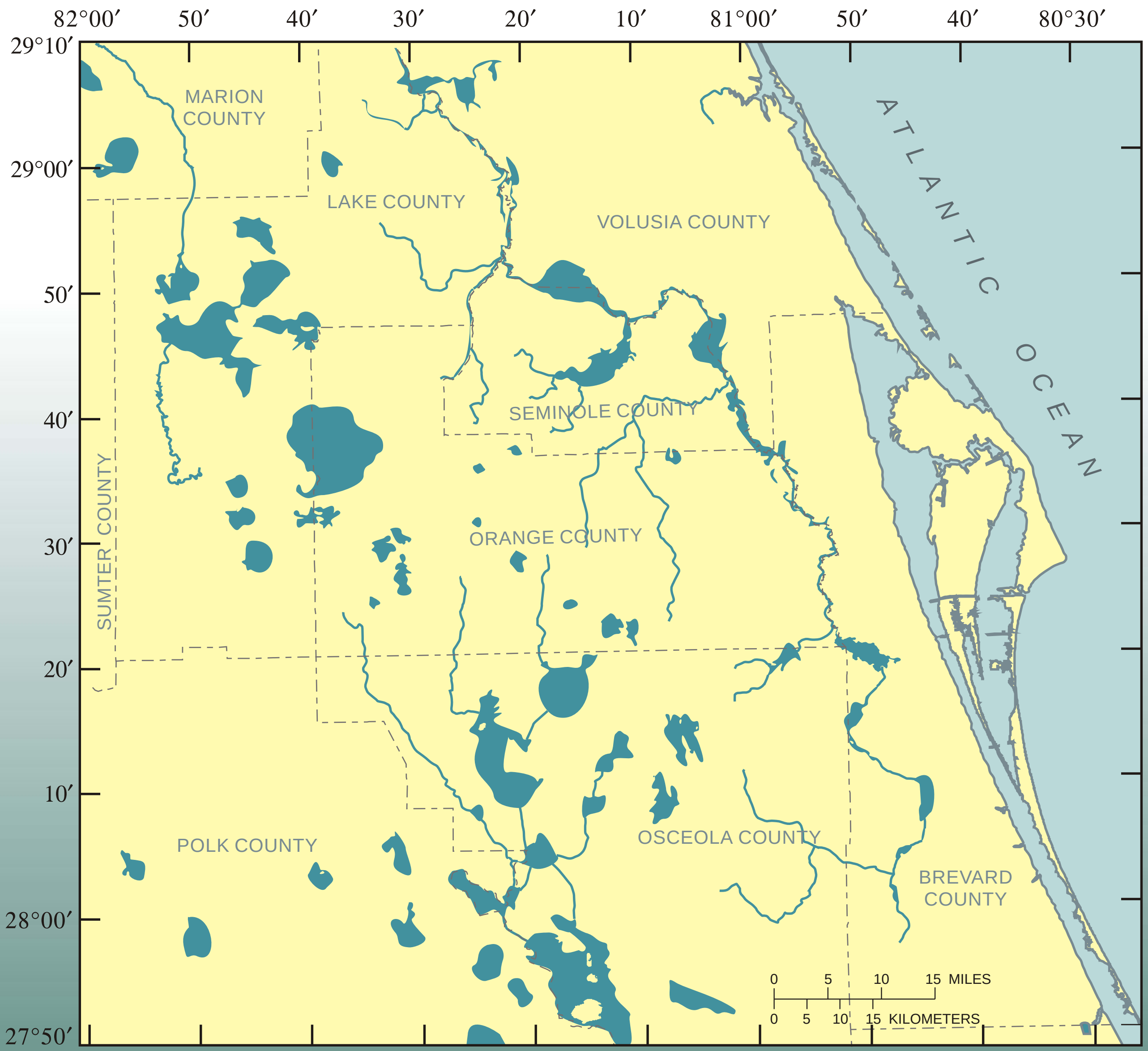
Hydrogeology and Water-Quality Characteristics of the Lower Floridan Aquifer in East-Central Florida

U.S. Geological Survey
Water-Resources Investigations Report 02-4193



Prepared in cooperation with the

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By Andrew M. O'Reilly *and* Rick M. Spechler, U.S. Geological Survey, *and*
Brian E. McGurk, St. Johns River Water Management District

U.S. GEOLOGICAL SURVEY

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Tallahassee, Florida
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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square foot (ft^2)	0.0929	square meter
square mile (mi^2)	2.590	square kilometer
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second
inch per year (in/yr)	25.4	millimeter per year
	Hydraulic Conductivity	
foot per day (ft/d)	0.3048	meter per day
	**Transmissivity*	
foot squared per day (ft^2/d)	0.0929	meter squared per day

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8.

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Altitude: In this report, altitude refers to distance above or below sea level.

*__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.

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD27).

Acronyms and additional abbreviations:

FDEP	Florida Department of Environmental Protection
FGS	Florida Geological Survey
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter at 25 °C
mg/L	milligrams per liter
NWIS	National Water Data Information System
RASA	Regional Aquifer System Analysis
SJRWMD	St. Johns River Water Management District
SFWMD	South Florida Water Management District
USGS	U.S. Geological Survey

Hydrogeology and Water-Quality Characteristics of the Lower Floridan Aquifer in East-Central Florida

By Andrew M. O'Reilly, Rick M. Spechler, and Brian E. McGurk

ABSTRACT

The hydrogeology and water-quality characteristics of the Lower Floridan aquifer and the relation of the Lower Floridan aquifer to the framework of the Floridan aquifer system were evaluated during a 6-year (1995-2001) study. The study area, a 7,500 square-mile area of east-central Florida, is underlain by three principal hydrogeologic units: the surficial aquifer system, the intermediate confining unit, and the Floridan aquifer system. The Floridan aquifer system, a carbonate-rock aquifer system composed of the Upper Floridan aquifer, a middle semiconfining unit, a middle confining unit, and the Lower Floridan aquifer, is the major source of water supply to east-central Florida. The Upper Floridan aquifer provides much of the water required to meet the current (2002) demand; however, the Lower Floridan aquifer is being used increasingly as a source of freshwater, particularly for municipal needs. For this reason, a better understanding of the aquifer is needed.

The Lower Floridan aquifer is present throughout east-central Florida. The aquifer is composed of alternating beds of limestone and dolomite, and is characterized by abundant fractured dolomite zones and solution cavities. The altitude of the top of the Lower Floridan aquifer ranges from less than 600 feet below sea level in the northern part of the study area to more than 1,600 feet below sea level in the southwestern part. Thickness of the unit ranges from about 910 to 1,180 feet. The top of the Lower Floridan aquifer generally is marked by an increase in formation resistivity and by an increase in the occurrence of fractures and solution cavities within the carbonates. Also, a noticeable increase in borehole flow often marks the top of the unit. The bottom of the Lower Floridan aquifer is based on the first occurrence of evaporites.

Ground-water in the Lower Floridan aquifer generally moves in a southwest-to-northeast direction across the study area. In September 1998, the altitude of the potentiometric surface of the Lower Floridan aquifer ranged from about 16 to 113 feet above sea level, and altitudes in May 1999 were about 2 to 7 feet lower than those measured in September 1998. The potentiometric surface of the Floridan aquifer system is constantly fluctuating, mainly in response to seasonal variations in rainfall and ground-water withdrawals. Seasonal fluctuations in the Lower Floridan aquifer typically range from about 2 to 10 feet.

Water samples from 50 Lower Floridan aquifer wells were collected during this study. Most samples were analyzed in the field for temperature, pH, and specific conductance, and in the laboratory for major cations and anions. Specific conductance ranged from 147 to 6,710 microsiemens per centimeter. Chloride concentrations ranged from 3.0 to 2,188 milligrams per liter; sulfate concentrations ranged from 0.2 to 750 milligrams per liter; and hardness ranged from 69 to 940 milligrams per liter. Water was least mineralized in the recharge areas of the Lower Floridan aquifer in the western part of the study area. The most mineralized water in the Lower Floridan

aquifer occurred along parts of the Wekiva and St. Johns Rivers and in much of the eastern and southern parts of the study area.

The altitude of the base of freshwater in the Floridan aquifer system (where chloride concentrations are equal to 250 milligrams per liter) is variable throughout the study area. The estimated position of the 250 milligram per liter isochlor surface is less than 200 feet below sea level in much of the eastern part of the study area, including the areas along the St. Johns River in Lake, Seminole, and Volusia Counties and near the Wekiva River in western Seminole County. The altitude of the 250 milligram per liter isochlor exceeds 3,000 feet below sea level in the extreme southwestern part of the study area.

INTRODUCTION

The east-central Florida area (fig. 1) continues to experience rapid population growth. Virtually all of the water required to meet municipal, industrial, and agricultural needs is pumped from the Floridan aquifer system. The Floridan aquifer system consists of two distinct production zones, the Upper and Lower Floridan aquifers, separated by less permeable middle semiconfining and middle confining units. As recently as 1995, about 81 percent of the total water withdrawn from the Floridan aquifer system was from the Upper Floridan aquifer (McGurk and Presley, in press). Therefore, previous data-collection efforts have been focused on the Upper Floridan aquifer, with relatively few wells drilled into the Lower Floridan aquifer. The Lower Floridan aquifer, however, is being used increasingly as a source of freshwater for the greater Orlando metropolitan area. The aquifer is highly transmissive and is not as susceptible to contamination from the surficial aquifer system or from drainage wells in the Orlando area as is the Upper Floridan aquifer.

Hydrogeologic and water-quality information that can be used by water-resource managers to assess the effects of current and future development of the Lower Floridan aquifer are insufficient. The aquifer framework, ground-water flow system, and water-quality conditions are not well defined. Existing maps that depict the tops, thicknesses, and lithologic characteristics of the Lower Floridan aquifer and semiconfining units within the aquifer are regional in scope and based on sparse data. Similarly, existing maps that show the areal distribution of poor quality water within the Lower Floridan aquifer, as well as the location of the freshwater-saltwater interface, are based on only a few data points. In response to the need for additional data, the U.S. Geological Survey (USGS), in cooperation with the St. Johns River (SJRWMD) and South Florida Water Management Districts (SFWMD), conducted a 6-year study (1995-2001) to evaluate the hydrogeology and water-quality conditions of the Lower Floridan aquifer in east-central Florida.

Purpose and Scope

This report presents a summary of the hydrogeologic framework and water-quality conditions in the Lower Floridan aquifer in east-central Florida. The objectives of this report are to: (1) describe the hydrogeologic framework of the Lower Floridan aquifer; (2) refine maps by Miller (1986) depicting the tops and thicknesses of the Lower Floridan aquifer and semiconfining and confining units within the Floridan aquifer system; (3) delineate directions and gradients of ground-water flow in the Lower Floridan aquifer; (4) describe the areal and vertical distribution of water quality in the Lower Floridan aquifer; and (5) better approximate the depth of the freshwater-saltwater interface.

Comparison of the maps in this report to those presented in Miller (1986) shows some discrepancies. Miller's (1986) maps were regional in extent and based on limited data. Much of the data used to construct the hydrogeologic maps presented in this report were collected after Miller's (1986) report was published.

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

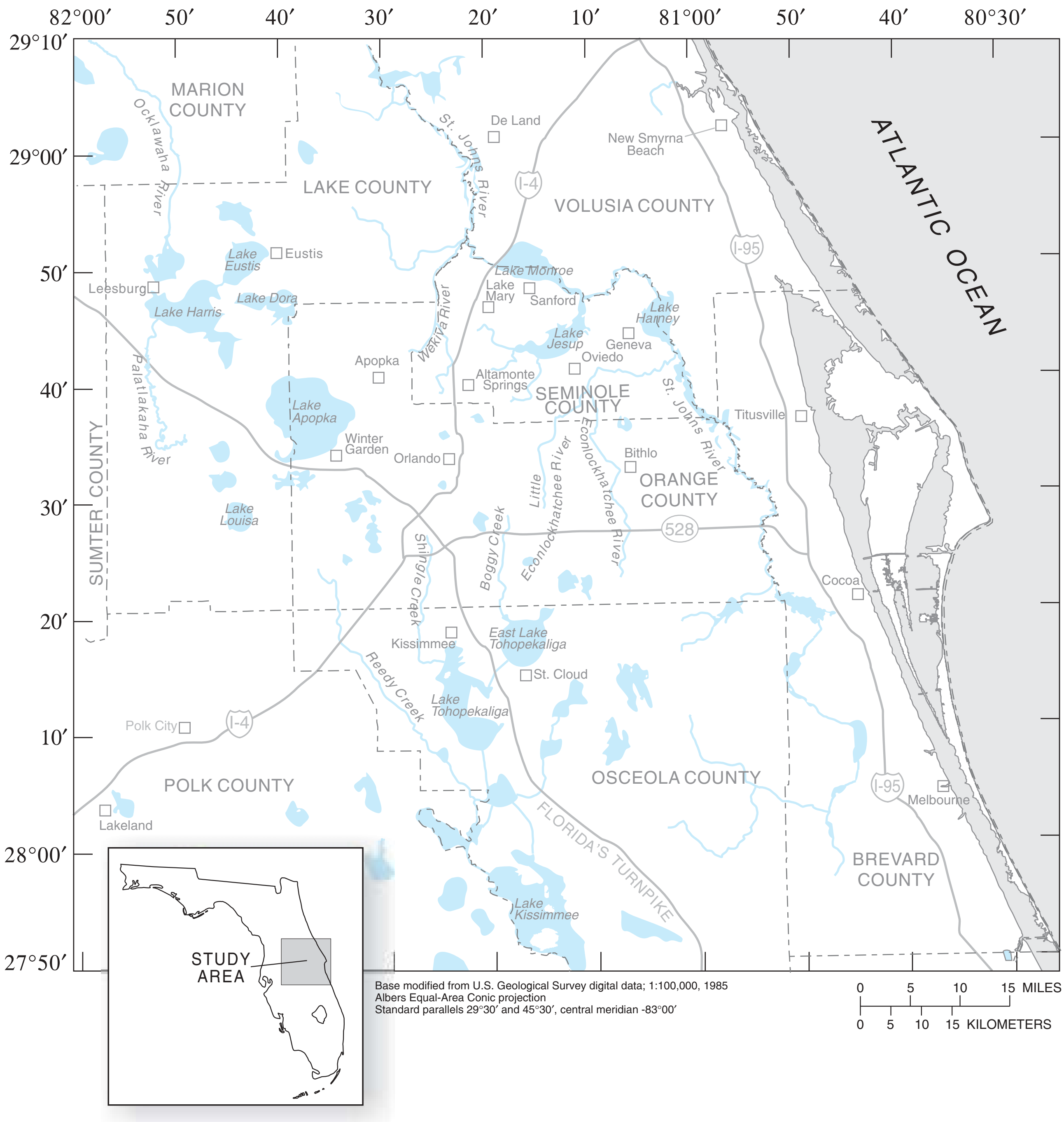


Figure 1. Location of study area.

Previous Investigations

Although many reports describe the ground-water resources of the Floridan aquifer system in east-central Florida, few studies focused specifically on the hydrogeology of the Lower Floridan aquifer. Current conceptualization of the Lower Floridan aquifer is based on data compiled from numerous site-specific drilling investigations published in USGS, SJRWMD, FGS, and private consultants' reports. Unpublished reports provided by the SJRWMD were particularly informative because they provided detailed lithologic, geophysical, and chemical data from the Lower Floridan aquifer at specific sites in east-central Florida.

The USGS Regional Aquifer System Analysis (RASA) program provided background information for this report. The RASA program began in 1978, following a congressional mandate to develop quantitative appraisals of the major ground-water systems of the United States. The final interpretive results of the RASA program are presented in a series of USGS Professional Papers describing the geology, hydrology, and geochemistry of each regional aquifer system. The hydrogeology of the RASA area (Florida, and parts of Georgia, Alabama, and South Carolina) that includes the Floridan aquifer system was described by Miller (1986). Between the end of the RASA program and the beginning of the present study, few data for the Lower Floridan aquifer have been collected.

Acknowledgments

The authors gratefully acknowledge the assistance given by many organizations and individuals during the study and especially appreciate the cooperation received from the St. Johns River Water Management District and the South Florida Water Management District. Cooperation from the numerous water utility departments and landowners who permitted access to their wells for data collection is greatly appreciated, as are data and reports provided by numerous private consulting firms.

Well-Numbering System

The USGS assigns a unique site identification number to each inventoried well. A 15-digit number based on latitude and longitude is used to identify wells in the USGS National Water Data Information System (NWIS). The first six digits denote the degrees, minutes, and seconds of latitude; the next seven digits denote degrees, minutes, and seconds of longitude; and the last two digits denote a sequential number for a site within a one-second grid. For example, well 283333081233501 is the first well inventoried at latitude 28°33'33" N, longitude 081°23'35" W. However, the latitudes and longitude stored in NWIS should be used rather than those defined by the 15-digit site number because the initial measurements may be inaccurate or successive measurements more accurate. The site identification number is not revised to reflect a change in the latitude or longitude.

The SJRWMD uses an identification system similar to the USGS for identifying wells, using latitude and longitude as a primary identifier. They also use a sequential local number assigned to each well as it is added to their network files. An abbreviation for the county where the well is located precedes the well number and thus distinguishes it from a well having the same number in another county. The prefixes S, OR, BR, L, OS, PO, and V, indicate a well drilled in Seminole, Orange, Brevard, Lake, Osceola, Polk and Volusia Counties, respectively.

Description of Study Area

The study area encompasses about 7,500 square miles (mi^2) in east-central Florida and includes all of Brevard, Orange, and Seminole Counties and parts of Lake, Marion, Osceola, Polk, Sumter, and Volusia Counties (fig. 1). Land-surface elevations range from sea level along the coast of the Atlantic Ocean to more than 300 feet (ft) above sea level in Polk and Lake Counties. Major rivers include the St. Johns, Wekiva, Palatlakaha, Ocklawaha, Econlockhatchee, and the Little Econlockhatchee Rivers; and major creeks include Reedy, Shingle, and Boggy Creeks (fig. 1). Major lakes include Lake Monroe, Jesup, Harney, Apopka, and Harris in the northern part of the study area, and Lakes Tohopekaliga and Kissimmee in the south. Numerous karst features, including sinkholes and springs, are present in the study area. Sinkholes in all stages of development are common throughout the area and range from small depressions a few feet in diameter to large lakes. Sinkholes can be dry or water-filled, internally drained depressions that commonly are areas of high recharge to the underlying aquifers. Numerous springs, located mainly in the northern half of the study area, discharge water from the Upper Floridan aquifer into rivers and streams that eventually flow into the Atlantic Ocean.

The climate of the study area is classified as humid subtropical. Summers are typically hot and wet, and winters are mild and dry. Temperatures commonly exceed 90^{o} F from June to September, but may fall below freezing for a few days in the winter months. Mean annual rainfall for the study area (1971-2000) was about 51 inches (averaged from rainfall data reported by the National Oceanic and Atmospheric Administration). About 55 percent of the average annual rainfall occurs in the summer (June through September) during local, intense thunderstorms. During the summer months and early fall, tropical storms and hurricanes also can bring heavy precipitation into the area. Winter rainfall generally is associated with large, frontal-type, cold air masses that move from the northern latitudes southward.

Data Collection

Data collection included biannual water-level measurements from September 1996 to May 1999 made in 105 wells, of which 69 tap the Lower Floridan aquifer. Water samples collected from 50 Lower Floridan aquifer wells were analyzed for common inorganic constituents. Most water-quality data were collected from 1996 through 2000. The locations of wells used for the collection of water-level and water-quality data are shown in figure 2. Well construction data and general information about the wells are presented in appendix 1. Hydrogeologic maps were generated by using data from borehole-geophysical logs and lithologic logs. Site locations for geophysical and lithologic data are shown in figure 3 and general information is tabulated in appendix 2. The USGS participated in the collection of data at one test well (well 9, app. 1) drilled by the SFWMD in northern Osceola County. At this site, rock cuttings were collected at 10-ft intervals and water levels and water samples were collected at 20-ft intervals to a depth of 2,210 ft.

Separate well numbers (fig. 2 and app. 1) and site numbers (fig. 3 and app. 2) were assigned because water-level and water-quality data were not always collected from the same well as geophysical, lithologic, or aquifer test data. For example, geophysical and lithologic data commonly were collected in multiple boreholes at the same site, and the boreholes were later modified (backplugged or deeper well casing set) and completed as monitoring wells. Often, only one monitoring well was used for water-level and water-quality data collection. In addition, most aquifer tests involved the use of multiple wells at the same site; these wells may or may not have been used to collect other types of data.

Delineation of Hydrogeologic Units using Borehole Geophysics

Hydrogeologic units within the Floridan aquifer system were delineated based primarily on the interpretation of borehole geophysical data. Most geophysical logs were obtained from the files of the SJRWMD and private consultants. Geophysical logs analyzed included caliper, natural-gamma radiation, fluid velocity (flow meter), static and flowing fluid temperature and resistivity, electric (normal, focused, and lateral resistivity), and neutron. Most of the wells, however, did not have a complete set of geophysical logs available. Lithologic and water-quality data, where available, also were used in combination with geophysical logs.

Geophysical logs are made by traversing various geophysical tools vertically through the well bore. The caliper log shows the diameter of the borehole and can indicate the presence and size of fractures or solution features. Where the formation is soft, the borehole generally is large and relatively uneven. Where the formation is hard, the borehole is more uniform in diameter and is about the same size as the drill bit used in drilling. The natural gamma-radiation log is used to delineate clay, phosphate-bearing deposits, and layers of peat by recording the naturally occurring radiation coming from the formation adjacent to the borehole. Gamma radiation penetrates the well casing, so data can be collected in both the cased and open sections of the borehole.

Fluid resistivity logs record the capacity of fluid in the borehole to conduct an electric current. The logs provide data about the concentration of dissolved solids in the fluid and aid in the identification of production zones having different water-quality characteristics. The several types of electric logs analyzed generally show the combined electrical properties of both the formation and water in the formation; therefore, a change in either lithology or water quality can cause a variation in the electric log trace. However, if fluid resistivity logs indicate negligible variations in the resistivity of the water in the formation and conductive mineral grains are not present (for example, a clay-free carbonate saturated with fresh or brackish water), then formation resistivity measured by an electric log primarily is a function of the effective porosity of the formation (Keys, 1988, p. 46 and 108; and Kwader, 1985).

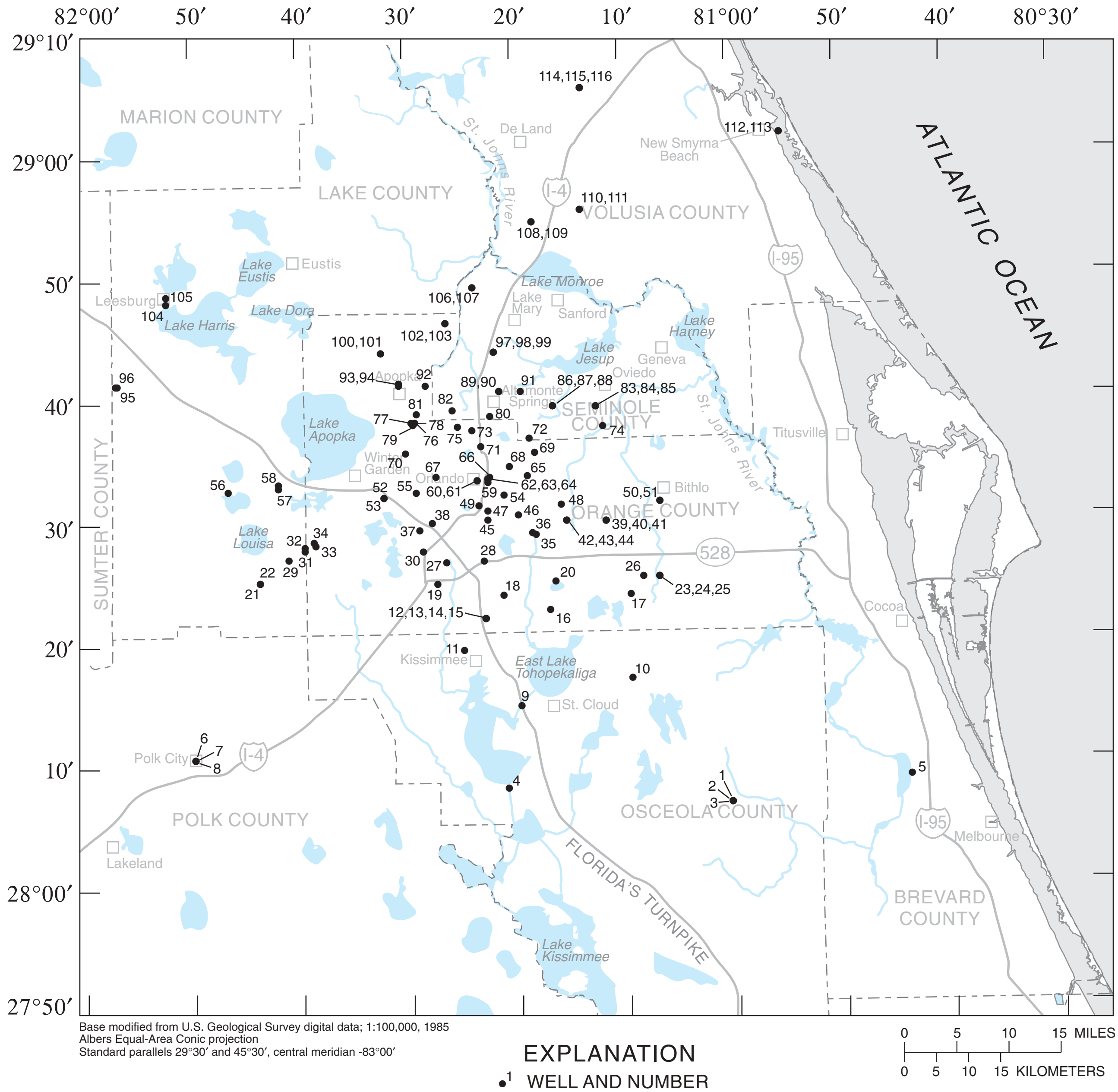


Figure 2. Location of wells used for collection of water-level and water-quality data (well number and information in appendix 1).

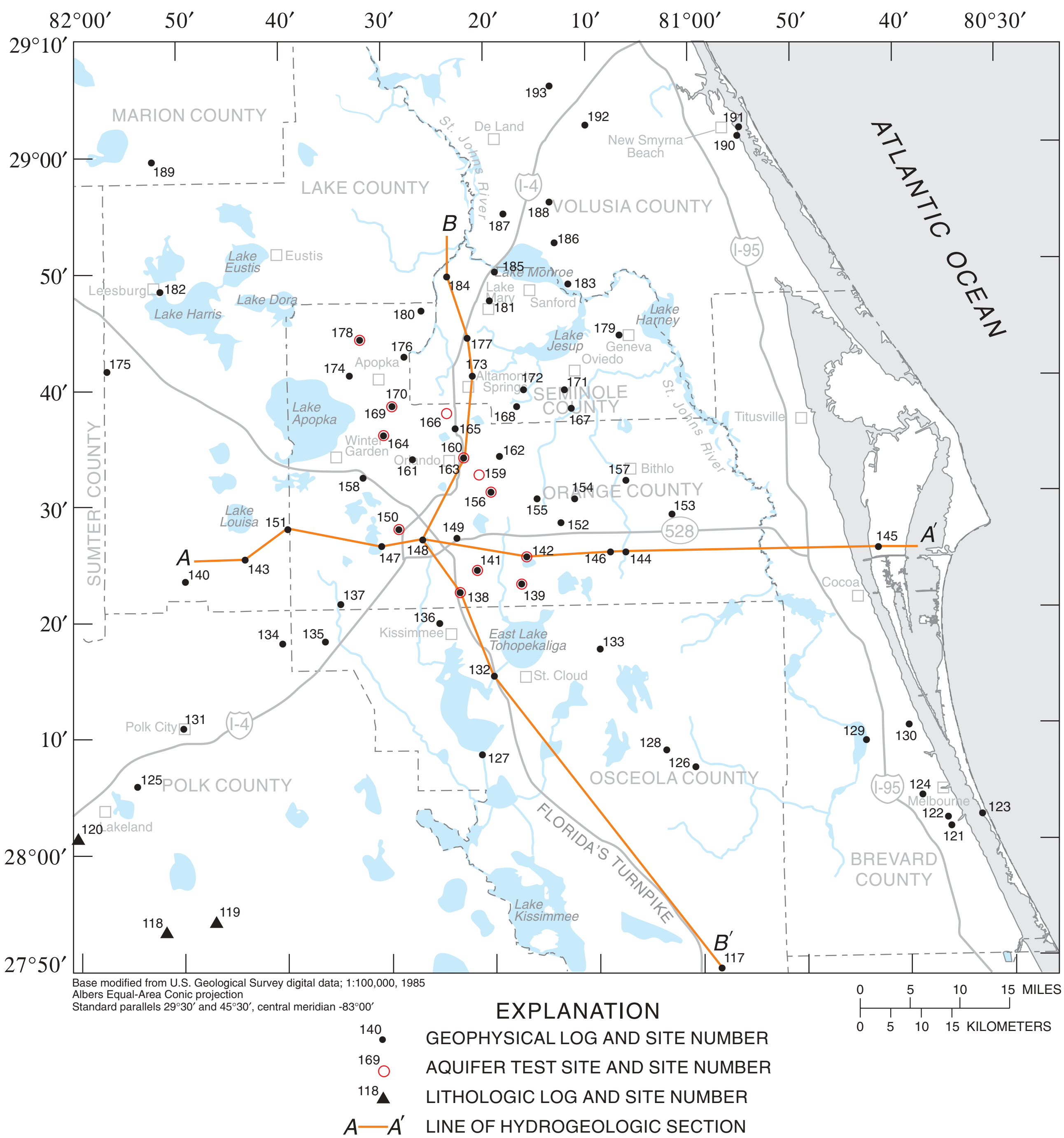


Figure 3. Location of geophysical and lithologic logs and aquifer test data-collection sites (site number and information in appendix 2).

Fluid velocity logs (flow meter) measured under static and flowing or pumping conditions are used in conjunction with caliper logs to delineate flow zones. Fluid velocity logs measure the velocity of the water moving up or down the borehole; given a constant flow rate, fluid velocity in the borehole is inversely proportional to the cross-sectional area of the borehole. Fluid velocity logs can be approximately corrected for this borehole effect by assuming that the caliper log represents the diameter of a circular borehole. A flow log, representing flow rate, can be calculated as the product of velocity (obtained from the fluid velocity log) and cross-sectional borehole area, calculated from the caliper log. Analysis of flow logs can be used to infer the vertical profile of relative transmissivity near the borehole (Paillet and Reese, 2000). Relative transmissivity is directly proportional to the flow profile calculated by subtracting the flow profile measured under steady-state pumping or flowing conditions from that measured under static conditions. Therefore, flow logs can be used not only to indicate the presence of flow zones, but also to determine which flow zones are most transmissive.

HYDROGEOLOGIC FRAMEWORK

The study area is underlain by a thick sequence of sedimentary rocks that overlie deeper volcanic, metamorphic, and sedimentary rocks (Smith and Lord, 1997). The primary water-bearing sediments are composed of limestone, dolomite, shell, clay, and sand that range in age from late Paleocene to Holocene. Descriptions of major stratigraphic units and corresponding hydrogeologic units penetrated by wells are provided in figure 4. The ground-water flow system beneath the study area is a multi-aquifer system. The

SERIES		STRATIGRAPHIC UNIT	LITHOLOGY	HYDROGEOLOGIC UNIT	
Holocene		Undifferentiated deposits	Alluvium, freshwater marl, peats and muds in stream and lake bottoms. Also, some dunes and other windblown sand.	Surficial aquifer system	
Pleistocene			Mostly quartz sand. Locally may contain deposits of shell and thin beds of clay.		
Pliocene			Interbedded deposits of sand, shell fragments, and sandy clay; base may contain phosphatic clay.		
Miocene		Hawthorn Group	Interbedded quartz, sand, silt and clay, often phosphatic; phosphatic limestone often found at base of formation.	Intermediate confining unit	
Eocene	Upper	Ocala Limestone	Cream to tan, soft to hard, granular, porous, foraminiferal limestone.	Floridan aquifer system	Upper Floridan aquifer
	Middle	Avon Park Formation	Light brown to brown, soft to hard, porous to dense, granular to chalky, fossiliferous limestone and brown, crystalline dolomite; intergranular gypsum and anhydrite.		Middle semiconfining unit; Middle confining unit
	Lower	Oldsmar Formation	Alternating beds of light brown to white, chalky, porous, fossiliferous limestone and porous crystalline dolomite.		Lower Floridan aquifer
Paleocene		Cedar Keys Formation	Dolomite, with considerable anhydrite and gypsum, some limestone.	Sub-Floridan confining unit	

Figure 4. Generalized geology and hydrogeology of east-central Florida (modified from Tibbals, 1990; and Spechler and Halford, 2001).

lithostratigraphic units form a multilayered sequence of aquifers and confining units. Each aquifer system has unique hydraulic characteristics that determine its potential for water supply. The principal water-bearing units in the study area are the surficial and Floridan aquifer systems (fig. 4). The surficial aquifer system is underlain by and separated from the Floridan aquifer system by the intermediate confining unit, which restricts the movement of water between the two aquifers. Underlying the Floridan aquifer system are low permeability limestone and dolomite containing considerable gypsum and anhydrite that define the bottom of the Floridan aquifer system in the study area. Variations in the distribution, thickness, and dip of the hydrogeologic units are depicted in generalized hydrogeologic sections (fig. 5), constructed primarily from geophysical and lithologic logs.

Surficial Aquifer System and Intermediate Confining Unit

The surficial aquifer system is the uppermost water-bearing unit in the study area. The unit generally consists of quartz sand and varying amounts of shell and clay of Pliocene to Holocene age. The surficial aquifer system is unconfined and the upper boundary of the system is defined by the water table. In the swampy lowlands and flatlands, the water table generally is at or near land surface throughout most of the year. In areas of higher elevations, the water table generally is a subdued reflection of land-surface topography and can be tens of feet below land surface. The thickness of the surficial aquifer system in the study area is highly variable and ranges from about 10 ft to more than 150 ft along the high ridge areas of western Orange and eastern Lake Counties and in a few areas in Osceola County (Schiner, 1993, p. 20; Murray and Halford, 1996, p. 8).

Recharge to the surficial aquifer system is primarily from rainfall and by upward leakage from the underlying Floridan aquifer system at locations where the altitude of the potentiometric surface of the underlying aquifers is higher than the water table. Other sources of recharge include seepage from streams, lakes, and irrigated lands. Discharge from the surficial aquifer system is principally by evapotranspiration or leakage to the Upper Floridan aquifer. Some discharge also occurs as seepage into lakes, streams, ditches, and wetlands. The surficial aquifer system provides small amounts of water for lawn irrigation and domestic use. The water is used for domestic supply primarily in rural areas where wells in the Upper Floridan aquifer yield water that is too highly mineralized for human consumption.

The intermediate confining unit underlies the surficial aquifer system, and throughout most of the study area, serves as a confining layer that restricts the vertical movement of water between the surficial aquifer system 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 (fig. 4). The unit consists of interbedded, locally highly phosphatic, clay, silt, sand, limestone, and dolomite. The basal part of the intermediate confining unit commonly contains permeable zones of limestone and dolomite.

Thickness of the intermediate confining unit is highly variable throughout the study area due to past erosional processes and sinkhole formation. Thickness ranges from less than 25 ft throughout many parts of the study area, to more than 200 ft in parts of southeastern Orange and Osceola Counties (Schiner, 1993; Murray and Halford, 1996; O’Reilly, 1998; Spechler and Halford, 2001; Knowles and others, in press). In western Orange, western Seminole, southwestern Volusia, and many parts of Lake County, some sinkhole depressions are filled with permeable sands, and the intermediate confining unit is relatively thin or absent in such locations.

Floridan Aquifer System

The Floridan aquifer system, the primary source of ground water in east-central Florida, underlies all of Florida, and parts of Alabama, Georgia, and South Carolina. In the study area, the aquifer is composed of a sequence of highly permeable carbonate rocks of Eocene and Late Paleocene age that average about 2,300 ft in thickness. The aquifer system includes the following stratigraphic units in descending order: the Ocala Limestone, the Avon Park Formation, the Oldsmar Formation, and the upper part of the Cedar Keys Formation (fig. 4).

The Floridan aquifer system contains two permeable zones, the Upper and Lower Floridan aquifers. The Upper Floridan aquifer generally consists of the Ocala Limestone and the dolomite and dolomitic limestones of the upper one-third of the Avon Park Formation.

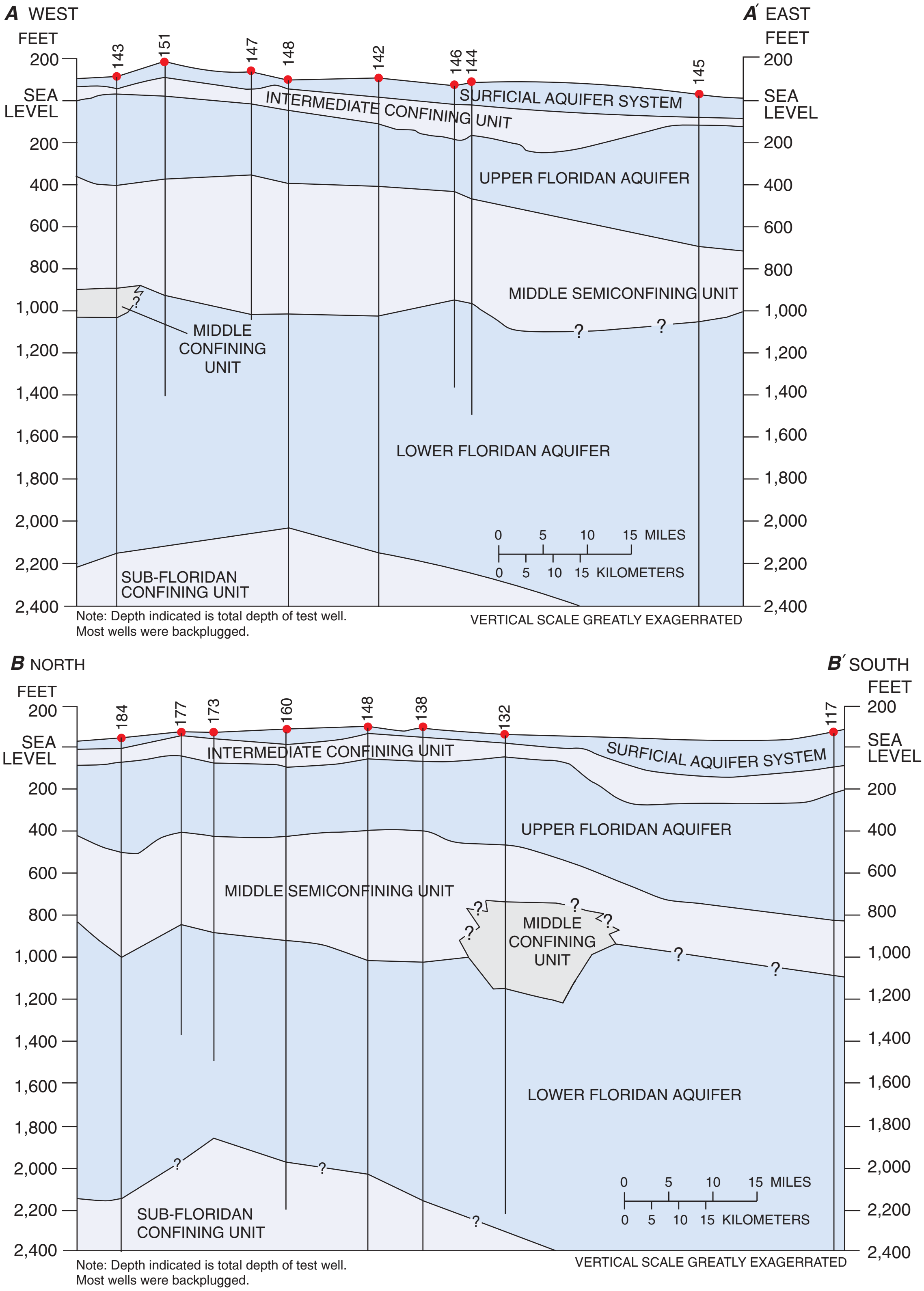


Figure 5. Generalized hydrogeologic sections A-A' and B-B' (section lines shown in figure 3).

Permeable intervals of the Ocala Limestone are characterized by vuggy to cavernous porosity. The permeability of the upper Avon Park Formation is primarily due to fractures and interconnecting solution cavities. Permeability of both units is enhanced by dissolution of the rock along bedding planes, joints, and fractures. The Lower Floridan aquifer generally consists of the lower part of the Avon Park Formation, the Oldsmar Formation, and, locally, the upper part of the Cedar Keys Formation. The aquifer layers are delineated on the basis of rock permeability, not necessarily on the basis of lithology, formation, or time-stratigraphic boundaries (Miller, 1986).

The surface of the Floridan aquifer system is irregular and paleokarstic. Sinkhole-type depressions on the surface are common. The Ocala Limestone is absent in some areas as a result of past erosional processes (Murray and Halford, 1996, p.11). Altitude of the top of the Floridan aquifer system in the study area ranges from about 100 ft above sea level in parts of northern Polk County to more than 300 ft below sea level in extreme southeastern Brevard County (Scott and others, 1991; Schiner, 1993; O'Reilly, 1998; Spechler and Halford, 2001; Knowles and others, in press).

The Upper Floridan aquifer in the study area is recharged primarily by downward leakage from the surficial aquifer system, and where present, through the intermediate confining unit. Relatively high rates of recharge occur in areas with abundant sinkholes or where the intermediate confining unit is thin or breached by collapse into underlying dissolution cavities.

The transmissivity of the Upper Floridan aquifer varies considerably throughout the study area. Transmissivity estimates for the Upper Floridan aquifer, as determined from aquifer and specific capacity tests, range from about 1,200 feet squared per day (ft^2/d) in Seminole County to greater than 500,000 ft^2/d in Orange County (Spechler and Halford, 2001, p. 24). However, permeability within the Upper Floridan aquifer in not uniform with depth (Spechler and Halford, 2001, p. 19; McGurk and Presley, in press). Flow logs from wells indicate that two distinct zones of different permeabilities (zones A and B) exist in the Upper Floridan aquifer (figs. 6 and 7). Zone A corresponds to about the upper two-thirds of the aquifer, and generally coincides with the Ocala Limestone. Zone B is equivalent to about the lower one-third of the Upper Floridan aquifer and has a hydraulic conductivity generally much larger than that of zone A. The bottom of zone B marks the base of the Upper Floridan aquifer. Zone B generally consists of hard, dense dolomite (indicated by high formation resistivity, figs. 6, 7, and 8) within the Avon Park Formation, and contains abundant fractures and other secondary porosity features (indicated by caliper logs, figs. 6, 7, and 8) (Spechler and Halford, 2001; McGurk and Presley, in press). Numerous reports describing production well drilling and test drilling in the greater Orlando area indicate that zone B is the major source of water in the Upper Floridan aquifer.

The middle semiconfining unit separates the Upper and Lower Floridan aquifers. The middle semiconfining unit (equivalent to the middle confining unit I mapped by Miller (1986, p. B57, fig. 11)) is composed of beds of softer, less permeable limestone and dolomite of variable thickness and coincides with about the middle one-third of the Avon Park Formation. Miller (1986) noted that the contrast in permeability between rocks of the middle semiconfining unit and the Lower Floridan aquifer was less than that of any other semiconfining unit in the RASA area. Also, the lithology of the semiconfining unit does not differ much from that of the Lower Floridan aquifer. This unit is considered semiconfining primarily because it lacks abundant fracture zones and solution cavities. Although individual zones can yield moderate amounts of water, the middle semiconfining unit is seldom used as a direct source of water supply. Flow logs indicate that the middle semiconfining unit is considerably less transmissive than either the Upper or Lower Floridan aquifers (figs. 6 and 7).

The top of the middle semiconfining unit ranges from about 250 ft below sea level in the extreme northwestern part of the study area to more than 800 ft below sea level in southern Brevard and southeastern Osceola Counties (fig. 9). The top of the unit generally is recognized on geophysical logs by a sharp decrease in formation resistivity compared to the overlying zone B and by a sharp decrease in flow as observed on flow meter logs (figures 6 and 7). Caliper logs of boreholes penetrating the middle semiconfining unit often indicate an enlarged borehole, presumably because the rock is soft and contains few fractures or cavities. Comparison of figure 9 to a map by Miller (1986, pl. 29) shows that the top of the middle semiconfining unit lies at a lower altitude than estimated by Miller (1986, pl. 29); in Miller (1986), the top of zone B of the Upper Floridan aquifer appears to have been mapped as the top of the middle semiconfining unit. Miller (1986), working with only a few data points, likely reasoned that the zone of high formation resistivity (zone B) observed on geophysical logs was a zone of low permeability dolomite.

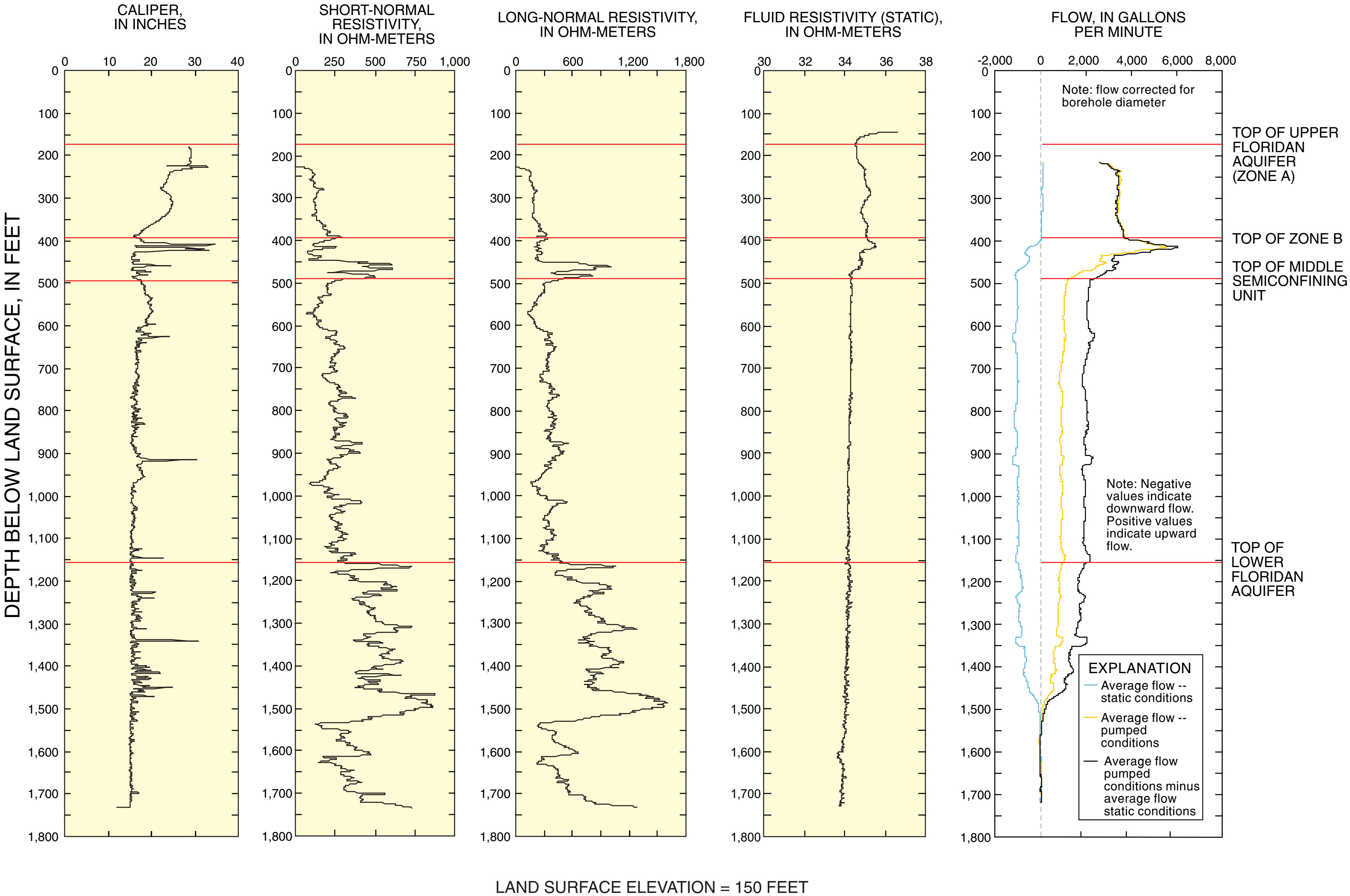


Figure 6. Selected geophysical logs and hydrogeologic units for site 150, near Orlando, Orange County, Florida (site number refers to figure 3).

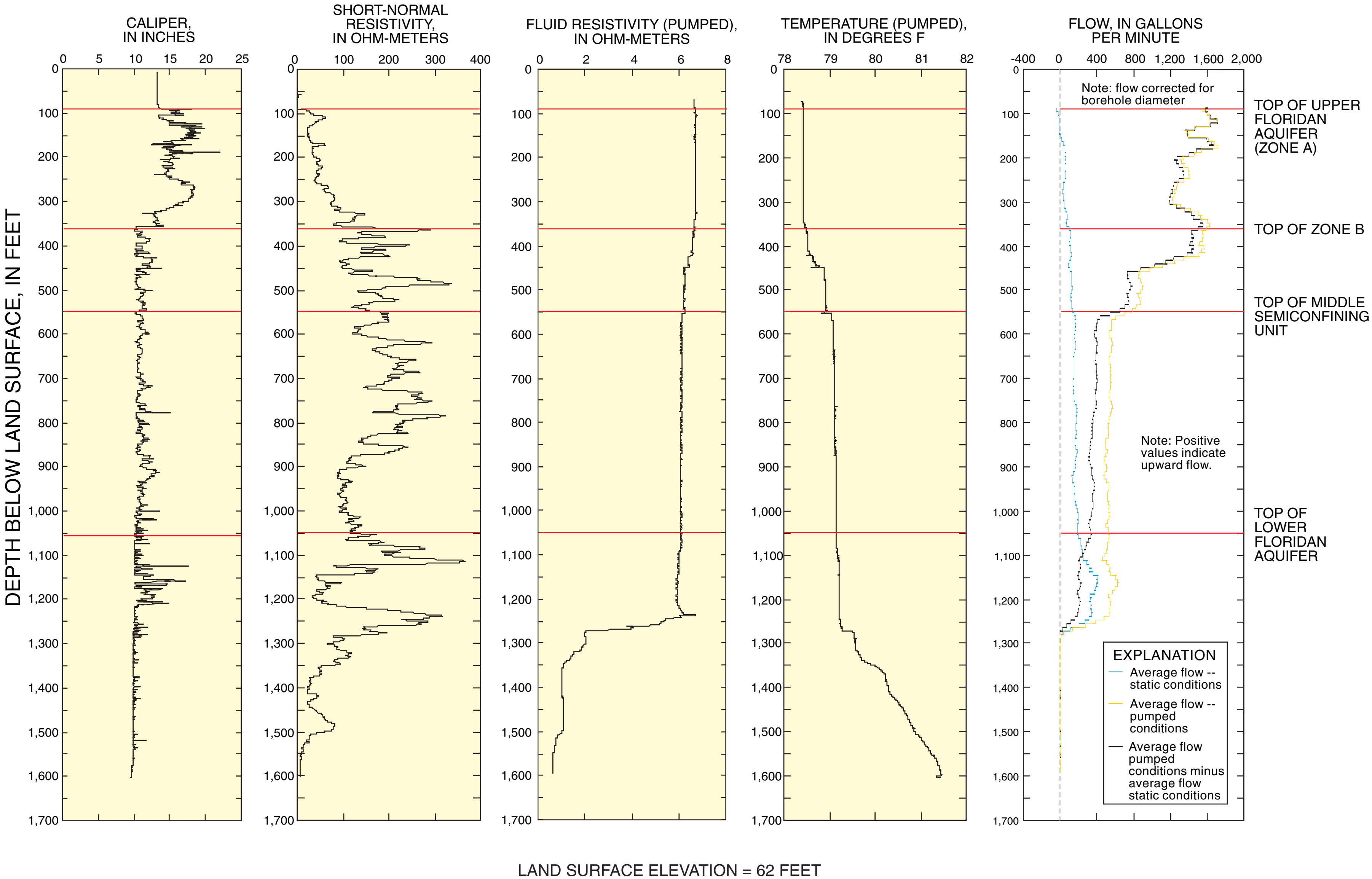


Figure 7. Selected geophysical logs and hydrogeologic units for site 171, near Oviedo, Seminole County, Florida (site number refers to figure 3).

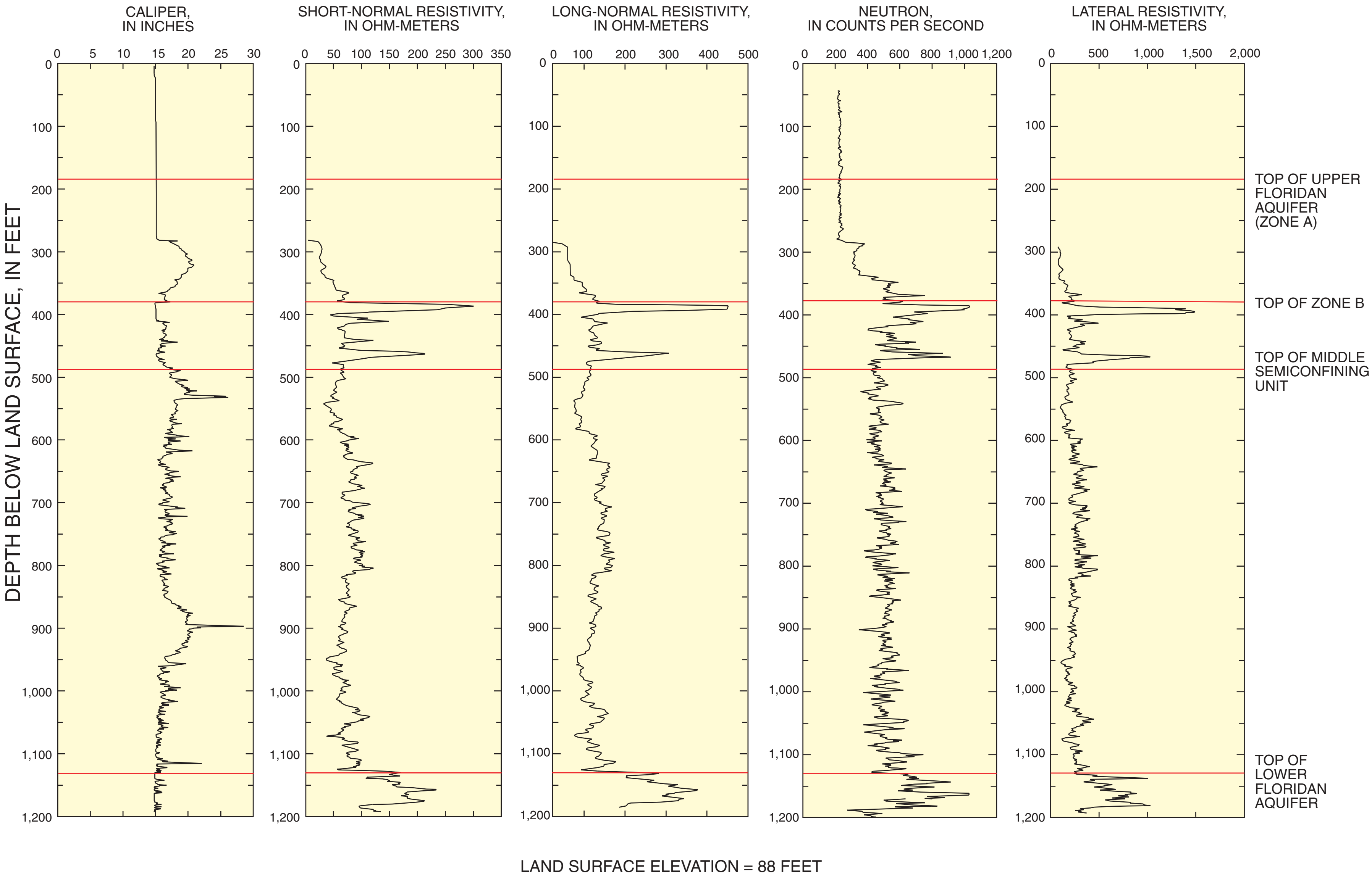
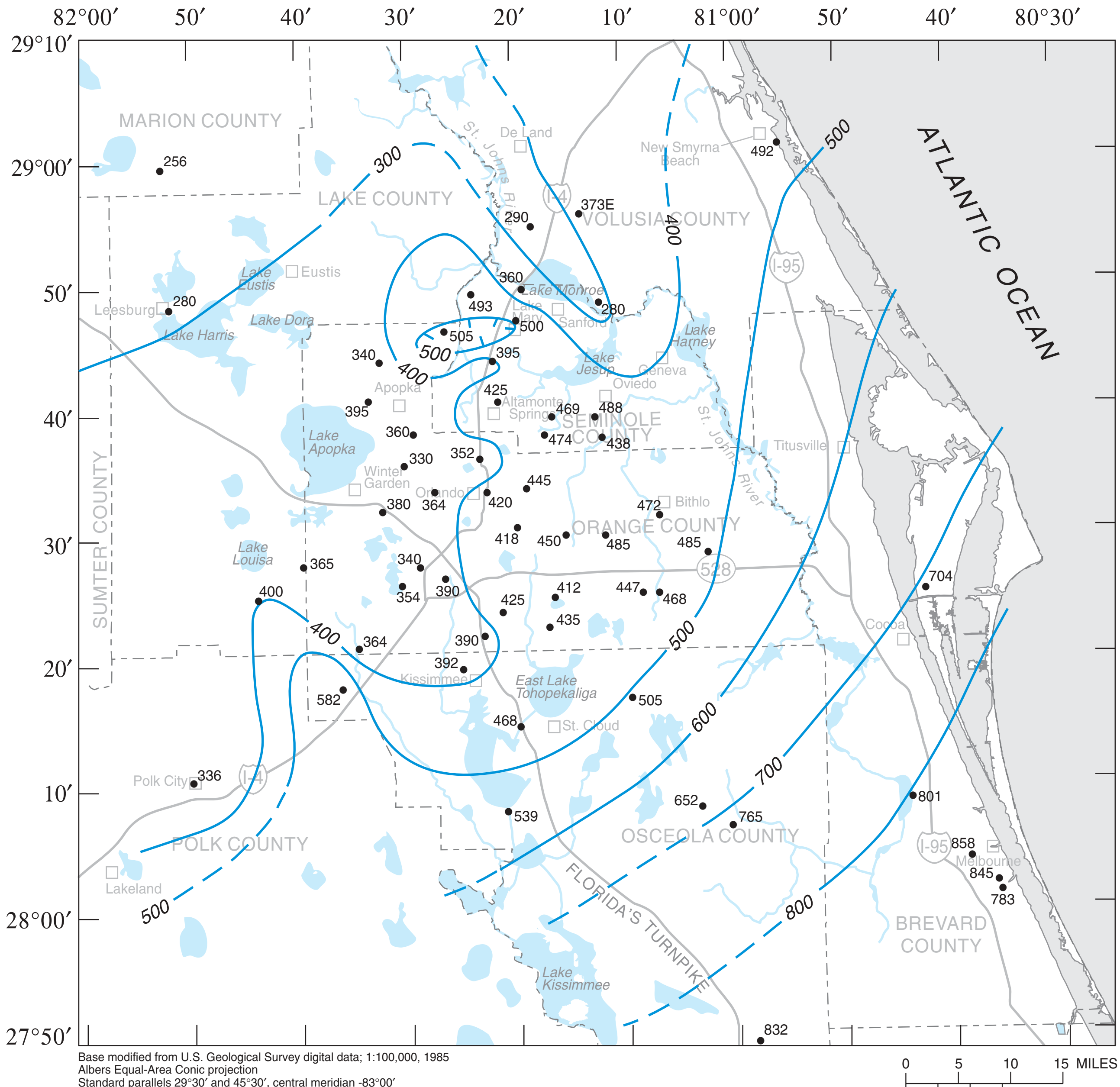


Figure 8. Selected geophysical logs and hydrogeologic units for site 136, near Kissimmee, Osceola County, Florida (site number refers to figure 3).



EXPLANATION

— 400 — STRUCTURE CONTOUR -- Shows altitude of the top of the middle semiconfining unit, in feet below sea level. Dashed where approximate. Hachures indicate depression. Contour interval 100 feet

• 765E WELL -- Number is altitude of the top of the middle semiconfining unit, in feet below sea level. "E" denotes estimated value

Figure 9. Altitude of the top of the middle semiconfining unit.

Lithologic descriptions from drillers' and geologists' logs confirm that Zone B consists of hard, dense dolomite. However, review of geophysical logs from wells drilled since the 1980's indicates that zones of high formation resistivity commonly are interspersed with abundant fractures (as indicated by caliper logs), which yield considerable amounts of water (as indicated by flow logs), all of which are primary characteristics of zone B (figures 6 and 7). The map depicting the top of the middle semiconfining unit (fig. 9) delineates the contact between the zone of high formation resistivity in the Upper Floridan aquifer (zone B) and the middle semiconfining unit.

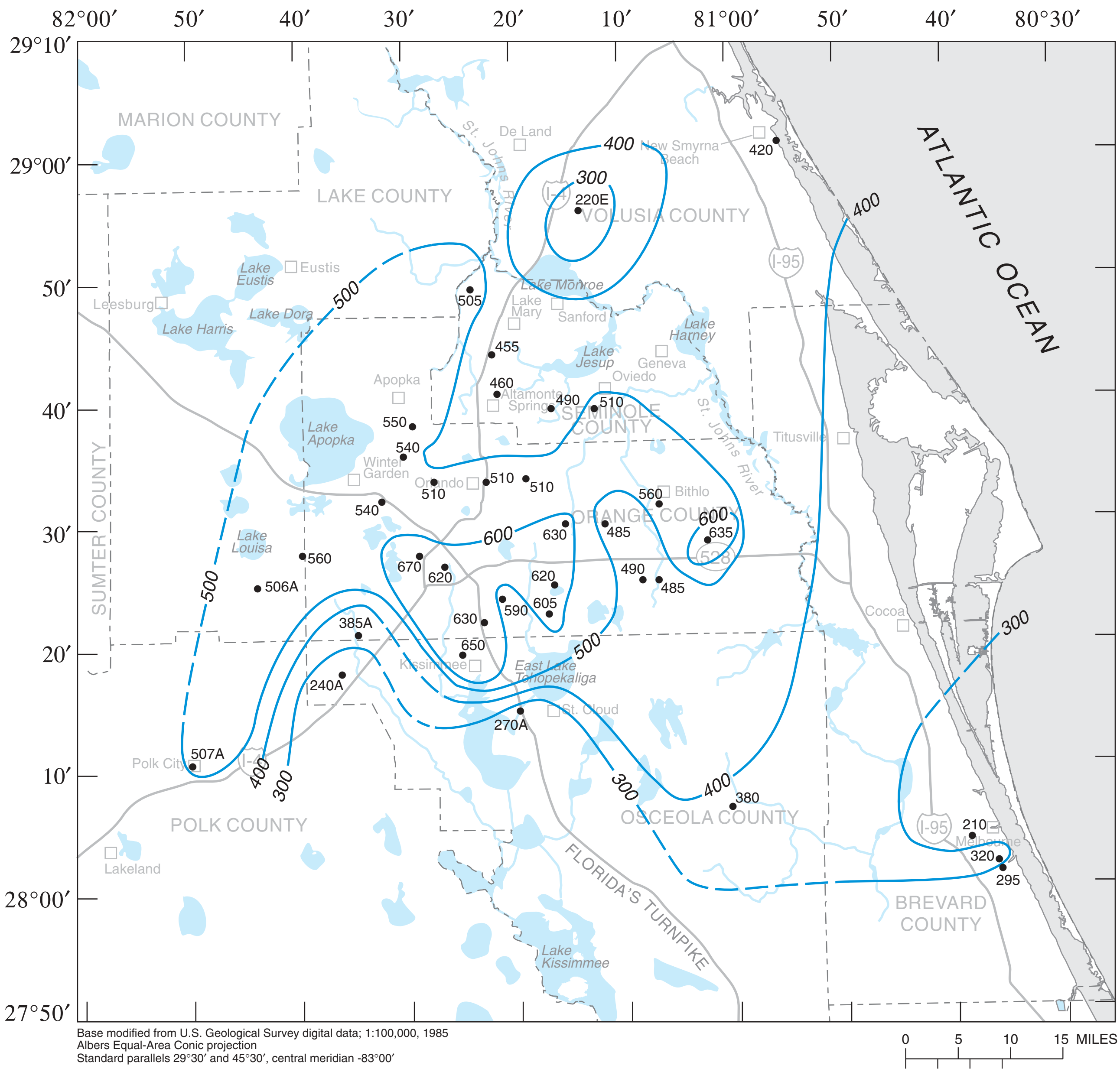
Data points for estimating the thickness of the middle semiconfining unit are sparse in the study area and are found mostly in Orange and southwestern Seminole Counties. Approximate thickness of the middle semiconfining unit ranges from less than 300 ft in the southern part of the study area to more than 600 ft in south-central Orange County and parts of northwestern Osceola County (fig. 10). In most of the study area, the thickness of the middle semiconfining unit was computed by subtracting the altitude of the top of the middle semiconfining unit from the altitude of the top of the Lower Floridan aquifer. In the southwestern part of the study area, the thickness of the middle semiconfining unit was computed differently. In this area, the middle confining unit underlies the middle semiconfining unit, and lying between these two units is a permeable zone of unknown thickness. Through the use of selected geophysical and lithologic logs, the base of the permeable zone (top of the middle confining unit) often could be defined. However, sufficient geophysical information generally was not available to distinguish the top of the permeable zone (base of the middle semiconfining unit). Therefore, in this report, the thickness of the middle semiconfining unit was computed by subtracting the altitude of the top of the middle semiconfining unit from the top of the middle confining unit.

As previously mentioned, a separate and distinct second confining unit underlies the middle semiconfining unit in the southwestern part of the study area (figures 4 and 5). The unit, referred to in this report as the middle confining unit (middle confining unit II of Miller, 1986, p. B56), is composed primarily of anhydritic and gypsiferous dolomite and dolomitic limestone and usually corresponds to the middle part of the Avon Park Formation (Miller, 1986, p. B56). This unit is considerably less permeable than the middle semiconfining unit that is found throughout the study area. The gypsum and anhydrite that is responsible for the low permeability is mostly intergranular and appears to fill preexisting pore spaces or voids in the rocks (Navoy, 1986; and Miller, 1986). Hydraulic data show that the middle confining unit forms an essentially nonleaky confining bed that separates freshwater from more mineralized water in the underlying rocks (Miller, 1986; and Navoy, 1986). Within this confining unit, however, thin, isolated zones of higher permeability can exist (Miller, 1986, p. B55; and Navoy, 1986, p. 23).

The easternmost extent of the middle confining unit, determined by using data from recently drilled test wells, is shown in figure 11. The eastern extent of the middle confining unit closely resembles the eastern boundary as originally defined by Miller (1986). However, water-quality and geologic data collected at a test well near St. Cloud (well 9, fig. 2) indicate the presence of evaporites at 738 ft below sea level (800 ft below land surface), thereby extending Miller's boundary farther to the east. The altitude of the top of the middle confining unit in the study area (based on the first occurrence of evaporites) ranges from about 750 ft below sea level near its eastern boundary to more than 1,000 ft below sea level southwest of Lakeland (fig. 11).

Some information is available on the thickness of the middle confining unit in the study area. Based on a few data points, the approximate thickness ranges from less than 150 ft in southern Lake County to 762 ft at a test well near Polk City (site 131, fig. 3) in northeastern Polk County (fig. 12). The thick area in northeastern Polk County is thought to have been caused by incomplete dissolution of gypsum and anhydrite in places where the deep flow system is very sluggish (Miller, 1986, p. B56). Thinner areas represent places where more vigorously circulating waters have dissolved much of the unit's interstitial evaporitic material, thereby increasing porosity and permeability (Miller, 1986, p. B56).

The Lower Floridan aquifer underlies the middle semiconfining unit (or where present, the middle confining unit). Because it is deeply buried and sufficient water could be obtained from the Upper Floridan aquifer, the Lower Floridan aquifer has not been intensively investigated. Consequently, the hydraulic character of the aquifer is not well known. However, because of the increase in water use in east-central Florida, additional wells have been drilled since the early 1990's to better define the hydrologic and water-quality characteristics of the Lower Floridan aquifer. These characteristics are discussed in the following sections of this report.

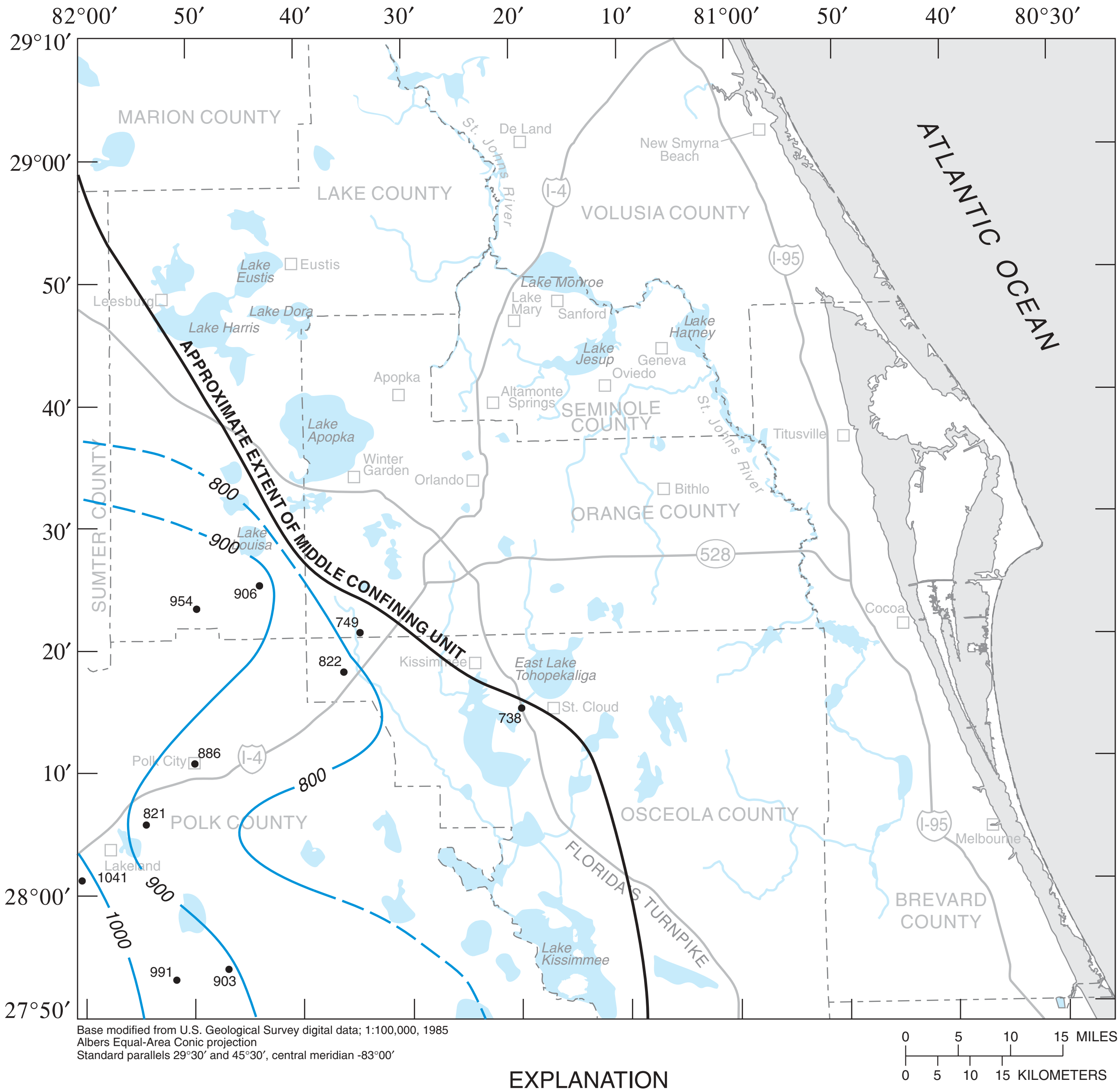


EXPLANATION

— 500 — LINE OF EQUAL THICKNESS -- Shows thickness of middle semiconfining unit. Dashed where approximate. Contour interval 100 feet

• 220A WELL -- Number is thickness of middle semiconfining unit, in feet. "A" denotes well where the thickness of the middle semiconfining unit was computed by subtracting the top of the middle semiconfining unit from the top of the middle confining unit. "E" denotes estimated value

Figure 10. Thickness of the middle semiconfining unit.



EXPLANATION

— *800* — STRUCTURE CONTOUR -- Shows altitude of the top of the middle confining unit, in feet below sea level. Dashed where approximate. Contour interval 100 feet

• 906 WELL -- Number is altitude of the top of the middle confining unit, in feet below sea level

Figure 11. Altitude of the top of the middle confining unit.

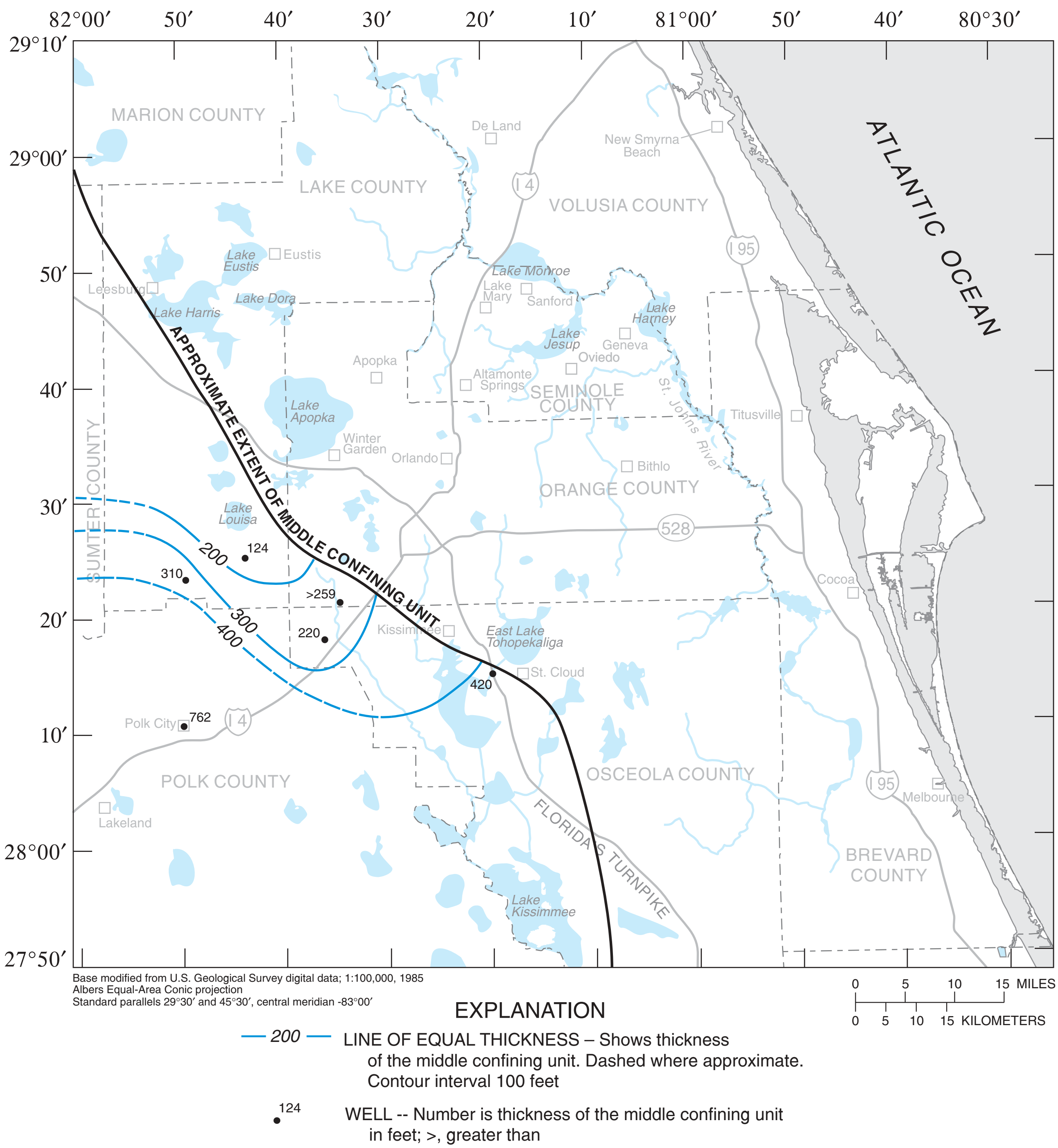


Figure 12. Thickness of the middle confining unit.

HYDROGEOLOGY OF THE LOWER FLORIDAN AQUIFER

The Lower Floridan aquifer consists of the lower part of the Avon Park Formation of middle Eocene age, the Oldsmar Formation of early Eocene age, and the upper part of the Cedar Keys Formation of late Paleocene age. The aquifer is composed of alternating beds of limestone and dolomite and is characterized by abundant fractured dolomite zones and solution cavities. The hydrogeology of the Lower Floridan aquifer was evaluated by using water-level and water-quality data, aquifer-test results, and geophysical and lithologic logs from about 100 sites (figs. 2 and 3).

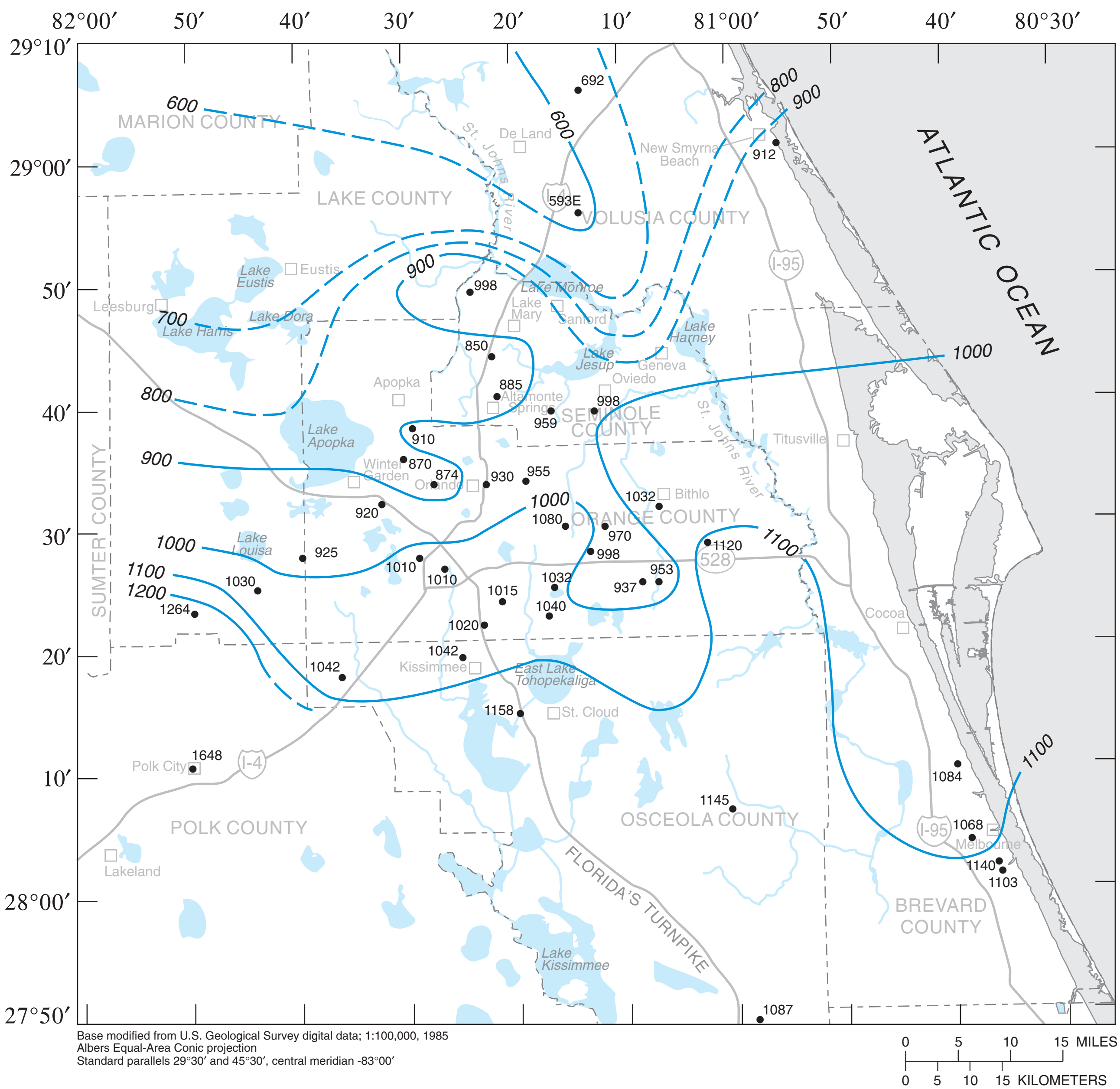
Extent and Thickness

The Lower Floridan aquifer is present throughout east-central Florida. The altitude of the top of the aquifer ranges from less than 600 ft below sea level in the extreme northwestern part of the study area to more than 1,600 ft below sea level in the southwestern part (fig. 13). In much of Seminole and Orange Counties, the altitude of the top of the Lower Floridan aquifer is fairly consistent, ranging from about 900 to 1,000 ft below sea level. In areas where the middle confining unit is absent (this occurs in most of the study area), the top of the Lower Floridan aquifer was defined as the base of the middle semiconfining unit. The top of the Lower Floridan aquifer generally is marked by an increase in formation resistivity due to the increasing presence of dolomite, and by an increase in the occurrence of fractures and solution cavities within the carbonates (figs. 6, 7, and 8). In addition, a noticeable increase in flow to the well commonly marks the contact between the Lower Floridan aquifer and the overlying unit (figs. 6 and 7).

The top of the Lower Floridan aquifer was defined differently in the southwestern part of the study area. As previously mentioned, the middle confining unit underlies the middle semiconfining unit in this area. At the Polk City well (site 131, fig. 3), Navoy (1986) reported that the middle semiconfining unit is about 307 ft thick, and the underlying middle confining unit is about 762 ft thick. Note that the 507 ft thickness of the middle semiconfining unit shown on figure 10 also includes approximately 200 ft of rock with higher permeabilities that Navoy (1986) described as separating the middle semiconfining unit from the middle confining unit. Overall, however, both the middle semiconfining unit and the middle confining unit probably act as a single confining unit within the main body of permeable limestone and dolomite that constituents the Floridan aquifer system. In the southwestern part of the study area, hydrologic data are sparse for the Floridan aquifer system. Whether or not the zone of higher permeability exists in other areas where the middle semiconfining and middle confining units are present is unknown. Therefore, the base of the middle confining unit (the deeper, less permeable unit) was defined in this report as the top of the Lower Floridan aquifer.

Limited data are available on the thickness of the Lower Floridan aquifer. Thickness values determined from eight test holes range from 910 to 1,180 ft in Seminole, Orange and southern Lake Counties (fig. 14). At two test holes in southern Brevard County, the Lower Floridan aquifer was at least 1,330 and 1,889 ft thick, although neither well penetrated the full thickness of the aquifer. Miller (1986, plate 32) indicated that the thickness of the Lower Floridan aquifer increased from north to south into Osceola, northeastern Polk, and southern Brevard Counties.

The base of the Lower Floridan aquifer is characterized by an increased presence of less permeable rocks. This unit of lower permeability rocks, called the sub-Floridan confining unit, consists of dolomite and limestone that contain abundant evaporite minerals. The uppermost stratigraphic occurrence of persistent evaporite deposits in the upper part of the Cedar Keys Formation generally is recognized by Miller (1986, p. B74) as the top of the sub-Floridan confining unit. Test drilling in Orange County, however, indicates that, based on hydraulic properties, the top of the sub-Floridan confining unit may be considerably shallower than mapped by Miller (1986, plate 33). At site 142 in south-central Orange County (fig. 3), minor amounts of gypsum were first found at about 2,150 ft below sea level (2,240 ft below land surface), and substantial amounts at 2,240 ft below sea level (2,330 ft below land surface) (McGurk and Sego, 1999, p.15). However, packer tests completed in the test hole indicated the presence of low permeability rocks below a depth of 1,990 ft below sea level (2,080 ft below land surface) (McGurk and Sego, 1999, p.19-20). Another test well in south-central Orange County (site 138, fig. 3), drilled to a depth of 2,467 ft, found gypsiferous dolomite at about 2,160 ft below sea level (2,250 ft below land surface) (Boyle Engineering Corporation, 1995, p. 16). Decreasing permeability, however, was reported in the dolomites and limestones below a depth of 1,960 ft below sea level (2,050 ft below land surface).



EXPLANATION

— 600 — STRUCTURE CONTOUR -- Shows altitude of the top of the Lower Floridan aquifer, in feet below sea level. Dashed where approximate. Contour interval 100 feet

• 593E WELL -- Number is altitude of the top of the Lower Floridan aquifer, in feet below sea level. "E" denotes estimated value

Figure 13. Altitude of the top of the Lower Floridan aquifer.

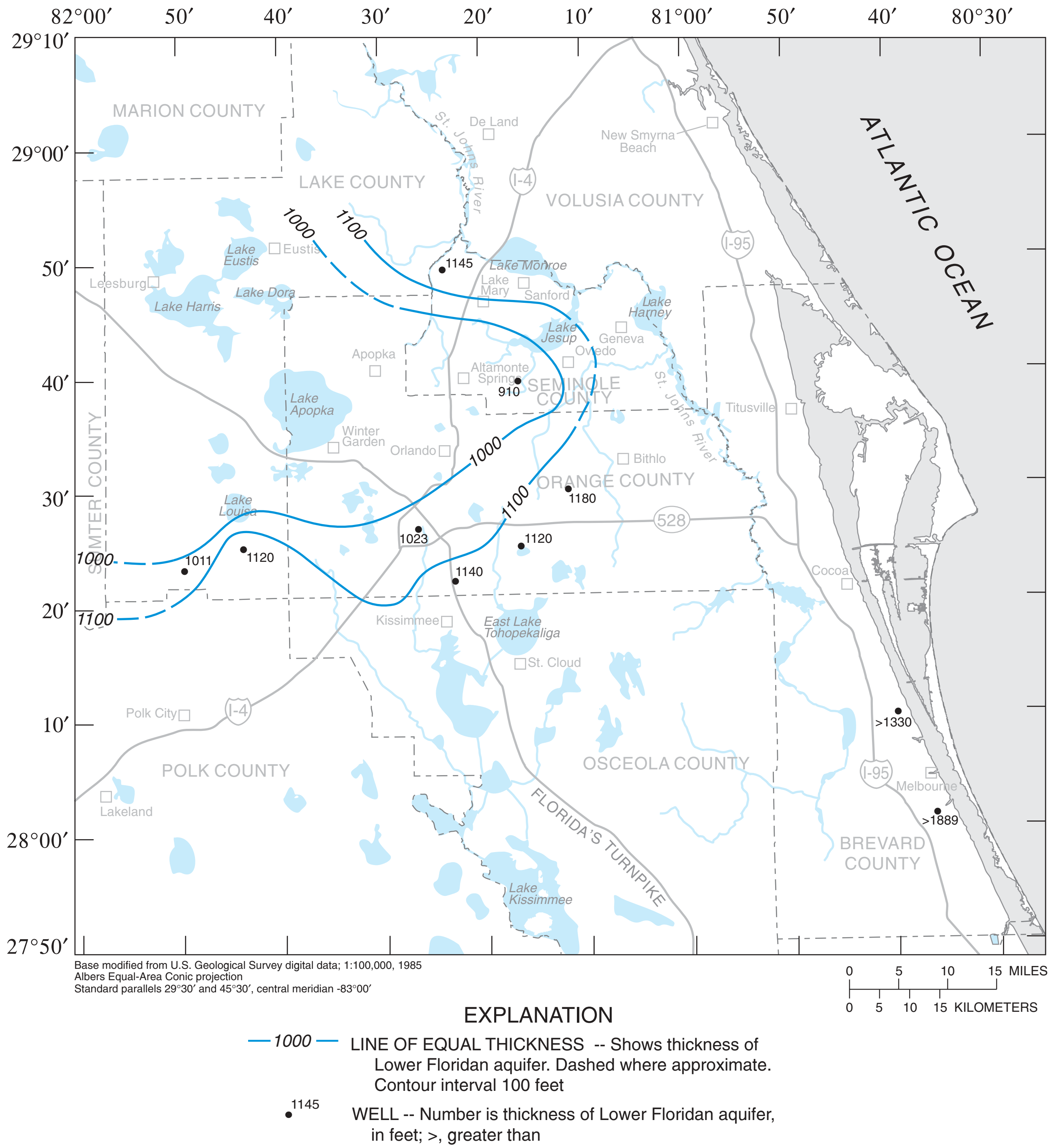


Figure 14. Thickness of the Lower Floridan aquifer.

The altitude of the top of the sub-Floridan confining unit in this report is mapped based on the first occurrence of evaporites (fig. 15). The first occurrence of evaporites was chosen as the top of the sub-Floridan confining unit because the evaporites are easily discernible on lithologic logs. The top of the unit, however, may be better defined by identifying zones of low permeability. Data indicating the first occurrence of lower permeability sediments, based on flow meter logs and packer tests, were included in figure 15 where available. Altitudes of the top of the sub-Floridan confining unit range from less than 1,900 to more than 3,000 ft below sea level within the study area. Little change in altitude occurs in the northeastern part of the study area, where the top of the unit averages about 2,200 ft below sea level. The depth to the top of the sub-Floridan confining unit increases toward the south.

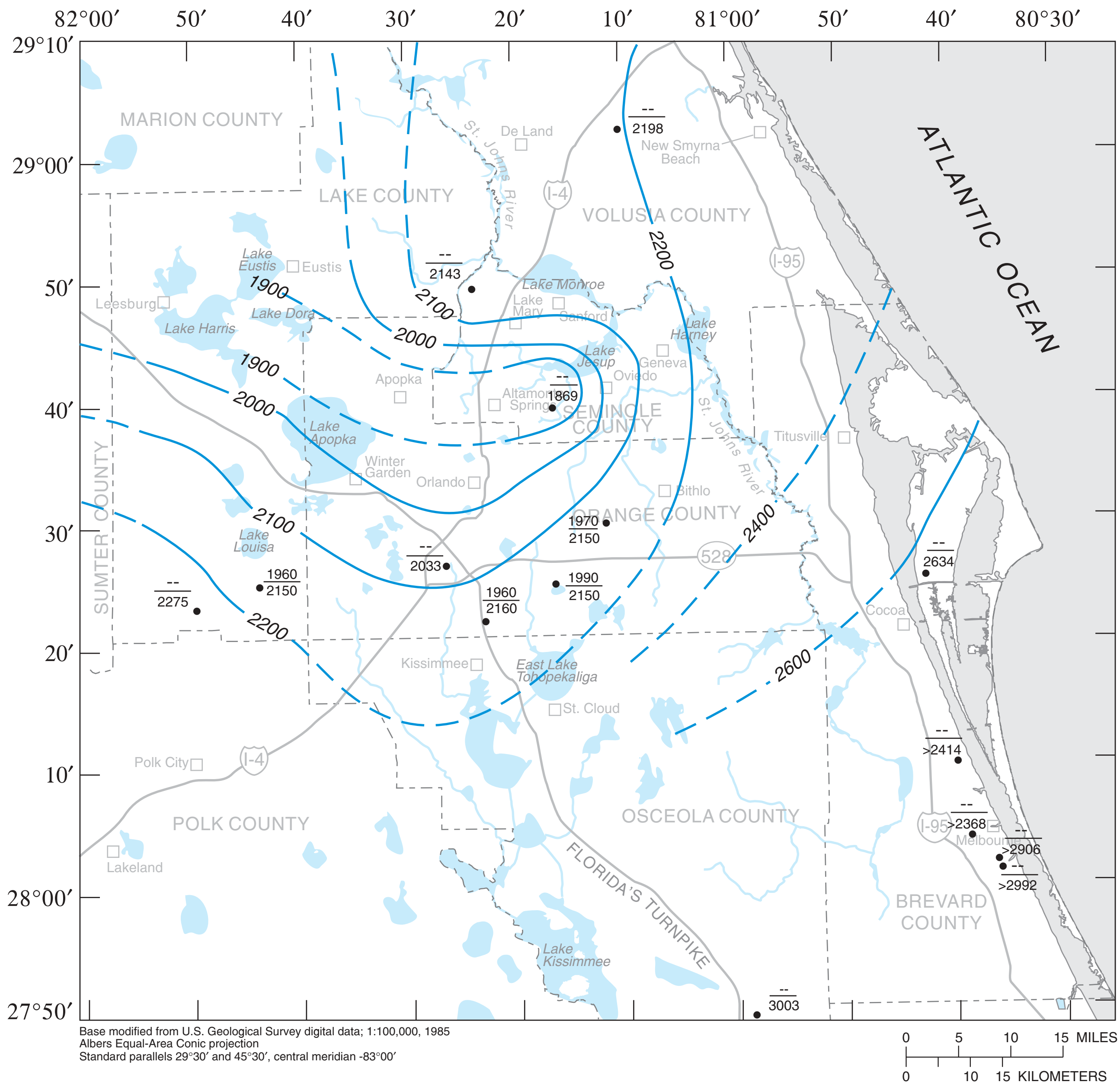
Transmissivity

Transmissivity of the Lower Floridan aquifer is a function of primary and secondary porosity of the aquifer. Secondary porosity resulting from fractures and solution features enhances permeability and probably is the primary cause of high transmissivity zones in the Floridan aquifer system. However, because of the irregular distribution of secondary porosity features, the transmissivity of the aquifer varies widely. Only a few values of transmissivity have been calculated for the Lower Floridan aquifer in the study area (fig. 16). A transmissivity of about 82,000 ft^2/d was reported in northwestern Orange County, just southwest of Altamonte Springs (Barnes, Ferland and Associates, Inc., 2000b). Transmissivity estimates exceeding 500,000 ft^2/d were reported from several aquifer tests conducted south of Orlando (Lichtler and others, 1968, p. 136; and Szell, 1993, p. 193). Model-derived transmissivity values for the Lower Floridan aquifer ranged from about 5,000 to 700,000 ft^2/d (Sepúlveda, 2002, p. 73).

Vertical Variations in Lithology and Permeability

Lithology and permeability within the Lower Floridan aquifer are not homogeneous throughout its thickness. Although only a few wells within the study area have penetrated the entire thickness of the Lower Floridan aquifer, borehole data from some wells indicate that layers of differing permeability exist. Using data from lithologic, geophysical, and video logs and packer test results, McGurk and Sego (1999) identified three zones of differing relative permeability at site 142 in south-central Orange County (fig. 3, app. 2). At this location, the vertical sequence within the Lower Floridan aquifer consists of two highly permeable zones separated by a less-permeable zone or semiconfining unit. The upper permeable zone is equivalent to the production zone that supplies water to the Orlando area. The two highly permeable zones consist primarily of dolomite and dolomitic limestone and contain borehole zones where inflow or outflow was noted during logging. The formation resistivity of both permeable zones is relatively high, and caliper and video logs indicate rough borehole walls with abundant fractures and cavities. In contrast, the semiconfining unit contains primarily softer limestone and is characterized by lower formation resistivity, smoother borehole walls, and no significant amount of observed fractures or borehole inflow or outflow. The semiconfining unit was found in the interval from approximately 1,535 to 1,745 ft below sea level. The top of the upper permeable zone (top of Lower Floridan aquifer) at site 142 is 1,032 ft below sea level. The base of the lower permeable zone at site 142 is approximately 1,990 ft below sea level. Specific capacity estimates derived from packer tests of the semiconfining unit were less than similarly derived estimates from the lower permeable zone. Static water-level measurements made during packer tests indicated an upward hydraulic gradient with several feet of head difference between the two permeable zones.

Lithologic, geophysical, and video logs from site 154 (fig. 3, app. 2) in central Orange County also indicated the presence of vertical stratification within the Lower Floridan aquifer. At this location, a thick upper zone consisting primarily of hard, fractured dolomite is separated from a deeper zone with similar characteristics by approximately 300 ft of softer dolomitic limestone without apparent fractures. The softer semiconfining unit was found in the interval from approximately 1,520 to 1,820 ft below sea level. The top of the upper permeable zone (top of the Lower Floridan aquifer) at site 154 was found at 970 ft below sea level. The base of the lower permeable zone of the Lower Floridan aquifer was at approximately 1,970 ft below sea level. Video and heat-pulse flow meter logs indicated that saline water was entering the borehole within the lower permeable zone, flowing upward through the middle, less permeable zone, and re-entering the formation near the base of the upper permeable zone.

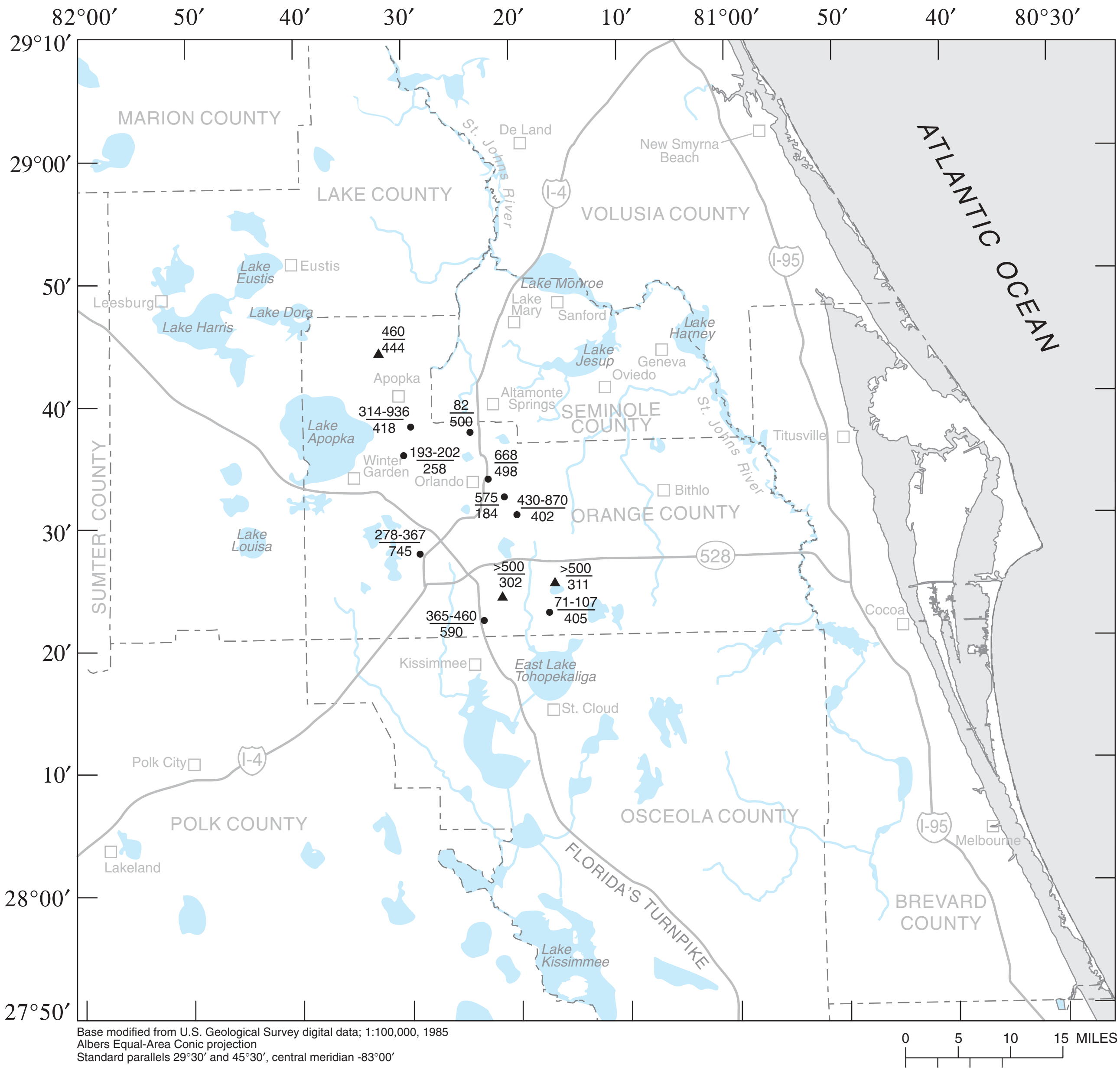


EXPLANATION

2000 — STRUCTURE CONTOUR -- Shows altitude of the top of the sub-Floridan confining unit, based on first occurrence of evaporites, in feet below sea level. Dashed where approximate. Contour interval 100 and 200 feet

1960 / 2150 — WELL -- Top number is first occurrence of low permeability sediments, in feet below sea level. Bottom number is first occurrence of evaporites, in feet below sea level; -- data not available; >, greater than

Figure 15. Altitude of the top of the sub-Floridan confining unit, based on the first occurrence of evaporites.



EXPLANATION

668/498 ● TRANSMISSIVITY OF THE LOWER FLORIDAN AQUIFER DETERMINED FROM AQUIFER TEST -- Top number is transmissivity in thousands of feet squared per day. Bottom number is thickness of aquifer penetrated by pumped well, in feet

500/302 ▲ TRANSMISSIVITY OF THE LOWER FLORIDAN AQUIFER DETERMINED FROM SPECIFIC CAPACITY TEST-- Top number is transmissivity in thousands of feet squared per day. Bottom number is thickness of aquifer penetrated by pumped well, in feet; >, greater than

Figure 16. Locations of aquifer tests and transmissivity values for the Lower Floridan aquifer (modified from Spechler and Halford, 2001).

The characteristics of the semiconfining unit found within the Lower Floridan aquifer at sites 142 and 154 match those of the middle confining unit VIII described by Miller (1986). Miller mapped this layer (Miller, 1986, fig. 24) throughout southeastern Florida; however, he mapped the northern extent of this layer only as far as southeastern Orange County. At present (2002), there are not sufficient data to consider extending the northern boundary of middle confining unit VIII throughout Orange County. Borehole data from the other test wells in the study area that penetrated the entire thickness of the Lower Floridan aquifer (sites 138, 143, 148, 184, fig. 3, app. 2) do not clearly indicate the presence of middle confining unit VIII. However, data from these wells do show significant vertical variations in lithology and geophysical log signatures within the Lower Floridan aquifer. These variations with depth qualitatively signify the existence of permeability variations due to variations in the development of secondary porosity.

Analyses of static and pumping flow logs indicate that the vertical profile of transmissivity in the Lower Floridan aquifer is quite variable, and that most of the water pumped from wells in the Lower Floridan aquifer is produced from discrete zones. For example, at site 150 in southwestern Orange County (fig. 6), the most transmissive zone of the Lower Floridan aquifer penetrated by the well is between the depths of 1,450 and 1,480 ft below land surface (1,300 to 1,330 ft below sea level). Less transmissive flow zones occur above and below this zone. At site 171 near Oviedo, the zone between the depths of 1,240 and 1,280 ft below land surface (1,178 to 1,218 ft below sea level) has a much greater transmissivity than the remaining approximately 550 ft of the Lower Floridan aquifer penetrated by the well (fig. 7). It is important to note that anomalous spikes on the flow profiles in figures 6 and 7 (for example, at depths of 420, 920, and 1,340 ft in figure 6) are artifacts of the process used to calculate the flow profile based on fluid velocity and caliper logs and should be ignored.

Ground-Water Flow Patterns

Flow patterns and fluctuations of ground-water levels in the Lower Floridan aquifer were evaluated using water-level data from a network of wells distributed across the study area. Ground-water levels were measured in the Lower Floridan aquifer in September 1998 and May 1999 (concurrent with measurements in wells tapping the Upper Floridan aquifer) to depict ground-water flow patterns and the seasonal change in head distribution in the Lower Floridan aquifer. Area-wide potentiometric surface maps for the Lower Floridan aquifer have not been constructed in the past because of the scarcity of observation wells. However, a number of Lower Floridan aquifer monitoring wells, primarily in Orange and Seminole Counties, have been drilled in recent years. The potentiometric surface maps presented in this report are based on water levels measured in about 60 wells tapping the Lower Floridan aquifer. Water levels were measured when the pumps were not operating and the water levels had recovered to static levels. Most of the wells were unsurveyed and measuring point datums were estimated from topographic maps.

Maps showing the potentiometric surface of the Lower Floridan aquifer for September 1998 and May 1999 (figs. 17 and 18, respectively) were constructed based on water levels collected during this investigation and on trends from potentiometric surface maps for the Upper Floridan aquifer (Bradner, 1999; and Bradner and Knowles, 1999). Comparisons of potentiometric-surface maps for the Lower Floridan aquifer and those of the Upper Floridan aquifer indicate that the potentiometric surfaces of the two aquifers are similar. Regional ground-water flow in both aquifers generally is from southwest to northeast across the study area.

The September 1998 potentiometric surface represents conditions near the end of the wet season, when withdrawals from the aquifer were near minimum and water levels generally were near their seasonal highs (fig. 17). In September 1998, water-levels measured in Lower Floridan aquifer wells ranged from about 16 to 113 ft above sea level. The May 1999 potentiometric surface represents conditions near the end of the dry season, when withdrawals from the aquifer were near maximum and water levels generally were at their seasonal lows (fig. 18). In May 1999, water-levels measured in Lower Floridan aquifer wells ranged from about 13 to 111 ft above sea level. Water levels in May 1999 were about 2 to 7 ft lower than the water levels measured in September 1998.

The potentiometric surface of the Lower Floridan aquifer is constantly fluctuating, mainly in response to seasonal variations in rainfall and ground-water withdrawals. Fluctuations of water levels in six wells open to the Lower Floridan aquifer in Seminole, Orange and Volusia Counties are shown in figures 19 and 20.

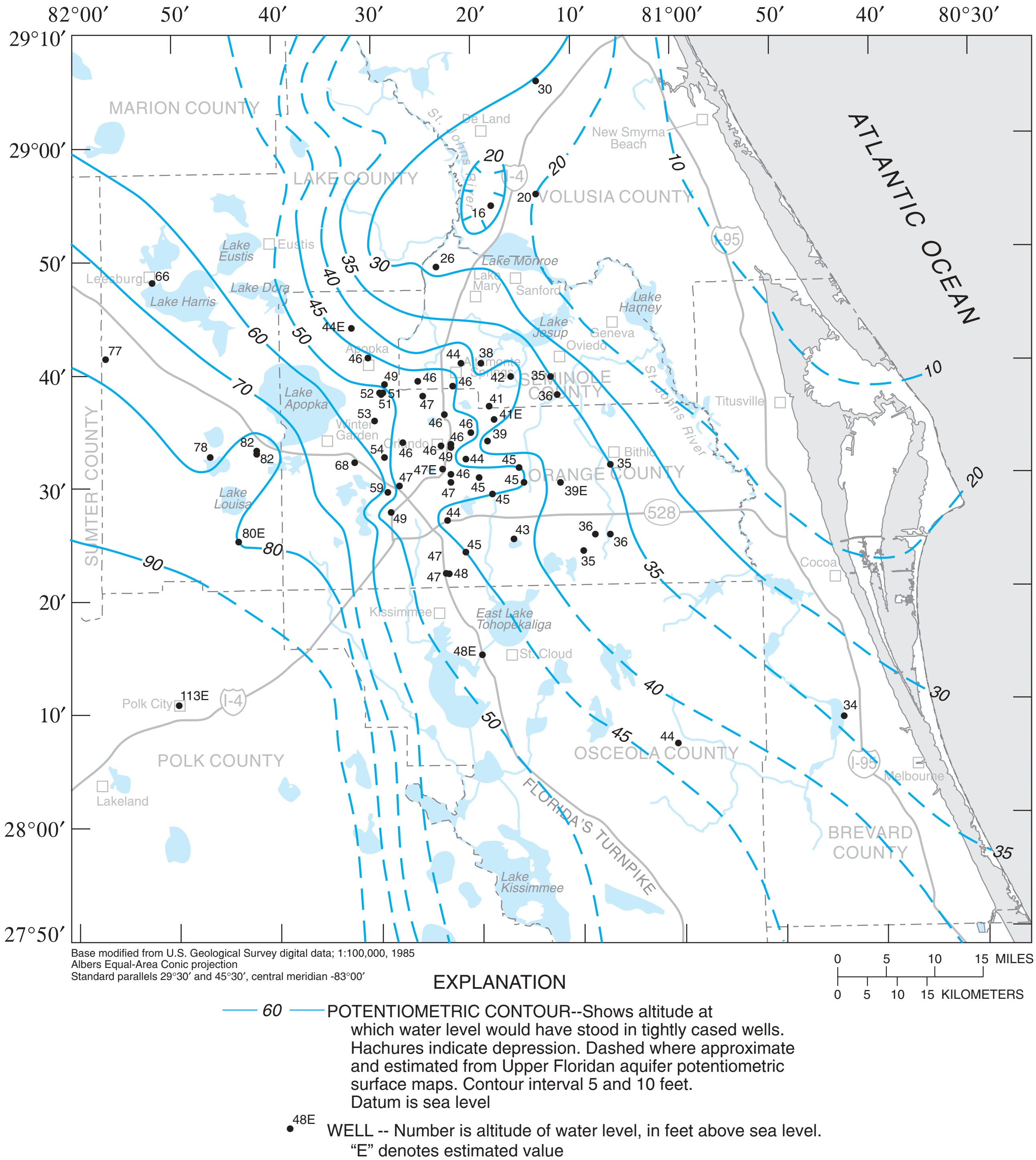
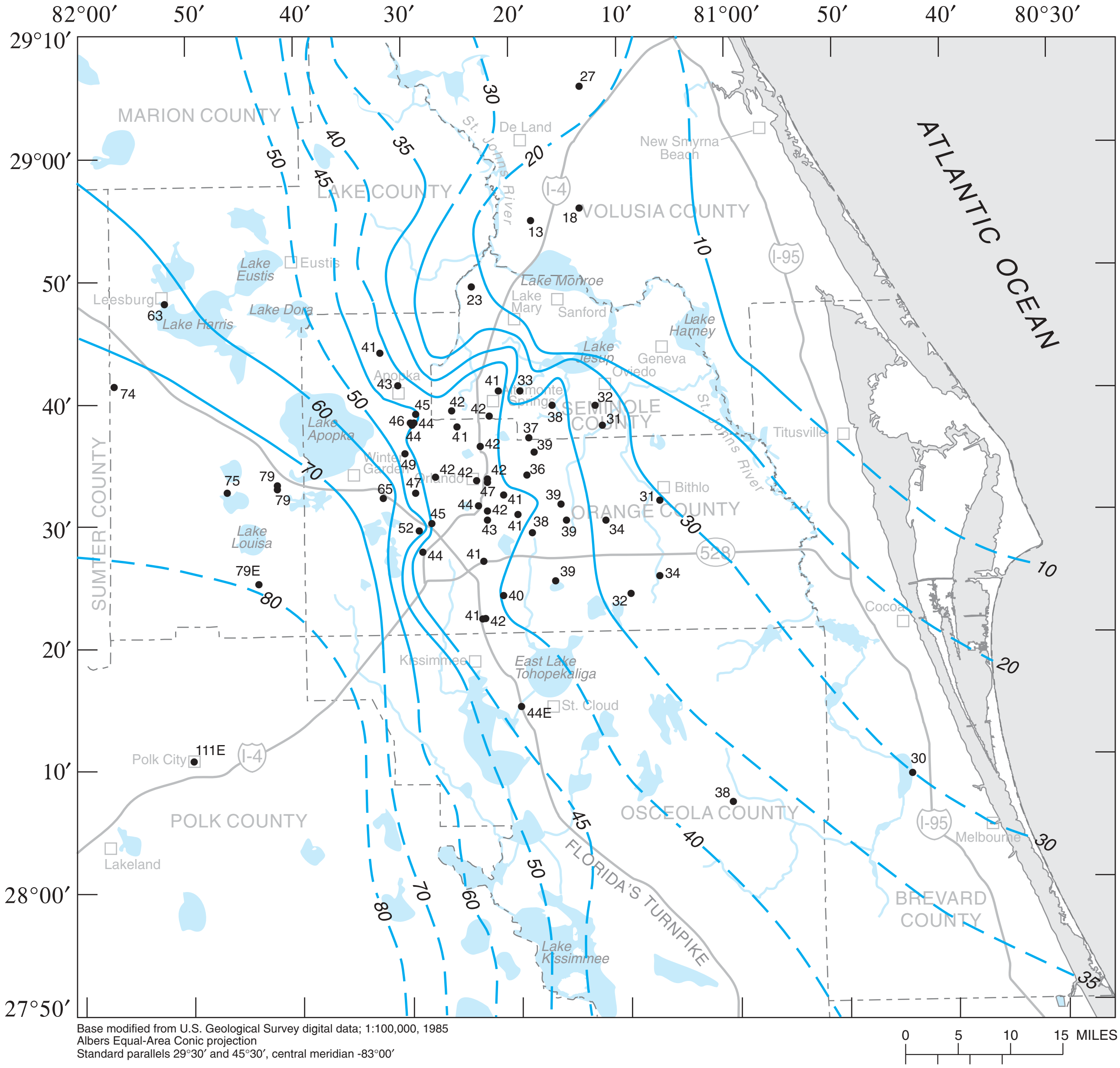


Figure 17. Generalized potentiometric surface of the Lower Floridan aquifer, September 1998.



EXPLANATION

50 — POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximate and estimated from Upper Floridan aquifer potentiometric surface maps. Contour interval 5 and 10 feet. Datum is sea level

44E — WELL -- Number is altitude of water level, in feet above sea level. "E" denotes estimated value

Figure 18. Generalized potentiometric surface of the Lower Floridan aquifer, May 1999.

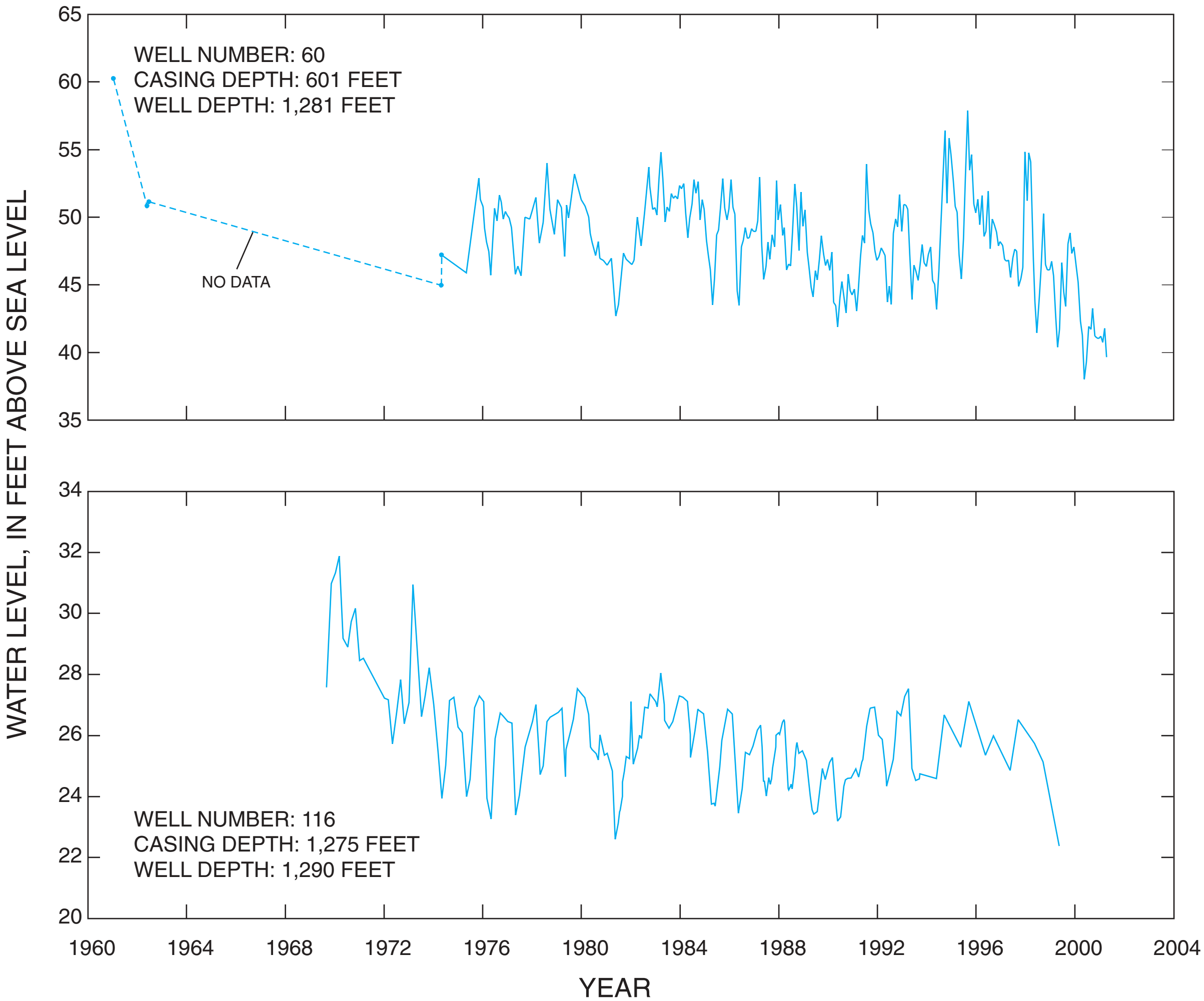


Figure 19. Water levels at wells 60 and 116, open to the Lower Floridan aquifer (well number refers to figure 2).

Seasonal fluctuations range from about 2 to 10 ft. Water-level data exceeding 30 years of record for wells tapping the Lower Floridan aquifer are sparse in east-central Florida. A long-term hydrograph for well 116 (fig. 19) indicates a general downward trend of water levels in the late 1960's and early 1970's, due probably in part to an increase in pumpage and to long-term below average rainfall. Based on limited data, water levels at well 60 appear to have declined primarily in the 1960's and again in the late 1990's (fig. 19). At sites with wells monitoring both the Upper Floridan and Lower Floridan aquifers, water-level trends in Lower Floridan aquifer wells generally mimic the trends observed in the Upper Floridan aquifer (fig. 20), indicating that the aquifers, at these locations, are hydraulically connected.

Vertical Distribution of Water Levels

Heads in the Floridan aquifer system typically increase with depth in discharge areas and decrease with depth in recharge areas. The magnitude of head differences between the Upper and Lower Floridan aquifers is directly related to the character of the confining units separating the aquifers. In areas not affected by pumpage, greater head differences between the two aquifers generally are found where the confining unit is less permeable, such as where the middle confining unit exists. Water-level data from the study area show a wide variation in the magnitude of head differences between the Upper and Lower Floridan aquifers (figs. 20 and 21).

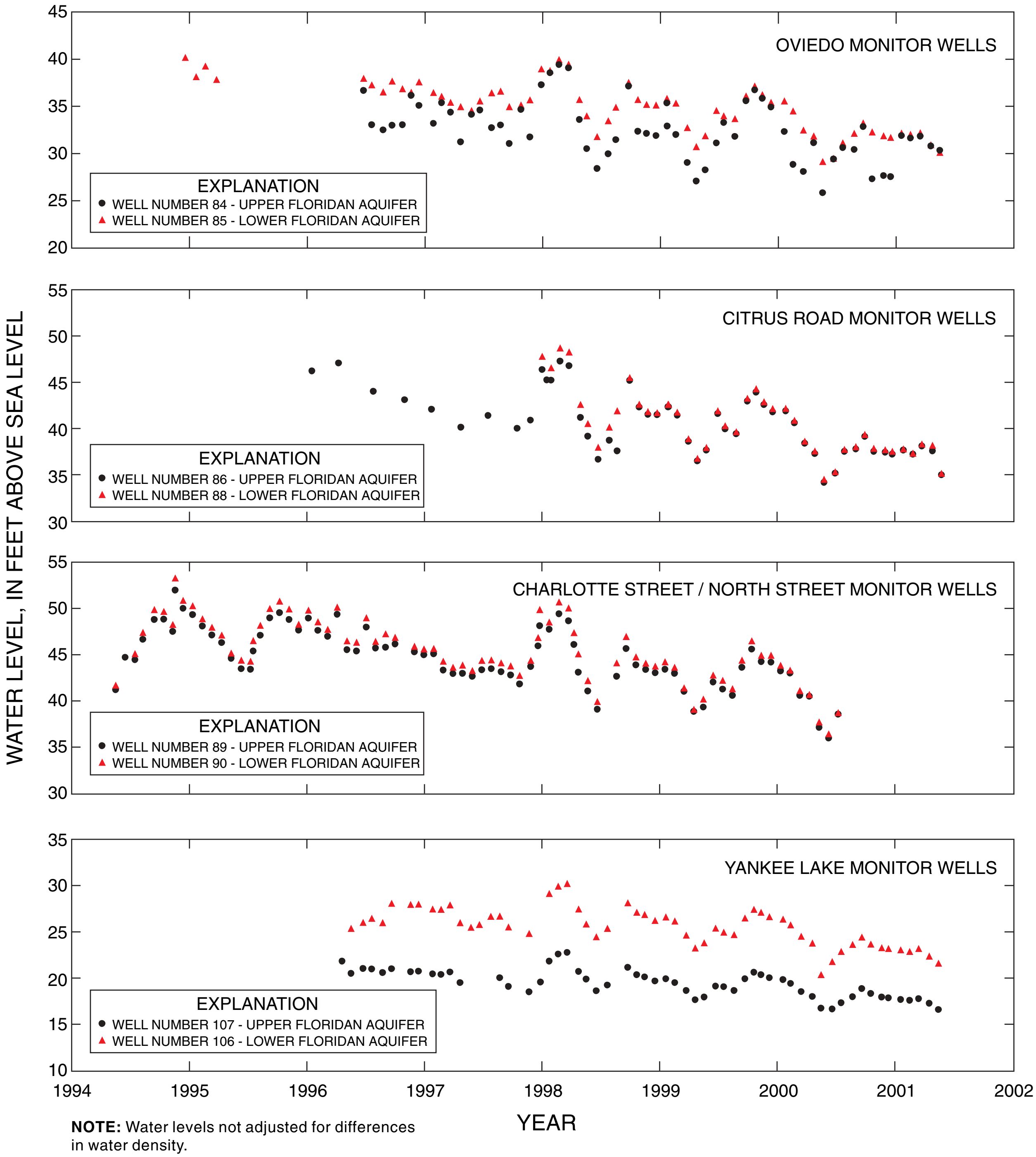
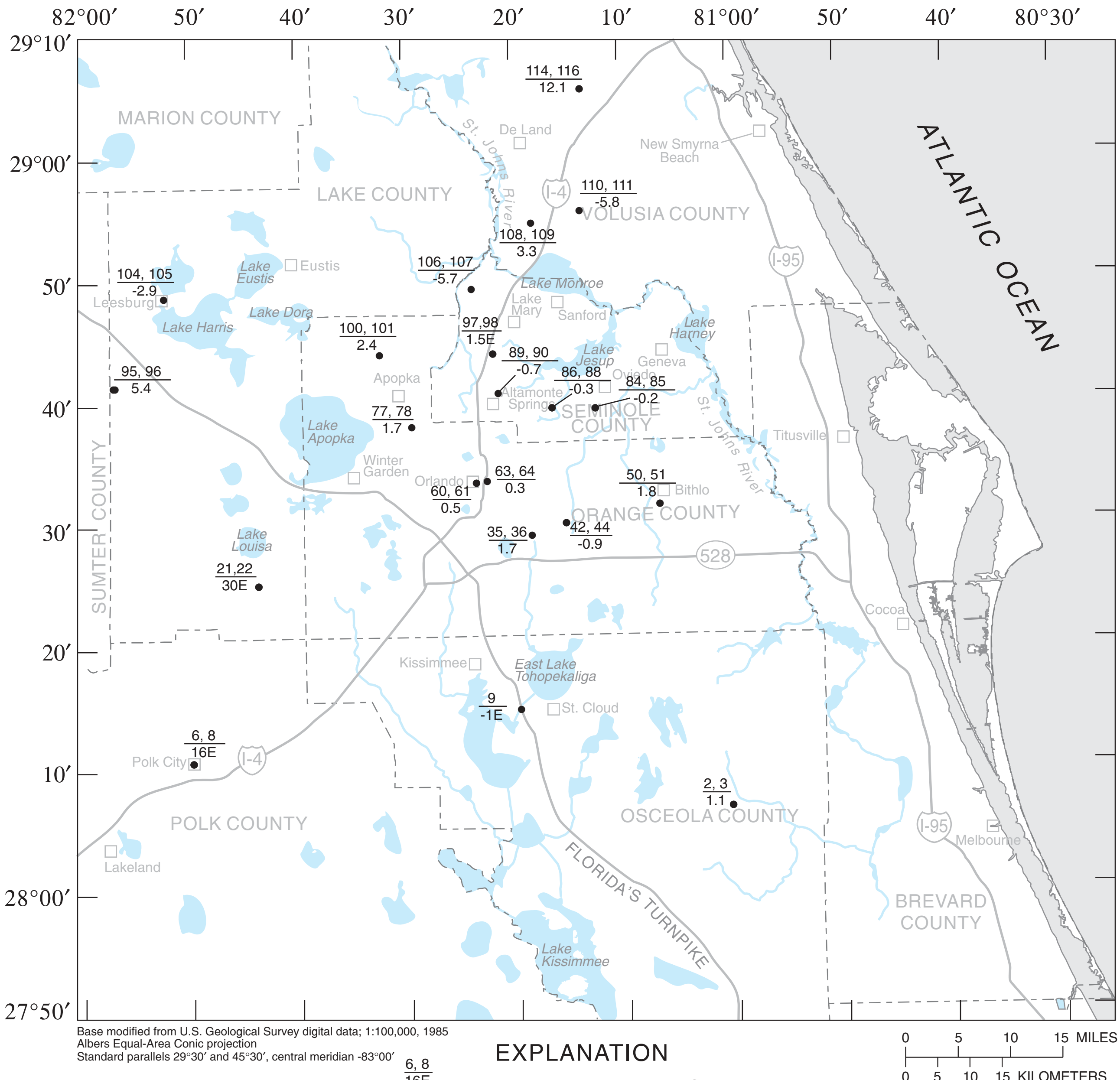


Figure 20. Water levels in selected Upper Floridan and Lower Floridan aquifer well pairs (well number refers to figure 2).



Base modified from U.S. Geological Survey digital data; 1:100,000, 1985
Albers Equal-Area Conic projection
Standard parallels 29°30′ and 45°30′, central meridian -83°00′

EXPLANATION

6, 8
16E

WATER LEVEL DIFFERENCE --
Point is location of well cluster.
Top numbers are site numbers.
Bottom number is measured water-level difference (Upper Floridan aquifer minus Lower Floridan aquifer, in feet).
"E" denotes estimated value

NOTE: Negative numbers indicate an upward head gradient and positive numbers indicate a downward head gradient.

Water levels not adjusted for differences in water density.

Figure 21. Head difference between the Upper Floridan and Lower Floridan aquifers, May 1999.

Upper Floridan aquifer heads generally were about 0 to 12 ft higher than heads in the Lower Floridan aquifer in May 1999 at 13 well pairs (fig. 21). However, in the southwestern part of the study area where the middle confining unit is present, Upper Floridan water levels at two wells were estimated to be 16 and 30 ft higher than those in the Lower Floridan aquifer. Lower Floridan aquifer heads were about 0 to 6 ft higher than the heads measured in the Upper Floridan aquifer at eight other well pairs. An upward head gradient within the Floridan aquifer system exists in much of Seminole County, whereas a downward head gradient occurs in much of Orange County. Head differences between the Upper and Lower Floridan aquifers also can be affected by localized pumpage. For example, the variation in the upward head gradient between the Upper and Lower Floridan aquifers at the Oviedo monitor wells (fig. 20) probably is caused by ground-water withdrawals from the Upper Floridan aquifer at this location.

Variations in water levels with depth can be illustrated by considering data collected during the drilling of four test wells (fig. 22). Two types of water-level measurements were obtained in the test wells: a water level within the drill stem and a water level in the well annulus (the annular space between the drill stem and the well casing or borehole wall). The annulus water level represents the average head for the entire open-hole portion of the well. If the bottom of the borehole is hydraulically isolated from the shallower part of the borehole, the drill stem water level represents, at least approximately, the discrete head at the bottom of the borehole near the drill bit. Differences between drill stem and annulus water levels might indicate that the drill stem water level is a discrete measurement or possibly that there is a difference in density between water near the drill bit and water in the well annulus. Water levels measured in the drill stem in several test wells decreased about 32 ft over the interval from 435 to 2,366 ft below land surface at well 21; about 11 ft from 403 to 1,488 ft at well 51; about 40 ft from 250 to 2,498 ft at well 39; and about 12 ft over the interval from 249 to 1,983 ft at well 87 (fig. 22). Water-level data presented in figure 22 were not adjusted for changes in water levels with time, nor for density differences between freshwater and mineralized water in various zones within each well. Regional changes of the potentiometric surface during the duration of drilling each test well could have affected the true head-depth relation within each well because the test wells took several weeks to several months to complete. Large differences between drill stem and annulus water levels for the four wells (fig. 22) correspond to depths where water samples obtained from the drill stem indicate significant increases in mineralization of the water.

Variations in the density of ground water will affect the water level measured in a well. This can be particularly problematic when evaluating vertical head differences between wells that tap zones of different water quality, because density differences can significantly change or even reverse the measured water-level difference. The magnitude of the effect of density differences on water levels is proportional to the depth of the well and the difference in density between freshwater and the mineralized water in the zone monitored by the well. Lusczynski (1961) describes the use of environmental-water heads for the calculation of vertical head gradients in water with variable density. The environmental-water head is the head that would be measured in a column of water with a density distribution identical to that in the aquifer. The required data are measured water level, land-surface altitude, well depth, and the vertical profile of ground-water density, from which the density at a point and the average density for a depth interval can be calculated (Lusczynski, 1961, equation 4a). The open interval of the well is assumed to be small so the heads represent a point measurement. Environmental-water heads were calculated for the drill-stem water-level data collected during drilling of a test well near St. Cloud (well 9, fig. 2). The vertical density profile was estimated from the specific conductance of water samples collected at the same depths water levels were measured. A linear regression of density and specific conductance was developed (correlation coefficient, *r*, of 0.97) based on data from 51 Floridan aquifer system wells in northeastern Florida reported by Spechler (1994, app. I), and was used to estimate the vertical density profile at the St. Cloud test well. A comparison of head differences between the Upper Floridan aquifer and the advancing depth of the drill stem using both environmental-water heads and unadjusted drill-stem water levels illustrates the importance of accounting for density differences (fig. 23). The environmental-water heads show an upward head difference throughout the Lower Floridan aquifer and little head difference in the middle semiconfining and confining units.

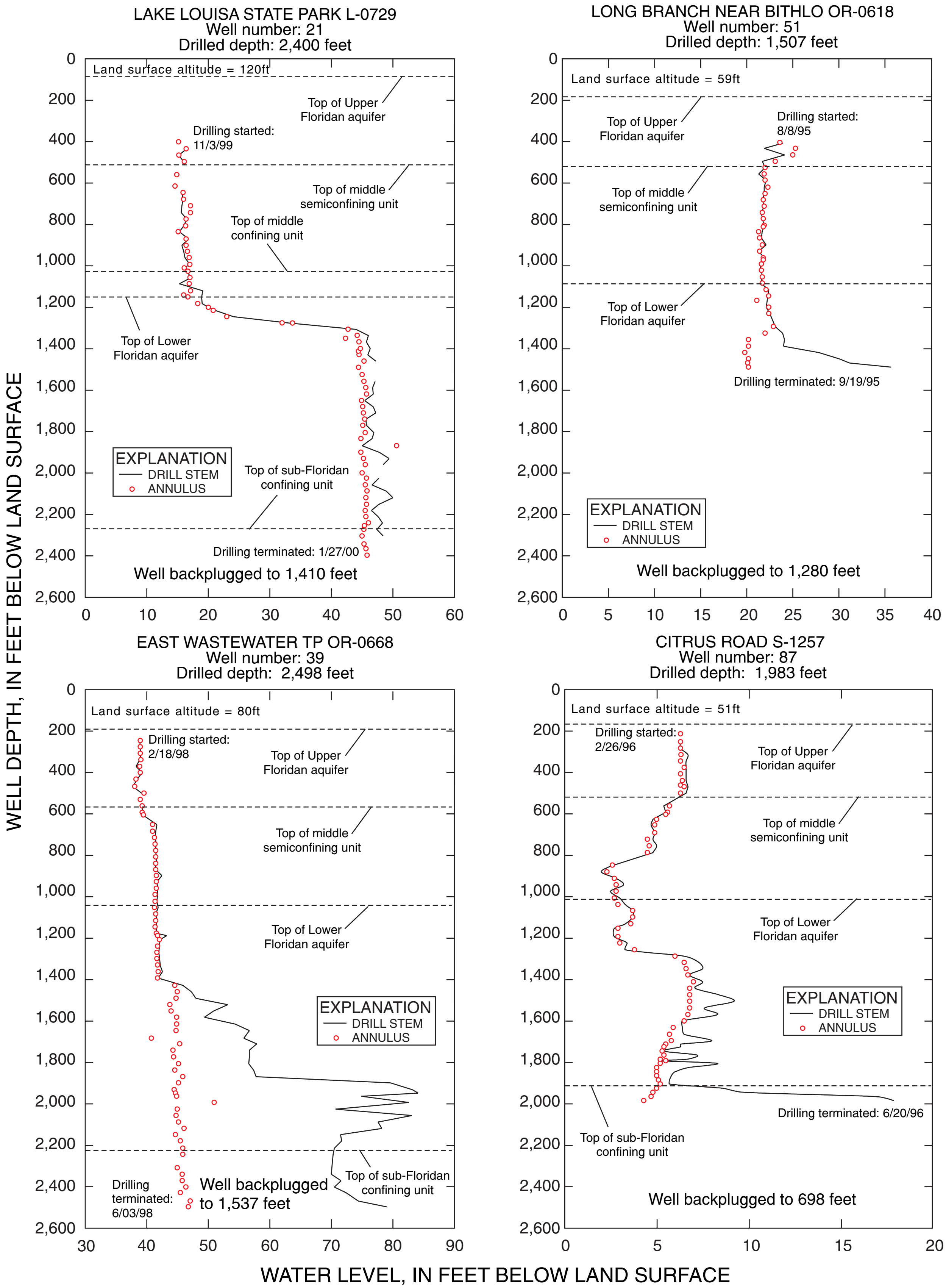


Figure 22. Water levels in the drill stem and annulus during drilling of monitoring wells 21, 39, 51, and 87 (data from the files of the St. Johns River Water Management District). (Well number refers to figure 2.)

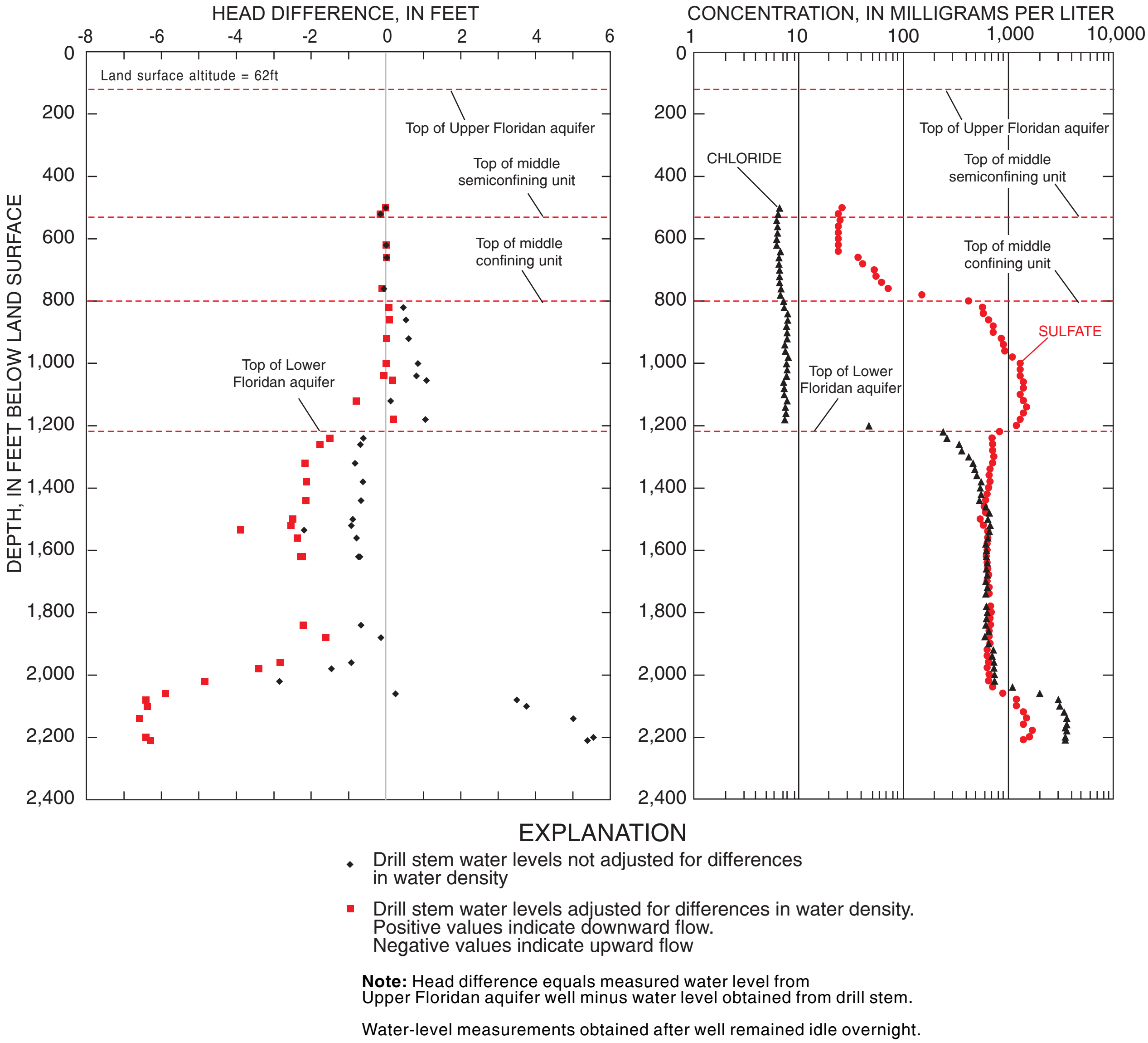


Figure 23. Water-level and water-quality data collected during drilling of well 9 near St. Cloud, Osceola County, Florida (well number refers to figure 2).

In contrast, the unadjusted drill-stem water levels show an apparent downward head difference in the middle confining unit and in the Lower Floridan aquifer below about 2,050 ft; these downward head differences do not indicate downward flow in these intervals but are caused by density differences. The static fluid conductivity log indicates higher, yet relatively constant values of fluid conductivity (compared to values obtained when the well penetrated only the Upper Floridan aquifer) between depths of 400 and 1,970 ft, implying upward flow of higher conductivity water in this interval, which is consistent with the upward head differences based on environmental-water heads.

WATER-QUALITY CHARACTERISTICS OF THE LOWER FLORIDAN AQUIFER

The geochemical properties of ground water are affected by many factors. Some of these factors include the initial chemical composition of water entering the aquifer, the composition and solubility of the aquifer material through which the water moves, and the length of time the water remains in contact with the aquifer. In addition, the quality of water may be affected by the mixing of freshwater with relict sea water in the aquifer.

The principal chemical constituents of ground water that affect potability in the study area are chloride and sulfate. The Florida Department of Environmental Protection (FDEP) has established primary drinking-water regulations for the quality of drinking water distributed by public water-supply systems (Florida Department of State, 1989). Secondary drinking-water standards, pertaining to the aesthetic qualities of water, set recommended limits for both chloride and sulfate concentrations at 250 milligrams per liter (mg/L) and for dissolved-solids concentration at 500 mg/L. Increasing chloride concentrations have received the most attention from water managers, but in the southwestern part of the study area, sulfate concentrations can be more of a concern than chloride because they exceed the recommended limits.

During this investigation, water samples from 33 wells tapping the Lower Floridan aquifer were analyzed by the USGS for major chemical constituents. In addition, water-quality data collected by SJRWMD (seven wells), FDEP (four wells), and private consultants (six wells) also were compiled and are included in table 1. Although most of the water samples were collected in Orange and Seminole Counties, a few samples also were collected in Brevard, Lake, Osceola, and Volusia Counties (fig. 2).

The wells sampled during this investigation generally tapped only the Lower Floridan aquifer. In a few cases, wells that were cased into the lower part of the middle semiconfining unit and open to the Lower Floridan aquifer also were included in the monitoring network and were sampled. Wells open to the Upper Floridan aquifer or to most of the middle semiconfining unit or middle confining unit were not sampled because water samples collected from these wells were not considered to be representative of water from the Lower Floridan aquifer. Because most of the water samples were collected at the wellhead, the samples represent a composite of water from the open-hole section of the aquifer. Water samples generally are representative of water in the upper part of the Lower Floridan aquifer because most wells sampled were only open to this zone.

Many of the wells sampled are in nearly continuous use. Such supply wells are equipped with deep well turbine pumps and were sampled after at least three casing volumes of water had been pumped. Other wells were pumped by using a submersible electric pump. Those wells also were sampled after at least three casing volumes of water had been pumped and after field measurements (specific conductance, temperature, and pH) had stabilized.

Water samples were processed at the time of collection using standard USGS protocol described by Wood (1976). Specific conductance, temperature, and pH were determined in the field. Samples collected to determine the dissolved-constituent concentrations were filtered through a 0.45-micrometer pore-size disposable capsule filter. Major ion and trace constituent samples were analyzed at the USGS Laboratory in Ocala, Fla.

Chemical Composition

Water samples were analyzed for major cations and anions and the trace constituent strontium (table 1). Concentrations of these constituents within the Lower Floridan aquifer varied widely across the study area. Maps of specific conductance, chloride, sulfate, and hardness of water from the Lower Floridan aquifer were constructed to delineate areas of poor water quality. These maps generally depict the quality of water in the upper part of the Lower Floridan aquifer, which is the interval most commonly tapped by Lower Floridan aquifer public supply wells in east-central Florida. Water in the deeper parts of the Lower Floridan aquifer generally will be of similar or poorer water quality. In some parts of the study area where water in the Lower Floridan aquifer is highly mineralized, few wells have been drilled and little is known about the water quality.

The extent of mineralization of water in the Lower Floridan aquifer is indicated by its specific conductance. In the wells sampled, specific conductance ranged from 147 to 6,710 microsiemens per centimeter (μS/cm) (fig. 24 and table 1). Water having specific conductance less than 250 μS/cm generally occurs in southwestern Seminole County, west-central Orange County, and south-central Lake County. Specific conductance values exceeding 2,500 μS/cm generally occur along much of the Wekiva and St. Johns Rivers, and in much of the eastern and southern parts of the study area.

Although specific conductance values cannot be used to determine precisely the dissolved-solids concentrations in natural waters, they can provide a practical estimate. The linear regression between specific conductance and dissolved-solids concentrations for 45 ground-water samples representative of the Lower Floridan aquifer in the study area has a correlation coefficient (r) of 0.993 (fig. 25). For the range of specific conductance values measured, multiplication of the specific conductance by 0.61 gives a reasonable approximation of the dissolved-solids concentration. Thus, specific conductance values (fig. 24) indicate that water in much of the eastern and southern parts of the study area exceeds the 500 mg/L recommended limit for dissolved solids (Florida Department of State, 1989).

Table 1. Chemical and physical data for water from Lower Floridan aquifer wells in east-central Florida

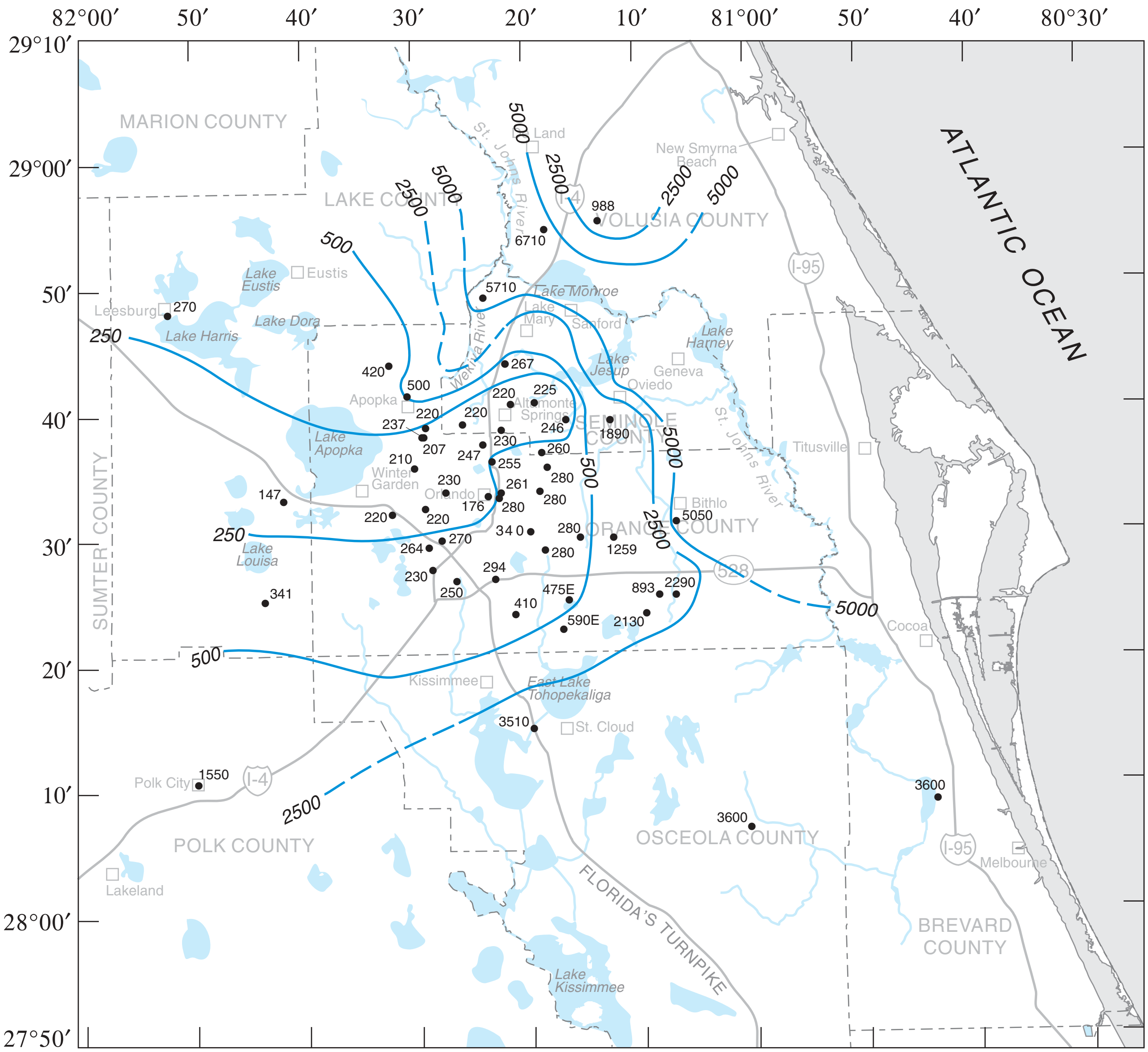
[Source of data: CR, consultant's report; FDEP, Florida Department of Environmental Protection; SJRWMD, St. Johns River Water Management District; USGS, U.S. Geological Survey. Samples analyzed by the USGS are dissolved; samples with an asterisk (*) are total concentration. In ground water, dissolved and total constituents are comparable if particulate matter is negligible. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; µg/L, micrograms per liter; --, not analyzed; <, less than. Site numbers are from Appendix 1; locations shown in figure 2]

Well number	USGS site identification number	Source of data	Date	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved solids (mg/L)	pH (standard units)	Hardness, total (mg/L as $CaCO_3$)	Silica (mg/L as SiO_2)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Strontium (µg/L as Sr)	Chloride (mg/L as Cl)	Sulfate (mg/L as SO_4)	Fluoride (mg/L as F)	Alkalinity (mg/L as $CaCO_3$)
3	280655081002904	USGS	08/25/00	27.0	3,600	2,040	7.8	510	15	100	61	500	16	7,200	930	170	0.32	104
5	280858080435501	CR	07/16/98	29.0	3,600	2,300	7.2	710	--	170	88	480	10	--	1,200	250	--	110
8	281058081495004	USGS	11/04/80	26.0	1,550	1,340	7.0	780	11	290	12	3.8	.9	1,100	5.9	750	.20	98
9	281506081194501	USGS	01/06/00	28.9	3,510	2,280	8.0	900	12	210	90	410	15	5,900	730	630	.49	87
16	282300081165501	CR	04/27/99	--	--	360	7.5	268	--	66	--	--	--	--	17	132	.28	--
17	282406081093602	USGS	04/25/00	27.8	2,130	1,590	7.6	840	18	230	61	200	7.1	12,100	370	570	.19	142
18	282411081211301	USGS	04/06/99	27.6	410	258	7.6	180	14	53	12	9.1	1.3	1,900	15	63	.20	119
20	282515081162601	CR	11/29/95	--	--	290	7.5	190	--	--	--	11	--	--	15	71	<.20	190
21	282520081434001	SJRWMD	02/15/00	25.0	341	210	7.4	--	*6.2	*45	*11	*6.7	*1.2	*621	8.3	20	.20	146
23	282530081065601	USGS	04/25/00	27.5	2,290	1,460	7.4	700	18	190	52	220	8.0	12,600	390	440	.15	158
26	282533081082204	USGS	04/25/00	23.4	893	533	8.2	360	20	110	17	44	2.3	10,400	81	140	.17	209
27	282650081262502	CR	07/31/76	23.0	250	185	--	120	4.8	38	5.8	8.4	--	--	3.0	2.0	.20	126
28	282657081230401	USGS	04/12/99	26.5	294	174	7.7	130	12	39	8.1	7.3	1.0	920	11	15	.19	121
30	282745081283501	USGS	03/28/00	24.1	230	125	7.6	99	9.3	27	7.4	4.7	.60	620	8.1	16	.17	82
36	282912081182901	FDEP	08/05/96	26.2	280	--	7.4	--	13	39	8.5	7.5	1.0	1,200	9.8	4.3	.17	117
37	282931081285901	USGS	04/29/99	27.1	264	156	7.9	120	11	33	8.4	5.1	.80	620	8.5	14	.15	110
38	283006081274101	USGS	03/28/00	25.5	270	149	7.4	120	11	35	8.1	5.2	.90	650	8.3	9.7	.17	109
40	283007081122704	SJRWMD	10/31/99	27.1	1,259	--	7.5	--	--	85	28	122	5.5	--	226	136	--	139
42	283011081152401	USGS	05/27/99	25.5	280	162	7.6	140	12	40	8.3	8.2	.90	830	11	11	.19	125
46	283048081194801	USGS	03/28/00	24.9	340	184	7.4	150	11	45	9.3	8.4	1.1	320	11	5.5	.14	150
51	283126081064502	USGS	04/14/99	28.1	5,050	3,280	7.3	940	14	210	100	640	23	6,500	1,200	590	.14	130
52	283216081320901	FDEP	05/07/96	25.1	220	--	7.8	--	11	29	7.2	4.2	.60	91	5.6	2.8	.12	105
55	283236081290901	USGS	04/03/00	24.6	220	121	7.2	100	9.7	26	8.8	4.3	1.1	64	7.2	4.0	.14	98
58	283322081415401	USGS	03/30/00	24.9	147	111	7.6	69	9.8	17	6.5	2.8	.50	30	4.8	1.1	<.10	68
59	283327081223201	USGS	03/28/00	--	280	154	7.5	120	10	35	8.2	8.2	1.0	230	12	5.5	.31	118

Table 1. Chemical and physical data for water from Lower Floridan aquifer wells in east-central Florida--Continued

[Source of data: CR, consultant's report; FDEP, Florida Department of Environmental Protection; SJRWMD, St. Johns River Water Management District; USGS, U.S. Geological Survey. Samples analyzed by the USGS are dissolved; samples with an asterisk (*) are total concentration. In ground water, dissolved and total constituents are comparable if particulate matter is negligible. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; µg/L, micrograms per liter; --, not analyzed; <, less than. Site numbers are from Appendix 1; locations shown in figure 2]

Well number	USGS site identification number	Source of data	Date	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved solids (mg/L)	pH (standard units)	Hardness, total (mg/L as $CaCO_3$)	Silica (mg/L as SiO_2)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Strontium (µg/L as Sr)	Chloride (mg/L as Cl)	Sulfate (mg/L as SO_4)	Fluoride (mg/L as F)	Alkalinity (mg/L as $CaCO_3$)
60	283333081233501	USGS	08/25/00	24.3	176	97	8.3	69	1.6	20	4.6	7.6	3.4	130	8.7	<.20	.10	79
65	283353081185801	USGS	03/28/00	24.3	280	160	7.6	130	9.5	38	8.3	6.8	.80	200	9.7	6.6	.13	123
66	283353081222401	USGS	04/12/99	25.4	261	152	7.7	120	11	34	8.1	6.2	.90	210	9.4	5.0	.14	117
67	283357081272201	USGS	03/28/00	24.9	230	123	7.6	100	9.8	29	7.6	4.5	.70	84	7.2	3.8	.10	100
69	283548081181401	USGS	04/03/00	24.9	280	152	7.7	120	10	37	7.8	6.5	.90	180	9.5	5.4	.15	120
70	283555081300801	USGS	04/03/00	24.8	210	116	7.3	98	11	28	6.8	3.8	.70	57	6.0	1.7	<.10	98
71	283623081230501	USGS	04/03/00	24.3	255	138	7.5	120	9.0	33	7.9	5.9	.90	91	9.7	8.2	.13	106
72	283702081183901	USGS	03/29/00	24.8	260	145	7.5	120	10	34	7.6	6.2	.90	180	9.4	5.7	.16	113
73	283742081235701	CR	10/27/99	--	247	194	7.9	--	--	--	--	5.0	--	--	15	20	.13	--
77	283818081291201	CR	04/29/88	--	207	172	8.2	92	--	24	8.0	3.2	1.2	--	6.3	6.1	.09	59
79	283819081292601	USGS	05/04/99	24.5	237	139	8.0	110	9.2	29	8.8	5.7	.80	73	7.1	7.8	.11	108
80	283848081221301	USGS	03/29/00	24.0	230	124	7.3	100	9.1	29	7.3	4.5	.70	79	7.6	4.2	.12	98
81	283906081290001	USGS	03/30/00	25.1	220	120	7.5	100	10	28	7.9	3.8	.80	74	6.2	3.4	.11	101
82	283917081254501	USGS	03/29/00	24.2	220	122	7.3	100	9.5	29	7.5	4.1	.70	110	6.6	2.6	.15	100
85	283933081123105	USGS	08/29/00	25.9	1,890	1,060	8.0	270	10	53	34	270	9.3	760	480	79	.16	114
88	283936081162804	SJRWMD	04/10/99	23.7	246	150	8.4	--	--	*34	*8.4	*5.8	*1.0	--	9.6	.51	--	116
90	284052081212605	SJRWMD	03/07/00	24.6	220	125	8.0	--	--	*28	*7.5	*5.1	*1.0	--	6.7	2.6	--	94
91	284057081191901	USGS	03/29/00	24.8	225	125	7.4	100	9.9	29	7.3	4.8	.80	120	7.8	3.3	.14	100
93	284128081320901	FDEP	05/07/96	25.9	500	--	7.6	--	11	68	17	5.0	1.0	1,270	7.3	130	.25	109
98	284407081215503	SJRWMD	02/11/99	25.0	267	170	--	--	4.3	45	8.2	4.7	.70	143	11	9.8	.82	111
100	284407081321601	USGS	03/30/00	25.6	420	276	7.7	210	11	56	17	6	1.0	890	8.8	100	.20	110
104	284822081520601	USGS	08/30/00	24.8	270	157	7.3	130	12	40	8.0	4.6	.80	66	7.3	.30	.11	133
106	284923081234801	SJRWMD	02/20/00	25.4	5,710	3,175	7.5	--	--	*190	*102	*821	*27	--	1,532	493	--	100
109	285442081181402	FDEP	02/19/00	23.4	6,710	4,478	7.6	--	--	242	144	840	11	--	2,188	58	--	--
110	285524081132401	SJRWMD	11/17/99	24.8	988	573	7.5	--	--	57	45	56	3.1	--	200	35	--	155



Base modified from U.S. Geological Survey digital data; 1:100,000, 1985
Albers Equal-Area Conic projection
Standard parallels 29°30′ and 45°30′, central meridian -83°00′

0 5 10 15 MILES
0 5 10 15 KILOMETERS

EXPLANATION

— 500 — LINE OF EQUAL SPECIFIC CONDUCTANCE -- Dashed where approximate. Interval is variable

351 WELL -- Number indicates specific conductance in microsiemens per centimeter at 25 degrees Celsius. "E" denotes estimated value determined from dissolved solids concentration

Figure 24. Generalized distribution of specific conductance of water from the Lower Floridan aquifer.

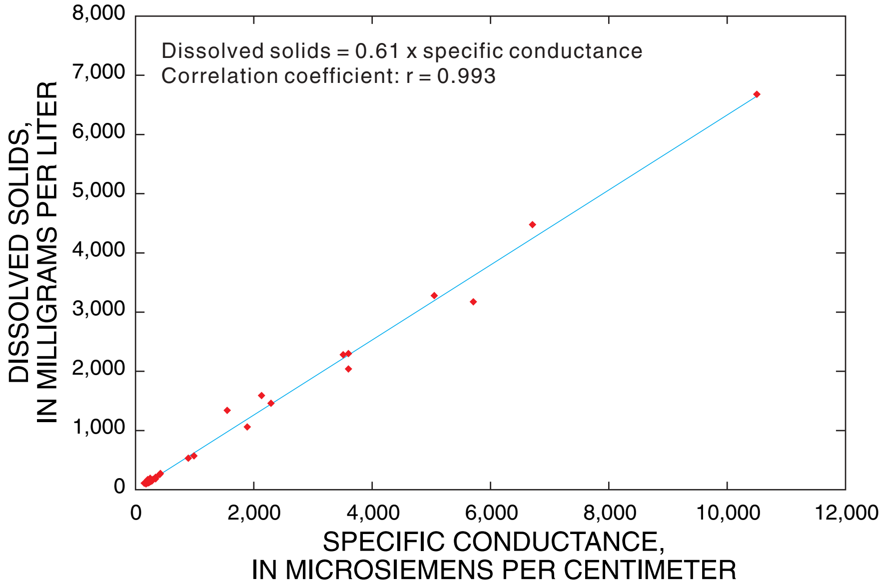


Figure 25. Relation between specific conductance and dissolved-solids concentrations of water from the Lower Floridan aquifer (data from table 1).

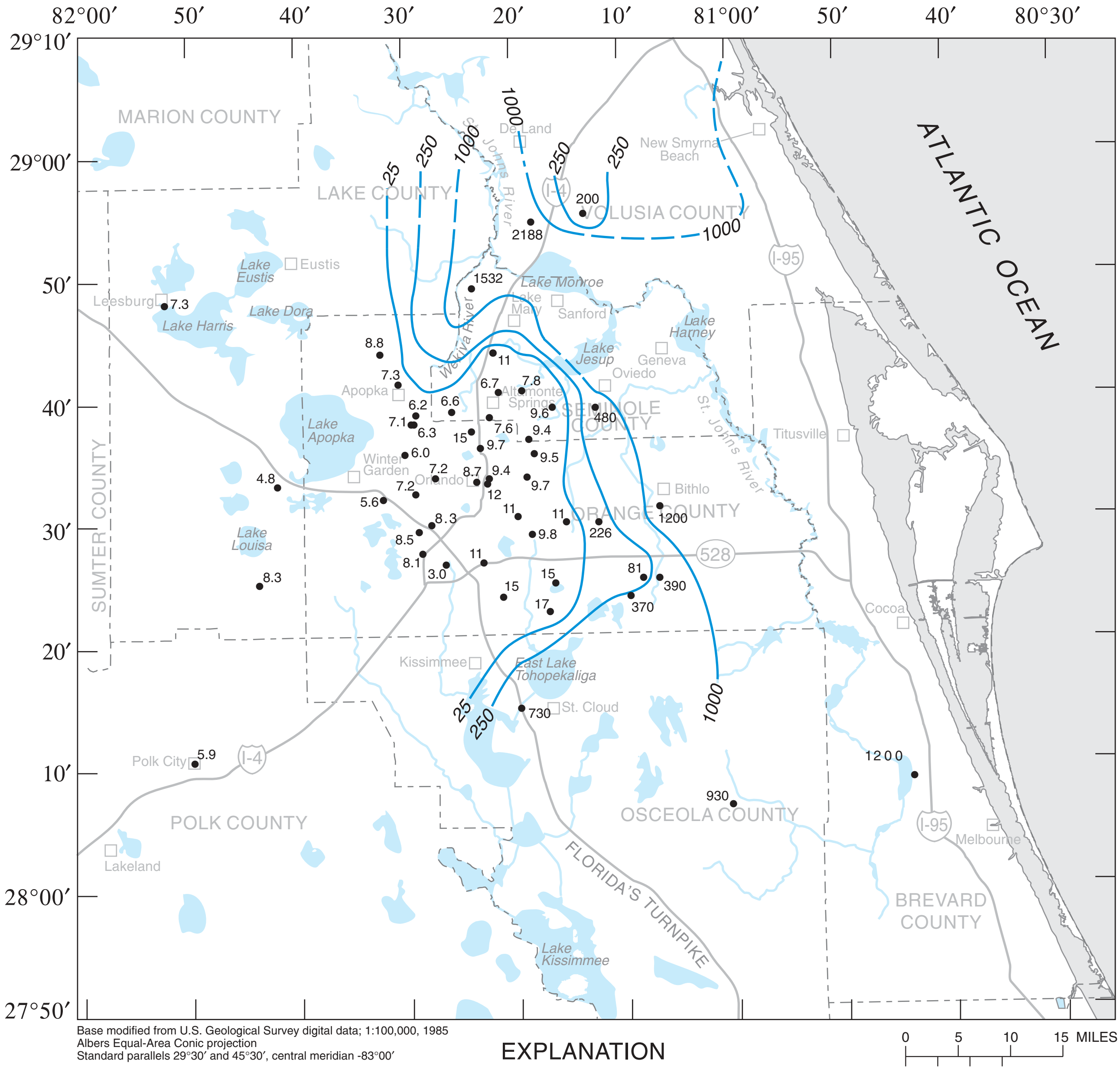
Sulfate concentrations of water in the Lower Floridan aquifer range from less than 0.2 to 750 mg/L (fig. 27 and table 1). Sulfate concentrations less than 10 mg/L occur primarily in southwestern Seminole County, west-central Orange, and in parts of central and south-central Lake Counties. Sulfate concentrations generally exceed the 250 mg/L recommended limit for drinking water along parts of the Wekiva and St. Johns Rivers, and in much of the eastern and southern parts of the study area. The highest sulfate concentration sampled during this investigation was 750 mg/L in northeastern Polk County (well 8).

Chloride concentrations of water sampled from the Lower Floridan aquifer range from 3.0 to 2,188 mg/L (fig. 26 and table 1). The lowest concentrations, generally less than 10 mg/L, occur primarily in the recharge areas in the central and western parts of the study area. Chloride concentrations of 25 to 250 mg/L occur primarily in a narrow, northerly trending area from southern Orange County to northeastern Lake County. Chloride concentrations generally exceed the 250 mg/L recommended limit for drinking water along the Wekiva and St. Johns Rivers, and throughout much of the eastern and southern parts of the study area. Although only a few water samples have been collected in areas where the quality of water is poor, chloride concentrations likely exceed 1,000 mg/L along the St. Johns River and throughout much of Brevard, eastern Orange, eastern Seminole, and southeastern Volusia Counties. Ground water having a chloride concentration exceeding 1,000 mg/L is unsuitable for drinking, for many industrial uses, and for the irrigation of most crops (Schiner, 1993).

Chloride in ground water can be derived from several sources, including the dissolution of chloride minerals in the aquifer, contamination from septic tank effluent, agricultural activities, industrial waste, and small amounts contributed by rainfall. Most of the mineralized water in the Floridan aquifer system in the study area is probably a mixture of freshwater and relict seawater that entered the aquifer system during a higher stand of sea level in the geologic past.

Primary sources of sulfate in ground water include the mixing of relict seawater with freshwater and the dissolution of sulfate-bearing minerals, such as gypsum or anhydrite. In much of the eastern part of the study area, the source of sulfate is primarily from mixing of relict seawater with freshwater. In the southwestern part of the study area, the high sulfate concentrations in water from the Lower Floridan aquifer is due to the presence of evaporites in the overlying middle confining unit.

The source of sulfate in ground water sometimes can be identified by considering the relation between the mass ratio of sulfate to chloride and the sulfate concentration (Rightmire and others, 1974) (fig. 28). One trend represents sulfate derived from the mixing of fresh ground water with seawater, and the other trend represents sulfate derived from the dissolution of gypsum within the Floridan aquifer system. Water samples that plot on or near the seawater-mixing line (fig. 28) indicate seawater as a possible source of sulfate in ground water. Water samples that plot on or near the dissolution of the gypsum mixing-trend line indicate that gypsum in the Floridan aquifer system is the major source of sulfate. Points between the two trend lines indicate both seawater and gypsum as possible sources of sulfate in ground water. Gypsum was found in the study area mostly in the rocks of the middle confining unit and sub-Floridan confining unit.



EXPLANATION

–250– LINE OF EQUAL CHLORIDE CONCENTRATION -- Dashed where approximate. Interval is variable

930 • WELL -- Number indicates chloride concentration, in milligrams per liter

Figure 26. Generalized distribution of chloride concentrations of water from the Lower Floridan aquifer.

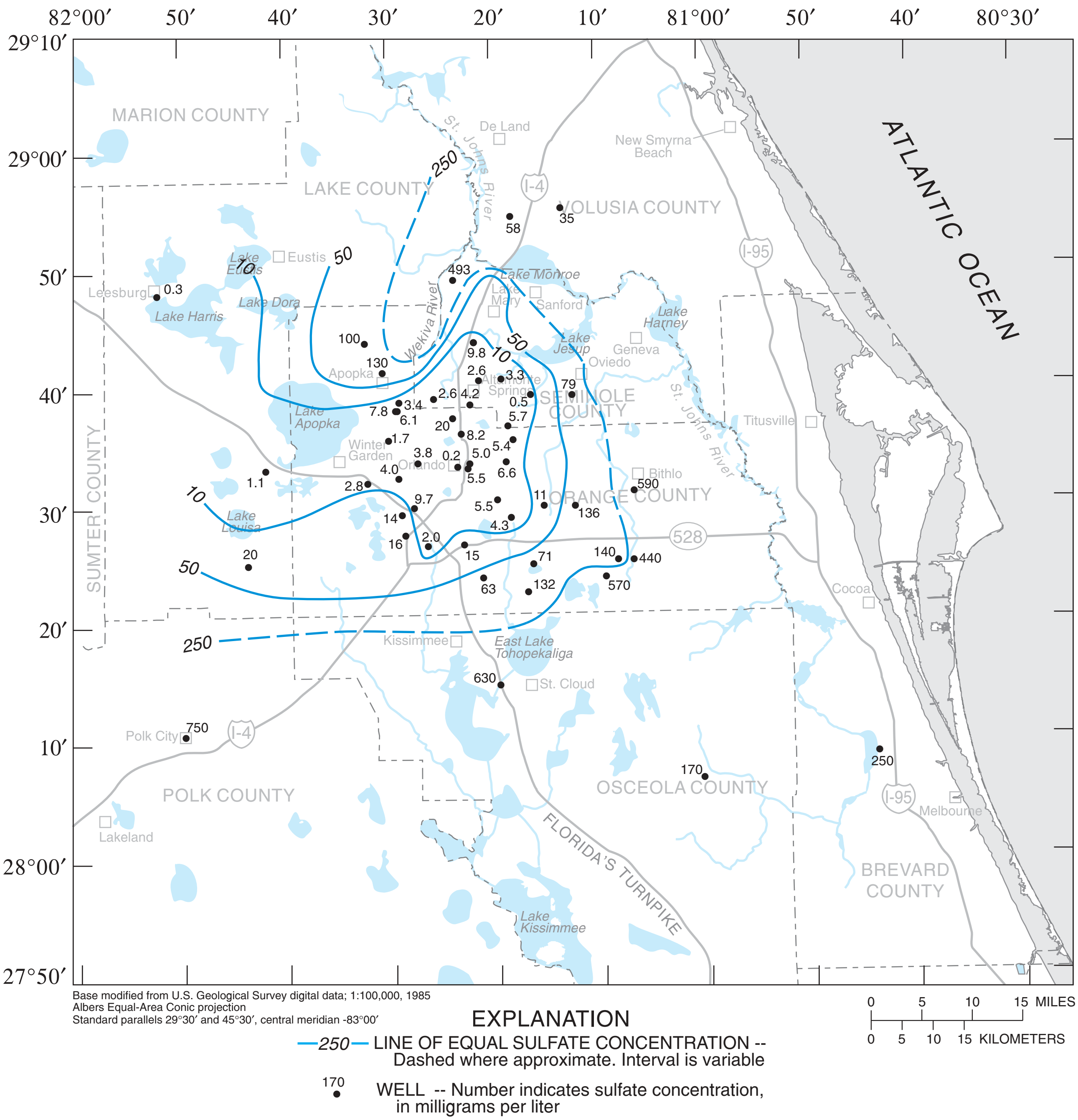


Figure 27. Generalized distribution of sulfate concentrations of water from the Lower Floridan aquifer.

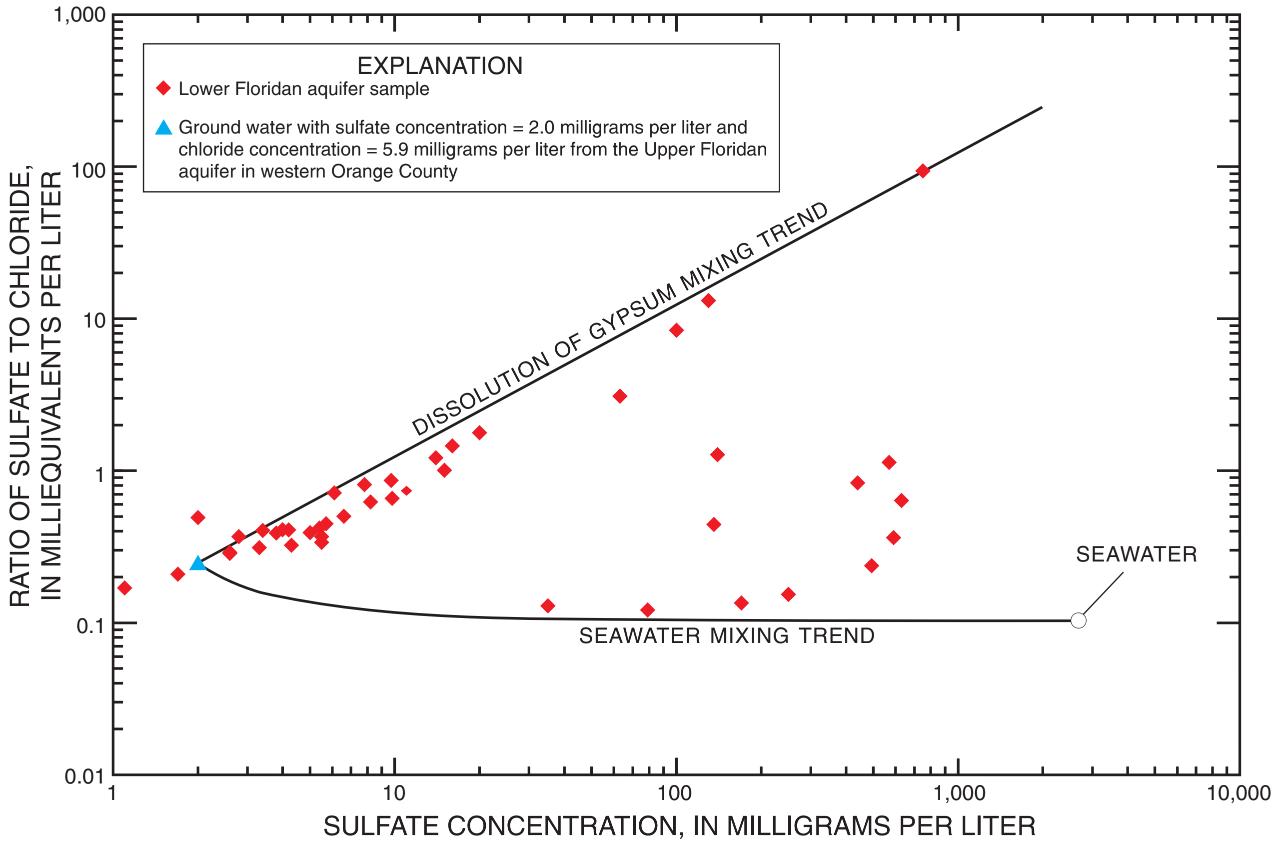


Figure 28. Relation between sulfate to chloride equivalent ratio and sulfate concentration in water from the Lower Floridan aquifer.

Water samples collected from the Lower Floridan aquifer wells also were analyzed for hardness. Hardness ranges from 69 to 940 mg/L (fig. 29 and table 1). Water having a hardness of 100 mg/L or less generally occurs in extreme southwestern Seminole County, in west-central Orange County, and south Lake County. Low hardness concentrations, along with low concentrations of chloride and sulfate (figs. 26 and 27), indicate potential areas of high recharge to the Lower Floridan aquifer. Hardness values exceeding 500 mg/L generally occur in much of the eastern and southern parts of the study area. Hardness concentration exceeding 500 mg/L may exist in other parts of the study area, such as along parts of the Wekiva and St. Johns Rivers; however, no data are available to confirm this hypothesis.

Chemical analyses of ground-water samples from wells tapping the Lower Floridan aquifer indicate differences in the ionic composition of the water. Three chemical types of ground water occur in the study area (fig. 30). The first type, dominated by calcium, magnesium, and bicarbonate ions, generally occurs in inland areas. This water type results from the dissolution of the carbonate rocks that form the aquifer; water likely travels along relatively short flow paths that originate in or near high recharge areas where the aquifer contains a thick layer of freshwater. The change in cation distribution from calcium to calcium-magnesium probably is related to an increase of dolomite in the carbonate sequence of the aquifer. The second ground-water type is enriched in calcium, magnesium, and sulfate. The increased mineralization primarily is due to the dissolution of gypsum. Calcium-magnesium-sulfate type water probably travels along longer and deeper flow paths than the fresher calcium-magnesium-bicarbonate type water. The third ground-water type, dominated by sodium and chloride, occurs primarily in the eastern part of the study area. The sodium-chloride water type represents the mixing of freshwater with entrapped relict seawater or from the upwelling of saline water from deeper zones.

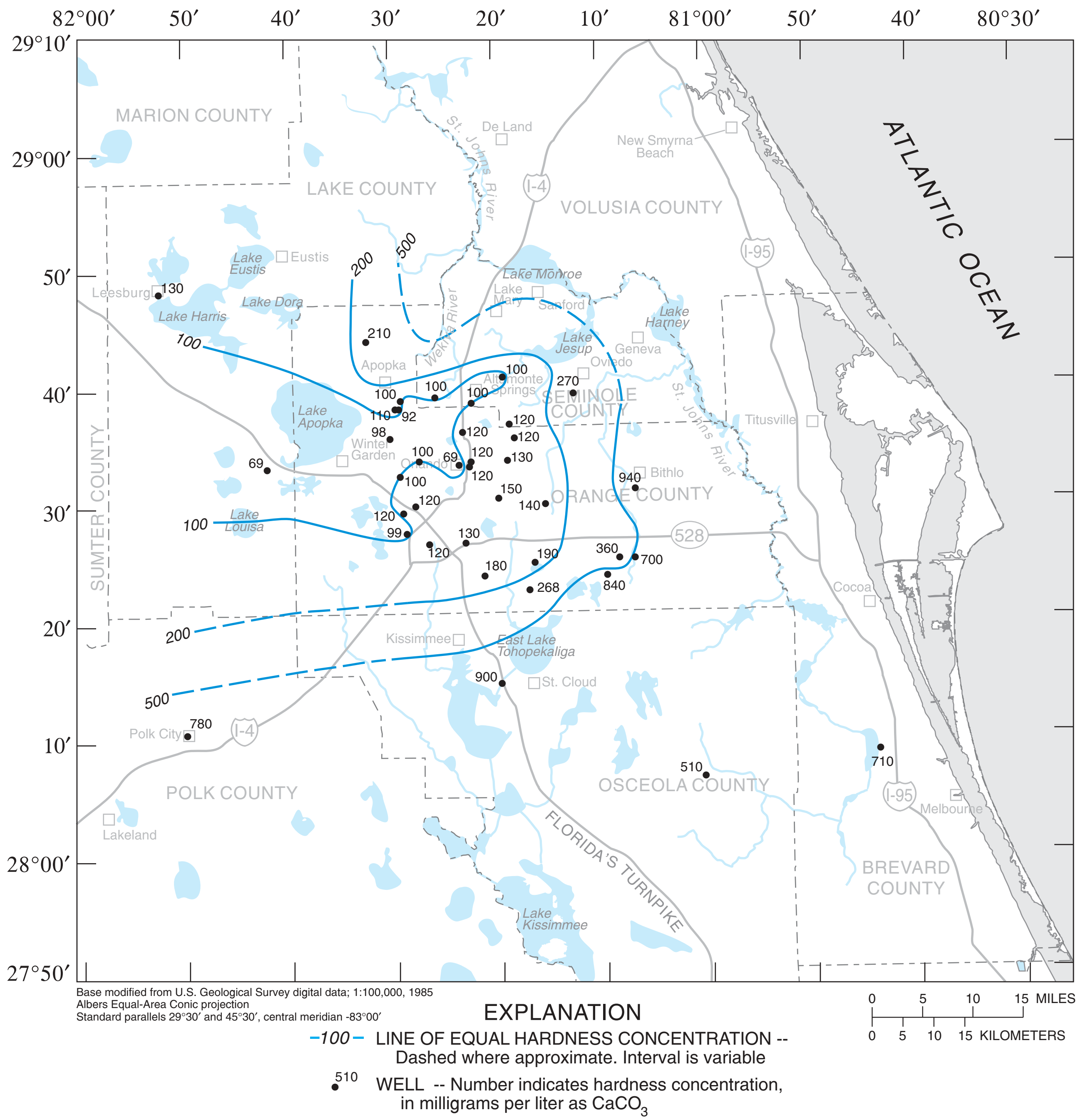


Figure 29. Generalized distribution of hardness concentrations of water from the Lower Floridan aquifer.

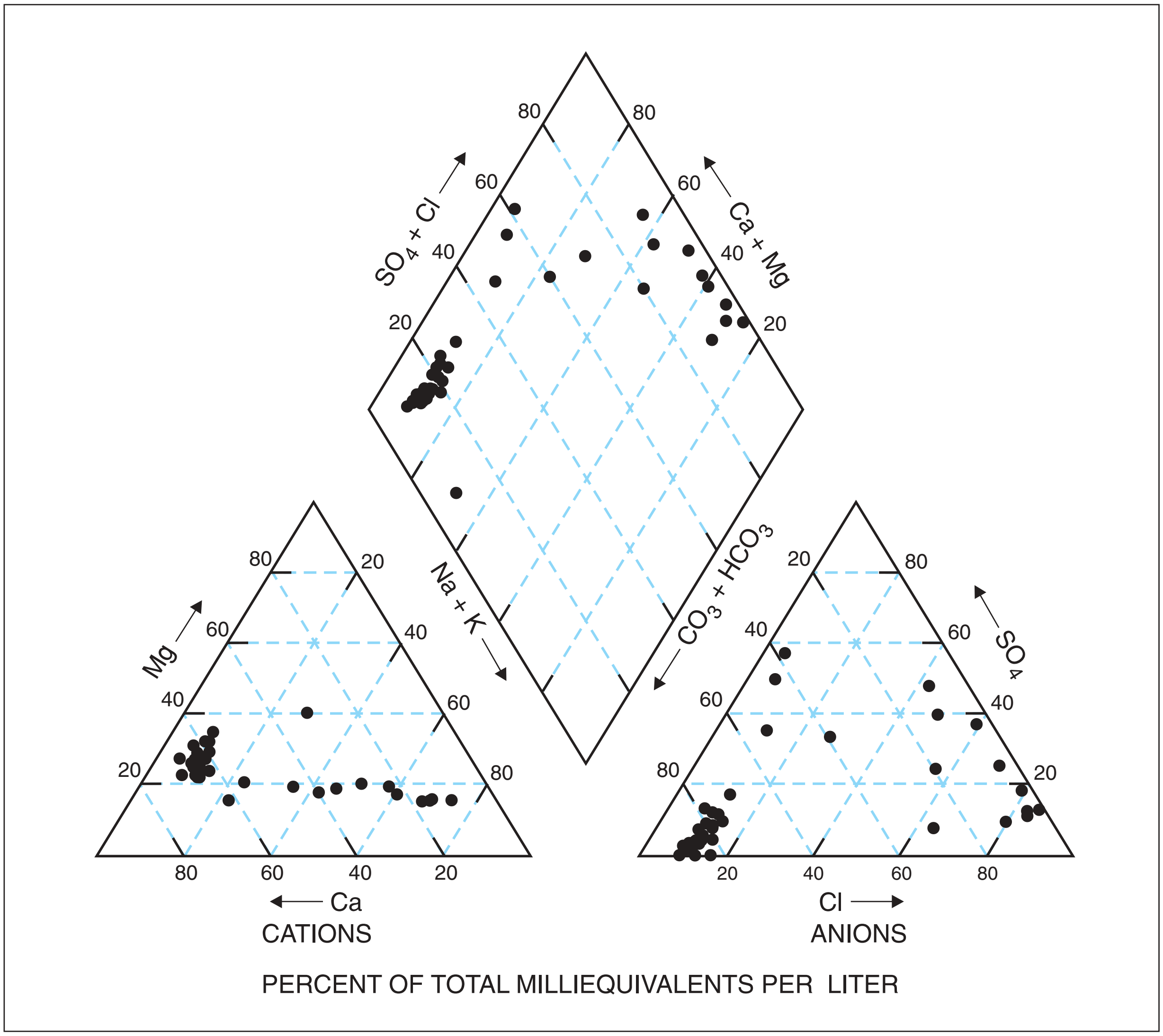


Figure 30. Chemical composition of water from selected wells open to the Lower Floridan aquifer.

Vertical Distribution of Chloride Concentrations

Delineation of the vertical water-quality changes underlying the study area was accomplished by evaluating the distribution of chloride concentrations in water samples collected during well drilling. Wells in the Floridan aquifer system in east-central Florida are commonly installed using the reverse-air rotary method, where air is injected into the drill pipe. The injected air provides the lift needed to bring the fluid and drill cuttings up the drill pipe to the surface (return flow). Water samples of this return flow, commonly called drill-stem samples, are collected at regular intervals during drilling. Under certain conditions, however, a change in water quality with depth may not be detected. This condition results if the permeability of the rock being drilled is low so that little of the return flow originates from the formation at or near the drill bit. Rather, most of the flow comes from a permeable zone higher in the hole. Drill-stem samples at eight selected sites in Seminole, Orange, and Osceola Counties were collected as the wells were drilled (figs. 31 and 32). In general, chloride concentrations increased with depth; water in the Lower Floridan aquifer was more mineralized than in the Upper Floridan aquifer, especially in areas where chloride concentrations exceed 250 mg/L in the Lower Floridan aquifer (fig. 26).

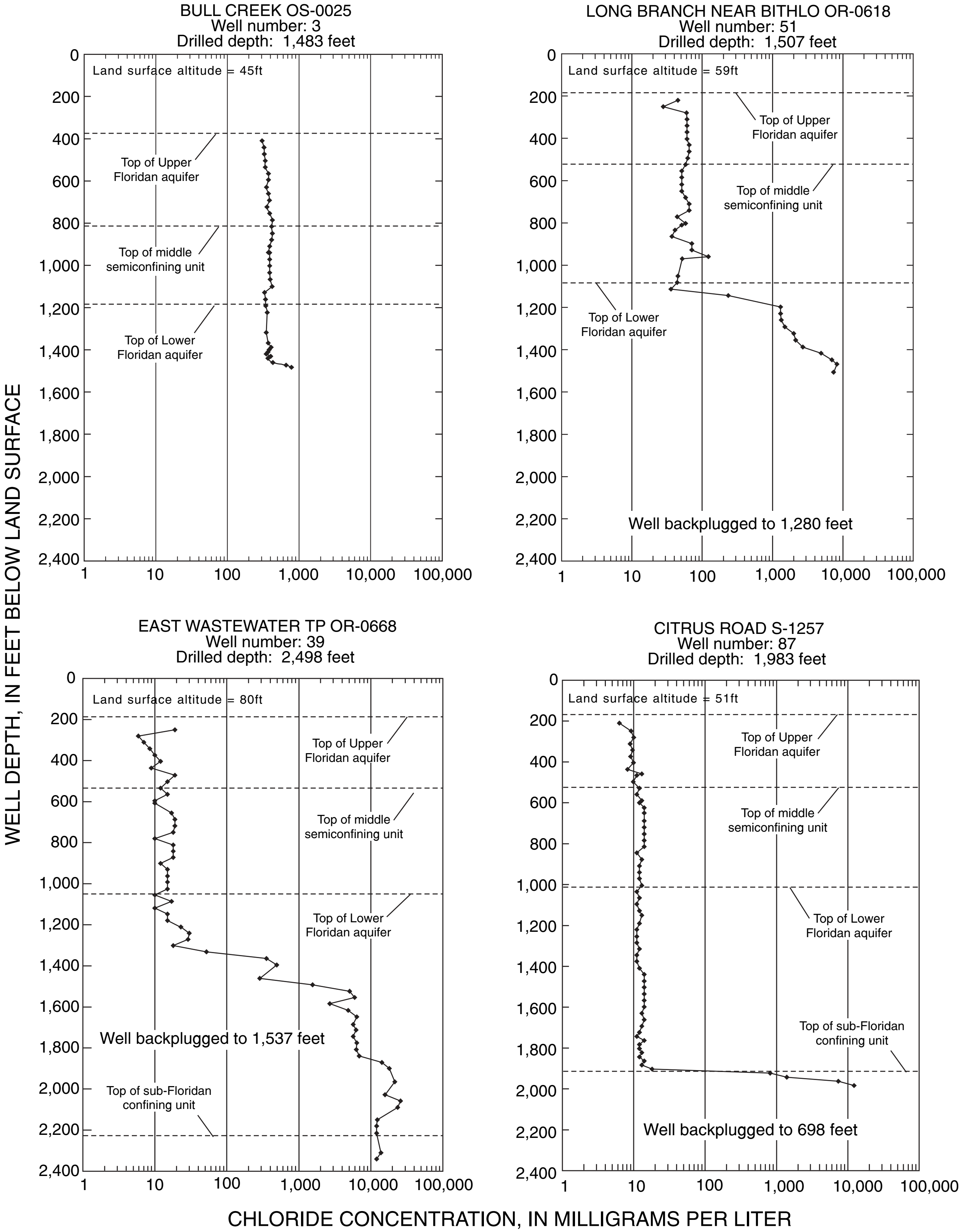


Figure 31. Chloride concentrations in water samples obtained through the drill stem during drilling of monitoring wells 3, 39, 51, and 87 (data from the files of the St. Johns River Water Management District; and Post, Buckley, Schuh, and Jernigan, Inc., 1990). (Well number refers to figure 2.)

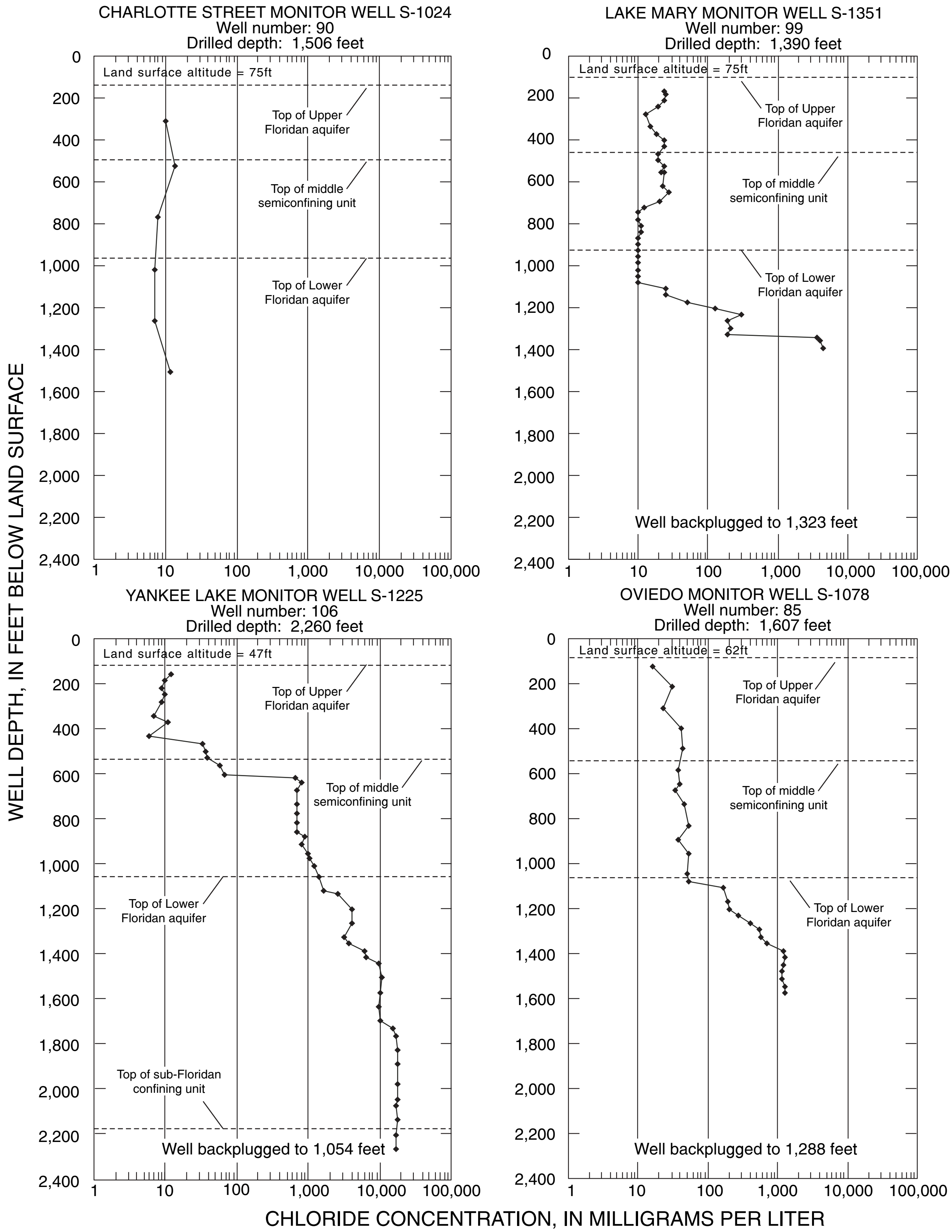


Figure 32. Chloride concentrations in water samples obtained through the drill stem during drilling of monitoring wells 90, 106, 99, and 85 (data from the files of the St. Johns River Water Management District; and Spechler and Halford, 2001). (Well number refers to figure 2.)

Ground water having chloride concentrations less than 100 mg/L extends to considerable depths in the Floridan aquifer system throughout much of the study area. At all the monitoring wells shown in figures 31 and 32, except well 3, chloride concentrations in the Upper Floridan aquifer were less than 100 mg/L. As the wells were deepened into the middle semiconfining unit, chloride concentrations at six of the eight sites either remained constant or decreased slightly. At well 106, a large abrupt change in chloride concentrations (increasing from about 10 to 800 mg/L) was observed near the contact between the Upper Floridan aquifer and middle semiconfining unit, whereas in well 85, the observed chloride concentration increased gradationally. At most of the drilling sites, increases in chloride concentrations were observed in the Lower Floridan aquifer. At several of the sites, increases in chloride concentrations were observed near the contact between the middle semiconfining unit and Lower Floridan aquifer. At two locations (wells 39 and 106), where the entire thickness of the Floridan aquifer system was penetrated, chloride concentrations exceeded 10,000 mg/L in the Lower Floridan aquifer.

Where the middle confining unit is present, vertical changes in water quality coincide well with the different hydrogeologic units. During the drilling of well 9, located near St. Cloud, a large increase in sulfate concentration was observed between 760 and 800 ft below land surface (fig. 23). This increase in sulfate concentration marks the approximate contact where evaporites are first found, which is considered to be the top of the middle confining unit. Between 1,180 and 1,220 ft below land surface, a sharp increase in chloride concentration was observed, along with a moderate decrease in sulfate concentration. This change in water quality corresponds with a change in head difference and apparently marks the base of the middle confining unit (the top of the Lower Floridan aquifer).

Generalized maps showing isochlor surfaces depicting the altitude of water with chloride concentrations of 250 and 5,000 mg/L were compiled (figs. 33 and 34, respectively). The maps are based primarily on chloride concentrations of water samples collected from monitoring and test wells, and to a lesser degree, time domain electromagnetic measurements that were collected in the mid to late 1990's (McGurk and others, 1998).

The altitude of the top of the 250 mg/L isochlor surface is variable throughout the study area (fig. 33). The estimated position of the 250 mg/L isochlor surface is less than 200 ft below sea level in much of the eastern part of the study area, including areas along the St. Johns River in Seminole, Lake, and Volusia Counties and near the Wekiva River in western Seminole County. The altitude of the top of the 250 mg/L isochlor surface exceeds 3,000 ft below sea level in the extreme southwestern part of the study area. However, the freshwater zone probably is considerably thinner south and west of the line that demarcates the inferred eastern extent of the middle confining unit (fig. 11). The limited data available indicate that beneath the middle confining unit the concentration of total dissolved solids could be too high (due to the high concentrations of sulfate) to consider the ground water fresh, even though the chloride concentrations are low.

The estimated altitude of the top of the 5,000 mg/L isochlor surface ranges from less than 200 ft below sea level in northeastern Seminole and northern Brevard Counties and in a small area northwest of DeLand in Volusia County. The altitude of the top of the 5,000 mg/L isochlor surface exceeds 2,800 ft below sea level in the extreme southwestern part of the study area. The 5,000 mg/L isochlor was mapped because in east-central Florida it is assumed to represent the position of the base of the freshwater flow system based on the following reasons (McGurk and Presley, in press): (1) the 5,000 mg/L chloride concentration approximately represents the boundary between moderately brackish water and very brackish to saline water; and (2) the thickness of the transition zone between the 5,000 and 10,000 mg/L chloride concentrations is relatively small.

A comparison of the altitudes of the top of the 5,000 mg/L isochlor surface (fig. 34) and the top of the Lower Floridan aquifer (fig. 13) indicates that the freshwater-saltwater interface is located above the top of the Lower Floridan aquifer along much of the St. Johns and Wekiva Rivers. The freshwater-saltwater interface also is above the top of the Lower Floridan aquifer in eastern and southern Volusia Counties and the northern half of Brevard County.

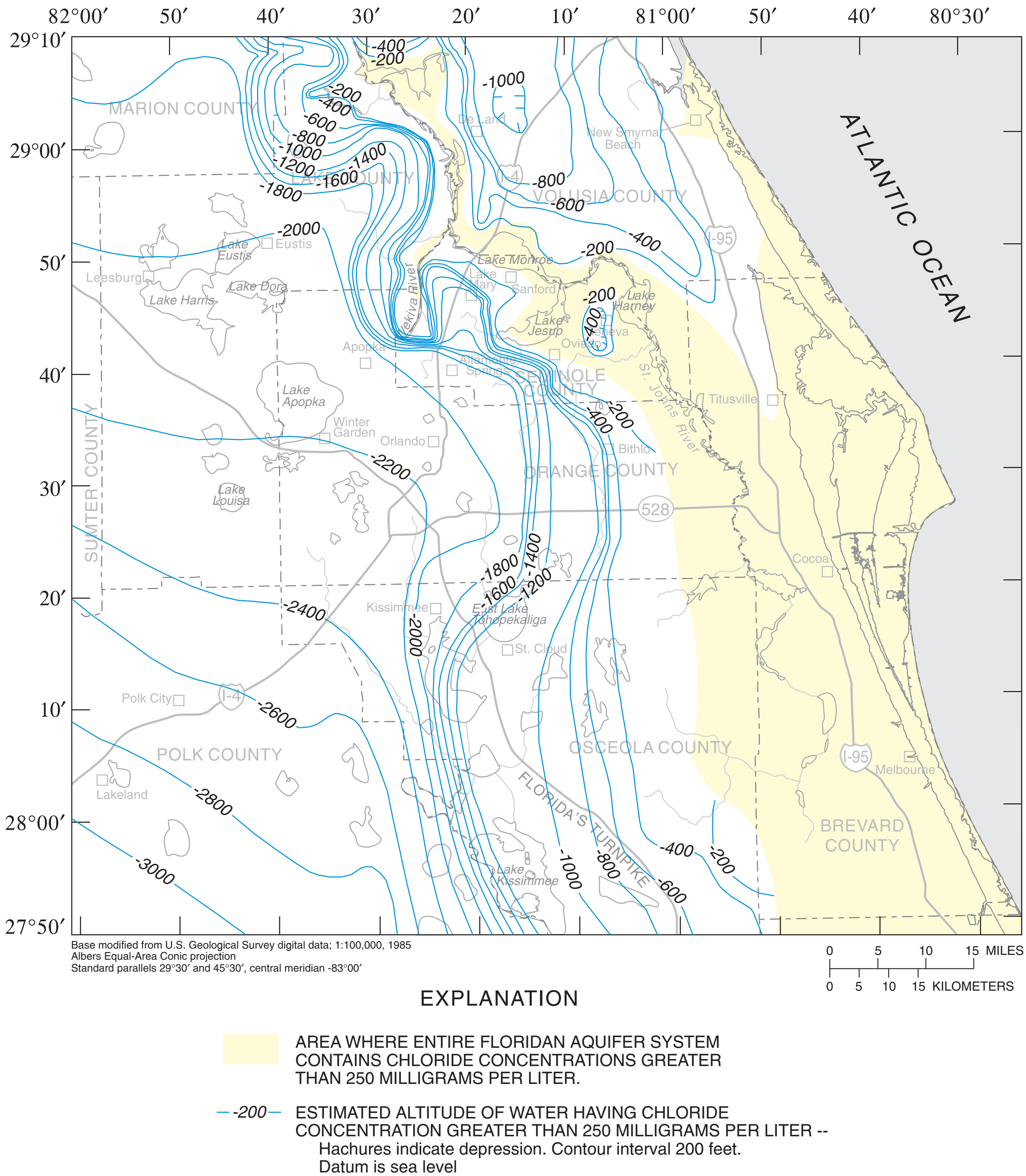


Figure 33. Estimated altitude of water in the Floridan aquifer system having chloride concentrations greater than 250 milligrams per liter (from McGurk and others, 1998).

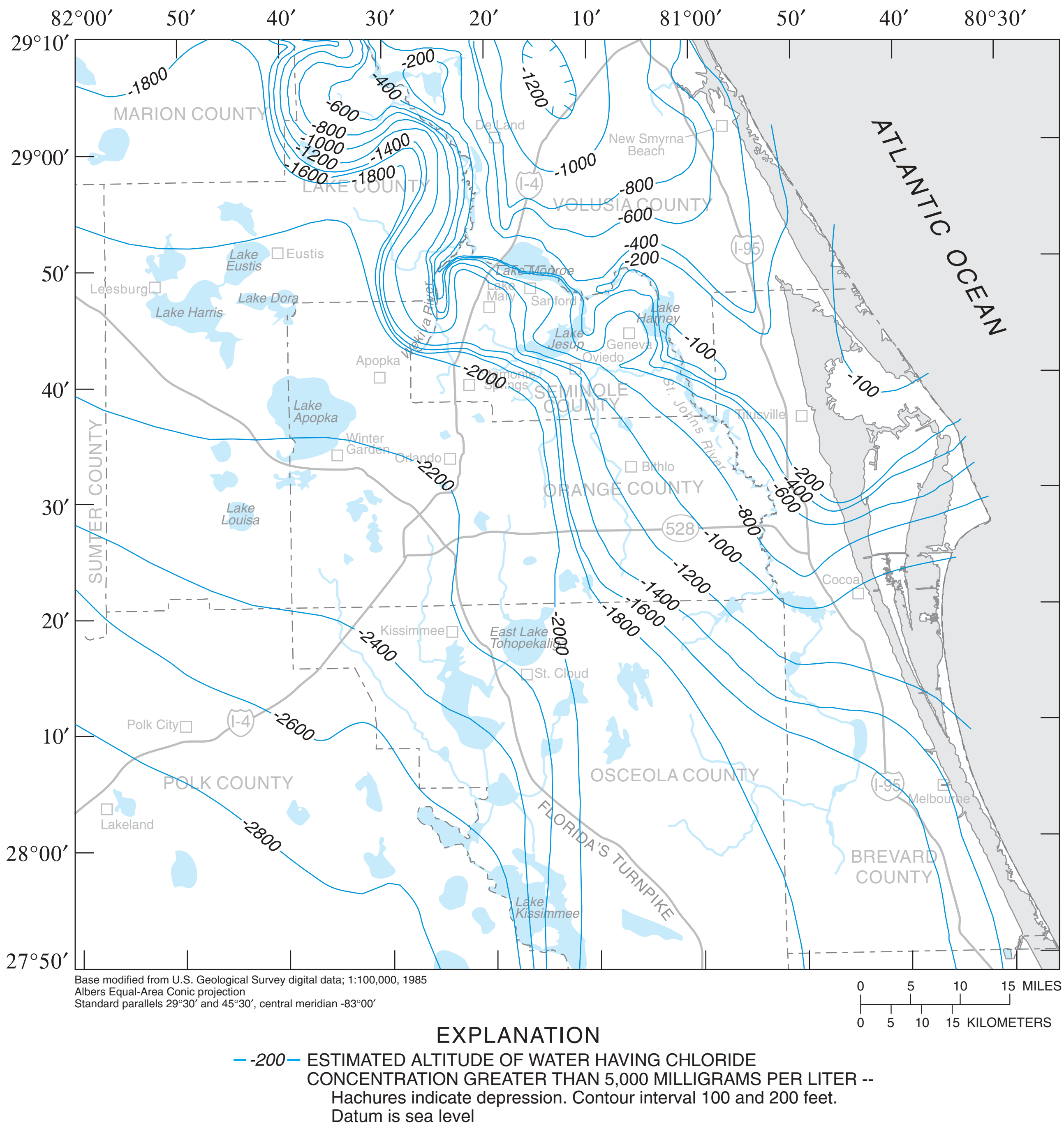


Figure 34. Estimated altitude of water in the Floridan aquifer system having chloride concentrations greater than 5,000 milligrams per liter (from McGurk and others, 1998).

SUMMARY

The hydrogeology and water-quality characteristics of the Lower Floridan aquifer and the relation of the Lower Floridan aquifer to the framework of the Floridan aquifer system were evaluated during a 6-year (1995-2001) study. The study area encompasses about 7,500 square miles in east-central Florida. It includes all of Brevard, Orange, and Seminole Counties and parts of Lake, Marion, Osceola, Polk, Sumter, and Volusia Counties. The principal water-bearing units in the study area are the surficial and Floridan aquifer systems. The surficial aquifer system is underlain by and separated from the Floridan aquifer system by the intermediate confining unit, a unit which restricts the movement of water between the two aquifers. The Floridan aquifer system, the principal source of ground water in east-central Florida, underlies all of Florida, and parts of Alabama, Georgia, and South Carolina. The aquifer system is composed of a sequence of highly permeable carbonate rocks of Eocene age that average about 2,300 feet in thickness across the study area. The Floridan aquifer system is divided into two aquifers of relatively high permeability, the Upper Floridan aquifer and the Lower Floridan aquifer. These aquifers are separated by a less permeable middle semiconfining unit that restricts the vertical movement of water, and additionally by a very low permeability middle confining unit in the southwestern part of the study area.

The Upper Floridan aquifer consists of the Ocala Limestone and the dolomite and dolomitic limestones of the upper one-third of the Avon Park Formation. Permeable intervals of the Ocala Limestone are characterized by vuggy and cavernous porosity. The permeability of the upper Avon Park Formation primarily is due to fractures and interconnecting solution cavities. Flow logs from wells show that two distinct zones of different permeability exist in the Upper Floridan aquifer (zones A and B). Zone A corresponds to about the upper two-thirds of the aquifer, and generally coincides with the Ocala Limestone. Zone B is equivalent to about the lower one-third of the Upper Floridan aquifer and has a hydraulic conductivity that can be much larger than in zone A. The bottom of zone B marks the base of the Upper Floridan aquifer. Zone B generally consists of hard, fractured dolomite within the Avon Park Formation.

The middle semiconfining unit and, where present, the middle confining unit separate the Upper and Lower Floridan aquifers. The middle semiconfining unit is composed of beds of relatively less permeable limestone and dolomite of variable thickness and coincides with about the middle one-third of the Avon Park Formation. The middle semiconfining unit contains primarily softer limestone or dolomitic limestone than the aquifer units above and below, and is considered a semiconfining unit primarily because it lacks abundant fracture zones and solution cavities. The approximate thickness of the middle semiconfining unit ranges from less than 300 feet in the southern part of the study area to more than 600 feet in south-central Orange County and parts of northwestern Osceola County. In the southwestern part of the study area, the middle confining unit underlies the middle semiconfining unit. Composed primarily of anhydritic and gypsiferous dolomite and dolomitic limestone, the middle confining unit usually corresponds to the middle part of the Avon Park Formation. The top of the middle confining unit ranges from about 750 feet below sea level near its eastern extent to more than 1,000 feet below sea level southwest of Lakeland. Thickness of the unit ranges from less than 150 feet in southern Lake County to 762 feet in northeastern Polk County.

The Lower Floridan aquifer is present throughout east-central Florida. The aquifer consists of the lower part of the Avon Park Formation of middle Eocene age, the Oldsmar Formation of early Eocene age, and the upper part of the Cedar Keys Formation of late Paleocene age. It is composed of alternating beds of limestone and dolomite and is characterized by abundant fractured dolomite zones and solution cavities. The altitude of the top of the Lower Floridan aquifer ranges from less than 600 feet in the northern part of the study area to more than 1,600 feet below sea level in the southwestern part. In much of Seminole and Orange Counties, the altitude of the top of the Lower Floridan aquifer is fairly consistent, ranging from about 900 to 1,000 feet below sea level. The top of the Lower Floridan aquifer generally is marked by an increase in formation resistivity due to the increasing presence of dolomite, and by an increase in the occurrence of fractures and solution cavities within the carbonates. In addition, a noticeable increase in borehole flow often marks the contact between the Lower Floridan aquifer and the overlying middle semiconfining or middle confining unit. Thickness of the Lower Floridan aquifer ranges from about 910 to 1,180 feet.

Ground water in the Lower Floridan aquifer generally moves in a southwest-to-northeast direction

across the study area. In September 1998, water levels measured in the Lower Floridan aquifer monitoring wells ranged from about 16 to 113 feet above sea level. Water levels measured in the Lower Floridan aquifer monitoring wells in May 1999 ranged from about 13 to 111 feet above sea level. Water levels in May 1999 were about 2 to 7 feet lower than water levels measured in September 1998. The potentiometric surface of the Lower Floridan aquifer is constantly fluctuating, mainly in response to seasonal variations in rainfall and ground-water withdrawals. Seasonal fluctuations typically range from about 2 to 10 feet. The water-level trends observed in Lower Floridan aquifer wells also generally mimic the trends observed in nearby wells tapping the Upper Floridan aquifer, indicating that the aquifers, at these locations, are hydraulically connected.

During this investigation, water samples from 33 wells tapping the Lower Floridan aquifer were analyzed by the USGS for major chemical constituents. These data were supplemented with samples collected from 17 additional wells by St. Johns River Water Management District, the Florida Department of Environmental Protection, and private consultants. Most samples were analyzed in the field for temperature, pH, and specific conductance, and in the laboratory for major cations and anions.

The chemical quality of water in the Lower Floridan aquifer varied considerably in the study area. Specific conductance ranged from 147 to 6,710 microsiemens per centimeter. Chloride concentrations of water in the Lower Floridan aquifer ranged from 3.0 to 2,188 milligrams per liter. Sulfate concentrations ranged from less than 0.2 to 750 milligrams per liter and hardness ranged from 69 to 940 milligrams per liter. Water was least mineralized in the recharge areas of the Floridan aquifer system in southwestern Seminole, west-central Orange, and south-central Lake Counties. The most mineralized water in the Lower Floridan aquifer occurred along parts of the Wekiva River, the St. Johns River west of Lake Monroe, and in much of the eastern and southern parts of the study area.

The altitude of the top of the 250 milligram per liter isochlor surface is variable throughout the study area. The estimated position of the 250 milligram per liter isochlor surface is less than 200 feet below sea level in much of the eastern part of the study area, including the areas along the St. Johns River in Lake, Seminole, and Volusia Counties, and near the Wekiva River in western Seminole County. The altitude of the 250 milligram per liter isochlor exceeds 3,000 feet below sea level in the extreme southwestern part of the study area. The altitude of the top of the 5,000 milligram per liter isochlor surface ranges from less than 200 feet below sea level in northeastern Seminole and northern Brevard Counties and in a small area northwest of DeLand in Volusia County to more than 2,800 feet below sea level in the extreme southwestern part of the study area. Water in the Lower Floridan aquifer in the southwestern part of the study area, however, may not be considered fresh, even though chloride concentrations are low. Limited data indicate that the water may be very mineralized due to high concentrations of sulfate.

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Appendixes

Appendix 1. Wells used for collection of water-level and water-quality data

[--, no data. Abbreviations for aquifer: UF, Upper Floridan aquifer; MSCU, middle semiconfining unit; MCU, middle confining unit; LF, Lower Floridan aquifer; SFCU, sub-Floridan confining unit. Abbreviations for data type: qw, water-quality sample; wl, ground-water level. Abbreviations for source of data: CR, consultant's report; FDEP, Florida Department of Environmental Protection; SJRWMD, St. Johns River Water Management District; USGS, U.S. Geological Survey. Well locations shown in figure 2]

Well number	USGS site identification number	Station name	Aquifer	Bottom of casing (feet)	Depth of well (feet)	Primary data type	Source of data	County
1	280655081002901	Bull Creek OS-0022	UF/MSCU	700	900	wl	USGS, SJRWMD	Osceola
2	280655081002902	Bull Creek OS-0023	UF	396	520	wl	USGS, SJRWMD	Osceola
3	280655081002904	Bull Creek OS-0025	LF	1,473	1,483	qw, wl	USGS, SJRWMD	Osceola
4	280823081210301	OSF-53 near Alcoma	UF/MSCU	180	963	wl	USGS	Osceola
5	280858080435501	Melbourne Lake Washington BR-0910	LF	1,180	1,204	qw, wl	CR	Brevard
6	281057081495002	Polk City ROMP 76A	UF	264	315	wl	USGS	Polk
7	281058081495001	Polk City USGS inner monitor	MSCU	840	908	wl	USGS	Polk
8	281058081495004	Polk City USGS core hole 2	MCU/LF	1,000	1,996	qw, wl	USGS	Polk
9	281506081194501	St. Cloud OSF-0081	LF	--	--[1]	qw	USGS	Osceola
10	281714081093001	Lake Joel OSF-0022	UF/MSCU	394	750	wl	USGS	Osceola
11	281937081245901	Bermuda Avenue OSF-0009	UF/MSCU/LF	280	1,200	wl	USGS	Osceola
12	282215081230001	So. Regional MW-2A	SFCU	2,050	2,467	wl	USGS	Orange
13	282215081230003	So. Regional MW-2B	LF	1,125	1,725	wl	USGS	Orange
14	282220081225401	So. Regional MW-1A	LF	1,160	1,705	wl	USGS	Orange
15	282220081225402	So. Regional MW-1B	MSCU	761	781	wl	USGS	Orange
16	282300081165501	Southeast #2	LF	1,045	1,441	qw	CR	Orange
17	282406081093602	Cocoa R OR-0611	LF	1,098	1,205	qw, wl	USGS	Orange
18	282411081211301	Orange Test Well	LF	1,098	1,424	qw, wl	USGS	Orange
19	282511081271701	Orangewood #4	UF	129	400	wl	USGS	Orange
20	282515081162601	Southeast test well near Lake Nona OR-0636	LF	1,090	1,399	qw, wl	CR, USGS	Orange
21	282520081434001	Lake Louisa State Park L-0729	LF	1,295	1,410	qw	SJRWMD	Lake
22	282520081434002	Lake Louisa State Park L-0730	UF	385	465	other	SJRWMD	Lake
23	282530081065601	Cocoa OR-0614	LF	1,170	1,256	qw, wl	USGS	Orange
24	282530081065602	Cocoa OR-0615	MSCU	900	1,050	wl	USGS	Orange
25	282530081065603	Cocoa OR-0613 Cocoa S	LF	1,428	1,500	wl	USGS	Orange
26	282533081082204	Cocoa C Zone 3	LF	1,218	1,224	qw, wl	USGS	Orange
27	282650081262502	Sand Lake Road	LF	2,005	2,030	qw, wl	CR, USGS	Orange
28	282657081230401	Sky Lake #2	LF	960	1,390	qw, wl	USGS	Orange
29	282718081405601	Conserv II 4W-3	UF/MSCU	157	1,000	wl	USGS	Lake
30	282745081283501	Southwest #3 (P-2)	LF	1,003	1,455	qw, wl	USGS	Orange
31	282758081392801	Conserv II 1W-2	UF/MSCU/LF	146	1,402	wl	USGS	Lake
32	282811081392901	Conserv II 1W-3	UF	178	536	wl	USGS	Lake
33	282821081382601	Conserv II 1W-5	UF/MSCU	236	1,020	wl	USGS	Orange
34	282839081383501	Conserv II JR2-F	MSCU	554	1,056	wl	USGS	Orange
35	282910081181301	Orange Conway #3	UF/MSCU	148	700	wl	USGS	Orange
36	282912081182901	Orange Conway #4 OR-0560	LF	1,100	1,400	qw, wl	FDEP, USGS	Orange
37	282931081285901	Hidden Springs #4	LF	1,250	1,401	qw, wl	USGS	Orange
38	283006081274101	Kirkman #3	LF	983	1,400	qw, wl	USGS	Orange
39	283007081122703	Wastewater TP East OR-0668	LF	1,490	1,537	wl	SJRWMD	Orange
40	283007081122704	Wastewater TP East OR-0676	LF	1,269	1,300	qw, wl	SJRWMD, USGS	Orange

Appendix 1. Wells used for collection of water-level and water-quality data--Continued

[--, no data. Abbreviations for aquifer: UF, Upper Floridan aquifer; MSCU, middle semiconfining unit; MCU, middle confining unit; LF, Lower Floridan aquifer; SFCU, sub-Floridan confining unit. Abbreviations for data type: qw, water-quality sample; wl, ground-water level. Abbreviations for source of data: CR, consultant's report; FDEP, Florida Department of Environmental Protection; SJRWMD, St. Johns River Water Management District; USGS, U.S. Geological Survey. Well locations shown in figure 2]

Well number	USGS site identification number	Station name	Aquifer	Bottom of casing (feet)	Depth of well (feet)	Primary data type	Source of data	County
41	283007081122705	Wastewater TP East OR-0678	UF	425	470	other	SJRWMD	Orange
42	283011081152401	E. Regional LFMW	LF	1,100	1,385	qw, wl	USGS	Orange
43	283011081152402	E. Regional IFMW	MSCU	850	950	wl	USGS	Orange
44	283012081152301	E. Regional UFMW	UF	210	550	wl	USGS	Orange
45	283026081224101	So. Fruit/Pineloch Man. Corp.	LF	1,100	1,250	wl	USGS	Orange
46	283048081194801	Conway #3	LF	1,063	1,350	qw, wl	USGS	Orange
47	283102081223401	Kuhl #1 W-4664	LF	953	1,283	wl	USGS	Orange
48	283135081155201	Rio Pinar MW	LF	1,000	1,120	wl	USGS	Orange
49	283135081234301	Layne Atlantic W-1607	LF	1,170	1,232	wl	USGS	Orange
50	283126081064501	Long Branch near Bithlo OR-0617	UF	210	550	wl	USGS, SJRWMD	Orange
51	283126081064502	Long Branch near Bithlo OR-0618	LF	1,140	1,280	qw, wl	USGS, SJRWMD	Orange
52	283216081320901	South #1 OR-0559	LF	800	1,450	qw	FDEP	Orange
53	283215081321201	South #2	LF	810	1,450	wl	USGS	Orange
54	283224081210201	Primrose #2	LF	993	1,146	wl	USGS	Orange
55	283236081290901	Oak Meadows #4	MSCU/LF	707	1,260	qw, wl	USGS	Orange
56	283249081463201	Seminole Avenue L-0019	MSCU/LF	517	840	wl	USGS	Lake
57	283308081415501	Greater Hills South	MSCU/LF	561	1,315	wl	USGS	Lake
58	283322081415401	Greater Hills North	LF	828	1,320	qw, wl	USGS	Lake
59	283327081223201	Highland #7	LF	943	1,415	qw, wl	USGS	Orange
60	283333081233501	Lake Adair 9 OR-0009	MSCU/LF	601	1,281	qw, wl	USGS	Orange
61	283333081233502	Lake Adair 10 OR-0046	UF	103	400	wl	USGS	Orange
62	283340081222801	Lake Ivanhoe Interface OR-0465	LF or SFCU	2,060	2,089	wl	USGS	Orange
63	283340081222802	Lake Ivanhoe OR-0467	LF	1,300	1,350	wl	USGS	Orange
64	283340081222803	Lake Ivanhoe OR-0468	UF	189	450	wl	USGS	Orange
65	283353081185801	Navy #1	LF	1,080	1,370	qw, wl	USGS	Orange
66	283353081222401	Highland #2	LF	945	1,450	qw	USGS	Orange
67	283357081272201	Pine Hills #1	LF	1,000	1,414	qw, wl	USGS	Orange
68	283441081203301	Glenridge Deep	LF	1,209	1,300	wl	USGS	Orange
69	283548081181401	University/FTU Blvd.	MSCU/LF	700	1,354	qw, wl	USGS	Orange
70	283555081300801	Forest Oaks #3	LF	1,192	1,450	qw, wl	USGS	Orange
71	283623081230501	Wymore & Lee Rd. #5	LF	1,163	1,275	qw, wl	USGS	Orange
72	283702081183901	South S-2	MSCU/LF	600	1,200	qw, wl	USGS	Seminole
73	283742081235701	Keller Road 6A	LF	850	1,350	qw	CR	Orange
74	283800081115501	Lake Hayes S-1215	MSCU/LF	582	904	wl	USGS	Seminole
75	283802081252001	Riverside #4	MSCU/LF	502	1,231	wl	USGS	Orange
76	283813081292101	W. Regional #2	LF	1,037	1,455	wl	USGS	Orange
77	283818081291201	W. Regional MW LF-1	LF	1,031	1,580	qw, wl	CR, USGS	Orange
78	283818081291202	W. Regional MW UF-1	UF	116	419	wl	USGS	Orange
79	283819081292601	W. Regional #1 TP-1	LF	1,032	1,450	qw, wl	USGS	Orange
80	283848081221301	A. S. #2, well #11	MSCU/LF	722	1,130	qw, wl	USGS	Seminole

Appendix 1. Wells used for collection of water-level and water-quality data--Continued

[--, no data. Abbreviations for aquifer: UF, Upper Floridan aquifer; MSCU, middle semiconfining unit; MCU, middle confining unit; LF, Lower Floridan aquifer; SFCU, sub-Floridan confining unit. Abbreviations for data type: qw, water-quality sample; wl, ground-water level. Abbreviations for source of data: CR, consultant's report; FDEP, Florida Department of Environmental Protection; SJRWMD, St. Johns River Water Management District; USGS, U.S. Geological Survey. Well locations shown in figure 2]

Well number	USGS site identification number	Station name	Aquifer	Bottom of casing (feet)	Depth of well (feet)	Primary data type	Source of data	County
81	283906081290001	Sheeler Oaks	MSCU/LF	600	1,200	qw, wl	USGS	Orange
82	283917081254501	A. S. #5, well #14	MSCU/LF	700	1,200	qw, wl	USGS	Seminole
83	283933081123102	Oviedo S-1189	MSCU	500	600	wl	USGS	Seminole
84	283933081123103	Oviedo S-1193	UF	87	220	wl	USGS	Seminole
85	283933081123105	Oviedo S-1078	LF	1,230	1,288	qw, wl	USGS	Seminole
86	283936081162801	Citrus Road S-1056	UF	156	365	wl	USGS	Seminole
87	283936081162802	Citrus Road S-1257	MSCU	600	698	wl	USGS	Seminole
88	283936081162804	Citrus Road S-1329	LF	1,050	1,150	qw, wl	SJRWMD, USGS	Seminole
89	284052081212601	Charlotte Street/North St. S-1014	UF	142	300	wl	USGS	Seminole
90	284052081212605	Charlotte Street/North St. S-1024	LF	1,246	1,506	qw, wl	SJRWMD, USGS	Seminole
91	284057081191901	North N2400	MSCU/LF	600	1,200	qw, wl	USGS	Seminole
92	284126081280801	Bent Oaks #2	UF/MSCU	92	850	wl	USGS	Orange
93	284128081320901	Apopka Grossenbacher, #4 OR-0554	MSCU/LF	660	1,400	qw, wl	FDEP, USGS	Orange
94	284132081303601	Apopka Grossenbacher, #2	MSCU/LF	588	1,260	wl	USGS	Orange
95	284134081564201	Sunshine Peat near Cason	UF	--	--	wl	USGS	Lake
96	284135081565501	Sunshine Peat Deep near Cason	MSCU/LF	483	754	wl	USGS	Lake
97	284407081215502	Lake Mary S-1407	UF	320	401	other	SJRWMD	Seminole
98	284407081215503	Lake Mary S-1406	LF	1,020	1,080	qw	SJRWMD	Seminole
99	284407081215504	Lake Mary S-1351	LF	1,260	1,323	other	SJRWMD	Seminole
100	284407081321601	Apopka Northwest, well #1	LF	859	1,303	qw, wl	USGS	Orange
101	284407081321701	Apopka Northwest, UFM-1	UF	155	446	wl	USGS	Orange
102	284634081262003	Rock Springs State Res OR-0652	MSCU	450	506	wl	USGS	Orange
103	284634081262004	Rock Springs State Res OR-0662	UF	150	180	wl	USGS	Orange
104	284822081520601	Leesburg #14	LF	851	938	qw, wl	USGS	Lake
105	284855081520401	Herlong Park	UF	100	105	wl	USGS	Lake
106	284923081234801	Yankee Lake S-1225	LF	950	1,054	qw, wl	SJRWMD, USGS	Seminole
107	284923081234802	Yankee Lake S-1230	UF	122	403	wl	USGS	Seminole
108	285442081181401	Orange City Tower V-0196	UF	95	230	wl	USGS	Volusia
109	285442081181402	Orange City Tower V-0780	LF	710	800	qw, wl	FDEP, USGS	Volusia
110	285524081132401	Galaxy V-0774	LF	740	780	qw, wl	SJRWMD,USGS	Volusia
111	285524081132403	Galaxy V-0772	UF	100	140	wl	USGS	Volusia
112	290153080550101	NSB MW R-1 V-0262	MSCU	750	900	wl	USGS	Volusia
113	290153080550102	NSB MW R-2	UF	150	180	wl	USGS	Volusia
114	290541081132902	USGS 04 TW near DeLand V-0081	UF/MSCU	94	575	wl	USGS	Volusia
115	290541081132903	USGS 05 TW near DeLand V-0012	LF	639	1,200	wl	USGS	Volusia
116	290541081132904	USGS 06 TW near DeLand V-0100	LF	1,275	1,290	wl	USGS	Volusia

[1]Well not completed. As of July 31, 2002, depth of well is 2,210 feet below land surface.

Appendix 2. Geophysical, lithologic, and aquifer test data-collection sites

[Abbreviations for data type: a, aquifer test; g, geophysical logs; l, lithologic log. Abbreviations for source of data: CR, consultant's report; FGS, Florida Geological Survey; SJRWMD, St. Johns River Water Management District; SFWMD, South Florida Water Management District; USGS, U.S. Geological Survey. Site locations shown in figure 3]

Site number	Latitude	Longitude	Site name	Primary data type	Source of data	County
117	274742	805853	Hayman	g	USGS	Osceola
118	275314	815142	Romp site 59 W-12640	l	FGS	Polk
119	275411	814656	Armour W-1801	l	FGS	Polk
120	280125	820018	US Gypsum W-10253	l	FGS	Polk
121	280130	803603	Port Malabar IW	g	SJRWMD	Brevard
122	280209	803617	Harris Corporation IW	g	SJRWMD	Brevard
123	280226	803300	South Beaches IW	g	SJRWMD	Brevard
124	280406	803840	West Melbourne IW	g	SJRWMD	Brevard
125	280555	815420	US Gypsum W-10254	g	FGS	Polk
126	280655	810029	Bull Creek TM	g	SJRWMD	Osceola
127	280823	812103	OSF-53 near Alcoma	g	SJRWMD	Osceola
128	280826	810318	Holopaw	g	CR	Osceola
129	280900	804359	Melbourne Lake Washington	g	CR	Brevard
130	281015	803952	D. B. Lee IW	g	SJRWMD	Brevard
131	281058	814950	Polk City monitor well	g	USGS	Polk
132	281506	811945	St. Cloud W-18109	g	SFWMD	Osceola
133	281714	810930	Lake Joel	g	USGS	Osceola
134	281810	814006	NE Polk County	g	USGS	Polk
135	281814	813600	Indian Ridge	g	CR	Osceola
136	281937	812459	Bermuda Avenue	g	SFWMD	Osceola
137	282128	813426	RCID	g	CR	Orange
138	282215	812300	Southern Regional	a, g	CR	Orange
139	282254	811657	Southeast	a, g	CR	Orange
140	282332	814932	Arnold #1 oil test well W-275	g	FGS	Lake
141	282411	812113	Orange test well	a, g	CR	Orange
142	282515	811626	Southeast near Lake Nona	a, g	SJRWMD	Orange
143	282520	814340	Lake Louisa State Park	g	SJRWMD	Lake
144	282530	810656	Cocoa S	g	SJRWMD	Orange
145	282533	804223	Merritt Island	g	SJRWMD	Brevard
146	282533	810822	Cocoa C	g	USGS	Orange
147	282617	813024	Dr. Phillips	g	USGS	Orange
148	282650	812625	Sand Lake Road IW	g	USGS	Orange
149	282700	812307	Sky Lake	g	SJRWMD	Orange
150	282747	812850	Southwest	a, g	CR	Orange
151	282758	813929	Conserv II	g	CR	Lake
152	282805	811301	George Terry #1	g	USGS	Orange
153	282845	810215	Texaco Deseret Farms 1	g	USGS	Orange
154	283007	811145	Wastewater TP East	g	SJRWMD	Orange
155	283011	811524	Eastern Regional	g	CR	Orange
156	283050	811943	Conway	a, g	CR	Orange

Appendix 2. Geophysical, lithologic, and aquifer test data-collection sites--Continued

[Abbreviations for data type: a, aquifer test; g, geophysical logs; l, lithologic log. Abbreviations for source of data: CR, consultant's report; FGS, Florida Geological Survey; SJRWMD, St. Johns River Water Management District; SFWMD, South Florida Water Management District; USGS, U.S. Geological Survey. Site locations shown in figure 3]

Site number	Latitude	Longitude	Site name	Primary data type	Source of data	County
157	283138	810645	Long Branch near Bithlo	g	SJRWMD	Orange
158	283215	813212	Ocoee South	g	CR	Orange
159	283225	812051	Primrose	a	CR	Orange
160	283340	812228	Lake Ivanhoe	g	SJRWMD	Orange
161	283350	812720	Pine Hills	g	SJRWMD	Orange
162	283353	811858	Navy	g	USGS	Orange
163	283353	812224	Lake Highland	a	SJRWMD	Orange
164	283555	813008	Forest Oaks	a, g	CR	Orange
165	283623	812305	Wymore and Lee Road	g	SJRWMD	Orange
166	283742	812357	Keller Road	a	CR	Orange
167	283800	811155	Lake Hayes	g	CR	Seminole
168	283812	811710	Consumers 3	g	CR	Seminole
169	283813	812928	Western Regional	a	CR	Orange
170	283818	812914	Western Regional	g	CR	Orange
171	283933	811231	Oviedo	g	CR	Seminole
172	283936	811628	Citrus Road	g	SJRWMD	Seminole
173	284052	812126	Charlotte Street/North Street	g	SJRWMD	Seminole
174	284102	813323	Plymouth drainage well	g	CR	Orange
175	284135	815655	Sunshine Peat	g	USGS	Lake
176	284238	812758	Wekiva Springs	g	SJRWMD	Orange
177	284407	812155	Lake Mary	g	SJRWMD	Seminole
178	284407	813216	Apopka Northwest	a, g	CR	Orange
179	284412	810711	Geneva	g	SJRWMD	Seminole
180	284634	812620	Rock Springs State Reserve	g	SJRWMD	Orange
181	284718	811936	Sheriff Rifle Range	g	SJRWMD	Seminole
182	284827	815133	Leesburg	g	SJRWMD	Lake
183	284840	811157	Osteen	g	SJRWMD	Volusia
184	284923	812348	Yankee Lake	g	SJRWMD	Seminole
185	284944	811910	Lake Monroe/Zoo	g	SJRWMD	Seminole
186	285211	811316	Snook Road near Osteen	g	SJRWMD	Volusia
187	285442	811814	Orange City Tower	g	SJRWMD	Volusia
188	285543	811338	Galaxy	g	SJRWMD	Volusia
189	285940	815220	Weirsdale Marion County	g	USGS	Marion
190	290103	805519	NSB Smith Street	g	SJRWMD	Volusia
191	290153	805501	NSB MW R-1	g	CR	Volusia
192	290210	811002	Sun Oil Company W-1118	g	FGS	Volusia
193	290541	811329	USGS well near DeLand	g	USGS	Volusia