Potential for Water-Quality Degradation of Interconnected Aquifers in West-Central Florida

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Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
foot per minute (ft/min)	0.3048	meter per second
mile (mi)	1.609	kilometer
foot squared per day (ft^2/ d)	0.0290	meter squared per day
square mile (mi^2)	2.590	square kilometer
million gallons per day (Mgal/d)	0.04381	cubic meters per second
gallons per minute (gal/min)	0.06308	liter per second

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 the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units:

mg/L milligrams per liter
μS/cm microsiemens per centimeter at 25 degrees Celsius

Acronyms

GIS = Geographical Information System
QWIP = Quality of Water Improvement Program
ROMP = Regional Observation and Monitor Well Program
SWFWMD = Southwest Florida Water Management District
USGS = U.S. Geological Survey
WUP = Water Use Permits

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By P. A. Metz *and* D. L. Brendle

Abstract

Thousands of deep artesian wells were drilled into the Upper Floridan aquifer in west-central Florida prior to well-drilling regulations adopted in the 1970's. The wells were usually completed with a short length of casing through the unconsolidated sediments and were left open to multiple aquifers containing water of varying quality. These open boreholes serve as a potential source of water-quality degradation within the aquifers when vertical internal borehole flow is induced by hydraulic-head differences. This potential for water-quality degradation exists in west-central Florida where both the intermediate aquifer system and Upper Floridan aquifer exist.

Measurements of caliper, temperature, gamma, fluid conductivity, and flow were obtained in 87 wells throughout west-central Florida to determine the occurrence of interaquifer borehole flow between the intermediate aquifer system and the Upper Floridan aquifer. Flow measurements were made using an impeller flowmeter, a heat-pulse flowmeter, and a video camera with an impeller flowmeter attachment. Of the 87 wells measured with the impeller flowmeter, 17 had internal flow which ranged from 10 to 300 gallons per minute. A heat-pulse flowmeter was used in 19 wells in which flow was not detected using the impeller flowmeter. Of these 19 wells, 18 had internal flow which ranged from 0.3 to 10 gallons per minute. Additionally, water-quality samples were collected from specific contributing zones in wells that had internal flow.

Analysis of geophysical and water-quality data indicates degradation of water quality has occurred from mineralized ground water flowing upward from the Upper Floridan aquifer into the intermediate aquifer system through both uncased boreholes and corroded black-iron well casings. In areas where there is a downward component of flow, data indicate that potable water from the intermediate aquifer system is artificially recharging the Upper Floridan aquifer through open boreholes.

A geographical area was defined where there is a potential for water-quality degradation due to improperly cased wells. This area was delineated based on where there is an upward component of ground-water flow and where there is an occurrence of poor-quality water. The delineated area includes parts of Hillsborough, Manatee, Sarasota, Charlotte, De Soto, and Hardee Counties.

To prevent further contamination of the aquifers, the Southwest Florida Water Management District began the Quality of Water Improvement Program in 1974 to restore hydrologic conditions altered by improperly constructed wells or deteriorating casings. As of May 1994, more than 3,000 wells have been inspected and approximately 1,350 have been plugged. To minimize interaquifer contamination, existing wells, especially ones with black-iron casing, should be inspected and, if necessary, repaired with new casing or plugged.

INTRODUCTION

Thousands of wells were drilled into the Upper Floridan aquifer in west-central Florida from 1900 to the early 1970's to obtain water for irrigation. Because potable water is also available in the intermediate aquifer system, most early irrigation wells that penetrated the more productive Upper Floridan aquifer were constructed so that they also were open to the intermediate aquifer system. The wells usually were completed with a short length of casing through unconsolidated sediments and were open to multiple aquifers with varying water quality. A confining unit exists between the two aquifers, but these open boreholes provide a conduit for ground water to move from zones of higher head to zones of lower head, thus shortcutting the slower route of leakage through the confining units.

Sutcliffe (1975) reported that, in Charlotte County, highly mineralized ground water had moved up the boreholes of many abandoned irrigation wells and had resulted in a deterioration of water quality in the shallow zones. Florida administrative code requires new wells to be constructed to prevent aquifer interconnection. However, a large number of existing multiple aquifer wells remains and the extent of aquifer degradation and exact area affected are unknown. In 1992, the U.S. Geological Survey (USGS), in cooperation with the Southwest Florida Water Management District (SWFWMD), began a study to determine if there was a potential for water-quality degradation due to improperly cased wells. The area of concern includes the southern half of the Southwest Florida Water Management District where both the intermediate aquifer system and Upper Floridan aquifer exist. This area includes all of De Soto, Hardee, Manatee, and Sarasota Counties and parts of Charlotte, Highlands, Hillsborough, and Polk Counties (fig. 1).

Purpose and Scope

This report describes the occurrence of interaquifer flow and defines a geographical area in west-central Florida where there is a potential for ground-water quality degradation as a result of internal borehole flow in wells that are open to multiple aquifers containing water of varying quality. The occurrence of interaquifer borehole flow and the extent of water-quality degradation between the intermediate aquifer system and the Upper Floridan aquifer were determined by collecting and analyzing geophysical logs, head difference maps, and water-quality data. The report presents a description of the hydrogeologic framework, aquifer head difference maps, well inventory data, composite geophysical logs of wells open to multiple water-bearing zones, maps of wells with interaquifer flow, a table of water-quality data, and maps of water quality. A data base of geophysical log information was established during this study to describe interaquifer flow characteristics.

Previous Investigations

The first study assessing the potential for water-quality degradation of interconnected aquifers in this area was done by Sutcliffe and Joyner (1966) who suggested that selective casing of wells or plugging could improve the quality of water produced from a well. Sutcliffe (1975) reported that nonpotable ground water had moved up the boreholes of many abandoned irrigation wells in Charlotte County. Boggess and others (1977) reported that saline water intrusion was related to well construction in Lee County. Wilson (1977) determined that the practice of drilling irrigation wells with many hundreds of feet of borehole open to multiple aquifers facilitated interaquifer flow in De Soto County. Healy (1978) documented many uncontrolled flowing artesian wells and concluded that the wells were the principal means for the deterioration of freshwater in the area because of upward leakage of saltwater into the shallow artesian aquifers. La Rose (1990) investigated the effects of a well-plugging program on the ground-water quality in Lee County and reported a slight decrease in chloride concentrations on a local scale. Hutchinson (1992) documented numerous improperly cased wells in Charlotte and Sarasota Counties that had upward internal borehole flow.

Acknowledgments

The authors are grateful to individual well owners and to public and private organizations for providing information on wells used for this study and for permitting the collection of water samples, geophysical logs, and hydrologic measurements. The authors would especially like to thank Albert Morris, Vincent Pelham, and Robert Parker of the Quality of Water Improvement Program at the Southwest Florida Water Management District in Venice, FL, for providing information and the location of many of the wells used in this study.

Description of Study Area

The study area includes the southern half of the Southwest Florida Water Management District where both the intermediate and Floridan aquifer systems exist. This area covers about 4,700 mi^2, and includes De Soto, Hardee, Manatee, and Sarasota Counties and parts of Charlotte, Highlands, Hillsborough, and Polk Counties (fig. 1).

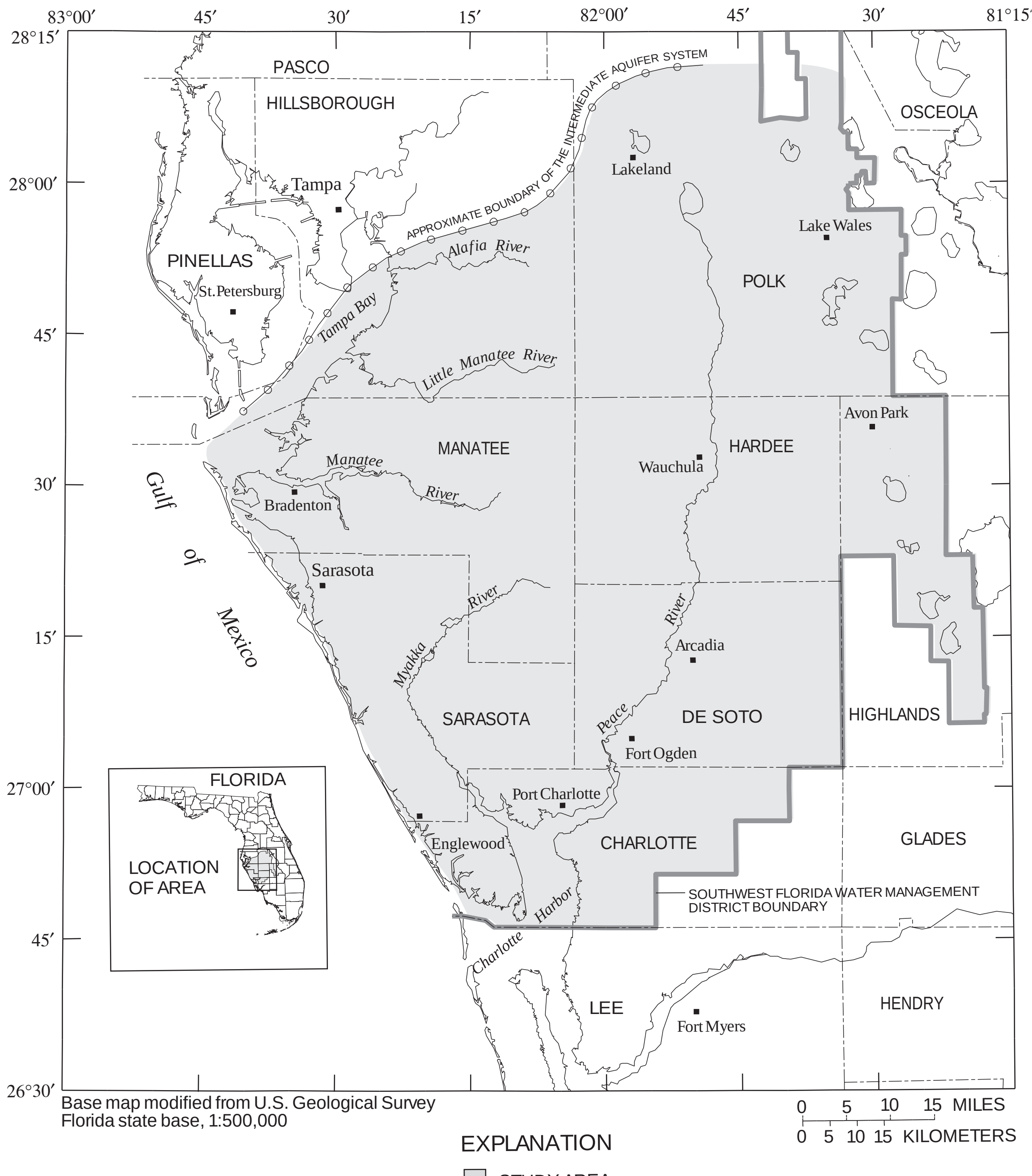


Figure 1. Location of study area.

The study area lies entirely in the mid-peninsular physiographic zone described by White (1970) and includes four subdivisions: the Polk Upland, the Lake Wales Ridge, the De Soto Plain, and the Gulf Coastal Lowlands. The subdivisions correspond approximately to several marine terraces or plains that were formed by marine regressions during the Pleistocene Epoch. The inland boundary of each subdivision is delineated by a low scarp or break in slope that represents the position of a former marine shoreline (Wilson, 1977). The Polk Upland is a broad sandy area that ranges in altitude from 100 to 245 ft above sea level. On the eastern side of the Polk Upland lies a part of the Lake Wales Ridge that ranges in altitude from 100 to 245 ft above sea level. This long, narrow ridge is a series of subparallel, eroded, sandy ridges with intervening valleys that contain numerous lakes. The De Soto Plain is a broad, gently sloping plain that ranges in altitude from 30 to 100 ft above sea level. The Gulf Coastal Lowlands, which encompasses a large part of the Peace River valley to the Gulf of Mexico, consists of poorly drained, low-lying land at altitudes of 30 to 40 ft above sea level in central and southwestern De Soto County to less than 5 ft above sea level along the coast (White, 1970).

The climate of the study area is subtropical humid and is characterized by warm, relatively wet summers and mild, relatively dry springs. Annual rainfall averages about 53 in. and varies seasonally with more that half the total rainfall occurring from June through September (Palmer and Bone, 1977).
In addition to seasonal variations, rainfall also tends to be distributed unevenly throughout the area at any given time, especially during the summer. This uneven distribution occurs because most summer rainfall in Florida is derived from localized, convective thunderstorms. Winter rainfall generally results from cold, frontal-type air masses that move from north to south and occurs over wide areas.

HYDROGEOLOGIC FRAMEWORK

The hydrogeologic units underlying the study area consist of deposits of sand, clay, marl, and carbonate rocks that were primarily deposited in a marine environment. Principal hydrogeologic units consist of the surficial aquifer, the intermediate aquifer system, and the Floridan aquifer system (Southeastern Geological Society, 1986). These hydrogeologic units, their equivalent stratigraphic units, and brief lithologic descriptions are presented in figure 2.

Surficial Aquifer

The surficial aquifer is contiguous with land surface and overlies the intermediate aquifer system. This aquifer is composed principally of unconsolidated to poorly indurated clastic deposits (Southeastern Geological Society, 1986). The surficial aquifer consists of predominately fine sand, interbedded clay, marl, shell, and phosphorite (fig. 2). The water-bearing properties of the surficial aquifer are largely dependent upon aquifer thickness and grain-size distribution of sediments within the aquifer (Wilson, 1977). Thickness of the surficial deposits ranges from about 350 ft in Highlands County to about 25 ft near the coast and in low-lying areas (Wolansky and others, 1979; SWFWMD, 1994). Transmissivity values for the surficial aquifer in the study area range from 600 to 8,000 ft^2/d (Wolansky and Corral, 1985). Because of low yield to wells and the potential for degradation, the surficial aquifer has limited use in most of the study area and generally is used for lawn and garden irrigation and for livestock watering.

Intermediate Aquifer System

The intermediate aquifer system includes all water-bearing units (aquifers) and confining units between the overlying surficial aquifer and the underlying Upper Floridan aquifer (Duerr and others, 1988). The intermediate aquifer system consists of the undifferentiated deposits of Pleistocene and Pliocene age and the Hawthorn Group of Miocene age (fig. 2).

The intermediate aquifer system consists of three or more hydrogeologic units (fig. 2): (1) a clayey and pebbly sand, clay, and marl upper confining unit that separates the water-bearing unit in the intermediate aquifer system from the surficial aquifer; (2) one to three water-bearing units composed primarily of carbonate rocks, sand, and discontinuous beds of sand and clay; and (3) a sandy clay and clayey sand lower confining unit that lies directly over the Upper Floridan aquifer (Ryder, 1985). The diversity in lithology of the intermediate aquifer system reflects the variety of depositional environments that occurred during the Miocene Epoch. These environments of deposition included open-marine, shallow-water, coastal-marine, fluvial, and estuarine (Gilboy, 1985).

The intermediate aquifer system underlies all of the study area and is hydraulically separated from the overlying surficial aquifer by the upper confining unit.

System	Series	Stratigraphic unit	General lithology	Major lithologic unit	Hydrogeologic unit	
Quarternary	Holocene and Pleistocene	Surficial sand, terrace sand, phosphorite	Predominantly fine sand; interbedded clay, marl, shell, and phosphorite.	Sand	Surficial aquifer	
Quarternary / Tertiary	Holocene and Pleistocene / Pliocene	Undifferentiated deposits[1] Tamiami Formation	Clayey and pebbly sand; clay, marl, shell, phosphatic.	Clastic / Carbonate and Clastic	upper confining unit	Intermediate Aquifer System
Tertiary	Miocene	Hawthorn Group: Peace River Formation; Arcadia Formation	Dolomite, sand, clay, and limestone, silty, phosphatic.	Carbonate and Clastic	aquifer	Intermediate Aquifer System
Tertiary	Miocene	Hawthorn Group: Arcadia Formation; Tampa member; Nocatee member	Limestone, sandy, phosphatic, fossiliferous; sand and clay in lower part in some areas.	Carbonate and Clastic	lower confining unit	Intermediate Aquifer System
Tertiary	Oligocene	Suwannee Limestone	Limestone, sandy limestone, fossiliferous.	Carbonate	Upper Floridan aquifer	Floridan Aquifer System
Tertiary	Eocene	Ocala Limestone	Limestone, chalky, foraminiferal, dolomitic, near bottom.	Carbonate	Upper Floridan aquifer	Floridan Aquifer System
Tertiary	Eocene	Avon Park Formation	Limestone and hard brown dolomite; intergranular evaporite in lower part in some areas.	Carbonate / Carbonate with evaporites	Upper Floridan aquifer / Middle Confining Unit	Floridan Aquifer System
Tertiary	Eocene / Paleocene	Oldsmar and Cedar Keys Formations	Dolomite and limestone with intergranular gypsum and anhydrite.	Carbonate with evaporites / Evaporites	Lower Floridan aquifer / Sub-Floridan Confining Unit	Floridan Aquifer System

[1]Includes all or parts of Caloosahatchee Marl and Bone Valley Member.

Figure 2. Hydrogeologic framework.

The upper confining unit has a low vertical hydraulic conductivity and, consequently, retards interaquifer flow. However, for most of the study area, the upper confining unit transmits, or leaks, water downward from the surficial aquifer into the intermediate aquifer system, and the system is referred to as a leaky-aquifer system (Wilson, 1977). Water is also transmitted upward through the upper confining unit into the surficial aquifer and the Peace River in areas where upward head gradients exist.

The water-bearing units of the intermediate aquifer system consist of limestone and dolomite. Clay beds of wide lateral extent and variable thickness may occur interbedded within these water-bearing units (Duerr and Enos, 1991). Transmissivities of the water-bearing units of the intermediate aquifer system, reported from aquifer tests, range from less than 100 to 13,000 ft^2 /d (Ryder, 1982). The wide range of transmissivity values for the intermediate aquifer system indicates formational heterogeneity that is substantiated by geophysical logs (Hutchinson, 1978). The area of highest transmissivity coincides with areas adjacent to the Peace River. This high transmissivity indicates a more active flow system exists where ground water moves upward into the river and enhances development of secondary porosity in the carbonate rock (Ryder, 1985). Thickness of the intermediate aquifer system ranges from less than 100 ft in central Hillsborough and northern Polk Counties to more than 800 ft in southern Charlotte County (Duerr and others, 1988).

A lower confining unit lies at the base of the intermediate aquifer system and to some extent hydraulically separates the intermediate aquifer system from the Upper Floridan aquifer. The lower confining unit has a low vertical hydraulic conductivity and consequently retards interaquifer flow. However, for most of the study area, the lower confining unit transmits, or leaks, water downward from the intermediate aquifer system into the Upper Floridan aquifer, and the system is referred to as a leaky-aquifer system (Wilson, 1977). Water is also transmitted upward from the Upper Floridan aquifer through the lower confining unit to the intermediate aquifer system where upward head gradients exist.

The intermediate aquifer system is used extensively as a source of water for irrigation and public and domestic supply. Wells open to the intermediate aquifer system generally yield less than 300 gal/min (Wilson, 1977). The yield to wells and total withdrawals of water from the intermediate aquifer system are greater than those of the surficial aquifer, but are much less than those of the deeper Upper Floridan aquifer.

Floridan Aquifer System

The Floridan aquifer system, as defined by Miller (1986, p. 44), is a vertically continuous sequence of carbonate rocks of generally high permeability that are mostly of Tertiary age. The rocks are hydraulically connected in varying degrees, and their permeability generally is an order to several orders of magnitude greater than that of the rocks bounding the system above and below. In the study area, the Floridan aquifer system consists of two aquifers: the Upper Floridan aquifer which contains freshwater and the Lower Floridan aquifer which contains highly mineralized water. The Upper and Lower Floridan aquifers are separated by the middle confining unit (Miller, 1986). The Upper Floridan aquifer commonly consists of a few highly permeable zones separated by less permeable zones (Johnston and Bush, 1988).

The top of the Upper Floridan aquifer is the horizon below which carbonate rocks persistently occur. The middle confining unit, which is the base of the Upper Floridan aquifer, is characterized by limestone and dolomite that have reduced permeability as a result of vertically persistent, intergranular evaporites (Southeastern Geological Society, 1986). The rocks below the middle confining unit have known or estimated low transmissivity; therefore, freshwater flow is limited to rocks above the section with intergranular evaporites (Ryder, 1985). This report is limited to ground-water flow in the freshwater part of the Floridan aquifer system, or the Upper Floridan aquifer.

The Upper Floridan aquifer consists of the Suwannee Limestone, the Ocala Limestone, and the Avon Park Formation of the Oligocene and Eocene series (fig. 2). Thickness of the Upper Floridan aquifer ranges from approximately 1,000 ft in northern Polk County to 1,200 ft in Charlotte and De Soto Counties. The Upper Floridan aquifer consists of limestone and dolomite that have solution-enlarged fractures. These fractures commonly yield abundant supplies of water to wells. The most productive part of the aquifer generally corresponds to dolomite sequences within the Avon Park Formation. Transmissivity of the Upper Floridan aquifer ranges from about 30,000 ft^2/d at the Gulf Coast to about 850,000 ft^2/d in northeastern De Soto County (Ryder, 1985).

The Upper Floridan aquifer is the most productive and widely used aquifer in the study area and supplies more than 10 times the amount of water pumped from either the surficial aquifer or the intermediate aquifer system. Thousands of wells have been drilled into this highly productive aquifer, and it is estimated that about 10 percent of these wells are open solely to the Upper Floridan aquifer. In the study area, most wells completed in the Upper Floridan aquifer are also open to the intermediate aquifer system (Metz, 1995).

The Upper Floridan aquifer is used extensively as a source of water for industrial, irrigation, public, and domestic supply and wells can yield as much as 5,000 gal/min (SWFWMD, 1994). However, the significance of the Upper Floridan aquifer as a source of potable water diminishes as the water quality degrades in the southern and western parts of the study area. In these areas, the importance of the intermediate aquifer system as a source of water increases (Duerr and others, 1988). The term poor-quality water is used in this report to indicate water having concentrations of chloride, sulfate, and dissolved solids that exceed 250, 250, and 1,000 mg/L, respectively.

FACTORS INFLUENCING VERTICAL BOREHOLE FLOW

Vertical flow in an open borehole of a well is influenced by well construction, the relative permeabilities of the aquifers, and the head differences between aquifers open to the borehole (Keys and MacCary, 1971). When a well is drilled into an aquifer, the open borehole serves as a local conduit in the aquifer matrix. Open boreholes may not affect regional flow, but the borehole represents a substantial local heterogeneity in the immediate flow field (Paillet and others, 1994).

Improperly constructed and corroded wells may serve as a source of water-quality contamination within the aquifers. A schematic diagram of a properly constructed well that is open to a single aquifer and a corroded well and an improperly constructed well that are open to multiple aquifers is presented in figure 3. Where heads in the Upper Floridian aquifer are higher than heads in the intermediate aquifer system, highly mineralized water may flow upward from the Upper Floridan aquifer into the intermediate aquifer system. Where heads in the intermediate aquifer system are higher than heads in the Upper Floridan aquifer, downward flow may occur through the open borehole resulting in a loss of potable water to the aquifer below.

The length of the casing in relation to the total depth of the well is important in controlling the quantity of water flowing internally. The well casing prevents the borehole from collapsing in unstable lithologies and limits aquifer connectivity, thus preventing interaquifer flow. Because potable water usually is available in the intermediate aquifer system, most wells that penetrate the more productive Upper Floridan aquifer are constructed so that they also are open to the intermediate aquifer system. Sproul and others (1972, p.10) reported that the internal flow within uncased parts of wells open to multiple aquifers ranges from about 30 to nearly 100 gal/min in the McGregor Isles area in Lee County.

The head gradient between the aquifers significantly controls the potential for vertical borehole flow in wells open to multiple aquifers. Head difference information used in this study was obtained from potentiometric-surface maps of the intermediate aquifer system and Upper Floridan aquifer. The potentiometric surfaces of the intermediate aquifer system and Upper Floridan aquifer in west-central Florida are mapped semiannually by the USGS, in cooperation with the SWFWMD, during periods when water levels are at their highest (September) and lowest (May). These maps show potentiometric contours based on synoptic measurements of water levels in hundreds of wells open to either the intermediate aquifer system or the Upper Floridan aquifer. The ARC/INFO GIS system was used as an aid in the construction of the head difference maps. GIS coverages were generated from digitized potentiometric-surface contour lines. These coverages were intersected with a 1-mi by 1-mi grid and head values were assigned to each cell by interpolation methods. Head difference maps were generated by subtracting the interpolated head values in the Upper Floridan aquifer from those in the intermediate aquifer system. Contours lines were drawn based on equal head difference values.

The head differences between the intermediate aquifer system and the Upper Floridan aquifer in September 1993 (Mularoni, 1994 a,b; fig 4) represent conditions at the end of the summer rainy season at a time when the aquifers generally are unstressed by irrigation pumpage. In September 1993, heads in the intermediate aquifer system were as much as 70 ft higher than heads in the Upper Floridan aquifer near the corner of Hillsborough, Manatee, Polk, and Hardee Counties. Water is transmitted downward through the confining unit and recharges the Upper Floridan

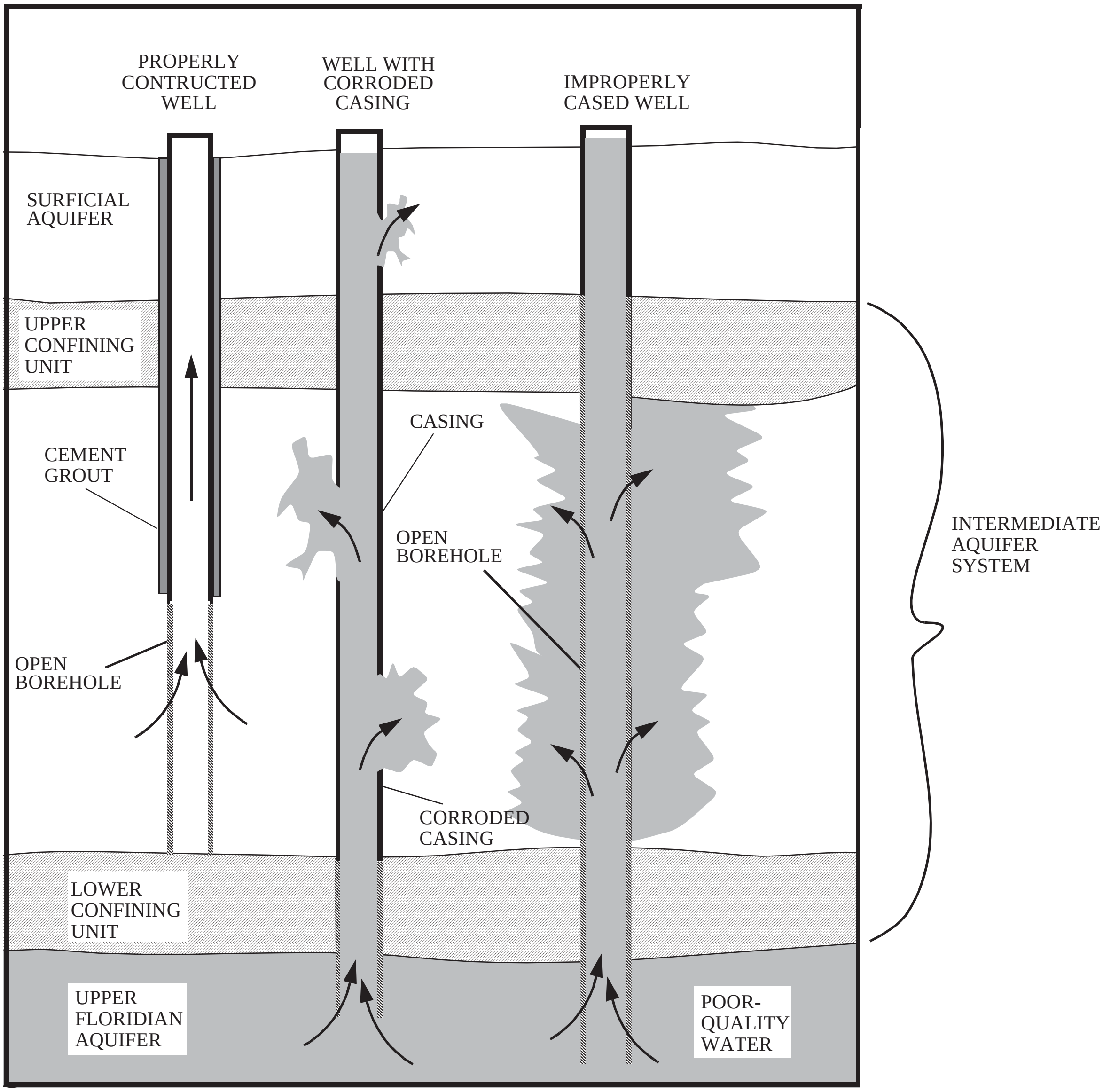


Figure 3. A properly constructed well open to a single aquifer, and a corroded well and an improperly constructed well that can allow water quality contamination between multiple aquifers.

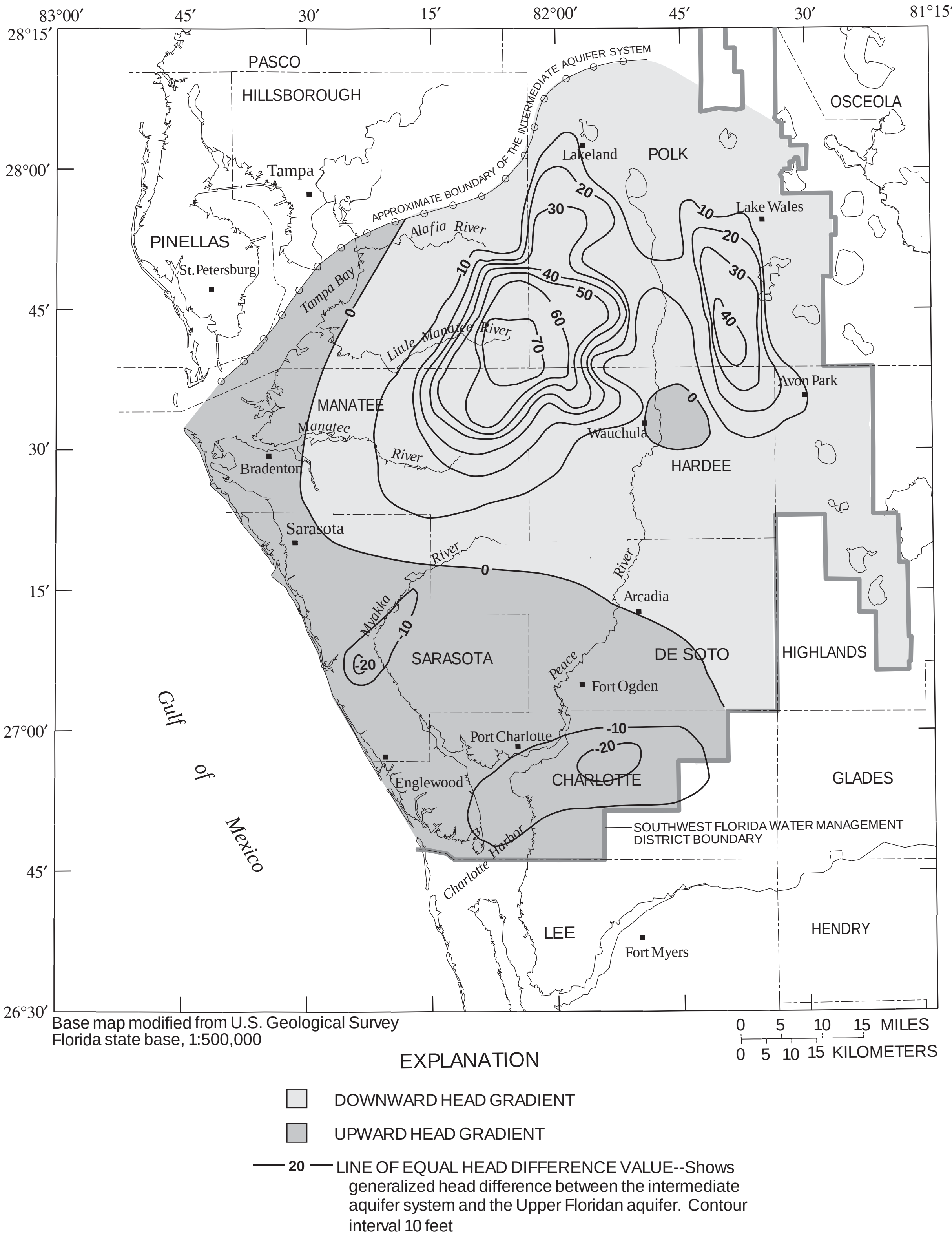


Figure 4. Generalized head difference between the intermediate aquifer system and the Upper Floridan aquifer, September 1993 (from Mularoni, 1994a,b).

aquifer. The head gradient reverses in the southern part of the study area where the Upper Floridan aquifer has higher heads than those of the intermediate aquifer system by as much as 20 ft in western Sarasota County and central Charlotte County. In these areas, water is transmitted upward through the lower confining unit and discharges to the intermediate aquifer system.

The head differences between the intermediate aquifer system and the Upper Floridan aquifer in May 1994 (Metz and Brendle, 1994 a,b; fig. 5) represent conditions near the end of a dry season during which extensive irrigation pumpage has occurred. In May 1994, heads in the intermediate aquifer system were as much as 90 ft higher than heads in the Upper Floridan aquifer near the corner of Hillsborough, Manatee, Polk, and Hardee Counties. These greater head differences are due to large seasonal ground-water withdrawals for irrigation from the Upper Floridan aquifer. In the southern part of the study area, heads were higher in the Upper Floridan aquifer than the intermediate aquifer system by as much as 20 ft.

METHODOLOGY AND INSTRUMENTATION

A well inventory was conducted to locate wells that had a short length of casing; were open to both the intermediate aquifer system and the Upper Floridan aquifer; and were accessible for the collection of borehole geophysical data. Several hundred wells were inventoried to locate wells that met the necessary casing, depth, and accessibility criteria.

The determination of interaquifer flow was accomplished by obtaining geophysical logs of caliper, gamma, temperature, flow, and fluid conductivity, and by the collection of water-quality samples and video borehole data. This information provided an understanding of the well construction, contacts between hydrogeologic units, zones of inflow and outflow, rates of interaquifer flow, chemical properties of water in the borehole, and locations of fractures and cavities.

Three different flowmeters were used to determine interaquifer flow because of the sensitivity and limitations of each meter. The three meters were: an impeller flowmeter, a borehole video camera with an impeller flowmeter attachment, and a heat-pulse flowmeter.

In the initial survey of each well, flow measurements were made using an impeller flowmeter. The impeller flowmeter consists of a helical turbine, or rotor, that is mounted on a vertical axis in a metal cylinder (fig. 6). Measurements were made in a fixed position at selected depth intervals in the open borehole and were repeated at these intervals to verify readings when internal flow was detected. To obtain flowmeter measurements under static conditions in artesian flowing wells, the flow was shut off using a standpipe or a well capping device.

To calibrate the impeller flowmeter, the instrument was raised and then lowered at a controlled speed in the cased part of a well with no internal flow. Flowmeter responses were plotted against logging speeds to obtain a velocity calibration curve. This calibration method was performed in 4-, 5-, 6-, 8-, 10-, and 12-in. diameter wells. Internal flow volume was calculated using the relation of cross-sectional area and measured borehole velocity. To account for irregular borehole diameters as indicated by caliper logs, all reported internal flow values were obtained from calibrated diameters.

The advantage of utilizing the impeller flowmeter is that high velocities can be recorded with this instrument. The limitations of the impeller flowmeter are that the direction of flow (either upward or downward) can not be distinguished accurately, and that the lower detection limit of the meter is about 5 ft/min. Additional geophysical-logging information on instrumentation, calibration, and standardization, is documented by Keys (1990).

In areas where upward and downward flow could not be distinguished, the impeller flowmeter was connected to a video camera. This design enabled the viewer to observe the direction of rotation of the impeller assembly hanging approximately 20 in. below the borehole video camera. The impeller blade turning clockwise indicated downward flow and counterclockwise indicated upward flow. A view of a borehole with the impeller flowmeter attachment is shown in figure 7. The advantages of this design are that the viewer can: (1) observe a continuous profile of the well borehole and the direction of flow; (2) locate fractures or cavities that may be associated with ground water flow to wells; and (3) inspect the casing for holes or breaks. The lower detection limit of this instrument is also 5 ft/min.

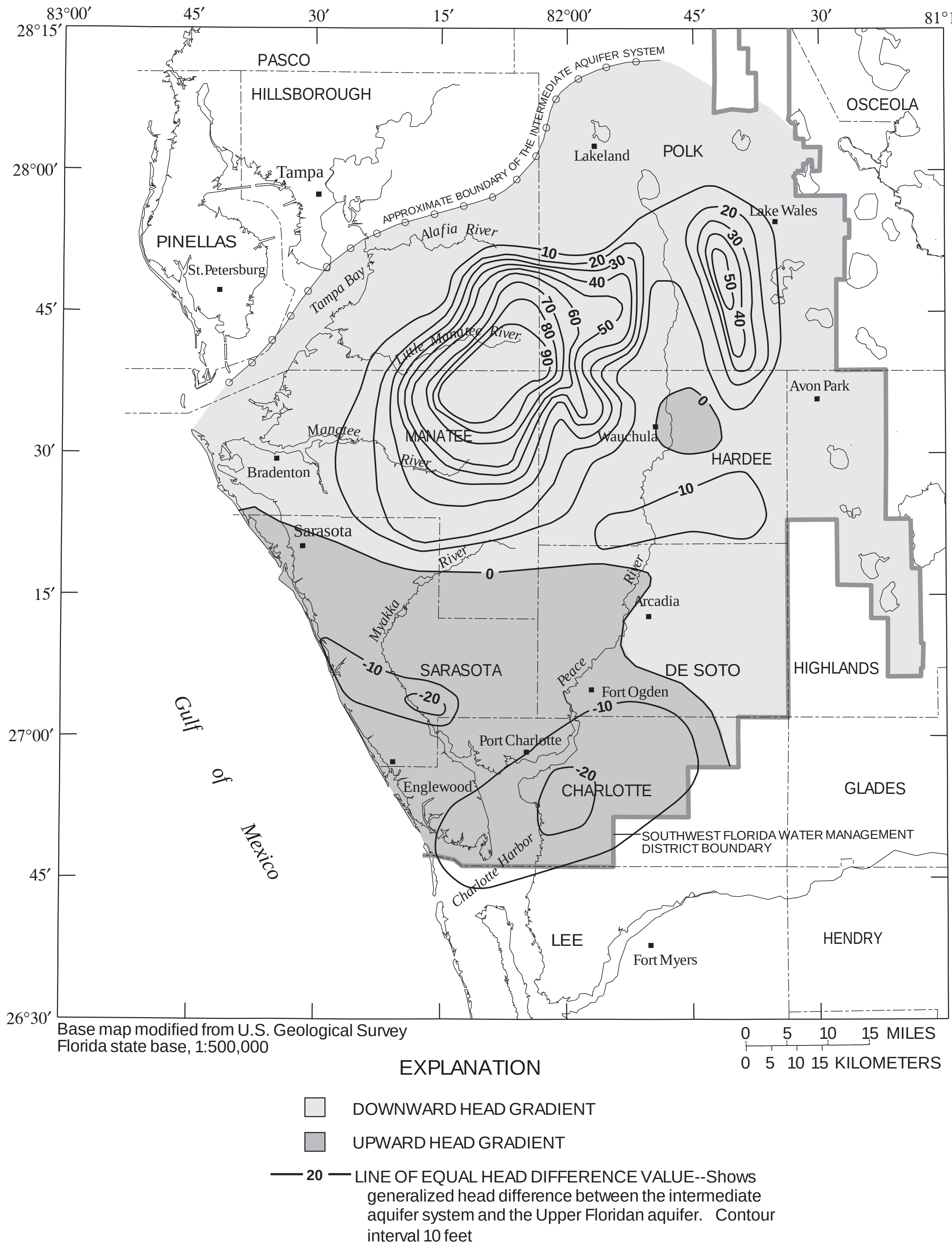


Figure 5. Generalized head difference between the intermediate aquifer system and the Upper Floridan aquifer, May 1994 (from Metz and Brendle 1994 a,b).

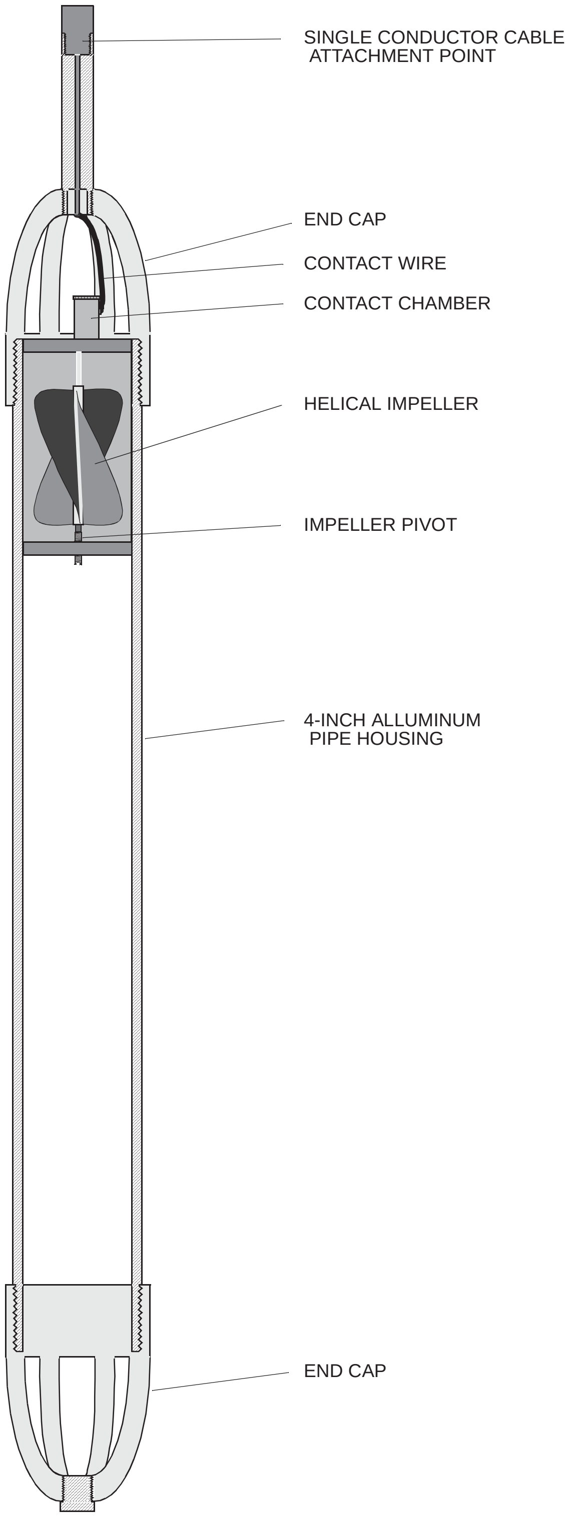


Figure 6. The components of the impeller flowmeter.

To determine flow below the detection limit of the impeller flowmeter, the USGS heat-pulse flowmeter developed by Hess (1990) was used. Measurable fluid velocities for the heat-pulse flowmeter range from about 0.1 to 20 ft/min. Rate and direction of vertical flow, was determined with this flowmeter. Resolution of flow direction was accomplished by using two temperature sensors, one above and one below a heater grid (fig. 8). When the heater grid received an electronic pulse, a parcel of water was heated. If there was internal flow in the borehole, either the lower or upper temperature sensor detected the heated water. Flow concentrating divertors were utilized to direct fluid flowing in the borehole through the flow sensor tube. The limitation of this meter is that it can not measure fluid velocity above 20 ft/min.

Water samples were collected from the borehole to delineate differences in ground-water quality from specific contributing zones in wells that had internal flow. A thief sampler connected to the geophysical logger was used to collect the discrete samples from the specific contributing zones. Water quality constituents analyzed from these samples included chloride, sulfate, and dissolved solids.

RESULTS AND INTREPRETATION OF GEOPHYSICAL WELL DATA

Borehole geophysical surveys were conducted in 87 wells to assess the rate and direction of interaquifer borehole flow in wells open to multiple permeable zones. Well records with geophysical logs that were obtained in each well are listed in table 1. Location of wells with corresponding index number from table 1 are shown in figure 9. The measured wells consisted of irrigation, municipal, recreational, industrial, and temporary observation wells with depths and casing lengths ranging from 335 to 1,679 ft and 16 to 454 ft, respectively. The following sections of this report describe composite geophysical logs of temperature, gamma ray, caliper, fluid conductivity, and flow of selected wells that characterize the nature of interaquifer borehole flow.

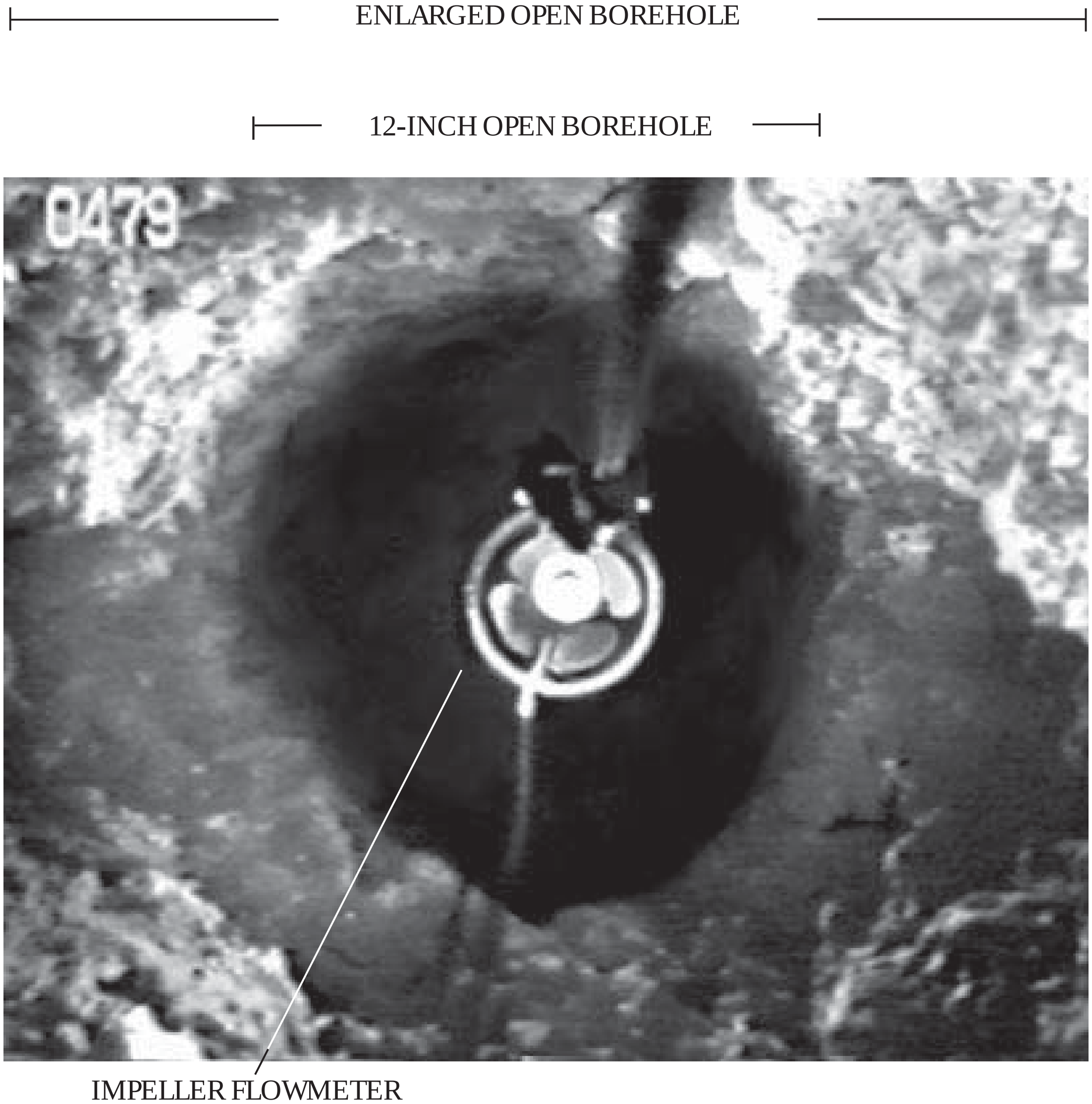


Figure 7. A borehole video camera with the impeller flowmeter attachment in a 12-inch open borehole at a depth of 479 feet below land surface.

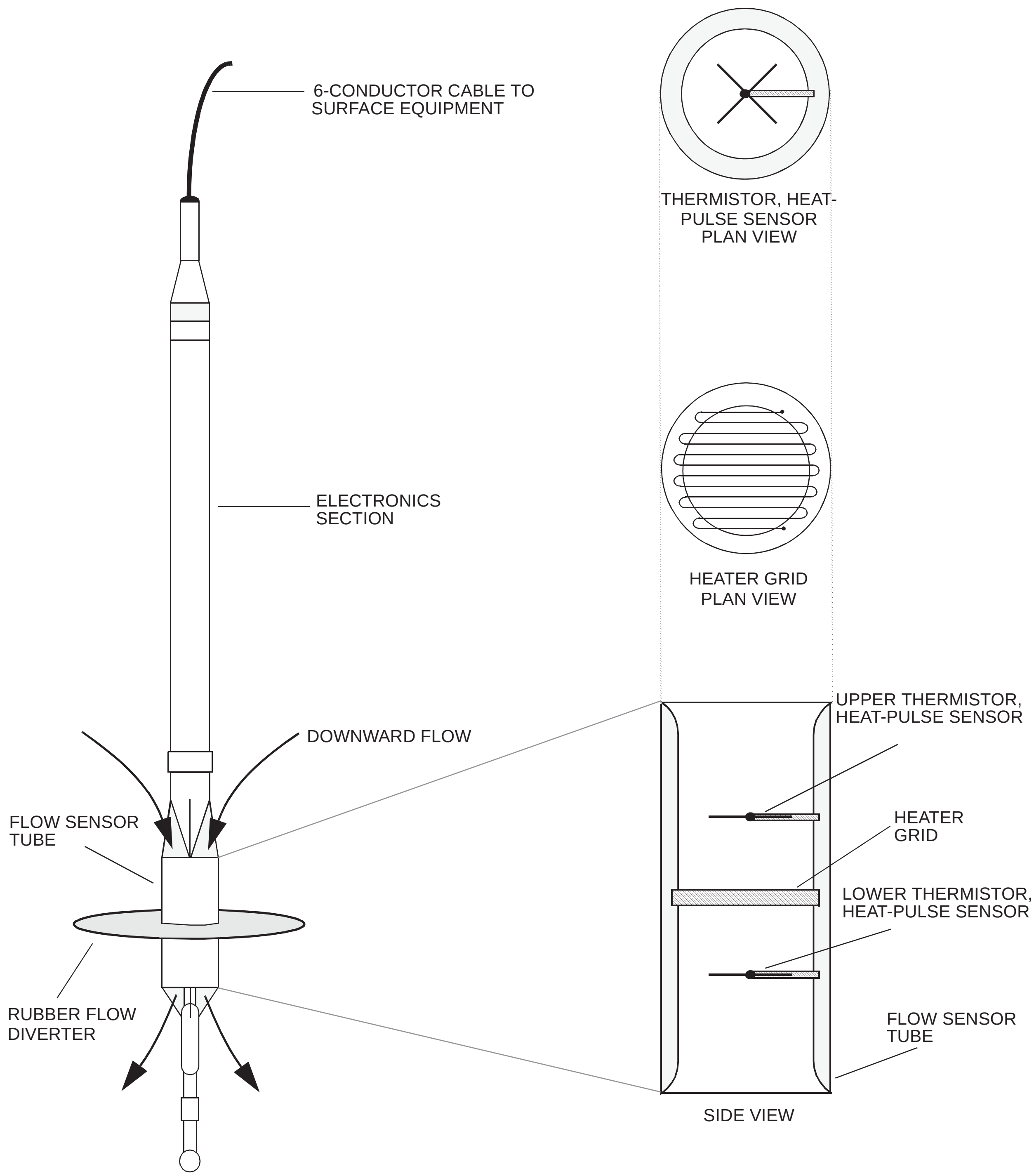


Figure 8. The components of the heat-pulse flowmeter (modified from Hess, 1990).

Table 1. Selected data for measured wells

[Data type: C, caliper; G, gamma; K, fluid-conductivity; T, temperature; E, electric; FS, impeller flowmeter survey; V, video; VFS, video flowmeter survey] Di, diameter of well in inches

Index no.	Site name	Latitude-longitude	Depth (feet) below land surface	Casing (feet)	Di	Date of measurement	Date type	Impeller flow rate, gallons per minute
1	ROMP TR3-3 Ocala	265531 821948	1,066	120	8	02-25-86	FS	45
2	Venetia (Berry 9)	270153 822126	620	224	6	06-27-87	FS	11
3	Venetia (Berry 4)	270203 822137	608	207	6	06-27-87	FS	10
4	Sorrenta Shores	270932 822835	669	308	6	06-27-87	FS	30
5	4-Star Tomato Packing	273121 823217	543	200	4	04-07-92	C, G, T, FS	0
6	Dave Lewis	273214 822896	570	16	8	04-07-92	C, G, T, E, FS	0
7	Bobby Jones No. 3	272039 822918	574	38	10	04-09-92	C, G, K, FS, V	0
8	Oscar Scherer State Park	271032 822745	728	294	8	04-10-92	C, G, K, T, FS,	0
9	ROMP 20	271138 822846	843	73	12	04-14-92	C, G, K, T, E, FS	110
10	Norris Brothers	270535 815745	534	74	6	04-17-92	C, G, T, FS	31
11	Verna P2	272248 821903	604	140	10	04-30-92	C, K, K, T, FS,	58
12	Griffin Deep near Parrish	273536 822603	576	43	8	05-01-92	C, G, K, T, E, FS	0
13	City of Sarasota: Boat Ramp	272052 823254	603	196	6	05-06-92	C, G, K, T, E, FS	0
14	Tropical River Groves: 14	271416 813746	1,492	193	12	05-07-92	C, G, K, FS	0
15	Marshall Deep	272010 814825	437	134	5	06-05-92	C, G, K, T, E, FS	0
16	Pioneer Park	273006 814800	611	315	8	06-08-92	C, G, T, E, FS	0
17	Florida Power and Light	273718 823155	930	104	12	06-10-92	C, G, K, T, E, FS	0
18	ROMP 57	275411 813720	581	160	6	06-11-92	C, G, T, E, FS	0
19	Smith	273103 813637	849	66	5	06-18-92	C, G, K, T, E, FS	0
20	ROMP 123	274031 821504	620	117	8	07-29-92	C, G, K, T, FS	0
21	Walker Farms	271931 822608	668	238	6	08-03-92	C, T, E, FS	0
22	City of Sarasota, Hickory St.	272129 823302	599	46	6	08-04-92	C, K, T, FS, V	300
23	City of Sarasota, 21st St.	272120 823227	548	327	4	08-06-92	C, G, K, T, E, FS	0
24	Busby Deep	273605 820711	996	153	12	08-13-92	C, G, K, T, E, FS, VFS	0
25	Stephens Deep	272442 820152	730	146	10	08-21-92	C, G, T, FS	0
26	Rusty Pot No. 2	271646 821122	1,017	148	10	08-26-92	C, G, T, FS	0
27	Rushing	270633 822204	371	33	6	08-31-92	C, T, FS	0
28	Rusty Pot No. 1	271713 821230	409	83	8	09-03-92	C, FS	0

Table 1. Selected data for measured wells --Continued

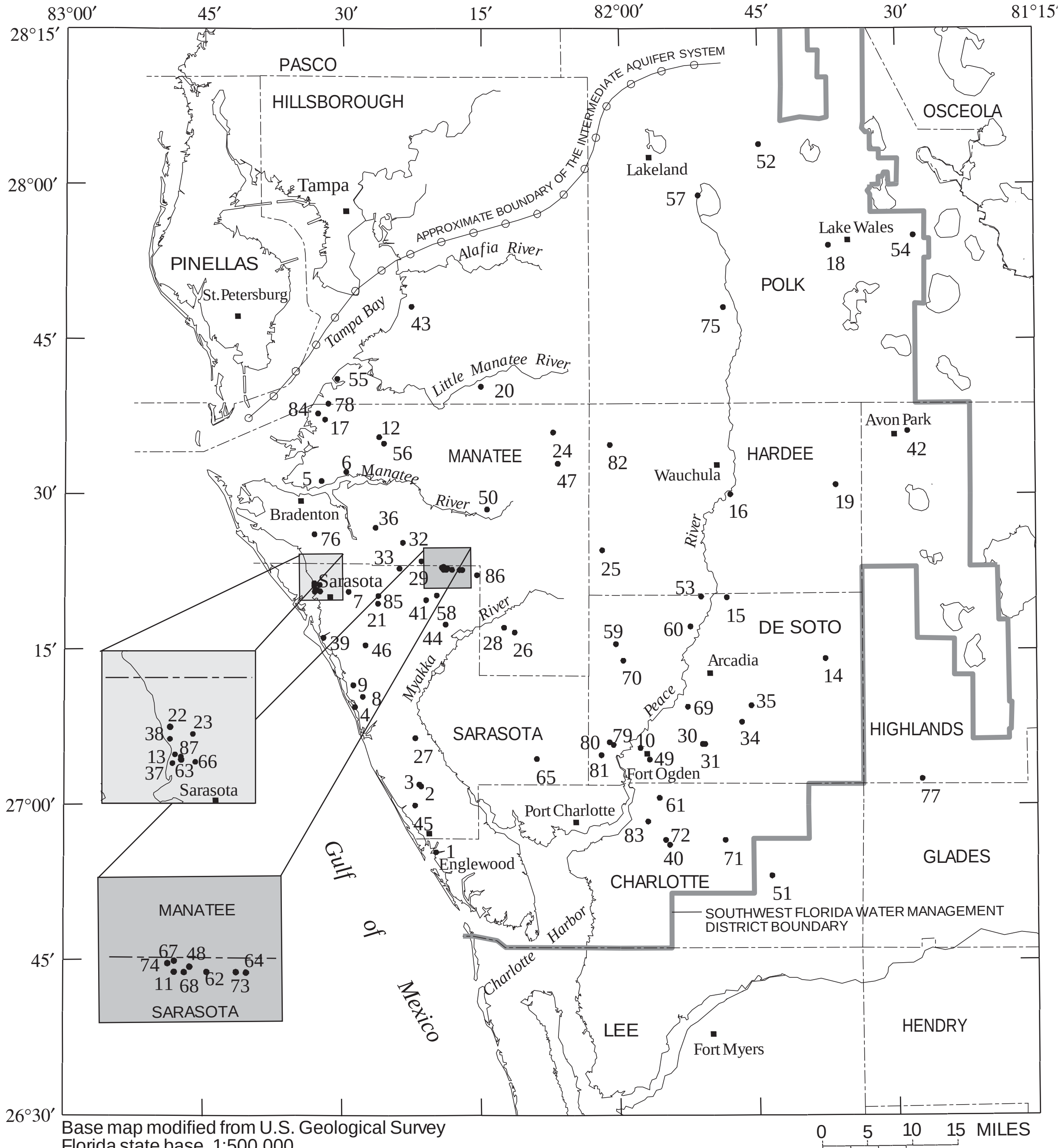
[Data type: C, caliper; G, gamma; K, fluid-conductivity; T, temperature; E, electric; FS, impeller flowmeter survey; V, video; VFS, video flowmeter survey] Di, diameter of well in inches

Index no.	Site name	Latitude-longitude	Depth (feet) below land surface	Cas-ing (feet)	Di	Date of measure-ment	Date type	Impeller flow rate, gallons per minute
29	Schroeder Manatee Ranch No. 44	272338 822127	562	118	12	09-03-92	C, G, K, T, FS	0
30	Kitchen Fish Farm No. 2	270559 815046	570	87	8	09-08-92	C, G, T, FS	0
31	Kitchen Fish Farm No. 1	270559 815101	591	88	8	09-08-92	C, FS	0
32	Schroeder Manatee Ranch No. 26	272525 822328	1,225	82	12	09-09-92	C, G, T, FS	0
33	Schroeder Manatee Ranch No. 38	272255 822349	1,276	454	8	09-10-92	C, G, T, FS	0
34	2X4 Ranch No. 1	270808 814647	545	158	10	09-21-92	C, FS	0
35	2X4 Ranch No. 3	270943 814546	1,679	126	12	09-21-92	C, G, T, FS	0
36	Schroeder Manatee Ranch No. 8	272651 822625	703	64	8	09-22-92	C, G, K, T, FS	0
37	Big Hog	272040 823258	555	90	12	09-30-92	C, G, K, T, FS	0
38	City of Sarasota: Alameda No. 2	272113 823302	537	306	8	10-05-92	C, G, K, T, FS	0
39	Phillipi Estates Park	271613 823201	611	243	5	10-16-92	C, G, K, FS	0
40	Florida State Fish pond No. 2	265615 815435	622	136	10	10-15-92	C, G, K, T, E, FS	0
41	Utopia No. 1	271952 822056	1,260	45	12	10-23-92	C, G, K, T, FS,	180
42	ROMP 43X	273615 812849	1,005	398	8	10-29-92	C, G, K, T, VFS	0
43	Powell Deep	274813 822236	335	26	6	11-18-87	C, G, K, T, E, FS	0
44	Hi Hat No. 12	271731 821849	494	117	12	11-16-92	C, G, T, FS	0
45	Jaceranda Blvd.	270002 822205	494	64	6	11-18-92	C, T, FS	0
46	Sunrise Golf Course	271530 822728	453	127	8	04-25-84	C, G, K, T, E, FS, VFS	0
47	Manatee County Duette	273303 820641	1,184	184	12	12-02-92	C, G, K, T, FS	140
48	Verna Production No. 8	272256 821837	611	140	10	12-04-92	C, K, T, FS	0
49	Trey's	270429 815644	498	78	6	12-08-92	C, G, K, T, FS	0
50	Kibler Deep	272838 821422	1,129	208	8	12-09-92	C, G, K, T, FS	0
51	Babcock	265316 814334	917	114	4	12-17-92	C, G, K, T, FS	58
52	City of Winter Haven	280356 814454	1,000	87	12	12-17-92	VFS	0
53	E&D Cattleranch	272014 815071	1,110	104	12	12-21-92	C, G, K, T, VFS	0
54	Machata	275510 812768	832	199	12	12-22-92	C, G, T, K, FS	0
55	ELAP	274114 823037	475	29	8	12-23-92	C, G, T, K, FS	0
56	Parrish Grove	273459 822532	583	102	6	12-28-92	C, G, T, K, FS, VFS	0
57	Cargill Phosphate	275859 815129	954	204	20	12-29-92	C, G, T, VFS	0
58	Verna T 0-4	272020 821948	500	140	6	02-09-93	C, G, T, K, FS	0

Table 1. Selected data for measured wells --Continued

[Data type: C, caliper; G, gamma; K, fluid-conductivity; T, temperature; E, electric; FS, impeller flowmeter survey; V, video; VFS, video flowmeter survey] Di, diameter of well in inches

Index no.	Site name	Latitude-longitude	Depth (feet) below land surface	Cas-ing (feet)	Di	Date of measure-ment	Date type	Impeller flow rate, gallons per minute
59	Amax Deep No. 3	271538 820023	1,547	340	8	02-18-93	C, G, T, FS	0
60	Mc Cormmick Grove	271721 815220	1,004	420	12	03-03-93	C, G, T, FS	0
61	Hudson Farms	270046 815541	1,256	368	12	03-26-93	C, G, T, K, FS	0
62	Verna P-11	272248 821808	550	141	8	04-12-93	C, G, T, K, FS	0
63	City of Sarasota 11th and Oregon	272049 823244	479	43	6	04-14-88	C, G, T, K, FS	0
64	Verna Production No. 23	272247 821702	492	192	10	04-19-93	C, T, K, E, FS	0
65	ROMP 9	270432 820857	760	117	6	04-27-93	C, G, T, K, FS	50
66	City of Sarasota Corehole No.1	272042 823223	1,102	355	4	05-21-93	C, G, T, K, E, FS, V	43
67	Verna Production No. 1	272305 821903	592	136	10	05-26-93	C, G, T, K, FS	0
68	Verna Production No. 5	272248 821846	589	142	10	05-26-93	C, G, T, K, FS	0
69	Brewer	270936 815237	532	74	8	06-17-93	C, G, T, K, FS	0
70	V.C. Hollingsworth	271339 815920	603	63	8	06-29-93	C, G, T, K, FS	0
71	ROMP 5 (temporary well)	265643 814835	1,000	124	6	12-02-93	C, G, T, K, FS	60
72	Ansin	265643 815500	766	108	4	02-14-94	C, G, T, K, FS	16
73	Verna P-20	272248 821719	520	142	10	02-15-94	C, G, T, K, FS	0
74	Verna KME-02	272301 821914	833	350	16	02-15-94	C, G, T, K, FS	0
75	DEP No. 8	274812 814846	610	121	6	02-25-94	C, G, T, FS	0
76	ROMP 7-2	272612 823301	706	336	12	03-18-94	C, G, T, K, FS	0
77	Fisheating Creek Dairy	270237 812721	1,602	230	16	05-02-94	C, T, FS	0
78	Reeder	273850 823135	600	206	8	05-05-94	C, G, T, FS	0
79	General Development No. 8	270554 820038	1,137	269	15	06-01-94	C, G, T, K, FS	0
80	General Development No. 10	270609 820104	1,070	62	8	06-01-94	C, G, T, K, FS	0
81	Boggess No. 19	270454 820157	716	84	10	06-02-94	C, G, T, K, FS	0
82	CF Industries UF-4	273453 820103	389	101	8	07-11-94	C, G, T, K, FS	0
83	Da Costa	265830 815655	928	178	5	09-21-94	C, G, T, FS	0
84	Port Manatee Authority	273753 823241	590	209	6	11-09-94	C, G, T, FS	0
85	Sarasota Co.Stormwater Util.	272016 822606	726	82	8	10-24-94	C, G, T, K, FS	0
86	Verna Production No. 35	272218 821527	600	142	10	01-26-95	C, G, T, K, FS	50
87	ROMP TR-SA-1	272049 823245	1,208	98	10	04-21-95	C, G, T, K, FS	139



EXPLANATION

53 • WELL LOCATION AND NUMBER--Number referenced in table 1

Figure 9. Locations of wells measured using various geophysical logging techniques.

Impeller Flowmeter Well Log Analysis

All 87 wells were measured with the impeller flowmeter; 17 (20 percent) of these wells had internal flow that was detectable with this meter. Internal flow rates ranged from 10 to 300 gal/min (fig. 10). Distinct patterns in areal distribution of internal flow were not observed. It was not unusual to find a well that was flowing internally and another well in close proximity in which no internal flow was detected. Variations in internal flow rates could be attributed to differences in well construction, relative permeabilities of hydrogeologic units open to the wells, and head differences in the aquifer open to the wells.

Examples of wells in Sarasota County in which internal flow was controlled by well construction were the Regional Observation and Monitor Well Program (ROMP) 20 well and Oscar Scherer State Park well (fig 9. and table 1). ROMP 20 was a temporary flowing monitor well, that had 73 ft of casing and a total depth of 843 ft. A composite geophysical log for ROMP 20 (fig. 11) shows the effects of a short cased well open to multiple producing zones. Analysis of the gamma log suggests that the hydrologic contact between the intermediate aquifer system and the Upper Floridan aquifer occurs where gamma-ray activity subsides at approximately 500 ft. The temperature log indicates mixing of slightly warmer water with cooler water at the formation contact that suggests an inflow point. The temperature remains nearly constant as the water moves up the borehole. Fluid conductivities are highest at the bottom of the well, and as the mineralized water moves up the borehole, it mixes with the fresher water in the zones above. The flow log indicates upward borehole flow, and the inflow appears to be from a producing zone located near the formation contact. The flow continues up the borehole until the water exits a large cavity at approximately 80 ft. The internal flow rate was measured at approximately 80 gal/min in a 10-in. diameter section of the well. This composite log analysis is typical of wells that have a short length of casing, are open to multiple producing zones, and have an upward component of borehole flow.

A composite geophysical log for a well that has a relatively long length of casing is shown in figure 12. The Oscar Scherer State Park well is 2 mi south of ROMP 20. Well information is listed in table 1 and the well location is shown in figure 9. The well is 728 ft deep and has 294 ft of casing. The head differences, water chemistry, and aquifer characteristics are similar to ROMP 20 but the Oscar Scherer State Park well is cased to a deeper depth. The composite geophysical log indicates that the casing length of 294 feet limited the aquifer connectivity; consequently, no internal flow was detected using the impeller flowmeter. Casing beyond the upper permeable zones prevented highly mineralized water from entering these zones. The heat-pulse flowmeter data is discussed in a later section of this report.

For several wells that had internal flow, the flow rates were determined to be affected by the head differences between the aquifers. Internal borehole flow controlled by head differences is illustrated by composite geophysical logs shown in figures 13, 14 and 15. Utopia No. 1 well is in northern Sarasota County and is 1,260 ft deep with 45 ft of casing (fig. 13). Well information is listed in table 1 and the well location is shown in figure 9. The gamma log indicates that the contact between the intermediate aquifer system and the Upper Floridan aquifer is at approximately 450 ft. The temperature and fluid conductivity logs indicate mixing at approximately 100, 200, 450, and 890 ft; these inflections in the log may represent hydrologic contacts or water exiting or entering the borehole. Downward flow was detected below a depth of 200 ft in the intermediate aquifer system at a rate of approximately 75 gal/min in a 12-in. diameter section of the borehole. The flow was observed to continue downward to the bottom of the hole. This flow direction was verified using a video camera with the impeller flowmeter attachment (fig. 7).

Seasonal flowmeter measurements were made in Utopia No. 1 well, from October 1992 through October 1994, using the impeller flowmeter to determine the effects that head differences had on internal flow rates (figs. 14 and 15). It was observed that the flow rates increased and decreased in response to head differences between the intermediate aquifer system and the Upper Floridan aquifer. For example, as shown in figure 14, the flow rates and an accompanying hydrograph indicate that when an approximate 10 ft head gradient exists between the aquifers, as in May, the flow rates increased to 150 gal/min in a 12-in. diameter section of the borehole. Lowering the head in the Upper Floridan aquifer, as a result of ground-water development, increased head differences between the two aquifers and increased the downward flow rate. Conversely, when the aquifers are unstressed by irrigation, water levels rebound, such as occurs during the summer months, and the head

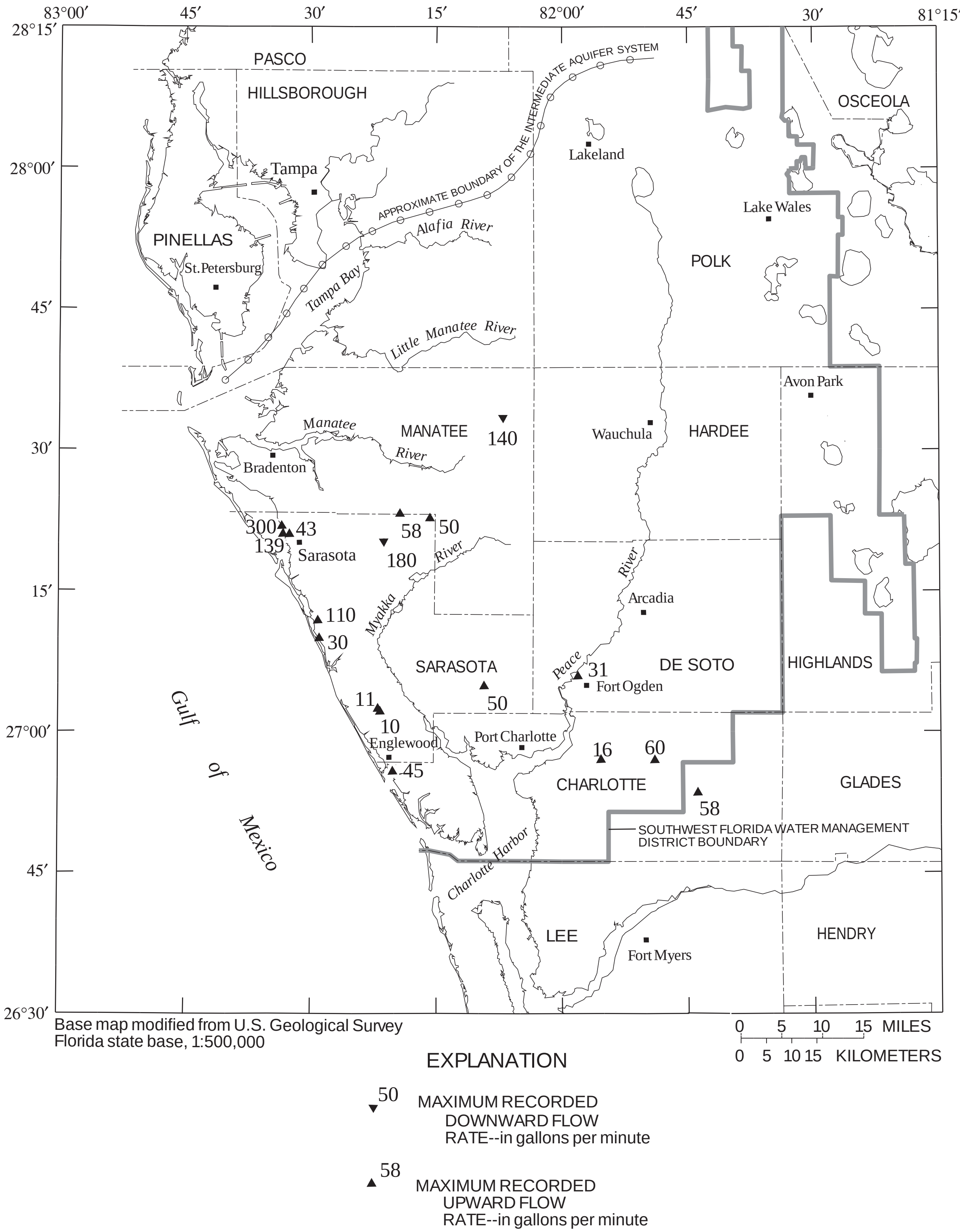


Figure 10. Locations of wells in which internal flow was detected using the impeller flowmeter and the maximum recorded borehole flow in gallons per minute.

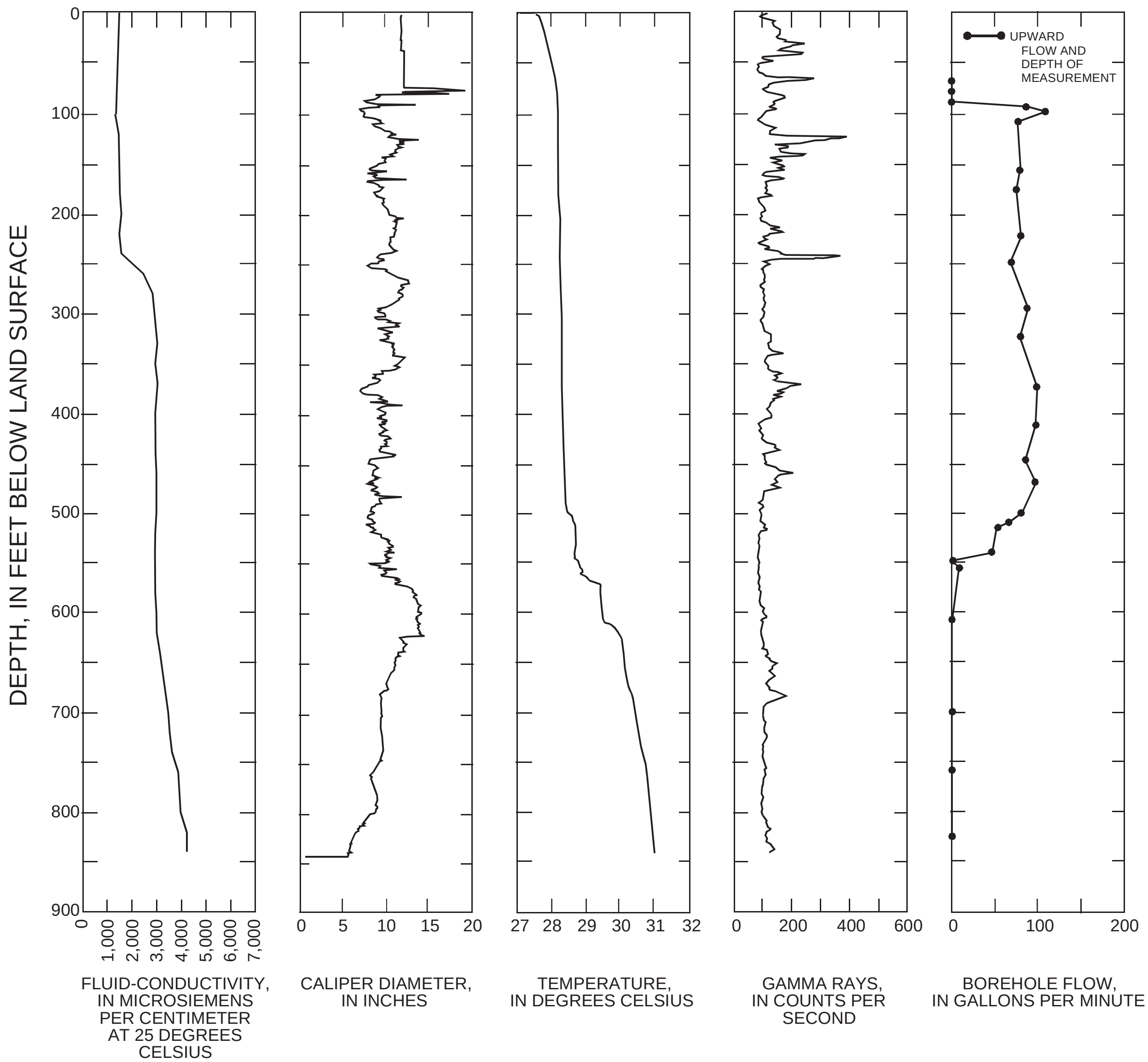


Figure 11. Composite geophysical log for ROMP 20 well in Sarasota County.

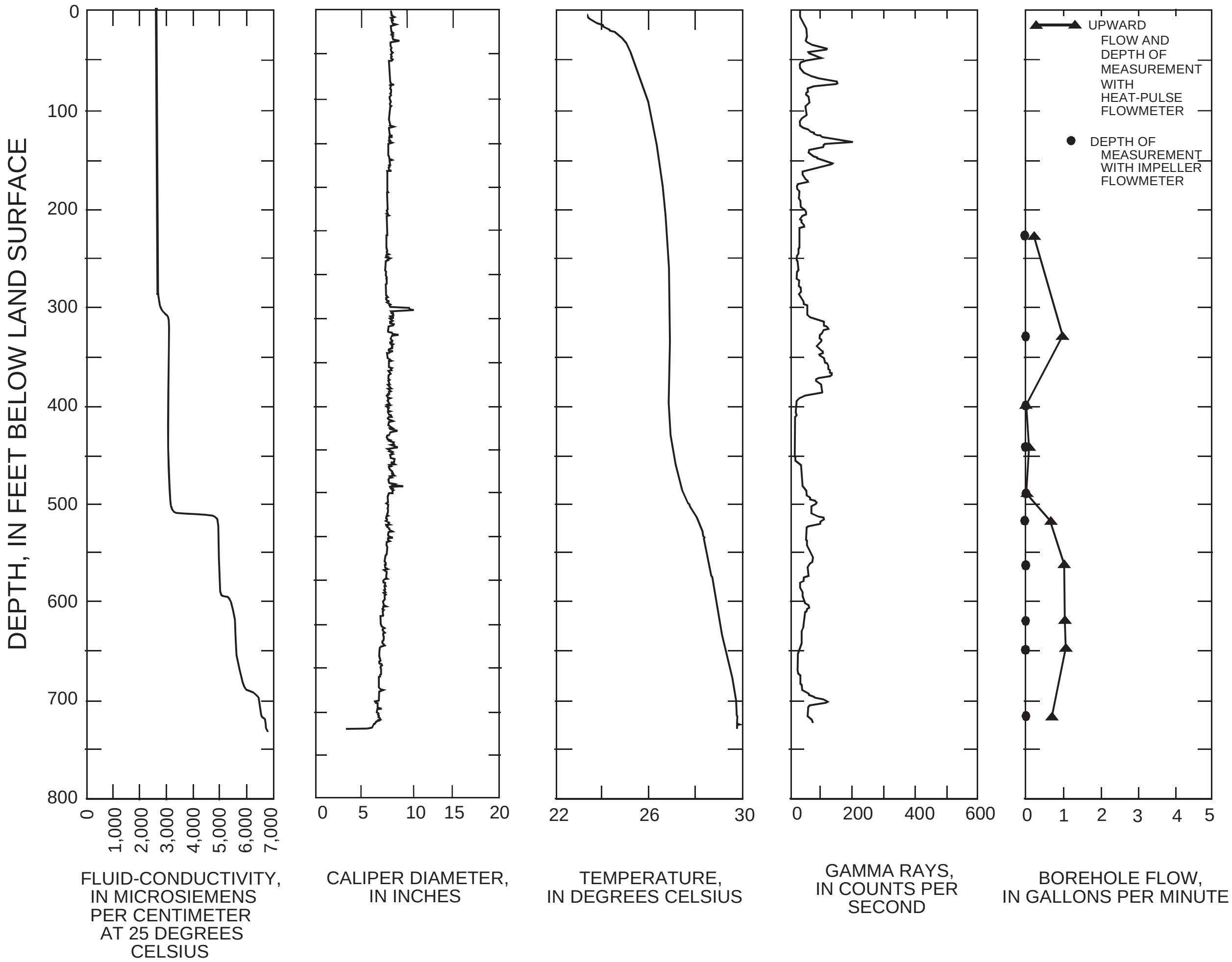


Figure 12. Composite geophysical log for Oscar Sherer State Park well in Sarasota County.

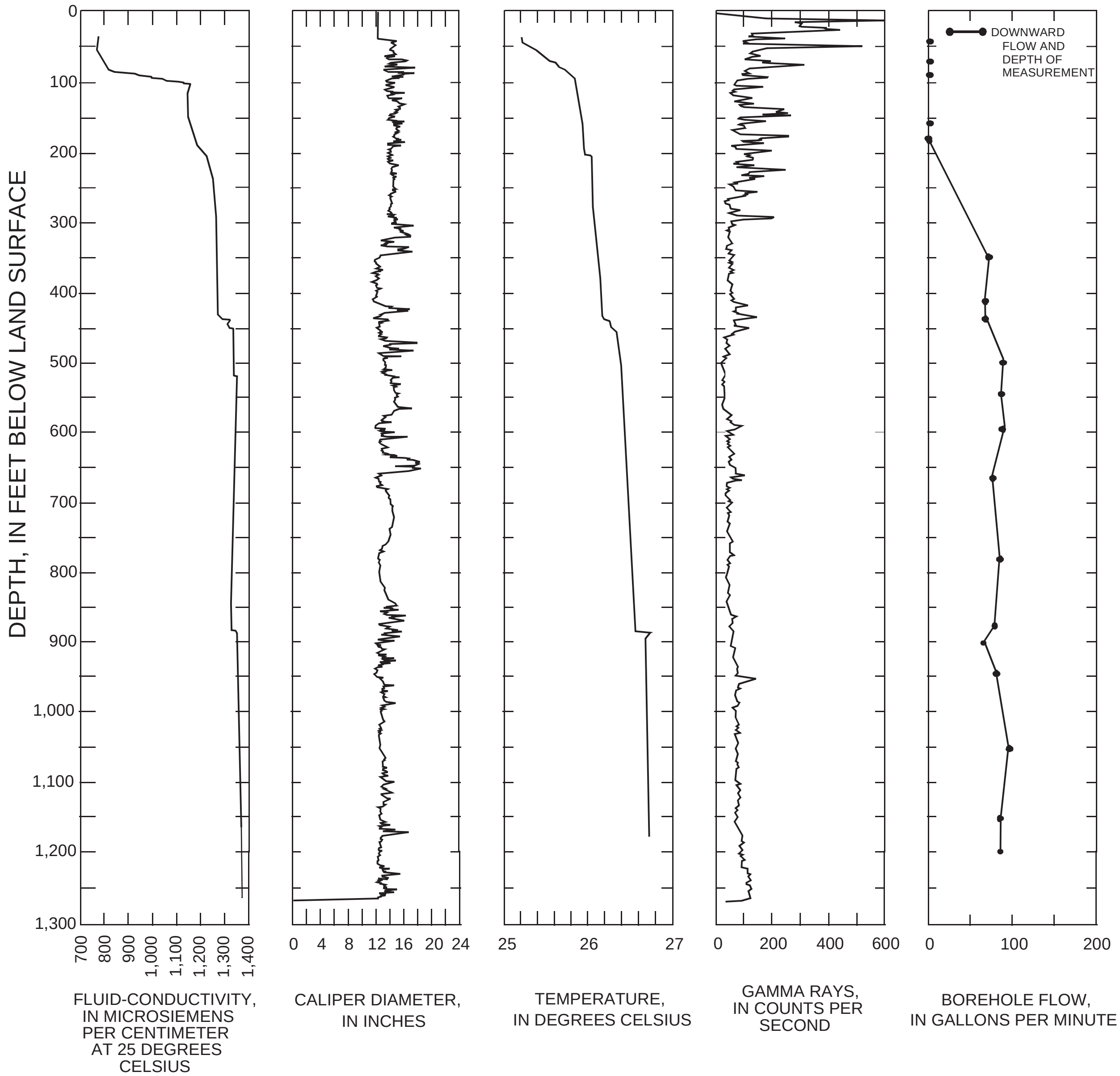


Figure 13. Composite geophysical log for Utopia No. 1 well in Sarasota County.

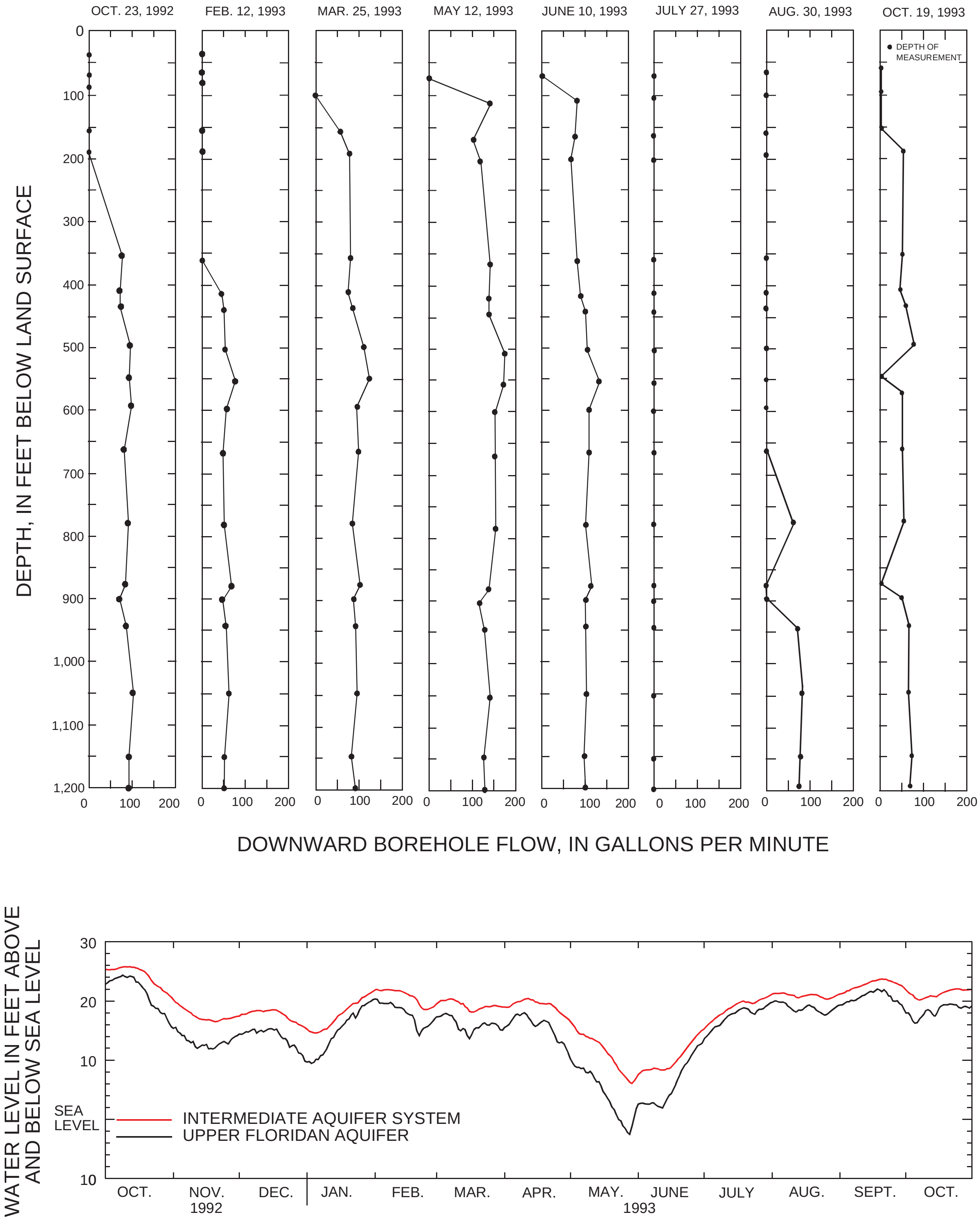
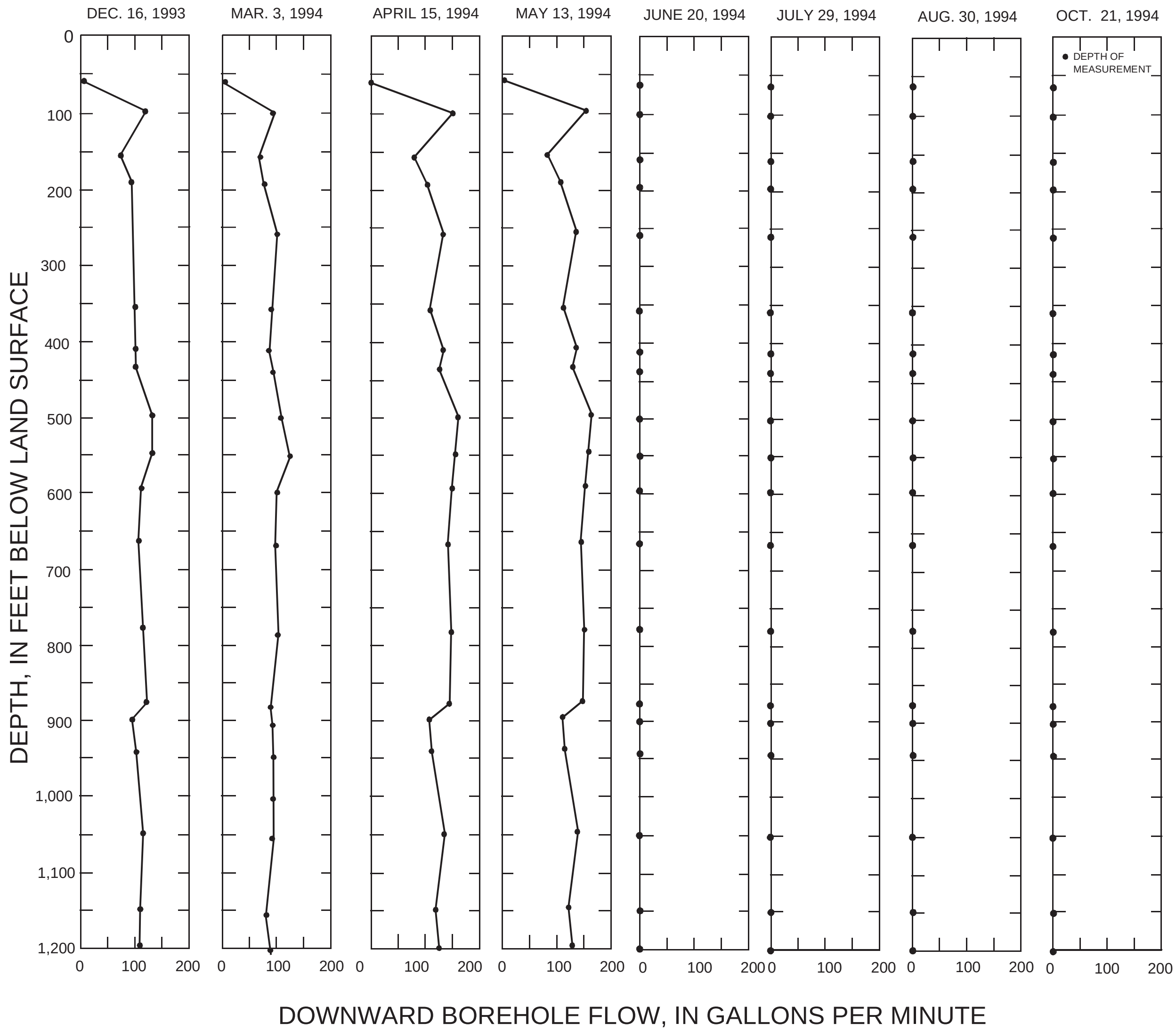


Figure 14. Seasonal flow measurements for Utopia No. 1 well in Sarasota County and hydrographs of the intermediate aquifer system and the Upper Floridan aquifer, October 1992 through October 1993.



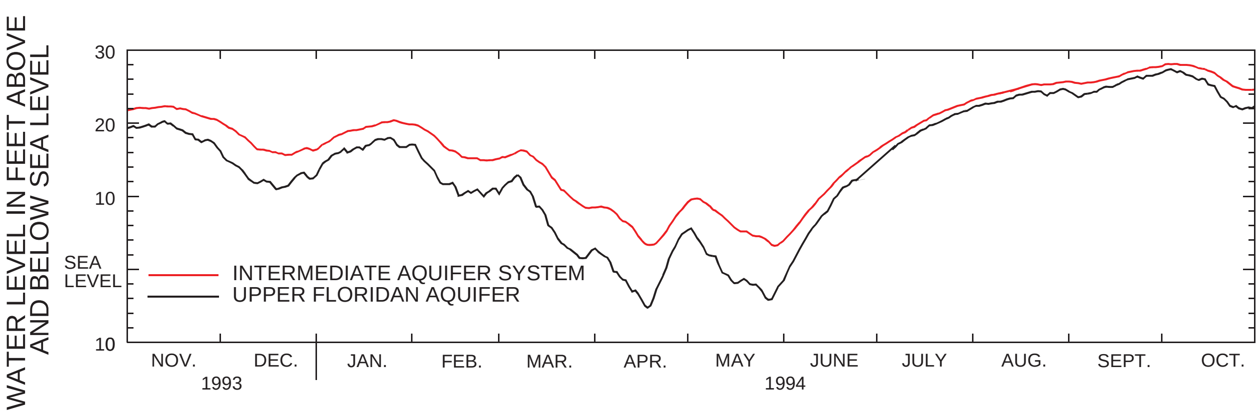


Figure 15. Seasonal flow measurements for Utopia No. 1 well in Sarasota County and hydrographs of the intermediate aquifer system and the Upper Floridan aquifer, November 1993 through October 1994.

difference is minimal between the Upper Floridan aquifer and the intermediate aquifer system. For example, as shown in figure 15, the flow rates and an accompanying hydrograph indicate that, when an approximate 2 ft head gradient exists between the aquifers as in late June, internal flow was not detected with the impeller flowmeter.

In addition to seasonal changes in flow rates, shallow and deep producing zones were also affected by the head gradient fluctuations. For example, in October 1992, between 46 and 190 ft, no flow was detected in the upper producing zones (fig. 14). In subsequent flow measurements, evidence of detectable flow occurs at varying depths. These variations in flow rates can be attributed to changes in head gradients between producing zones. When the shallower producing zones were in equilibrium with lower producing zones, as in July 1993, no internal flow occurred. When shallower producing zones were not in equilibrium with lower producing zones, as in May 1993, internal flow occurred to compensate for the head differences. Internal flow in May 1993 also occurred at a shallower depth (between 80 and 100 ft) than it did in October 1992 because of larger head differences. Lower producing zones were also affected by head gradient fluctuations-- for example, as shown in figure 14 for August and October 1993 between the interval 450 and 900 ft.

During the course of this study, several wells had internal flow that was caused by nearby municipal or irrigation pumping. Hickory Street well is a monitor well for the city of Sarasota and is 599 ft deep with 46 ft of casing. Production No. 3 well for the city of Sarasota is 549 ft deep with 260 ft of casing and is 30 ft from the monitoring well. The composite geophysical log for Hickory Street well when the nearby Production No. 3 well was under pumping and nonpumping conditions in shown in figure 16. The gamma log does not indicate an apparent hydrologic contact between the intermediate aquifer system and the Upper Floridan aquifer because there is no subsidence in gamma activity. The temperature log indicates that there is slightly warmer water mixing with cooler water at approximately 80, 260, and 550 ft. Fluid conductivity is approximately 3,000 µS/cm from 80 to 550 ft and increases to 12,500 µS/cm at the bottom of the borehole. The contact between the intermediate aquifer system and the Upper Floridan aquifer may be inferred to be at 550 ft because of changes in the temperature and fluid conductivity at this depth. There was no measurable internal borehole flow in the monitoring well using the impeller flowmeter during nonpumping conditions of the nearby production well.

A composite geophysical log for Hickory Street well with the nearby production well pumping approximately 350 gal/min is shown in figure 16. A sharp interface where the 260-ft casing depth for the production well ends is shown by the temperature, fluid conductivity, and flow logs (fig. 16). The borehole flow in the monitoring well was measured using the impeller flowmeter at a maximum rate of 300 gal/min. Fluid conductivity increased from approximately 12,000 to 15,000 µS/cm at the bottom of the hole. The composite well log analysis indicates that the nearby pumping well induced upward borehole flow to occur within the monitor well and caused upward movement of highly mineralized water. This highly mineralized water may migrate into shallower formations when the pump is turned off.

Heat-Pulse Flowmeter Well Log Analysis

A heat-pulse flowmeter was used in 19 wells throughout the study area to measure low flow velocities in wells open to multiple permeable zones. Well information is listed in table 2 and the well locations are shown in figure 9. The heat-pulse flowmeter was used in wells that did not have detectable flow with the impeller flowmeter. The measured wells had depths and casing lengths ranging from 335 to 1,547 ft and 26 to 398 ft, respectively. Of the 19 wells measured, 18 (95 percent) had detectable internal borehole flow with maximum values ranging from 0.3 to 10.0 gal/min. Well locations and maximum recorded flow values are shown in figure 17.

Distinct regional patterns of internal flow were not observed using the heat-pulse flowmeter and for several wells flow direction did not follow regional trends from the head difference maps (figs. 4 and 5). In addition, several wells had multiple flow zones with opposing flow directions. Flow rate and direction were very localized for each well. In some instances, localized flow was influenced by a discharge area, such as a nearby river, municipal pumping, or agricultural pumping.

A number of factors must be considered when analyzing heat-pulse flowmeter data which include: (1) turbulent thermal convection and other secondary flow circulations occur within the borehole; (2) actual flow regimes are often changing with time as measurements

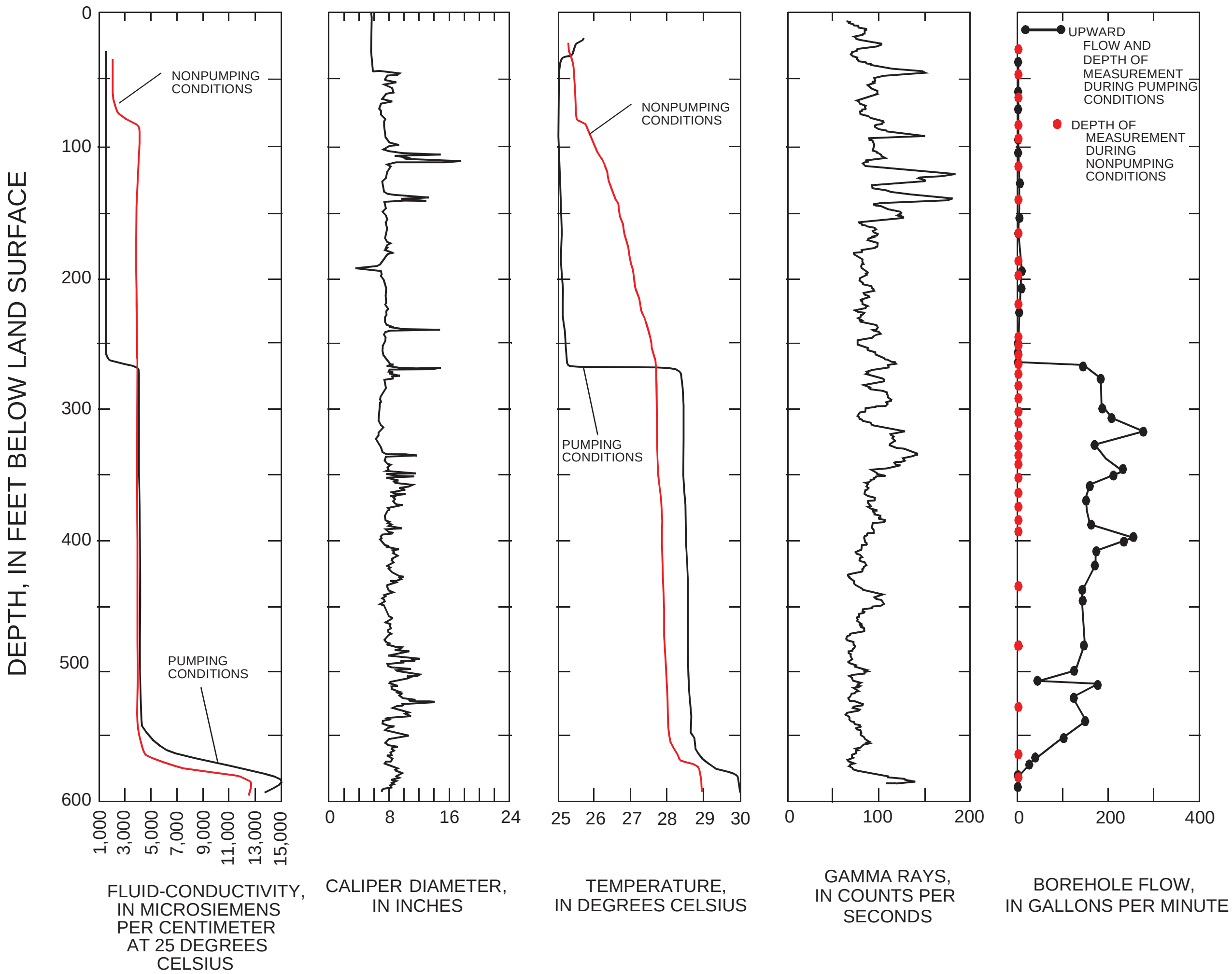


Figure 16. Composite geophysical log for Hickory Street well in Sarasota County with Production No. 3 well under nonpumping and pumping conditions.

Table 2. Records for wells using the heat-pulse flowmeter

Index no.	Site name	Latitude-longitude	Depth (feet) below land surface	Casing (feet)	Dia-meter (inches)	Date of measure-ment	Heat-pulse flow rate, gallons per minute
8	Oscar Scherer State Park	271032 822745	728	294	8	02-16-94	1.2
19	Smith	273103 813637	849	66	5	02-22-94	0.3
20	ROMP 123	274031 821504	620	117	8	11-06-92	1.0
21	Walker Farms	271931 822608	668	238	6	03-05-93	1.0
24	Busby Deep	273605 820711	996	153	12	02-19-94	8.5
26	Rusty Pot No. 2	271646 821122	1,017	148	10	02-21-94	10.0
36	Schroeder Manatee Ranch No. 8	272651 822625	703	64	8	03-05-93	0.7
37	Big Hog	272040 823258	555	90	12	11-06-92	0.3
42	Romp 43X	273615 812849	1,005	398	8	02-22-94	0.0
43	Powell Deep	274813 822236	335	26	6	11-05-92	10.0
50	Kibler Deep	272838 821422	1,129	208	8	03-04-93	0.5
56	Parrish Grove	273459 822532	583	102	6	03-03-93	1.0
58	Verna T 0-4	272020 821948	500	140	6	02-16-94	0.8
59	Amax Deep No. 3	271538 820023	1,547	340	8	02-18-94	2.0
61	Hudson Farms	270046 815541	1,256	368	12	02-26-94	3.0
72	Ansin	265643 815500	766	108	4	02-17-94	2.4
73	Verna P-20	272248 821719	520	142	10	02-15-94	2.7
74	Verna KME-02	272301 821914	833	350	16	02-15-94	2.8
75	DEP No. 8	274812 814846	610	121	6	02-25-94	0.8

are made; and, 3) not all permeable intervals may be producing vertical flow under ambient conditions. These factors are described in detail by Crowder and others (1994) and Paillet and others (1994).

A composite geophysical log of the Oscar Scherer State Park well in Sarasota County in which the impeller and heat-pulse flowmeters were used to determine the occurrence of interaquifer flow is shown in figure 12. This analysis indicates that even though flow was not detected using the impeller flowmeter, a small amount of internal flow was detected in this well with the more sensitive heat-pulse flowmeter. The heat-pulse flowmeter data indicate two zones of inflow and two zones of outflow. From below 500 ft, inflow of approximately 1.2 gal/min occurs and continues up the borehole until the flow exits the borehole near 500 ft. Above 400 ft, a second flow zone produces upward flow of 1.0 gal/min. Analysis of the heat-pulse flowmeter data and accompanying geophysical logs indicate that highly mineralized water flows upward from the bottom of the well and exits a cavity near 500 ft. Upward flow is also present between 330 and 400 feet and exits above 225 feet, indicating a leaky casing.

Figure 18 is a composite geophysical log of Schroeder Manatee Ranch No. 8 well in Manatee County. The well is 703 ft deep and has 64 ft of casing (table 2 and fig. 9). The gamma log indicates that the hydrologic contact between the intermediate aquifer system and the Upper Floridan aquifer is at an approximate depth of 360 ft. Analysis of the heat-pulse flowmeter data and accompanying geophysical logs indicates that a small amount of flow occurs at the bottom of the well and increases slightly at approximately 560 ft. The low volume flow continued up the borehole and the rate increased between 250 to 100 ft. Flow between these depths is also indicated on the temperature and fluid-conductivity logs.

The heat-pulse flowmeter proved to be a useful tool in detecting low-flow volumes and locations of the low-flow contributing zones. Of the 19 wells

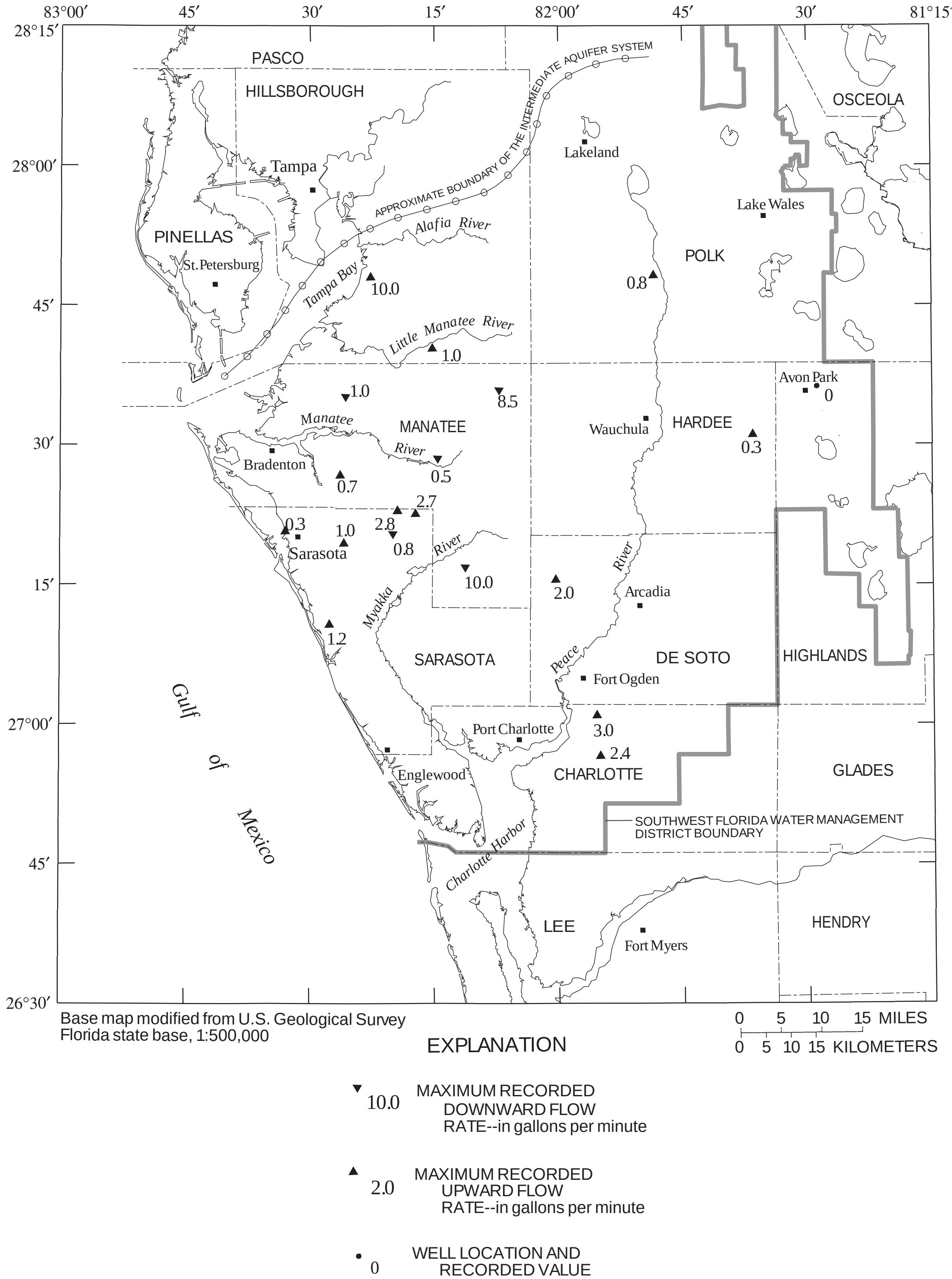


Figure 17. Locations of wells measured with the heat-pulse flowmeter and the maximum recorded flow measurement in the borehole in gallons per minute.

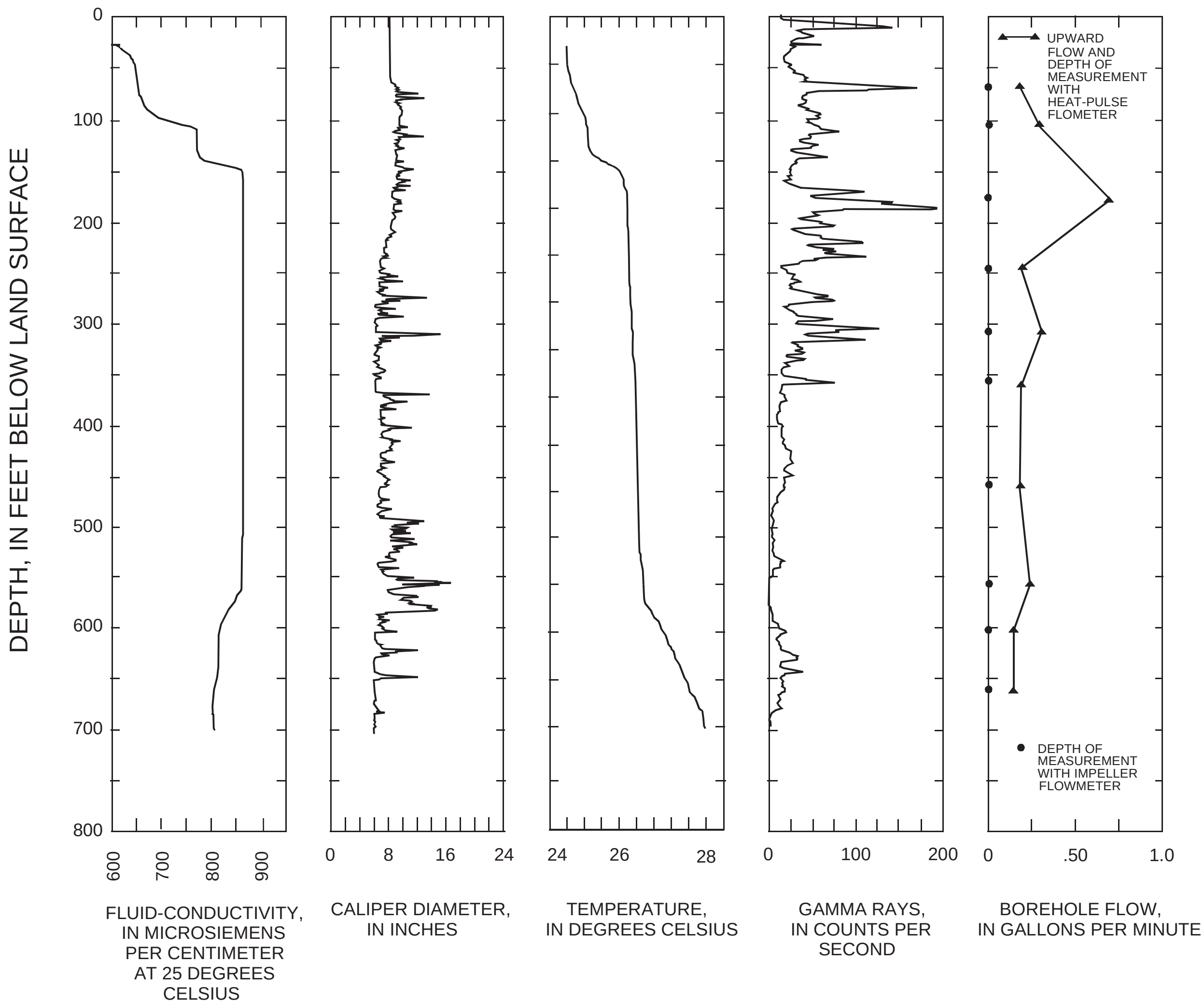


Figure 18. Composite geophysical log for Schroeder Manatee Ranch No. 8 well in Manatee County using the heat-pulse flowmeter.

measured with the heat-pulse flowmeter, 18 (95 percent) had measurable internal borehole flow, in comparison, with the 87 wells measured using the impeller flowmeter in which 17 (20 percent) had measurable internal borehole flow. Further data collection are needed, using the heat-pulse flowmeter, to determine if internal flow could be detected in all wells penetrating multiple permeable zones.

WATER QUALITY

The water chemistry in the intermediate aquifer system and the Upper Floridan aquifer is controlled by the lithology and mineralogy of units within each aquifer, the residence time of water in contact with the aquifer matrix, and the different sources of water that recharge each aquifer. The lithology that controls the hydrochemistry of the water in the intermediate aquifer system consists of limestone, dolomite, sand, clay, and phosphorite. Major sources of recharge water to the aquifer include downward leakage from the surficial aquifer in the northern half of the study area and upward leakage from the Upper Floridan aquifer in the southern half.

The chemical composition of water in the intermediate aquifer system is distinctly different in areas where it is recharged by the surficial aquifer, as compared to areas where the Upper Floridan aquifer discharges into the intermediate aquifer system. Ground water in the surficial aquifer within the study area is a mixed calcium bicarbonate and sodium chloride type; in the Upper Floridan aquifer it is a mixed calcium magnesium sulfate and sodium chloride type. The chemistry of the water in the intermediate aquifer system is a transitional type of ground water between the two sources of water moving into the aquifer (Berndt and Katz 1992).

The hydrochemistry of water in the Upper Floridan aquifer is controlled by the lithologic composition of limestone, dolomite, and gypsum, and by the sources of water that recharge the aquifer. In the study area, sources of recharge to the aquifer include downward leakage from the intermediate aquifer system and the lateral, westward flow of the regional groundwater system. The major ion concentrations of water in the Upper Floridan aquifer is affected predominately by processes such as dissolution of gypsum and dolomite, calcite precipitation, and seawater mixing (Katz, 1992). In the study area, there is a general increase with depth in dissolved solids and sulfate concentration (Wilson, 1977) . This increase in major ion concentrations with depth in the Upper Floridan aquifer is supported by the concept that, as temperatures increase with depth, both the solubility and the rate of dissolution of most rock minerals increase (Hem, 1989).

The chemical characteristics of the water in the intermediate aquifer system and in the Upper Floridan aquifer are presented in table 3. The water-quality data used in this report are from analyses of water samples collected during the course of this study, from historical data of the USGS, and from the Ambient Ground-Water Quality Monitoring Program of SWFWMD. Analyses are grouped according to the principal aquifer yielding water to each well. In a number of water-quality analyses for the Upper Floridan aquifer, wells also were open to the intermediate aquifer system. However, because the intermediate aquifer system contributes only a fraction of the water to a well that also penetrates the more productive Upper Floridan aquifer, the chemical analyses are probably more representative of the water in the Upper Floridan aquifer.

The principal chemical constituents in ground water within the study area that affect potability are chloride, sulfate, and dissolved solids. Generalized maps of chloride, sulfate, and dissolved solids concentrations in water from the intermediate aquifer system and the Upper Floridan aquifer were developed to delineate areas of potential water-quality degradation as a result of interconnected aquifers (figs. 19-24).

Chloride

Chloride is one of the predominant anions in water from the intermediate aquifer system and the Upper Floridan aquifer in the study area. Chloride in ground water may be derived from several sources including dissolution of aquifer minerals that contain chloride; saltwater intrusion; degraded water sources such as septic tank seepage, agricultural activities, and industrial wastes; and rainfall that contains a small amount of chloride ions. In addition, aquifers may contain saline or brackish water, which, in part, is relict seawater that has not been completely flushed by freshwater circulation (Wilson, 1977).

The maximum chloride concentration permitted for public drinking water supplies in Florida is 250 mg/L (Florida Department of Environmental Regulation, 1985). Throughout most of the study area, the chloride concentrations in water from the intermediate

Table 3. Chloride, sulfate, and dissolved-solids concentrations in water from selected wells

[Aq, aquifer; IA, intermediate aquifer system; UF, Upper Floridan aquifer; --- no data]

Site name	Identification number	Sample date	Depth (feet) below land surface	Casing (feet) below land surface	Aq	Chlo-ride (mg/L)	Sulfate (mg/L)	Dissol-ved solids (mg/L)	Source of data
Babcock well	265316081433401	03-12-93	917	300	IA	580	200	1,320	USGS
Englewood well 14	265834082202401	09-22-87	55	44	IA	320	44	980	USGS
Englewood test well C-8	265927082195201	04-09-81	110	56	IA	670	13	1,630	USGS
Englewood test well C-7	270018082201301	04-09-81	120	47	IA	250	16	590	USGS
Venetia (Berry 8)	270032082205801	04-10-81	253	52	IA	830	430	2,170	USGS
Venetia (Berry 7)	270057082210501	04-09-81	185	48	IA	190	210	791	USGS
Englewood deep zone well 3	270106082214101	09-15-87	135	109	IA	70	14	360	USGS
Englewood test well C-9	270112082201201	04-09-81	120	65	IA	270	16	756	USGS
Englewood production well 8	270112082213301	01-14-80	70	58	IA	110	---	531	USGS
Englewood production well 5	270113082223302	08-05-86	70	40	IA	180	26	650	USGS
Venetia (Berry 3)	270203082210101	01-31-84	315	212	IA	380	600	1,200	USGS
Venetia (Berry 5)	270205082284001	01-30-84	472	290	IA	680	850	1,700	USGS
Manatee Jr. College south well	270219082185801	03-21-84	274	102	IA	1,100	840	2,900	USGS
Manatee Jr. College middle well	270223082185701	03-21-84	158	41	IA	170	30	500	USGS
ROMP TR4-2	270240082235701	05-19-82	475	460	IA	260	720	1,600	USGS
Plantation monitor well 1	280403082220001	03-11-87	180	66	IA	69	53	326	USGS
Plantation monitor well 2	270404082215801	03-11-87	65	52	IA	29	198	228	USGS
Plantation RO test well 2	270407082215801	05-16-82	366	228	IA	358	972	2,058	USGS
Venice Gardens injection monitor 400	270420082230503	06-10-85	400	200	IA	642	1,320	2,930	USGS
Venice RO 6	270534082260901	06-13-82	441	206	IA	300	1,200	2,750	USGS
Venice well 2	270536082253901	06-05-82	140	77	IA	130	415	1,240	USGS
Venice well 35	270542082261801	11-20-87	163	86	IA	110	270	660	USGS
ROMP TR5-1 Hawthorn well	270808082270502	11-23-87	289	275	IA	33	1,200	1,400	USGS
Henry Ranch 1	270822082231101	04-01-81	286	40	IA	30	1,300	1,900	USGS
ROMP TR5-2 upper Hawthorn well	270919082234202	05-06-86	120	100	IA	54	730	1,300	USGS
ROMP TR5-2 lower Hawthorn well	270919082234203	05-06-86	265	245	IA	36	1,100	1,700	USGS
ROMP TR5-2 Tampa well	270919082234204	05-06-86	400	360	IA	38	1,500	2,300	USGS
Ewing Ranch (Holland)	270931082252901	07-09-86	256	44	IA	40	1,500	2,200	USGS
ROMP 19 WS	270959082203003	02-18-82	67	32	IA	56	---	390	USGS
Sarasota County Historical Society	271222082295201	02-08-82	224	41	IA	36	1,100	1,700	USGS
D.T. Brown 15 (46-43)	270246081424301	09-15-88	408	62	IA	130	62	488	USGS
Nichols Ranch (35)	270359081464401	09-15-87	377	44	IA	55	25	---	USGS
Bill Athey (Foster)	270412081474901	09-03-87	460	112	IA	60	58	361	USGS
Rob Lane (Russell)	270417081575601	09-03-87	411	70	IA	220	190	813	USGS
NAFCO Groves	270540081335101	03-08-89	300	100	IA	360	19	1,090	USGS
Gen. Development T-2	270540082001102	09-12-88	496	393	IA	140	230	737	USGS
Dees--while drilling UF	270725081500701	02-26-88	430	254	IA	69	130	472	USGS

Table 3. Chloride, sulfate, and dissolved-solids concentrations in water from selected wells --Continued

[Aq, aquifer; IA, intermediate aquifer system; UF, Upper Floridan aquifer; --- no data]

Site name	Identification number	Sample date	Depth (feet) below land surface	Casing (feet) below land surface	Aq	Chlo-ride (mg/L)	Sulfate (mg/L)	Dissol-ved solids (mg/L)	Source of data
Hancock Groves (Brantly)	270803081502401	08-16-88	418	77	IA	120	290	805	USGS
G.P. Wood Hospital	270810081481201	09-19-85	565	70	IA	71	281	644	USGS
Red Hawk Ranch (Nunez)	270858081582201	09-12-88	428	63	IA	90	260	717	USGS
Blocker	271010081505301	09-15-88	450	420	IA	57	60	408	USGS
Bright Hour Ranch 15-21	271015081432101	08-19-88	396	96	IA	89	15	431	USGS
Vance Stansel	271058081471601	08-18-88	335	110	IA	49	31	365	USGS
Minute Maid (44) D-69	271113081543301	06-17-87	384	99	IA	88	87	548	USGS
ROMP 16 Hawthorn	271115081462702	07-24-85	340	300	IA	41	20	214	USGS
Bright Hour Ranch 51-08	271151081410801	08-19-88	335	105	IA	70	3	396	USGS
Bright Hour Ranch 28-11	271228081371101	08-19-88	291	126	IA	14	2	347	USGS
City of Arcadia No. 4	271244081504201	08-16-88	353	112	IA	46	15	380	USGS
City of Arcadia No. 2	271308081522601	07-25-85	372	263	IA	47	16	344	USGS
City of Arcadia No. 1	271310081522701	02-24-89	250	84	IA	45	25	375	USGS
AMAX (Hollingsworth 716)	271407082000401	08-16-88	430	60	IA	57	79	465	USGS
Joshua Tier Barn 3	271512081344701	08-18-88	300	90	IA	35	170	488	USGS
Carl Regan	271517081502201	09-10-87	327	84	IA	42	27	322	USGS
Allen Burtscher (704)	271517081542201	08-16-88	320	130	IA	53	74	496	USGS
Joshua Tier Barn 1 (TRG)	271520081394201	08-18-88	294	105	IA	76	17	360	USGS
Joshua Tier Barn 2 (TRG)	271521081374301	08-18-88	300	150	IA	83	42	424	USGS
Camp Chanyatah No. 3	271624081520001	09-03-87	208	80	IA	24	260	631	USGS
J.H. Brock (50) (D-122)	271713081504901	06-17-87	257	47	IA	35	110	454	USGS
ROMP 26 Hawthorn	271757081493003	07-31-85	180	140	IA	3	109	325	USGS
D.E. Marshall	272012081482501	07-31-85	478	137	IA	21	197	525	USGS
Hollingsworth 751	272014081595701	02-24-89	430	144	IA	13	17	326	USGS
Hazel Williams	272103081480701	02-24-89	199	129	IA	14	4	307	USGS
Hollingsworth 620	272108081582601	02-24-89	335	146	IA	20	250	593	USGS
ROMP 31 Hawthorn	272714081545902	03-29-88	350	130	IA	87	76	550	USGS
Wilbur Robertson (20)	272715081401601	11-23-87	343	103	IA	9	40	217	USGS
Thomas Spuckler	272718081342401	03-08-89	372	231	IA	9	53	229	USGS
ROMP 30 Tampa	272728081474702	08-14-85	316	280	IA	25	142	388	USGS
William Anderson	272917081453901	09-09-87	140	42	IA	14	15	198	USGS
Jeff Surrency (Martens)	272932081492001	09-09-87	177	34	IA	14	110	369	USGS
Scott (T.C. Hart) 604	272924081495701	09-10-87	321	82	IA	11	60	302	USGS
Rowell	273156081451401	08-15-85	267	39	IA	8	9	194	USGS
Charlie Stevens	273345081371701	02-24-89	225	100	IA	3	1	111	USGS
Ed McClelland	273356081371701	02-24-89	226	110	IA	7	22	138	USGS
Ed Jernigan (26)	273403081494701	11-23-87	298	83	IA	7	1	191	USGS
Harold McClelland	273423081371701	02-24-89	210	110	IA	9	3	169	USGS

Table 3. Chloride, sulfate, and dissolved-solids concentrations in water from selected wells --Continued

[Aq, aquifer; IA, intermediate aquifer system; UF, Upper Floridan aquifer; --- no data]

Site name	Identification number	Sample date	Depth (feet) below land surface	Casing (feet) below land surface	Aq	Chlo-ride (mg/L)	Sulfate (mg/L)	Dissol-ved solids (mg/L)	Source of data
Henderson (Geiger) (624)	273435081444001	11-12-87	293	105	IA	21	110	393	USGS
Dewey Waters	273543081590301	12-09-87	400	90	IA	27	14	251	USGS
Paynes Creek Historical	273714081483101	09-09-87	130	119	IA	39	32	304	USGS
Sweat well Hillsborough HRS34	274533082155202	03-01-89	220	156	IA	4	1	---	USGS
Polk ROMP 55 Suwannee	274730081333801	07-14-87	250	212	IA	8	7	---	USGS
Babcock Florida Corp. 2126	265321081442601	12-22-93	404	42	IA	73	1	486	SWFWMD
Port Charlotte Deep	270133082034601	03-29-94	350	312	IA	745	292	1,698	SWFWMD
Port Charlotte Utility Deep	265920082045601	03-29-94	156	128	IA	77	20	309	SWFWMD
Punta Gorda Heights	265141082002201	01-12-94	125	84	IA	372	71	953	SWFWMD
ROMP 10 Hawthorn (Flowing)	270152082002801	03-21-94	210	110	IA	378	158	878	SWFWMD
ROMP 10 Tampa	270152082002801	03-21-94	488	303	IA	451	242	1,157	SWFWMD
ROMP 11 Deep	265837081561101	03-29-94	335	220	IA	695	259	1,535	SWFWMD
ROMP TR 1-2 L Hawthorn	265026081585401	01-12-94	600	520	IA	931	278	2,014	SWFWMD
ROMP TR 1-2 U. Intermediate	265026081585401	01-12-94	255	218	IA	476	136	1,134	SWFWMD
ROMP TR 3-1 L Hawthorn	265638082130701	03-25-94	400	380	IA	640	460	1,827	SWFWMD
ROMP TR 3-1 U. Intermediate	265638082130701	03-25-94	160	140	IA	950	9	1,773	SWFWMD
ROMP TR 3-3 L Hawthorn	265531082194801	03-20-94	410	370	IA	2,858	493	5,443	SWFWMD
ROMP TR 3-3 U. Intermediate	265531082194801	03-20-94	175	155	IA	1,107	149	2,101	SWFWMD
Rotunda Water Plant 18	265158082171701	03-21-94	146	121	IA	4,503	456	8,600	SWFWMD
State Hwy 74 Dp Well	265646081554501	01-24-94	280	194	IA	122	101	549	SWFWMD
USGS C-1	265127081532501	02-25-94	264	214	IA	1,170	287	2,440	SWFWMD
USGS C-3	265504082000601	03-30-94	205	153	IA	89	4	356	SWFWMD
USGS Tuckers Corner	265124081453701	12-22-93	235	212	IA	35	1	354	SWFWMD
GDU Well T-2	270540082001101	03-14-94	496	393	IA	142	230	679	SWFWMD
NAFCO Groves Intermediate	270540081335101	01-06-94	300	100	IA	275	15	812	SWFWMD
Prairie Creek U. Intermediate	270245081465101	01-06-94	80	60	IA	144	59	639	SWFWMD
Rob Lane (G.V. Russell)	270417081575601	03-31-94	411	70	IA	300	175	879	SWFWMD
ROMP 14	270858081211101	06-23-92	1,249	389	IA	3	6	278	SWFWMD
ROMP 28	272207081260401	02-03-93	2,060	200	IA	5	2	93	SWFWMD
Bradburn Well	275223082195001	12-28-93	80	83	IA	52	15	345	SWFWMD
ROMP TR 9-1	274421082275401	12-21-93	288	124	IA	31	358	778	SWFWMD
Riverside Village	274212082264901	12-21-93	197	40	IA	42	442	909	SWFWMD
El Conquistador North Well	272558082360601	12-20-93	399	49	IA	370	536	1,524	SWFWMD
Horse Shoe Loop Terra Ceia	273347082354101	01-10-94	423	22	IA	232	543	1,303	SWFWMD
Manatee Fairgrounds	273134082344601	12-20-93	273	216	IA	251	719	1,729	SWFWMD
Palma Sola-Wayne Davis	273055082394701	12-20-93	246	196	IA	689	492	2,078	SWFWMD
ROMP 23 Intermediate	271852082104101	01-11-94	363	303	IA	17	5	206	SWFWMD
ROMP TR 7-1	272510082345701	03-09-94	340	320	IA	109	364	844	SWFWMD

Table 3. Chloride, sulfate, and dissolved-solids concentrations in water from selected wells --Continued

[Aq, aquifer; IA, intermediate aquifer system; UF, Upper Floridan aquifer; --- no data]

Site name	Identification number	Sample date	Depth (feet) below land surface	Casing (feet) below land surface	Aq	Chloride (mg/L)	Sulfate (mg/L)	Dissolved solids (mg/L)	Source of data
ROMP TR 7-2 U Hawthorn	272612082330101	02-09-94	105	60	IA	75	47	356	SWFWMD
ROMP TR 8-1 Upper Hawthorn	273458082324701	01-07-94	160	100	IA	99	36	514	SWFWMD
City of Sarasota 27th Street	272133082324701	11-18-92	343	45	IA	178	320	767	SWFWMD
Englewood Prod. No. 5 Hawthorn	270113082223301	03-11-94	70	40	IA	815	132	1,823	SWFWMD
Knights Trail Upper Intermediate	270945082234401	02-03-94	140	63	IA	67	212	696	SWFWMD
Mabry Carlton No. 6	271227082084801	03-30-94	369	311	IA	48	232	642	SWFWMD
Macarthur Tract 14DS	270807082123001	05-31-91	210	40	IA	74	32	---	SWFWMD
Manasota Deep Well 14	270137082235301	03-22-94	305	263	IA	54	31	363	SWFWMD
Plantation Hawthorn No. 126	270406082220101	02-24-94	180	66	IA	64	28	364	SWFWMD
ROMP 19 WUAM	270959082203001	03-03-94	205	87	IA	92	56	503	SWFWMD
ROMP 20 Lower Hawthorn	271138082284601	03-10-94	370	250	IA	73	1,530	2,436	SWFWMD
ROMP 20 Upper Hawthorn	271138082284601	03-10-94	125	75	IA	89	698	1,333	SWFWMD
ROMP 22 L. Intermediate	271813082201201	02-18-94	290	230	IA	168	71	632	SWFWMD
ROMP TR 5-1 Tampa	270808082270501	03-11-94	289	275	IA	34	1,004	1,664	SWFWMD
ROMP TR 5-2 L. Hawthorn	270919082234201	02-16-94	265	245	IA	36	1,062	1,789	SWFWMD
ROMP TR 6-1 Tampa	271601082330501	02-09-94	315	300	IA	478	1,093	2,514	SWFWMD
Sarasota Historical Society	271222082295201	03-10-94	224	44	IA	39	1,158	1,996	SWFWMD
Southbay Utilities Deep	271035082285901	02-03-94	450	220	IA	213	1,653	3,035	SWFWMD
Test 18 Blackburn Well	270714082155201	03-15-94	351	282	IA	172	540	1,218	SWFWMD
USGS Well 35 at Venice	270542082261801	03-04-94	163	86	IA	130	371	968	SWFWMD
VO No. 3	270853082090101	03-22-94	350	32	IA	262	448	1,267	SWFWMD
Venice Shallow Wellfield 68	270558082241501	03-04-94	110	76	IA	153	301	911	SWFWMD
Whitaker Bayou Well	272119082325101	02-07-94	337	54	IA	153	170	757	SWFWMD
Babcock well	265316081433401	03-12-93	917	700	UF	920	310	2,020	USGS
ROMP TR3-3 Suwannee well	265531082194803	05-28-87	900	680	UF	8,000	1,100	14,000	USGS
ROMP TR3-1 Suwannee well	265638082130706	02-02-86	620	600	UF	410	470	1,500	USGS
Englewood injection monitor MW-1	265716082205102	02-04-86	550	500	UF	2,400	264	4,490	USGS
North Port onsite monitor well	270058082152502	11-13-87	750	730	UF	7,910	1,450	15,000	USGS
North Port onsite monitor well	270058082152503	11-13-87	600	560	UF	5,400	975	10,900	USGS
Venetia 2 (Berry 4)	270203082213701	02-01-84	608	207	UF	460	730	1,500	USGS
Plantation zone 4 monitor well	270406082215901	03-11-87	650	630	UF	892	1,250	3,520	USGS
Venice Gardens injection monitor 800	270420082230502	06-10-85	800	770	UF	1,116	1,320	3,780	USGS
ROMP TR5-1 Suwannee well	270808082270502	11-23-87	510	492	UF	54	1,400	1,600	USGS
ROMP TR5-2 Suwannee well	270919082234205	05-07-86	700	510	UF	41	1,700	2,500	USGS
ROMP TR5-2 Ocala well	270919082234206	05-06-86	890	850	UF	20	1,600	2,400	USGS
Atlantic Utilities test/injection well	271853082280902	05-19-88	1,240	1,130	UF	117	1,040	1,800	USGS
Hancock and Lawrence	270256081472801	07-09-87	900	700	UF	340	180	954	USGS
Emerald Island Farms C	270313081391001	09-13-88	1,500	610	UF	290	190	954	USGS

Table 3. Chloride, sulfate, and dissolved-solids concentrations in water from selected wells --Continued

[Aq, aquifer; IA, intermediate aquifer system; UF, Upper Floridan aquifer; --- no data]

Site name	Identification number	Sample date	Depth (feet) below land surface	Casing (feet) below land surface	Aq	Chlo-ride (mg/L)	Sulfate (mg/L)	Dissol-ved solids (mg/L)	Source of data
Smith (Aborgia) W-6073	270333081473101	06-17-87	1,211	685	UF	460	190	1,240	USGS
NAFCO Groves FLRD	270347081342901	03-08-89	1,520	150	UF	290	130	889	USGS
Lettuce Lake	270414081584701	08-05-85	1,190	105	UF	161	207	729	USGS
Cromwell No. 1	270440081434401	09-13-88	1,500	666	UF	92	72	447	USGS
Roper Groves	270442081494301	06-16-87	1,189	640	UF	260	160	864	USGS
Gen. Development M-2	270540082001101	09-12-88	897	605	UF	68	450	915	USGS
General Development	270554082003601	08-19-80	1,411	1,326	UF	200	310	1,090	USGS
Dees (C. Harrison)	270725081500701	02-23-89	1,280	654	UF	120	260	793	USGS
Carlton 2 by 4 No. 5	271023081462301	08-17-88	1,500	540	UF	54	360	784	USGS
D.L. Cullifer	271113081574801	02-23-89	1,315	511	UF	40	340	792	USGS
ROMP 16 Floridan	271115081462701	06-17-87	942	757	UF	39	320	686	USGS
Bright Hour Ranch 35-25	271135081372501	08-19-88	1,478	180	UF	35	110	429	USGS
ROMP 15 Floridan	271232081392201	10-09-85	1,360	575	UF	39	329	658	USGS
Avant Groves	271314081445901	06-16-87	1,412	630	UF	35	320	754	USGS
Joshua J-14 (TRG)	271416081374601	08-18-88	1,492	193	UF	33	330	728	USGS
Cunningham AMAX NPFO 4	271610081565401	08-01-85	1,040	350	UF	30	693	1,240	USGS
W.F. Underhill (Conger)	271653081464701	06-17-87	1,300	460	UF	29	86	384	USGS
Sorrell Groves 17-26	271717081522601	06-17-87	893	511	UF	16	820	1,460	USGS
Joshua J-18.1 (TRG)	271743081374601	08-21-85	698	137	UF	12	216	672	USGS
Joshua J-36 (TRG)	271748081345101	08-18-88	1,361	180	UF	16	360	717	USGS
ROMP 26 Floridan	271757081493002	08-07-85	1,320	580	UF	16	357	701	USGS
Davis 10 Mi Grade 2	272036081384701	12-14-88	1,250	450	UF	12	330	637	USGS
Davis 10 Mi Grade 1	272043081384701	12-14-88	1,200	200	UF	13	290	598	USGS
Circle 5 Ranch (Bowen)	272118081473401	06-30-88	1,345	580	UF	14	3	271	USGS
Schoonover	272403081410501	12-14-88	1,261	425	UF	7	240	485	USGS
Edwin Sasser	272709081591701	06-30-88	1,280	479	UF	15	65	297	USGS
ROMP 31 Floridan	272714081545901	08-14-85	1,152	460	UF	12	101	359	USGS
ROMP 30 Floridan	272728081474701	08-14-85	1,266	380	UF	18	2	485	USGS
Zolfo Springs No. 1	272944081474001	12-09-87	1,002	350	UF	18	170	464	USGS
Zolfo Springs No. 2	272945081474101	12-09-87	933	350	UF	18	180	466	USGS
Albert Carlton	273033081513801	12-13-88	1,280	680	UF	22	22	314	USGS
M.A. Smith	273103081363701	09-25-85	849	66	UF	6	19	136	USGS
Doyle Carlton Jr.	273112081595601	12-13-88	1,360	900	UF	39	22	271	USGS
City of Wauchula No. 4	273254081480601	12-09-87	1,152	420	UF	10	250	535	USGS
Floyd Smith	273337081393301	02-23-89	1,119	178	UF	10	20	206	USGS
Peace Valley Groves	273608082023001	12-14-88	1,160	450	UF	14	64	283	USGS
C.F. Industries A	273744081565301	12-09-87	1,205	600	UF	7	70	258	USGS
C.F. Industries C	273821081564701	12-09-87	950	600	UF	9	79	271	USGS

Table 3. Chloride, sulfate, and dissolved-solids concentrations in water from selected wells --Continued

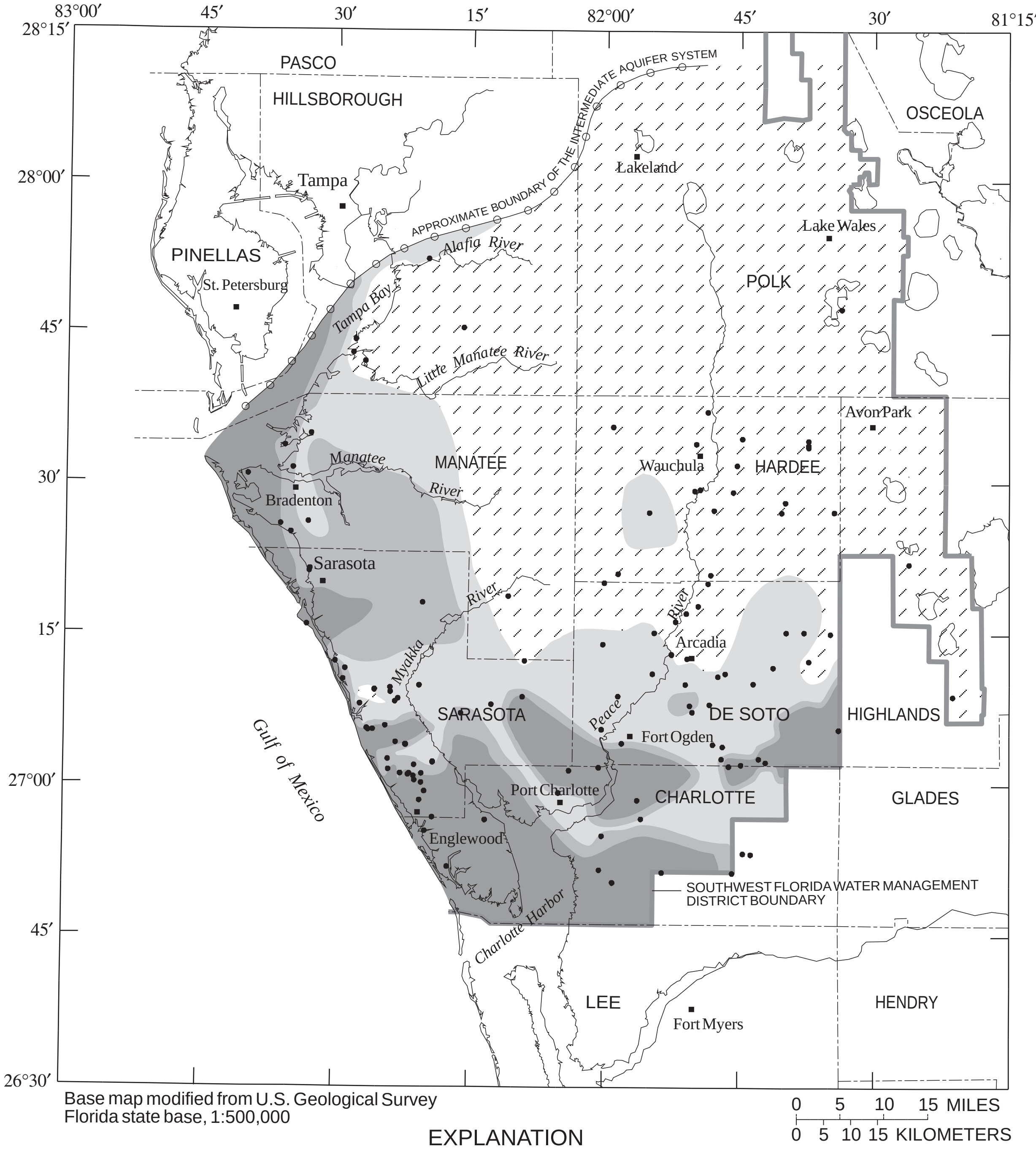
[Aq, aquifer; IA, intermediate aquifer system; UF, Upper Floridan aquifer; --- no data]

Site name	Identification number	Sample date	Depth (feet) below land surface	Casing (feet) below land surface	Aq	Chlo-ride (mg/L)	Sulfate (mg/L)	Dissol-ved solids (mg/L)	Source of data
City of Bowling Green 4	273821081493901	12-09-87	1,218	418	UF	10	330	646	USGS
Charlotte ROMP TR3-1 Suwannee	265638082130706	02-02-86	620	600	UF	410	470	---	USGS
Charlotte ROMP 10 Deep Creek 917	270152082002801	02-02-86	917	596	UF	180	410	---	USGS
De soto Hancock and Lawrence	270256081472801	07-09-87	900	700	UF	340	180	---	USGS
Sarasota ROMP TR5-2	270919082234205	10-06-87	700	510	UF	44	1,400	---	USGS
De Soto ROMP 16 Ocala	271115081462701	06-17-87	942	757	UF	39	320	---	USGS
De Soto ROMP 26	271757081493002	02-05-86	580	132	UF	14	340	---	USGS
Coca Cola well Highlands	272408081232501	05-31-89	595	546	UF	16	3	---	USGS
Manatee ROMP 32-2	272814082034802	11-02-87	600	560	UF	20	77	---	USGS
Hardee Zolfo Springs 1	272944081474001	02-05-86	1,000	350	UF	17	180	---	USGS
Hillsborough Sun City 1	274318082202801	02-04-86	800	271	UF	11	190	---	USGS
Hillsborough ROMP 48	274427082083701	02-03-86	541	215	UF	15	42	---	USGS
Polk Lake Garfield Nurseries	274910081452201	02-03-86	817	316	UF	8	16	---	USGS
Pebbledale Road	275009081540901	02-23-89	303	288	UF	10	28	---	USGS
ROMP TR 1-2 SWNN	265026081585401	01-12-94	1,184	980	UF	994	264	2,110	SWFWMD
ROMP TR 3-1 SWNN	265638082130701	03-25-94	620	600	UF	454	458	1,532	SWFWMD
ROMP TR 3-3 SWNN	265531082194801	03-20-94	900	680	UF	8,130	1,103	14,990	SWFWMD
Cromwell Well No. 4	270440081434401	03-31-94	1,500	666	UF	380	135	969	SWFWMD
DT Brown G-36	270223081421101	08-12-93	925	632	UF	317	56	652	SWFWMD
Emerald Island Farms	270313081391001	03-31-94	1,300	610	UF	163	140	611	SWFWMD
GDU Well M-2	270540082001101	03-14-94	897	605	UF	103	344	807	SWFWMD
Gen Development Corp Avon Park	270554082003601	03-24-94	1,411	1,326	UF	276	285	1,008	SWFWMD
Hancock & Lawrence	270256081472801	03-25-94	900	700	UF	306	162	809	SWFWMD
Morgan Deep	270410081565201	03-30-94	1,010	208	UF	90	230	679	SWFWMD
ROMP 15 Deep	271232081392201	03-25-94	1,360	586	UF	31	345	734	SWFWMD
ROMP 17 SWNN	271026081583601	01-06-94	670	620	UF	65	382	827	SWFWMD
ROMP 28	272207081260401	12-12-91	2,060	684	UF	11	5	211	SWFWMD
ROMP 123 Deep	274031082150401	01-06-94	620	117	UF	13	16	265	SWFWMD
ROMP 48	274427082083701	02-08-94	541	215	UF	12	46	235	SWFWMD
ROMP 49 SWNN	274546082151601	01-13-94	526	410	UF	13	56	270	SWFWMD
ROMP 50	274240082212701	01-06-94	562	200	UF	13	165	428	SWFWMD
ROMP TR 12-3	280034082323701	04-16-92	345	310	UF	290	59	842	SWFWMD
ROMP TR 9-2 Ocala	274554082233801	01-24-94	677	622	UF	367	452	1,310	SWFWMD
ROMP TR 9-2 Suwannee (Pump)	274554082233801	01-24-94	460	250	UF	172	377	946	SWFWMD
ROMP TR 9-3 Suwannee	274428082251501	01-28-94	525	289	UF	433	908	2,274	SWFWMD
Florida Power & Light at Piney Point	273718082315501	03-14-94	946	104	UF	507	566	1,654	SWFWMD
Manatee Fruit No. 3	272807082401501	01-10-94	492	262	UF	663	590	2,010	SWFWMD
Manatee Fruit-Midway	272738082384701	12-20-93	511	415	UF	198	196	857	SWFWMD

Table 3. Chloride, sulfate, and dissolved-solids concentrations in water from selected wells --Continued

[Aq, aquifer; IA, intermediate aquifer system; UF, Upper Floridan aquifer; --- no data]

Site name	Identification number	Sample date	Depth (feet) below land surface	Casing (feet) below land surface	Aq	Chlo-ride (mg/L)	Sulfate (mg/L)	Dissol-ved solids (mg/L)	Source of data
Manatee Injection Well	272705082373501	03-09-94	1,150	980	UF	3,760	1,259	7,890	SWFWMD
Midway Groves	272438082325201	03-09-94	796	331	UF	96	500	987	SWFWMD
Myakka Head No. 5	272735082083401	03-04-94	560	514	UF	12	97	326	SWFWMD
Perico Island Well	272949082404001	12-20-93	600	170	UF	546	507	1,880	SWFWMD
ROMP 23-1 Deep	271852082104101	01-10-94	1,000	904	UF	16	438	813	SWFWMD
ROMP 32 Avon Park	272814082034801	01-11-94	1,215	909	UF	11	81	---	SWFWMD
ROMP 33 Suwannee	272728082152901	03-11-94	750	404	UF	17	69	361	SWFWMD
ROMP 39 Avon Park	272728082150501	03-25-94	1,120	950	UF	12	118	370	SWFWMD
ROMP 39 SWNN	272728082150501	04-08-94	700	523	UF	15	127	369	SWFWMD
ROMP TR 7-2 Sh U Floridan	272612082330101	02-09-94	708	358	UF	270	523	1,346	SWFWMD
ROMP TR 7-4 SWNN	272539082292001	01-26-94	800	500	UF	38	344	722	SWFWMD
ROMP TR 7-4 Tampa	272539082292001	01-26-94	500	380	UF	29	230	546	SWFWMD
ROMP TR 8-1 Ocala	273458082324701	01-07-94	680	640	UF	97	479	1,025	SWFWMD
ROMP TR 8-1 Suwannee - pumped	273458082324701	01-07-94	530	390	UF	147	490	1,090	SWFWMD
ROMP TR 8-1 Upper Avon Park	273458082324701	01-07-94	940	900	UF	1,307	717	3,163	SWFWMD
Snead’s Island	273159082373101	01-10-94	525	200	UF	232	663	1,490	SWFWMD
ROMP 40 Avon Park	273851082031501	01-27-94	1,140	408	UF	11	44	224	SWFWMD
City of Sarasota 21st and RR Well	272120082322701	02-09-94	557	120	UF	212	835	1,699	SWFWMD
U Florida Cities Test Well	271619082240201	01-07-94	446	104	UF	40	579	1,069	SWFWMD
Macarthur Tract 10H	271242082171701	03-03-94	312	272	UF	29	354	790	SWFWMD
Macarthur Tract 14FS	270807082123001	02-24-94	550	500	UF	112	489	1,107	SWFWMD
OM-41	270928082172401	03-28-94	750	700	UF	24	753	1,283	SWFWMD
Plantation Monitor Well Suwannee	270406082220101	02-24-94	650	630	UF	966	1,302	3,468	SWFWMD
ROMP 18 SWNN	271137082074801	03-30-94	845	505	UF	33	218	598	SWFWMD
ROMP 19 ELAM	271021082151601	03-03-94	425	410	UF	33	526	1,017	SWFWMD
ROMP 19 WLAM	270959082203001	03-03-94	420	410	UF	31	802	1,347	SWFWMD
ROMP 20 Ocala-Avon Park	271138082284601	03-10-94	1,165	1,105	UF	1,365	1,820	4,753	SWFWMD
ROMP 20 SWNN	271138082284601	03-10-94	840	500	UF	537	1,754	3,415	SWFWMD
ROMP 22 SWNN	271813082201201	02-18-94	635	400	UF	22	378	767	SWFWMD
ROMP TR 4-2	270240082235701	07-19-93	475	460	UF	286	772	1,761	SWFWMD
ROMP TR 5-1 Suwannee	270808082270501	03-11-94	510	492	UF	78	1,552	2,438	SWFWMD
ROMP TR 5-2 Ocala	270919082234201	02-16-94	890	850	UF	20	1,645	2,534	SWFWMD
ROMP TR 5-2 SWNN	270919082234201	02-16-94	630	510	UF	43	1,740	2,704	SWFWMD
Sarasota Co. Test Well No. 1	272316082302601	02-09-94	583	350	UF	68	495	1,009	SWFWMD
Venice 2E	270705082250101	03-04-94	580	514	UF	301	1,701	2,947	SWFWMD
ROMP 14	270858081211101	07-08-92	1,249	689	UF	6	8	150	SWFWMD
ROMP 28	272207081260401	12-10-91	2,060	604	UF	8	8	228	SWFWMD



EXPLANATION

GENERALIZED DISTRIBUTION OF CHLORIDE CONCENTRATION, in milligrams per liter

- < 50
- 51-100
- 101-250
- >250
- WELL LOCATION

Figure 19. Generalized distribution of chloride in water from the intermediate aquifer system.

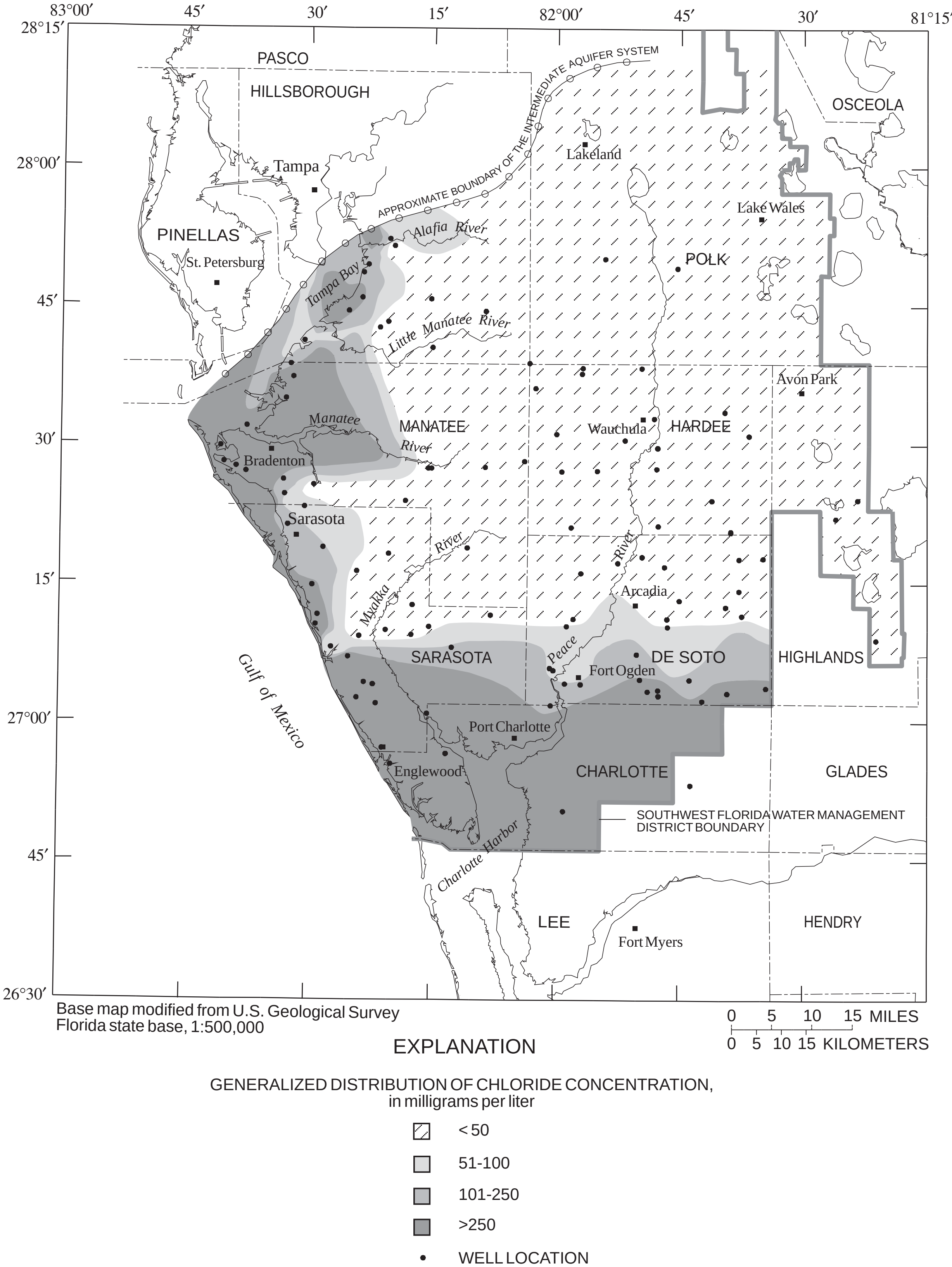


Figure 20. Generalized distribution of chloride in water from the Upper Floridan aquifer.

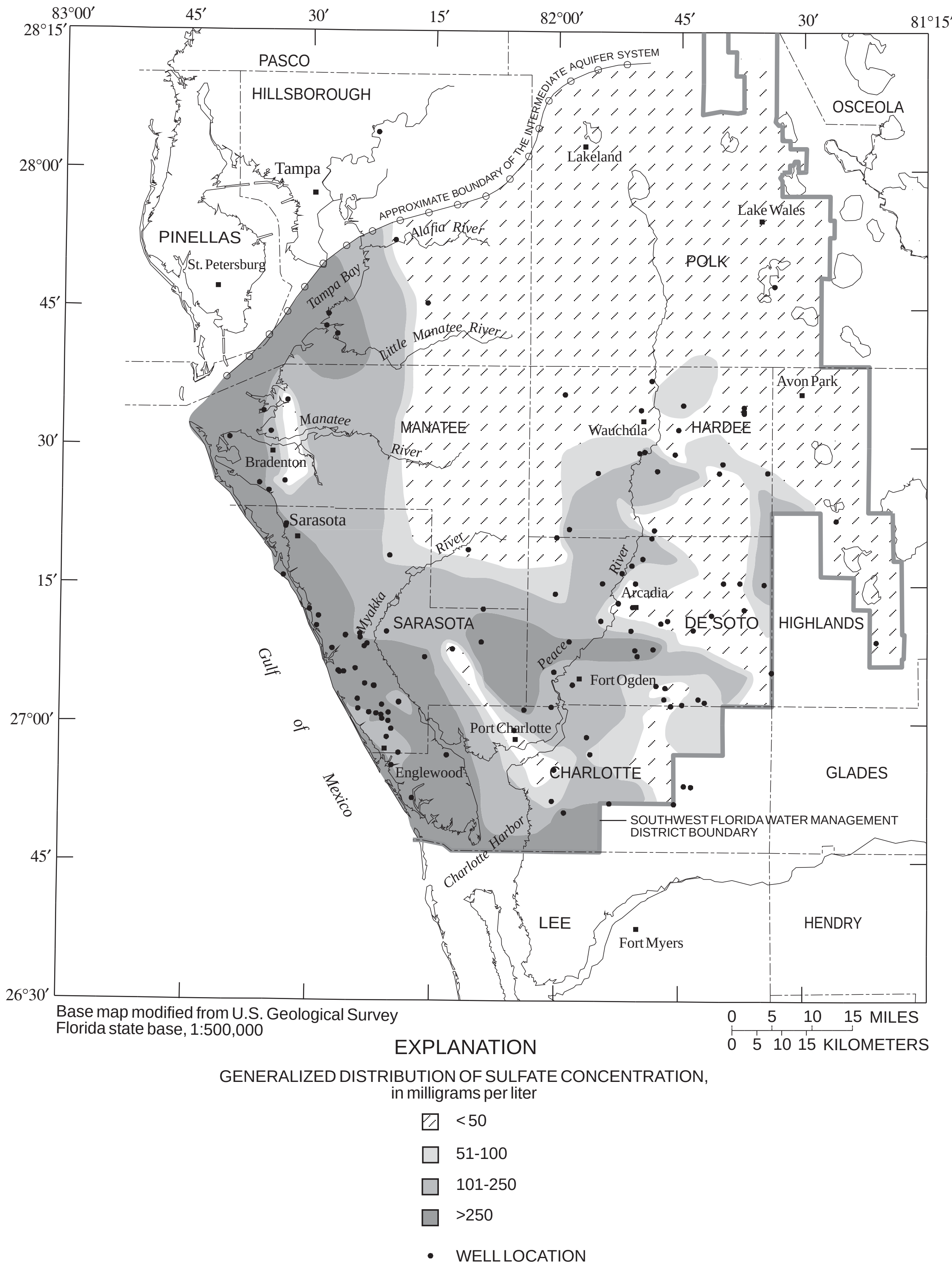


Figure 21. Generalized distribution of sulfate in water from the intermediate aquifer system.

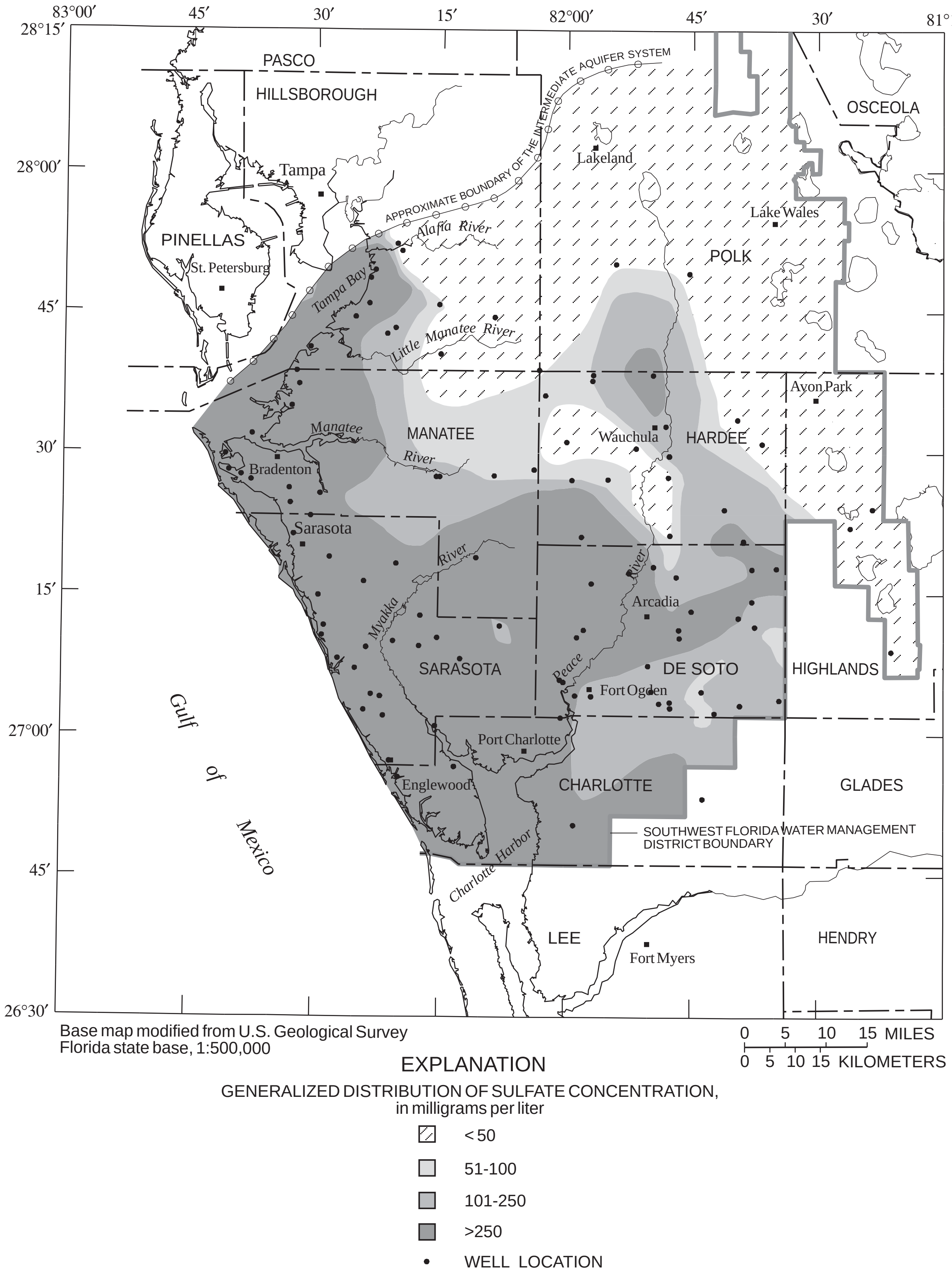


Figure 22. Generalized distribution of sulfate in water from the Upper Floridan aquifer.

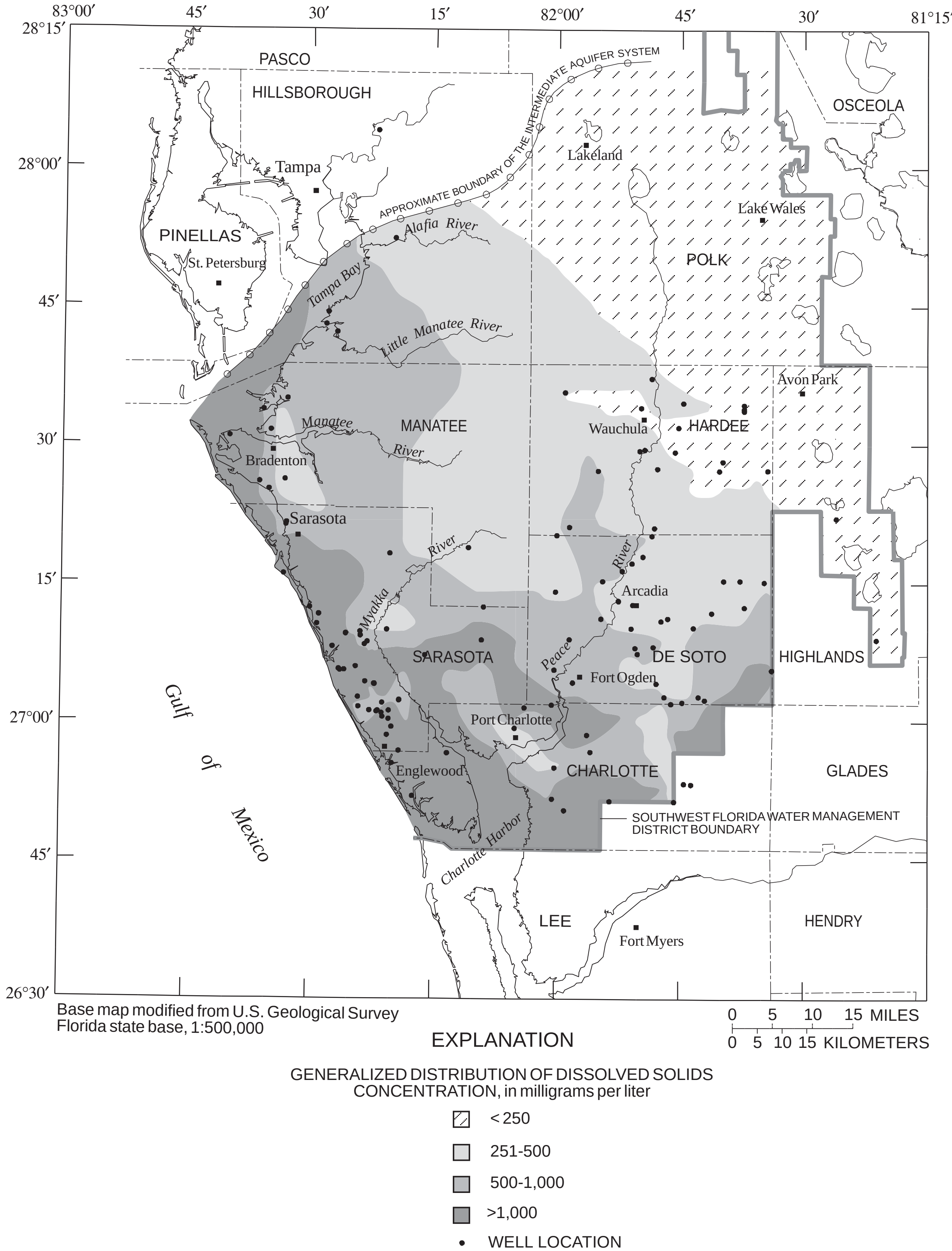


Figure 23. Generalized distribution of dissolved solids in water from the intermediate aquifer system.

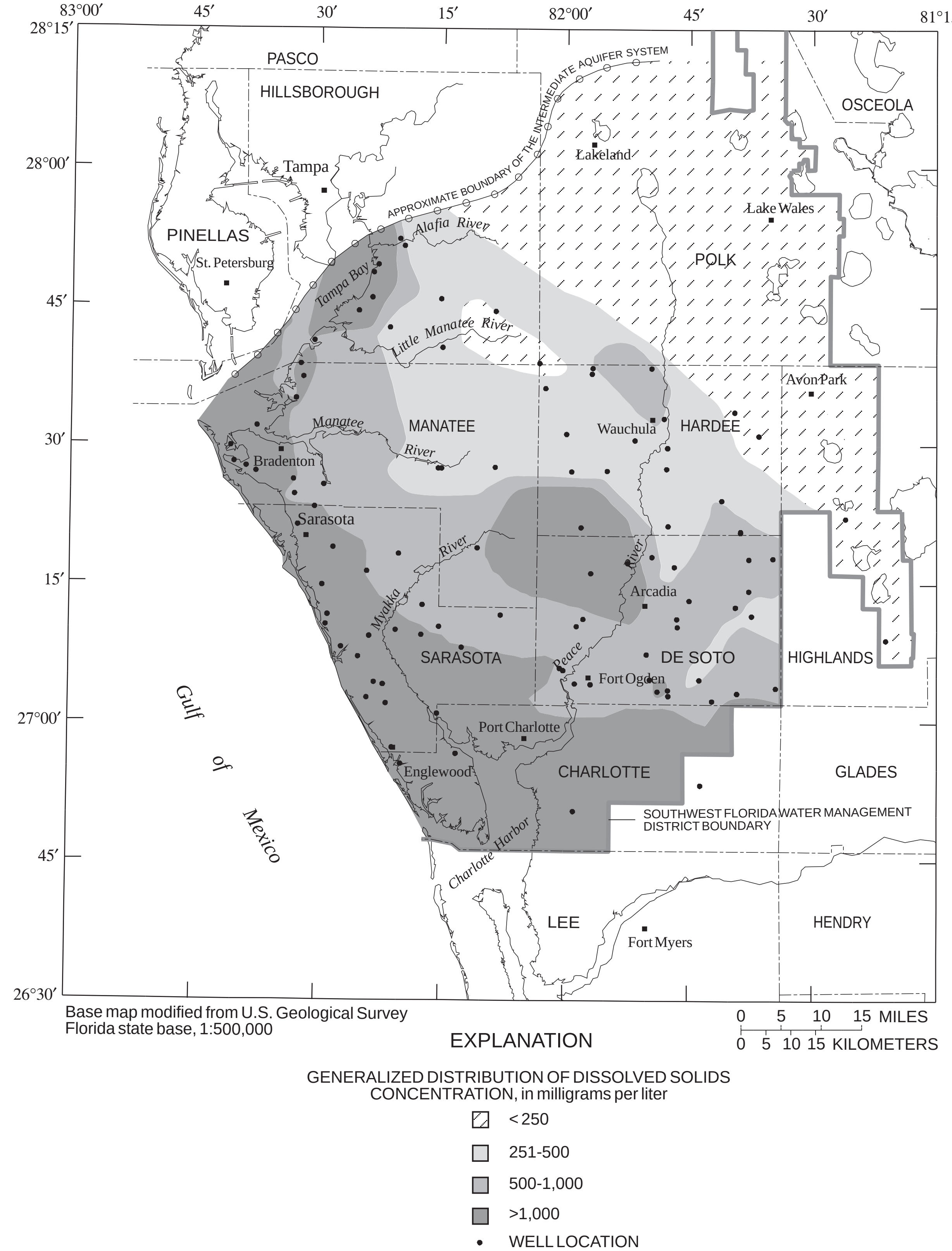


Figure 24. Generalized distribution of dissolved solids in water from the Upper Floridan aquifer.

aquifer system and the Upper Floridan aquifer are less than 50 mg/L (figs. 19 and 20, respectively). Chloride concentrations increase towards the coast, and in water from many wells in Charlotte, Sarasota, Manatee, and De Soto Counties, concentrations exceed 250 mg/L in water from both aquifers. Chloride concentrations range from 3 mg/L in the central and eastern regions of the study area to about 4,500 mg/L in southern Charlotte County in water from the intermediate aquifer system, and from 6 mg/L in the central and eastern regions of the study area to approximately 8,000 mg/L in southern Charlotte County in water from the Upper Floridan aquifer.

Sulfate

In the intermediate aquifer system, sulfate is derived mostly from upward flow of high-sulfate water from the Upper Floridan aquifer and limited amounts from pyrite oxidation. In the Upper Floridan aquifer, sulfate is derived from mixing of seawater with freshwater and from the dissolution of gypsum and anhydrite (calcium-sulfate minerals) contained principally in the Avon Park Formation (Wilson, 1977). Two other identified sources of sulfate in recharge areas of the intermediate aquifer system and the Upper Floridan aquifer are oceanic aerosols and the atmospheric oxidation of sulfides (Rye and others, 1981).

The maximum sulfate concentration recommended for public water supplies in Florida is 250 mg/L (Florida Department of Environmental Regulation, 1985). Throughout most of the study area, the sulfate concentrations in water from the intermediate aquifer system are less than 100 mg/L. Sulfate concentrations in water from the intermediate aquifer system range from approximately 1 mg/L in many parts of the study area to slightly more than 1,600 mg/L south of the city of Sarasota. The areal distribution of sulfate in water from the intermediate aquifer system is highly variable (fig. 21). This highly variable distribution of sulfate in water from the intermediate aquifer system may be from upwelling of high-sulfate ground-water from the Upper Floridan aquifer; improperly cased wells open to multiple aquifers containing water of varying quality; or through leaky and corroded well casings in areas of poor-quality water.

Throughout most of the study area, the sulfate concentrations in water from the Upper Floridan aquifer are greater than 100 mg/L (fig. 22). Sulfate concentrations in water from the Upper Floridan aquifer range from approximately 2 mg/L in the central region of the study area to about 1,800 mg/L near the City of Sarasota.

Along the coast and in the Peace River Valley, water with high concentrations of sulfate has discharged into the intermediate aquifer system from the deeper Upper Floridan aquifer, as indicated on figures 21 and 22. In Hardee and De Soto Counties, many deep irrigation wells tap the Avon Park Formation where high concentrations of sulfate occur (Wilson 1977). Pumping wells that tap these deep formations containing high sulfate concentrations may facilitate mixing and cause contamination of the upper zones when wells are open to multiple units.

Dissolved Solids

Dissolved solids in ground water is a measure of the sum of concentrations of dissolved mineral constituents contained in the water. The predominant sources of dissolved solids in ground water in the study area are mineral dissolution reactions and mixing of seawater with freshwater. Dissolved solids concentrations generally increase with depth because as rock temperature increases with depth, the solubility and the rate of dissolution of the rock minerals increase.

The maximum dissolved solids concentrations recommended for public water supply in Florida is 500 mg/L (Florida Department of Environmental Regulation, 1985). However, use of water with concentrations of up to 1,000 mg/L has been permitted when no other source is available. The areal distribution of dissolved solids concentrations in water from the intermediate aquifer system is highly variable (fig. 23). For approximately half of the study area, the dissolved solids concentrations in water from the intermediate aquifer system are less than 500 mg/L. Dissolved solids concentrations range from approximately 100 mg/L in northeastern Hardee County to more than 8,600 mg/L along the coast in southern Charlotte County. Dissolved solids concentrations in water from the intermediate aquifer system tend to increase along the coast and the Peace River Valley, which are natural discharge areas for the underlying Upper Floridan aquifer (fig. 23).

Throughout most of the study area, the dissolved solids concentrations in water from the Upper Floridan aquifer are greater than 500 mg/L and range from approximately 130 mg/L in northeastern Hardee County to 15,000 mg/L in southern Sarasota County (fig. 24). The areal distribution of dissolved solids concentrations closely matches the areal distribution of chloride and sulfate in water from the Upper Floridan aquifer. In areas where mixing with seawater has occurred, chloride is the major component of dissolved solids. In areas where there is a high rate of dissolution of gypsum, sulfate is the major component of dissolved solids.

POTENTIAL FOR WATER-QUALITY DEGRADATION

Degradation of water quality may occur in both the intermediate aquifer system and Upper Floridan aquifer from improperly cased wells open to multiple aquifers containing water of varying quality, through leaky and corroded well casings in zones of poor-quality water, and from saltwater intrusion. Degradation of water quality in the intermediate aquifer system may also occur from the natural discharge of highly mineralized water and from ground-water development in the underlying Upper Floridan aquifer.

The Avon Park Formation is a highly productive water-bearing unit in the Upper Floridan aquifer. Numerous irrigation wells 10 to 16 in. in diameter are open to this formation and yield as much as 5,000 gal/min. In the southern part of the study area, water in the Avon Park Formation is highly mineralized and may degrade the fresher zones within the Upper Floridan aquifer and intermediate aquifer system when wells are open to multiple zones. Induced head gradients could result from irrigation pumpage which would increase the amount of upwelling of highly mineralized ground water.

In many parts of the study area, particularly in Manatee, Sarasota, and Charlotte Counties, the use of black-iron casing for well construction has been widespread. This type of casing deteriorates relatively rapidly because of the corrosive effects of high chloride and sulfate concentrations in the ground water. These corroded wells may leak highly mineralized water into overlying fresher zones in areas where there is an upward component of flow. In addition, contamination of underlying aquifers has occurred from downward flow of saltwater through the corroded casings of wells drilled in areas adjacent to tidal water bodies in Lee County (Boggess and others, 1977).

Ground-water development may affect the magnitude of flow, the natural flow direction, and the water quality between the aquifers. In the southern part of the study area where the Upper Floridan aquifer discharges into the intermediate aquifer system, upward flow would be reduced during irrigation periods because head differences are less between the two aquifers. During nonirrigation periods, the Upper Floridan aquifer heads recover and the upward head gradient and flow rate increase between the two aquifers (Metz, 1995). In this discharge area, flow rates of highly mineralized water would increase during nonirrigation periods. In the northern part of the study area, which is a recharge area, the opposite condition exists. During irrigation periods, the downward head gradient and flow rate increase between the intermediate aquifer system and Upper Floridan aquifer. In the study area, the downward flow gradient could be reversed and could extend the area in which upward flow of poor-quality water occurs.

A geographical area was delineated to determine where a potential for water-quality degradation exists because of improperly cased wells. This area was delineated based on the location of poor-quality water and where there is an upward component of flow from the Upper Floridan aquifer. The area of poor-quality water was defined by maps of the Upper Floridan aquifer where chloride concentrations were greater than 250 mg/L (fig. 20), sulfate concentrations were greater than 250 mg/L (fig. 22), and dissolved solids concentrations were greater than 1,000 mg/L (fig. 24). The upward component of flow was based on head difference maps between the intermediate aquifer system and Upper Floridan aquifer (fig. 4 and 5). The area where a potential for water-quality degradation exists includes parts of Hillsborough, Manatee, Sarasota, Charlotte, De Soto, and Hardee Counties (fig. 25).

ESTIMATED MAGNITUDE OF INTERAQUIFER FLOW

An evaluation was performed to estimate the potential magnitude of interaquifer flow in wells open to multiple aquifers within the study area. Information that was needed for this evaluation was the distribution of wells open to multiple aquifers and the open borehole flow rates. A well inventory was performed,

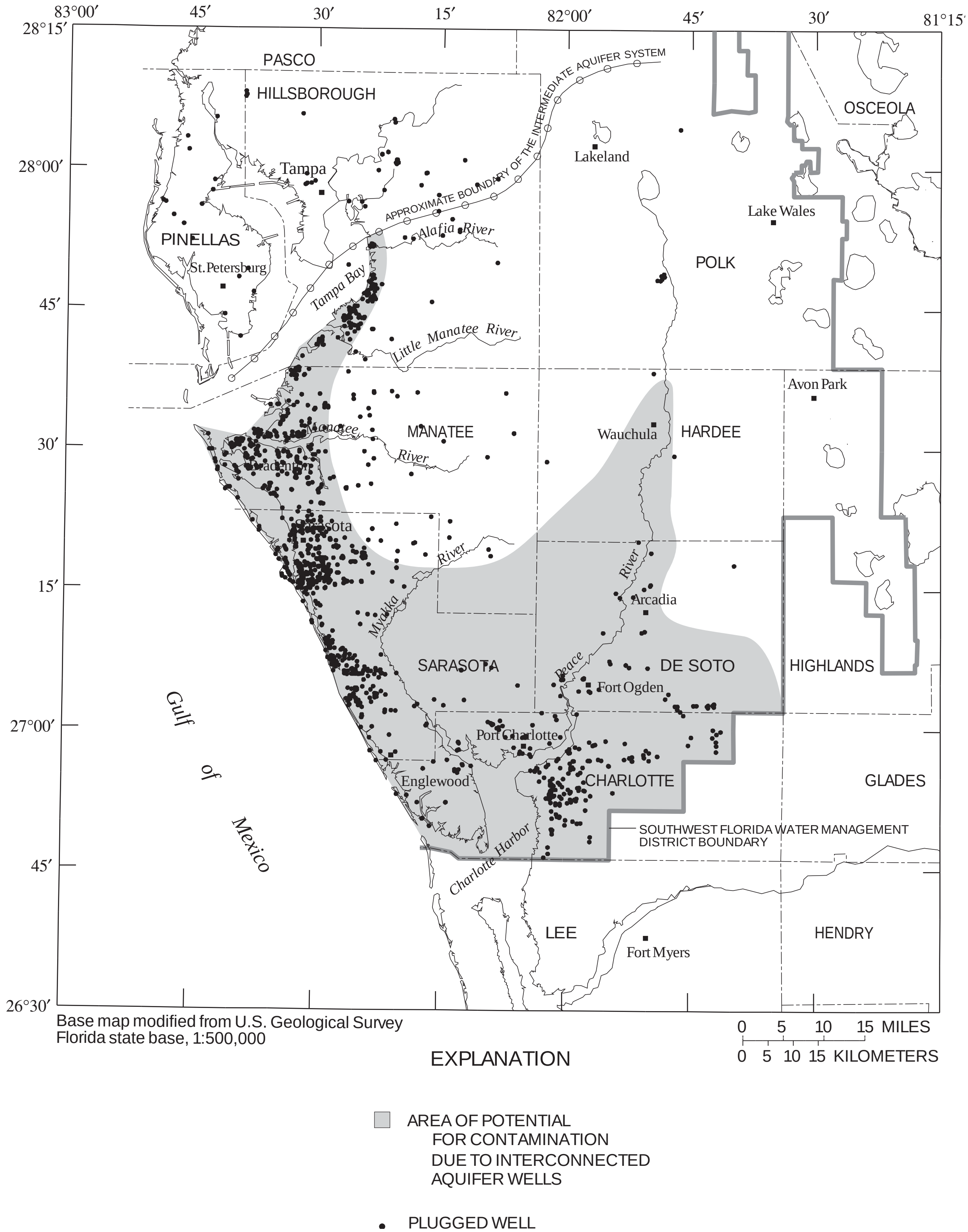


Figure 25. Area where there is a potential for water-quality degradation as a result of interconnected aquifers and locations of wells that have been plugged.

using the Water Use Permitting (WUP) data base of SWFWMD, to determine the occurrence and distribution of interconnected aquifer wells in the study area. Water use permits do not delineate wells by aquifer; therefore, selection of wells was based on well-construction data, including total depth and cased interval, and aquifer depth. Many wells in this data base did not have reported casing depths. Metz (1995), conducted a detailed inventory of Upper Floridan aquifer wells in Hardee and De Soto Counties and concluded that 10 percent of wells are open only to this unit; the remaining wells are open to both the intermediate aquifer system and Upper Floridan aquifer. Therefore, for the purpose of this evaluation, wells that had no reported casing depth were considered open to both the intermediate aquifer system and Upper Floridan aquifer. From this above approach, approximately 8,000 wells were reported and estimated to be open to both the intermediate aquifer system and the Upper Floridan aquifer (fig. 26). This inventory is considered incomplete because some wells were installed prior to well permitting regulations and well information is unknown or was not reported correctly. Even though this information is incomplete, it gives an indication of the number and distribution of wells that may provide a conduit for ground water to move from zones of higher head to zones of lower head, thus circumventing the slower route of leakage through the confining units.

In this evaluation, interaquifer flow rates obtained from the measurements made by the impeller and heat-pulse flowmeters were used to estimate the potential magnitude of interaquifer flow. A degree of error must be considered to be inherent in this evaluation because interaquifer flow rates in wells were not measured concurrently. For the flow rates to be accurate in this method of evaluation, all measurements must be made concurrently because flow rates may increase or decrease seasonally.

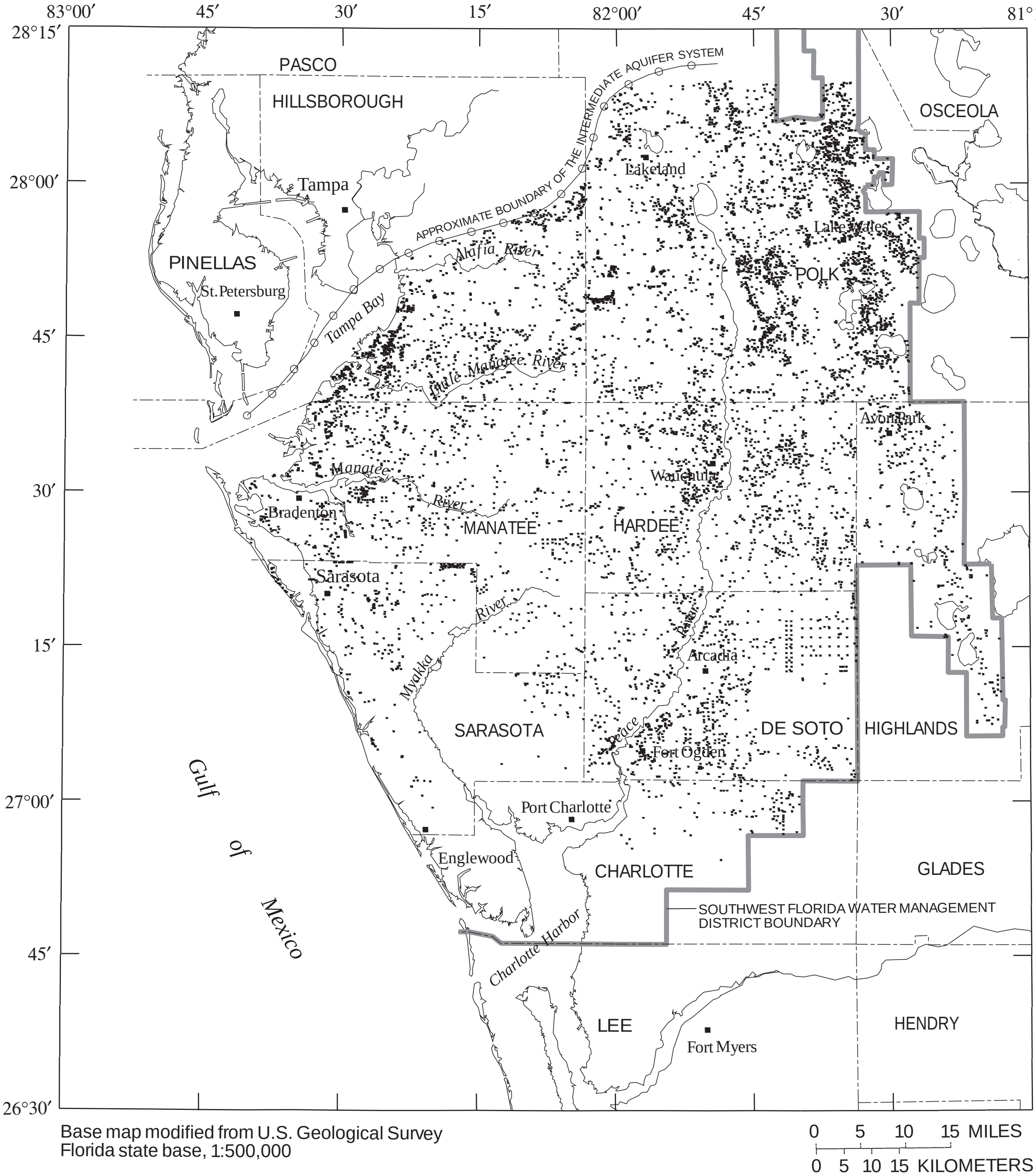
A Geographical Information System (GIS) was used to aid in the estimation of interaquifer flow rates in wells open to both the intermediate aquifer system and the Upper Floridan aquifer. The ARC/INFO GIS system was used for the input data-base design and the calculation of interaquifer flow rates for the approximate 8,000 wells. A 1-mi by 1-mi grid was used to assign a location to each well and to total the number of wells in each grid cell (fig. 27). An interpolated 3-dimensional flow surface was created with measured flow rates from both the impeller and heat-pulse flowmeters (fig. 10 and 17). Flow rates were assigned either an upward or downward flow direction based on field observations and head difference maps. This interpolated flow surface was then intersected with the grid network containing the apportioned wells. The total number of wells in each grid cell was multiplied by the assigned flow rate to obtain a cumulative flow rate for each cell. Cumulative flow rates were then summed for upward and downward flow direction.

Using this approach, an estimated cumulative downward flow rate of 127 Mgal/d is being lost to the Upper Floridan aquifer from the intermediate aquifer system through interaquifer wells. This loss of water to the Upper Floridan aquifer may result in a loss of artesian pressure in the intermediate aquifer system and may change the natural flow gradient in some regions of the study area. Since the water of the intermediate aquifer system is of better quality than that of the Upper Floridan aquifer, this downward flow should not adversely affect the water quality of the Upper Floridan aquifer.

An estimated cumulative upward flow rate of 85 Mgal/d is discharging into the intermediate aquifer system from the Upper Floridan aquifer through interaquifer wells. The location of upward and downward flow through open boreholes in gallons per day is shown in figure 27. The estimated upward flow is considered low in Sarasota County because there are no records for many of the wells in the central part of the county. In Charlotte County, many wells were plugged, well records were nonexistent, or many wells were not drilled into the deeper Upper Floridan aquifer because the water was highly mineralized. In the majority of this designated area of upward flow, concentrations of chloride, sulfate, and dissolved solids exceed 250, 250, and 1,000 mg/L, respectively, and this upward borehole flow is contaminating the intermediate aquifer system.

QUALITY OF WATER IMPROVEMENT PROGRAM

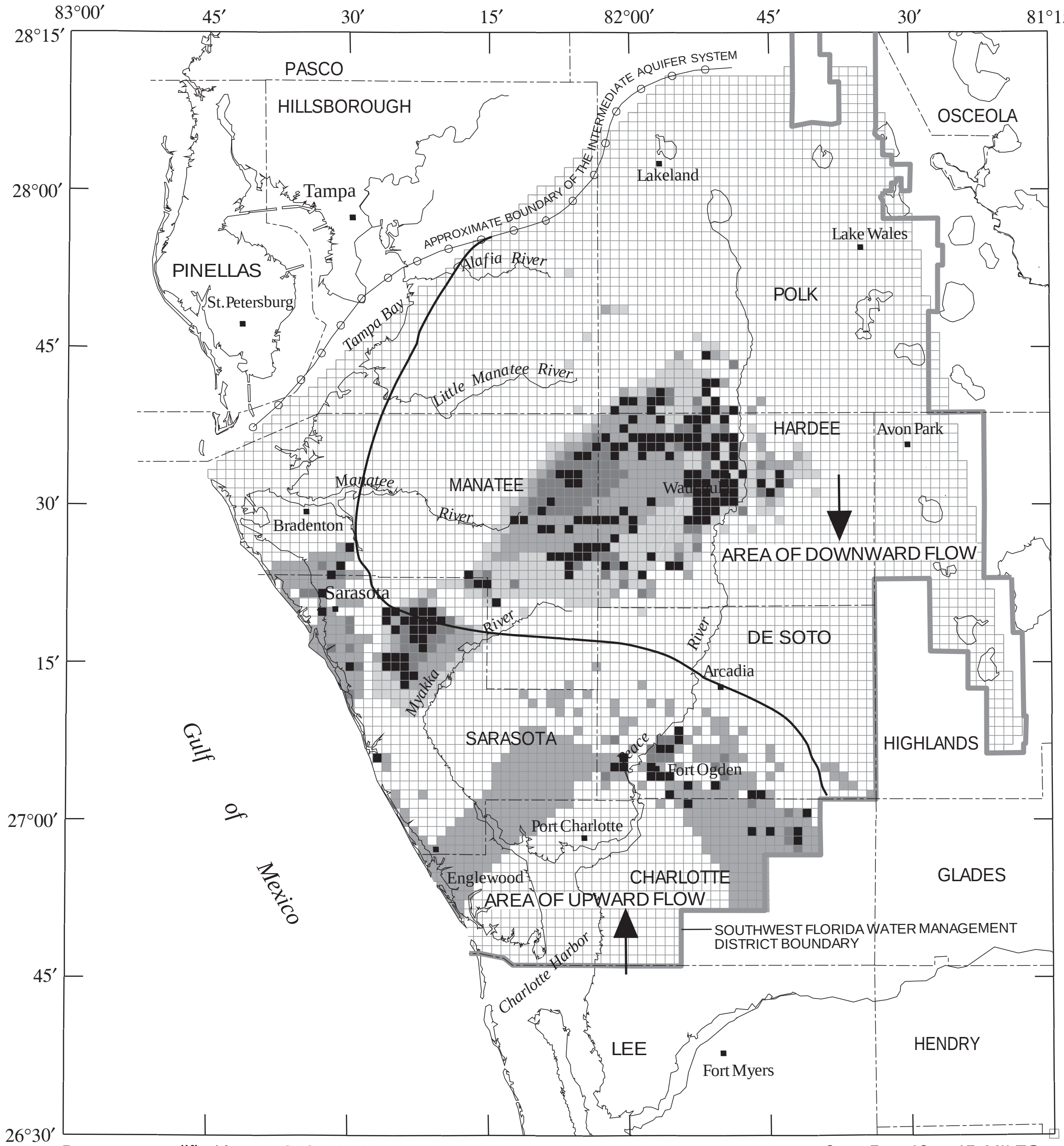
Southwest Florida Water Management District began the Quality of Water Improvement Program (QWIP) in 1974 to restore hydrologic conditions altered by poorly installed wells or deteriorating casings. More than 3,000 wells have been inspected and approximately 1,350 have been plugged (fig. 25) as of May 1994. Hutchinson (1992) concluded that



EXPLANATION

· WELLS OPEN TO THE INTERMEDIATE AQUIFER SYSTEM AND UPPER FLORIDAN AOUIFER

Figure 26. Locations of wells in the study area that are reported and estimated to be open to both the intermediate aquifer system and the Upper Floridan aquifer.



Base map modified from U.S. Geological Survey Florida state base, 1:500,000

EXPLANATION

ESTIMATED UPWARD AND DOWNWARD FLOW THROUGH OPEN BOREHOLES--in gallons per day

- 0 - 50,000
- 50,001 - 100,000
- 100,001 - 150,000
- 150,001 - 200,000
- GREATER THAN 200,000
- APPROXIMATE BOUNDARY BETWEEN AREAS OF UPWARD AND DOWNWARD FLOW

Figure 27. Grid network with cumulative downward and upward flow rates for wells open to both the intermediate aquifer system and the Upper Floridan aquifer.

dissolved solids concentrations in water from a supply well decreased 50 percent after a nearby uncontrolled flowing artesian well was plugged.

Sutcliffe and Joyner (1966) conducted a detailed study in Sarasota County using packers in wells for isolating various strata within an existing well for the collection of water samples and measurements of water levels. They concluded that: (1) better quality of water may be obtained in some areas by selectively casing wells; (2) contamination of the water within the various producing zones of a well may occur even though the well has flowed continuously; and 3) improperly cased flowing wells, which are capped and contain water of poor quality, rapidly contaminate all the strata in the area to the extent that the strata that formerly contained good water no longer contain potable water.

Through an understanding of the hydrogeologic system in the study area, various techniques can be evaluated and undertaken to promote the most efficient and beneficial use of the ground-water resource. Alternative techniques that could help prevent further contamination of the aquifers include: (1) accurate reporting of well construction and use by land owners and well drillers; (2) selective casing of wells to obtain better water quality; (3) continued plugging of wells; and (4) inspection and monitoring of wells with black-iron casing in areas of poor-quality water.

SUMMARY AND CONCLUSIONS

Thousands of deep artesian wells were drilled into the Upper Floridan aquifer in west-central Florida prior to the adoption of well-drilling regulations in the 1970’s. The wells usually were completed with a short length of casing through the unconsolidated sediments and were left open to multiple aquifers containing water of varying quality. These open boreholes serve as a source of water-quality degradation within the aquifers when vertical flow is induced by hydraulic-head differences. The area where there is a potential for water-quality degradation because of interconnected aquifers includes the southern half of the Southwest Florida Water Management District where both the intermediate aquifer system and Upper Floridan aquifer exist.

The hydrogeologic units underlying the study area consist of deposits of sand, clay, marl, and carbonate that were deposited primarily in a marine environment. Principal hydrogeologic units are the surficial aquifer, the intermediate aquifer system, and the Upper Floridan aquifer. The Upper Floridan aquifer is the most productive aquifer in the study area and supplies more than 10 times the amount of water pumped from either the surficial aquifer or the intermediate aquifer system. Most wells that penetrate the Upper Floridan aquifer are constructed so that they are also open to the intermediate aquifer system.

In wells open to multiple aquifers, well construction, the relative permeabilities of the aquifers, and the head differences between aquifers control the magnitude of vertical borehole flow. In September 1993, heads in the intermediate aquifer system were as much as 70 ft higher than heads in the Upper Floridan aquifer near the corner of Hillsborough, Manatee, Polk, and Hardee Counties. Water is transmitted downward through the confining unit and recharges the Upper Floridan aquifer. The head gradient reverses in the southern part of the study area where the Upper Floridan aquifer has higher heads than those of the intermediate aquifer system by as much as 20 ft in western Sarasota County and central Charlotte County. In these areas, water is transmitted upward through the lower confining unit and discharges to the intermediate aquifer system.

The head differences between the intermediate aquifer system and the Upper Floridan aquifer in May 1994 represent conditions near the end of a dry season during which extensive irrigation pumpage has occurred. In May 1994, heads in the intermediate aquifer system were as much as 90 ft higher than heads in the Upper Floridan aquifer near the corner of Hillsborough, Manatee, Polk, and Hardee Counties. In the southern part of the study area, heads were higher in the Upper Floridan aquifer than the intermediate aquifer by as much as 20 ft.

The determination of interaquifer flow was accomplished by obtaining geophysical logs of caliper, gamma, temperature, flow, and fluid conductivity, and by the collection of water-quality samples and video borehole data. Three different flowmeters were used to determine interaquifer flow-- an impeller flowmeter, a heat-pulse flowmeter, and a borehole video camera with an impeller flowmeter attachment because of the sensitivities and limitations of each meter. The advantage of the impeller flowmeter is that it can be used to measure high velocities. The limitations of the impeller flowmeter are that the direction of flow (either upward or downward) can not be distinguished accurately, and the meter has a lower detection limit of about 5 ft/min. The advantage of the heat-pulse flowmeter is that low-flow volumes and locations of the low-flow contributing zones can be detected. The limitation of the heat-pulse flowmeter is that velocities greater than 20 ft/min can not be measured accurately. In areas where direction of internal borehole flow could not be distinguished, the impeller flowmeter was connected to a video camera. The design proved to be useful in this study and enabled the viewer to observe a continuous profile of the well borehole and the direction of flow, to locate fractures or cavities associated with ground-water flow, and to inspect the casing for holes or breaks.

Borehole geophysical surveys were conducted in 87 wells throughout the study area to assess the nature of interaquifer borehole flow in wells open to multiple permeable zones. During the initial survey of each well, flow measurements were made using an impeller flowmeter. Of the 87 wells, 17 (20 percent) had detectable internal flow using the impeller flowmeter. The internal flow rates ranged from 10 to 300 gal/min. A heat-pulse flowmeter was used in 19 wells in which flow was not detected using the impeller flowmeter. Of 19 wells measured, 18 (95 percent) had detectable internal borehole flow, with values ranging from 0.3 to 10 gal/min.

Composite geophysical logs of fluid conductivity, caliper, temperature, gamma, and flow and water-quality data indicate that mineralized ground water from the Upper Floridan aquifer has moved upward through many open boreholes into the overlying fresher water zones in areas where there is an upward component of flow. Composite geophysical logs and water-quality data also indicate potable water from the intermediate aquifer system is artificially recharging the underlying Upper Floridan aquifer in areas where there is a downward component of flow. Monthly measurements of internal flow were made using the impeller flowmeter and indicate that flow rates change in response to seasonal head differences between the intermediate aquifer system and the Upper Floridan aquifer. Head changes between the aquifers, as a result of ground-water development, may increase recharge, reduce discharge, or may reverse the natural flow direction between the intermediate aquifer system and Upper Floridan aquifer.

The chemical composition of water in the intermediate aquifer system is distinctly different in areas where the surficial aquifer recharges the intermediate aquifer system as compared to areas where the Upper Floridan aquifer discharges into the intermediate aquifer system. The intermediate aquifer system contains a transitional type of ground water with chemistry reflecting the two sources of water moving into the aquifer and the water can be characterized as a mixed calcium bicarbonate, calcium magnesium sulfate, and sodium chloride type. Water in the Upper Floridan aquifer can be characterized as a calcium magnesium sulfate and sodium chloride type. The chemistry of the water in the Upper Floridan aquifer is predominately affected by processes such as dissolution of gypsum and dolomite, calcite precipitation, and seawater mixing.

Ground water in the intermediate aquifer system and the Upper Floridan aquifer with the lowest chloride, sulfate, and dissolved solids concentrations occurs in recharge areas in northeastern Polk County and Highlands County. Ground water in the intermediate aquifer system and the Upper Floridan aquifer with the highest chloride, sulfate, and dissolved solids concentrations occurs in discharge areas along the coast and in the Peace River Valley. For most of the study area, water in the Upper Floridan aquifer is more mineralized than that in the overlying intermediate aquifer system.

Degradation of water quality can occur in the intermediate aquifer system from the natural discharge of highly mineralized water from the underlying Upper Floridan aquifer. Degradation of water quality may also occur in both the intermediate aquifer system and Upper Floridan aquifer through saltwater intrusion, improperly cased wells open to multiple aquifers containing water of varying quality, and leaky and corroded black-iron well casings in areas of poor-quality water. A geographical area where there is a potential for water-quality degradation because of improperly cased wells was defined. This area was delineated based on an upward component of flow and the occurrence of poor-quality water. The delineated area includes parts of Hillsborough, Manatee, Sarasota, Charlotte, De Soto, and Hardee Counties.

An evaluation was performed to estimate the potential magnitude of interaquifer flow in wells open to multiple aquifers within the study area. This evaluation used a Geographical Information System to estimate interaquifer flow rates in wells open to both the intermediate aquifer system and the Upper Floridan aquifer. An estimated cumulative downward flow rate of 127 Mgal/d is artificially recharging the Upper Floridan aquifer from the intermediate aquifer system through interaquifer wells. An estimated cumulative upward flow rate of 85 Mgal/d is artificially discharging into the intermediate aquifer system from the Upper Floridan aquifer through interaquifer wells. In most of this area of upward flow, concentrations of chloride, sulfate, and dissolved solids, exceed 250, 250, and 1,000 mg/L, respectively, and this upward borehole flow may be contaminating the upper zones.

In 1974, Southwest Florida Water Management District began the Quality of Water Improvement Program to restore hydrologic conditions altered by poorly installed wells or deteriorating casings. As of May 1994, more than 3,000 wells have been inspected and approximately 1,350 have been plugged. Studies indicate that better quality of water may be obtained in some areas by plugging wells and by selectively casing wells in zones of poor-quality water.

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