. This variability results from several factors, including the lithology of the sediments, interaction with the Upper Floridan aquifer, and most importantly, effects of land use. Concentrations of specific conductance and major ions are generally low. Specific conductance ranged from 32 to 723 microsiemens per centimeter (µS/cm), chloride concentrations ranged from 2.6 to 54 milligrams per liter (mg/L), sulfate concentrations ranged from 0.2 to 87 mg/L, and hardness (as $CaCO_3$) ranged from 4.0 to 159 mg/L. Of the samples collected in the surficial aquifer, only nitrate concentrations exceeded the Florida primary drinking-water standard of 10 mg/L. The application of fertilizers related to citrus farming is the most likely source of nitrate in groundwater in this area.

Specific conductance of water in the intermediate aquifer system in Highlands County ranged from 66 to 11,500 µS/cm, and concentrations of chloride and sulfate ranged from 3.8 to 3,770 and 0.12 to 111 mg/L, respectively. With only a few exceptions, concentrations of total dissolved solids, chloride, sulfate, and nitrate were below State drinking-water standards.

Specific conductance of water in the Upper Floridan aquifer ranged from 133 to 1,900 µS/cm, and concentrations of chloride and sulfate ranged from 4.4 to 403 and less than 0.18 to 255 mg/L, respectively. Water from the Upper Floridan aquifer in most of the county is hard, ranging from 64 to 410 mg/L. Nitrate concentrations ranged from less than 0.04 to 0.22 mg/L; however, most of the water samples collected from the Upper Floridan aquifer had concentrations less than 0.04 mg/L.

Concentrations of chemical constituents in the Upper Floridan aquifer vary both areally and with depth. Inorganic constituent concentrations in water from the Upper Floridan aquifer generally were below State and Federal drinking-water standards, except in the southeastern and southwestern parts of the county where the water is more mineralized. The sources of the mineralized water are from relict seawater that entered the aquifer during a higher stand of sea level in the geologic past and has not been completely flushed from the aquifer, and from the dissolution of sulfur-bearing minerals in the aquifer.

Introduction

Groundwater use in central Florida has increased substantially over the past several decades. In Highlands County, groundwater withdrawals have increased from about 37 Mgal/d in 1965 to 107 Mgal/d in 2005. Some of this increase is due to an expanding population, which has increased in the county from about 21,000 in 1960 to about 99,000 in 2007. Much of this increase in water use, however, is related to agricultural activities, especially citrus cultivation, which increased more than 300 percent from 1965 to 2005. The expansion of development and agriculture has placed increased demands on limited water resources in the area.

As the demand for water in Highlands County increases, additional information about the underlying aquifers is needed to manage and develop the water supply effectively. With the exception of the Lake Wales Ridge area, the hydrogeologic framework, groundwater flow system, and water-quality conditions are not well defined. The last comprehensive countywide hydrogeologic investigation of Highlands County was completed in 1956 (Bishop, 1956). Existing maps that depict the tops, thicknesses, and lithologic characteristics of the various hydrogeologic units are generally regional in scope, are based on sparse data, and generally end at the water management district boundaries. Similarly, existing maps that show the areal distribution of water-quality characteristics are based on limited data points. To address the need for additional data, the U.S. Geological Survey (USGS), in cooperation with Highlands County, the South Florida Water Management District (SFWMD), and the Southwest Florida Water Management District (SWFWMD), began a study in 2006 to evaluate the hydrogeology and groundwater quality of the county. The study provides information useful for the conservation, development, and management of the water resources of Highlands County.

Purpose and Scope

The purpose of this report is to document a comprehensive study of hydrogeology, hydrologic characteristics, and water quality in Highlands County, Florida. The report includes data that describe (1) the lithology, depth, thickness, and extent of the surficial aquifer, intermediate aquifer system, and Floridan aquifer system in Highlands County based on geologic, geophysical, and drillers' logs; (2) water levels and water-level trends in the aquifer systems using maps and hydrographs; and (3) areal and vertical water-quality characteristics within the aquifer systems.

Data used in this report are derived from publications and files of the USGS, SWFWMD, SFWMD, Florida Department of Environmental Protection (FDEP), Florida Geological Survey (FGS), and reports prepared by private consultants. Additional data collected by the USGS from 2006 to 2008 were used to supplement previously available data.

Previous Studies

Over the years, reports have documented the geology, hydrology, and groundwater resources of Highlands County. Discussions of Florida geology with reference to Highlands County are included in reports by Cooke (1945), Stringfield (1966), White (1970), Scott (1988), and Arthur and others (2008). The first comprehensive investigation of the hydrogeology and groundwater resources of Highlands County was done by Bishop (1956). A number of subsequent studies have described the hydrogeology of selected areas within Highlands County. Shaw and Trost (1984) evaluated the regional hydrogeology of the Kissimmee River basin. Miller (1986) described the hydrogeologic framework of the Floridan aquifer system. Duerr and others (1988) and Knochenmus (2006) described the hydrogeologic framework of the intermediate aquifer system in west-central Florida. Basso and Hood (2005) discussed groundwater resources of the intermediate aquifer system in the southern part of the SWFWMD. The hydrogeology of the Lake Wales Ridge was described by Barcelo and others (1990) and Yobbi (1996). Tihansky and others (1996) utilized continuous high-resolution seismic-reflection techniques beneath four lakes along the Lake Wales Ridge in Polk and Highlands Counties to describe the local geologic structure. Groundwater flow modeling studies that include all or part of the study area are presented by Tibbals (1990), Barcelo and Basso (1993), Yobbi (1996), Sepúlveda (2002), and Radin and others (2005).

Various water-quality studies have included all or part of Highlands County. Sprinkle (1989) discussed the chemical quality of groundwater in the Floridan aquifer system in Florida. 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. Moore and others (1986) summarized information from the ambient groundwater-quality monitoring program for the SWFWMD. Nitrate in groundwater in the vicinity of the Lake Wales Ridge was evaluated by Tihansky and Sacks (1997) and Wheaton and Graham (2000). Agricultural chemicals in the surficial aquifer in the Lake Wales Ridge were investigated by Choquette and others (2005).

The hydrology of lakes within Highlands County has been documented in several reports. Kohout and Meyer (1959) described the hydrologic features of the Lake Istokpoga and Lake Placid areas. The hydrology of the Lake Placid area was reported by Adams and Stoker (1985). The hydrology of Lake June in Winter was described by Belles and Martin (1985). Sacks and others (1998) estimated groundwater exchange with lakes in the ridge areas of Polk and Highlands Counties by using water-budget and chemical mass-balance approaches. A report by Choquette and Kroening (2009) summarizes the results of water-quality data collected at eight lakes along the Lake Wales Ridge in Polk and Highlands Counties, with emphasis on pesticides and their degradates.

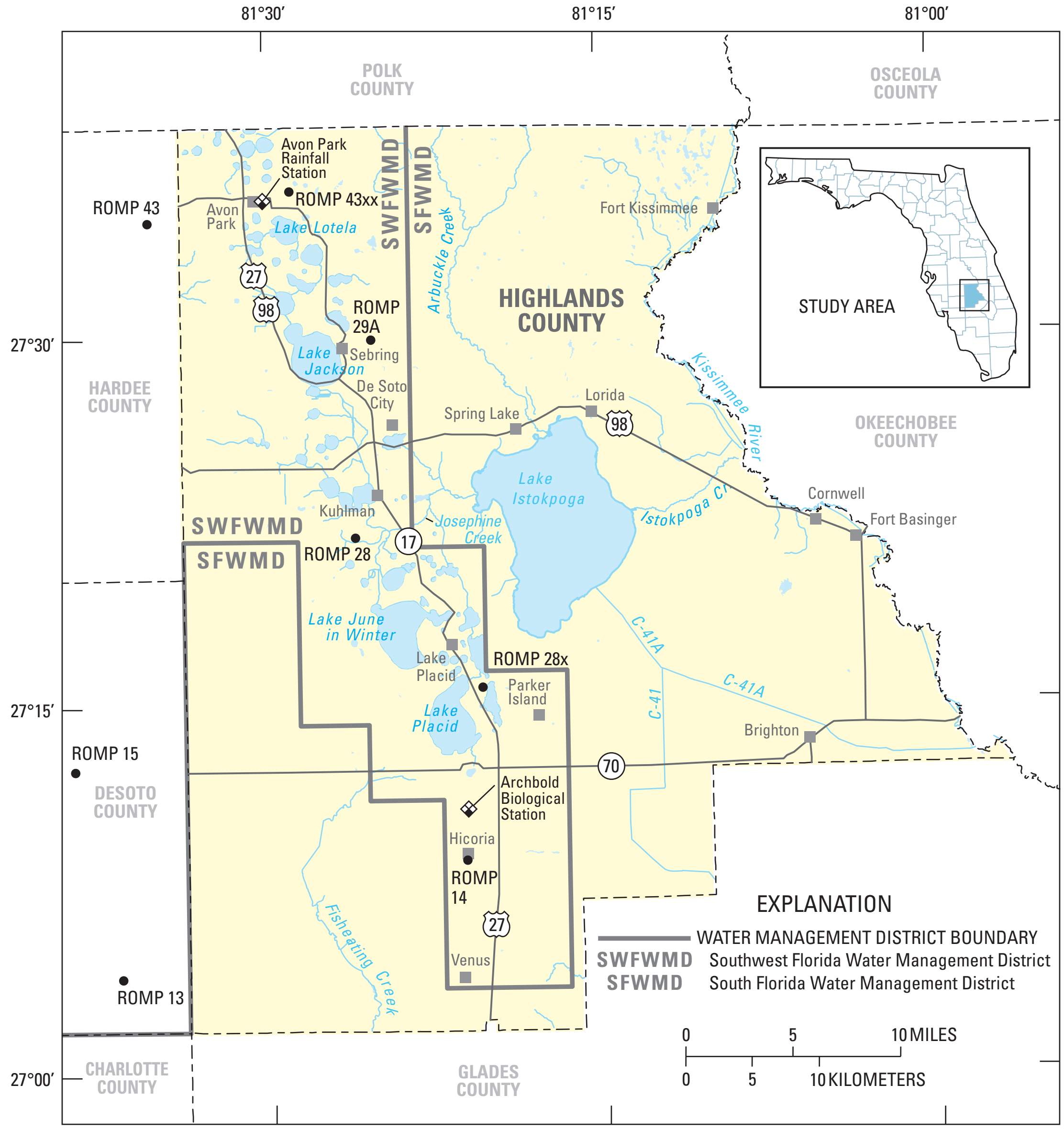
Description of Study Area

Highlands County, located in the south-central part of the Florida Peninsula, is the 14th largest county in Florida (fig. 1). The county is bordered on the north by Polk County, on the east by Okeechobee County, on the south by Glades County, and on the west by Hardee and DeSoto Counties. Highlands County has a total surface area of about 1,106 mi^2, of which 78 mi^2 are water (*http://www.city-data.com/county/Highlands_County-FL.html*). Land-surface altitudes range from about 20 to 210 ft above NGVD 29 (fig. 2). The lowest altitudes occur near the Kissimmee River east of Brighton and the highest altitudes are found on the Lake Wales Ridge in the vicinity of Archbold Biological Station. The county is located within the jurisdiction of the SFWMD and SWFWMD—two of the five water management districts in Florida. The more rural part of the county, about two-thirds of the total area, is located within the SFWMD (fig. 1). The area along the Lake Wales Ridge, about one-third of Highlands County, is within the jurisdiction of the SWFWMD. All areas of Highlands County within the jurisdiction of the SWFWMD are part of the Southern Water Use Caution Area (SWUCA), which includes all or part of eight counties in southwestern Florida. The SWUCA was designated in 1992 in response to the effects that increasing groundwater withdrawals had on causing saltwater intrusion along the coast, its contributions to reduced flows in the upper Peace River, and the declining lake levels in the Lake Wales Ridge area of Polk and Highlands Counties (Southwest Florida Water Management District, 2006). The SFWMD has designated the area including Lake Istokpoga and much of the southeastern part of Highlands County as a Water Resource Caution Area (WRCA) (Florida Department of Environmental Protection, 2006).

Population, Industry, and Land Use

In 1960, the population of Highlands County was about 21,000. By 2007, the population increased to about 99,000 and is projected to reach about 120,000 by 2020 (fig. 3). Most of the population is concentrated along the Lake Wales Ridge region, whereas the rest of the county is predominantly rural. Out of 67 counties, Highlands population was ranked 34th largest in the State in 2007 (Office of Economic and Demographic Research, 2008). Highlands County has three incorporated cities: Sebring, which is the county seat, Avon Park, and Lake Placid (fig. 1). Most of the remaining population lives in the unincorporated towns of Brighton, Cornwell, DeSoto City, Fort Basinger, Hicoria, Lorida, Spring Lake, and Venus.

Agriculture is the predominant economic activity in Highlands County. Various types of agriculture are a major part of the local economy, and many are significant water users. The most important type of agriculture is the growing of citrus, principally oranges and grapefruits. In 2005–06, Highlands County ranked second in the State in citrus production, yielding



Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 1. Location of study area in south-central Florida.

about 14 percent of the citrus grown in Florida (U.S. Department of Agriculture, 2007). Cattle ranching is also a major part of agriculture. Ranches are typically extensive and are located on the plains east and west of the Lake Wales Ridge. In 2007, Highlands County ranked second in the State in the production of cattle and calves, with a total of about 111,000 head (*http://www.agcensus.usda.gov/publications/2007/online_highlights/county_profiles/Florida/index.asp*). Truck-farming and other agricultural categories are of less importance to the economy of the county. The other major economic activity in Highlands County is tourism, which is estimated to increase the population of the county by as much as 20 percent during the winter months (Highlands County Economic Development Commission, oral commun., 2009).

Agriculture, wetlands, urban land, forests, water, and rangelands were the major land-use categories in the county in 2004 (fig. 4). Agriculture is the predominant land-use category, composing about 54 percent of the county area. Agricultural lands are scattered throughout the county, and include citrus groves, dairies, pasture, sod, and truck farms. As noted earlier, citrus is the primary agricultural product, but is mostly concentrated along the Lake Wales Ridge. Wetlands compose about 18 percent of the county and generally are found in the eastern and southwestern parts of the county. Urban land composes about 10 percent of the county, and is mostly concentrated around the cities of Avon Park, Sebring, and Lake Placid. Water covers about 7 percent of the county. Numerous lakes and sinkholes are concentrated along the Lake Wales Ridge, although the

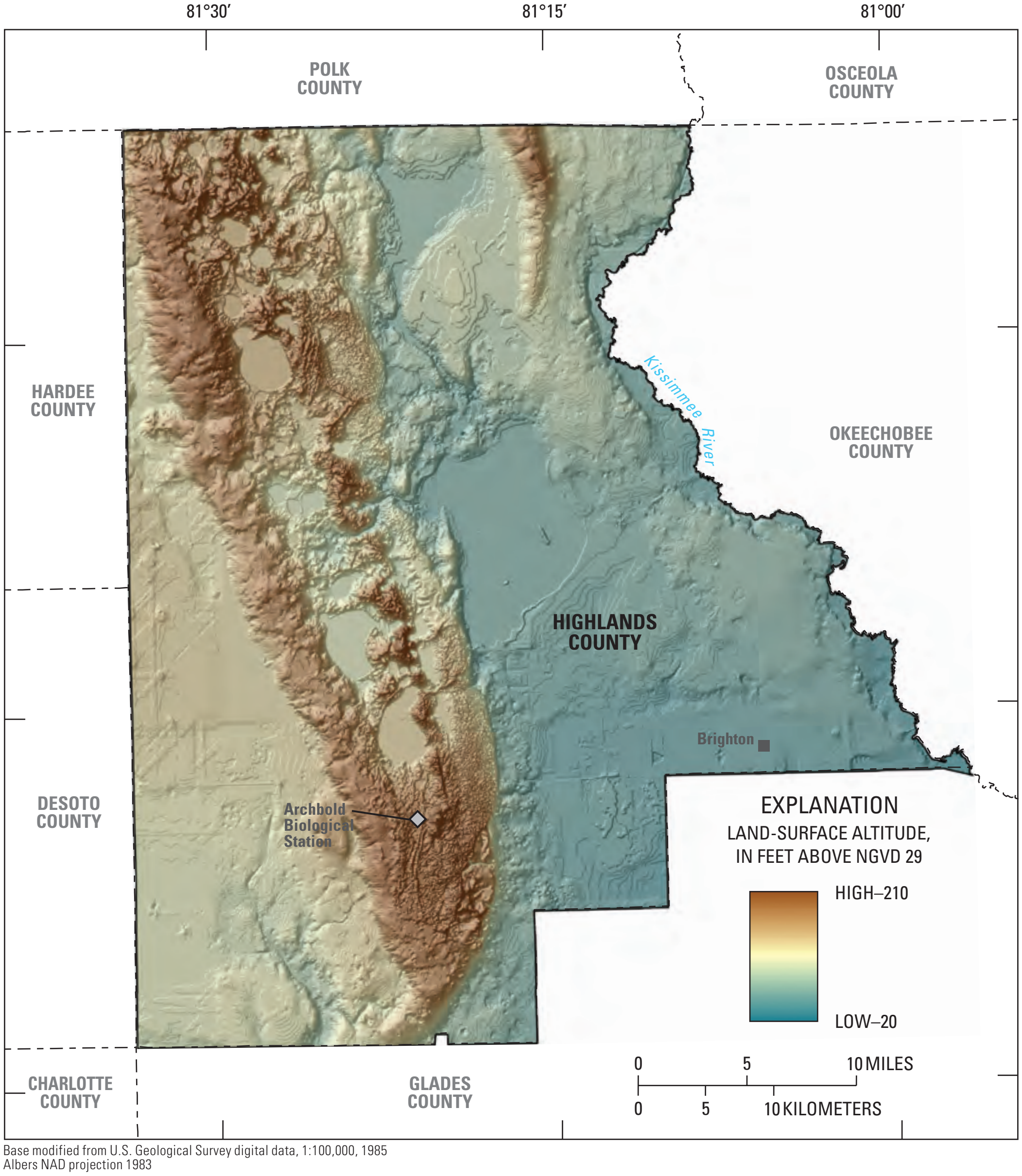


Figure 2. Topography of Highlands County.

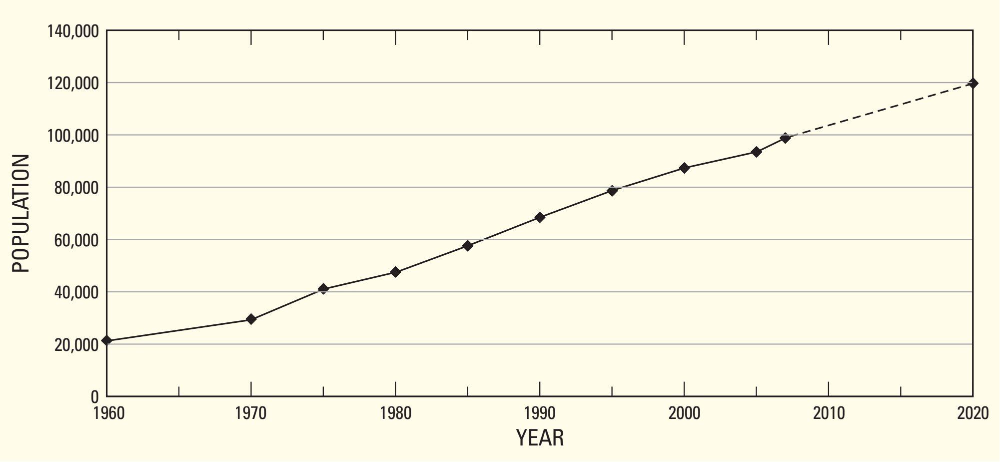
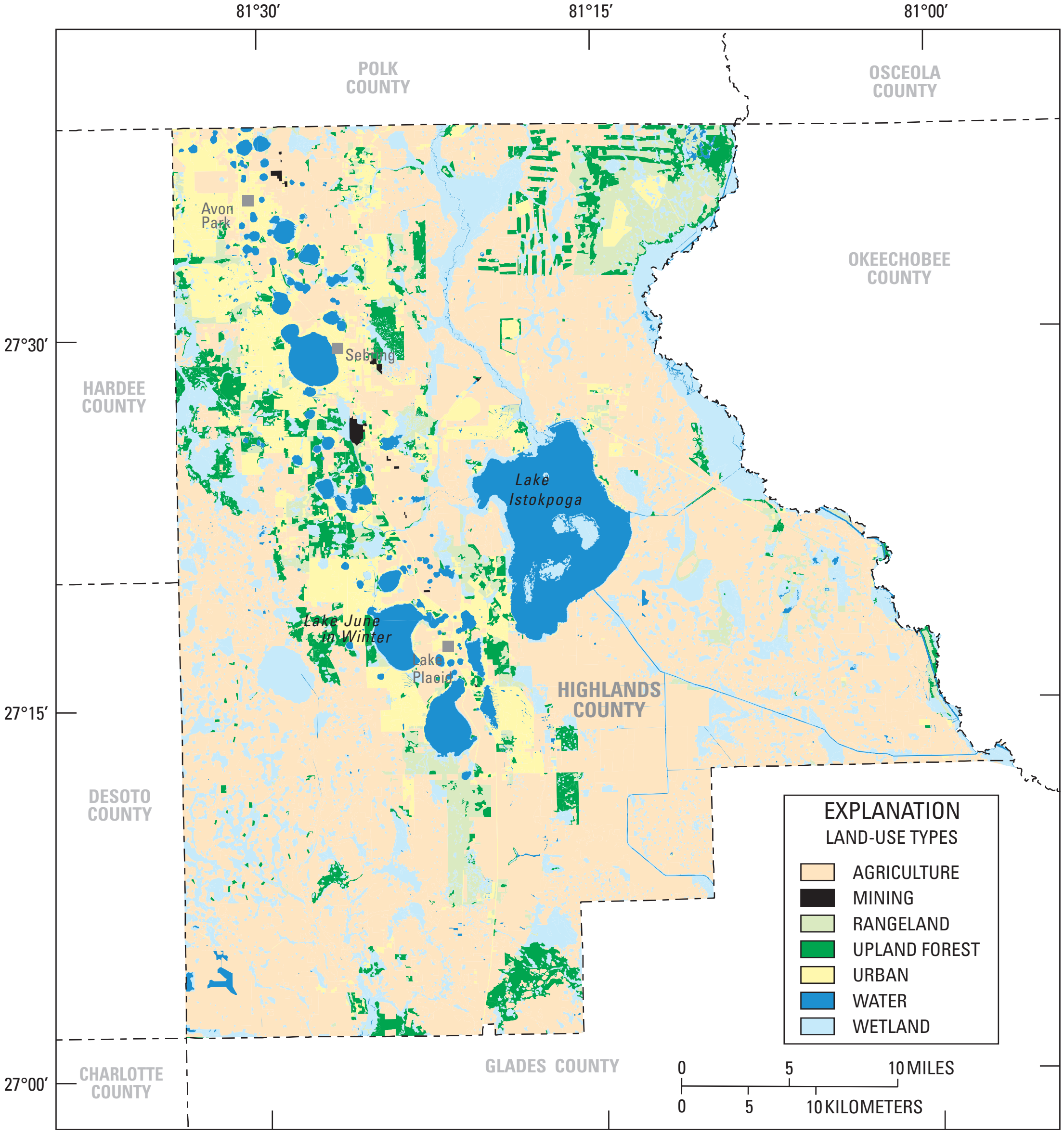


Figure 3. Historical and projected population growth for Highlands County. From U.S. Bureau of the Census (1995) and Office of Economic and Demographic Research (2008).



Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

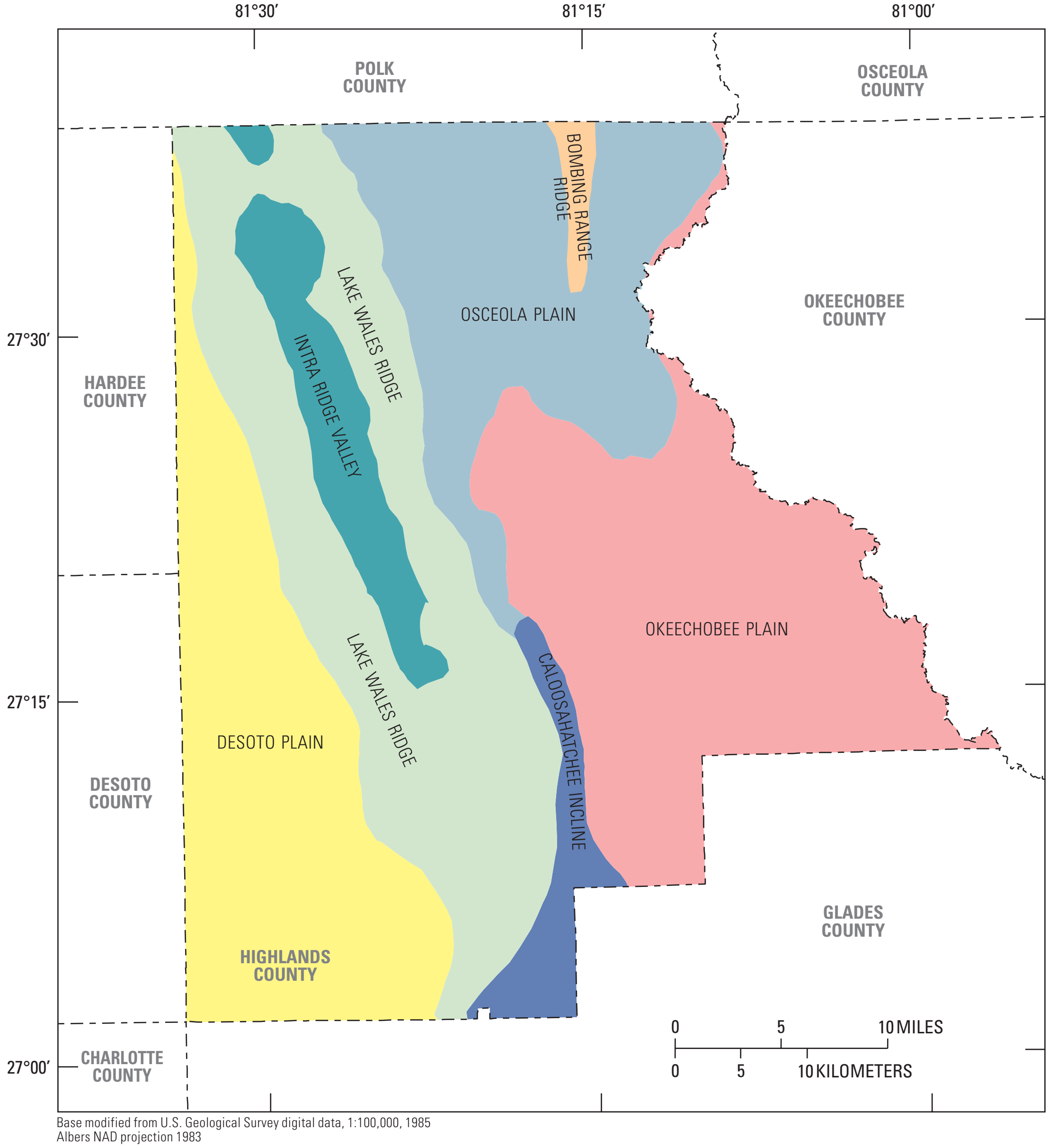
Figure 4. Generalized land use in Highlands County, 2004.

largest lake in the county, Lake Istokpoga, is located just east of the ridge. Forest covers about 6 percent of the county, primarily in the northeastern and western areas. Rangelands compose about 5 percent of the county. Unlike Polk County to the north, mining areas are nearly nonexistent, composing about 0.1 percent of the county.

Physiography

Highlands County lies entirely in the mid-peninsular physiographic zone described by White (1970). The major physiographic features that compose the county are the Lake Wales Ridge, Osceola Plain, Bombing Range Ridge, DeSoto Plain, Okeechobee Plain, Intra Ridge Valley, and the Caloosahatchee Incline (fig. 5). The shape and character of these landforms have all been influenced by interactions of sea-level changes and karst processes.

The most prominent topographic feature of the Florida Peninsula is the Lake Wales Ridge. This long, narrow ridge extends from Lake County south past the Glades-Highlands County line. The configuration of the ridge, with wave-cut terraces and parallel alignment with present shorelines, suggests that these features were developed by wave action during periods when sea level was higher (Geraghty and Miller, 1980). The morphology of the eastern flank of the Lake Wales Ridge was probably controlled by high-energy shoreline currents throughout the Pleistocene (and possibly the late



Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 5. Generalized physiography of Highlands County. From White (1970).

Pliocene), as indicated by the sharp topographic relief on the eastern side of the ridge (Arthur and others, 2008). In contrast, the western side of the ridge is more irregular and slopes off more gradually.

Land-surface altitudes on the Lake Wales Ridge are the highest in the county and range from about 60 to 210 ft above NGVD 29 (fig. 2). In much of the county, the Lake Wales Ridge is composed of two secondary ridges separated by the Intra Ridge Valley, where altitudes range from about 50 to 100 ft above NGVD 29 (Choquette and Sepúlveda, 2000). Generally maintaining a width of about 2 miles, this valley was formed by the dissolution of the underlying limestone and contains numerous karst features (White, 1970).

The Lake Wales Ridge forms the surface-water divide between the Kissimmee River basin to the east, the Peace River basin to the west, and the tributaries to the south that flow into Lake Okeechobee. Surface stream drainage is poorly developed or absent in most areas (Choquette and Kroening, 2009). The Lake Wales Ridge is characterized by numerous surface depressions and closed basin lakes. Although many of the lakes are in closed depressions and have no surface outlets, some surface-water flow occurs between interconnected lakes and along the flanks of the ridge (Choquette and Sepúlveda, 2000).

The Osceola Plain is a broad marine terrace that lies east of the Lake Wales Ridge. It is characterized by little relief change and generally varies in altitude from about 40 to 80 ft above NGVD 29 in Highlands County. A distinctive feature within the Osceola Plain is the Bombing Range Ridge. Present in southeastern Polk County and extending into northeastern Highlands County, this north/south trending sand ridge has a maximum altitude of 146 ft near its crest in Highlands County. This ridge was probably a marine sand bar when sea level was higher (White, 1970).

The Okeechobee Plain occupies southeastern Highlands County and has land altitudes that dip gradually to the south and generally range from about 20 to 50 ft above NGVD 29. The Caloosahatchee Incline in Highlands County borders the extreme southeastern part of the Lake Wales Ridge and the western part of the Okeechobee Plain. This area is characterized by a long, narrow incline that gently slopes eastward and has altitudes that generally range from 30 to 60 ft above NGVD 29. White (1970) suggested that the Caloosahatchee Incline was the steeper slope at the distal or down-current end of a submarine shoal and was preserved during emergence because of a low energy environment. The DeSoto Plain is a broad, gently sloping area west of the Lake Wales Ridge. Land-surface altitudes decrease gradually toward the south and range from about 95 ft above NGVD 29 in the northern part of the county to about 55 ft above NGVD 29 in the southern part. The DeSoto Plain contains many shallow depressions that fill with water during the rainy season (Bishop, 1956).

Surface-Water Features

The study area is divided into three major surface-water drainage basins and numerous minor surface-water drainage basins. The major surface-water drainage basins are the Kissimmee River basin, Peace River basin, and the Fisheating Creek basin. These drainage basins, streams, canals, and lakes are shown in figure 6.

The Kissimmee River basin is typically subdivided into the upper and lower basins. The lower Kissimmee River basin includes much of the northern and eastern parts of Highlands County. The basin is partially drained by the Kissimmee River, the most prominent surface-water feature in the study area. The relatively low, flat prairie land lying in the lower Kissimmee River basin in Highlands County is characterized by relatively shallow lakes (mostly along the Lake Wales Ridge) and Lake Istokpoga to the east. Part of the basin also drains into Lake Istokpoga, which eventually drains into Lake Okeechobee.

Principal water bodies within the lower Kissimmee River basin include Arbuckle Creek, Josephine Creek, Carter Creek, Lake Istokpoga, and the lakes along the Lake Wales Ridge. Waters from Arbuckle Creek, Josephine Creek, and Carter Creek all discharge into Lake Istokpoga. Lake Istokpoga drains into the Kissimmee River and the C-41A canal, which then drains into Lake Okeechobee. At 44 mi^2, Lake Istokpoga is the fifth largest lake in Florida (Radin and others, 2005). Of the many lakes along the Lake Wales Ridge, some of the largest include Lake Lotela, Lake Jackson, Lake Placid, and Lake June in Winter.

Most of the Kissimmee River basin is regulated for flood-control purposes. To expedite the movement of water and provide flood protection for central Florida, channelization of the Kissimmee River began in 1962 and ended in 1971. The 103-mile-long meandering river was replaced by a 56-mile-long canal, referred to as C-38 (Florida Department of Environmental Protection, 2006). The channelized river is about 30 ft deep (U.S. Army Corps of Engineers, 1991). The Kissimmee River (C-38) is divided into five pools (pools A–E) by a series of combined locks and spillways (Radin and others, 2005).

Regulation of the Kissimmee River basin has adversely affected the ecology of the watershed. The construction of the C-38 canal drained much of the floodplain, stabilized water levels, and greatly modified flow characteristics. As a result, 44 percent of these wetlands were drained and replaced with improved and unimproved pasture (Toth and others, 1995). This change resulted in a substantial loss of habitat for wading birds and plant communities of the river channel and floodplains (Bousquin and others, 2005). Drainage also eliminated the natural nutrient-filtering effects of these wetlands, and stimulated agricultural development in floodplains and adjacent wetlands, all of which contributed to an increase in nutrient loading to Lake Okeechobee (Florida Department of Environmental Protection, 2006).

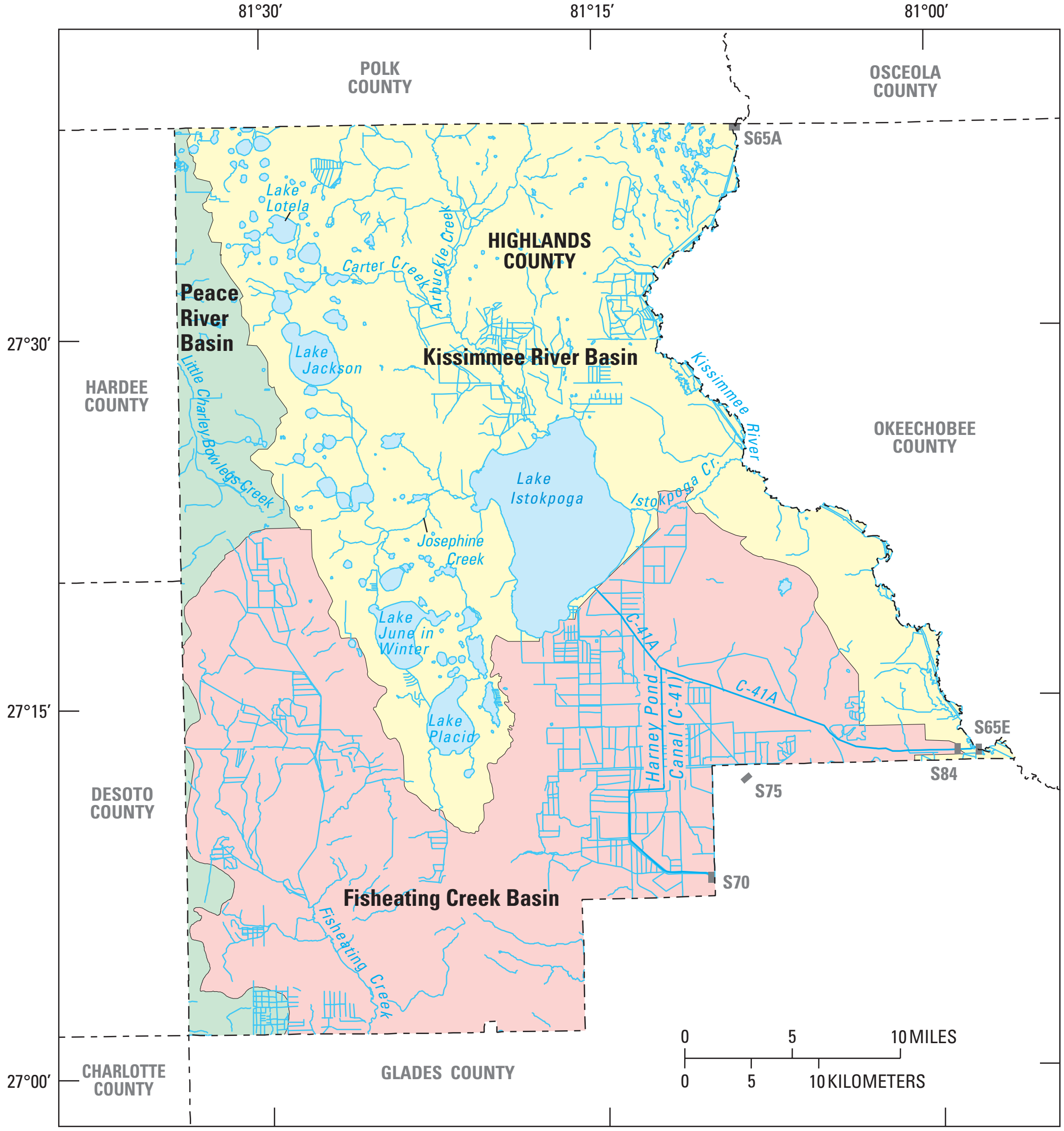
The environmental effects of channelization were quickly recognized and calls for restoration of the river began—even during the canal construction. Restoration of the Kissimmee River began in 1999 with the intent to backfill about 22 miles of the C-38 canal, remove two water-control structures and floodplain levees, and recarve about 9 miles of the river channel (Radin and others, 2005). The plan also was to redirect flows through the historic river channel and restore the floodplain river ecosystem that was disrupted by channelization.

The Fisheating Creek basin encompasses much of southern Highlands County and extends southward into northern Glades County, then eastward toward Lake Okeechobee. Principal water bodies include Fisheating Creek and the C-41 and C-41A canals. Fisheating Creek, which is 56 miles long, originates in western Highlands County and flows south into Glades County where the stream turns east and flows into Lake Okeechobee.

Only a small area in western Highlands County lies within the Peace River basin. In this area, water drains into Little Charley Bowlegs Creek and eventually into the Peace River, which generally flows southward for about 75 miles and discharges into the northeastern part of Charlotte Harbor in Charlotte County.

Climate, Rainfall, and Evapotranspiration

The climate of Highlands County is classified as humid subtropical and is characterized by hot, wet summers and mild, relatively dry winters. During the summer months, daily maximum air temperatures usually exceed 90 °F.



Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 6. Major surface-water drainage basins, streams, canals, and lakes in Highlands County.

Winter daily minimum air temperatures may occasionally drop below freezing. Mean annual temperature for Avon Park is 72.0 °F. Minimum and maximum monthly average temperatures are 60.6 and 81.2 °F, occurring in January and July, respectively.

Although annual rainfall in Highlands County has averaged about 51 inches over the past 30 years, wide variations in rainfall occur between years and locations. Rainfall occurs in southern Florida during two distinct periods—the wet season and the dry season. In most years, about 55 to 60 percent of the average annual rainfall occurs from June through September. Average monthly rainfall during this period generally ranges from about 6 to 8 inches, with June being the wettest month. Thunderstorms account for most of the summer rainfall, which is usually unevenly distributed throughout the county. These storms can produce heavy but localized rainfall, often resulting in several inches of precipitation. During the summer and early fall, tropical storms and hurricanes can cause widespread excessive rainfall and associated flooding. For example, Hurricanes Charley, Frances, and Jeanne, passing through Florida in August and September 2004, produced about 13 inches of rainfall in Highlands County, and Tropical Storm Fay, passing through Florida in September 2008, produced about 6 inches. Winter rains are generally associated with large-scale frontal weather systems, which are usually of longer duration and greater areal uniformity than summer convectional precipitation. However, December and January typically are the driest months, with an average monthly rainfall of about 2 inches.

Long-term rainfall data are available for the Avon Park and Archbold Biological rainfall stations in Highlands County (figs. 1 and 7). Mean annual rainfall at the Avon Park station, obtained from National Oceanic and Atmospheric Administration records (1931–2007), is 52.28 inches. Mean annual rainfall at the Archbold Biological Station (Hilary Swain, Archbold Biological Station, written commun., 2009) from 1932 to 2007 is 53.37 inches (excluding 1 year for which data are unavailable). Thirty-year mean annual rainfall totals from 1978 to 2007 at the Avon Park and Archbold Biological rainfall stations were 50.43 and 52.19 inches, respectively. Although a considerable amount of variation in annual rainfall occurs from year to year, cycles of wet and dry periods are present, as indicated by a 5-year moving average shown in figure 7. No consistent linear trends in annual rainfall rates are present for the period of record at the two rainfall stations. Statistical analysis (Kendall’s tau) also indicates that no long-term trend in rainfall has resulted at the Avon Park or Archbold Biological rainfall stations for the period of record (table 1).

Even with abundant rainfall, Florida is not immune to drought, and extended periods of deficient rainfall do occur. The lowest annual rainfall totals recorded at the Avon Park and Archbold Biological rainfall stations occurred in 2000, and were 26.10 and 27.31 inches, respectively. Average rainfall for the 2-year period (2006–07) was 35.64 inches at Avon Park and 40.86 inches at Archbold Biological Station. The highest annual rainfall totals occurred in 1953 and were 80.08 and 76.73 inches at Avon Park and Archbold Biological Station, respectively.

Much of the precipitation in Florida is recycled directly back into the atmosphere by evapotranspiration. The largest percentage of water lost annually from the area is through

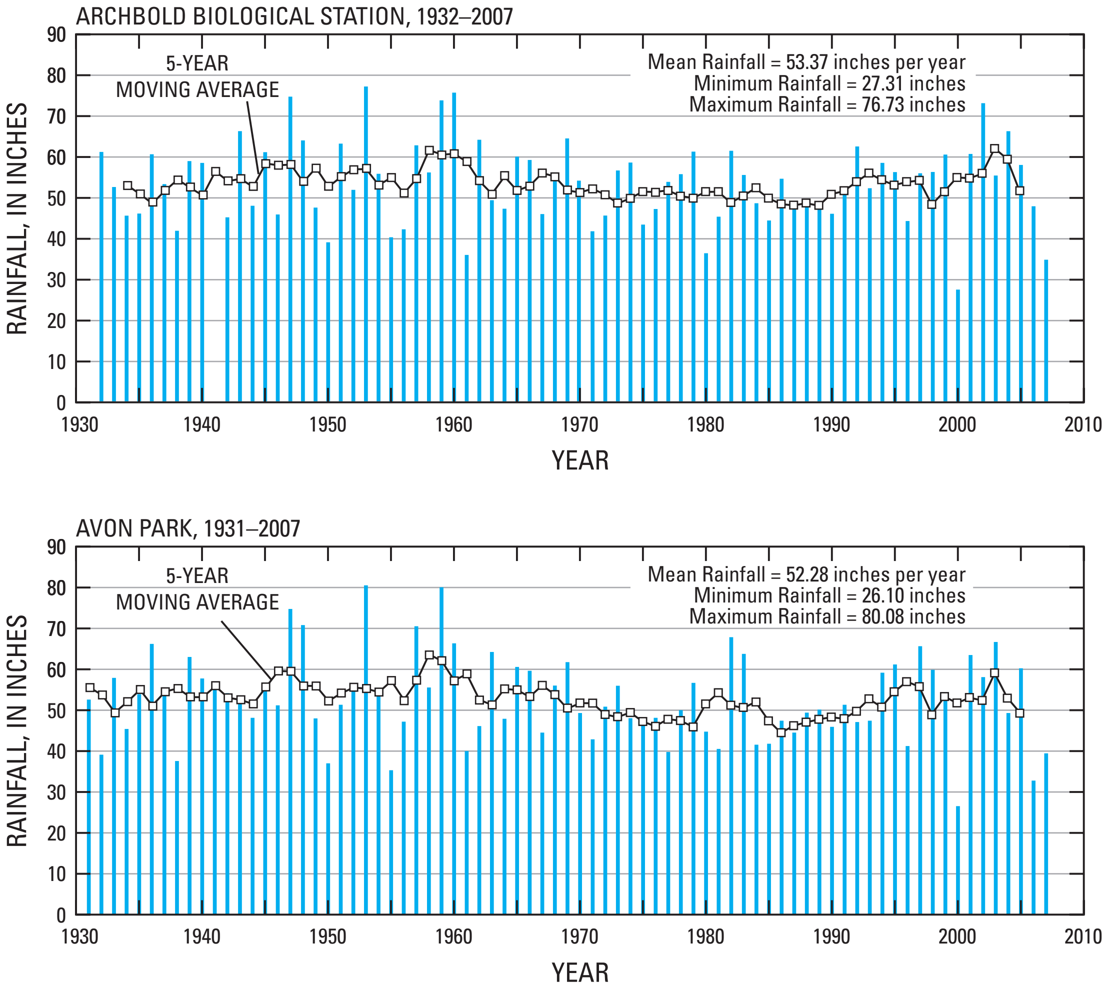


Figure 7. Annual rainfall at Archbold Biological Station and Avon Park, Florida. Rainfall data from the Archbold Biological Station obtained from Hilary Swain (Archbold Biological Station, written commun., 2009). Rainfall data from the Avon Park station obtained from National Oceanic and Atmospheric Administration records.

Table 1. Results of trend anaysis for rainfall stations and long-term observation wells in Highlands County.

[Locations of wells and rainfall stations shown in figure 11. USGS, U.S. Geological Survey; SA, surficial aquifer; IAS, intermediate aquifer system; UFA, Upper Floridan aquifer; NA, not applicable]

Rainfall station (RS) or well number	USGS site identification number	Station name	Aquifer	Bottom of casing (feet below land surface)	Depth of well (feet below land surface)	Period of record analyzed	p-value	Kendall's tau
RS	Not applicable	Archbold Biological Station	NA	NA	NA	1932-2007	0.7212	-0.0285
RS	Not applicable	Avon Park	NA	NA	NA	1931-2007	.2952	-.0817
1	270157081203101	H-15A	SA	19	23	1975-2008	.1494	.0129
43	271226081194301	Bairs Den	SA	28	35	1977-2008	.0000	.0906
53	271330081113401	HIF-37 Sun Ray Farms	UFA	619	1,450	1982-2008	.0074	-.2880
67	271559081242501	Lake Grove Rd.	SA	13	23	1972-2008	.0000	-.0629
88	272207081260402	ROMP 28 Intermediate	IAS	370	420	1996-2008	.0009	.0963
89	272207081260404	ROMP 28 Suwannee	UFA	485	600	1996-2008	.0000	.1194
103	272504081120101	H-11A	SA	13	16	1975-2008	.0092	-.0226
105	272512081122901	HIF-13 Meztger	UFA	NA	1,106	1982-2008	.6376	-.0509
126	272835081251701	Maranatha Village	UFA	NA	841	1979-2008	.8061	-.0239
166	273704081245501	Richards	IAS	140	260	1986-2008	.0687	-.1889

evapotranspiration, defined as the combined processes of evaporation of water from land and water surfaces and transpiration by plants. The rate of evapotranspiration is controlled by several factors, primarily net solar radiation, wind speed, relative humidity, surface area of open water bodies, density and type of vegetation cover, available soil moisture, root depth, water-table depth, and season. The term potential evapotranspiration is a measure of the ability of the atmosphere to remove water from the surface through the processes of evaporation and transpiration assuming no limit on water supply. Actual evapotranspiration is the quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration. Actual evapotranspiration is always less than or equal to potential evapotranspiration.

Estimated average monthly potential evapotranspiration from 1996 to 2007 for Highlands County is shown in figure 8 (Michael Holmes, U.S. Geological Survey, written commun., 2009). The methods used to create these values are described in Jacobs and others (2008). Average monthly potential evapotranspiration is lowest in December (1.8 inches) and is followed by rapidly increasing rates with increasing solar radiation and temperatures during the spring. The highest monthly evapotranspiration (greater than 6 inches) occurs from May to August, and then decreases steadily into December.

Although difficult to quantify, the upper and lower limits of annual evapotranspiration can be estimated. The upper limit of evapotranspiration is approximately equal to the rate at which water can evaporate from a free-water surface and is highest in the lakes, swamps, and marshes where water is near or above land surface much of the time (Tibbals, 1990). Actual lake evaporation measured at Lake Starr in Polk County during August 1996 to July 1998 was 57.08 and 55.88 in/yr, respectively (Swancar and others, 2000). Also defining the generalized upper limits of evapotranspiration is the estimated potential evapotranspiration for the county from 1996 to 2007 (fig. 8). Average total potential evapotranspiration for this period was 53.17 in/yr (Michael Holmes, U.S. Geological Survey, written commun., 2009).

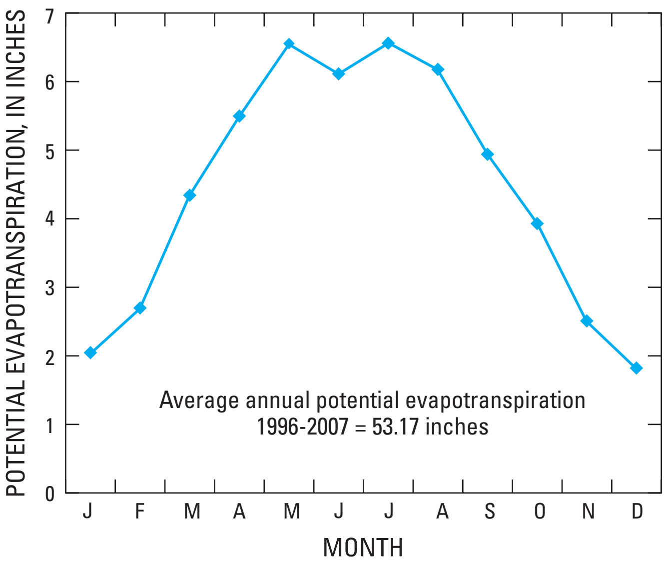


Figure 8. Average monthly potential evapotranspiration for Highlands County, 1996-2007. From U.S. Geological Survey (2009).

The lower limits of evapotranspiration occur in areas that have well drained soils and deep water tables. Tibbals (1990) related evapotranspiration to water-table depth in east-central Florida and estimated that the minimum rate of evapotranspiration occurred where the water table was greater than 13 ft below land surface. At a Bahia grass and palmetto site in eastern Polk County where the water table is shallow, actual annual evapotranspiration ranged from 30.2 to 40.2 in/yr during 2001–07 (D.M. Sumner, U.S. Geological Survey, written commun., 2009). In a deforested area along the Lake Wales Ridge in Orange County, Sumner (1996) determined that annual evapotranspiration was about 27 inches. This site probably represents a minimum evapotranspiration value for central Florida because of the presence of shallow-rooted plants, rapidly drained soil, and a relatively deep water table.

Water Use

Highlands County relies heavily on groundwater for its water supply, and groundwater use has increased substantially over the past several decades. In 1965, groundwater withdrawals in the county were about 37 Mgal/d (fig. 9). In 2000, withdrawals totaled about 157 Mgal/d, an increase of more than 300 percent (Marella, 2009). In 2005, total groundwater use declined to about 107 Mgal/d, largely as a result of above average rainfall of about 60 inches. The dominant factor causing this increase in water use over the past 40 years has been the expansion of agriculture or, more specifically, the expansion of the citrus industry. Water use from agricultural irrigation has increased dramatically, from 32 Mgal/d in 1965 to 95 Mgal/d in 2005 (fig. 9). Water use for public supply, the second largest water-use category for Highlands County, increased from 4 to about 9 Mgal/d from 1965 to 2005 (Marella, 2009).

Of the six water-use categories, agricultural irrigation accounted for the largest percentage of groundwater withdrawn in 2005 (fig. 10). Of the total groundwater withdrawn, about 89 percent was used for agriculture, 8 percent for public supply, 2 percent for recreational irrigation, 1 percent for domestic, and less than 0.1 percent for both commercial/industrial and thermoelectric power generation. The Upper Floridan aquifer is the primary source of water supply, but the surficial aquifer and, locally, the intermediate aquifer system provide drinking water for rural domestic wells and some irrigation and public supply.

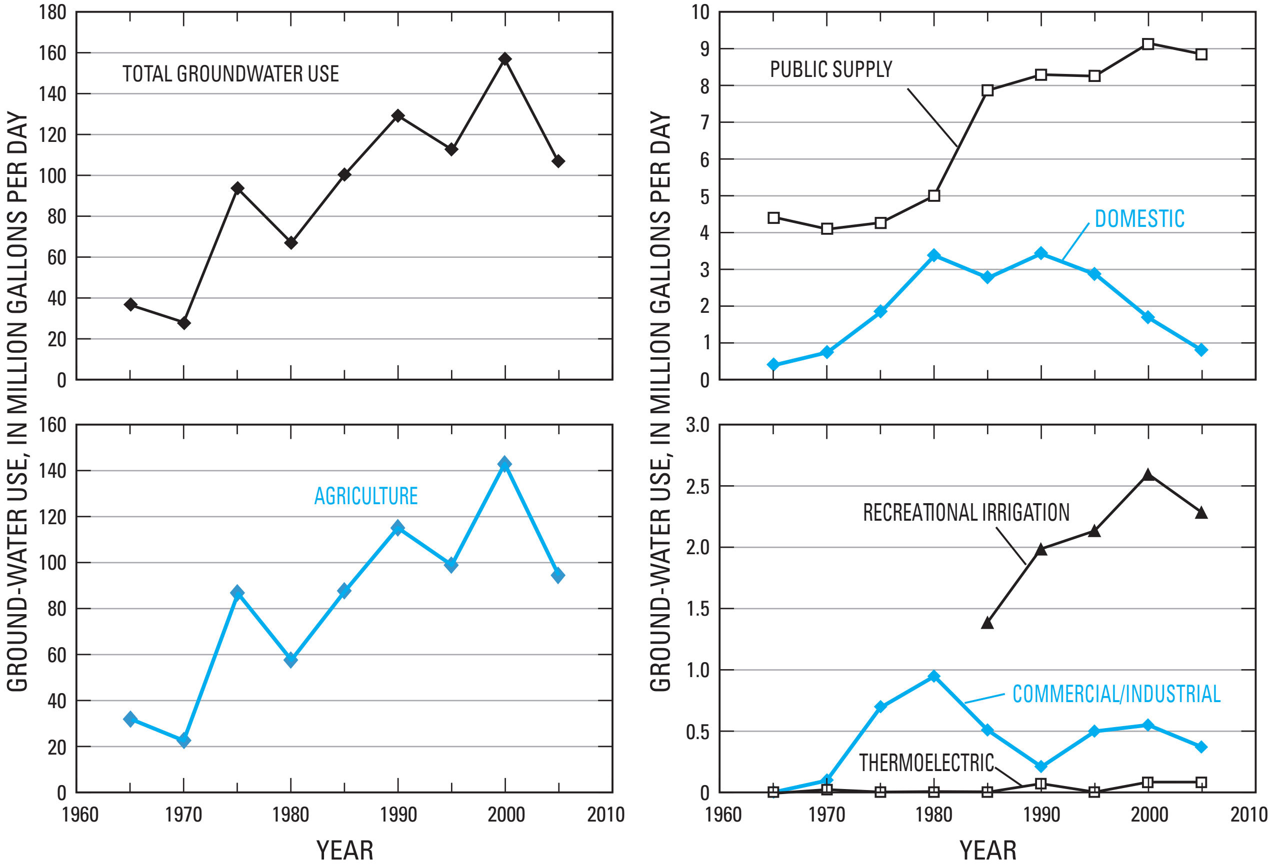


Figure 9. Historical groundwater use in Highlands County, 1965-2005. From Marella (2009).

The principal source of groundwater supply in Highlands County is the Upper Floridan aquifer. As of 2005, about 89 percent of the groundwater withdrawn from the county was obtained from this aquifer. The surficial aquifer was the source for about 9 percent of groundwater (M. Beach, Southwest Florida Water Management District, written commun., 2009). Most of the water from the surficial aquifer is obtained from wells along the Lake Wales Ridge. The intermediate aquifer system is only a minor source of water supply, contributing about 2 percent of the total groundwater withdrawn (M. Beach, Southwest Florida Water Management District, written commun., 2009).

Although poorly documented, little groundwater is withdrawn from the Lower Floridan aquifer for water supply in Highlands County. In the northern part of the county where the top of this aquifer is closer to land surface, some wells may be open to both the Upper Floridan and Lower Floridan aquifers to increase well yields. In much of the county, however, the increased mineralization of water from the Lower Floridan aquifer has prevented it from becoming a source of water supply.

Moderate amounts of water are being withdrawn from surface-water sources, which are primarily used for agricultural irrigation. Surface-water withdrawals in the study area are largely from a network of canals augmented by groundwater and rainfall. Of the 153.93 Mgal/d of surface water withdrawn in 1975, 58.7 Mgal/d was used for agricultural irrigation with most of the remainder used for power generation. In 2005, a total of only 11.45 Mgal/d of surface water was withdrawn, of which 10.94 Mgal/d was used for agricultural irrigation (Marella, 2009).

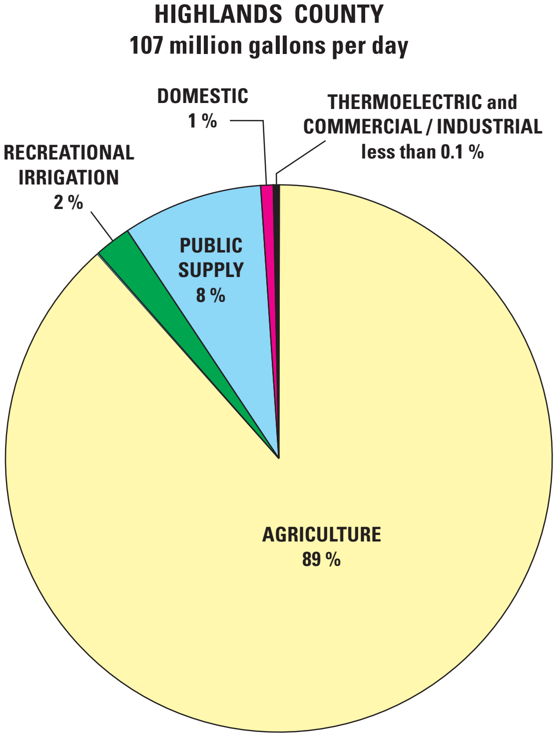


Figure 10. Total groundwater use, by category, for 2005. From Marella (2009).

Methods of Data Evaluation and Collection

This section describes the types of well records and the site numbering used in this report. In addition, the collection and analyses of geologic and geophysical-log, water-level, and water-quality data are discussed. Finally, the collection of quality-assurance samples is described.

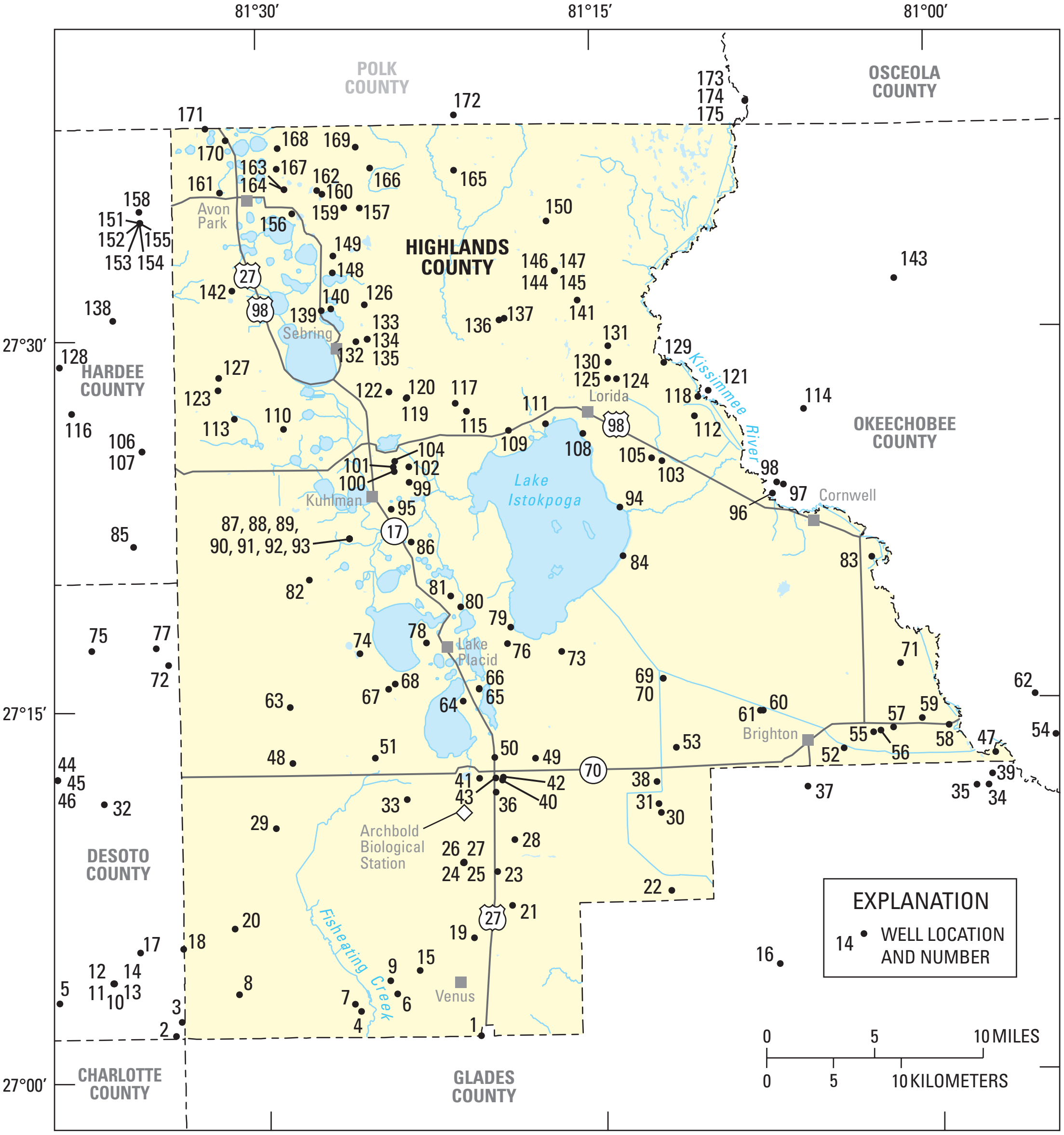
A network of monitoring wells was established for the collection of groundwater samples from the surficial aquifer, intermediate aquifer system/intermediate confining unit, and Upper Floridan aquifer. Data-collection sites were inventoried based on a review of wells and available water-quality data in the study area. Additional wells added to the inventory were obtained from well permits, well construction reports, and the files of the USGS. The locations of wells used for data collection, including wells used for the collection of water-quality data, are shown in figure 11.

Well Records and Site Identification

Well records in Highlands County are maintained by several government agencies. The USGS, SWFWMD, and SFWMD have computerized databases and paper files on wells that contain water-quality, water-level, geologic, hydrologic, geophysical-log, and water-use data. The USGS assigns a unique 15-digit number based on latitude and longitude that 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 (using three digits beginning with 0), minutes, and seconds of longitude; and the last two digits denote a sequential number to identify wells within a 1-second grid. For example, well 271114081122401 is the first well inventoried at latitude 27° 11′ 14″ N, longitude 081° 12′ 24″ W. Once assigned, a site identification number does not change even though the locations determined by latitude and longitude may be revised later.

The FGS keeps records of geologic data throughout the State, including more than 100 wells in Highlands County. Well data from the files of the FGS are identified using their “W” prefix followed by a number.

Information from selected wells used in this study is given in appendix 1. Wells included are completed in the surficial aquifer, intermediate aquifer system/intermediate confining unit, and Floridan aquifer system. Included in this appendix are the types of data collected during this study, well construction data, and general information about the wells. A map reference well number up to three digits is used to identify wells throughout this report.



Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 11. Location of wells used for data collection. Well numbers and information shown in appendix 1.

Geologic and Geophysical-Log Data Collection

Geologic and geophysical log data from about 240 wells were used to construct various hydrogeologic maps and sections of the surficial aquifer, the intermediate aquifer system/intermediate confining unit, and the Upper Floridan aquifer in the study area. This information was obtained from the files of the USGS, FGS, SFWMD, SWFWMD, and from published reports, including geophysical logs and lithologic descriptions of well cuttings by geologists and drillers. Because of the scarcity of geologists' logs and geophysical log data in some parts of the county, in some instances, drillers' logs were used to help construct the hydrogeologic maps. Caution was taken when using these data, and only drillers' logs with supporting geologic data were assumed to be reliable and were used.

Water-Level Data Collection

Water-level data from a network of wells distributed across Highlands and adjacent counties were used to construct generalized potentiometric surface maps of the Upper Floridan aquifer. Water-level data were collected semiannually from the monitoring well network in May and September 2007 to depict the seasonal changes in water-level distribution and groundwater-flow patterns in the Upper Floridan aquifer. Potentiometric surface maps of the Upper Floridan aquifer in northern and central Florida are published semiannually by the USGS in cooperation with the SFWMD, SJRWMD, SWFWMD, and other local agencies.

Water-Quality Data Collection and Analysis

Water samples were collected by the USGS and State agencies from 129 wells between 2000 and 2008 to characterize groundwater quality in the Highlands County area (apps. 2 and 3). Water-quality samples from 58 wells were collected specifically for this study by the USGS and analyzed for common inorganic constituents and nutrients, primarily during 2006–08. Additionally, water-quality data from 71 wells collected by the FDEP, SFWMD, SWFWMD, and Highlands County during 2000–08 were also used and presented in this report. Although most of the groundwater samples were collected in Highlands County, a few samples were also collected in adjacent DeSoto, Hardee, Glades, Okeechobee, and Polk Counties.

Water samples collected for this study were obtained from irrigation wells, public-supply wells, domestic wells, dedicated monitoring wells, and free-flowing wells. Most of the wells sampled were regularly used and equipped with permanently installed pumps. These wells were sampled after allowing the pump to run for about 10 minutes and after field properties had stabilized. Wells that had not been used recently were purged until at least three casing volumes of water were removed, and temperature, specific conductance, and pH had stabilized.

Water samples were collected following standard USGS protocol (Wilde, 2008). Field measurements of specific conductance, temperature, and pH were recorded at all well sites using a multiparameter sonde in a flow-through chamber. The flow-through chamber, which is closed to ambient air, prevents the exchange of carbon dioxide and oxygen between the collected water and the atmosphere. The loss of carbon dioxide from or the gain of oxygen to groundwater during field measurements can affect the pH and specific conductance values. Alkalinity was determined by titration with sulfuric acid using the incremental titration method.

Water samples were collected for laboratory analysis of major inorganic constituents and physical characteristics, trace metals, and nutrients. Major ions and other physical characteristics include calcium, magnesium, potassium, sodium, chloride, fluoride, sulfate, alkalinity, silica, water temperature, specific conductance, total dissolved solids, pH, and hardness (app. 2). Trace metals and nutrients include strontium, iron, ammonia as nitrogen (ammonia), nitrite as nitrogen (nitrite), nitrate plus nitrite as nitrogen (nitrate), total nitrogen, phosphorus, and orthophosphate as phosphorus (app. 3). In this report, the combined concentration of nitrite plus nitrate reported by the laboratory is referred to as “nitrate,” because nitrite generally was below the detection limits. A list of the constituents analyzed in groundwater in Highlands County and the analytical methods used are given in table 2.

Samples collected to determine analyses of major inorganic constituents and nutrients were filtered through a 0.45-µ pore-size disposable encapsulated filter. Cation and trace metal samples were collected in acid-washed polyethylene bottles and acidified with 2 mL of 4.5 N nitric acid to adjust the sample pH to less than 2. Nutrient samples were collected in a brown polyethylene bottle and packed in ice. All water samples were shipped to the USGS National Water-Quality Laboratory in Denver, Colorado.

Table 2. Analytical methods and drinking-water standards for inorganic analytes collected by the U.S. Geological Survey.

[Concentrations shown in milligrams per liter, except for iron and stronium which are in micrograms per liter. Method of analysis: C, colorimetry; G, residue evaporation at 180 degrees Celsius; °C, ion-exchange chromatography; ICP, induction-coupled argon plasma atomic emission spectrometry; ISE, ion-selective electrode; T, inflection-point titration. Drinking-water standards: MCL, maximum contaminant limit (Florida Primary Drinking Water Standards); SS, Florida Secondary Drinking Water Standards.

Constituent	Method of analysis[1]	Reporting limit[1,2]	Drinking water standards[3]
Alkalinity	T	5.0	None
Ammonia, as nitrogen	C	.02	None
Calcium	ICP	.04	None
Chloride	IC	.12	250 (SS)
Fluoride	ISE	.12	4.0 (MCL), 2.0 (SS)
Iron	ICP	8.0	300 (SS)
Magnesium	ICP	.02	None
Nitrate	C	.04	10 (MCL)
Nitrite	C	.002	1 (MCL)
Phosphorus	C	.006	None
Phosphorus, ortho, as phosphorus	C	.006	None
Potassium	ICP	.02	None
Silica	ICP	.02	None
Sodium	ICP	.12	160 (MCL)
Strontium	ICP	.4	None
Sulfate	IC	.18	250 (SS)
Total dissolved solids	G	10	500 (SS)

[1] Fishman and Friedman (1985) and U.S. Geological Survey (USGS) National Water Quality Laboratory, Denver, Colorado.

[2] Analytical reporting limits are for USGS National Water Quality Quality Laboratory, Denver, Colorado. Reporting limits for other laboratories may differ.

[3] Florida Department of Environmental Protection (2008).

Quality-Assurance Samples

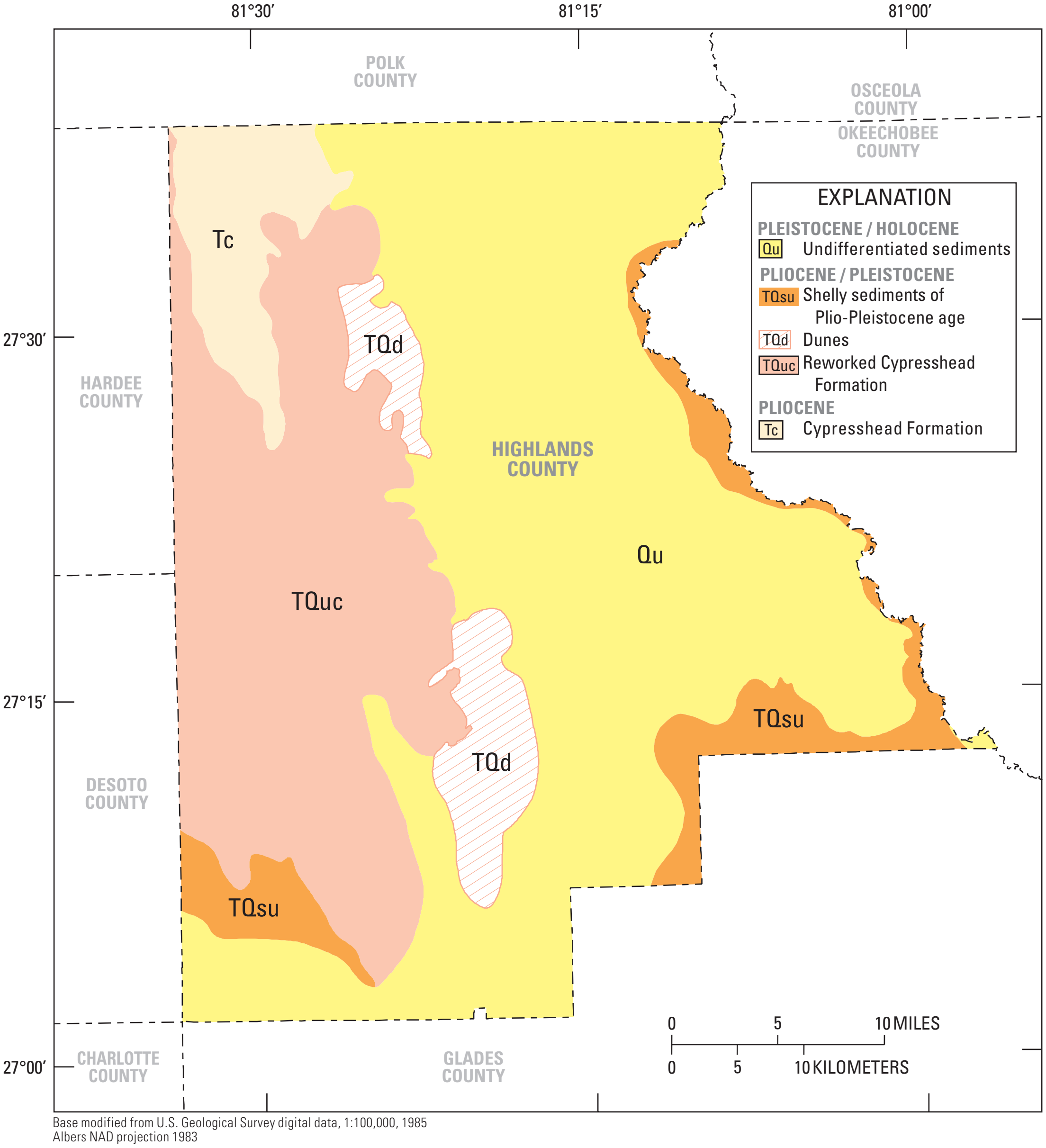
Quality-assurance samples were collected to ensure the integrity of water-quality samples. Analysis of quality-assurance samples provides information about the potential for sample contamination during collection, processing, and laboratory analysis. Quality assurance for water samples included replicate groundwater samples and field equipment blank samples. Replicate samples consist of two or more sets of samples collected concurrently so that both samples are assumed to have identical chemical compositions. Replicate samples were used to measure variability and precision characteristics associated with sampling and analytical procedures. Field equipment blanks provide information on possible contamination introduced to the sample during cleaning, collection, and processing of the sample in the field (Francy and others, 2005). About 10 percent of the water samples collected during this study was quality-assurance samples consisting of both equipment blanks and replicate samples.

Geologic Framework

Highlands County is underlain by sediments of Cenozoic age to a depth of about 5,000 ft below land surface (Bishop, 1956; Chen, 1965). These sediments consist primarily of sand, clay, phosphate grains, carbonates (limestone and dolostone), and evaporites (gypsum and anhydrite). Geologic units corresponding to these sediments, 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. 12). All of the geologic units that are exposed (crop out) at the surface are composed of unconsolidated siliciclastic sediments of Pliocene to Holocene age (fig. 13).

<table>
<tr><th>SERIES</th><th colspan="2">STRATIGRAPHIC UNIT</th><th>GEOLOGY AND LITHOLOGY</th><th colspan="3">HYDROGEOLOGIC UNIT</th></tr>
<tr><td>Holocene and Pleistocene</td><td colspan="2" rowspan="4">Undifferentiated surficial deposits
Cypresshead Formation</td><td rowspan="2">Sand</td><td colspan="3" rowspan="3">Surficial aquifer</td></tr>
<tr><td rowspan="3">Pliocene</td></tr>
<tr><td rowspan="2">Sand, clay</td></tr>
<tr><td rowspan="7">Intermediate aquifer system or Intermediate confining unit</td><td colspan="2" rowspan="2">Confining unit</td></tr>
<tr><td rowspan="6">Miocene</td><td rowspan="6">Hawthorn Group</td><td rowspan="2">Peace River Formation</td><td rowspan="6">Phosphate, clay, sand, limestone, and dolostone</td></tr>
<tr><td colspan="2" rowspan="2">upper Arcadia aquifer (Zone 2)</td></tr>
<tr><td rowspan="3">Arcadia Formation</td></tr>
<tr><td colspan="2">Confining unit</td></tr>
<tr><td colspan="2">lower Arcadia aquifer (Zone 3)</td></tr>
<tr><td>Nocatee Member</td><td colspan="2">Confining unit</td></tr>
<tr><td>Oligocene</td><td colspan="2">Suwannee Limestone</td><td rowspan="3">Limestone and dolostone</td><td rowspan="5">Floridan aquifer system</td><td rowspan="3">Upper Floridan aquifer</td><td>Upper permeable zone</td></tr>
<tr><td rowspan="4">Eocene</td><td colspan="2">Ocala Limestone</td><td>Semi-confining unit</td></tr>
<tr><td colspan="2" rowspan="2">Avon Park Formation</td><td>Lower permeable zone (Avon Park permeable zone)</td></tr>
<tr><td rowspan="2">Limestone and dolostone with some intervals containing inclusions of gypsum and anhydrite</td><td colspan="2">Middle confining units I, II, and/or VI</td></tr>
<tr><td colspan="2">Oldsmar Formation</td><td>Lower Floridan aquifer</td><td>Boulder Zone</td></tr>
<tr><td>Paleocene</td><td colspan="2">Cedar Keys Formation</td><td>Limestone and dolostone with beds of gypsum and anhydrite</td><td colspan="3">Sub-Floridan confining unit</td></tr>
</table>

Figure 12. Relation of stratigraphic and hydrogeologic units. Modified from Spechler and Kroening (2007).



Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 13. Geologic map of Highlands County. From Scott and others (2001).

Some differences are present between the geologic nomenclature used in earlier water-resource assessments of Highlands (Bishop, 1956) and adjacent counties (Pride and others, 1966; Stewart, 1966; Wilson, 1977) and those used in this report. 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, the term Lake City Limestone was abandoned, and all of the lithologic units within the Lake City Limestone were reclassified as Avon Park Limestone. Miller (1986) also renamed the unit the Avon Park Formation, because it contained appreciable amounts of rock types other than limestone. The Ocala Group, which included the Inglis, Williston, and Crystal River Formations, is 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). Two formations were introduced to the Hawthorn Group (Scott, 1988)—the Arcadia Formation and the Peace River Formation. Two members were named in the Arcadia Formation—the Tampa Member and Nocatee Member.

Stratigraphy

The basal Tertiary unit within the study area is the Cedar Keys Formation of late Paleocene age (fig. 12). It consists primarily of dolomite and evaporites with minor amounts of limestone (Chen, 1965). The evaporites are present as thick massive beds in the lower part of the formation and generally decrease toward the top of the formation. The Cedar Keys Formation has very low permeability and, thus, functions as the sub-Floridan confining unit at the base of the Floridan aquifer system. The top of the Cedar Keys Formation is about 2,900 to 3,550 ft below NGVD 29 in Highlands County (Miller, 1986) and has a thickness of about 1,600 ft (Chen, 1965). Conformably overlying the Cedar Keys Formation is the Oldsmar Formation of Eocene age. The Oldsmar Formation consists of a sequence of white to gray, micritic limestone and interbedded tan to light-brown crystalline dolomite. Thin beds of chert and evaporites are present within the unit (Miller, 1986). The top of the Oldsmar Formation is about 1,800 to 2,200 ft below NGVD 29 in Highlands County (Miller, 1986).

The middle Eocene Avon Park Formation, a thick sequence of marine limestone and dolostone, conformably overlies the Oldsmar Formation. The limestone is generally tan to light brown, poorly to well indurated, fossiliferous, skeletal wackestone, grainstone, or packstone with minor mudstone. Porosity is primarily intergranular (Arthur and others, 2008). The limestone can be interbedded with dark-brown to tan, very fine- to coarse-grained, vuggy, fossiliferous dolostone. Thick intervals containing primarily dolostone, but in some places interbedded with limestone, are commonly present in the middle to lower Avon Park Formation. The Avon Park Formation typically contains a zone that is highly fractured, particularly in the dolomitic units. This zone is highly transmissive and produces some of the highest volumes of water from the Upper Floridan aquifer. Gypsum and anhydrite also are present in the lower parts of the formation, either as bedded deposits or as nodules, intergranular or pore-filling material in the carbonate rocks. Foraminifera characteristic of the Avon Park Formation are the cone-shaped *Dictyoconus* sp. The top of the Avon Park Formation ranges from about 450 ft below NGVD 29 in the northeastern part of the county to about 950 ft below NGVD 29 in the southern part (Arthur and others, 2008). The thickness of the formation ranges from about 1,200 to 1,400 ft (Miller, 1986).

An erosional unconformity separates the Avon Park Formation from the overlying Ocala Limestone of late Eocene age (Stewart, 1966). The Ocala Limestone consists primarily of white to cream, soft, poorly consolidated, fossiliferous, carbonate mud-rich limestone. Two principal lithofacies are present within the Ocala Limestone, as described by Ward and others (2003): (1) large benthic foraminiferal (*Nummulities* and *Lepidocyclina*) wackestone with a soft micritic matrix; and (2) poorly indurated, large benthic-foraminiferal, mud-dominated packstone. Other fossils in these lithofacies include planktic foraminifera, small benthic foraminifera, bivalves, echinoids, bryozoans, ostracodes, and planktic crinoids (Ward and others, 2003). The top of the Ocala Limestone ranges from about 300 ft below NGVD 29 in the northwestern part of the county to about 675 ft below NGVD 29 in the extreme southwestern part (Arthur and others, 2008). The thickness of the formation is relatively uniform, ranging from 300 to 400 ft (Arthur and others, 2008).

Unconformably overlying the Ocala Limestone is the Suwannee Limestone of early Oligocene age. The limestone is white to tan, poorly to well indurated, mostly soft, fossiliferous grainstone, packstone, and wackestone. The formation locally contains dolomitized or silicified zones and may contain small amounts of fine-grained quartz sand (Stewart, 1966). Porosity is variably moldic and intergranular. The Suwannee Limestone has undergone extensive erosion and is absent in much of the eastern part of the county. Where present, the thickness of the formation ranges from less than 50 ft to about 150 ft (Arthur and others, 2008). The top of the Suwannee Limestone ranges from about 200 ft below NGVD 29 in the northwestern part of the county to about 600 ft below NGVD 29 in the southwestern part (Arthur and others, 2008).

Unconformably overlying the Suwannee Limestone is the Hawthorn Group of late Oligocene to Miocene age (Scott and others, 2001). The Hawthorn Group generally consists of phosphatic siliciclastics and carbonates that range in thickness from about 150 to 600 ft across the study area (Arthur and others, 2008). The high phosphate and clay content results in intervals of high activity on natural gamma ray logs that are characteristic of the Hawthorn Group. In Highlands County, the Hawthorn Group consists of two formations—the Arcadia Formation, which includes the Nocatee Member, and the overlying Peace River Formation. The Tampa Member of the Arcadia Formation and the Bone Valley Member of the Peace River Formation are absent in Highlands County, but present in adjacent Polk and Hardee Counties.

The Arcadia Formation is composed of limestone and dolostone containing varying amounts of quartz sand, clay, and phosphate grains. Although limestone is present, dolostones are most common. Thin beds of quartz sand and clay are scattered throughout the section. Phosphate concentrations are highly variable, ranging from 10 to 25 percent (Scott, 1988). The porosity of this unit is generally intergranular and moldic. The top of the Arcadia Formation ranges from about 50 ft to 270 ft below NGVD 29, and the thickness of this unit ranges from about 150 to 450 ft (Scott, 1988; Arthur and others, 2008).

The lowermost sediments of the Arcadia Formation form the Nocatee Member. The Nocatee Member is a predominantly siliciclastic unit containing an interbedded sequence of quartz sands, clays, and carbonates all containing variable amounts of phosphate (Scott, 1988). Phosphate concentrations are variable, ranging from about 1 to 10 percent (Scott, 1988). Clay beds are common. The unit is absent in parts of eastern Highland County. Where present, the top of the Nocatee Member ranges from about 150 ft to more than 525 ft below NGVD 29 (Arthur and others, 2008). The thickness of the unit ranges from about 50 ft to more than 100 ft.

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 are the predominant lithology in this unit, composing more than two-thirds of the formation (Scott, 1988); however, carbonate bed occurrence increases with depth. The Peace River Formation is present throughout all of Highlands County. The top of the unit generally ranges from about 25 ft above to 200 ft below NGVD 29 (Arthur and others, 2008). The thickness of the unit ranges from about 60 to 120 ft (Arthur and others, 2008).

Overlying the Hawthorn Group are the undifferentiated clastic (surficial) deposits of Pliocene to Holocene age, which include the Cypresshead Formation (fig. 12). The undifferentiated surficial deposits consist of varying percentages of sand, clay, and shell. The upper part of this unit is composed of unconsolidated, fine to medium-grained quartz sand with minor organic material. The lower unit contains sand and some shell fragments intermixed with clay layers. These deposits are present throughout all of Highlands County and reach their maximum thickness of more than 300 ft under the Lake Wales Ridge.

Sinkholes

Sinkholes are a common topographic feature in the study area and exist as closed depressions in the land surface formed by dissolution of underlying rocks or by the collapse of the roofs of underground caverns. Sinkholes typically develop in areas where groundwater recharge rates are relatively high and where the overlying siliciclastic sediments are relatively thin or permeable. Although sinkholes in all stages of development are present in Highlands County, most occur along the Lake Wales Ridge, and range from small depressions to large lakes. The locations of sinkholes and depressions in Highlands County are shown in figure 14. These features, which were delineated from USGS topographic maps, include lakes, ponds, and topographic depressions, as well as manmade features.

Along much of the Lake Wales Ridge, lakes commonly occupy the depressions created by sinkhole collapse. Some of the smaller lakes are the result of a single sinkhole, whereas others are a coalescent group of smaller sinks. Continuous high-resolution seismic-reflection surveys of lakes on the Lake Wales Ridge indicate that many of these lakes probably were formed by subsidence (Lee and others, 1991; Evans and others, 1994; Tihansky and others, 1996; Sacks and others, 1998).

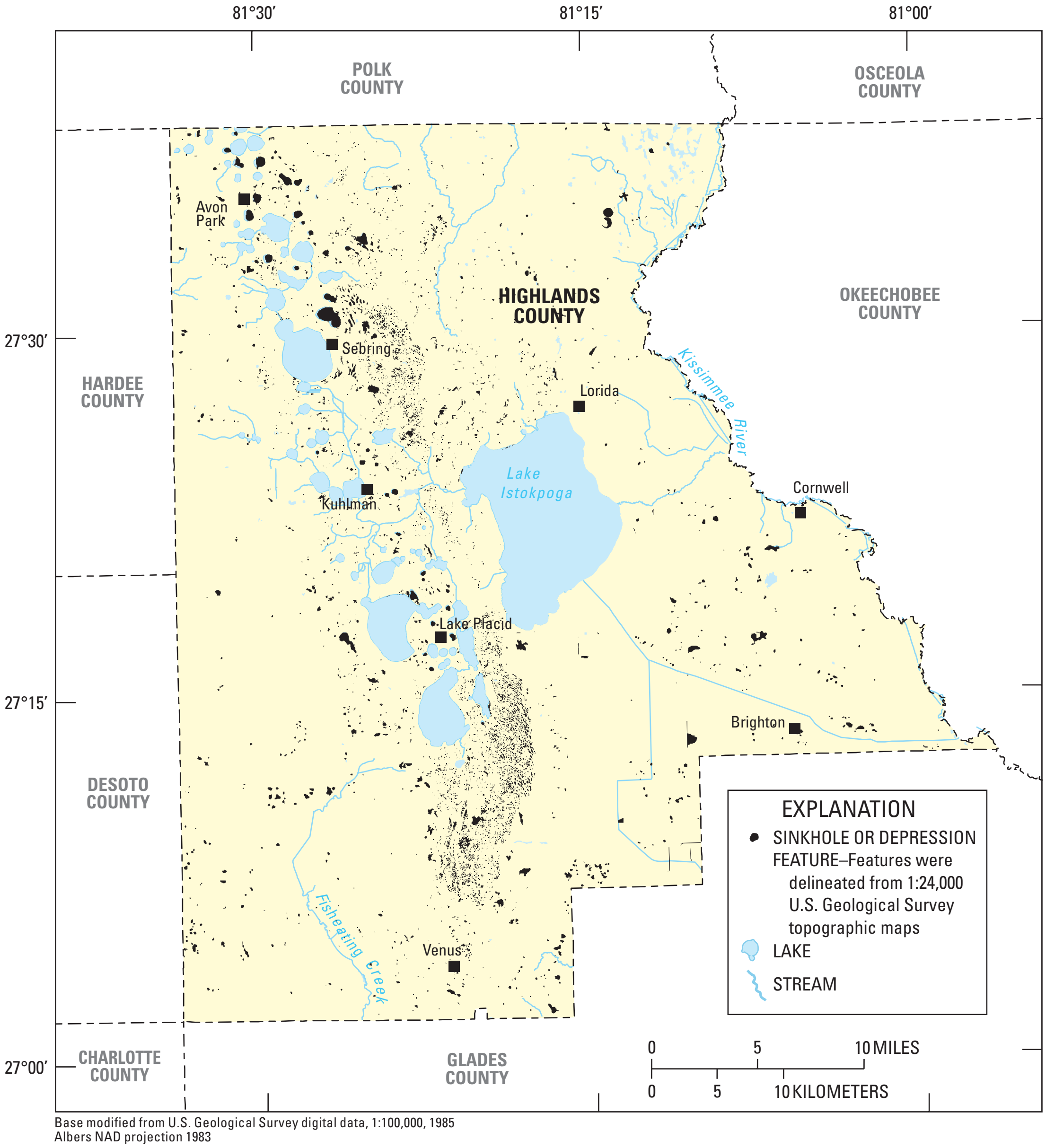
Sinkholes can form a direct connection from land surface to the underlying aquifers, allowing surface water to move directly into the aquifers. Although the bottoms of some of these sinkhole lakes have accumulated substantial organic-rich deposits with relatively low permeability (Geraghty and Miller, 1980; Tihansky and others, 1996), most of the lakes have sandy bottoms with relatively high permeability and provide a good hydraulic connection to the underlying aquifers (Geraghty and Miller, 1980).

The dissolution of carbonate rocks by acidic water is the cause of the collapse or subsidence that creates sinkholes. As rain falls through the atmosphere, it absorbs some carbon dioxide and other gases and becomes slightly acidic. Additional carbon dioxide is absorbed as rainwater percolates through the soil and reacts with decaying vegetation, becoming a weak carbonic acid. This water passes through insoluble sediments until it reaches the underlying carbonate rocks. Dissolution of rocks is enhanced where the flow of water is concentrated. The most common features that concentrate the downward flow of water are along fractures or joints. These small solution openings slowly become larger as more of the acidic water moves through the aquifer. Over a long period of time, the enlarged spaces eventually form a network of caves, pipes, and other types of conduits, all of which collect and channel large volumes of groundwater. As solution caverns enlarge, their roofs in some instances cannot support the overlying sediment and collapse, forming a sinkhole. Sinkholes form slowly and expand gradually under natural conditions; however, sinkholes can expand more rapidly in areas of heavy groundwater withdrawals.

The type and frequency of sinkhole subsidence activity depend on the composition and thickness of overburden materials, the degree of solution within the underlying carbonate rocks, and local hydrologic conditions (Tihansky, 1999). Three general types of sinkholes occur:

- Dissolution sinkhole depressions in the limestone surface caused by chemical erosion of limestone;
- Cover subsidence sinkholes formed as overburden materials gradually infill subsurface cavities; and
- Cover-collapse sinkholes, also formed by movement of cover material into subsurface voids, but characteristically forming abruptly (Tihansky, 1999).

The latter two types, according to Sinclair and Stewart (1985), generally are present in Highlands County where there is a thick clastic unit overlying the limestone.

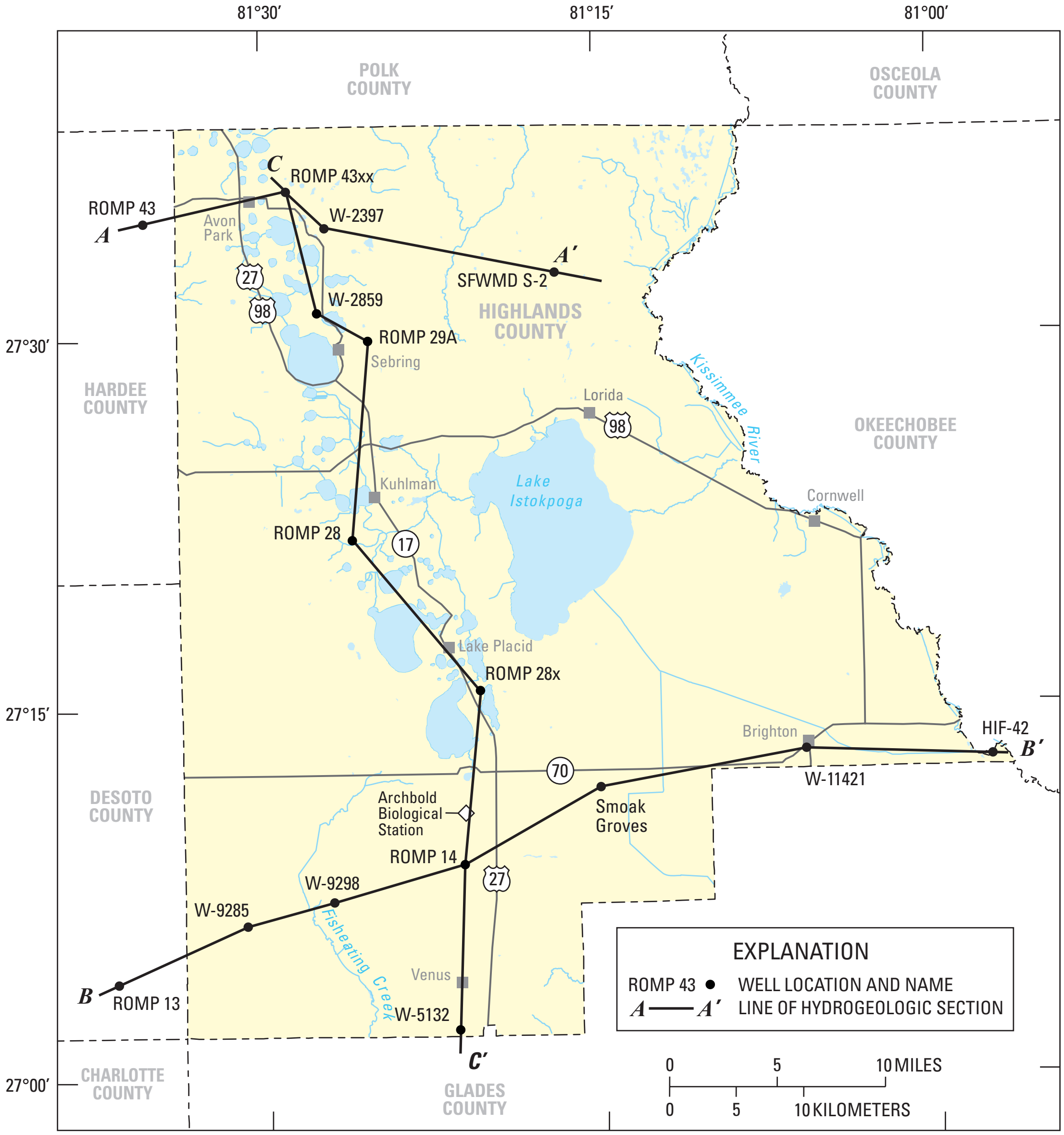


Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

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

Hydrogeology

The hydrogeologic system in Highlands County consists of a thick sequence of sedimentary rocks that include sands, clays, and carbonates. These lithostratigraphic units form a multilayered sequence of aquifers and confining units. Three hydrogeologic units present in Highlands County, in order of increasing depth, are the surficial aquifer, the intermediate aquifer system/intermediate confining unit (IAS/ICU), and the Floridan aquifer system. The surficial aquifer is the uppermost water-bearing unit and underlies all of Highlands County. The IAS/ICU, which contains sediments of lower permeability, restricts the movement of water between the overlying and underlying aquifers. The Floridan aquifer system consists of the Upper Floridan aquifer and Lower Floridan aquifer, which are separated by less-permeable middle confining units I, II, and/or VI (Miller, 1986). The base of the Floridan aquifer system is marked by low-permeability limestone and dolostone that contain considerable gypsum and anhydrite of the upper Cedar Keys Formation. Variations in the distribution, thickness, and dip of the hydrogeologic units based on geophysical and geologic logs (locations shown in fig. 15) are depicted in three generalized hydrogeologic sections shown in figures 16 and 17. Stratigraphic units, general lithology, and corresponding hydrogeologic units underlying Highlands County are shown in figure 12.



Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
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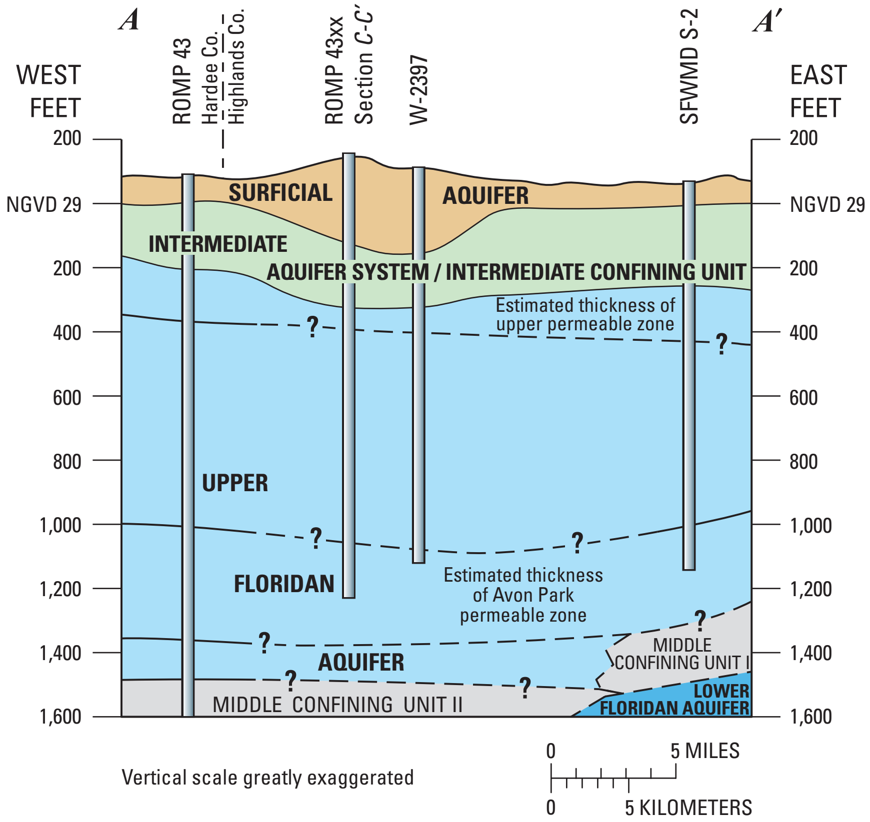
Figure 15. Location of hydrogeologic sections.

Surficial Aquifer

The sediments that compose the surficial aquifer range from Pliocene to Holocene in age and are contiguous with land surface. Groundwater in the surficial aquifer is under unconfined or water-table conditions. The surficial aquifer is composed primarily of fine-to-medium grained quartz sand that grades with depth to silty and clayey sands. In this study, the base of the surficial aquifer is defined as the first persistent bed of Pliocene-age sediments containing a substantial increase in clay or silt. The hydrogeologic term, "surficial aquifer system" is generally used in referring to this aquifer in Florida (Southeastern Geological Society Ad Hoc Committee on Hydrostratigraphic Unit Definition, 1986). However, because in Highlands County there is just one permeable unit and no confining unit present, the term "surficial aquifer" is used here. This aquifer has also been referred to as "water table aquifer" or "nonartesian aquifer" in earlier reports.

A generalized contour map of the thickness of the surficial aquifer in Highlands County is shown in figure 18, which includes both saturated and unsaturated undifferentiated sediments. The thickness of the surficial aquifer is highly variable, ranging from less than 50 to more than 300 ft. In much of eastern, west-central, and extreme southwestern Highlands County, the thickness of the surficial aquifer generally ranges from about 50 to 100 ft. At a few locations within the county, however, the thicknesses of these sediments are less than 50 ft.



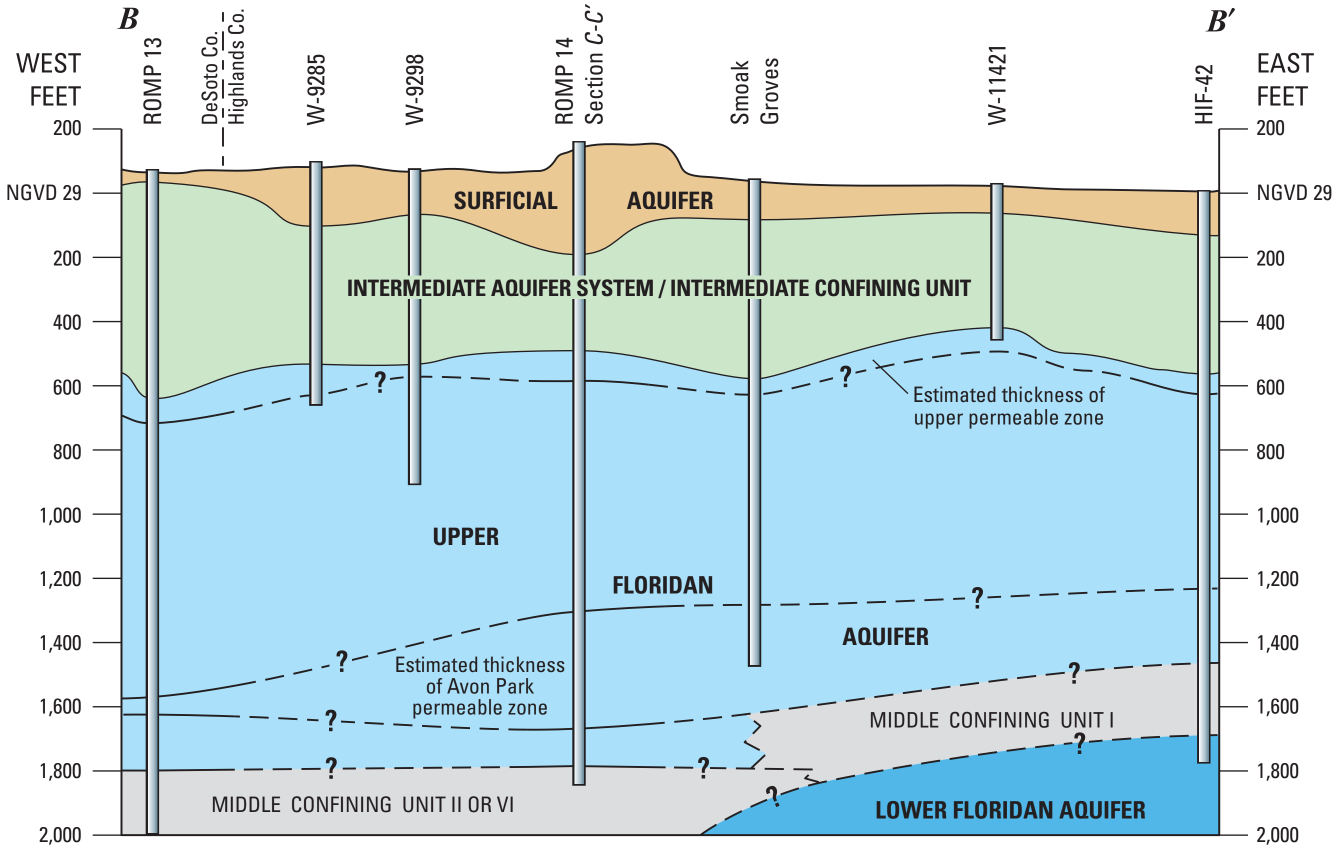


Figure 16. Generalized hydrogeologic sections *A–A′* and *B–B′*. Section lines shown in figure 15.

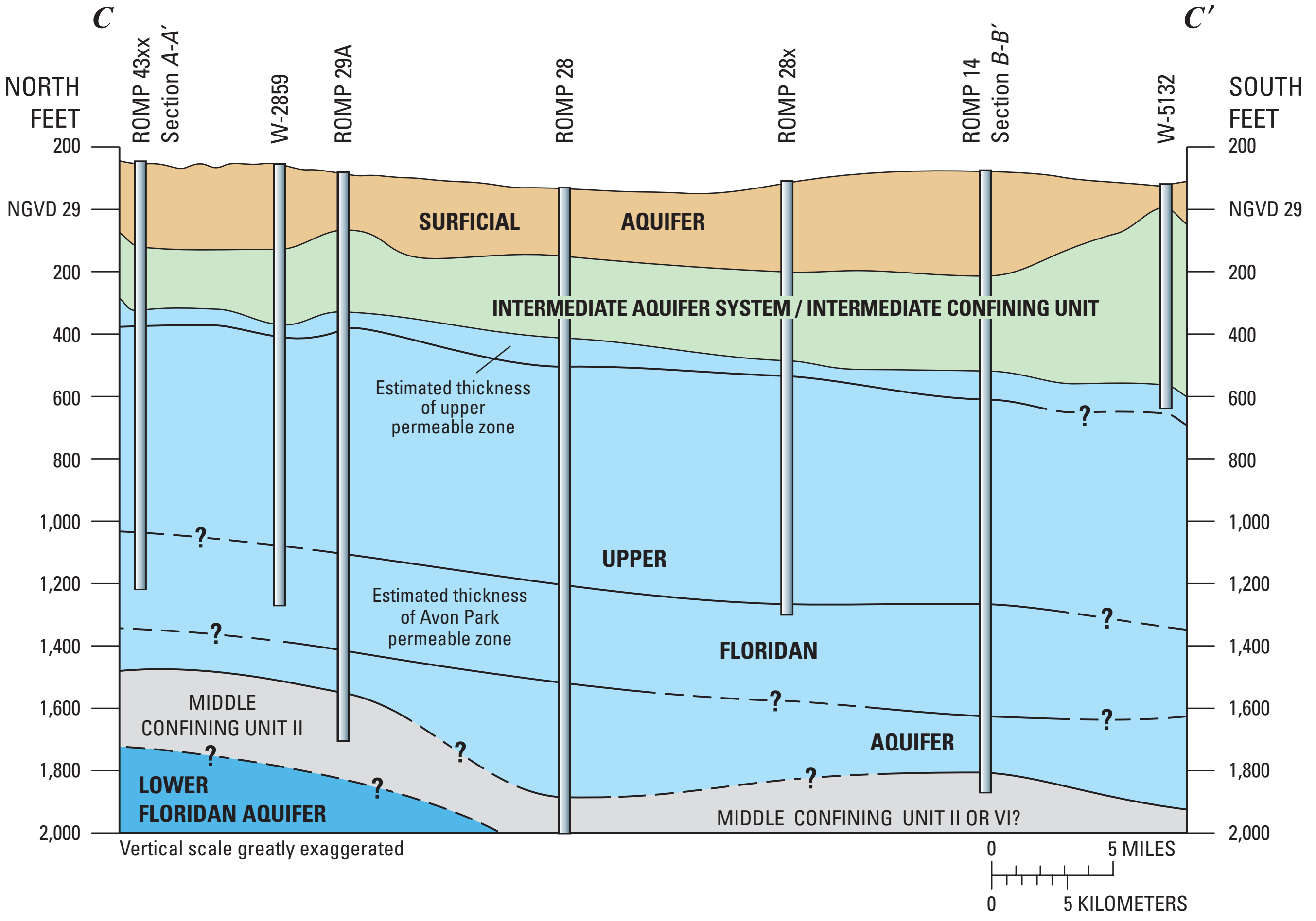
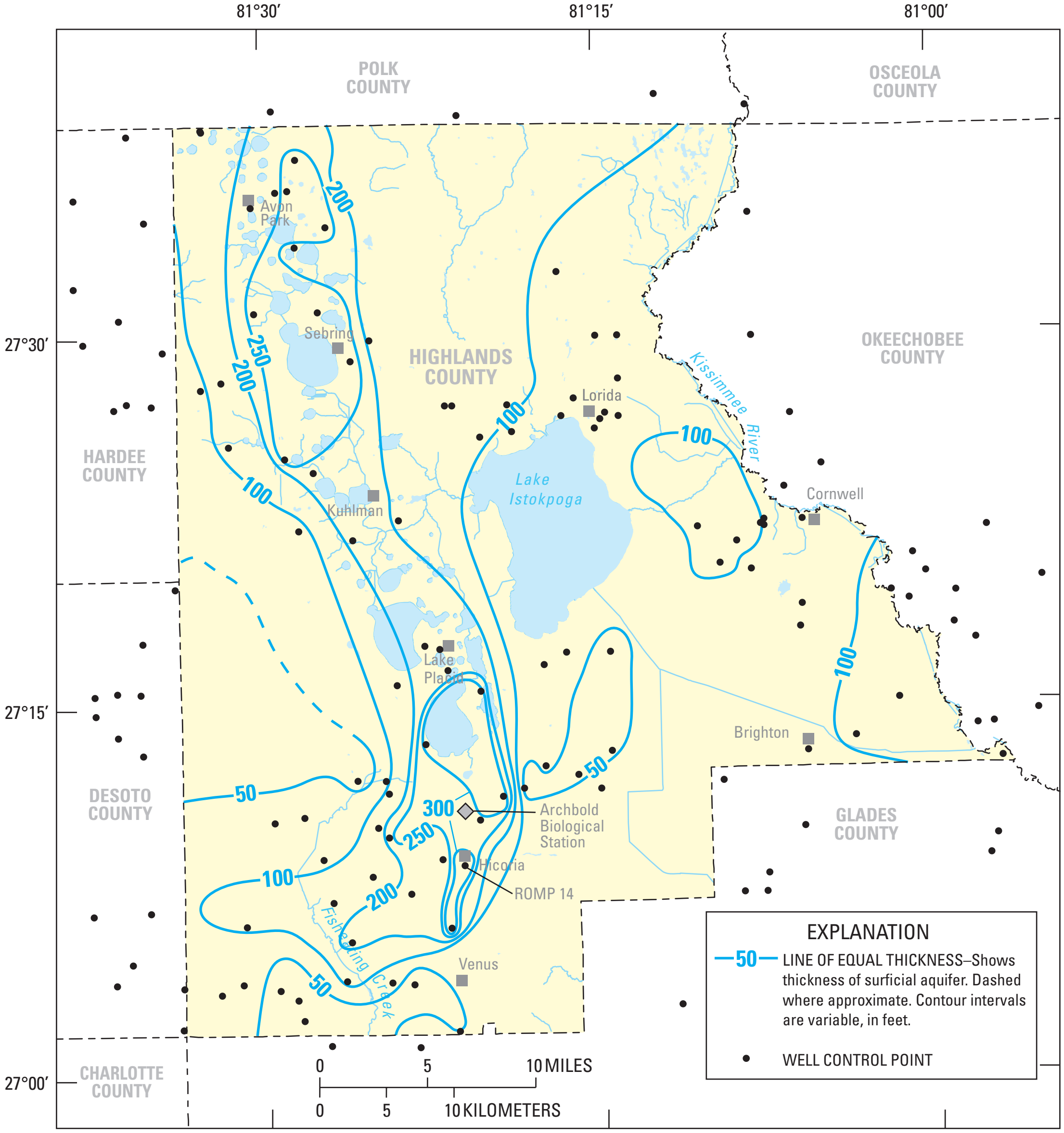


Figure 17. Generalized hydrogeologic section *C–C′*. Section line shown in figure 15.

The surficial aquifer is thickest along the Lake Wales Ridge, especially near the southernmost part of the county. At well ROMP 14, located near Hicoria, the surficial aquifer is about 350 ft thick (Clayton, 1998).

The hydraulic properties of the surficial aquifer vary considerably and are largely dependent upon aquifer thickness, physical characteristics (such as grain-size and sorting), and the types of material that compose the aquifer. Few data are available on the hydraulic characteristics of the surficial aquifer in Highlands County. Transmissivity estimates from four wells in the county range from 2,400 to 16,300 ft^2/d (Clayton, 1998; DeWitt, 1998; Baldini and Ruppuhn, 1999; Southwest Florida Water Management District, 2000; and Mallams and Lee, 2005) (fig. 19). However, all four wells are located on the Lake Wales Ridge where the aquifer is thick and transmissivities are generally high. Transmissivity values range from 8 to 2,400 ft^2/d in Polk County (Spechler and Kroening, 2007) and from 14 to 5,300 ft^2/d in Hardee and DeSoto Counties (Seaburn and Robertson, 1979; Southwest Florida Water Management District, 2000; LaRoche, 2007). Horizontal hydraulic conductivity values from three ROMP (Regional Observation and Monitoring-Well Program) wells in Highlands County range from 35 to 58 ft/d (Clayton, 1998; DeWitt, 1998; Mallams and Lee, 2005). Horizontal hydraulic conductivities determined for 20 wells along the Kissimmee River in both Highlands and Okeechobee Counties range from 0.8 to 27 ft/d (Jose Valdes, South Florida Water Management District, written commun., 2007). Horizontal hydraulic conductivity values from six wells in Polk County range from 0.3 to 55 ft/d (Southwest Florida Water Management District, 2000). Additional horizontal hydraulic conductivity values reported for wells in adjacent Hardee and DeSoto Counties range from about 1 to 102 ft/d (Southwest Florida Water Management District, 2000; LaRoche, 2007).

The altitude of the water levels in wells open to the surficial aquifer represents the water-table level. The water table is not a flat surface, but instead, a sloping surface that may resemble hills and valleys similar to land surface. The depth below land surface to the water table in the surficial aquifer varies from one physiographic region to another. In upland areas, the water table generally is a subdued reflection of land-surface topography. Depths ranging from 10 to 40 ft



Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 18. Generalized thickness of the surficial aquifer.

are common, but can exceed 50 ft below land surface along some parts of the Lake Wales Ridge in Highlands County. In the low-lying, poorly drained areas, the water table generally is at or within a few feet of the land surface.

The altitude of the water table fluctuates in response to the net rate at which water in the surficial aquifer is recharged or discharged. The principal factors controlling the rate and magnitude of fluctuations in water levels are related to changes in precipitation, evapotranspiration, and local and regional pumping from the surficial aquifer, and to a lesser degree, groundwater withdrawals from the intermediate and Floridan aquifer systems. Groundwater levels in the surficial aquifer fluctuate seasonally and generally reach an annual maximum in September or October (near the end of the wet season) and decline to a minimum in April or May (near the end of the dry season). Spring water levels usually are lower than fall water levels because only about 30 percent of the total yearly rainfall occurs from November through April. Seasonal recharge by infiltration of precipitation causes water levels to rise in the summer months when rainfall totals are normal or above normal. Drier climatic conditions cause water levels to decline within a relatively short period of time following seasonal-high water levels in the summer. Although the magnitude of the water-level fluctuation in wells varies across the county, hydrographs show seasonal fluctuations of water levels ranging from about 1 to 5 ft (fig. 20).

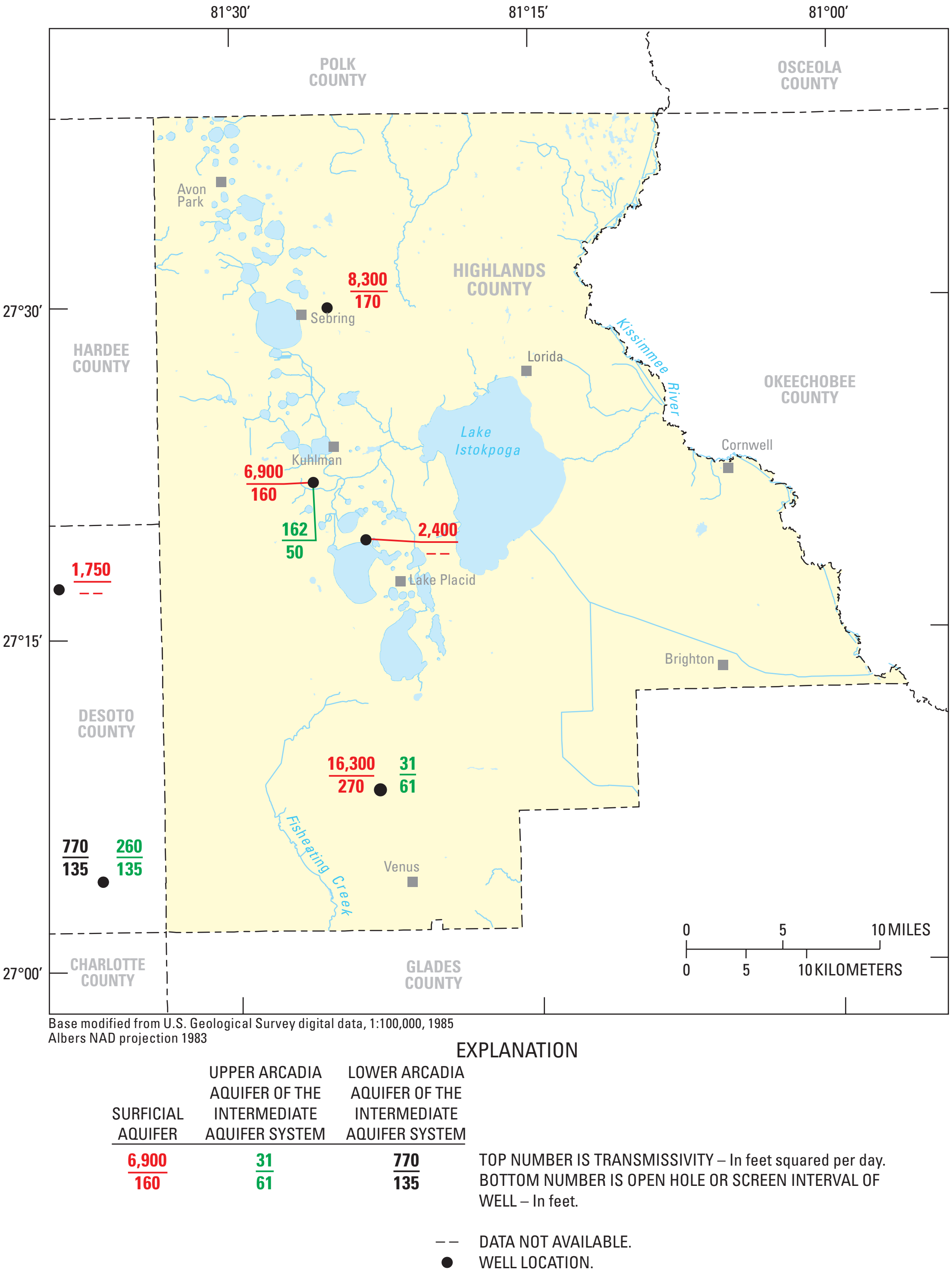


Figure 19. Transmissivity of the surficial aquifer and intermediate aquifer system. From Clayton (1998), DeWitt (1998), Baldini and Ruppuhn (1999), Southwest Florida Water Management District (2000), and Mallams and Lee (2005).

The water level fluctuations shown in figure 20 include rising and declining trends over short periods of time; however, as indicated by the LOWESS smoothing curves, no substantial long-term declining trends are evident. This lack of trends indicates that, at least over the periods of record shown in figure 20, precipitation received during the summer rains has been able to replenish the water being discharged from the surficial aquifer in drier months, resulting in negligible changes in aquifer storage.

The surficial aquifer is an important component of the groundwater system because it provides temporary storage for infiltrating water that eventually percolates down to the underlying aquifers or moves laterally to discharge areas. In Highlands County, the area of highest recharge is along the Lake Wales Ridge, which is characterized by poorly developed stream drainage and many closed depressions. The thick permeable deposits of sand along the Lake Wales Ridge provide rapid infiltration and absorb much of the rainfall not

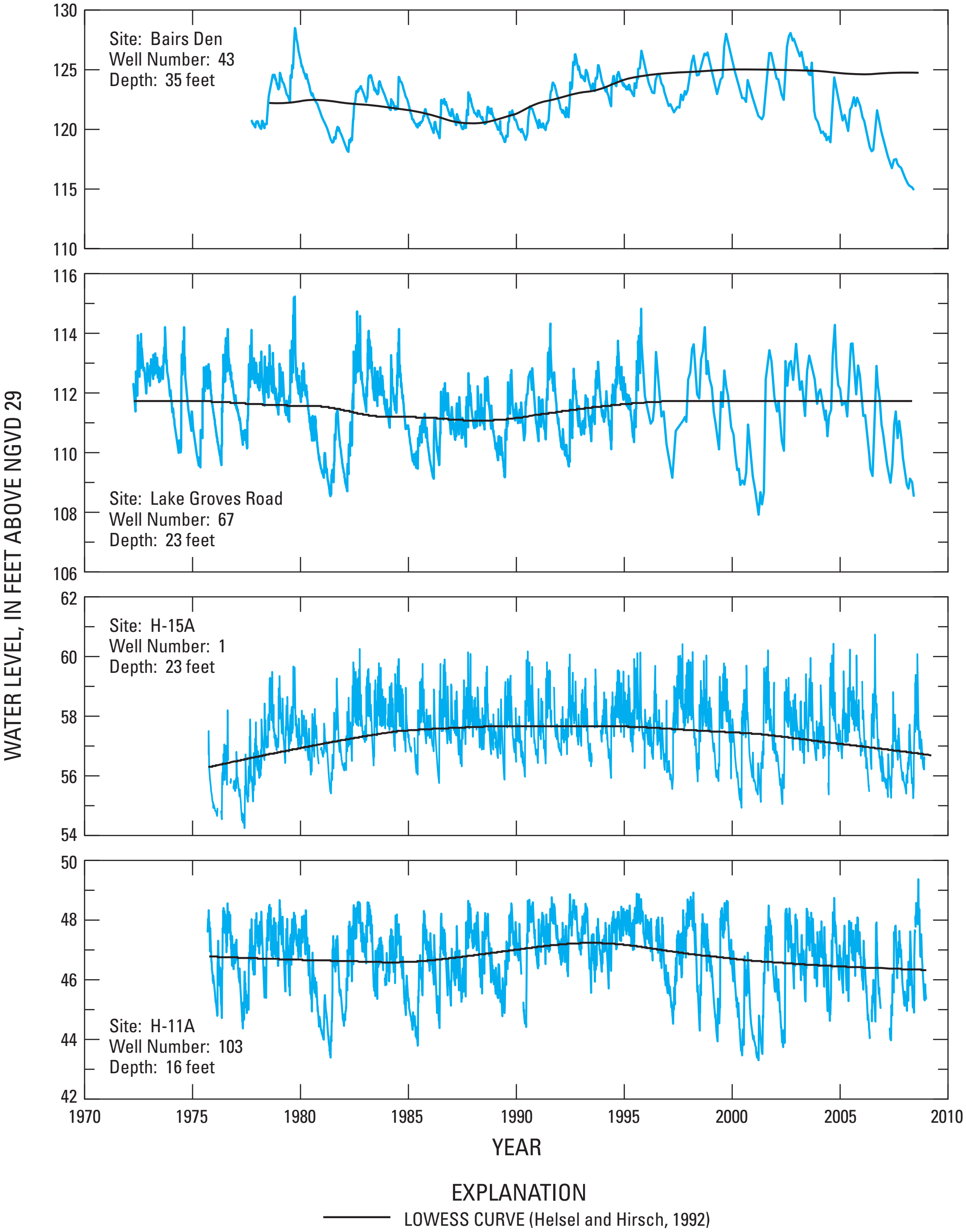


Figure 20. Water levels in selected wells completed in the surficial aquifer. Well locations shown in figure 11.

lost to evapotranspiration. Recharge to the underlying Upper Floridan aquifer takes place where the confining beds are thin or permeable or where they have been breached by sinkholes. The rate of leakage is dependent on the hydraulic gradient between the surficial and Upper Floridan aquifers, as well as on the vertical hydraulic conductivity and thickness of the IAS/ICU.

Recharge to the surficial aquifer occurs primarily through the infiltration of rainfall. Other sources of recharge include septic-tank effluent, irrigation of agricultural land or residential areas, seepage from lakes and streams, and the lateral groundwater inflow from adjacent areas. Recharge can also occur by upward leakage of water from the underlying Upper Floridan aquifer where water levels are higher than in the surficial aquifer. However, in the eastern part of the county where these conditions are present, the actual rate of recharge to the surficial aquifer may be low because the IAS/ICU that separates the surficial aquifer and Upper Floridan aquifer is thick and generally has low permeability, thereby limiting upward leakage. In such areas, rainfall can still recharge the surficial aquifer as long as the surficial sediments are unsaturated.

Water is discharged from the surficial aquifer primarily by evapotranspiration in areas where the water table is relatively shallow. Some discharge also occurs by: (1) withdrawals from wells; (2) lateral flow to lakes, streams, canals, and marshes; and (3) downward leakage through sinkholes and the confining layer to the Upper Floridan aquifer in areas where the potentiometric surface of this aquifer is below the water table.

The surficial aquifer is not a substantial source of water supply in the study area. In 2005, about 9.6 Mgal/d, or about 9 percent of the total groundwater used in Highlands County, was withdrawn from the surficial aquifer (M. Beach, Southwest Florida Water Management District, written commun., 2009). In areas where there are citrus groves, or in areas where septic tanks are common, water in the surficial aquifer can have elevated concentrations above background levels of nutrients, pesticides, or bacteria. In addition, the water can contain high concentrations of dissolved iron, which is an undesirable impurity in domestic and industrial supplies. Lawn irrigation and, in some areas, domestic supply are the main uses of water from the surficial aquifer. Water from the surficial aquifer is also used to irrigate citrus groves (Adams and Stoker, 1985; Barcelo and others, 1990; Yobbi, 1996). However, to obtain larger yields, irrigation wells are often drilled into the deeper parts of the Upper Floridan aquifer.

Well yields depend on the thickness and permeability of the surficial aquifer and generally range from about 10 to several hundred gallons per minute. The lower yields are from small diameter wells or from wells that are open to fine sand or clayey layers. The higher yields are from larger diameter wells that are open to thick layers of permeable coarse sand, such as present along the Lake Wales Ridge. A yield of about 900 gal/min was obtained from a 300-ft deep surficial aquifer well during an aquifer performance test at the ROMP 14 well near Hicoria (Clayton, 1998). The 12-inch monitoring well was screened from 30 to 300 ft below land surface.

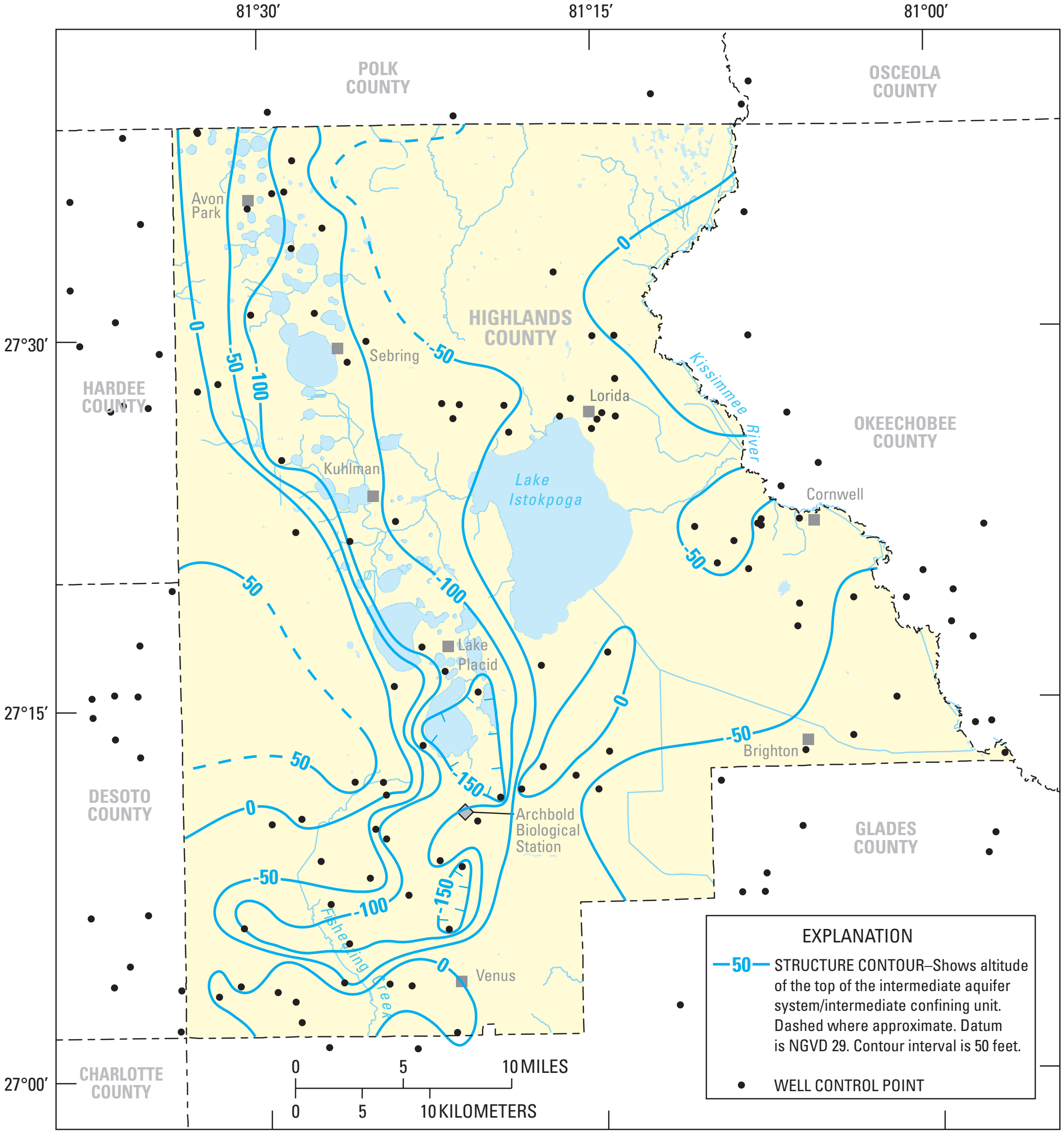
Intermediate Aquifer System/Intermediate Confining Unit

The intermediate aquifer system/intermediate confining unit (IAS/ICU) includes all of the rock units that lie between the overlying surficial aquifer and the underlying Floridan aquifer system (Southeastern Geological Society Ad Hoc Committee on Hydrostratigraphic Unit Definition, 1986). The IAS/ICU generally coincides with the stratigraphic units designated as the Hawthorn Group, although the top of the unit can also include the clayey sediments of early Pliocene age (fig. 12). Throughout Highlands County, IAS/ICU acts as a confining layer (except where breached by sinkholes) that restricts the vertical movement of water between the surficial aquifer and Upper Floridan aquifer. The sediments have varying degrees of permeability, consisting of permeable limestone, dolostone, or sand or relatively impermeable layers of clay, clayey sand, or clayey carbonates.

Presently (2010), it is not clear where in Highlands County the transitional boundary of the sediments change from an aquifer system to a confining unit. Previous studies have identified the approximate extent of the intermediate aquifer system in adjacent Polk, Hardee, and DeSoto Counties. Duerr and others (1988), Basso and Hood (2005), and Knochenmus (2006) indicated that the intermediate aquifer system is present in parts of western Highlands County; however, these studies ended at the SWFWMD boundary (fig. 1). Information available at some ROMP wells also indicates the intermediate aquifer system is present along parts of the Lake Wales Ridge (Clayton, 1998; DeWitt, 1998). Arthur and others (2008) suggest that the transitional boundary may extend into central Highlands County. Although little hydrogeologic information about the aquifer system is available east of the Lake Wales Ridge, water-use permits, well completion reports, and wells inventoried for this study indicate that permeable units may extend into parts of eastern Highlands County.

Hydrogeologic sections showing the relative position and thickness of the IAS/ICU over the county are shown in figures 16 and 17. A generalized structure contour map of the altitude of the top of the IAS/ICU is shown in figure 21. The top of the unit is defined as the first persistent clays of Pliocene or Miocene age. The altitude of the top of the IAS/ICU is highest in the western part of the county where it is more than 50 ft above NGVD 29 (fig. 21). Altitudes of more than 150 ft below NGVD 29 occur along the southern part of the Lake Wales Ridge. In much of the eastern part of the county, altitudes range from about 0 to 50 ft below NGVD 29. The thickness of the IAS/ICU ranges from about 200 ft in northwestern Highlands County to more than 600 ft in the southwestern part of the county (fig. 22).

As previously mentioned, it is not clear where the predominantly Miocene sediments of the intermediate aquifer system grade into the intermediate confining unit. The intermediate confining unit, where present in eastern Highlands County, acts as a confining layer that restricts the

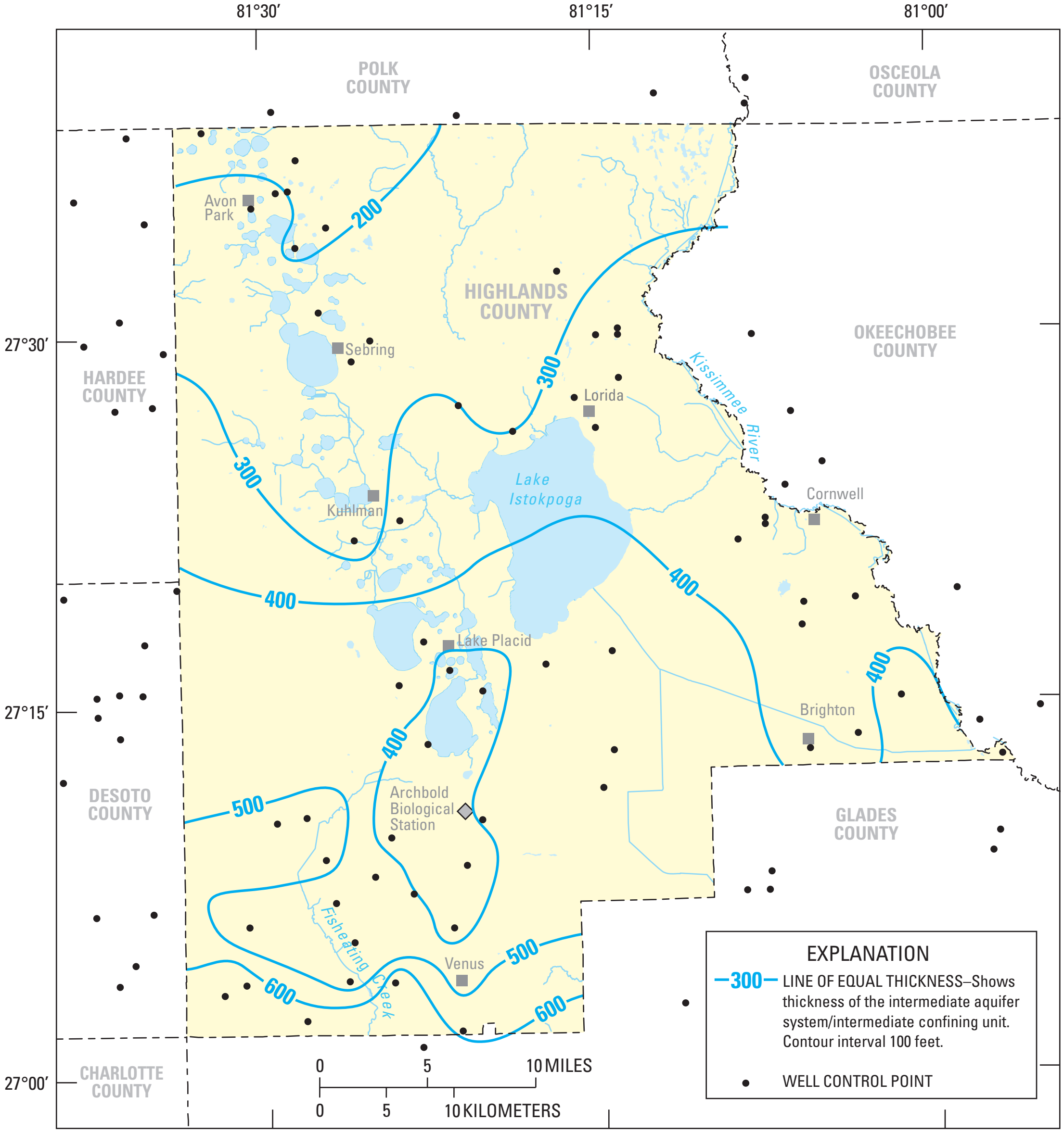


Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 21. Generalized altitude of the top of the intermediate aquifer system/intermediate confining unit.

vertical movement of water between the surficial aquifer and the Upper Floridan aquifer. The intermediate confining unit consists primarily of Hawthorn Group sediments of Miocene age, and in some areas, low permeability beds of early Pliocene age. The unit consists of interbedded clay, silt, sand, phosphate, limestone, and dolostone.

The intermediate aquifer system, believed to be present in parts of Highlands County, consists of the more permeable sediments of the Peace River and Arcadia Formations. The intermediate aquifer system in Highlands County consists of three hydrogeologic units: a sandy clay or clay confining unit that separates the water-bearing units from the surficial aquifer; one or two water-producing units composed primarily of sand and carbonate rocks; and a sandy clay to clayey sand lower confining unit that overlies the Upper Floridan aquifer. The confining units are highly variable both areally and vertically. In addition, the water-producing units are separated by less-permeable units that restrict the vertical movement of groundwater between these zones. As a whole, however, the entire system, including the water-producing units, has substantially lower permeability than the Upper Floridan aquifer and is classified as a confining unit. The hydrogeologic term “intermediate aquifer system” is equivalent with the term "secondary artesian aquifer" as used by Stewart (1966) and the term "upper unit of the Floridan aquifer system" as used by Wilson (1977) and Hutchinson (1978).



Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 22. Generalized thickness of the intermediate aquifer system/intermediate confining unit.

Various names have been used to describe the permeable units within the intermediate aquifer system in southwestern Florida. Recent reports have used zone numbers (PZ1, PZ2, and PZ3) to designate the permeable units identified in the intermediate aquifer system (Barr, 1992; Torres and others, 2001; Basso, 2003; Basso and Hood, 2005). The zones are distinguished as separate units by intervening confining units and by differences in water quality and water levels. Knochenmus (2006) renamed these permeable units (in order of increasing depth) as Zone 1, Zone 2, and Zone 3. More recently, DeWitt and Mallams (2007) and Mallams and DeWitt (2007) proposed that Zone 2 and Zone 3 of the intermediate aquifer system be renamed the upper Arcadia aquifer and lower Arcadia aquifer, respectively. This report uses the nomenclature of DeWitt and Mallams (2007) and Mallams and DeWitt (2007).

The lateral continuity and water-bearing potential of the various units within the intermediate aquifer system are highly variable due to the heterogeneity that is typical of Hawthorn Group sediments. Where multiple water-producing units are present, they generally are laterally discontinuous and difficult to map (Basso and Hood, 2005). Up to two water-producing units within the intermediate aquifer system are believed to extend into Highlands County. Earlier studies indicate that these units are limited in vertical extent and present at various depths (Knochenmus, 2006). The uppermost water-producing units in Highlands County, the upper Arcadia aquifer (Zone 2), consists of discontinuous thin beds of limestone, dolostone, sand, and shell within the lower Peace River and/or the upper Arcadia Formations (Basso and Hood, 2005; LaRoche, 2007). According to Knochenmus (2006), the aquifer extends into west-central Highlands County. The upper Arcadia aquifer appears to be the most geographically extensive water-producing unit within the intermediate aquifer system, and can be mapped in much of southwestern Florida (Basso and Hood, 2005). The lowermost water-producing unit, the lower Arcadia aquifer (Zone 3), consists primarily of limestone, with varying amounts of interbedded siliciclastics in the lower part of the Arcadia Formation (Clayton, 1998; DeWitt, 1998; Basso, 2003; Basso and Hood, 2005; LaRoche, 2007). The lower Arcadia aquifer is generally the most productive aquifer within the intermediate aquifer system in southwestern Florida (Basso, 2003). Based on limited data, the lower Arcadia aquifer may not be present in Highlands County. However, this aquifer is present at well ROMP 13 in DeSoto County (fig. 1), which is located about 5 miles from the Highlands County line.

Data on the hydraulic properties of the intermediate aquifer system in Highlands County are limited, and estimates are primarily available from regional flow-model simulations. Transmissivity estimates for the upper Arcadia aquifer (Zone 2) at two sites in Highlands County (fig. 19) ranged from 31 to 162 ft^2/d (Clayton, 1998; DeWitt, 1998). Model-derived transmissivity values ranged from about 100 to 3,000 ft^2/d in the intermediate aquifer system in Highlands County (Sepúlveda, 2002). In comparison, reported transmissivity values ranged from 1 to 8,800 ft^2/d at 43 sites in the upper Arcadia aquifer (Zone 2) in southwestern Florida (Knochenmus, 2006). Reported transmissivity values ranged from 20 to 43,000 ft^2/d at 36 sites in the lower Arcadia aquifer (Zone 3) in southwestern Florida (Knochenmus, 2006).

The confining units present within the intermediate aquifer system have low hydraulic conductivity and restrict the vertical movement of water. The confining units consist primarily of clays and sands that hydraulically separate the intermediate aquifer system from the adjacent aquifers. However, depending on the hydraulic gradients and the permeability of the units, these confining units may transmit water or allow water to leak from one water-bearing unit to another. Leakance values calibrated in a regional flow model ranged from 1×10^{-6} to 6×10^{-4} (ft/d)/ft in the upper confining unit of the intermediate aquifer system and from 1×10^{-6} to 1×10^{-3} (ft/d)/ft in the lower confining unit (Sepúlveda, 2002). In another model, calibrated leakance ranged from 5×10^{-6} to 1×10^{-3} (ft/d)/ft in the upper confining unit along the Lake Wales Ridge in Highlands County and from 1×10^{-6} to 5×10^{-4} (ft/d)/ft in the lower confining unit (Yobbi, 1996). Leakance values are highest along the Lake Wales Ridge where aquifer recharge is highest and the confining beds are relatively thin, permeable, or breached by karst features. The lowest leakance values occur along the flanks of the Lake Wales Ridge where karst features are less numerous, the confining units are relatively thick or have lower permeability, and aquifer recharge rates are low (Yobbi, 1996).

Water levels in the intermediate aquifer system respond seasonally to rainfall and pumping. Seasonal water-level fluctuations in two wells completed in the intermediate aquifer system are shown in figure 23. Water levels generally are at, or near, their minimum levels during May, then begin to rise through September or October in response to the summer rains and the reduction of irrigation pumping. Seasonal fluctuations in water levels in the intermediate aquifer system range from about 1 to 20 ft.

The IAS/ICU is recharged primarily by downward leakage from the overlying surficial aquifer, and more directly, through sinkholes. Recharge can also occur by upward leakage from the underlying Upper Floridan aquifer. Discharge from the IAS/ICU occurs as pumpage, by downward leakage into the Upper Floridan aquifer, upward leakage to the surficial aquifer, and lateral outflow from the county.

The intermediate aquifer system is a minor source of water supply in Highlands County. About 2.1 Mgal/d, totaling 2 percent of the total groundwater used in Highlands County, was withdrawn from the intermediate aquifer system in 2005 for domestic, irrigation, or public supply (M. Beach, Southwest Florida Water Management District, written commun., 2009).

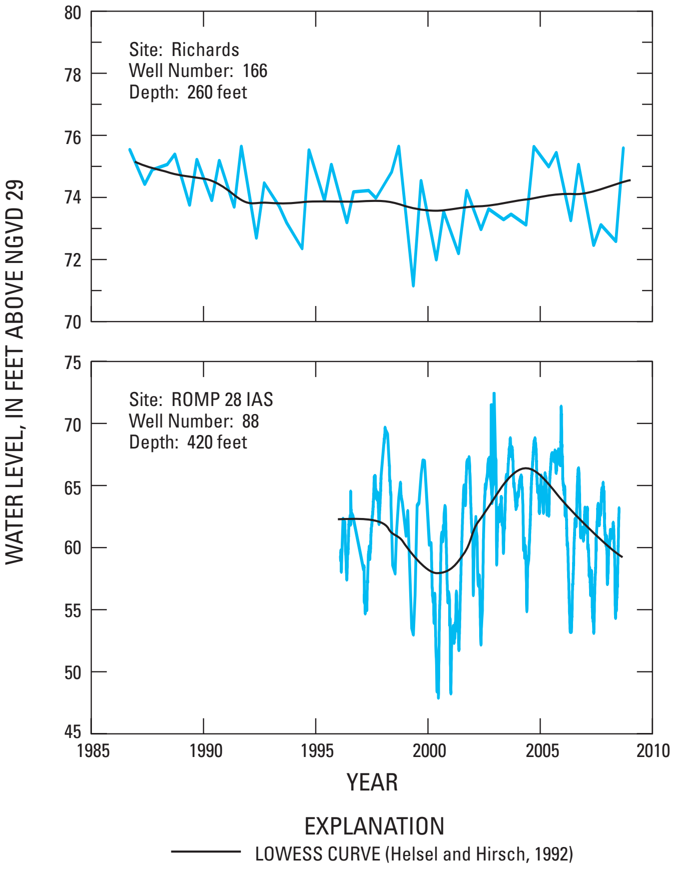


Figure 23. Water levels in selected wells completed in the intermediate aquifer system. Well locations shown in figure 11.

Floridan Aquifer System

The Floridan aquifer system underlies the entire Florida Peninsula, as well as parts of Alabama, Georgia, and South Carolina. As previously mentioned, this aquifer system is the principal source of municipal, agricultural, and industrial water supply in Highlands County. It is composed of a thick sequence of limestone and dolostone of late Paleocene to Oligocene age that is generally high in permeability and hydraulically connected in varying degrees. The Floridan aquifer system ranges from about 2,800 to 3,400 ft in thickness in Highlands County (Miller, 1986) and includes the following stratigraphic units in ascending order—the upper part of the Cedar Keys Formation, the Oldsmar Formation, the Avon Park Formation, the Ocala Limestone, and the Suwannee Limestone (fig. 12). The base of the Floridan aquifer system is defined by the first occurrence of vertically persistent beds of gypsum or anhydrite found in the upper part of the Cedar Keys Formation. The top of the Floridan aquifer system in Highlands County generally coincides with the top of the Suwannee Limestone where it is present. If the Suwannee Limestone is absent, the top of the Floridan aquifer system coincides with the top of the Ocala Limestone.

The Floridan aquifer system is divided into aquifers of relatively high permeability—the Upper Floridan aquifer and Lower Floridan aquifer. Both aquifers are separated by less-permeable units (where present) called the middle confining unit I, II, or VI. The aquifer layers are delineated on the basis of rock permeability characteristics, rather than formation or time-stratigraphic boundaries (Miller, 1986). Over most of Highlands County, the Upper Floridan aquifer generally contains freshwater, and the Lower Floridan aquifer contains more mineralized water.

Upper Floridan Aquifer

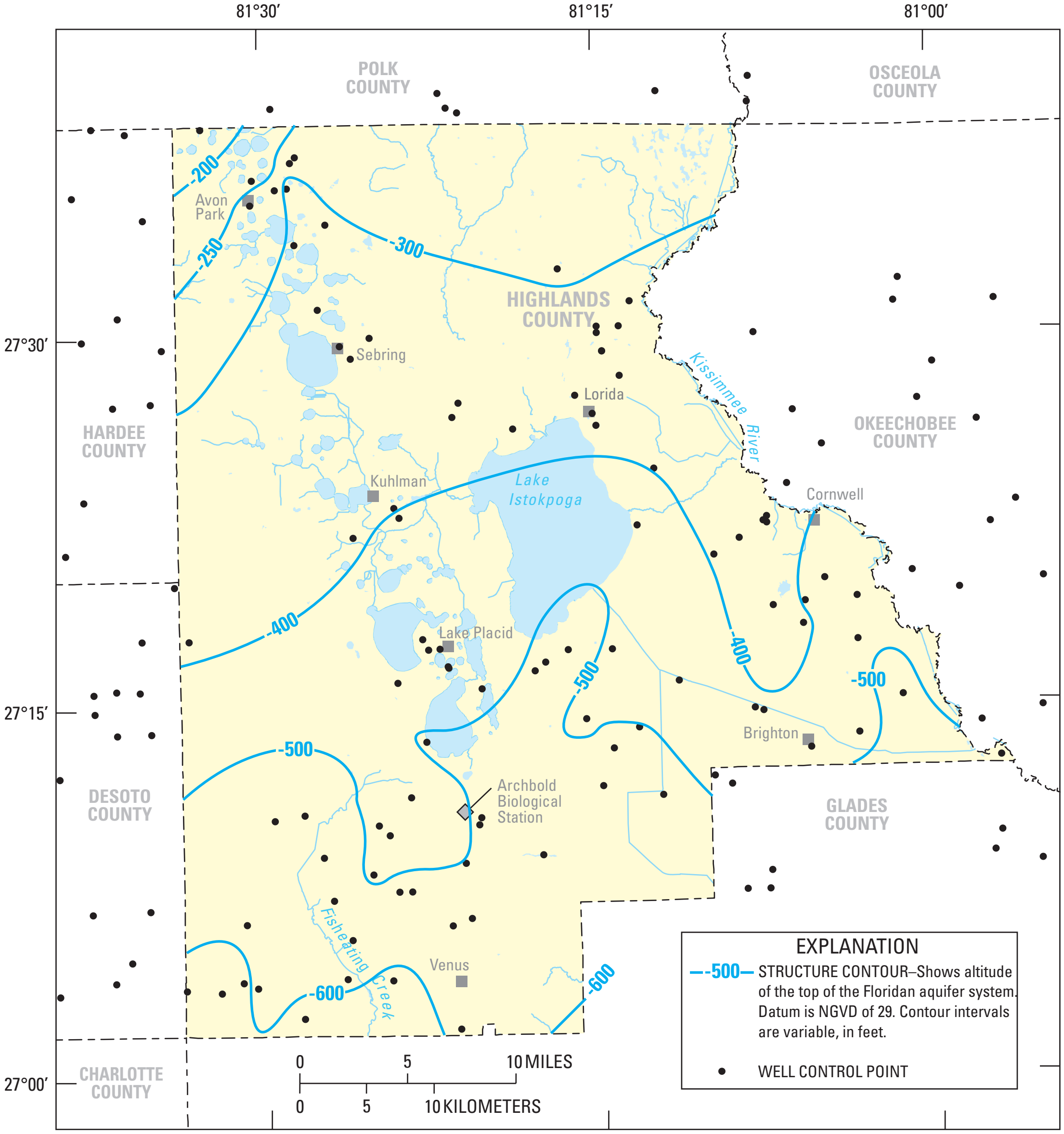
The Upper Floridan aquifer underlies all of Highlands County and is composed of a thick sequence of carbonate rocks that include the upper half of the Avon Park Formation, the Ocala Limestone, and the Suwannee Limestone where present. A generalized structure contour map of the altitude of the top of the Upper Floridan aquifer (top of the Floridan aquifer system) is shown in figure 24. The altitude of the top of the Upper Floridan aquifer is highest in the extreme northwestern part of the county just north of Avon Park, where it is less than 200 ft below NGVD 29. The top of the aquifer dips toward the south, to more than 600 ft below NGVD 29 in the southwestern part of the county. The thickness of the Upper Floridan aquifer ranges from about 1,150 to 1,500 ft in Highlands County (Clayton, 1998; DeWitt, 1998; Mallams and Lee, 2005; Arthur and others, 2008). The base of the Upper Floridan aquifer is defined by the first occurrence of vertically persistent beds of gypsum or anhydrite found in the Avon Park Formation (middle confining unit II). If the middle confining unit I is present, then the base of the aquifer is considered to be the top of the middle confining unit I.

In Highlands County, the Upper Floridan aquifer consists of three hydrogeologic units: (1) the moderately permeable Suwannee Limestone, referred to as the upper permeable zone; (2) the semiconfining Ocala Limestone; and (3) the highly permeable fractured crystalline dolostone in the Avon Park Formation, referred to as the lower permeable zone or Avon Park permeable zone.

The Suwannee Limestone is the uppermost permeable zone of the Upper Floridan aquifer. The permeability of the Suwannee Limestone appears to be primarily intergranular, with some minor parts attributed to moldic porosity (Basso, 2003). In the eastern part of Highlands County, the Suwannee Limestone has been removed by erosion and the Ocala Limestone generally is the uppermost permeable zone of the Upper Floridan aquifer. Although the Ocala Limestone generally does not contain intervals that are highly productive, at ROMP 14 and ROMP 28 (Clayton, 1998; DeWitt, 1998) the uppermost parts of the formation were included in the uppermost permeable zone. Bishop (1956) noted that yields from the Ocala Limestone were not as large as yields from deeper Eocene formations; however, in some parts of southeastern Highlands County, the Ocala Limestone was capable of producing relatively large volumes of water. Stewart (1966) stated that in some areas in Polk County, where the Suwannee Limestone is missing, the lower part of the Ocala Limestone can also produce moderate amounts of water to wells. Wells completed in the Suwannee Limestone generally yield more water than wells completed in the Ocala Limestone.

Underlying the Suwannee Limestone is a semiconfining unit that generally corresponds stratigraphically to the Ocala Limestone. The unit is composed primarily of a soft, poorly consolidated, fossiliferous, carbonate mud-rich limestone. In much of the study area, this semiconfining unit generally includes all or part of the Ocala Limestone, but in some areas, also may include the upper part of the Avon Park Formation (Basso, 2003). Data collected from ROMP 29A (fig. 15) in Highlands County show that the semiconfining unit included all of the Ocala Limestone, and all but about the uppermost 25 ft of the Ocala Limestone at ROMP 14 and ROMP 28 (fig. 15). At ROMP 14, however, the semiconfining bed also included 199 ft of the upper Avon Park Formation.

The carbonate section of the upper Avon Park Formation, which consist of grainstones and grain-dominated packstones, can be moderately productive. Visual examination of core samples and thin sections suggests these grainy lithofacies have relatively high intergranular porosity and relatively high matrix permeability (Ward and others, 2003). Thus, these carbonate rocks are a heterogeneous interlayering of thin conduit flow and carbonate rock diffuse flow zones. However, the lowermost permeable zone and the most productive interval of the Upper Floridan aquifer occur in the hard fractured dolostone within the Avon Park Formation. This highly permeable zone, also referred to as the Avon Park permeable zone (Reese and Richardson, 2008), is the most important water-producing zone of the Upper Floridan aquifer and is utilized whenever large quantities of groundwater



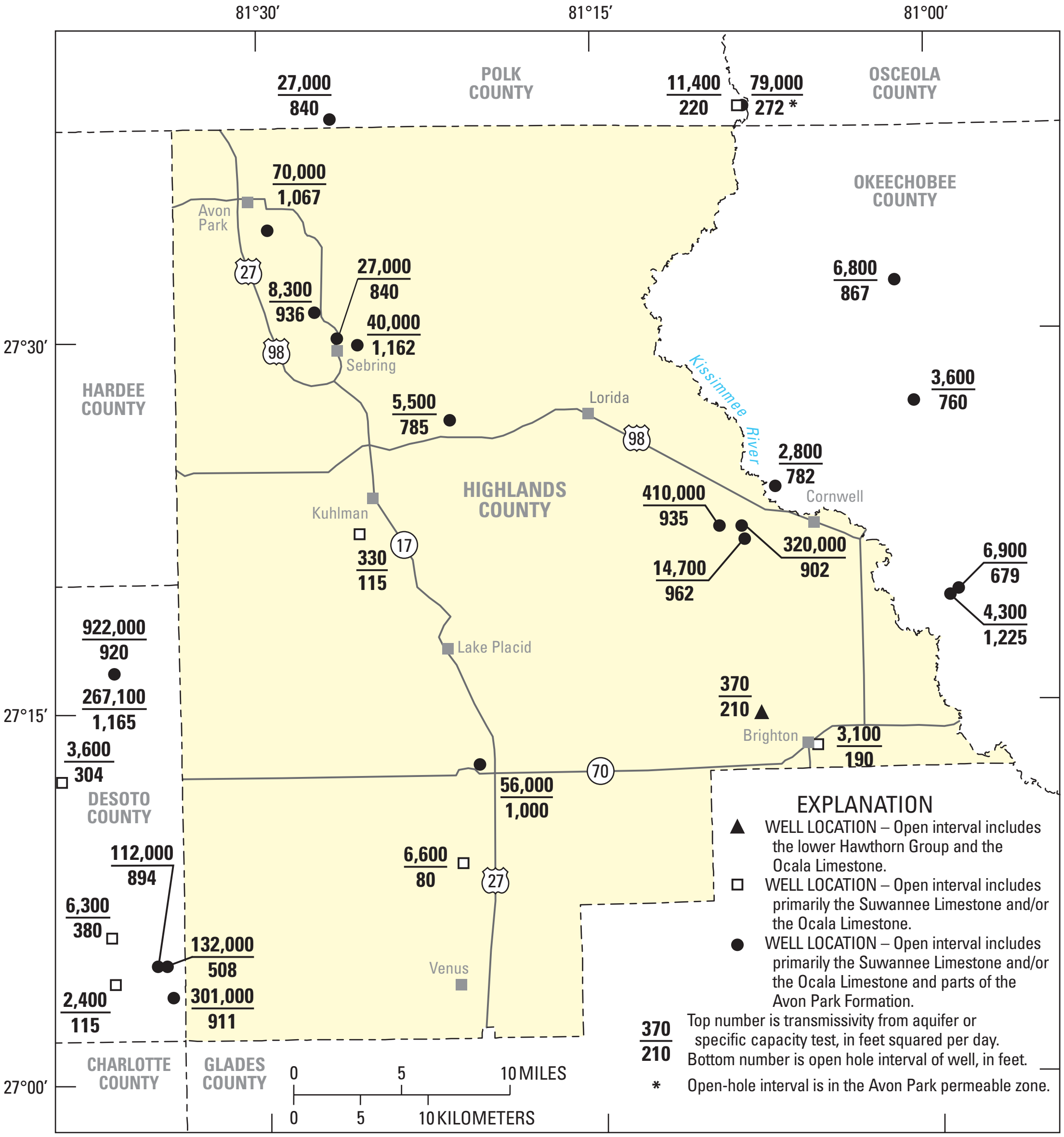
Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 24. Altitude of the top of the Floridan aquifer system.

are needed for municipal or irrigation supplies. Yields from large diameter wells completed in this zone can range from 2,000 to 3,000 gal/min (Basso, 2003). The thickness of this zone ranges from about 200 to 350 ft in Highlands County (Clayton, 1998; DeWitt, 1998; Mallams and Lee, 2005; Reese and Richardson, 2008).

The top of the Avon Park permeable zone generally is marked by an increase in formation resistivity (as seen in geophysical logs) because of the increasing presence of dolostone. The high transmissivity and fractured rock in this zone commonly results in a change in the borehole from a size that is similar to the drill bit to a borehole with numerous, abrupt, large hole enlargements (O'Reilly and others, 2002; Reese and Richardson, 2008). Borehole flowmeter logs can also indicate large flow zones, marked by large temperature or fluid resistivity curve deflections (Reese and Richardson, 2008).

The transmissivity of the Upper Floridan aquifer varies throughout the area. Transmissivity, or the capacity of an aquifer to transmit water, is one way of measuring the ease with which groundwater flows through an aquifer. Variations in transmissivity of the rock strata within the Upper Floridan aquifer are complex and are related to the areal differences in



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Albers NAD projection 1983

Figure 25. Transmissivity of the Upper Floridan aquifer. From Shaw and Trost (1984), Bradner (1994), Clayton (1998), DeWitt (1998), Baldini and Rappuhn (1999), Southwest Florida Water Management District (2000), and Mallams and Lee (2005).

primary and secondary porosity of the aquifer, with the latter being more important to the flow of groundwater. Primary porosity refers to the porosity remaining after sediments have been compacted, but without considering changes resulting from subsequent chemical action or flow of water through the sediments. Secondary porosity develops from fracturing and dissolution of carbonate rocks. As a result, transmissivity can be high with a wide range in values.

Transmissivity values of the Upper Floridan aquifer determined from aquifer and specific capacity tests in Highlands County range from less than 1,000 to about 410,000 ft^2/d (fig. 25), and model-derived transmissivity values for the Upper Floridan aquifer range from about 10,000 to 500,000 ft^2/d (Sepúlveda, 2002). Transmissivity data from the upper permeable zone of the Upper Floridan aquifer are limited in Highlands County, with values generally less than 7,000 ft^2/d (fig. 25). Most of the transmissivity values available in Highlands County are the result of wells that penetrate multiple geologic units including the Suwannee Limestone, Ocala Limestone, and various parts of the Avon Park Formation (including the Avon Park permeable zone), which generally results in considerably higher transmissivity values.

Middle Confining Units

Miller (1986) mapped three low-permeability units of subregional extent and thickness that separate the Upper Floridan aquifer from the Lower Floridan aquifer in Highlands County. These units (middle confining units I, II, and VI) are present at different altitudes within Highlands County and contain rock types that are different from one another. According to Miller (1986), any of these low permeability units may locally contain thin zones of moderate to high permeability; however, overall the units act as a single confining unit.

Middle confining unit I (Miller, 1986), equivalent to the term "middle semiconfining unit" as used in other reports, is a sequence of softer, relatively less-permeable limestone and dolomitic limestone of variable thickness. Miller (1986) noted that contrast in permeability between the rocks of this unit and the permeable rocks above or below it was less than that for any other middle confining unit that was mapped. Data points for estimating the extent and thickness of middle confining unit I are nearly nonexistent in Highlands County, so it is unclear where the unit pinches out. According to Miller (1986), middle confining unit I is absent in the western part of the county. The estimated thickness of the unit in Highlands County ranges from 0 to 600 ft (Miller, 1986).

Underlying middle confining unit I is a separate and distinct second confining unit. The unit, which consists primarily of low-permeability gypsiferous dolostone and dolomitic limestone in the middle to lower part of the Avon Park Formation, is referred to herein as middle confining unit II (Miller, 1986). The unit is equivalent to the term "middle confining unit" as used in other reports in central Florida. Middle confining unit II, which is considerably less permeable than middle confining unit I, forms a virtually nonleaky confining bed that separates freshwater in the Upper Floridan aquifer from the more mineralized water in the underlying rocks. The top of middle confining unit II, generally defined as the first occurrence of evaporites, ranges (where present) from about 1,250 ft below NGVD 29 in northeastern Highlands County to more than 1,600 ft below NGVD 29 in the southwestern part of the county (Miller, 1986). Based on limited data, the unit may not be present in parts of eastern Highlands County. The thickness of middle confining unit II ranges from 0 to 300 ft over most of the county (Miller, 1986).

In southwestern Highlands County is another confining unit called middle confining unit VI, which underlies middle confining unit II (Miller, 1986). The rocks of middle confining unit VI form a sequence of interbedded finely to coarsely crystalline dolomite and finely pelletal, micritic limestone that is commonly argillaceous (Miller, 1986). In much of the unit, the intergranular pore space of the carbonate rocks is filled with gypsum. The top of middle confining unit VI (where present) ranges from about 1,900 ft below NGVD 29 in central Highlands County to about 2,000 ft below NGVD 29 in the southwestern part of the county (Miller, 1986). The thickness of middle confining unit VI ranges from 0 to 200 ft (Miller, 1986).

Little information is available on the hydraulic properties of the middle confining units in Highlands County. Horizontal hydraulic conductivity values of middle confining unit II based on packer tests at ROMP 14 and ROMP 28 ranged from 0.003 to 0.125 ft/d (Clayton, 1998; DeWitt, 1998). Horizontal hydraulic conductivity values based on slug tests at ROMP 29A ranged from 0.05 to 0.3 ft/d (Mallams and Lee, 2005). Horizontal hydraulic conductivity values of middle confining unit II based on packer tests in Hillsborough, Manatee, and Sarasota Counties ranged from 0.002 to 0.04 ft/d (Basso, 2003). Horizontal hydraulic conductivities determined from cores taken at different depths within middle confining unit II at the Polk City test well in Polk County generally ranged from about 0.000024 to 0.90 ft/d, although two samples yielded hydraulic conductivities values of 6.6 and 19.0 ft/d (Navoy, 1986).

Lower Floridan Aquifer and Sub-Floridan Confining Unit

The geologic characteristics and hydraulic properties of the Lower Floridan aquifer in Highlands County are not well known. Because of its greater depths, the likelihood that the Lower Floridan aquifer contains more mineralized water, and sufficient water generally can be obtained from the Upper Floridan aquifer, few wells have been drilled into this aquifer. The Lower Floridan aquifer is present throughout Highlands County and underlies middle confining units I, II, and VI. Altitudes of the top of the Lower Floridan aquifer are estimated to range from about 1,050 to 1,850 ft below NGVD 29 (Miller, 1986). Much of the variation observed in the top of the aquifer is the result of discontinuities in the configuration of the middle confining units caused by variations in their altitudes and thicknesses over the county.

The Lower Floridan aquifer consists of the upper part of the Cedar Keys Formation, the Oldsmar Formation, and the lower part of the Avon Park Formation (fig. 12). In much of Highlands County, the Lower Floridan aquifer is composed of a thick sequence of mostly low-permeability rocks separated by relatively thin permeable zones (Miller, 1986). In contrast, the Lower Floridan aquifer is considerably more permeable in east-central and northeastern Florida.

A highly permeable zone present within the lower part of the Lower Floridan aquifer is the "Boulder Zone." Present in much of southern Florida, this zone is believed to extend into the southeastern part of Highlands County (Miller, 1986; Reese and Richardson, 2008). Rocks in this zone consist primarily of massively bedded dolostone having extensively developed secondary (cavernous) porosity. Borehole televiewer surveys show that this zone consists of a series of thin to moderately thick horizontal openings connected vertically by fractures, some of which have been opened and enlarged into vertical tubes by dissolution (Miller, 1986). The Boulder Zone contains saline water and is commonly used in parts of southern Florida for the disposal of treated wastewater through injection wells (Reese and Richardson, 2008). The zone is overlain in most places by confining units that prevent the upward movement of injected wastewater. The cavernous nature of the Boulder Zone was created by the vigorous circulation of groundwater through the carbonate rocks in geologic past, and was not created by the present groundwater-flow system (Miller, 1990). Estimated altitudes to the top of the Boulder Zone in Highlands County range from 3,000 to 3,400 ft below NGVD 29 (Miller, 1986).

No data are available to describe the hydraulic properties of the Lower Floridan aquifer in Highlands County. In south-central Florida, the unit is of relatively low permeability because of the presence of intergranular gypsum. Where the Boulder Zone is present, however, transmissivities can be high because of its cavernous nature. Transmissivity for the Boulder Zone in southeastern Florida is estimated to exceed 3,000,000 ft^2/d (Meyer, 1974).

A base of low-permeability dolostone and massive evaporite beds of Paleocene age forms the sub-Floridan confining unit, or the base of the Floridan aquifer system. The base is defined as the first occurrence of vertically persistent beds of evaporites in the upper part of the Cedar Keys Formation (Miller, 1986). These beds have very low permeability and range in depth from about 3,150 ft below NGVD 29 in the northern part of Highlands County to more than 3,900 ft below NGVD 29 in the southern part (Miller, 1986).

Groundwater System and Characteristics

An understanding of the groundwater system in Highlands County is needed to efficiently manage the water resources of this area. This section discusses (1) the potentiometric surface of the Upper Floridan aquifer; (2) groundwater withdrawals, recharge, and discharge in the aquifers; (3) long-term trends in groundwater levels; (4) water-level comparisons; and (5) water-budget components.

Potentiometric Surface of the Upper Floridan Aquifer

The potentiometric maps shown in figures 26 and 27 represent the hydraulic head in the Upper Floridan aquifer and depict the level to which water will rise in tightly cased wells. The slope of the potentiometric surface determines the general direction of groundwater movement. Groundwater in the Upper Floridan aquifer flows downgradient from potentiometric highs to potentiometric lows. The arrows superimposed on the maps show the direction of groundwater movement, which is perpendicular to the potentiometric contours.

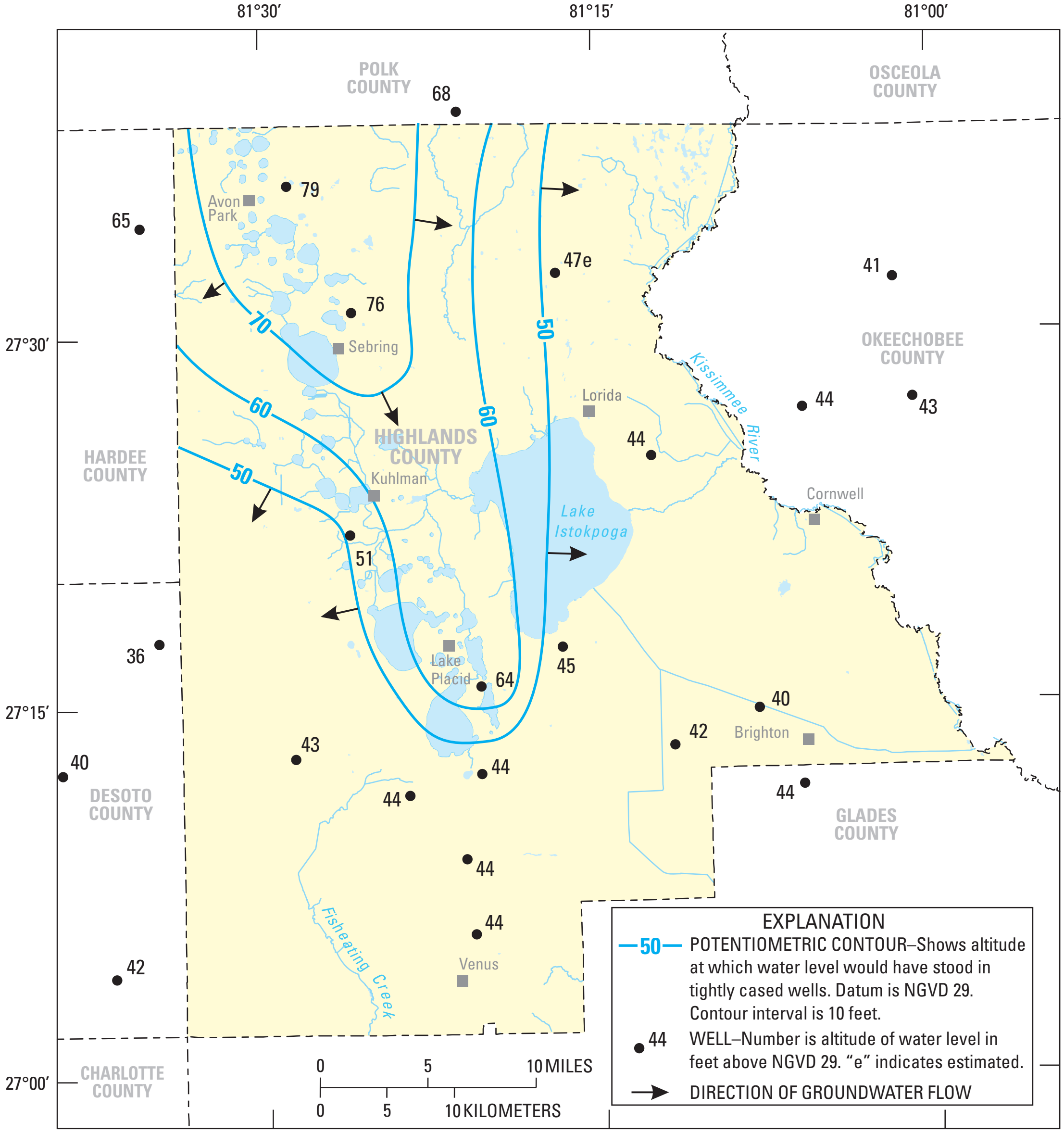
The potentiometric surface of the Upper Floridan aquifer in May 2007 (Kinnaman and Dixon, 2007) and September 2007 (Kinnaman and Dixon, 2008) is highest in northwestern Highlands County, and a groundwater divide is present along the Lake Wales Ridge (figs. 26 and 27). West of the Lake Wales Ridge, the direction of groundwater flow is to the southwest. East of the ridge, the direction of flow is toward the Kissimmee River.

The May 2007 potentiometric surface map (fig. 26) represents hydrologic conditions near the end of the dry season, when groundwater withdrawals from the aquifer for agricultural irrigation and public supply are near their annual maximums and water levels generally are near their annual minimums (fig. 26). The potentiometric surface ranges from about 79 ft above NGVD 29 in northwestern Highlands County to about 40 ft above NGVD 29 in the southeastern part of the county. In much of the southern and eastern parts of the county, water levels generally are less than 45 ft above NGVD 29.

The September 2007 potentiometric surface map (fig. 27) represents hydrologic conditions near the end of the wet season, when withdrawals from the aquifer for agricultural irrigation and public supply are near minimum levels, and water levels generally are near their annual highs. The potentiometric surface ranges from about 85 ft above NGVD 29 in northwestern Highlands County to about 43 ft above NGVD 29 in the southeastern part of the county. Differences in water levels of the Upper Floridan aquifer ranged from about 3 to 10 ft higher in September 2007 compared to May 2007. However, the potentiometric surface configuration and general direction of groundwater flow did not change substantially between September and May 2007.

Groundwater Withdrawals, Recharge, and Discharge

Groundwater levels in the Upper Floridan aquifer respond seasonally, and over the long term, to climatic effects (rainfall and drought) and groundwater withdrawals. The extent to which these hydrologic factors affect groundwater levels can vary throughout the county. The spatial and temporal distribution of pumpage, as well as the proximity and degree of the hydraulic connection of the aquifer to overlying and underlying hydrologic units, all affect groundwater levels. Seasonal water-level fluctuations in four wells open to the Upper Floridan aquifer in Highlands County are shown in figure 28. Groundwater levels in the Upper Floridan aquifer usually reach their maximum levels in September or October in response to summer rains and a decline in agricultural irrigation. During the winter and spring, water levels gradually decline in response to reduced precipitation and increased agricultural water use. Seasonal water-level fluctuations in the Upper Floridan aquifer range from about 1 to 20 ft (fig. 28). Generally, fluctuations are largest in areas where the aquifer is confined and is heavily pumped for irrigation or public supply. Fluctuations are considerably smaller in areas where the overlying confining beds are thin or leaky and where groundwater withdrawals from the Upper Floridan aquifer are minimal.

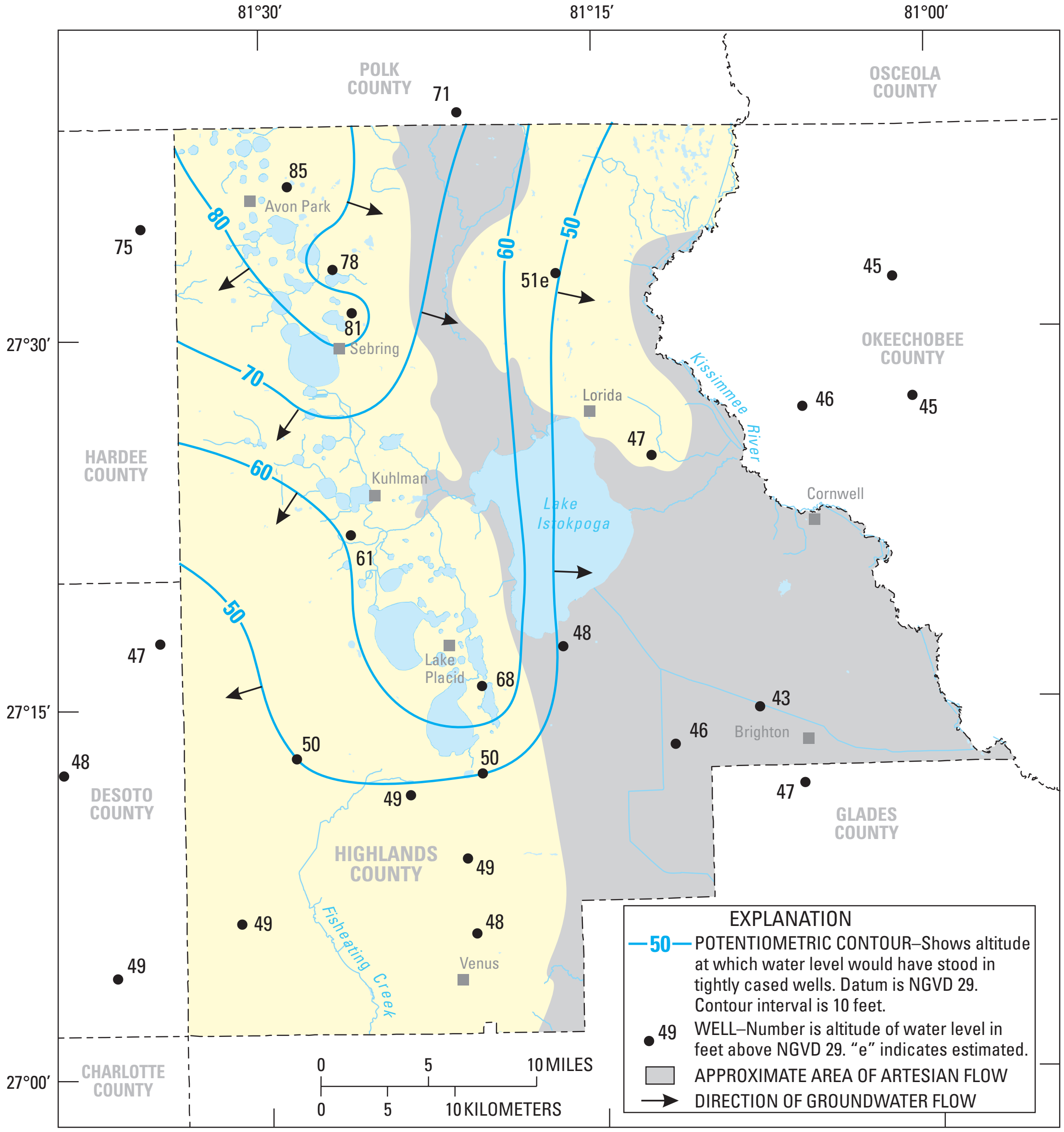


Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 26. Potentiometric surface of the Upper Floridan aquifer, May 2007. Modified from Kinnaman and Dixon (2007).

In Highlands County, the Upper Floridan aquifer is recharged by the downward leakage of water through the surficial aquifer and IAS/ICU and by lateral inflow from adjacent counties. The rate of recharge varies with the vertical hydraulic conductivity, thickness of the surficial aquifer and underlying units, and magnitude of the downward head gradient. Flow simulations show that vertical leakage rates (recharge rates) from the surficial aquifer to the Upper Floridan aquifer range from about 0 to 25 in/yr in Highlands County (fig. 29), and at a few locations, exceeding 25 in/yr (Sepúlveda, 2002). The highest rates of recharge occur along the Lake Wales Ridge, the Intra Ridge Valley, and the Bombing Range Ridge in northeastern Highlands County (fig. 5). Lower rates of recharge from the surficial aquifer to the Upper Floridan aquifer occur adjacent to the ridges and in the southwestern part of the county. The areas of high recharge are characterized by numerous closed basins or lakes where sinkholes have breached the IAS/ICU, by overlying confining beds that are relatively thin or permeable, and by a downward hydraulic gradient. Very low to moderate recharge rates occur in areas where a downward gradient is present, but the permeability and thickness of the confining bed and the magnitude of the downward gradient are less favorable for recharge as compared to the most effective recharge areas (Phelps, 1985).

Discharge from the Upper Floridan aquifer in Highlands County occurs by diffuse upward leakage in discharge areas where the potentiometric surface is above the water table



Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
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Figure 27. Potentiometric surface of the Upper Floridan aquifer, September 2007. Modified from Kinnaman and Dixon (2008).

(fig. 29). Discharge also occurs by pumping, free-flowing wells, and lateral outflow to adjacent counties. Wells open to the aquifer will flow in areas where the potentiometric surface of the Upper Floridan aquifer lies above land surface. Areas of artesian flow from the Upper Floridan aquifer for September 2007 in Highlands County are shown in figure 27. During September 2007, areas of artesian flow occurred primarily east of the Lake Wales Ridge. Though not shown on figure 26, areas of artesian flow from the Upper Floridan aquifer for May 2007 did not change substantially from September 2007. Sepúlveda (2002) indicated that model-derived leakage rates from the Upper Floridan aquifer to the surficial aquifer ranged from 0 to less than 10 in/yr in the discharge area of eastern Highlands County **(**fig. 29**).**

Long-Term Trends in Groundwater Levels

Long-term water-level data from monitoring wells completed in the surficial and intermediate aquifer systems and the Upper Floridan aquifer were analyzed statistically for significant trends (table 1) using the nonparametric Kendall's tau analysis (Helsel and Hirsch, 1992). A probability level of 5 percent was chosen as the criterion for statistical significance. LOWESS curves, a robust smoothing technique described by Helsel and Hirsch (1992), were used to provide visual indications of possible trends in groundwater levels.

Long-term water-level data in Highlands County are available for only a few wells. For the surficial aquifer, three monitoring wells have water-level data that began in the early

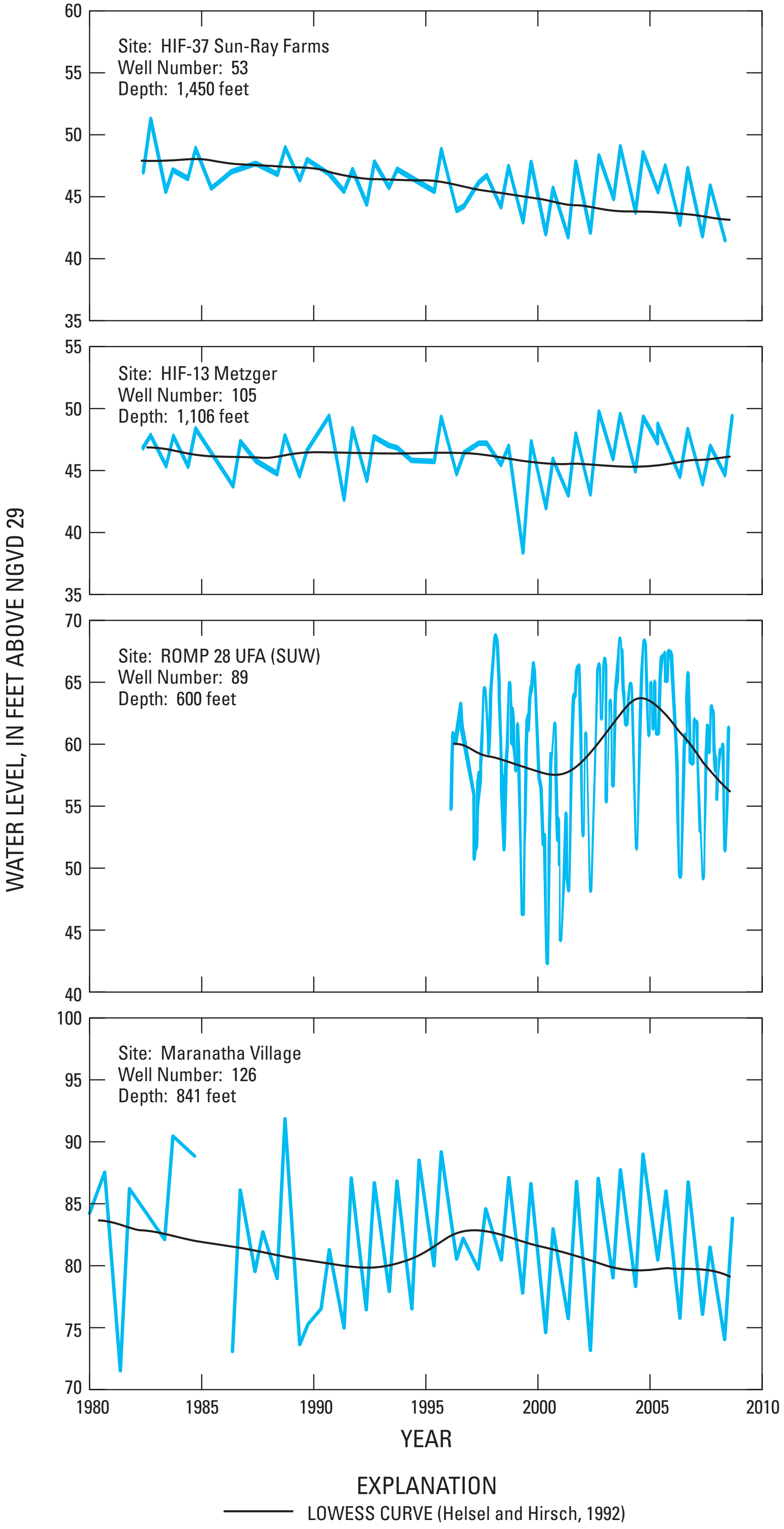
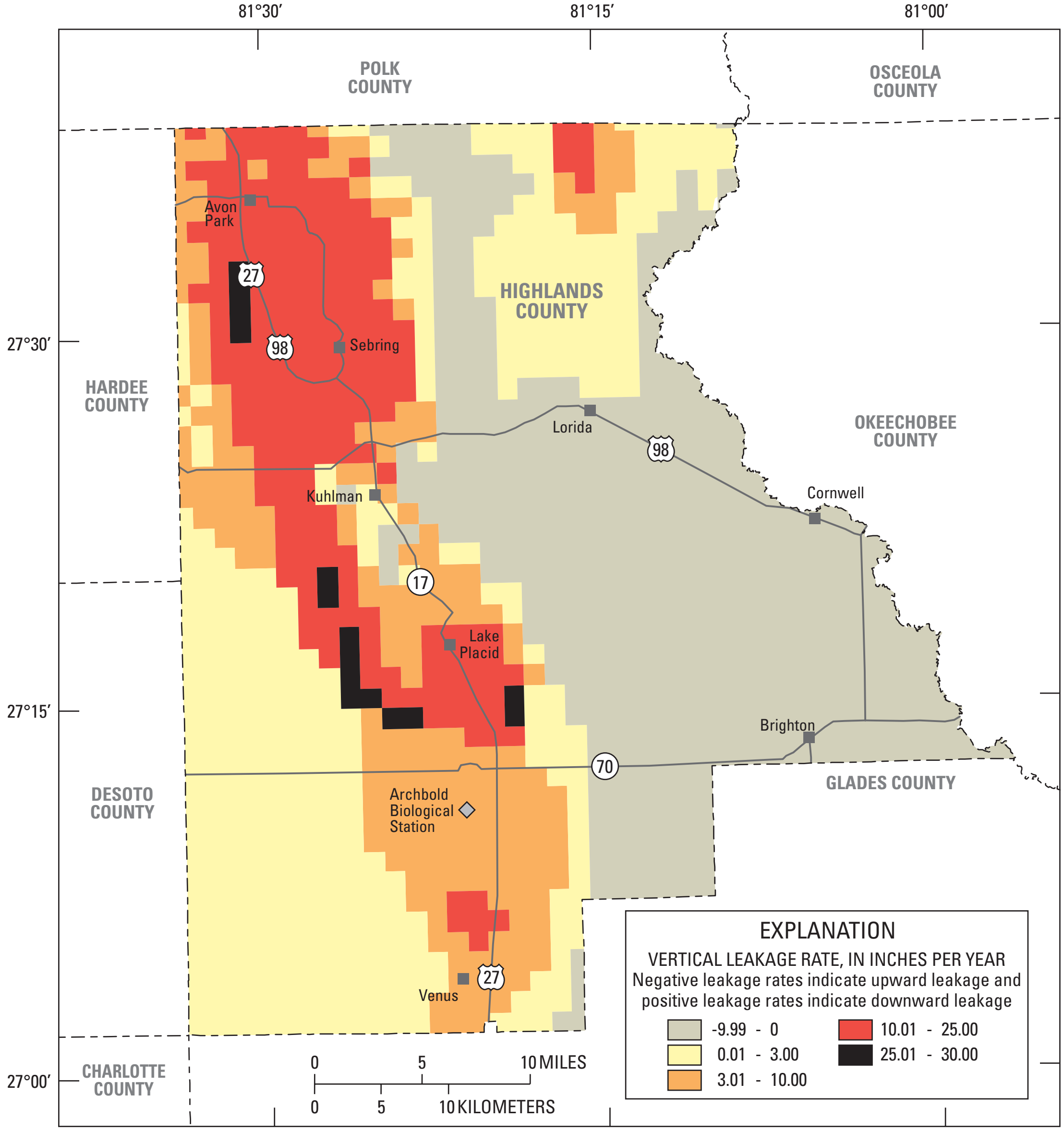


Figure 28. Water levels in selected wells completed in the Upper Floridan aquifer. Well locations shown in figure 11.



Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 29. Simulated vertical leakage rates to and from the Upper Floridan aquifer. From Sepulveda (2002).

or mid 1970s (sites 1, 67, and 103), and one that began in the late 1970s (site 43). Results of the Kendall's tau analyses indicate that water levels in three of the four surficial aquifer wells showed significant trends over respective periods of record ($p < 0.05$, table 1). One well (site 43) showed a slight rise in water levels while two wells (sites 67 and 103) showed slight declines.

Long-term water-level data from two monitoring wells completed in the intermediate aquifer system (sites 88 and 166) and four monitoring wells completed in the Upper Floridan aquifer (sites 53, 89, 105, and 126) also were analyzed for trends (table 1). One of the intermediate aquifer system monitoring wells had water levels that began in the mid 1980s and another in the mid 1990s. Three of the Upper Floridan aquifer monitoring wells had water-level data that began in the early 1980s and one that began in the mid 1990s. Water-level altitudes in one intermediate aquifer system well (site 88) showed a significant but small rise in water levels (table 1). One Upper Floridan aquifer well showed a significant decline in water levels (site 53), whereas another showed a significant but small rise in water levels (site 89). Water levels in the remaining three wells (sites 105, 126, and 166) showed no significant trends.

Although the Kendall's tau revealed water-level trends for the entire period of record for some wells, these trends may not be continuous and may vary over time. The use of LOWESS for trend analysis for the period of record shows these short-term rises and declines in water levels (figs. 20, 23, and 28). For example, although Kendall's tau trend indicated a rise in water levels at site 43 for the period of record (fig. 20), the LOWESS line indicates that the rise was not constant. Specifically, water levels in the well decreased from the beginning of the record until the late 1980s, and then gradually increased after that period. The LOWESS lines for some of the other wells also indicate changing water-level trends over time. These oscillations probably are the result of cyclic variations in rainfall and related pumping over time. In addition, changes in the distribution of pumping also could account for some of the observed water-level trends.

Water-Level Comparisons

Comparisons of water levels in wells completed in the surficial aquifer, intermediate aquifer system, and Upper Floridan aquifer can be used to qualitatively evaluate the degree of hydraulic connection between these units and the direction of the vertical hydraulic gradient. The magnitude of the water-level difference at a particular site reflects the degree of confinement between aquifers, and is related to the lithology and thickness of the confining units. Thicker and hydraulically tighter confining units typically result in greater water-level differences and a reduced hydraulic connection between aquifers whereas smaller water-level differences between hydrologic units typically indicate a better hydraulic connection.

Water-level data comparisons for ROMP well pairs in Highlands and eastern DeSoto Counties show a wide variation in the magnitude of water-level differences between the surficial, intermediate, and Floridan aquifer systems (fig. 30). Hydrographs for wells 93 and 89 (ROMP 28) and wells 164 and 163 (ROMP 43XX) in northern Highlands County show a water-level difference of about 10 to 20 ft between the surficial aquifer and Upper Floridan aquifer. Hydrographs at wells 26 and 27 (ROMP 14) in southern Highlands County show large water-level differences between the surficial aquifer and Upper Floridan aquifer. Water levels at the site are about 85 to 95 ft higher in the surficial aquifer than in the underlying Upper Floridan aquifer. At ROMP 14, a thick sequence of clays in the intermediate aquifer system separates the surficial aquifer from the Upper Floridan aquifer. These clays tend to restrict the downward movement of water to the underlying Upper Floridan aquifer.

Hydrographs of wells at ROMP 15 (wells 46 and 44) and ROMP 28 (wells 88 and 89) show relatively small water-level differences between the intermediate aquifer system and Upper Floridan aquifer. Water-level fluctuations in the intermediate aquifer system also mimic those observed in the Upper Floridan aquifer at these sites. This similarity in water level fluctuations indicates that leaky, relatively permeable or thin confining beds at these locations result in relatively good connection between the aquifers.

Variations in water levels with depth can be illustrated by data collected during the drilling of four ROMP test wells (fig. 31). Three of the ROMP sites were located on the Lake Wales Ridge in Highlands County (ROMP 14, 28, and 29A), and one site was located in extreme southeastern DeSoto County (ROMP 13). Water-level data collected at the sites were not adjusted for changes in water levels with time or for density differences in the water that may have occurred between the various zones within each well.

Water levels at all four of the ROMP sites show a general decrease in water levels with depth until penetration of the Upper Floridan aquifer (fig. 31) where the water levels become relatively steady. This indicates the potential for recharge from the surficial aquifer to the Upper Floridan aquifer. Water levels within the Upper Floridan aquifer at ROMP sites 14, 28, and 29A changed little as the drilling progressed. However, a substantial decrease in head was observed from about 1,100 to 1,300 ft below land surface at ROMP 28, where water levels averaged about 22 ft below land surface. This decline, however, was related to a regional potentiometric surface decline caused by dry conditions that typically prevail in May (DeWitt, 1998). Water levels also declined to about 27 ft below land surface as drilling progressed into middle confining unit II. According to DeWitt (1998), some of the observed decline in water levels can be attributed to an increase in fluid density due to an increase in mineralization of the groundwater.

Water-Budget Components

A water budget is an accounting of flow of water into and out of an area during a specific period of time. A generalized water budget for Highlands County was made by using measured or estimated values of rainfall, net lateral subsurface outflow, and net surface-water outflow. An estimate of evapotranspiration was calculated from the water-budget equation. A generalized water budget can be described by the following equation:

$$ET = P - Q_0 - Q_R - \Delta S \qquad (1)$$

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 net surface-water outflow, in inches per year; and
ΔS is the change in storage over time period.

A generalized water budget was computed for Highlands County over a 10-year period from 1998 to 2007. A budget averaged over this length of time is more likely to be more representative of long-term conditions than a budget averaged over a shorter timeframe. When long-term average annual values of the various water-budget components are used, water released from or accumulated as storage (ΔS) within

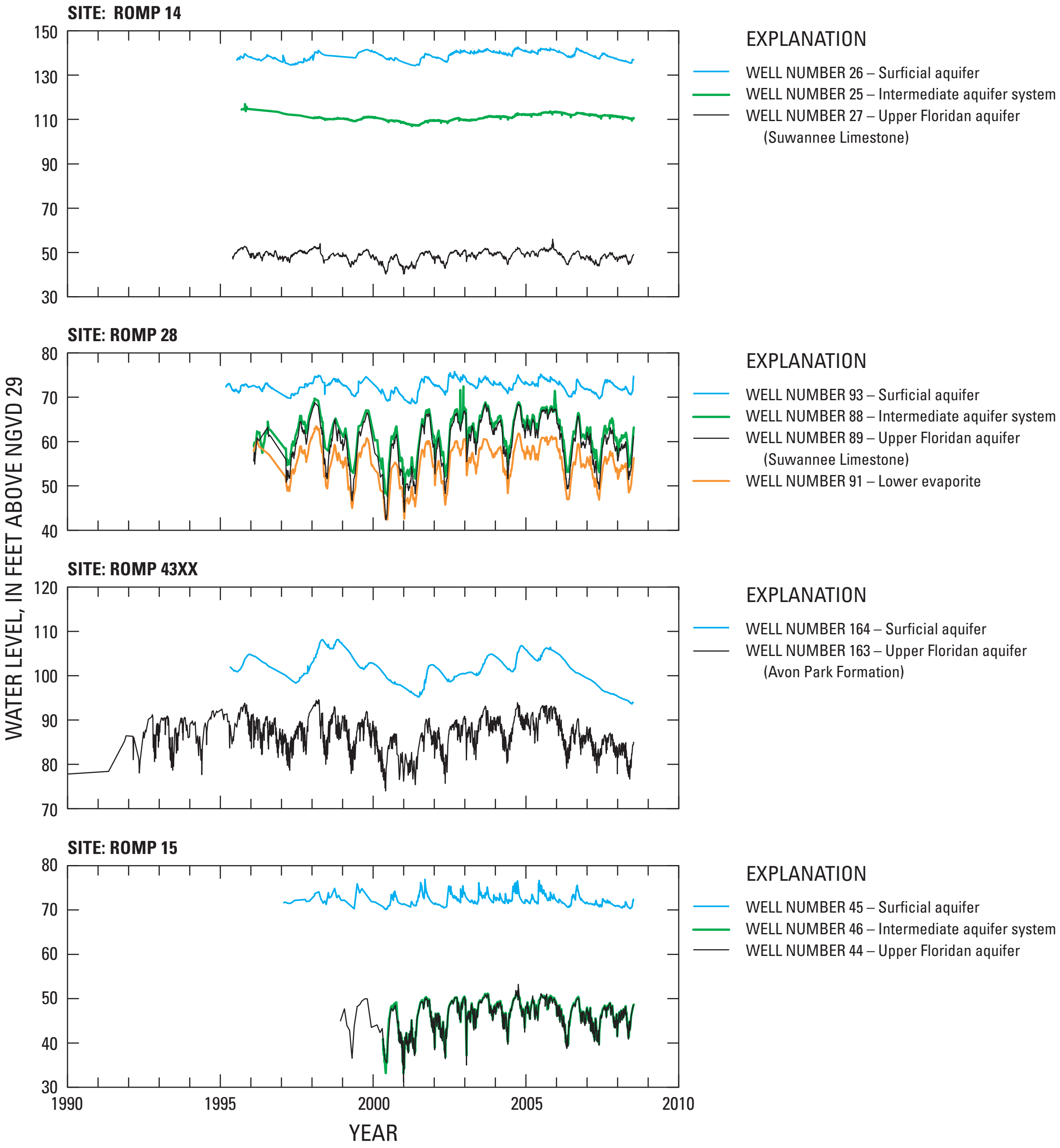


Figure 30. Water levels in selected wells open to the surficial aquifer, intermediate aquifer system, and Upper Floridan aquifer. Well locations shown in figures 1 and 11.

the surficial aquifer can assume to be negligible. Therefore, assuming there is no change in storage, inputs are balanced by outputs. It was also assumed that all groundwater pumped out was returned to the system as wastewater or irrigation return flow and that no groundwater was being imported into or exported out of the county.

The largest input component in the water budget was precipitation, which averaged 51.9 in/yr from 1998 to 2007 at three rainfall stations (Archbold Biological Station, Avon Park, and DeSoto). Ten-year rainfall averages varied across Highlands County during this period, ranging from 50.5 in/yr at Avon Park to 53.6 in/yr at Archbold Biological Station.

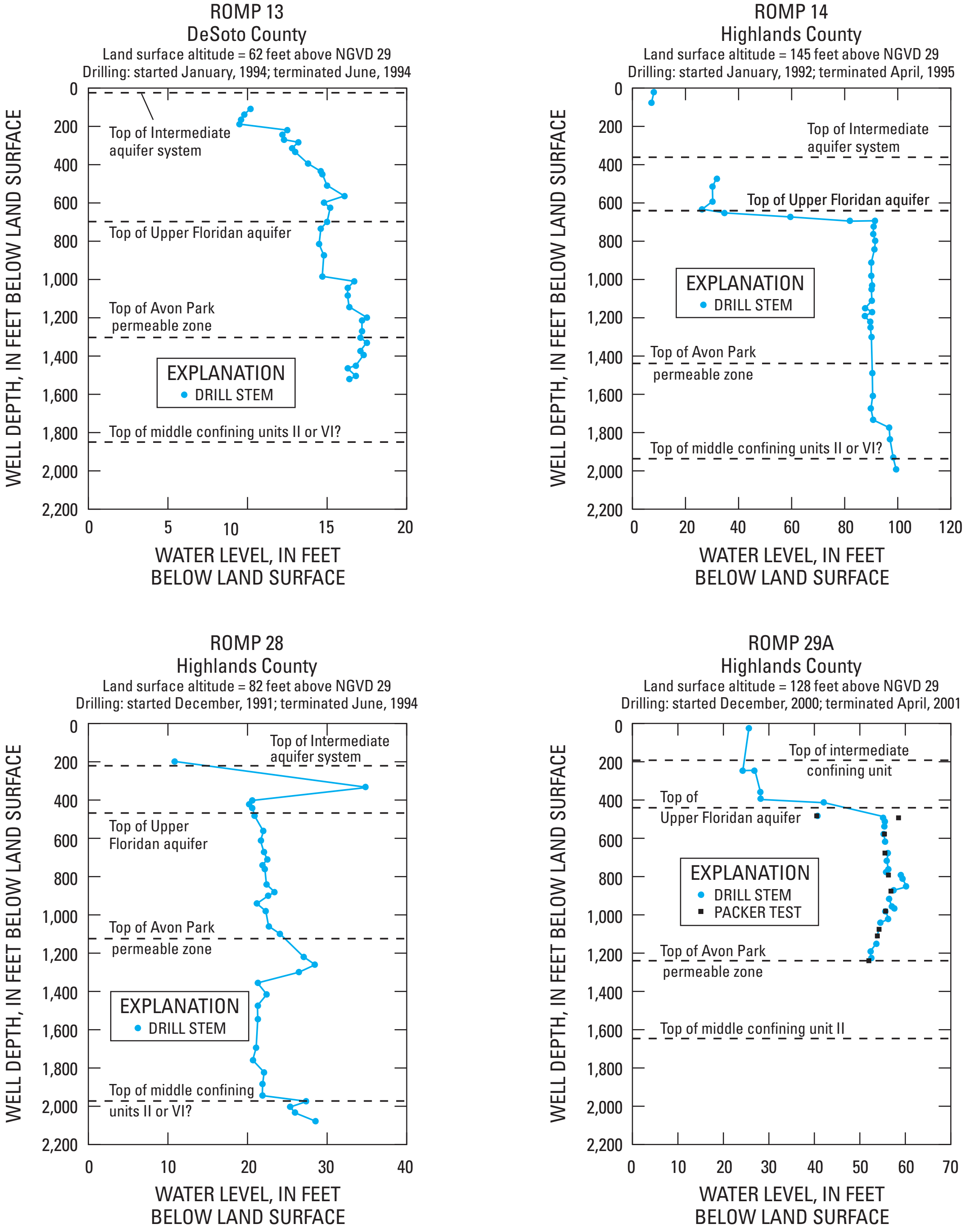


Figure 31. Water levels during drilling of monitoring wells. Modified from Peterman and Rappuhn (1997), Clayton (1998), DeWitt (1998), and Mallams and Lee (2005). Site numbers refer to figure 1.

Net lateral subsurface outflow (Q_O) from Highlands County was determined by using a USGS modular groundwater flow model (Nicasio Sepúlveda, U.S. Geological Survey, written commun., 2009). Net lateral outflow was determined for the surficial aquifer (0.02 in/yr), the intermediate aquifer system (0.06 in/yr), the Upper Floridan aquifer (0.69 in/yr), and the Lower Floridan aquifer (0.23 in/yr). Net lateral subsurface outflow from the four aquifers was 1.00 in/yr.

Water leaving the county as streamflow (Q_R) averaged about 9.7 in/yr from 1998 to 2007, based on the analysis of streamflow records at 12 USGS and SFWMD gaging sites located within or just outside Highlands County. These gaged surface-water sites include Arbuckle Creek near DeSoto City (station number-02270500), Arbuckle Creek near Avon Park (02269600), Carter Creek near Sebring (02270000), Fisheating Creek near Lake Placid (02255600), Fisheating Creek at Palmdale (02256500), Fisheating Creek near Venus (02256000-discontinued site), Little Charley Bowlegs Creek near Sebring (02296222 and 02296223), Kissimmee River at S65A, Kissimmee River at S65E, S70 (Harney Pond Canal), S75 (C-40 Canal), and S84 (C-41A Canal). At Little Charlie Bowlegs Creek, discharge measurements were not available from 1998 to 2007. Instead, historical discharge measurements from 1953 to 1982 and 2005 were averaged in lieu of current discharge measurements. Flows entering or exiting the county from Arbuckle Creek and Fisheating Creek, respectively, were estimated based on the ratios of drainage areas and measured at stations upstream and downstream from the county line. It was assumed in the water budget that one-half of the streamflow from the Lower Kissimmee River basin originated in Highlands County and the other half in Okeechobee County.

Evapotranspiration is the largest output component in the water budget. Evapotranspiration was calculated from equation 1 and accounted for 41.0 in/yr of water removed from the hydrologic system. This back-calculated value of evapotranspiration is a reasonable estimate for Highlands County, because it 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 for a 2-year period at Lake Starr in east-central Polk County (Swancar and others, 2000). This latter value is likely indicative of a potential evapotranspiration rate.

Assessment of Groundwater Quality

The quality of groundwater is controlled by the chemical reactions that occur as groundwater moves through an aquifer. When rainfall enters the soil, it absorbs additional carbon dioxide to produce a weak carbonic acid. As water moves through the sediments, it is chemically altered through mineral dissolution, precipitation, cation exchange, oxidation-reduction anion exchange, and sorption of organic molecules (Crandall, 2000). The effects on water chemistry are also determined by aquifer and overburden geology, rates of groundwater flow, the residence time of water in contact with the aquifer matrix, and the impact of human influence. Additionally, in parts of Highlands County, the effects of periodic Pleistocene inundations of the sea are present in the form of residual diluted seawater. The resultant products of these various reactions determine whether the groundwater will be of suitable quality for a particular purpose. For example, water containing high total dissolved-solids or chloride concentrations may be too mineralized for public supply, industrial, or agricultural use. The limiting concentrations of chloride recommended for plants, animals, and industrial use are shown in figure 32.

Knowledge about variations in water quality within an aquifer is important in assessing the availability of water for public, agricultural, industrial, or other uses. For many uses, water-quality standards have been established that set acceptable concentration limits on constituents in water used for a particular purpose. For water that is being distributed by public-supply systems, the Florida Department of Environmental Protection (2008) has established primary and secondary standards for drinking water. The primary drinking-water standards establish maximum limits that 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 cause offensive taste, odor, color, corrosivity, foaming, or staining. Secondary standards are not enforceable and are intended only as guidelines. The principal chemical constituents in groundwater that can affect potability of groundwater in the area are nitrate, chloride, sodium, sulfate, and the amount of total dissolved solids in the water. Concentrations of nitrate as nitrogen greater than 10 mg/L exceed State primary drinking-water standards, as do sodium concentrations exceeding 160 mg/L. Secondary drinking-water standards specify maximum limits of 250 mg/L for chloride and sulfate concentrations, and 500 mg/L for total dissolved-solids concentrations (Florida Department of Environmental Protection, 2008).

Total dissolved-solids concentrations are often not included in the chemical analyses of groundwater. Estimates of dissolved-solids concentrations, however, can easily be obtained by measuring specific conductance. Specific conductance is the ability of water to conduct an electrical current and is related to the presence of charged ionic species in the water. As ion concentrations increase, the conductance of the solution increases; therefore, the specific conductance provides an indication of ion concentration (Hem, 1985). Figure 33 shows a plot of the total dissolved-solids concentration with the specific conductance for all of the wells sampled in the study area. Although most of the values plotted in the graph are from Highlands County, some of the data are from adjacent counties. For the range of specific conductance values measured, multiplication of the specific conductance by 0.59 gives a reasonable approximation of dissolved-solids concentrations.

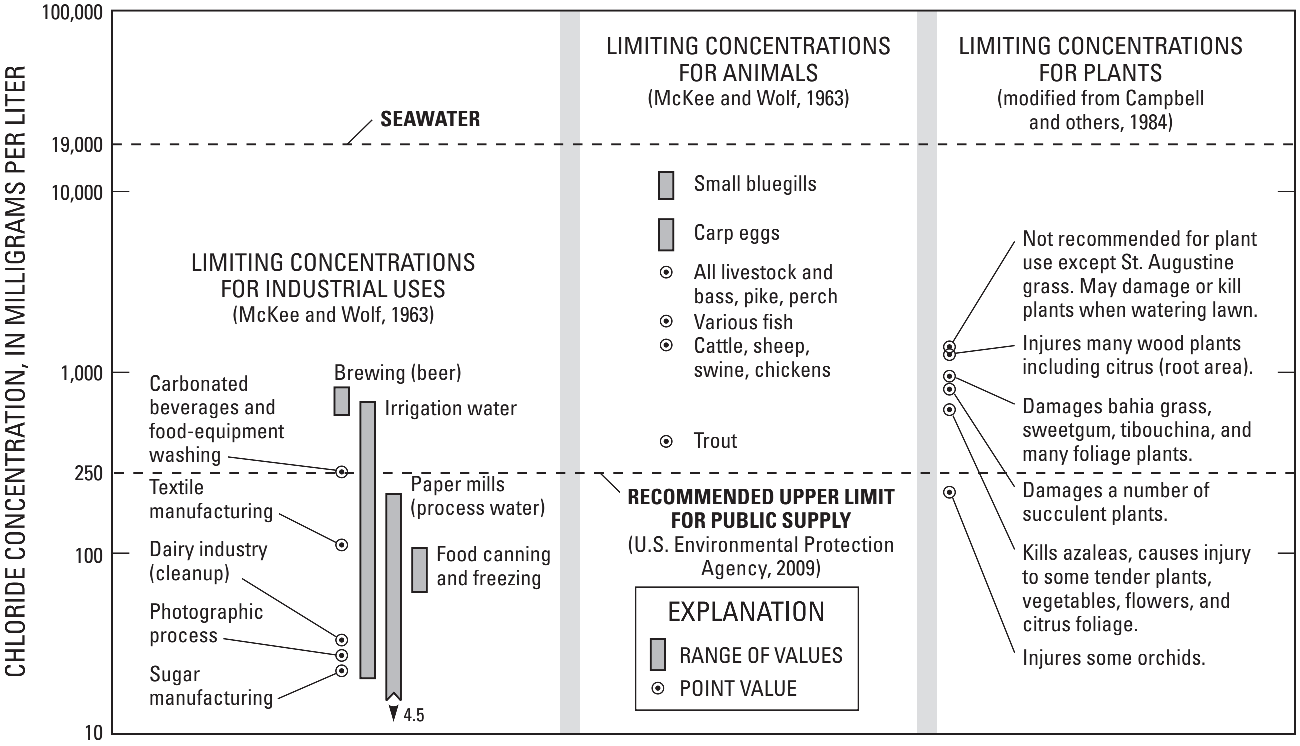


Figure 32. Limiting concentrations of chloride recommended for plants, animals, public-supply, and industrial use. Modified from Schiner (1993).

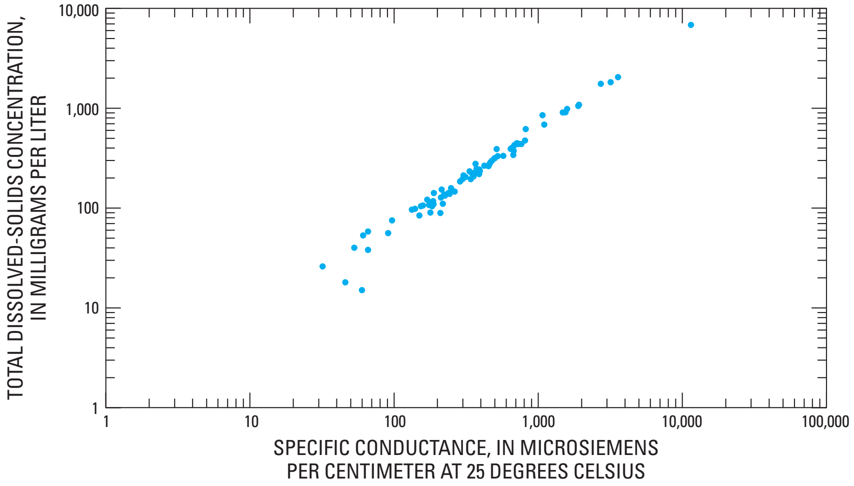


Figure 33. Relation between specific conductance and total dissolved-solids concentration.

When chloride concentrations are not available, chloride concentrations can also be estimated by measuring specific conductance. The relation between chloride concentration and specific conductance is shown in figure 34. The plot shows that the relation between specific conductance and chloride concentration is not as strong as between specific conductance and total dissolved-solids concentration, particularly at specific conductance values below about 800 µS/cm. Reasonable estimates of chloride can be provided at conductance values above this threshold value. In some less-mineralized waters, chloride may not be the major constituent and specific conductance instead may be more closely related to other constituents.

Water-chemistry data collected by the USGS and State agencies were compiled for this study (apps. 2 and 3). During this study, additional water samples from 58 wells were collected and analyzed by the USGS for major chemical constituents from 2006 to 2008. Samples were collected from 6 wells completed in the surficial aquifer, 15 wells completed in the intermediate aquifer system, and 37 wells completed in the Upper Floridan aquifer. In addition, water-quality samples from 71 wells were collected by the SFWMD, SWFWMD, FDEP, and Highlands County during 2000–08 and are also included in appendixes 2 and 3. These data include 40 samples from the surficial aquifer, 10 samples from the intermediate aquifer system, and 21 samples from the Upper Floridan aquifer. Listed for comparison in tables 3 and 4 are the minimum, maximum, and median values for all of the groundwater-quality constituents used in this report.

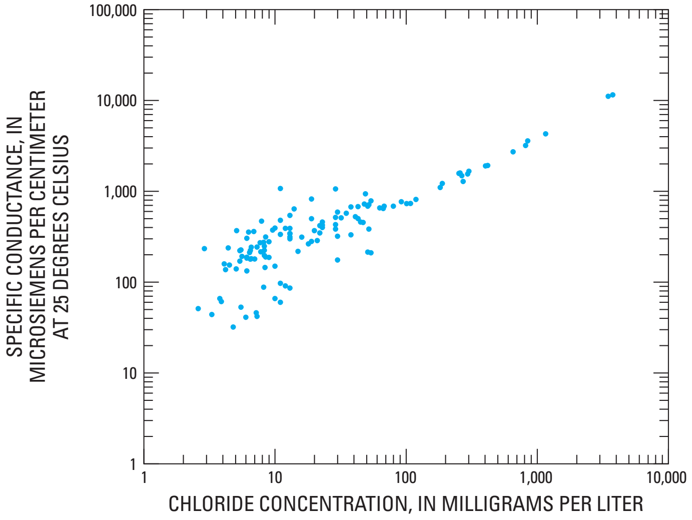


Figure 34. Relation between chloride concentration and specific conductance.

Table 3. Summary statistics of groundwater quality of the surficial aquifer and intermediate aquifer system in Highlands County.

[Concentrations shown in milligrams per liter, except for pH, in standard units; specific conductance, in microsiemens per centimeter; strontium, in micrograms per liter; and temperature, in degrees Celsius. <, less than the value]

Constituent	Surficial aquifer				Intermediate aquifer system			
	Number of samples	Minimum	Median	Maximum	Number of samples	Minimum	Median	Maximum
Alkalinity, as $CaCO_3$	35	0.50	13	300	15	21	154	290
Calcium	41	.27	19	120	16	5.5	36	160
Chloride	43	2.6	13	54	19	3.8	13	3,770
Fluoride	37	<.02	.10	1.2	17	<.12	.44	1.9
Hardness, as $CaCO_3$	7	4.0	13	159	12	17	175	1,200
Magnesium	41	.03	5.2	20	16	.87	14	186
Nitrate plus nitrite, as N	37	.004	.79	22	13	.004	<.04	<.04
Orthophosphate, as P	20	.004	.027	4.5	13	.004	.007	1.5
pH	40	4.1	5.2	7.3	19	6.4	7.5	8.7
Phosphorus	36	.004	.016	5.2	13	.003	<.006	1.6
Potassium	42	.06	1.9	23	16	1.2	2.4	37
Silica	26	.29	6.3	20	14	11	29	47
Sodium	43	1.1	5.5	58	16	3.9	15	1,940
Specific conductance	40	32	217	723	19	66	424	11,500
Strontium	24	6.8	<250	2,190	15	28	720	26,900
Sulfate	38	.20	23	87	19	.12	2.5	111
Temperature	40	21.5	25.9	29.5	19	19.7	24.1	25.2
Total dissolved solids	22	15	109	443	15	58	265	6,810

Table 4. Summary statistics of groundwater quality of the Upper Floridan aquifer in Highlands County.

[Concentrations shown in milligrams per liter, except for pH, in standard units; specific conductance, in microsiemens per centimeter; strontium, in micrograms per liter; and temperature, in degrees Celsius. <, less than the value]

Constituent	Number of samples	Minimum	Median	Maximum
Alkalinity, as $CaCO_3$	28	55	100	205
Calcium	28	4.4	28	71
Chloride	34	4.4	12	403
Fluoride	26	.09	.28	3.6
Hardness, as $CaCO_3$	23	64	130	410
Magnesium	28	4.3	13	57
Nitrate plus nitrite, as N	22	<.04	<.04	.22
Orthophosphate, as P	22	.005	.010	.251
pH	30	7.0	8.0	9.6
Phosphorus	22	<.006	.011	.272
Potassium	29	.63	1.8	9.3
Silica	28	9.7	17	35
Sodium	29	3.8	12	208
Specific conductance	34	133	307	1,900
Strontium	28	725	5,150	20,730
Sulfate	33	<.18	23	255
Temperature	30	22.4	25.3	28.4
Total dissolved solids	28	96	199	1,050

Surficial Aquifer

Concentrations of major ions and nutrients in groundwater in the surficial aquifer are variable and distinct patterns are evident. Several factors are responsible for this variability, including the lithology of the sediments, the interaction with the underlying aquifer, and most importantly, the effects of land use. Along the Lake Wales Ridge, citrus production has been prominent in the area since the early 1900s because of its sandy well-drained soils (Southwest Florida Water Management District, 2004a). Fertilizers, insecticides, fungicides, and herbicides are often applied to the groves to help increase crop yields and control pests and disease. These sandy soils, however, often have a low organic content and a limited capacity for filtering contaminants from water recharging the aquifer, thus increasing the vulnerability of the surficial aquifer to chemical contamination (Choquette and Sepúlveda, 2000).

Groundwater in the surficial aquifer in Highlands County generally has low concentrations of major ions and total dissolved-solids. The water types of the surficial aquifer are variable, and as indicated in the trilinear diagram on figure 35, can be a calcium bicarbonate, calcium sulfate, sodium chloride, or mixed cation and anion water type. Mixed water types associated with water in the surficial aquifer may reflect contributions of irrigation water as well as the addition of fertilizers to soil in citrus groves (Crandall, 2000). The results of chemical analyses of water from the surficial aquifer in Highlands and adjacent counties are presented in appendixes 2 and 3**.** Of the constituents analyzed for this study, with the exception of nitrate, water quality of the surficial aquifer in Highlands County is within the FDEP primary and secondary drinking-water standards.

Major Ions and Physical Characteristics

The generalized distributions of specific conductance, chloride, and sulfate in water from the surficial aquifer are shown in figures 36 to 38. As evident, water-quality data in the surficial aquifer are sparse in western and parts of eastern Highlands County. In Highlands County, specific conductance ranged from 32 to 723 µS/cm (fig. 36, app. 2, and table 3), with a median value of 217 µS/cm. Although data are lacking in parts of the county, the lowest specific conductance values (less than 200 µS/cm) generally occur just east and west of the Lake Wales Ridge, and the highest values (greater than 350 µS/cm) occur in a few areas along the Lake Wales Ridge and in the eastern part of the county. Total dissolved-solids

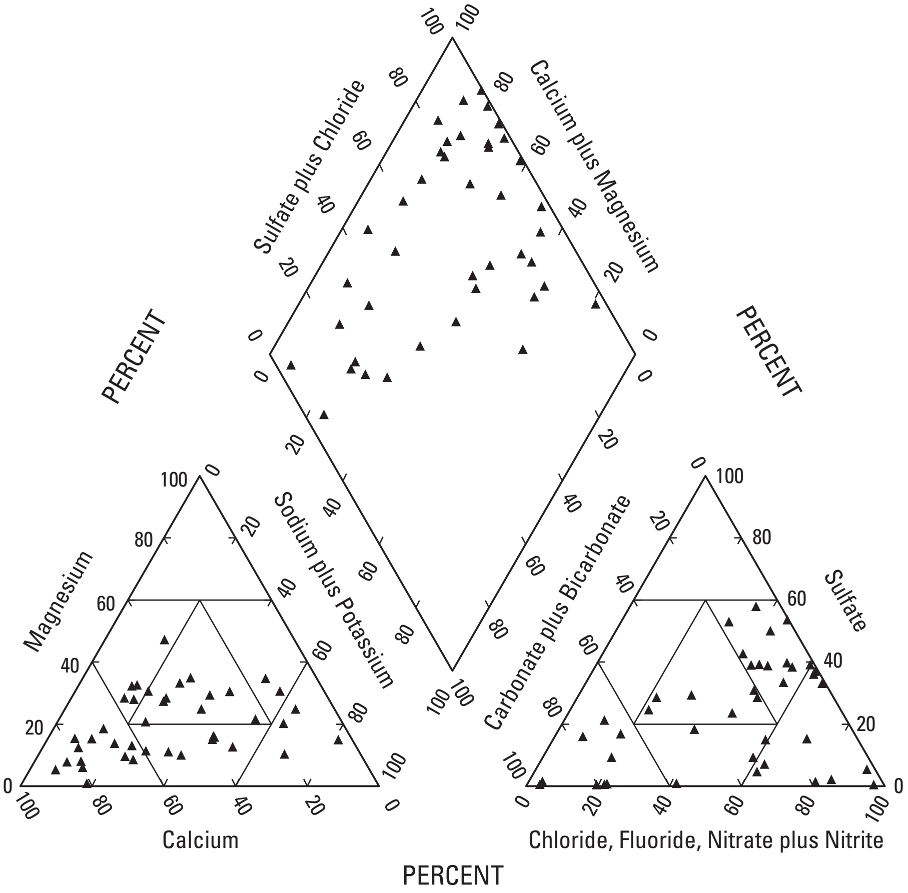


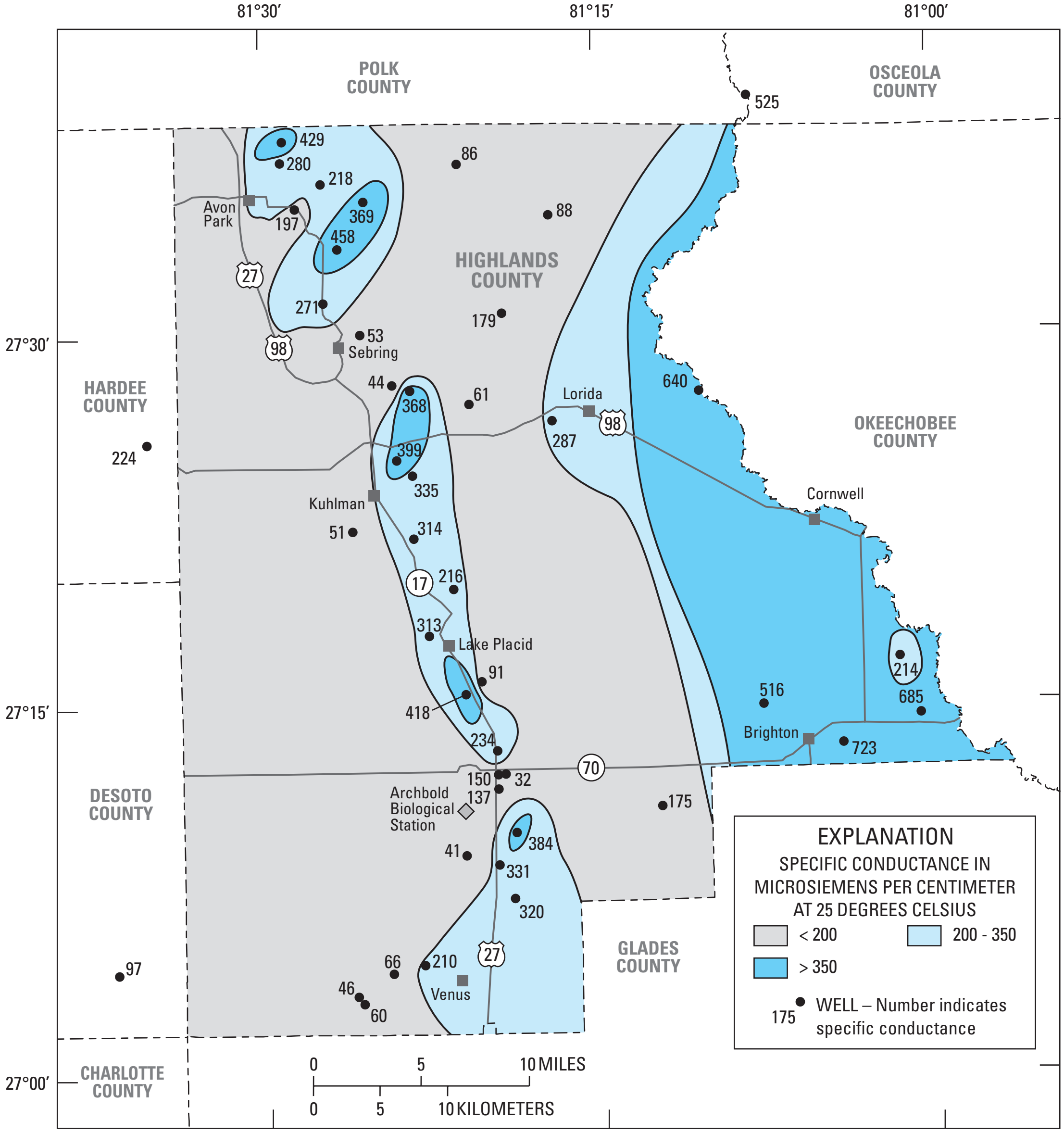
Figure 35. Chemical composition of water from the surficial aquifer.

concentrations in the surficial aquifer, determined from actual measured values and calculated values, are below the 500-mg/L recommended FDEP limits.

Chloride in groundwater from the surficial aquifer may be derived from several sources including the upward leakage of water from the Upper Floridan aquifer (in the eastern part of the County), septic-tank effluent, industrial waste, and small amounts contributed by rainfall. However, the most likely source of increased chloride and other inorganic constituents measured in groundwater from the surficial aquifer is through the use of agricultural chemicals in citrus areas and by the application of irrigated water from the Upper Floridan aquifer. Along the Lake Wales Ridge, fertilizers are the most likely source of increased chloride as well as potassium, sodium, and sulfate concentrations to groundwater, because fertilizers have been applied as potassium nitrate, potassium chloride, or sulfate salts (Choquette and Kroening, 2009).

Chloride concentrations in water from the surficial aquifer in Highlands County ranged from 2.6 to 54 mg/L, with a median value of 13 mg/L (fig. 37, app. 2, table 3). Chloride concentrations less than 10 mg/L occurred over much of the central and western parts of the county. Over parts of the Lake Wales Ridge and eastern Highlands County, concentrations ranged from 10 to 25 mg/L. Highest concentrations (exceeding 25 mg/L) occurred primarily in the southeastern part of the county and in a small area along the southern part of the Lake Wales Ridge.

Sulfate concentrations in water sampled from the surficial aquifer ranged from 0.20 to 87 mg/L (fig. 38, app. 2), with a median value of 23 mg/L (table 3). Sulfate concentrations were generally less than 10 mg/L throughout much of the eastern and western parts of Highlands County. Sulfate concentrations greater than 30 mg/L occurred primarily along the Lake Wales Ridge and in a small area in the southeastern part of the county. Small amounts of sulfate are obtained from oceanic sulfate aerosols and from the atmospheric oxidation of sulfides (Rye and others, 1981). In Highlands County, sulfate in the surficial aquifer 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). In areas where the Upper Floridan aquifer is used for irrigation and contains higher sulfate concentrations, additional sulfate may be added to surficial aquifer groundwater.



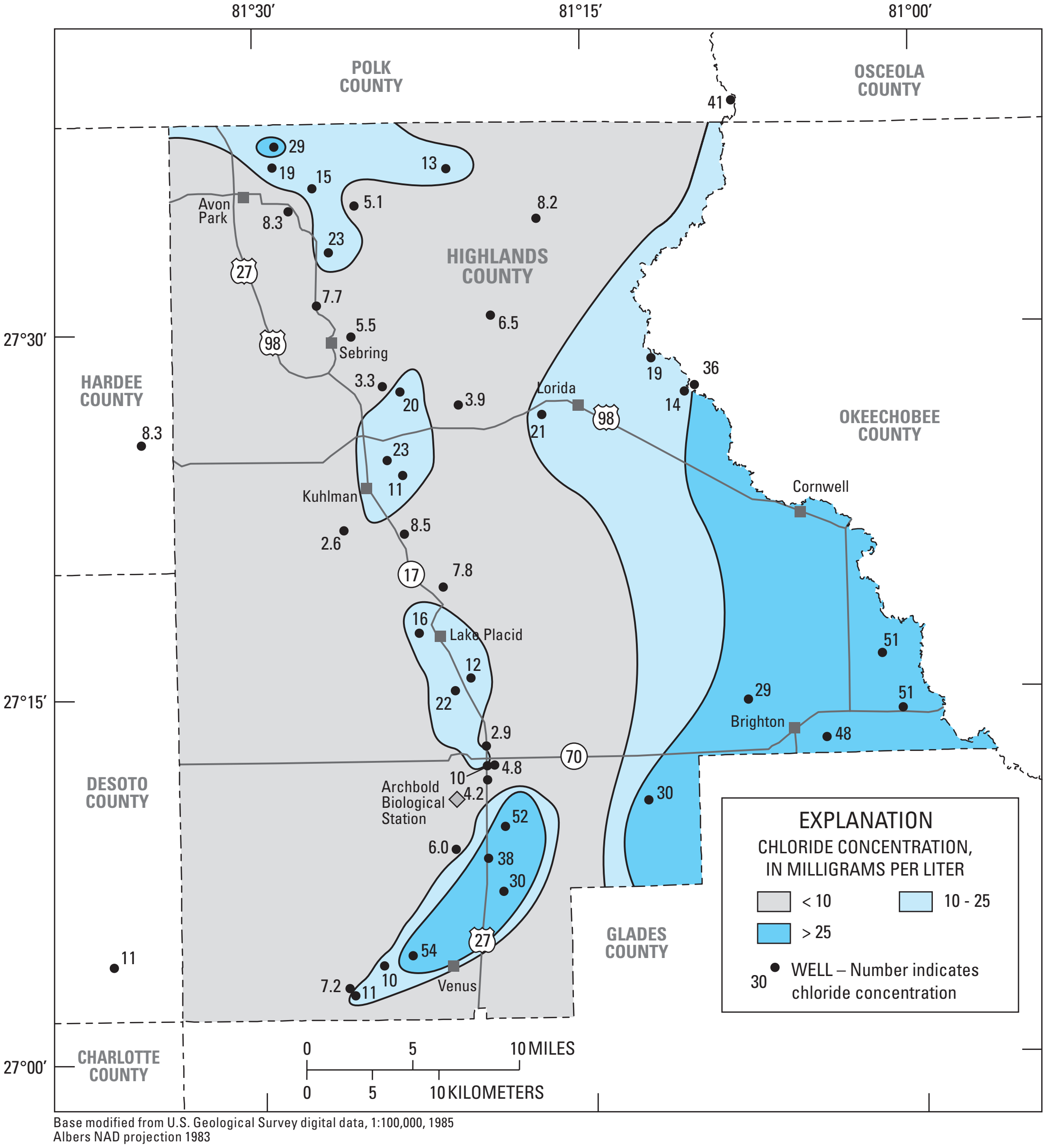
Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 36. Generalized distribution of specific conductance in water from the surficial aquifer.

Nutrients

Nutrient analyses are an important component of a groundwater-quality assessment, because the surficial aquifer can be contaminated with nitrogen and phosphorus compounds. Nitrogen occurs in a number of chemical forms, is part of many biological processes, and is required for the production of food (Wheaton and Graham, 2000). Nitrogen and phosphorus compounds in groundwater generally are the result of human activities, such as the application of fertilizers or because of the presence of human or animal waste. In surface water, high nutrient concentrations accelerate eutrophication. Dense vegetation growth can result in oxygen depletion in water due to plant death and subsequent decay. In groundwater, nitrate concentrations are an important limiting factor for potable water supply. High concentrations of nitrate in drinking water may cause methemoglobinemia in small children (Hem, 1985).

Most of the Lake Wales Ridge is underlain by soils that have been classified as vulnerable to leaching of agrichemicals (Choquette and Kroening, 2009). A group of soils common to the ridge areas that has been classified as vulnerable to leaching includes the Candler, Astatula, and Paola Soil Series (Choquette and Kroening, 2009). These soils exhibit minimal soil development, contain little organic matter, consist of



Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
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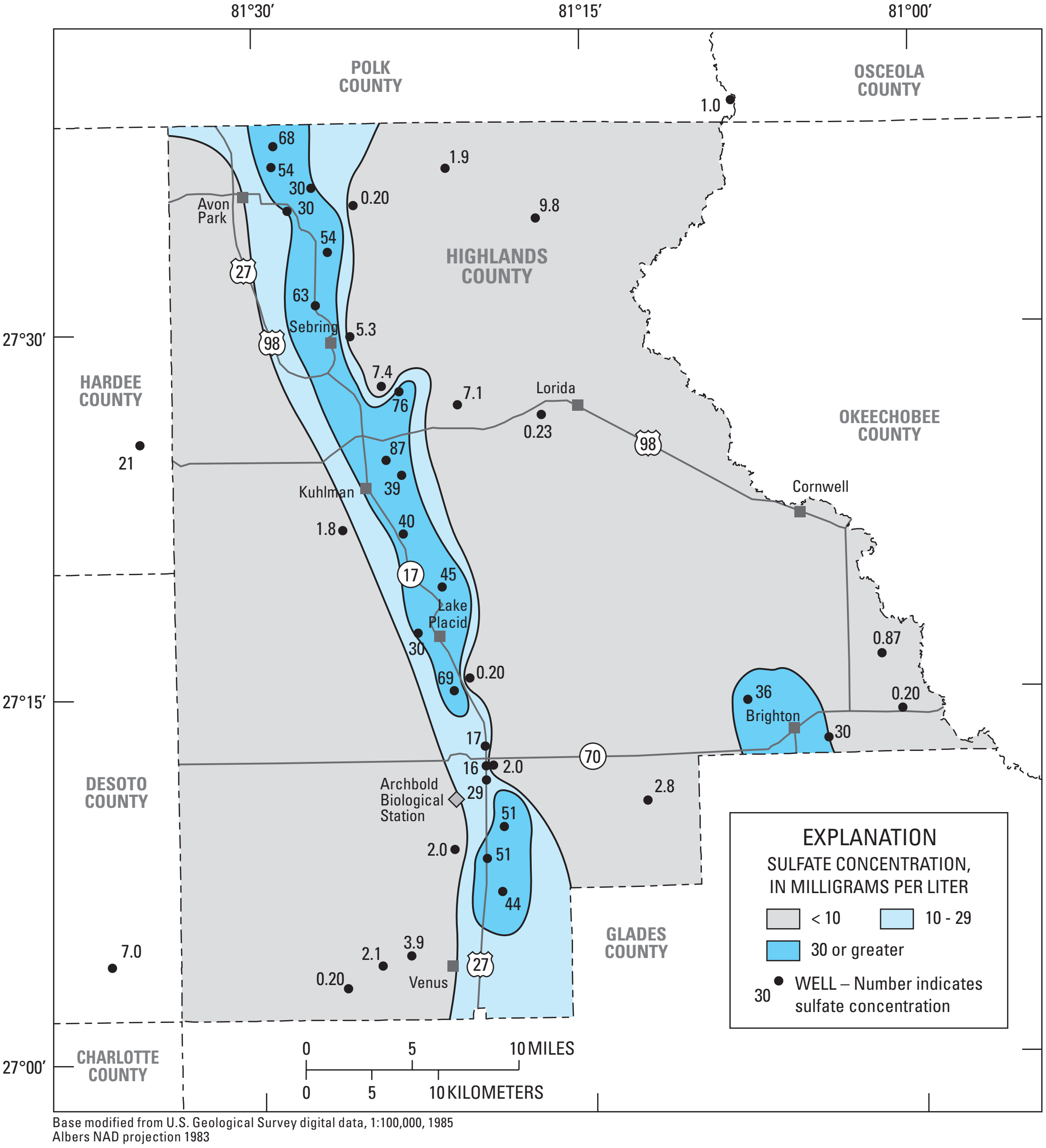
Figure 37. Generalized distribution of chloride concentrations in water from the surficial aquifer.

about 97 to 99 percent sand-sized particles, and have a high hydraulic conductivity (Choquette and Kroening, 2009). Nitrates are not retained by these soils, and nitrate not taken up by plants readily moves into the groundwater with rainfall or excessive irrigation.

Nitrate concentrations in water from the surficial aquifer ranged from 0.004 to 22 mg/L (fig. 39 and app. 3), with a median value of 0.79 mg/L (table 3). About half of the samples had nitrate concentrations less than or equal to the USGS reporting limit of 0.04 mg/L as nitrogen. The lowest concentrations generally were found east and west of the Lake Wales Ridge. Nitrate concentrations above the maximum contaminant level (MCL) are often found in the surficial aquifer along the Lake Wales Ridge. Water samples from seven wells along the Lake Wales Ridge had nitrate concentrations greater than 10 mg/L. Data obtained from the Florida Department of Environmental Protection (Rick Hicks, written commun., 2007) also show a number of water samples from wells along the Lake Wales Ridge with nitrate concentrations exceeding 10 mg/L (fig. 39) and a maximum concentration of 52 mg/L. Tihansky and Sacks (1997) reported nitrate concentrations in groundwater samples ranging from 4.9 to 57 mg/L in the citrus land-use areas of Polk and Highlands Counties. Nitrate concentrations greater than 10 mg/L as nitrogen exceed State primary drinking-water standards (Florida Department of Environmental Protection, 2008).



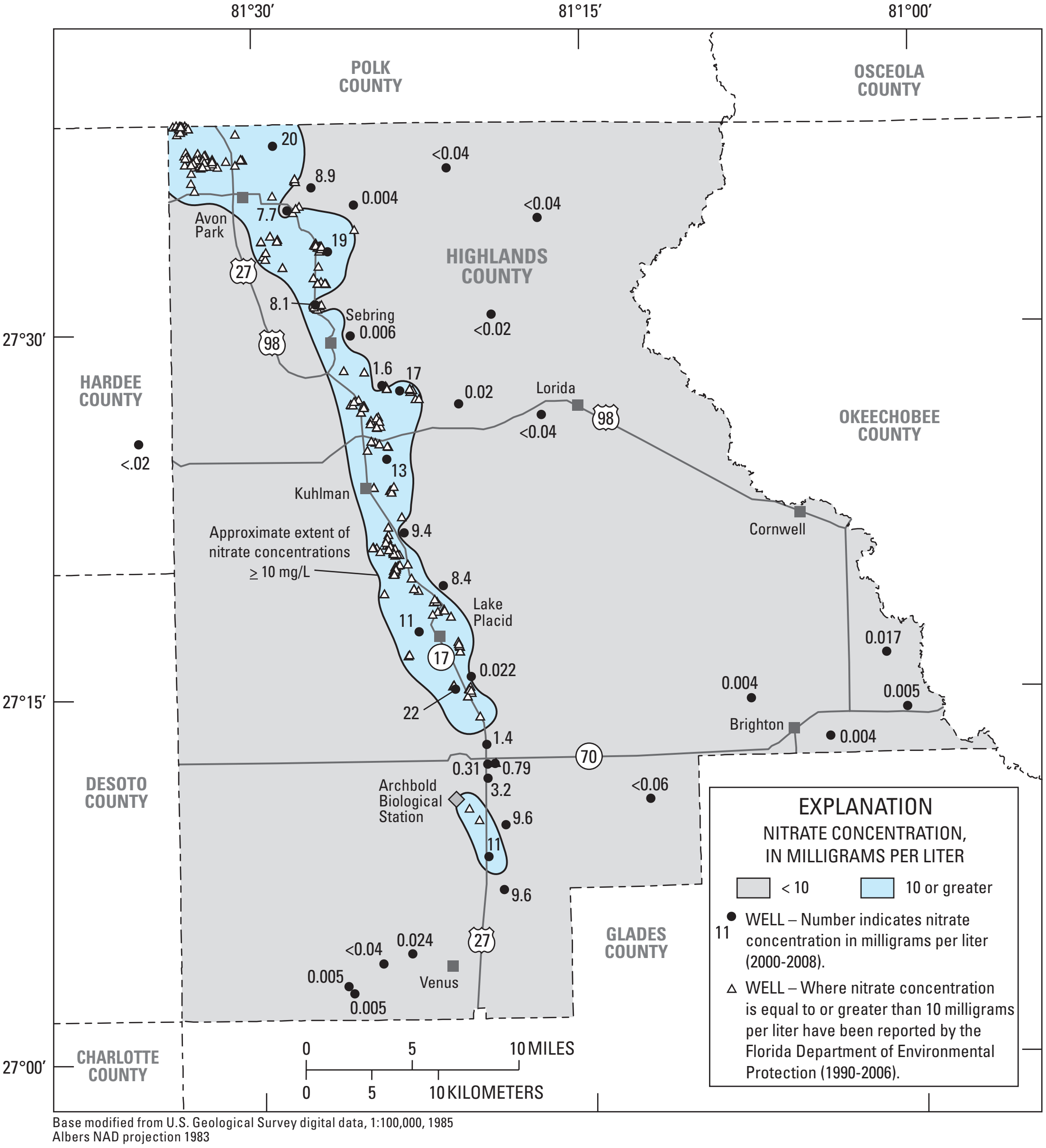
Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 38. Generalized distribution of sulfate concentrations in water from the surficial aquifer.

Concentrations of nitrate in groundwater underlying undeveloped areas generally are low, indicating that natural sources of nitrate do not contribute substantially to concentrations in groundwater. Nitrate concentrations of water samples underlying the Ocala National Forest in Lake and Marion Counties were less than 1.0 mg/L (Adamski and Knowles, 2001). Water samples collected from the surficial aquifer beneath undeveloped land at two sites in Polk and Highlands Counties had concentrations of less than 0.002 mg/L (Tihansky and Sacks, 1997). Likely sources of nitrate in these undeveloped areas are usually organic matter in soils and atmospheric deposition. In central Florida, the concentration of nitrate in rainwater generally is less than 1.0 mg/L (Adamski and German, 2004).

Other nutrients of interest in the study area are orthophosphate and phosphorus. Concentrations of dissolved orthophosphate in water from the surficial aquifer in Highlands County ranged from 0.004 to 4.5 mg/L, with a median value of 0.027 mg/L. Phosphorous concentrations ranged from 0.004 to 5.2 mg/L, with a median value of 0.016 mg/L (app. 3 and table 3).

Orthophosphate concentrations are typically low in the surficial aquifer because phosphate-bearing minerals are generally uncommon in the surficial aquifer (at least in the upper part). In addition, because of the ability of phosphate ions to sorb onto metal oxides, especially ferric and manganese oxyhydroxides, background concentrations in water greater than a



Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 39. Generalized distribution of nitrate concentrations in water from the surficial aquifer.

few tenths or hundredths of a milligram per liter are rare (Hem, 1985). Sources of orthophosphates in the surficial aquifer can be mineral (primarily apatite), sewage effluent, animal waste, or fertilizers. The maximum concentration of phosphorus is not regulated in drinking water; however, elevated concentrations of phosphorus in surface water can cause excessive growth of algae and cyanobacteria (Adamski and German, 2004).

Intermediate Aquifer System

The chemical composition of most of the groundwater sampled from the intermediate aquifer system is dominated by calcium and bicarbonate. Major cation and anion equivalent concentrations are illustrated on a trilinear diagram in figure 40. Analytical data of water from the intermediate aquifer system in Highlands and adjacent counties are given in appendixes 2 and 3. The water producing units were not differentiated because geologic or hydrologic information was not available for many of the sites. In general, most constituent concentrations were less than the FDEP primary and secondary drinking-water standards. Specific conductance

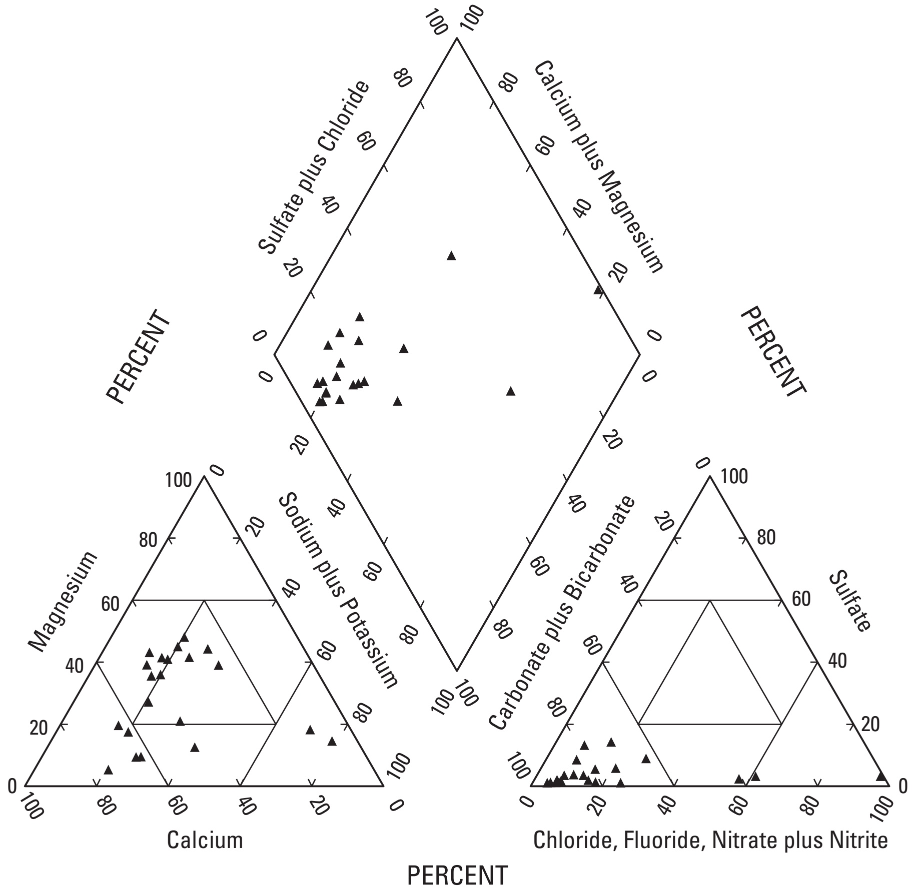


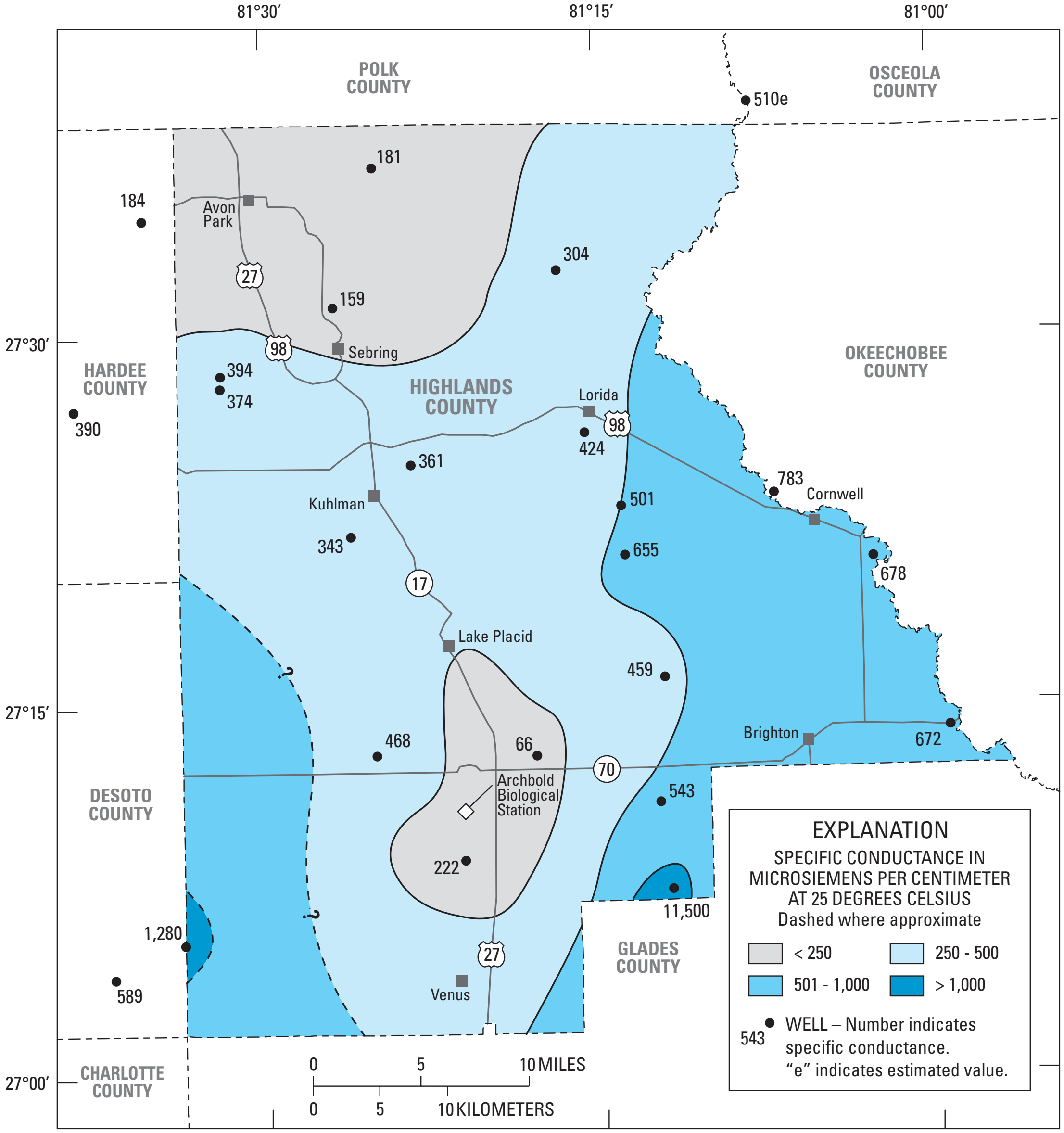
Figure 40. Chemical composition of water from the intermediate aquifer system.

and chloride concentrations in water from the intermediate aquifer system are shown in figures 41 and 42. Specific conductance values for Highlands County ranged from 66 to 11,500 µS/cm, with a median value of 424 µS/cm. Chloride concentrations in water ranged from 3.8 to 3,770 mg/L, with a median value of 13 mg/L. Specific conductance and chloride concentrations were lowest primarily in the northwestern and south-central parts of the county and highest in the southwestern and southeastern parts. Sulfate concentrations ranged from 0.12 to 111 mg/L, and hardness as $CaCO_3$ (calcium carbonate) concentrations ranged from 17 to 1,200 mg/L. The median values for sulfate and hardness were 2.5 and 175 mg/L, respectively. Nitrate, orthophosphate, and phosphorus concentrations ranged, respectively, from 0.004 to less than 0.04 mg/L, 0.004 to 1.5 mg/L, and 0.003 to 1.6 mg/L.

The highest values for specific conductance, chloride concentration, and water hardness (as $CaCO_3$) in the intermediate aquifer system were obtained from a 500-ft deep well (well 22) in southern Highlands County. These values also were the highest values reported from any aquifer in the county. The specific conductance of water from this well was 11,500 µS/cm. Hardness and chloride concentrations were 1,200 and 3,770 mg/L, respectively. Sulfate concentration, although not anomalously high, was 111 mg/L. The source of this highly mineralized water is probably relict seawater that entered the intermediate aquifer system during Pleistocene age. This zone of mineralized water, probably trapped in strata of low permeability, has not been removed by the modern-day freshwater flow system.

Upper Floridan Aquifer

The Upper Floridan aquifer is the most productive and widely used aquifer in Highlands County. In much of the county, water in the Upper Floridan aquifer generally meets FDEP primary and secondary drinking-water standards. However, more mineralized water is present at depth beneath the entire county. Chemical analyses of groundwater samples from wells completed in the Upper Floridan aquifer indicate differences in the ionic composition of water, and several chemical types of groundwater occur in the study area.



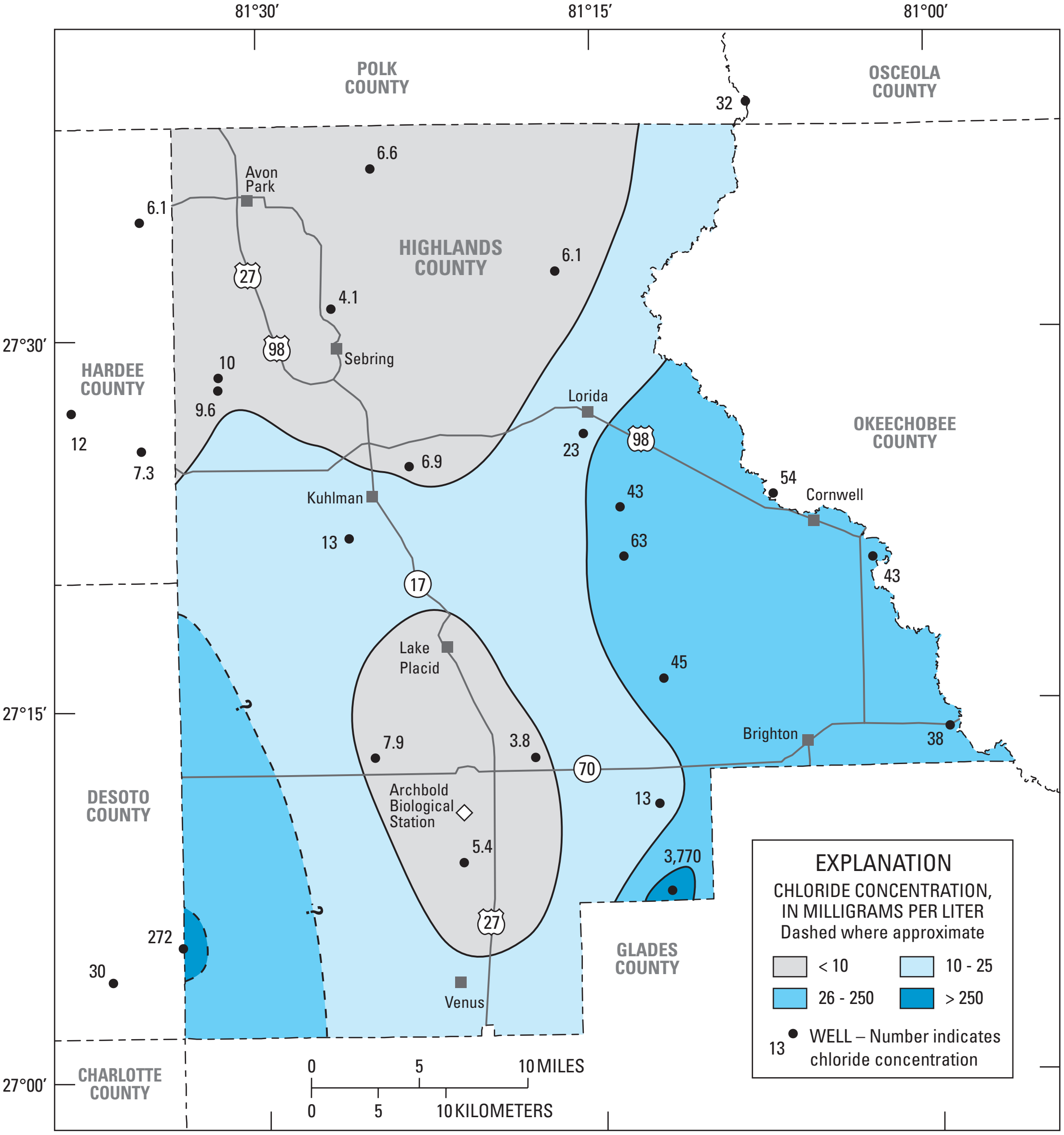
Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 41. Generalized distribution of specific conductance in water from the intermediate aquifer system.

The first chemical type, dominated by calcium, magnesium, and bicarbonate ions, generally occurs in the recharge area along the Lake Wales Ridge. This water type results from the dissolution of carbonate rocks that form the aquifer. The relatively large percentage of magnesium in the water samples is probably related to the dissolution of dolomite in the carbonate sequence of the aquifer. This first water type, which is generally low in dissolved solids, is represented by the data just above the left apex of the diamond-shaped area in figure 43. The second groundwater type contains calcium, magnesium, and sulfate. This water type, represented by samples from wells that plot toward the upper apex of the diamond, is often more mineralized than the calcium bicarbonate type and is primarily due to the dissolution of sulfate-bearing minerals. The third groundwater type, dominated by sodium and chloride, occurs primarily in the eastern part of Highlands County. The sodium chloride water type represents the mixing of freshwater with relict seawater. Analyses of sodium chloride water are plotted above the right apex of the diamond (fig. 43).

Major Ions and Physical Characteristics

Maps of specific conductance, chloride, sulfate, and water hardness (as $CaCO_3$) for the Upper Floridan aquifer were constructed to delineate water-quality differences across



Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 42. Generalized distribution of chloride concentrations in water from the intermediate aquifer system.

Highlands County (figs. 44–47). Concentrations of these constituents varied areally and with depth in the study area. The majority of water samples collected from wells completed in the Upper Floridan aquifer came from wellhead samples. In Highlands County, wells are commonly constructed with tens to hundreds of feet of open-hole section. Water pumped from these wells consists of water derived from the open-hole section of the borehole, and the water may come from more than one producing zone. Because each zone can have distinctive water-quality characteristics, the quality of water pumped from a well depends on which zones are tapped and the proportion of water derived from each zone. In cases where a well is completed in both the upper and lower parts of the Upper Floridan aquifer, the quality of the pumped water is likely to be more representative of the lower part of the Upper Floridan aquifer (Avon Park permeable zone) because of its higher transmissivity.

Specific conductance in the Upper Floridan aquifer in Highlands County ranged from 133 to 1,900 µS/cm, with a median value of 307 µS/cm (fig. 44, table 4). The areas of lowest specific conductance (less than 250 µS/cm) generally occurred in the northwestern and west-central parts of the county. In the area roughly adjacent to and including parts of the Lake Wales Ridge, specific conductance ranged from about 250 to 500 µS/cm. Specific conductance values were greatest (more than 1,000 µS/cm) in the extreme southwestern and eastern parts of the county, with the latter being a discharge area.

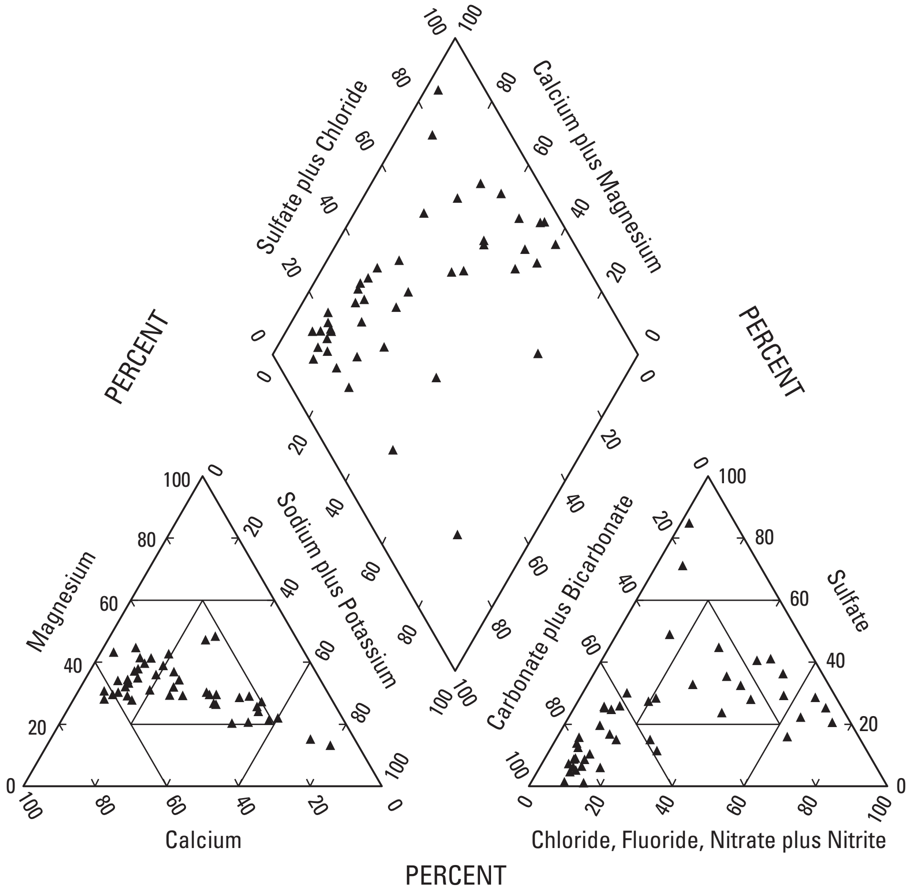


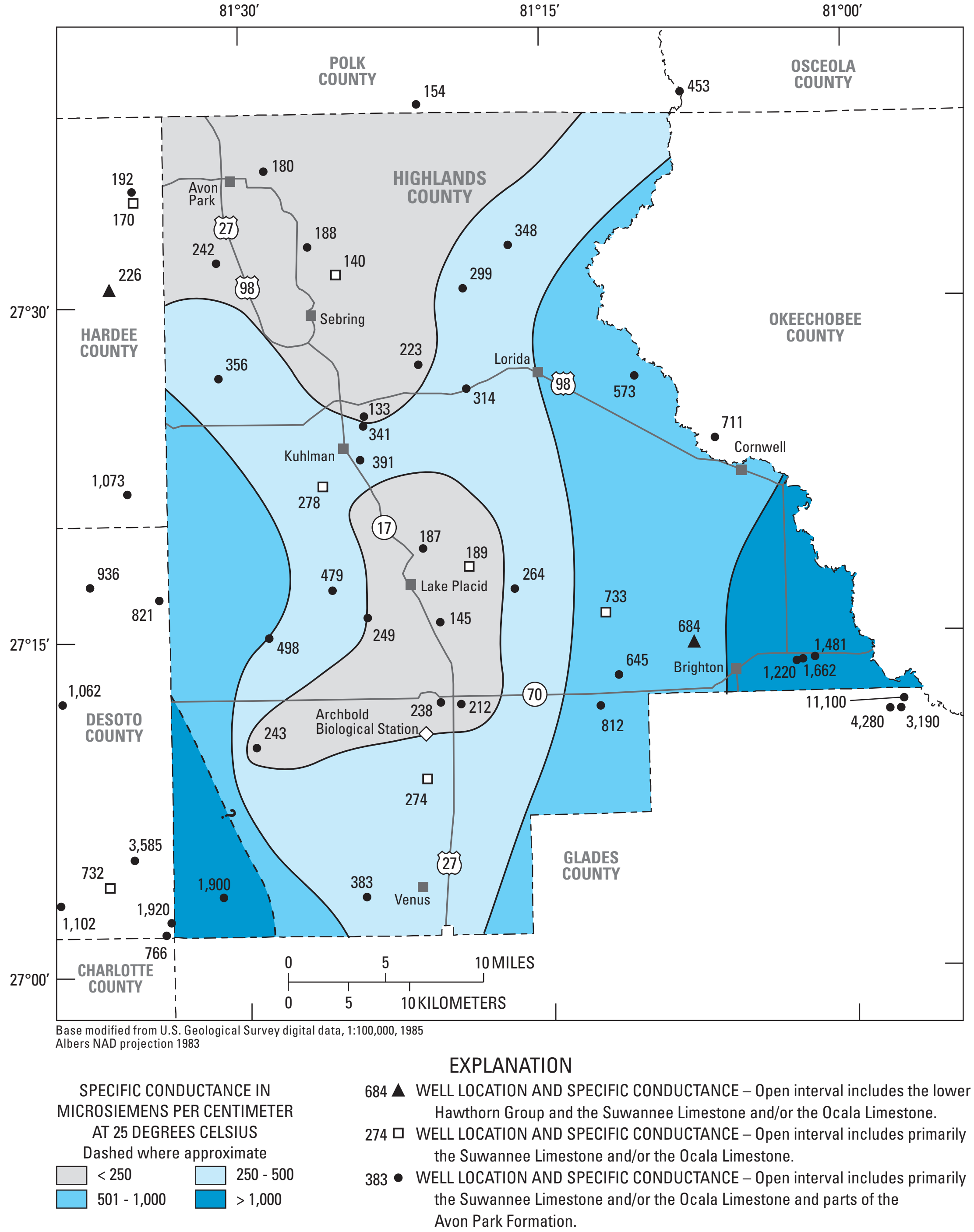
Figure 43. Chemical composition of water from the Upper Floridan aquifer.

Measured total dissolved-solids values (app. 2, table 4) indicate that total dissolved solids in water in the Upper Floridan aquifer in Highlands County ranged from 96 to 1,050 mg/L, with a median value of 199 mg/L. Most calculated total dissolved-solids values determined from specific conductance (fig. 33) also fell within this range. With the exception of the areas in the extreme southwestern and extreme eastern Highlands County, total dissolved-solids concentrations were below the 500-mg/L recommended FDEP limits.

Chloride concentrations in the Upper Floridan aquifer in Highlands County ranged from 4.4 to 403 mg/L (fig. 45, app. 2), with a median value of 12 mg/L (table 4). The lowest concentrations, less than 10 mg/L, generally occurred along the recharge area of the Lake Wales Ridge. Concentrations ranging from 26 to 250 mg/L occurred in the southwestern and eastern parts of the county. Chloride concentrations were below the 250-mg/L recommended limit for drinking water throughout most of the county, with the exception of the extreme southwestern and extreme eastern parts of the county. Bradner (1994) reported chloride concentrations greater than 400 mg/L in Okeechobee County just east of Brighton, and Klein and others (1964) reported chloride concentrations exceeding 1,000 mg/L in the extreme northeastern part of Glades County.

Chloride concentration often is used as an indicator to delineate the extent of saltwater intrusion within an area. Most of the mineralized water in the Upper Floridan aquifer in southeastern Highlands County (and into Glades County) probably is a mixture of freshwater and relict seawater that entered the aquifer during a higher stand of sea level in the geologic past and has not been completely flushed from the aquifer. Natural salts of chloride (halite) are not present in the Upper Floridan aquifer (Sprinkle, 1989).

Sulfate concentrations in the Upper Floridan aquifer in Highlands County ranged from less than 0.18 to 255 mg/L (fig. 46, app. 2), with a median value of 23 mg/L (table 4). Concentrations of less than 10 mg/L generally occurred in the northwestern and west-central parts of the county and from 30 to 250 mg/L in much of the western and eastern parts of the county. Sulfate concentrations exceeded 250 mg/L in the extreme southeastern part of the county near the Kissimmee River, and possibly in the extreme western part of the county near the DeSoto/Hardee County line.



Base modified from U.S. Geological Survey digital data, 1:100,000, 1985
Albers NAD projection 1983

Figure 44. Generalized distribution of specific conductance in water from the Upper Floridan aquifer.

The principal processes responsible for the presence of sulfate in water from the Upper Floridan aquifer are the dissolution of sulfur-bearing minerals in the aquifer and the mixing of freshwater with water having a chemical composition similar to that of seawater. The dissolution of gypsum and dilution of seawater have distinct trends on a plot of the relation of the mass ratio of sulfate to chloride and the sulfate concentration of water samples (Rightmire and others, 1974). Figure 47 shows that groundwater having a low sulfate-chloride ratio and a high sulfate concentration is represented by points plotting near the seawater-mixing trend line. Groundwater having a high sulfate-chloride ratio is represented by points plotting near the dissolution of the gypsum-mixing trend line, indicating that gypsum is the major source of sulfate in water in the Upper Floridan aquifer. Most samples plot

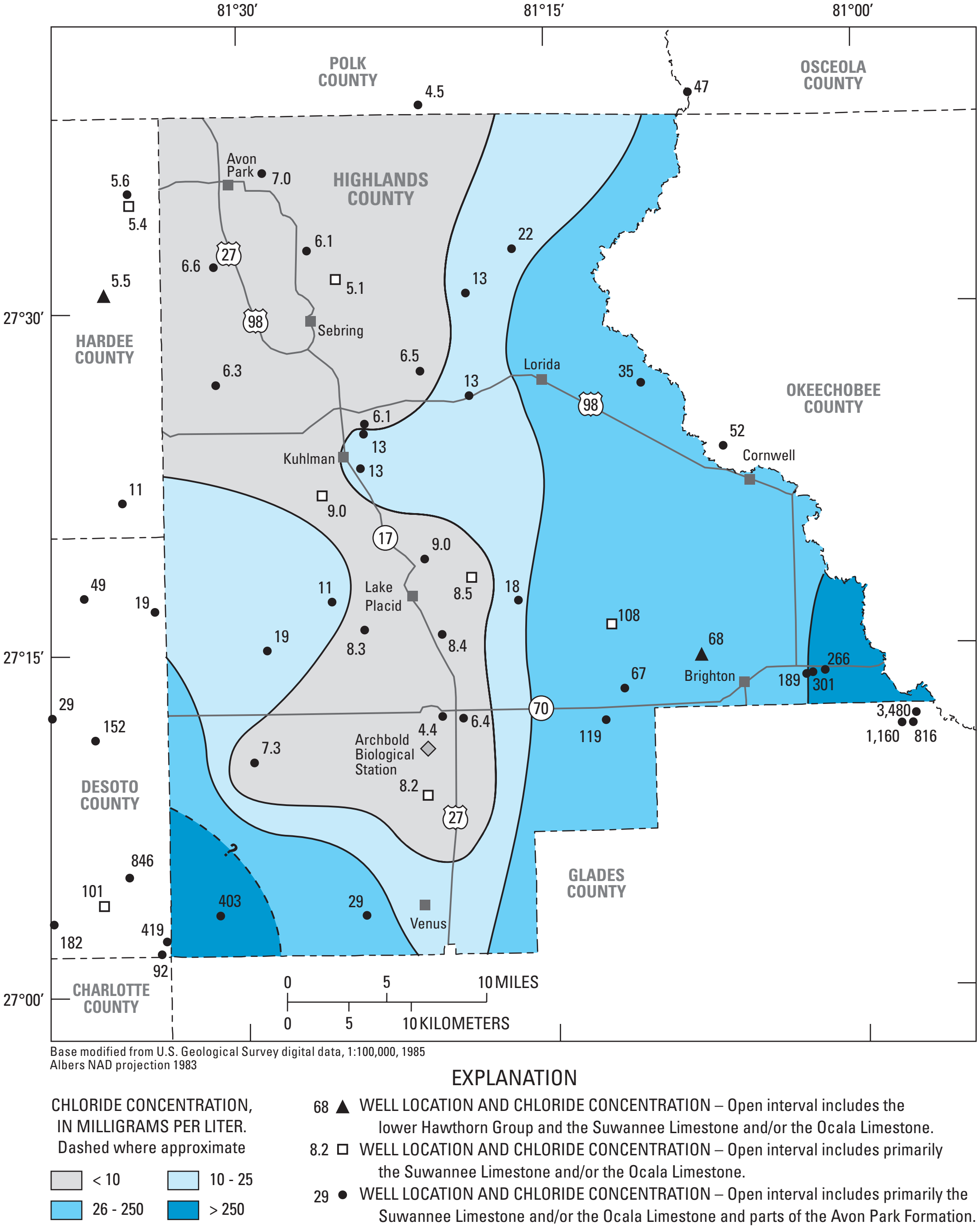


Figure 45. Generalized distribution of chloride concentrations in water from the Upper Floridan aquifer.

somewhere between these trend lines, indicating varying degrees of freshwater-seawater mixing and gypsum dissolution.

Hardness is used to describe the resistance of water to produce lather from soap. Hardness results from the presence of dissolved calcium and magnesium ions, and is expressed in terms of equivalent milligrams per liter of calcium carbonate (Hem, 1985). Hardness is classified as soft (0–60 mg/L), moderately hard (61–120 mg/L), hard (121–180 mg/L), and very hard (greater than 180 mg/L) (Hem, 1985). Currently, the U.S. Environmental Protection Agency (2009) has not established a recommended limit for hardness. Hard water causes scaling, which is the formation of mineral deposits that remain after the water evaporates. Scaling can clog pipes and damage water heaters.

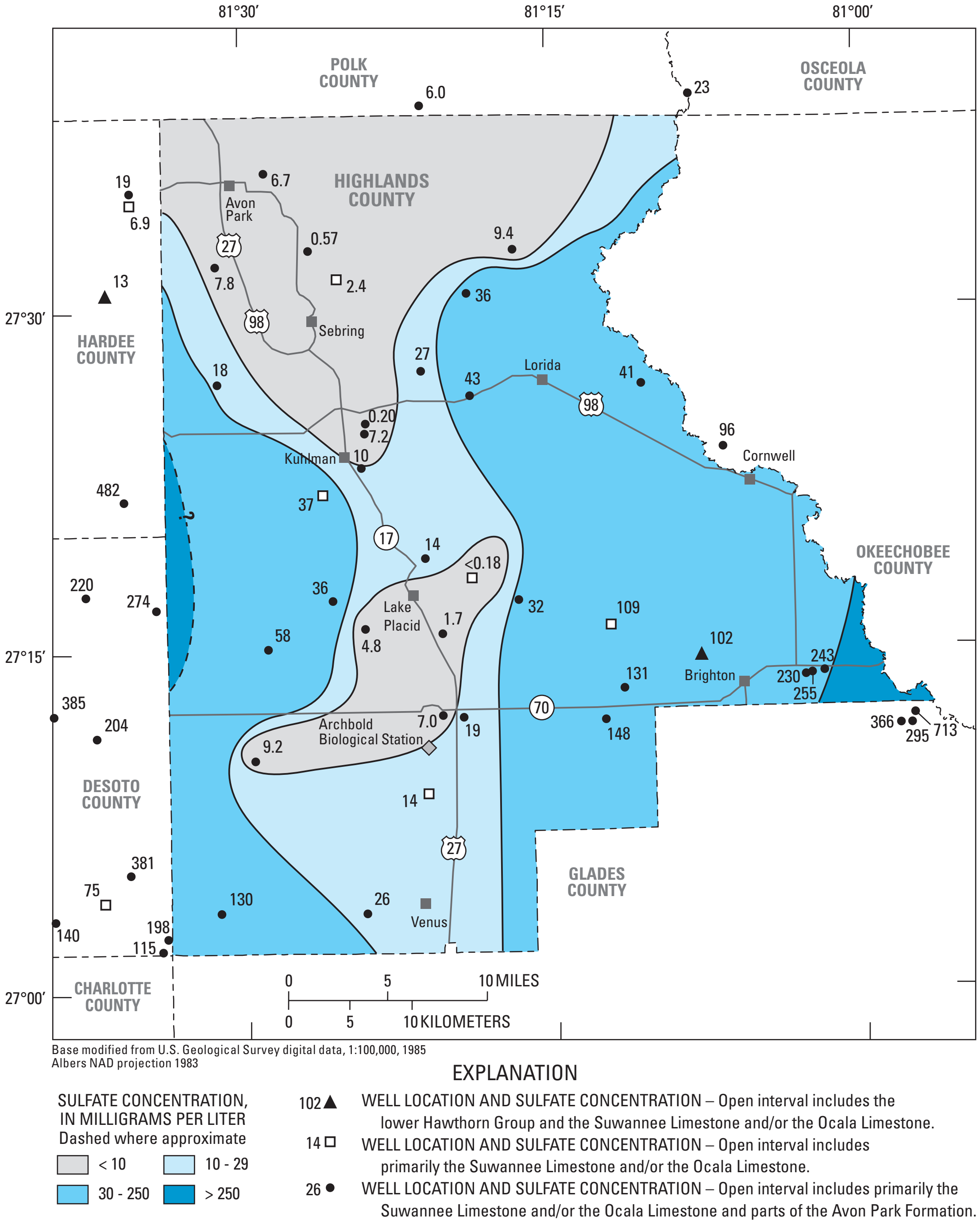


Figure 46. Generalized distribution of sulfate concentrations in water from the Upper Floridan aquifer.

Hardness in water sampled from the Upper Floridan aquifer in Highlands County ranged from 64 to 410 mg/L (fig. 48, app. 2), with a median value of 130 mg/L (table 4). Lowest concentrations (less than 120 mg/L) occurred in the recharge area, primarily along or adjacent to the Lake Wales Ridge. The highest concentrations (greater than 180 mg/L) occurred primarily in the eastern and southwestern parts of the county. The principal processes responsible for the hardness in water from the Upper Floridan aquifer are the dissolution of limestone, dolomite, and gypsum, and the mixing of freshwater with relict seawater. The hardness of groundwater in the Upper Floridan aquifer generally increases with the amount of time water is in contact with calcium or magnesium-rich rocks.

Nitrate Concentration

Unlike the surficial aquifer, nitrate concentrations in groundwater from the Upper Floridan aquifer in Highlands County generally were very low. Nitrate concentrations in water ranged from less than 0.04 to 0.22 mg/L (app. 3), and were less than the detection limit in 21 of 22 samples from the Upper Floridan aquifer.

Processes that may be responsible for the low nitrate concentrations in groundwater in the Upper Floridan aquifer underlying Highlands County are denitrification and dilution. Where sinkholes are absent, nitrate concentrations typically decrease with depth below land surface. Denitrification is the primary process likely responsible for the reduction in nitrate concentration with depth. Nitrate accumulates in groundwater under aerobic conditions (nitrification) and is converted to reduced species of nitrogen under anaerobic conditions (denitrification). Geochemical factors required for denitrification to occur include: (1) the presence of nitrogen oxides as terminal electron acceptors; (2) the presence of bacteria capable of reducing nitrate; (3) suitable electron donors, such as organic carbon and iron; and (4) anaerobic conditions or restricted availability of dissolved oxygen (Tihansky and Sacks, 1997).

Low nitrate concentrations in the Upper Floridan aquifer can also result from the dilution of high nitrate water from the surficial aquifer with low nitrate water naturally present in the Upper Floridan aquifer. However, the occurrence of somewhat elevated chloride and sulfate concentrations (two indicators of agricultural activity) and elevated specific conductance above background levels from wells completed in the Upper Floridan aquifer indicate that dilution is probably not the dominant process responsible for the decrease in nitrate with depth. Where sinkholes are present, breaches in the IAS/ICU can allow nitrate from the surficial aquifer to directly enter the Upper Floridan aquifer, which may explain locally elevated nitrate concentrations in groundwater from the aquifer.

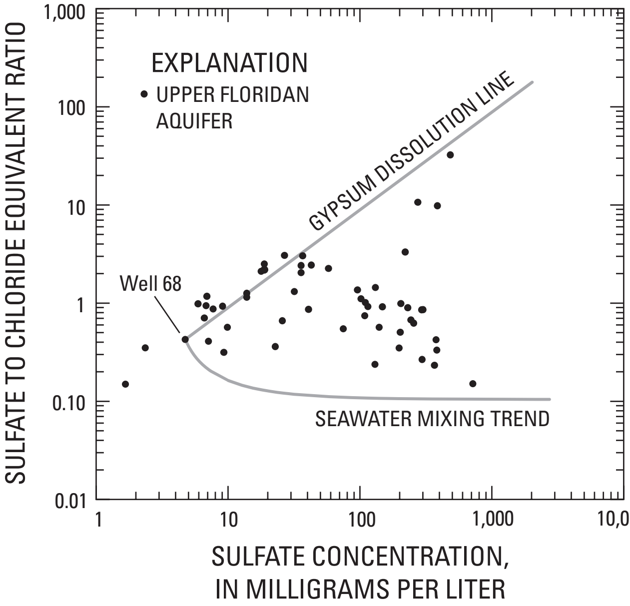


Figure 47. Relation between sulfate-chloride equivalent ratio and sulfate concentration in water from the Upper Floridan aquifer.

Vertical Distribution of Chloride and Sulfate Concentrations

Data from deep wells drilled throughout Florida indicate that mineralized water underlies the entire State. The depth to the mineralized water varies considerably and is controlled by the subsurface stratigraphy, land-surface altitude, and the altitude of the freshwater head (Franks, 1982). Several monitoring wells have been drilled into the middle confining units in Highlands and adjacent counties to acquire information about variations in water quality within the intermediate aquifer system and Upper Floridan aquifer. Profiles of chloride and sulfate concentrations of four monitoring wells drilled to nearly 2,000 ft are illustrated in figure 49. Water samples from these wells were either collected through the drill stem as the wells were drilled or collected using bailer or packer test methods. In general, limited well data indicate that in much of the study area, groundwater having chloride and sulfate concentrations of less than 100 mg/L extends to considerable depths in the Upper Floridan aquifer, and chloride and sulfate concentrations generally increase with depth. Sulfate concentrations increase rapidly with depth just above the top of middle confining unit II at ROMP 13, 14, and 29A. Chloride concentrations increase in a similar manner in ROMP 13 and ROMP 14.

At ROMP 13 (figs. 1 and 49), chloride concentrations are less than 100 mg/L in the intermediate aquifer system and the upper part of the Upper Floridan aquifer (Baldini and Rappuhn, 1998). Chloride concentrations in the intermediate aquifer system ranged from about 30 to 90 mg/L. Chloride concentrations in much of the Upper Floridan aquifer were slightly higher, ranging from about 50 to 100 mg/L between 699 and 1,579 ft below land surface. Chloride concentrations increased rapidly from 107 to 1,981 mg/L between 1,579 ft and 1,610 ft below land surface. Chloride concentrations further increased from 1,981 to 4,804 mg/L at depths of between 1,610 and 2,075 ft below land surface.

Sulfate concentrations in ROMP 13 increased slightly with depth in the intermediate aquifer system, ranging from about 2 to 64 mg/L. In the Upper Floridan aquifer, sulfate concentrations changed little with depth, ranging from 42 to 91 mg/L in the interval from 699 and 1,579 ft. Sulfate concentrations increased sharply to 745 mg/L at about 1,610 ft and eventually leveled off at about 1,700 mg/L. This sharp increase in the mineralization of the groundwater, which was also observed at ROMP 14 and to a lesser degree at ROMP 28, indicates a less

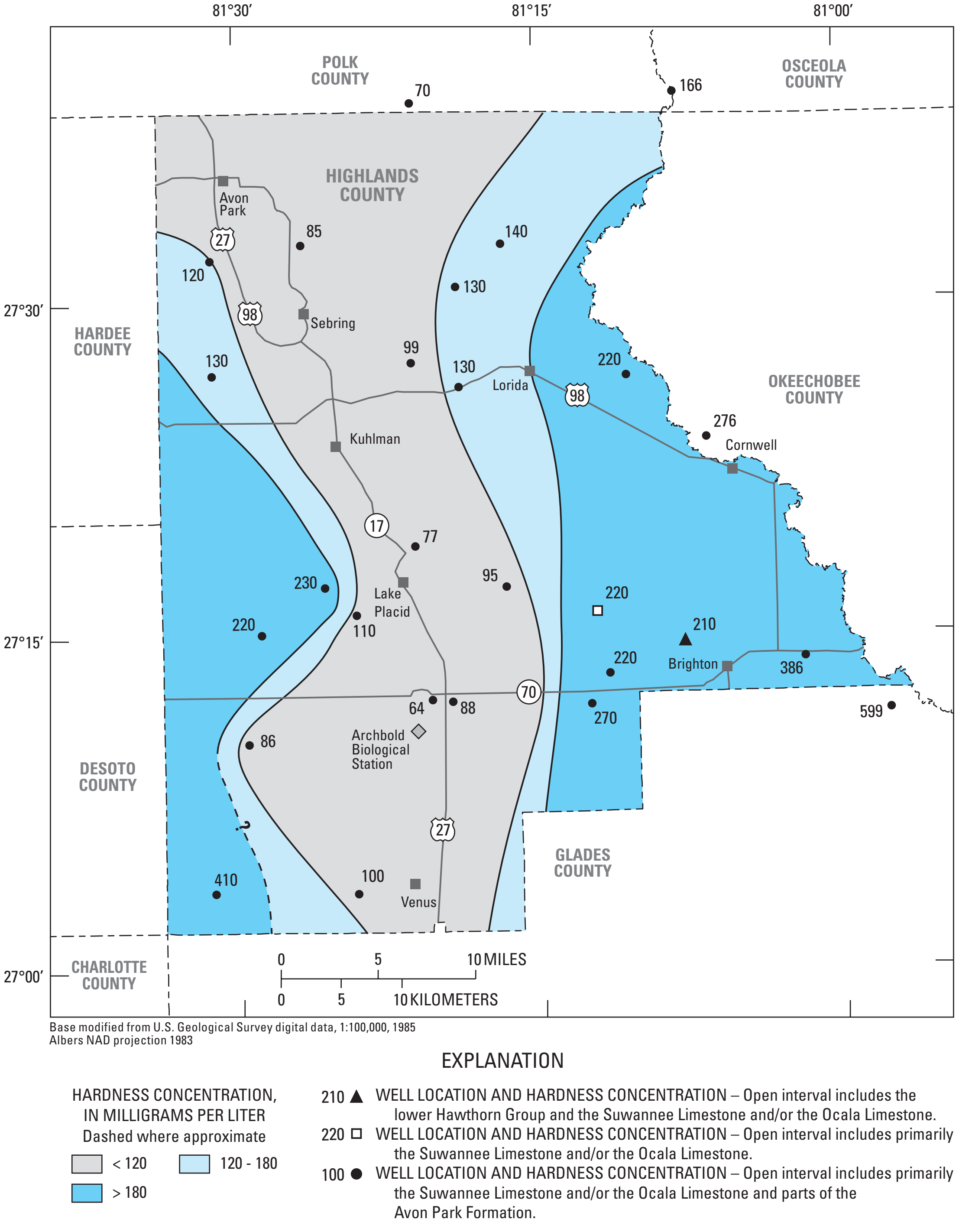


Figure 48. Generalized distribution of hardness concentrations in water from the Upper Floridan aquifer.

active flow system below the base of the Avon Park permeable zone (DeWitt, 1998). In the interval from 1,641 to 2,075 ft, sulfate concentrations ranged from 923 to 2,563 mg/L.

Chloride concentrations in water from ROMP 14 increased gradually with depth between 400 and 1,730 ft below land surface, ranging from about 3 to 73 mg/L (Clayton, 1998). Chloride concentrations increased sharply to 2,180 mg/L from 1,730 to 1,755 ft below land surface. From 1,776 ft to the bottom of the hole (1,995 ft below land surface), chloride concentrations ranged from 2,313 to 2,780 mg/L. Sulfate concentrations also increased gradually with depth, ranging from 3 to 111 mg/L to a depth of 1,730 ft. At about 1,735 ft below land surface, sulfate concentrations increased sharply to 1,093 mg/L. In the interval from 1,755 to 1,995 ft below land surface, concentrations varied from 1,495 to 2,100 mg/L.

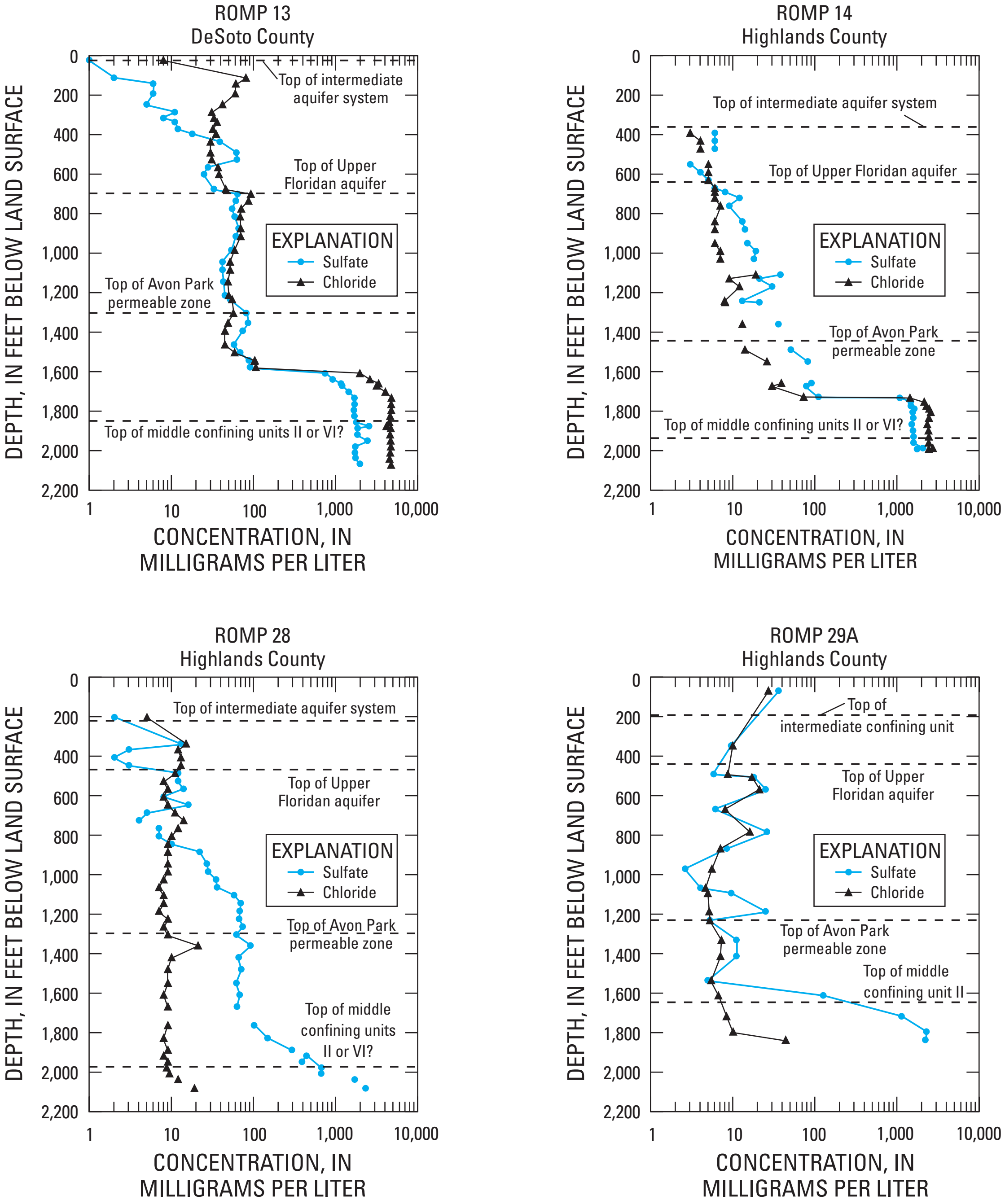


Figure 49. Chloride and sulfate concentrations in water samples obtained during drilling of monitoring wells. Modified from Peterman and Rappuhn (1997), Clayton (1998), DeWitt (1998), and Mallams and Lee (2005). Site numbers refer to figure 1.

Water-quality data collected at ROMP 28 show that chloride concentrations changed little during drilling and remained below 25 mg/L to the bottom of the hole (2,085 ft below land surface). Sulfate concentrations were more variable and gradually increased from about 2 to 102 mg/L from 200 to 1,765 ft below land surface. Concentrations increased more rapidly, from 102 to 2,356 mg/L, in the interval from 1,765 to 2,085 ft below land surface (DeWitt, 1998).

At ROMP 29A, chloride concentrations changed little during drilling and generally remained below 25 mg/L to a depth of about 1,800 ft below land surface (Mallams and Lee, 2005). In the interval from 1,800 ft to the bottom of the hole (1,875 ft below land surface), chloride concentrations increased slightly from about 10 to 40 mg/L. Sulfate concentrations also varied little with depth, remaining below 30 mg/L to a depth of 1,537 ft below land surface. From 1,537 ft to the bottom of the hole, sulfate concentrations increased sharply from about 5 mg/L to a maximum concentration of 2,320 mg/L. This increase in sulfate concentrations roughly corresponds with the top of middle confining unit II, which is estimated to be at 1,650 below land surface.

Summary and Conclusions

Highlands County, which encompasses about 1,823 mi^2 in the south-central part of the Florida Peninsula, is the 14th largest county in the State. The county is predominantly rural, with most of the population concentrated along the Lake Wales Ridge. Continued population growth in Highlands County is expected to increase the demand for potable water. The population of Highlands County has increased from about 21,000 in 1960, to 99,000 in 2007, and is projected to reach about 120,000 by 2020. In 2007, the county population was the 34th largest in the State.

Total groundwater use increased steadily in Highlands County from about 37 Mgal/d in 1965 to about 107 Mgal/d in 2005. Much of this increase in water use is related to agricultural activities, especially citrus cultivation, which increased more than 300 percent from 1965 to 2005. The principal source of groundwater supply for the county is the Upper Floridan aquifer, which provides about 89 percent of the groundwater withdrawn. Of the total groundwater withdrawn in 2005, about 89 percent was used for agriculture, 8 percent for public supply, 2 percent for recreational irrigation, 1 percent for domestic, and less than 0.1 percent for both commercial/industrial and thermoelectric power generation.

The principal hydrogeologic units underlying the study area include the surficial aquifer, the intermediate aquifer system/intermediate confining unit (IAS/ICU), and the Floridan aquifer system. The surficial aquifer is the uppermost water-bearing unit and underlies the entire county. The sediments range from Pliocene to Holocene in age and consist mostly of fine-to-medium grained quartz sand with varying amounts of clay and silt. The aquifer is unconfined, and the base is defined as the first persistent unit of sediments containing a substantial increase in clay or silt. The thickness of the surficial aquifer is highly variable, ranging from less than 50 to more than 300 ft. The water table in the surficial aquifer fluctuates about 1 to 5 ft seasonally. The hydraulic properties of the surficial aquifer vary considerably across the county and depend largely upon aquifer thickness, physical characteristics such as grain size and sorting, and types of material that compose the aquifer. Groundwater in the surficial aquifer is recharged primarily by precipitation, but also by septic tanks, irrigation by wells, seepage from lakes and streams, and lateral groundwater inflow from adjacent areas. About 9 percent of the total groundwater used in Highlands County is withdrawn from the surficial aquifer and is used for domestic and irrigation purposes.

The IAS/ICU includes all of the rock units that lie between the overlying surficial aquifer and the underlying Floridan aquifer system. These rock units generally coincide with the stratigraphic units designated as the Hawthorn Group, although the top of the units can also include the clayey sediments of early Pliocene age. Throughout Highlands County, the units act as a confining layer (except where breached by sinkholes) that restricts the vertical movement of water between the surficial aquifer and the underlying Upper Floridan aquifer. The sediments have varying degrees of permeability and consist of permeable limestone, dolostone, or sand, or relatively impermeable layers of clay, clayey sand, or clayey carbonates. The altitude of the top of the IAS/ICU ranges from more than 50 ft above NGVD 29 in the western part of the county to more than 150 ft below NGVD 29 along the southern part of the Lake Wales Ridge. The thickness of the IAS/ICU ranges from about 200 ft in northwestern Highlands County to more than 600 ft in the southwestern part of the county.

The intermediate confining unit is present in the eastern part of the county, although it is unclear where the confining unit grades into an aquifer system. In Highlands County, up to two aquifers are present in the intermediate aquifer system. The lateral continuity and water-bearing potential of the various aquifers within the intermediate aquifer system are highly variable due to the heterogeneity of the Hawthorn Group sediments. About 2 percent of the total groundwater used in Highlands County is withdrawn from the intermediate aquifer system and is used for public supply and irrigation purposes.

The Floridan aquifer system is composed of a thick sequence of limestone and dolostone of Upper Paleocene to Oligocene age. The principal formations of the aquifer system are the Suwannee Limestone, Ocala Limestone, Avon Park Formation, Oldsmar Formation, and upper part of the Cedar Keys Formation. The top of the aquifer system ranges from less than 200 ft below NGVD 29 in the extreme northwestern part of the county to more than 600 ft below NGVD 29 in the southwestern part. The thickness of the aquifer system ranges from about 2,800 to 3,400 ft.

The Floridan aquifer system is divided into two aquifers of relatively high permeability, referred to as the Upper Floridan aquifer and the Lower Floridan aquifer. These aquifers are separated by less-permeable middle confining units. The Upper Floridan aquifer is further divided by another semiconfining unit into two water-bearing zones within the study area—the upper water-bearing zone of the Upper Floridan aquifer and the Avon Park permeable zone.

The transmissivity of the Upper Floridan aquifer varies throughout the study area. Transmissivity determined from aquifer and specific capacity tests in Highlands County range from less than 1,000 to about 410,000 ft^2/d. Model-derived transmissivity values for the Upper Floridan aquifer range from about 10,000 to 500,000 ft^2/d. Groundwater in the Upper Floridan aquifer flows downgradient from potentiometric highs to potentiometric lows. West of the Lake Wales Ridge, the direction of groundwater flow is southwest, toward the

Peace River. East of the ridge, the direction of flow is toward the Kissimmee River. The potentiometric surface of the Upper Floridan aquifer is constantly fluctuating, mainly in response to seasonal variations in rainfall and groundwater withdrawals. In May 2007, the potentiometric surface ranged from about 79 ft above NGVD 29 in northwestern Highlands County to about 40 ft above NGVD 29 in the southeastern part of the county. In September 2007, the potentiometric surface ranged from about 85 ft above NGVD in northwestern Highlands County to about 43 ft above NGVD 29 in the southeastern part of the county. Potentiometric surface altitudes in September 2007 were about 3 to 10 ft higher than those measured in May 2007.

Groundwater quality was assessed by sampling 58 wells and by compiling data collected from 71 additional wells by State and County agencies. Inorganic constituents were the focus of water-quality analyses.

Water quality in the surficial aquifer can be highly variable. This variability results from several factors, including the lithology of the sediments, interaction with the Upper Floridan aquifer, but most importantly, the effects of land use. The water types within the surficial aquifer are diverse and include calcium bicarbonate, calcium sulfate, sodium chloride, or mixed cation and mixed anion types. Concentrations of major ions and specific conductance are generally low: specific conductance ranged from 32 to 723 µS/cm, and none of the samples had concentrations of total dissolved-solids, chloride or sulfate that exceeded State or Federal drinking-water standards. However, nitrate concentrations in water from the surficial aquifer ranged from 0.004 to 22 mg/L, and often exceeded the State primary drinking-water standard of 10 mg/L along the Lake Wales Ridge. Water from seven wells along the Lake Wales Ridge had nitrate concentrations greater than 10 mg/L. Data obtained from the Florida Department of Environmental Protection also showed a number of wells along the Lake Wales ridge with nitrate concentrations exceeding 10 mg/L. Fertilizers applied for citrus farming are the most likely source of nitrate to the groundwater in this area.

Water in the intermediate aquifer system was primarily a calcium bicarbonate water type. Specific conductance ranged from 66 to 11,500 µS/cm, and concentrations of chloride and sulfate ranged from 3.8 to 3,770 and 0.12 to 111 mg/L, respectively. Nitrate concentrations ranged from 0.004 to less than 0.04 mg/L. One well tapping the intermediate aquifer system in southern Highlands County had some of the highest inorganic constituents reported for any aquifer in the county. The source of this highly mineralized water is probably relict seawater that entered the aquifer system during the Pleistocene. This zone of mineralized water, probably trapped in strata of low permeability, has not been removed by the modern-day freshwater flow system.

Water in most of the Upper Floridan aquifer in Highlands County is typically a calcium magnesium bicarbonate, a calcium magnesium sulfate, or a sodium chloride water type. Concentrations of chemical constituents vary both areally and with depth. Inorganic constituent concentrations generally were below State and Federal drinking-water standards, except in the extreme southeastern and southwestern parts of the county. Specific conductance in water ranged from 133 to 1,900 µS/cm. Chloride concentrations ranged from 4.4 to 403 mg/L, and sulfate concentrations ranged from less than 0.18 to 255 mg/L. Water from the Upper Floridan aquifer in most of the county is hard, ranging from 64 to 410 mg/L. Nitrate concentrations in water from the Upper Floridan aquifer ranged from less than 0.04 to 0.22 mg/L. Nitrate concentrations were less than the detection limit in 21 of 22 samples from the Upper Floridan aquifer. Lower nitrate concentrations in the Upper Floridan aquifer indicate that denitrification may be occurring as groundwater moves downward, but lower concentrations also may be due to dilution.

Most of the mineralized water in the Upper Floridan aquifer in the southeastern and southwestern parts of Highlands County probably is a mixture of freshwater and relict seawater that entered the aquifer during a higher stand of sea level in the geologic past and has not been completely flushed from the aquifer. In addition, the principal source of sulfate in water from the Upper Floridan aquifer is dissolved sulfur-bearing minerals in the aquifer.

Highlands County appears to have sufficient groundwater resources of good chemical quality for present and future needs. The expected continued growth in population and agriculture in Highlands County and adjacent counties warrants the need for additional information on the quantity and quality of groundwater resources in Highlands County. Continuing to monitor groundwater levels would provide a basis for detecting changes in the potentiometric surface of the Upper Floridan aquifer. An expansion of deep monitoring wells in eastern and southwestern Highlands County would provide water managers a more accurate evaluation about the effects of withdrawals on the occurrence and quality of the groundwater resources. Additional monitoring wells also could be used to characterize the geology, hydrology, and water quality of the subsurface. The additional information would increase knowledge of the spatial distribution and hydraulic relation of the aquifers and their confining units in Highlands County.

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Appendixes

Appendix 1. Inventory of wells used in this study.

[Well locations shown in figure 11. Hydrogeologic unit: SA, surficial aquifer; IAS, intermediate aquifer system; UFA, Upper Floridan aquifer; LFA, Lower Floridan aquifer. Primary data type: QW, water-quality sample; WL, groundwater level. Source of data: Consult, consultant report; FDEP, Florida Department of Environmental Protection; HC, Highlands County; SFWMD, South Florida Water Management District; SWFWMD, Southwest Florida Water Management District; USGS, U.S. Geological Survey; —, no data]

Well No.	USGS site ID No.	Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Bottom of casing (feet below land surface)	Well depth (feet below land surface)	Hydrogeologic unit	County	Primary data type	Source of data
1	270157081203101	H-15A	270158	812032	19	23	SA	Highlands	WL	USGS, SWFWMD
2	270208081341201	VC Hollingsworth #8	270209	813413	673	1,100	UFA	DeSoto	QW	SWFWMD
3	270242081335701	4 N 1 Groves P-4 (DID #4)	270242	813357	601	1,225	UFA	DeSoto	QW	SWFWMD
4	270302081255501	270302081255501	270302	812555	25	35	SA	Highlands	QW	FDEP, SFWMD
5	270313081391001	Emerald Island (DID #5)	270331	813925	610	1,300	UFA	DeSoto	QW	SWFWMD
6	270344081241601	Sherley Deep	270344	812416	650	1,500	UFA	Highlands	QW	USGS
7	270348081261201	270348081261201	270320	812611	20	30	SA	Highlands	QW	FDEP, SFWMD
8	270348081312101	Southern Farms	270348	813121	700	1,400	UFA	Highlands	QW	USGS
9	270415081243401	Sherley Shallow	270415	812434	45	55	SA	Highlands	QW	USGS
10	270418081365801	ROMP 13 Avon Park	270419	813659	1,550	1,600	UFA	DeSoto	WL, QW	SWFWMD
11	270418081365802	ROMP 13 Suwannee (MW-4)	270419	813658	671	786	UFA	DeSoto	QW, WL	SWFWMD, USGS
12	270418081365803	ROMP 13 Lower Arcadia	270419	813658	510	592	IAS	DeSoto	WL, QW	SWFWMD, USGS
13	270418081365804	ROMP 13 Upper Arcadian	270419	813658	282	417	IAS	DeSoto	QW, WL	SWFWMD, USGS
14	270418081365805	ROMP 13 Surficial	270419	813659	7.5	24	SA	DeSoto	QW, WL	SWFWMD, USGS
15	270437081231601	270437081231601	270439	812315	40	45	SA	Highlands	QW	FDEP, SFWMD
16	—	BREX-1	270441	810706	640	1,216	UFA	Glades	QW	Consult
17	270531081354401	Sunpure LTD #304 (DID #4)	270531	813545	638	1,308	UFA	DeSoto	QW	SWFWMD
18	270540081335101	Nafco Groves	270540	813349	100	300	IAS	DeSoto	QW	SWFWMD
19	270556081204701	HIF-26 Hendrie Dairy	270556	812047	—	1,610	UFA	Highlands	WL	USGS
20	270627081313101	HIF-23 Graham Dairy	270627	813131	—	1,560	UFA	Highlands	WL	USGS
21	270717081185701	Gould Road Surficial	270714	811903	22	32	SA	Highlands	QW	SWFWMD
22	270743081115401	Center South	270743	811154	360	500	IAS	Highlands	QW	USGS
23	270835081194201	Hickory Branch Road Surficial	270835	811942	80	90	SA	Highlands	QW	SWFWMD
24	270858081211101	ROMP 14 AVPK	270859	812114	1,003	1,670	UFA	Highlands	WL, QW	SWFWMD, USGS
25	270858081211102	ROMP 14 Low Htrn	270859	812112	460	521	IAS	Highlands	QW, WL	SWFWMD
26	270858081211103	ROMP 14 Surficial	270859	812112	30	300	SA	Highlands	QW, WL	SWFWMD, USGS
27	270858081211104	ROMP 14 Suwannee	270859	812112	650	730	UFA	Highlands	QW, WL	SWFWMD, USGS
28	270952081183101	Womble Road Surficial	270953	811855	40	50	SA	Highlands	QW	SWFWMD
29	—	Perry Brothers (well 225)	271029	812936	680	990	UFA	Highlands	QW	SWFWMD
30	271052081121901	Lower Tropical East	271052	811219	40	45	SA	Highlands	QW	USGS
31	271114081122401	Tropical East	271114	811224	100	110	IAS	Highlands	QW	USGS
32	271132081371801	Bright Hour Ranch	271132	813718	—	1,485	UFA	DeSoto	QW	SWFWMD
33	271134081234301	HIF-05 Stidham	271134	812343	602	1,510	UFA	Highlands	WL	USGS
34	271147080573601	Stratton-Slough Pasture	271147	805736	—	—	UFA	Glades	QW	USGS
35	271147080580801	Stratton-100 acre	271147	805808	—	—	UFA	Glades	QW	USGS
36	271148081194201	Rozier Road Surficial	271148	811942	40	50	SA	Highlands	QW	SWFWMD
37	271150081054401	GL-155	271150	810544	—	600	UFA	Glades	WL	USGS

Appendix 1. Inventory of wells used in this study.—Continued

[Well locations shown in figure 11. Hydrogeologic unit: SA, surficial aquifer; IAS, intermediate aquifer system; UFA, Upper Floridan aquifer; LFA, Lower Floridan aquifer. Primary data type: QW, water-quality sample; WL, groundwater level. Source of data: Consult, consultant report; FDEP, Florida Department of Environmental Protection; HC, Highlands County; SFWMD, South Florida Water Management District; SWFWMD, Southwest Florida Water Management District; USGS, U.S. Geological Survey; —, no data]

Well No.	USGS site ID No.	Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Bottom of casing (feet below land surface)	Well depth (feet below land surface)	Hydrogeologic unit	County	Primary data type	Source of data
38	271207081122901	Sun Ray A2	271207	811229	525	1,530	UFA	Highlands	QW	USGS
39	271214080572601	Stratton-Coon Hammock	271214	805726	—	—	UFA	Glades	QW	USGS
40	271217081192501	Sunshine 1,200 ft	271217	811925	615	1,200	UFA	Highlands	QW	USGS
41	271223081202601	Lake Placid Groves 12” UFA	271223	812026	900	1,200	UFA	Highlands	QW, WL	USGS
42	271225081192201	Sunshine	271225	811922	200	400?	SA	Highlands	QW	USGS
43	271226081194301	Bairs Den Well	271223	811942	28	35	SA	Highlands	QW, WL	FDEP, SWFWMD
44	271232081392201	ROMP 15 10” UFA	271232	813922	577	1,360	UFA	DeSoto	QW, WL	SWFWMD, USGS
45	271232081392202	ROMP 15 SAS	271232	813922	45	55	SA	DeSoto	WL	SWFWMD, USGS
46	271232081392203	ROMP 15 Arcadia well	271232	813922	260	330	IAS	DeSoto	WL	SWFWMD, USGS
47	—	HIF-42 Paradise Run Upper	271305	805715	560	1,050	UFA	Highlands	QW	Consult
48	271306081284801	HIF-08 Box Ranch	271306	812848	—	1,450	UFA	Highlands	WL	USGS
49	271310081175501	Rothman	271310	811755	180	200	IAS	Highlands	QW	USGS
50	271313081194401	SR 70 Surficial	271313	811944	25	35	SA	Highlands	QW	SWFWMD
51	271315081250601	Westby Shallow	271315	812506	—	120	IAS	Highlands	QW	USGS
52	271321081040401	C41A-So	271321	810404	—	43	SA	Highlands	QW	FDEP, SFWMD
53	271330081113401	HIF-37 Sun Ray Farms	271330	811134	619	1,450	UFA	Highlands	QW, WL	USGS
54	271340080504001	OKF-31	271340	805040	—	1,079	UFA	Okeechobee	QW, WL	USGS
55	271359081024301	Coco Sod Farm #3	271359	810243	—	—	UFA	Highlands	QW	USGS
56	271403081022401	Coco Sod Farm #2	271403	810224	—	—	UFA	Highlands	QW	USGS
57	271409081014901	Coco Sod Farm #1	271409	810149	—	—	UFA	Highlands	QW	USGS
58	271412080591901	Kissimmee River FR	271412	805919	110	—	IAS	Highlands	QW	USGS
59	271430081003201	HIG2-01	271430	810032	60	70	SA	Highlands	QW	FDEP, SFWMD
60	271456081073901	C41A-No	271456	810739	—	36	SA	Highlands	QW	FDEP, SFWMD
61	271456081074701	HIF-06, 4-in	271456	810747	310	520	UFA, IAS	Highlands	QW, WL	USGS
62	271514080511601	OKF-23 Okeechobee	271514	805116	—	925	UFA	Okeechobee	QW, WL	USGS
63	271522081285301	Carlton Ranch	271522	812853	550	1,450	UFA	Highlands	QW	USGS
64	271529081210701	Old State Road 8 Surficial	271529	812107	50	60	SA	Highlands	QW	SWFWMD
65	271559081202301	ROMP 28X Deep	271559	812023	585	1,385	UFA	Highlands	QW, WL	SWFWMD, USGS
66	271559081202302	ROMP 28X Surficial	271600	812022	50	60	SA	Highlands	QW, WL	SWFWMD, FDEP
67	271559081242501	Lake Groves Road	271602	812427	13	23	SA	Highlands	WL	SWFWMD
68	271614081240901	Placid Lakes #2	271614	812409	596	1,340	UFA	Highlands	QW	USGS
69	271618081120701	HIH-1	271618	811207	320	360	IAS	Highlands	QW	USGS
70	271618081120801	HIF-40	271618	811208	460	540	UFA	Highlands	QW	USGS
71	—	Larson Dairy Barn #2	271645	810128	—	16	SA	Highlands	QW	FDEP, SFWMD
72	271707081341801	Rutland Ranch #1 (DID #1)	271708	813418	550	1,500	UFA	DeSoto	QW	SWFWMD
73	271726081163901	HIF-14 P G Phypers	271726	811639	—	1,500	UFA	Highlands	QW, WL	USGS
74	271728081254301	Westby Deep	271728	812543	600	1,200	UFA	Highlands	QW	USGS

Appendix 1. Inventory of wells used in this study.—Continued

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Well No.	USGS site ID No.	Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Bottom of casing (feet below land surface)	Well depth (feet below land surface)	Hydrogeologic unit	County	Primary data type	Source of data
75	271743081374601	Tropical River Grove	271745	813745	137	698	UFA, IAS	DeSoto	QW, WL	SWFWMD, USGS
76	—	RIDGE WRAP H-8 Surficial	271748	811906	45	65	SA	Highlands	WL	SWFWMD
77	271748081345101	Trg J36 12” UFA	271748	813451	352	1,360	UFA	DeSoto	WL	USGS
78	271753081224201	Jackson Road 2 Surficial	271752	812244	33	43	SA	Highlands	QW	SWFWMD
79	271828081185501	Windy Point Park	271828	811855	470	600	UFA	Highlands	QW	USGS
80	271918081211001	Tropical Harbor	271918	812110	510	1,284	UFA	Highlands	QW	USGS
81	271947081213501	Walker Road Surficial	271945	812135	23	33	SA	Highlands	QW	SWFWMD
82	—	RIDGE WRAP H-7 Surficial	272029	812757	20	40	SA	Highlands	WL	SWFWMD
83	272104081023901	Hidden Acres Estates	272104	810239	190	267	IAS	Highlands	QW	USGS
84	272115081134901	Mossy Cove FC	272115	811349	—	—	IAS	Highlands	QW	USGS
85	272154081354901	Bentley Grove 28 (DID #28)	272154	813549	475	1,494	UFA	Hardee	QW	SWFWMD
86	272158081232101	Dinner Lake Rd Surficial	272158	812321	20	30	SA	Highlands	QW	SWFWMD
87	272207081260401	ROMP 28 AP	272208	812607	960	1,642	UFA	Highlands	WL	SWFWMD, USGS
88	272207081260402	ROMP 28 Intermediate	272208	812607	370	420	IAS	Highlands	QW, WL	SWFWMD
89	272207081260404	ROMP 28 Suwannee	272208	812607	485	600	UFA	Highlands	QW, WL	SWFWMD
90	272207081260405	ROMP 28 L Avon Park	272208	812607	1,913	1,933	UFA	Highlands	WL, QW	SWFWMD
91	272207081260406	ROMP 28 Evaporite	272208	812607	2,083	2,112	UFA	Highlands	WL, QW	SWFWMD
92	272207081260407	ROMP 28 Up. Avon Park	272208	812607	973	1,650	UFA	Highlands	WL, QW	SWFWMD
93	272207081260408	ROMP 28 Surficial	272208	812607	40	200	SA	Highlands	QW, WL	SWFWMD
94	272314081135701	Trails End FR	272314	811357	135	155	IAS	Highlands	QW	USGS
95	—	Latt Maxcy Corp (well 224)	272317	812413	253	1,494	UFA, IAS	Highlands	QW	SWFWMD
96	272341081070401	SFWMD Cornwell Marsh W.	272341	810704	—	—	IAS?	Highlands	QW	USGS
97	272403081065801	OKF-42 SFWMD, S65C	272403	810634	372	1,152	UFA	Okeechobee	QW, WL	USGS
98	—	OKF-105	272407	810651	370	1,400	UFA	Okeechobee	QW	USGS, SFWMD
99	—	Yonce	272422	812322	100	125	SA	Highlands	QW	SWFWMD
100	—	Ben Griffin (well 227)	272448	812403	740	1,384	UFA	Highlands	QW	SWFWMD
101	272459081240401	17th St. South Surficial	272459	812404	70	80	SA	Highlands	QW	SWFWMD
102	272500081232301	272500081232301	272500	812323	247	510	IAS	Highlands	QW	FDEP, SFWMD
103	272504081120101	H-11A Surficial	272505	811200	—	7	SA	Highlands	WL	USGS
104	272510081235001	Desoto Tower well	272514	812400	500	—	UFA	Highlands	QW	FDEP, SWFWMD
105	272512081122901	HIF-13 Metzger	272512	811229	—	1,106	UFA	Highlands	WL	USGS
106	272538081350801	Crewsville Sh-AGW	272545	813523	6	26	SA	Hardee	QW	SWFWMD
107	272538081350802	Crewsville UP INT-AG	272545	813523	96	116	IAS	Hardee	QW	SWFWMD
108	272614081153201	Palm Estates	272614	811532	258	480	IAS/UFA	Highlands	QW	USGS
109	272625081185301	Spring Lake 1,000 ft	272625	811853	350	1,000	UFA	Highlands	QW	USGS
110	—	RIDGE WRAP H-4 Surficial	272634	812860	30	50	SA	Highlands	WL	SWFWMD
111	272638081171301	Lake Istokpoga Park	272638	811713	—	60	SA	Highlands	QW	USGS

Appendix 1. Inventory of wells used in this study.—Continued

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Well No.	USGS site ID No.	Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Bottom of casing (feet below land surface)	Well depth (feet below land surface)	Hydrogeologic unit	County	Primary data type	Source of data
112	272652081103101	HIF-43 Hickory Hammock	272652	811031	405	835	UFA	Highlands	QW	USGS
113	272702081311201	Country Club #1	272702	813112	450	1,180	UFA	Highlands	QW	USGS
114	272704081053501	OKF-56 Micco Road	272704	810535	—	—	UFA	Okeechobee	WL	USGS
115	—	MR-0158	272713	812045	—	10	SA	Highlands	QW	FDEP, SFWMD
116	272702081383001	Johnson-HRS	272719	813831	58	70	IAS	Hardee	QW	SWFWMD
117	272731081211601	Sebring Airport #2	272731	812116	380	1,060	UFA	Highlands	QW	USGS
118	—	KRBFFM	272738	811021	—	38	SA	Highlands	QW	SFWMD
119	272745081232601	Sebring 412 surf (replacement)	272748	812326	40	66	SA	Highlands	QW, WL	SWFWMD, FDEP
120	272746081232701	Sebring well 412 (destroyed)	272746	812327	41	45	SA	Highlands	WL	SWFWMD
121	—	KRAFFM	272753	810952	—	34	SA	Highlands	QW	SFWMD
122	272801081242301	Paradise Drive Surficial	272801	812414	22	32	SA	Highlands	QW	SWFWMD
123	272811081315501	Highlands Hammock 230 ft	272811	813155	—	230	IAS	Highlands	QW	USGS
124	272825081135901	Donley-Myers #4	272825	811359	452	1,642	UFA/LFA?	Highlands	QW	USGS
125	272826081142201	Donley-Myers #1	272826	811422	451	1,642	UFA/LFA?	Highlands	QW	USGS
126	272835081251701	Maranatha Village 6” UFA	273135	812517	—	841	UFA	Highlands	QW	USGS
127	272842081315501	Highlands Hammock Park	272841	813153	—	260	IAS	Highlands	QW	FDEP, SWFWMD
128	272855081400701	Peace River Ranch 10” UFA	272855	814007	141	1,160	UFA	Hardee	WL	USGS
129	272902081115101	KRDFFM	272902	811151	—	46	SA	Highlands	QW, WL	SFWMD
130	272906081142001	HIF-04 Yucan Ranch	272906	811420	—	1,300	UFA	Highlands	WL	USGS
131	272945081142001	Donley-Myers #3	272945	811420	470	1,642	UFA/LFA?	Highlands	QW	USGS
132	—	Highlands Co. Landfill 7207	273005	812540	—	25	SA	Highlands	QW	FDEP
133	—	ROMP 29A shallow	273010	812511	34	203	SA	Highlands	QW, WL	SWFWMD
134	273009081251001	ROMP 29A Intermediate	273010	812510	310	414	IAS	Highlands	QW, WL	SWFWMD
135	273010081251301	ROMP 29A UFA	273010	812511	478	1,640	UFA	Highlands	QW, WL	SWFWMD
136	—	Highlands Co. Landfill MW-1 Sh	273053	811913	—	17.5	SA	Highlands	QW	HC
137	273055081185901	Highlands County Landfill	273055	811859	300	1,000	UFA	Highlands	QW	USGS
138	273103081363701	Smith Deep	273104	813636	66	849	UFA/IAS	Hardee	QW, WL	SWFWMD
139	273122081271201	Arbuckle Creek Rd Surficial	273122	812713	40	50	SA	Highlands	QW	SWFWMD
140	273125081264601	Dees Dinner Lake	273125	812646	—	—	IAS?	Highlands	QW	USGS
141	273138081154201	HIF-03 Howerton	273138	811542	—	1,280	UFA	Highlands	WL	USGS
142	273212081311401	Sun and Lakes	273212	813114	190	1,220	UFA	Highlands	QW	USGS
143	273217081012601	OKF-34	273217	810126	—	1,143	UFA	Okeechobee	WL	USGS
144	273249081164201	AP Air Force Range SS5	273249	811642	30	48	SA	Highlands	--	SFWMD
145	273249081164202	AP Air Force Range SI4	273249	811642	180	193	IAS	Highlands	QW	USGS
146	273249081164203	AP Air Force Range SF3	273249	811642	320	906	UFA	Highlands	QW	USGS
147	273249081164204	AP Air Force Range S2	273249	811642	1,010	1,183	UFA	Highlands	--	SFWMD
148	273252081264101	Bonnet Lake 6” UFA	273252	812641	462	1,029	UFA	Highlands	QW, WL	USGS

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Well No.	USGS site ID No.	Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Bottom of casing (feet below land surface)	Well depth (feet below land surface)	Hydrogeologic unit	County	Primary data type	Source of data
149	273333081264301	Altvater Road Surf	273333	812638	9	19	SA	Highlands	QW	SWFWMD
150	273450081170201	AP Air Force Range MW10	273450	811702	2	12	SA	Highlands	QW	USGS
151	—	ROMP 43 MW1 Surficial	273500	813519	2	12	SA	Hardee	WL, QW	SWFWMD
152	—	ROMP 43 MW2 Up Arcadia	273500	813519	52	116	IAS	Hardee	WL, QW	SWFWMD
153	—	ROMP 43 MW3 Low Arcadia	273500	813519	196	233	IAS	Hardee	QW, WL	SWFWMD
154	—	ROMP 43 MW4 Suwannee	273500	813519	306	464	UFA	Hardee	QW, WL	SWFWMD
155	—	ROMP 43 MW5 Avon Park	273500	813519	720	1,210	UFA	Hardee	WL, QW	SWFWMD
156	273517081282801	Sears Rd Surficial	273517	812828	25	35	SA	Highlands	QW	SWFWMD
157	273520081253201	273520081253201	273528	812525	170	190	SA	Highlands	QW	FDEP, SFWMD
158	273525081352101	Thomas Watkins	273526	813522	450	1,200	UFA	Hardee	QW	SWFWMD
159	273528081260901	Lotela_G (MR-0156)	273529	812607	—	10	SA	Highlands	WL	SFWMD, FDEP
160	273603081270501	Wabasso (Dressler) Dairy D	273603	812705	200	350	IAS	Highlands	WL	USGS
161	—	RIDGE WRAP H-2 Surficial	273611	813143	65	85	SA	Highlands	WL	SWFWMD
162	—	LC Dairy	273612	812720	—	20	SA	Highlands	QW	FDEP, SFWMD
163	273615081284901	ROMP 43XX 8”UFA	273616	812848	409	1,363	UFA	Highlands	QW, WL	SWFWMD, USGS
164	273615081284902	ROMP 43XX Surficial	273616	812848	32	83	SA	Highlands	WL	SWFWMD
165	273656081210901	AP Air Force Range MW4	273656	812109	2	12	SA	Highlands	QW	USGS
166	273704081245501	Richards	273704	812456	140	260	IAS	Highlands	QW, WL	USGS
167	273705081290901	CR 627 Surficial	273705	812909	50	60	SA	Highlands	QW	SWFWMD
168	273754081290401	Alpine Road Surficial	273755	812904	66	76	SA	Highlands	QW	SWFWMD
169	273755081253401	HRWRAP H-10	273756	812535	30	50	SA	Highlands	WL	SWFWMD
170	—	RIDGE WRAP H-1 Surficial	273816	813125	40	60	SA	Highlands	WL	SWFWMD
171	273845081321901	Clenny UFA	273845	813219	227	1,050	UFA	Highlands	WL	USGS
172	273903081185201	Avon Park Prison #1 (POF-9)	273911	812108	—	1,035	UFA	Polk	WL,QW	USGS
173	—	POS-3	273933	810758	75	90	SA	Polk	QW, WL	SFWMD
174	—	POH-1	273933	810759	180	200	IAS	Polk	QW, WL	SFWMD
175	273929081080601	S-65A (POF-20R; 397 ft)	273933	810759	287	397	UFA	Polk	QW, WL	USGS, SFWMD

Appendix 2. Summary of major inorganic constituents and physical characteristics in the surficial aquifer and intermediate and Floridan aquifer systems in Highlands County and parts of adjacent counties.

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Well No.	Hydro-geologic unit	Source of data	Sampling date	Calcium	Magnesium	Potassium	Sodium	Chloride	Fluoride	Sulfate	Silica	Water tempera-ture	Specific conduc-tance	Total dis-solved solids	pH	Hardness as $CaCO_3$	Alkalinity as $CaCO_3$
2	UFA	SWFWMD	10/01/04	17	12	4.3	113	92	—	115	13	28.8	766	437	8.3	—	—
3	UFA	SWFWMD	02/13/03	76	48	5.6	203	419	—	198	15	28.3	1,920	1,079	7.7	—	—
4	SA	FDEP, SFWMD	04/17/01	0.27	0.58	0.29	6.0	11	0.02	—	0.29	25.1	60	15	4.4	—	0.5
5	UFA	SWFWMD	05/25/07	70	33	3.5	93	182	—	140	19	28.6	1,102	684	7.4	—	130
6	UFA	USGS	11/07/07	17	13	3.2	39	29	3.6	26	14	26.0	383	227	8.2	100	112
7	SA	FDEP, SFWMD	04/17/01	0.63	0.92	0.17	3.2	7.2	—	0.20	—	25.9	46	18	4.5	—	1.7
8	UFA	USGS	12/05/07	71	57	9.3	208	403	1.4	130	35	24.6	1,900	1,050	7.6	410	180
9	SA	USGS	11/07/07	2.5	1.7	1.2	3.9	10	<0.12	2.1	12	24.7	66	38	5.0	13	8
11	UFA	SWFWMD	09/07/07	41	23	2.7	57	101	0.48	75	17	26.9	732	—	7.5	—	118
13	IAS	SWFWMD	09/07/07	33	32	6.4	37	30	2.2	13	53	25.6	589	—	7.2	—	243
14	SA	SWFWMD	09/07/07	6.1	1.5	2.5	7.0	11	—	7.0	8.0	26.3	97	75	5.1	—	18
15	SA	FDEP, SFWMD	04/17/01	4.2	6.0	0.47	17	54	0.06	3.9	—	24.1	210	89	4.6	—	2.1
16	UFA	Consult	06/27/07	164	74	—	364	655	—	376	—	—	2,720	1,750	—	696	86
17	UFA	SWFWMD	03/13/03	155	93	10	484	846	—	381	17	29.9	3,585	2,044	7.5	—	—
18	IAS	SWFWMD	09/10/07	112	30	4.3	89	272	0.72	13	48	26.0	1,280	—	7.0	—	226
21	SA	SWFWMD	11/08/07	15	7.8	13	12	30	0.08	44	7.7	26.9	320	—	4.2	—	—
22	IAS	USGS	09/25/07	160	186	37	1,940	3,770	1.9	111	11	25.0	11,500	6,810	7.5	1,200	77
23	SA	SWFWMD	11/08/07	20	12	10	14	38	0.06	51	4.0	25.9	331	—	4.9	—	2.9
25	IAS	SWFWMD	06/21/07	16	12	4.3	11	5.4	0.87	2.8	19	25.2	222	—	8.7	—	108
26	SA	SWFWMD	06/30/05	2.4	0.58	0.21	3.2	6.0	<0.02	2.0	3.3	24.8	41	—	5.0	—	3.7
27	UFA	SWFWMD	06/21/07	4.4	4.3	3.9	48	8.2	2.5	14	11	25.7	274	—	8.7	—	117
28	SA	SWFWMD	08/16/07	23	9.3	14	19	52	<0.02	51	7.1	26.1	384	—	4.6	—	1.8
29	UFA	SWFWMD	09/06/00	—	—	2.7	22	7.3	—	9.2	16	—	243	138	—	86	94
30	SA	USGS	09/25/07	11	2.4	0.80	14	30	0.10	2.8	10	24.6	175	107	5.4	37	23
31	IAS	USGS	09/25/07	—	—	—	—	13	—	<0.18	—	24.4	543	—	6.9	—	—
32	UFA	SWFWMD	10/27/01	—	—	—	—	152	—	204	—	—	—	—	—	—	—
34	UFA	USGS	03/19/08	105	76	12	392	816	0.52	295	13	27.8	3,190	1,820	7.6	599	83
35	UFA	USGS	03/19/08	—	—	—	—	1,160	—	366	—	28.6	4,280	—	7.7	—	—
36	SA	SWFWMD	08/15/07	19	1.0	2.0	1.2	4.2	<0.02	29	6.8	27.4	137	—	5.5	—	9.9
38	UFA	USGS	11/07/07	59	25	1.6	49	119	0.20	148	11	27.4	812	474	7.8	270	63
39	UFA	USGS	03/19/08	—	—	—	—	3,480	—	713	—	29.6	11,100	—	7.4	—	—
40	UFA	USGS	12/05/07	15	10	2.0	7.8	6.4	0.63	19	13	—	212	127	—	88	—
41	UFA	USGS	09/26/07	15	5.7	2.1	25	4.4	3.3	7.0	10	24.4	238	141	7.9	64	—
42	SA	USGS	12/05/07	0.47	0.63	0.85	2.7	4.8	<0.12	2.0	12	24.3	32	26	4.9	4	0.50

Appendix 2. Summary of major inorganic constituents and physical characteristics in the surficial aquifer and intermediate and Floridan aquifer systems in Highlands County and parts of adjacent counties.—Continued

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Well No.	Hydro-geologic unit	Source of data	Sampling date	Calcium	Magnesium	Potassium	Sodium	Chloride	Fluoride	Sulfate	Silica	Water tempera-ture	Specific conduc-tance	Total dis-solved solids	pH	Hardness as $CaCO_3$	Alkalinity as $CaCO_3$
43	SA	FDEP, SWFWMD	04/30/01	21	0.71	1.6	1.1	10	0.02	16	—	29.5	150	84	6.6	—	130
44	UFA	SWFWMD	11/15/07	106	61	3.7	22	29	1.0	385	23	28.7	1,062	—	7.3	—	112
47	UFA	Consult					—	—									1.7
49	IAS	USGS	12/05/07	5.5	0.87	2.8	3.9	3.8	0.22	1.3	30	23.8	66	58	6.4	17	180
50	SA	SWFWMD	11/06/07	37	1.6	9.7	2.1	2.9	0.04	17	4.0	27.5	234	—	6.9	—	8.0
51	IAS	USGS	03/18/08	46	22	2.0	23	7.9	0.21	0.20	43	24.9	468	287	7.5	210	118
52	SA	FDEP, SFWMD	04/18/01	76	9.2	2.0	58	48	0.36	30	—	24.5	723	443	7.1	—	243
53	UFA	USGS	09/25/07	47	21	1.5	32	67	0.28	131	11	27.4	645	390	7.8	220	18
55	UFA	USGS	06/12/08	—	—	—	—	189	—	230	—	27.7	1,220	—	7.8	—	2.1
56	UFA	USGS	06/12/08	—	—	—	—	301	—	255	—	28.4	1,662	—	7.7	—	86
57	UFA	USGS	06/12/08	69	46	5.7	139	266	0.53	243	13	27.7	1,481	905	7.8	386	—
58	IAS	USGS	11/06/07	94	7.9	1.9	43	38	0.31	3.0	29	25.1	672	339	7.3	270	226
59	SA	FDEP, SFWMD	04/06/00	90	11	1.5	40	51	0.25	0.20	—	24.2	685	424	7.1	—	—
60	SA	FDEP, SFWMD	04/18/01	69	8.3	2.7	22	29	0.17	36	—	23.9	516	389	7.0	—	77
61	UFA, IAS	USGS	09/25/07	43	23	4.3	51	68	0.60	102	24	24.7	684	424	7.6	210	2.9
62	UFA	USGS	09/25/07	64	44	6.6	169	295	0.65	202	17	26.1	1,550	909	7.7	358	108
63	UFA	USGS	03/18/08	53	19	1.6	14	19	0.27	58	20	28.4	498	314	7.5	220	3.7
64	SA	SWFWMD	11/06/07	35	13	23	3.1	22	0.55	69	7.7	27.2	418	—	4.8	—	117
65	UFA	SWFWMD	08/24/00	—	—	—	—	8.4	—	1.7	—	24.6	145	—	8.4	—	1.8
66	SA	SWFWMD	04/27/00	7.4	0.85	0.24	6.6	12	0.11	0.20	—	25.8	91	56	5.6	—	94
68	UFA	USGS	12/05/07	29	9.0	0.84	6.1	8.3	0.17	4.8	17	25.6	249	158	7.8	110	23
69	IAS	USGS	01/24/08	24	21	3.9	34	45	1.2	18	25	23.2	459	275	8.3	160	—
70	UFA	USGS	01/24/08	46	22	3.5	62	108	0.42	109	12	22.4	733	437	8.2	220	—
71	SA	FDEP, SFWMD	04/06/00	4.9	3.5	0.57	21	51	0.17	0.87	—	21.5	214	153	5.3	—	83
72	UFA	SWFWMD	03/09/04	91	41	2.3	14	19	—	274	18	—	821	616	7.6	—	—
73	UFA	USGS	09/25/07	22	8.1	0.84	9.5	18	0.16	32	10	25.0	264	146	8.2	95	9.9
74	UFA	USGS	03/18/08	64	17	1.7	9.1	11	0.20	36	23	27.4	479	298	7.2	230	63
75	UFA, IAS	SWFWMD	11/14/07	87	41	3.1	41	49	1.0	220	30	26.2	936	—	7.2	—	—
78	SA	SWFWMD	11/05/07	38	6.1	12	2.3	16	0.09	30	2.0	26.8	313	—	6.3	—	—
79	UFA	USGS	01/17/08	—	—	—	—	8.5	—	<0.18	—	24.0	189	141	8.2	—	—
80	UFA	USGS	12/04/07	19	5.9	0.63	5.3	9.0	0.14	14	9.7	25.2	187	117	8.3	77	0.5
81	SA	SWFWMD	08/13/07	29	1.7	5.7	2.2	7.8	<0.02	45	2.3	26.2	216	—	4.9	—	130
83	IAS	USGS	11/06/07	93	8.1	1.3	46	43	0.29	0.72	25	23.9	678	373	7.2	270	112
84	IAS	USGS	01/16/08	—	—	—	—	63	—	1.2	—	23.9	655	398	7.5	—	1.7

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Well No.	Hydro-geologic unit	Source of data	Sampling date	Calcium	Magnesium	Potassium	Sodium	Chloride	Fluoride	Sulfate	Silica	Water tempera-ture	Specific conduc-tance	Total dis-solved solids	pH	Hardness as $CaCO_3$	Alkalinity as $CaCO_3$
85	UFA	SWFWMD	04/15/02	128	62	2.5	8.9	11	—	482	16	—	1,073	848	7.6	—	180
86	SA	SWFWMD	10/31/07	43	5.3	8.0	3.9	8.5	0.05	40	4.5	27.2	314	—	6.3	—	8.0
88	IAS	SWFWMD	03/16/04	24	22	4.4	15	13	0.50	4.8	31	24.1	343	—	8.0	—	—
89	UFA	SWFWMD	03/16/04	35	10	4.1	9.4	9.0	0.19	37	18	24.5	278	—	9.6	—	—
93	SA	SWFWMD	06/29/05	5.2	0.44	0.87	1.7	2.6	1.2	1.8	8.7	25.9	51	—	5.5	—	161
94	IAS	USGS	11/07/07	54	17	2.6	23	43	0.55	E.12	47	22.4	501	316	7.7	210	186
95	UFA, IAS	SWFWMD	01/09/02	30	17	2.5	15	13	—	10	31	—	391	243	—	—	161
96	IAS?	USGS	03/19/08	—	—	—	—	54	0.44	22	—	23.4	783	—	7.2	—	—
97	UFA	USGS	01/24/08	36	40	5.1	41	52	0.60	96	26	24.0	711	444	7.6	276	199
99	SA	SWFWMD	04/12/00	—	—	1.5	8.5	11	—	39	20	—	335	233	—	159	120
100	UFA	SWFWMD	12/06/01	38	16	1.8	12	13	—	7.2	17	—	341	194	—	—	143
101	SA	SWFWMD	10/31/05	36	14	12	5.8	23	0.06	87	7.5	27.9	399	—	4.7	—	1.0
102	IAS	FDEP, SFWMD	02/24/00	26	20	4.0	15	6.9	1.3	1.8	—	24.8	361	225	7.4	—	176
104	UFA	FDEP, SWFWMD	03/13/00	12	4.7	2.2	6.8	6.1	0.18	0.2	—	22.5	133	96	7.0	—	55
106	SA	SWFWMD	04/29/02	32	3.0	1.4	4.0	8.3	0.09	21	—	24.6	224	135	5.9	—	71
107	IAS	SWFWMD	09/24/07	0.70	0.65	1.3	4.1	7.3	0.06	0.23	11	24.8	—	—	5.0	—	7.5
108	IAS/UFA	USGS	11/07/07	39	18	2.1	16	23	0.37	27	30	24.2	424	265	7.6	180	150
109	UFA	USGS	11/07/07	25	14	1.5	9.1	13	0.28	43	17	25.2	314	204	8.0	130	88
111	SA	USGS	01/15/08	32	7.2	1.5	16	21	0.24	0.23	17	23.2	287	184	6.3	110	109
112	UFA	USGS	03/19/08	26	34	5.0	36	35	0.75	41	23	25.3	573	332	7.7	220	205
113	UFA	USGS	12/03/07	33	9.6	1.8	5.4	6.3	0.26	18	18	27.8	356	206	7.5	130	114
115	SA	FDEP, SFWMD	04/05/00	9.1	0.03	0.10	2.3	3.9	0.10	7.1	—	23.2	61	53	5.5	—	13
116	IAS	SWFWMD	02/07/02	37	19	1.3	13	12	0.49	24	—	23.9	390	218	7.6	—	161
117	UFA	USGS	03/19/08	21	9.7	1.5	5.6	6.5	0.30	27	17	25.1	223	136	8.1	99	76
118	SA	SFWMD	10/25/00	120	7.6	2.5	18	14	—	—	—	23.7	640	—	7.3	—	300
119	SA	SWFWMD, FDEP	05/01/00	44	16	15	5.6	20	0.10	76	—	26.1	368	277	6.9	—	37
121	SA	SFWMD	01/30/01	100	8.4	1.9	31	36	—	—	—	—	—	330	—	—	280
122	SA	SWFWMD	10/31/07	4.3	0.33	0.58	1.8	3.3	<0.02	7.4	3.3	27.1	44	—	4.6	—	1.5
123	IAS	USGS	12/03/07	32	19	3.0	14	9.6	1.1	1.3	37	23.7	374	247	7.6	170	184
124	UFA/LFA?	USGS	03/19/08	103	54	4.2	129	258	0.25	300	20	27.1	1,590	980	7.6	480	95
125	UFA/LFA?	USGS	03/19/08	—	—	—	—	253	—	293	—	—	1,570	—	—	—	—
126	UFA	USGS	01/16/08	—	—	—	—	5.1	—	2.4	—	24.9	140	98	8.1	—	—
127	IAS	FDEP, SWFWMD	02/27/02	52	9.4	2.3	14	10	0.10	<0.20	—	24.2	394	234	7.4	—	192
129	SA	SFWMD	01/31/01	110	5.1	1.9	25	19	—	—	—	—	—	350	—	—	—

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Well No.	Hydro-geologic unit	Source of data	Sampling date	Calcium	Magnesium	Potassium	Sodium	Chloride	Fluoride	Sulfate	Silica	Water tempera-ture	Specific conduc-tance	Total dis-solved solids	pH	Hardness as $CaCO_3$	Alkalinity as $CaCO_3$
131	UFA/LFA?	USGS	03/19/08	—	—	—	—	80	—	110	—	—	684	—	—	—	—
132	SA	FDEP	05/16/00	0.86	0.46	0.11	2.2	5.5	0.10	5.3		23.6	53	40	4.2	—	1.0
136	SA	HC	12/06/07	—	—	—	3.8	6.5	—	—	—	25.6	179	90	4.4	—	—
137	UFA	USGS	01/16/08	25	13	1.4	8.1	13	0.20	36	19	26.3	299	194	7.8	130	92
138	IAS/UFA	SWFWMD	03/05/02	20	10	1.2	5.1	5.5	0.44	13	—	24.2	226	133	8.0	—	92
139	SA	SWFWMD	10/30/07	17	6.2	14	2.7	7.7	0.22	63	6.7	27.3	271	—	4.1	—	—
140	IAS?	USGS	12/04/07	20	3.3	1.8	6.4	4.1	<0.12	E.17	26	24.3	159	106	7.3	63	73
142	UFA	USGS	12/04/07	30	8.9	0.65	3.8	6.6	0.13	7.8	12	25.7	242	141	8.0	120	107
145	IAS	USGS	01/25/08	48	1.9	1.5	15	6.1	0.12	<0.18	36	20.2	304	212	8.4	130	154
146	UFA	USGS	01/25/08	26	15	2.5	17	22	0.31	9.4	33	23.4	348	221	8.7	140	143
148	UFA	USGS	11/08/07	21	7.9	1.2	4.6	6.1	0.09	0.57	20	24.9	188	109	8.1	85	84
149	SA	SWFWMD	10/30/07	47	14	15	5.1	23	0.16	54	5.5	—	458	—	6.7	—	43
150	SA	USGS	01/15/08	3.8	0.81	0.06	6.6	8.2	<0.12	9.8	5.9	23.9	88	122	4.1	13	—
153	IAS	SWFWMD	04/13/07	15	9.2	1.8	7.4	6.1	—	6.8	12	24.4	184	104	8.4	—	79
154	UFA	SWFWMD	04/13/07	18	7.9	1.1	4.5	5.4	—	6.9	12	25.2	170	121	8.1	—	71
156	SA	SWFWMD	08/06/07	17	5.2	7.3	2.1	8.3	0.04	30	3.6	26.6	197	—	5.4	—	11
157	SA	FDEP, SFWMD	02/23/00	60	7.0	3.7	4.7	5.1	0.10	0.20	—	24.0	369	224	6.9	—	190
158	UFA	SWFWMD	09/05/01	—	—	—	—	5.6	—	19	—	—	192	—	8.3	—	—
162	SA	FDEP, SFWMD	04/13/00	13	4.7	5.5	5.5	15	0.10	30	—	24.0	218	110	4.1	—	1.0
163	UFA	SWFWMD	10/18/07	19	6.5	0.71	4.5	7.0	0.15	6.7	11	25.7	180	—	8.1	—	71
165	SA	USGS	01/15/08	2.7	0.77	0.29	9.9	13	<0.12	1.9	9.6	23.2	86	92	5.3	10	9.0
166	IAS	USGS	01/15/08	16	9.4	1.2	4.9	6.6	1.1	2.2	14	19.7	181	113	8.0	81	77
167	SA	SWFWMD	04/26/07	18	9.1	8.1	9.9	19	0.09	54	4.2	27.3	280	—	4.5	—	—
168	SA	SWFWMD	10/29/07	26	20	14	5.4	29	0.03	68	5.4	26.2	429	—	4.4	—	—
172	UFA	USGS	07/15/03	17	6.1	0.50	3.0	4.5	0.10	6.0	11	25.7	154	104	8.2	70	65
173	SA	SFWMD	06/04/07	58	6.5	1.8	32	41	—	1.0	—	23.3	525	330	7.6	—	200
174	IAS	SFWMD	06/04/07	42	9.9	1.5	24	32	—	0.17	—	24.5	510E	310	7.5	—	170
175	UFA	USGS	01/23/08	35	18	1.7	26	47	0.63	23	31	25.0	453	262	7.7	166	132

Appendix 3. Summary of selected trace metals and nutrients in the surficial aquifer and intermediate and Floridan aquifer systems in Highlands County and parts of adjacent counties.

[Well locations shown in figure 11. U.S. Geological Survey site identification numbers and station names are given in appendix 1. Concentrations shown in milligrams per liter, except for strontium and iron which are in micrograms per liter. Hydrogeologic unit: SA, surficial aquifer, IAS, intermediate aquifer system; UFA, Upper Floridan aquifer; LFA, Lower Floridan aquifer. Source of data: Consult, consultant report; FDEP, Florida Department of Environmental Protection; HC, Highlands County; SFWMD, South Florida Water Management District; SWFWMD, Southwest Florida Water Management District; USGS, U.S. Geological Survey. —, not analyzed; <, less than the value, E, estimated value.]

Well No.	Hydrogeologic unit″	Source of data	Sampling date	Strontium	Iron	Ammonia as N, dissolved	Nitrite as N, dissolved	Nitrate + nitrite as N, dissolved	Total nitrogen, dissolved	Ortho-phosphate as P, dissolved	Phosphorus, dissolved
2	UFA	SWFWMD	10/01/04	9,440	19.3	—	—	—	—	—	—
3	UFA	SWFWMD	02/13/03	37,700	40	—	—	—	—	—	—
4	SA	FDEP, SFWMD	04/17/01	—	—	0.46	—	0.005		0.004	0.006
5	UFA	SWFWMD	05/25/07	23,700	<12.5	—	—	—	—	—	—
6	UFA	USGS	11/07/07	5,210	29	0.136	<0.002	<0.04	0.15	0.013	0.014
7	SA	FDEP, SFWMD	04/17/01	—	—	0.20	—	0.005	—	0.024	0.037
8	UFA	USGS	12/05/07	999	263	0.388	<0.002	<0.04	0.44	0.01	<0.006
9	SA	USGS	11/07/07	31	1,100	0.175	<0.002	<0.04	0.37	0.047	0.059
11	UFA	SWFWMD	09/07/07	15,400	<12.5	—	—	—	—	—	—
13	IAS	SWFWMD	09/07/07	8,490	<12.5	—	—	—	—	—	—
14	SA	SWFWMD	09/07/07	<250	880	—	—	—	—	—	—
15	SA	FDEP, SFWMD	04/17/01	—	—	0.16	—	0.024		0.041	0.034
16	UFA	Consult	06/27/07	—	—	—	—	—	—	—	—
17	UFA	SWFWMD	03/13/03	62,700	13	—	—	—	—	—	—
18	IAS	SWFWMD	09/10/07	3,320	88.2	—	—	—	—	—	—
21	SA	SWFWMD	11/08/07	2,050	42.4	—	<0.005	9.6	—	—	0.015
22	IAS	USGS	09/25/07	26,900	<90	1.1	<0.002	<0.06	1.2	E.006	<0.006
23	SA	SWFWMD	11/08/07	1,470	<12.5	—	0.0097	11	—	—	0.005
25	IAS	SWFWMD	06/21/07	720	<12.5	—	—	—	—	—	—
26	SA	SWFWMD	06/30/05	<250	102	—	—	—	—	—	—
27	UFA	SWFWMD	06/21/07	1,550	<12.5	—	—	—	—	—	—
28	SA	SWFWMD	08/16/07	2,190	24.9	—	<0.005	9.6	—	—	<0.005
29	UFA	SWFWMD	09/06/00	1,980	60	—	—	—	—	—	—
30	SA	USGS	09/25/07	76	2,270	0.494	<0.002	<0.06	1.8	0.105	0.101
31	IAS	USGS	09/25/07	—	—	—	—	—	—	—	—
32	UFA	SWFWMD	10/27/01	—	—	—	—	—	—	—	—
34	UFA	USGS	03/19/08	23,200	E24	0.241	<0.002	<0.04	0.28	E.006	<0.006
35	UFA	USGS	03/19/08	—	—	—	—	—	—	—	—
36	SA	SWFWMD	08/15/07	<250	<12.5	—	<0.005	3.2	—	—	<0.005
38	UFA	USGS	11/07/07	17,100	27	0.195	<0.002	<0.04	0.18	0.009	0.008
39	UFA	USGS	03/19/08	—	—	—	—	—	—	—	—
40	UFA	USGS	12/05/07	6,370	8.0	0.115	<0.002	<0.04	0.41	E.006	0.01
41	UFA	USGS	09/26/07	2,600	10	0.291	<0.002	<0.06	0.33	0.016	0.014
42	SA	USGS	12/05/07	6.8	15	<0.020	<0.002	0.79	0.85	0.006	0.006

Appendix 3. Summary of selected trace metals and nutrients in the surficial aquifer and intermediate and Floridan aquifer systems in Highlands County and parts of adjacent counties.—Continued

[Well locations shown in figure 11. U.S. Geological Survey site identification numbers and station names are given in appendix 1. Concentrations shown in milligrams per liter, except for strontium and iron which are in micrograms per liter. Hydrogeologic unit: SA, surficial aquifer, IAS, intermediate aquifer system; UFA, Upper Floridan aquifer; LFA, Lower Floridan aquifer. Source of data: Consult, consultant report; FDEP, Florida Department of Environmental Protection; HC, Highlands County; SFWMD, South Florida Water Management District; SWFWMD, Southwest Florida Water Management District; USGS, U.S. Geological Survey. —, not analyzed; <, less than the value, E, estimated value.]

Well No.	Hydrogeologic unit″	Source of data	Sampling date	Strontium	Iron	Ammonia as N, dissolved	Nitrite as N, dissolved	Nitrate + nitrite as N, dissolved	Total nitrogen, dissolved	Ortho-phosphate as P, dissolved	Phosphorus, dissolved
43	SA	FDEP, SWFWMD	04/30/01	—	—	0.068	—	0.31	—	0.004	0.004
44	UFA	SWFWMD	11/15/07	18,700	<12.5	—	—	—	—	—	—
47	UFA	Consult		—	—						
49	IAS	USGS	12/05/07	28	<8.0	<0.020	<0.002	<0.04	<0.06	1.5	1.6
50	SA	SWFWMD	11/06/07	<250	<12.5	—	<0.005	1.4	—	—	0.103
51	IAS	USGS	03/18/08	451	<8.0	0.303	<0.002	<0.04	0.36	0.012	E.004
52	SA	FDEP, SFWMD	04/18/01	—	—	0.51	—	0.004	—	0.052	0.054
53	UFA	USGS	09/25/07	15,600	23	0.184	<0.002	<0.06	0.21	0.01	0.008
55	UFA	USGS	06/12/08	—	—	—	—	—	—	—	—
56	UFA	USGS	06/12/08	—	—	—	—	—	—	—	—
57	UFA	USGS	06/12/08	20,730	10	0.183	<0.002	<0.04	0.16	0.006	<0.006
58	IAS	USGS	11/06/07	631	9.0	0.342	<0.002	<0.04	0.52	0.006	<0.006
59	SA	FDEP, SFWMD	04/06/00	—	—	0.39	—	0.005	—	0.005	0.043
60	SA	FDEP, SFWMD	04/18/01	—	—	0.76	—	0.004	—	0.035	0.032
61	UFA, IAS	USGS	09/25/07	9,140	<6.0	0.307	<0.002	<0.06	0.41	0.008	<0.006
62	UFA	USGS	09/25/07	16,700	22	0.261	<0.002	<0.06	0.29	0.01	E.004
63	UFA	USGS	03/18/08	11,400	23	0.541	<0.002	<0.04	0.61	0.041	0.043
64	SA	SWFWMD	11/06/07	640	15.9	—	<0.005	22	—	—	0.006
65	UFA	SWFWMD	08/24/00	—	—	—	—	—	—	—	—
66	SA	SWFWMD	04/27/00	—	—	0.42	—	0.022	—	—	0.14
68	UFA	USGS	12/05/07	2,050	82	0.214	<0.002	<0.04	0.27	0.022	0.023
69	IAS	USGS	01/24/08	9,840	<8.0	0.274	<0.002	<0.04	0.33	0.007	<0.006
70	UFA	USGS	01/24/08	14,000	<8.0	0.211	<0.002	<0.04	0.23	E.005	<0.006
71	SA	FDEP, SFWMD	04/06/00	—	—	1.3	—	0.017	—	0.034	0.052
72	UFA	SWFWMD	03/09/04	23,800	16.4	—	—	—	—	—	—
73	UFA	USGS	09/25/07	6,350	28	0.183	<0.002	<0.06	0.98	0.018	0.015
74	UFA	USGS	03/18/08	5,090	46	0.516	<0.002	<0.04	0.59	0.097	0.101
75	UFA, IAS	SWFWMD	11/14/07	12,400	62.2	—	—	—	—	—	—
78	SA	SWFWMD	11/05/07	360	<12.5		<0.005	11	—	—	0.009
79	UFA	USGS	01/17/08	—	—	—	—	—	—	—	—
80	UFA	USGS	12/04/07	4,240	E6	0.148	<0.002	<0.04	0.16	0.014	0.014
81	SA	SWFWMD	08/13/07	<250	<12.5		<0.005	8.4			0.007
83	IAS	USGS	11/06/07	500	E5	0.58	<0.002	<0.04	0.90	0.006	<0.006
84	IAS	USGS	01/16/08	—	—	—	—	—	—	—	—

Appendix 3. Summary of selected trace metals and nutrients in the surficial aquifer and intermediate and Floridan aquifer systems in Highlands County and parts of adjacent counties.—Continued

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Well No.	Hydrogeologic unit"	Source of data	Sampling date	Strontium	Iron	Ammonia as N, dissolved	Nitrite as N, dissolved	Nitrate + nitrite as N, dissolved	Total nitrogen, dissolved	Ortho-phosphate as P, dissolved	Phosphorus, dissolved
85	UFA	SWFWMD	04/15/02	18,900	<30	—	—	—	—	—	—
86	SA	SWFWMD	10/31/07	460	<12.5	—	<0.005	9.4	—	—	0.017
88	IAS	SWFWMD	03/16/04	1,870	<12.5	—	—	—	—	—	—
89	UFA	SWFWMD	03/16/04	2,560	<12.5	—	—	—	—	—	—
93	SA	SWFWMD	06/29/05	<250	413	—	—	—	—	—	—
94	IAS	USGS	11/07/07	4,690	<8.0	0.456	<0.002	<0.04	0.59	0.01	<0.006
95	UFA, IAS	SWFWMD	01/09/02	1,640	60	—	—	—	—	—	—
96	IAS?	USGS	03/19/08	615	—	—	—	—	—	—	—
97	UFA	USGS	01/24/08	17,800	16	—	—	—	—	—	—
99	SA	SWFWMD	04/12/00	—	50	—	—	—	—	—	—
100	UFA	SWFWMD	12/06/01	4,380	50	—	—	—	—	—	—
101	SA	SWFWMD	10/31/05	930	<12.5	0.012	0.006	13	—	0.01	0.01
102	IAS	FDEP, SFWMD	02/24/00	—	—	0.26	—	0.004	—	0.004	0.004
104	UFA	FDEP, SWFWMD	03/13/00	—	—	0.071	—	0.22	—	0.051	0.043
106	SA	SWFWMD	04/29/02	—	—	0.19	—	<0.02	—	0.14	0.15
107	IAS	SWFWMD	09/24/07	<250	644	—	—	—	—	—	—
108	IAS/UFA	USGS	11/07/07	9,910	<8.0	0.329	<0.002	<0.04	0.42	0.007	E.004
109	UFA	USGS	11/07/07	11,200	14	0.115	<0.002	<0.04	0.12	E.006	<0.006
111	SA	USGS	01/15/08	801	410	0.337	<0.002	<0.04	0.51	0.40	0.43
112	UFA	USGS	03/19/08	11,500	34	0.355	<0.002	<0.04	0.40	0.009	E.006
113	UFA	USGS	12/03/07	7,110	460	0.254	<0.002	<0.04	0.32	0.251	0.272
115	SA	FDEP, SFWMD	04/05/00	—	—	0.062	—	0.02	—	0.004	0.005
116	IAS	SWFWMD	02/07/02	—	—	0.16	—	0.004	—	0.021	0.018
117	UFA	USGS	03/19/08	5,010	15	0.122	<0.002	<0.04	0.12	0.009	0.007
118	SA	SFWMD	10/25/00	—	220	—					—
119	SA	SWFWMD, FDEP	05/01/00	—	—	0.01	—	17	—	4.5	5.2
121	SA	SFWMD	01/30/01	—	890	—	—		—	—	—
122	SA	SWFWMD	10/31/07	<250	<12.5	—	<0.005	1.6	—	—	<0.005
123	IAS	USGS	12/03/07	6,620	<8.0	0.297	<0.002	<0.04	0.32	0.009	E.003
124	UFA/LFA?	USGS	03/19/08	999	27	0.254	<0.002	<0.04	0.27	0.009	0.006
125	UFA/LFA?	USGS	03/19/08	—	—	—	—	—	—	—	—
126	UFA	USGS	01/16/08	—	—	—	—	—	—	—	—
127	IAS	FDEP, SWFWMD	02/27/02	—	—	<0.01	—	0.011	—	0.006	<0.004
129	SA	SFWMD	01/31/01	—	420	—	—	—	—	—	—

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Well No.	Hydrogeologic unit”	Source of data	Sampling date	Strontium	Iron	Ammonia as N, dissolved	Nitrite as N, dissolved	Nitrate + nitrite as N, dissolved	Total nitrogen, dissolved	Ortho-phosphate as P, dissolved	Phosphorus, dissolved
131	UFA/LFA?	USGS	03/19/08	—	—	—	—	—	—	—	—
132	SA	FDEP	05/16/00	—	—	0.071	—	0.006	—	0.005	0.01
136	SA	HC	12/06/07	—	0.39	—	—	<0.02	—	—	—
137	UFA	USGS	01/16/08	10,500	32	0.137	<0.002	<0.04	0.15	0.015	0.012
138	IAS/UFA	SWFWMD	03/05/02	—	—	0.18	—	<0.004	—	0.006	0.006
139	SA	SWFWMD	10/30/07	360	19.3	—	<0.005	8.1	—	—	0.011
140	IAS?	USGS	12/04/07	70	775	0.193	<0.002	<0.04	0.19	0.221	0.108
142	UFA	USGS	12/04/07	3,500	21	0.187	<0.002	<0.04	0.18	0.031	0.03
145	IAS	USGS	01/25/08	302	9.4	—	—	—	—	—	—
146	UFA	USGS	01/25/08	11,200	<8.0	—	—	—	—	—	—
148	UFA	USGS	11/08/07	725	57	0.133	<0.002	<0.04	0.15	0.006	0.006
149	SA	SWFWMD	10/30/07	<250	<12.5	—	<0.005	19	—	—	0.392
150	SA	USGS	01/15/08	35	432	0.041	0.004	<0.04	1.4	0.05	0.062
153	IAS	SWFWMD	04/13/07	3,230	12.5	—	—	—	—	—	—
154	UFA	SWFWMD	04/13/07	2,510	12.5	—	—	—	—	—	—
156	SA	SWFWMD	08/06/07	<250	<12.5	—	<0.005	7.7	—	—	<0.005
157	SA	FDEP, SFWMD	02/23/00	—	—	0.27	—	0.004	—	0.026	0.036
158	UFA	SWFWMD	09/05/01	—	—	—	—	—	—	—	—
162	SA	FDEP, SFWMD	04/13/00	—	—	0.01	—	8.9	—	0.012	0.022
163	UFA	SWFWMD	10/18/07	1,490	<12.5	—	—	—	—	—	—
165	SA	USGS	01/15/08	24	5,200	0.225	<0.002	<0.04	0.92	0.027	0.031
166	IAS	USGS	01/15/08	2,270	14	0.059	<0.002	<0.04	0.06	E.006	<0.006
167	SA	SWFWMD	04/26/07	<250	<12.5	—	<0.005	7.1	—	—	0.006
168	SA	SWFWMD	10/29/07	<250	<12.5	—	<0.005	20	—	—	<0.005
172	UFA	USGS	07/15/03	1,910	5.0	0.02	<0.010	<0.02	—	0.01	—
173	SA	SFWMD	06/04/07	—	—	—	—	—	—	—	—
174	IAS	SFWMD	06/04/07	—	—	—	—	—	—	—	—
175	UFA	USGS	01/23/08	4,069	26	—	—	—	—	—	—

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