Description and Monitoring of the Saltwater-Freshwater Transition Zone in Aquifers along the West-Central Coast of Florida

By J.T. Trommer

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 93-4120

Prepared in cooperation with the
SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT and the
WEST COAST REGIONAL WATER SUPPLY AUTHORITY

Tallahassee, Florida
1993

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CONVERSION FACTORS, VERTICAL DATUM, ABBREVIATED WATER-QUALITY UNITS, AND ACRONYMS

Multiply	By	To obtain
inch (in.)	25.4	millimeters
foot (ft)	0.3048	meter
foot per day per foot [(ft/d)/ft]	1.0	meter per day per meter
mile (mi)	1.609	kilometer
foot squared per day (ft^2/d)	0.0929	square meter per day
square mile (mi^2)	2.590	square kilometer
gallon per minute (gal/min)	0.06309	liter per second
gallon (gal)	0.06309	liter

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

°F = 1.8 x °C = 5/9 (°F - 32)

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:

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

ACRONYMS

ROMP	Regional Observation and Monitor-Well Program
SWFWMD	Southwest Florida Water Management District
USGS	U.S. Geological Survey
WCRWSA	West Coast Regional Water Supply Authority

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Abstract

A zone of brackish ground water forms the transition zone between saltwater and freshwater in the aquifer systems underlying the west-central coast of Florida. Continuing stress on and declining heads in the freshwater aquifers have increased the potential for the landward movement (intrusion) or vertical movement (upconing) of saltwater.

Water in the transition zone in the northern part of west-central Florida reflects a simple mixing of freshwater and seawater. Water in the transition zone in the southern part of the study area is more mineralized than water in the northern part of the study area and probably reflects a longer residence time in the aquifers, an incomplete flushing of residual seawater, and dissolution of gypsum from deep evaporite beds. The zone extends inland about 5 miles from the coast in the north and as far as the eastern boundary of the study area in the south.

Regression analyses of chloride data from ground water in 24 coastal wells indicate rising chloride concentrations since 1970 in water from 14 wells. Water from two wells had declining chloride concentrations and water from eight wells remained unchanged since 1970.

Comparison of various sampling methods indicates that a single sampling method cannot be applied to all wells that are currently being used to monitor the transition zone. Monitoring wells in the transition zone could be constructed specifically for that purpose. They should have boreholes open to a single flow zone that is above the saltwater-freshwater interface so that water quality in the flow zone is not tidally influenced. In properly constructed monitoring wells in the transition zone, samples should be collected only after purging the well sufficiently to allow specific conductance, pH, and temperature to stabilize.

A network of 163 transition-zone monitoring wells was sampled during the study. Data from this network have been provided to the Southwest Florida Water management District, and the network has been included in their Coastal Ground-Water Quality Monitoring Program. The network was initially sampled by Southwest Florida Water Management District personnel in March 1991.

INTRODUCTION

Continuing ground-water withdrawals and below normal rainfall have resulted in declining heads in aquifers in parts of west-central Florida. The increase in population, particularly in coastal areas, and the resulting increased demand for freshwater has further stressed the ground-water system, which results in an increased potential for saltwater intrusion into the freshwater aquifers.

The saltwater-freshwater interface (250-mg/L line of equal chloride concentration) in the Upper Floridan aquifer along the west-central coast of Florida was described and mapped in 1979 by Causseaux and Fretwell (1982). Much of the data used in that study were at least 15 years old. Also, tidal influence on water quality was not considered, and the actual depth from which the water sample was collected or the possibility of multiple flow zones sometimes was unknown. The 1979 study concentrated on the Upper Floridan aquifer; however, water-producing zones exist in the intermediate aquifer system that overlies the Upper Floridan aquifer in Hillsborough, Manatee, Sarasota, De Soto, and Charlotte Counties. These zones are the major sources of potable water in parts of west-central Florida and need to be monitored.

Additional data from borehole-geophysical logs and flowmeter surveys, as well as water quality and drilling data, are now available to describe more accurately the transition zone between saltwater and freshwater in aquifers along the coast of west-central Florida. Recognizing the need to describe and monitor the saltwater-freshwater transition zone, a 5-year study of the transition zone was begun in October 1986 by the U.S. Geological Survey (USGS), in cooperation with the Southwest Florida Water Management District (SWFWMD) and the West Coast Regional Water Supply Authority (WCRWSA). The study area covers about 6,600 mi^2 in west-central Florida and includes Citrus, Hernando, Pasco, Pinellas, Hillsborough, Manatee, Sarasota, and De Soto Counties, and the parts of Levy and Charlotte Counties that lie within the boundary of the SWFWMD (fig. 1).

Purpose and Scope

This report presents a description of the saltwater-freshwater transition zone and delineates the current (1987-90) position of the 250-mg/L line of equal chloride concentration (the saltwater-freshwater interface; Causseaux and Fretwell, 1982) in the production zones of the intermediate aquifer system and the Upper Floridan aquifer in coastal west-central Florida. Well locations, well-construction data, and water-quality data for 163 wells that have been included in the transition-zone monitoring network also are presented, as well as information on the effects that head fluctuation, well construction, and sampling methods have on the reliability of water-quality data.

The saltwater-freshwater transition zone along the coastline of west-central Florida was defined by identifying trends in concentrations of chloride in ground water at monitoring wells, by examining seasonal and daily correlations between changes in head and changes in specific conductance of water from the intermediate aquifer system and the Upper Floridan aquifer, and by testing various methods for sampling wells in the transition zone. Information contained in this report is based on data collected during the study period (October 1986-September 1990); historical data from the files of the USGS, the SWFWMD, and the WCRWSA; and data from previously published reports. Data compiled and analyzed in this report include ground-water level measurements, ground-water quality analyses, borehole- and surface-geophysical data, aquifer properties, lithologic descriptions, and tests of various sampling methods.

Previous Investigations

The ground-water resources of west-central Florida have been discussed in varying detail in several reports published by the U.S. Geological Survey, the Florida Geological Survey, and private organizations. Stringfield (1933a; 1933b) discussed the geography, geology, and ground-water conditions in parts of southwest Florida and called attention to the problem of saltwater contamination of freshwater aquifers. Vernon (1951), in a report on the geology of Citrus and Levy Counties, briefly discussed ground-water conditions, including the possible occurrence of saltwater near the coast. Pinellas County experienced a salinity problem in the 1920's when water-quality degradation became significant (Heath and Smith, 1954). Cherry (1966) concluded that salinity problems did not increase significantly in Pinellas County between 1950-60 because ground-water withdrawals had not increased in the county during that time. Peek (1958) estimated the extent of saltwater contamination in the Manatee County coastal areas. Peek (1959), Menke and others (1961), and Hutchinson (1982) noted increasing trends in concentrations of selected dissolved constituents in the coastal parts of Manatee and Hillsborough Counties. Wetterhall (1964) noted that vertical layering of freshwater and saltwater occurs along the coast in Hernando and Pasco Counties. The location of the 250-mg/L line of equal chloride concentration was first delineated by Reichenbaugh (1972) in Pasco County and later by Mills and Ryder (1977) for Citrus and Hernando Counties. Sutcliffe (1975) discussed the problems of saltwater intrusion in the surficial and upper part of the intermediate aquifer systems in an appraisal of the geology and hydrology of Charlotte County.

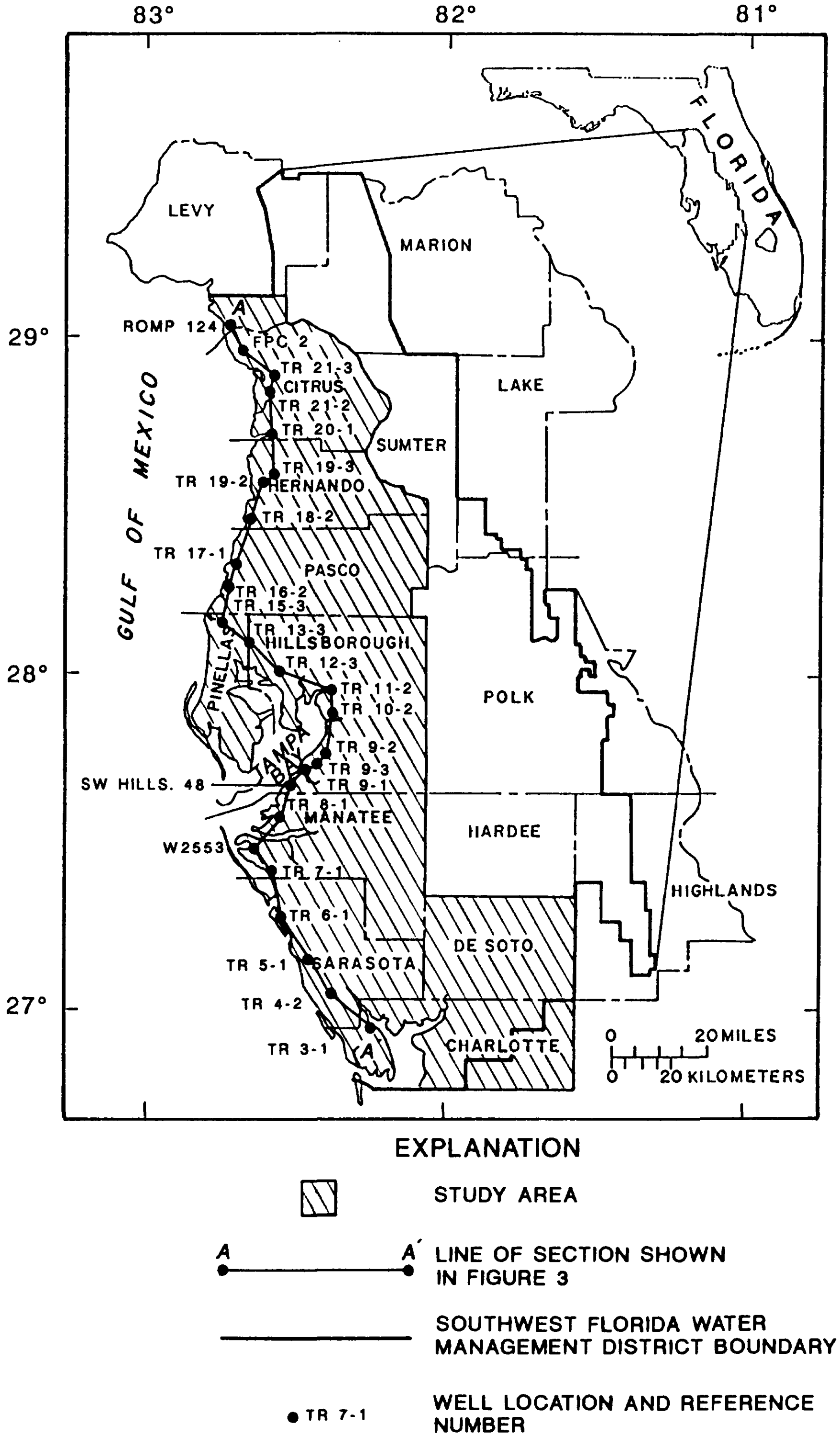


Figure 1. Study area in west-central Florida.

Wilson (1977) reported chloride concentrations in De Soto and Hardee Counties were higher in the lower part of the Upper Floridan aquifer than in the upper part. Causseaux and Fretwell (1982; 1983) mapped the location of the 250-mg/L line of equal chloride concentration and discussed chloride concentrations in the Floridan aquifer system along the coastal margin of west-central Florida. Surface-geophysical studies (electrical resistivity and electromagnetic) have been used to locate the saltwater-freshwater interface along the west-central coast of Florida with varying degrees of success (Bisdorf and Zohdy, 1979; Fretwell and Stewart, 1981; Stewart and Gay, 1986).

Acknowledgments

The author gratefully acknowledges the assistance provided by the SWFWMD and WCRWSA personnel in conjunction with this investigation and particularly the property owners who permitted access to the wells used for geophysical logging, water-quality sampling, and water-level measurements.

Methods of Investigation

A review of existing wells and water-quality data collected within the study area was conducted to determine the availability of wells to monitor the saltwater-freshwater transition zone and to determine where additional data collection was needed. Hydrogeologic conditions throughout the study area were evaluated using previously collected lithologic data, borehole-geophysical logs, and aquifer-test analyses.

Water-level and specific-conductance recorders were installed in selected wells to continuously monitor changes in head and specific conductance. Specific-conductance and water-level data were collected at five wells to evaluate seasonal and daily changes. Specific-conductance and water-level data also were collected at six additional wells to evaluate tidally influenced changes. Changes in specific conductance were used as an indicator of changes in the quality of water in a well.

Analyses of water samples collected from 250 wells between 1987 and 1990 were used to delineate the transition zone along coastal west-central Florida. Sampled wells included domestic, public-supply, irrigation, monitoring, and unused wells. Monitored wells and unused irrigation and supply wells without permanently installed pumps were sampled by using a portable centrifugal pump. Public-supply, domestic, and irrigation wells with permanently installed pumps were sampled as close to the wellhead as possible to preclude any possible water-quality changes as a result of chemical treatment. Monitored wells that had a drop-pipe or an airlift system were sampled using a centrifugal pump or a small air compressor. Whenever possible, wells were purged until temperature, pH, and specific conductance stabilized (Wood, 1976, p. 4).

Water samples were analyzed at a USGS Laboratory for chemical and physical properties, including temperature, pH, specific conductance, chloride, sulfate, and other major ions. Trends were determined by simple linear regression analysis of chloride-concentration data for selected wells with 5 to 20 years of data. Of the 250 wells sampled, 163 were included in a proposed monitoring network that was provided to the SWFWMD for implementation into a permanent transition-zone monitoring network. Water-quality data for the proposed monitoring wells are presented in the appendix.

Water-quality sampling methods were evaluated at three wells in different hydrogeologic settings by comparing the analytical results of samples collected using each method. Continuous monitoring of specific-conductance and periodic borehole geophysical logging were used to identify changes in specific conductance that occurred in the ground water in each well during the testing of the sampling methods.

Hydrogeology

The hydrogeologic system in west-central Florida consists of clastic deposits of sand, silt, and clay underlain by thick sequences of carbonate rock that form the surficial aquifer system, the intermediate aquifer system or intermediate confining unit, and the Floridan aquifer system (fig. 2). The stratigraphic nomenclature used in this report is that of the Florida Geological Survey.

The surficial aquifer system generally is composed of undifferentiated Holocene and Pleistocene age sediments consisting of sand and clayey sand. This aquifer system thins toward the north, between central Hillsborough and northern Pasco Counties. The thickness of the surficial aquifer system in this part of the study area ranges between 1 and 35 ft and acts as a single hydrologic unit.

System	Series	Stratigraphic unit	General lithology	Major lithologic unit	Hydrogeologic unit
Quaternary	Holocene and Pleistocene	Surficial sand, terrace sand, phosphorite	Predominantly fine sand; interbedded clay, marl, shell, and phosphorite.	Sand	SURFICIAL AQUIFER SYSTEM
Tertiary	Pliocene	Undifferentiated deposits[1] Tamiami Formation	Clayey and pebbly sand; clay, marl, shell, phosphatic.	Clastic	INTERMEDIATE AQUIFER SYSTEM OR INTERMEDIATE CONFINING UNIT
	Miocene	Hawthorn Group: Peace River Formation	Dolomite, sand, clay, and limestone; silty, phosphatic.	Carbonate and clastic	
		Hawthorn Group: Arcadia Formation			
		Hawthorn Group: Tampa Member	Limestone, sandy, phosphatic, fossiliferous; sand and clay in lower part in some areas.		
	Oligocene	Suwannee Limestone	Limestone, sandy limestone, fossiliferous.	Carbonate	FLORIDAN AQUIFER SYSTEM
	Eocene	Ocala Limestone	Limestone, chalky, foraminiferal, dolomitic near bottom.		Upper Floridan aquifer
		Avon Park Formation	Limestone and hard brown dolomite; intergranular evaporite in lower part in some areas.		Middle confining unit
		Oldsmar Formation	Dolomite and limestone, with intergranular gypsum in most areas.		Lower Floridan aquifer
	Paleocene	Cedar Keys Formation	Dolomite and limestone with beds of anhydrite.	Carbonate with evaporites	Sub-Floridan confining unit

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

Figure 2. Hydrogeologic system in west-central Florida. (Modified from Ryder, 1985, and Scott, 1988.)

A continuous surficial aquifer system does not exist north of Pasco County. The surficial aquifer system thickens south of Hillsborough County (figs. 1 and 3) and may contain lenses of shell, shelly marl, or intermixed stringers of limestone. The surficial aquifer system in this part of the study area can be as much as 100 ft thick and acts as a multilayered system (Wolansky, 1983, p. 9). Depth to the water table is 5 to 10 ft below land surface throughout most of the study area; however, the water table can be more than 35 ft below land surface in some sand-ridge areas. Recharge to the surficial aquifer system is almost entirely from precipitation. Seasonal fluctuation of the water table varies within a 5-ft range; its lowest level is in the spring and at its highest level is in the fall.

Hydraulic properties of the surficial aquifer system vary according to the lithology and thickness of the saturated deposits. Transmissivity is estimated to range from 100 to 10,000 ft^2/d, and the storage coefficient ranges from $4x10^{-3}$ to $2x10^{-1}$ as reported by Wolansky and Corral (1985, p. 7).

Water in the surficial aquifer system generally is of acceptable quality for potable use except near the coast and along tidally affected river estuaries, streams, and canals. Because of the potential for pollution and generally low yields, this aquifer system is used primarily for lawn irrigation and livestock watering. It is, however, a major source of potable water in parts of Sarasota and Charlotte Counties where deeper aquifer systems contain saltwater. The surficial aquifer system provides some recharge to the underlying aquifer systems.

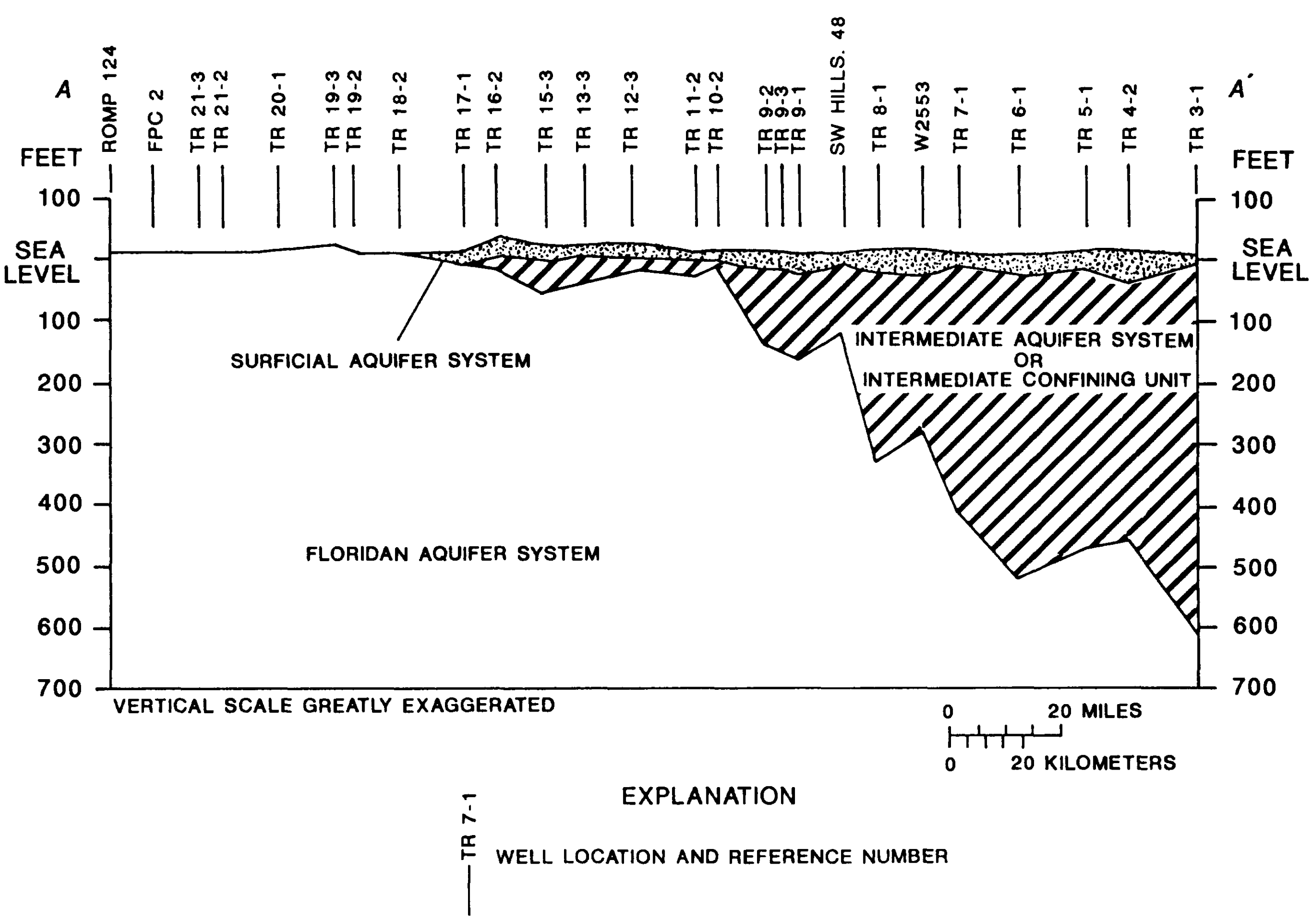


Figure 3. Generalized hydrogeologic section A-A' in west-central Florida. (Location of section is shown in fig. 1)

The surficial and Floridan aquifer systems are separated by deposits of clay, silt, and sandy calcareous clay of Pleistocene, Pliocene, and Miocene age. These deposits are thin and discontinuous north of Pasco County; however, between Pasco County and Hillsborough County, they thicken and form the intermediate confining unit (Southeastern Geological Society, 1986). These deposits continue to thicken to the south (fig. 3) and contain discontinuous water-bearing zones composed of sand, gravel, shell, limestone, and dolomite.

All water-bearing zones and semiconfining materials that lie between the surficial aquifer system and the Floridan aquifer system in this part of the study area are known collectively as the intermediate aquifer system (Duerr and others, 1988, p. 5). The intermediate aquifer system contains a single aquifer at its northern and eastern limits, but is a multilayered system in the southwestern part of the study area, particularly along the coast in Sarasota and Charlotte Counties (Duerr and others, 1988, p. 19). In parts of Manatee, De Soto, Sarasota, and Charlotte Counties, all or part of the Arcadia Formation of Miocene age (formerly the Tampa Limestone; renamed by Scott, 1988) is hydraulically connected to the Peace River Formation and is included in the intermediate aquifer system. The Arcadia Formation in the northern part of the study area is included in the Floridan aquifer system.

The intermediate aquifer system ranges from less than 100 ft thick in central Hillsborough County to more than 800 ft thick in Charlotte County (Duerr and others, 1988, p. 9). Transmissivity of the intermediate aquifer system is estimated to range from less than 200 to more than 13,000 ft^2/d (Duerr and others, 1988, p. 21).

The altitude of the potentiometric surface of the intermediate aquifer system ranges from about 110 ft above sea level in southeastern Hillsborough and northeastern Manatee Counties to less than 10 ft above sea level near the coast, except for an area in southern Hillsborough County. Average heads in the intermediate aquifer system were 9 ft higher in September 1989 (Knochenmus and Barr, 1990a) than in May 1989 (Barr, 1989a). The greatest fluctuation occurred in southern Hillsborough County where dry season (May) pumpage for agricultural irrigation was heavy. Heads in this area fluctuated from more than 20 ft below sea level in May 1989 to about 20 ft above sea level in September 1989 (fig. 4).

The general direction of ground-water flow within the intermediate aquifer system is west toward the coast. The direction of flow in southern Hillsborough and northern Manatee Counties, however, was reversed in 1989 during the dry season as a result of increased ground-water withdrawals and the subsequent lowering of the potentiometric surface. The potential for saltwater encroachment into the aquifer from Tampa Bay and the Gulf of Mexico is enhanced under these conditions.

The intermediate aquifer system is an important source of water where water in the underlying Upper Floridan aquifer is too salty for potable use, especially in Charlotte and Sarasota Counties. The intermediate

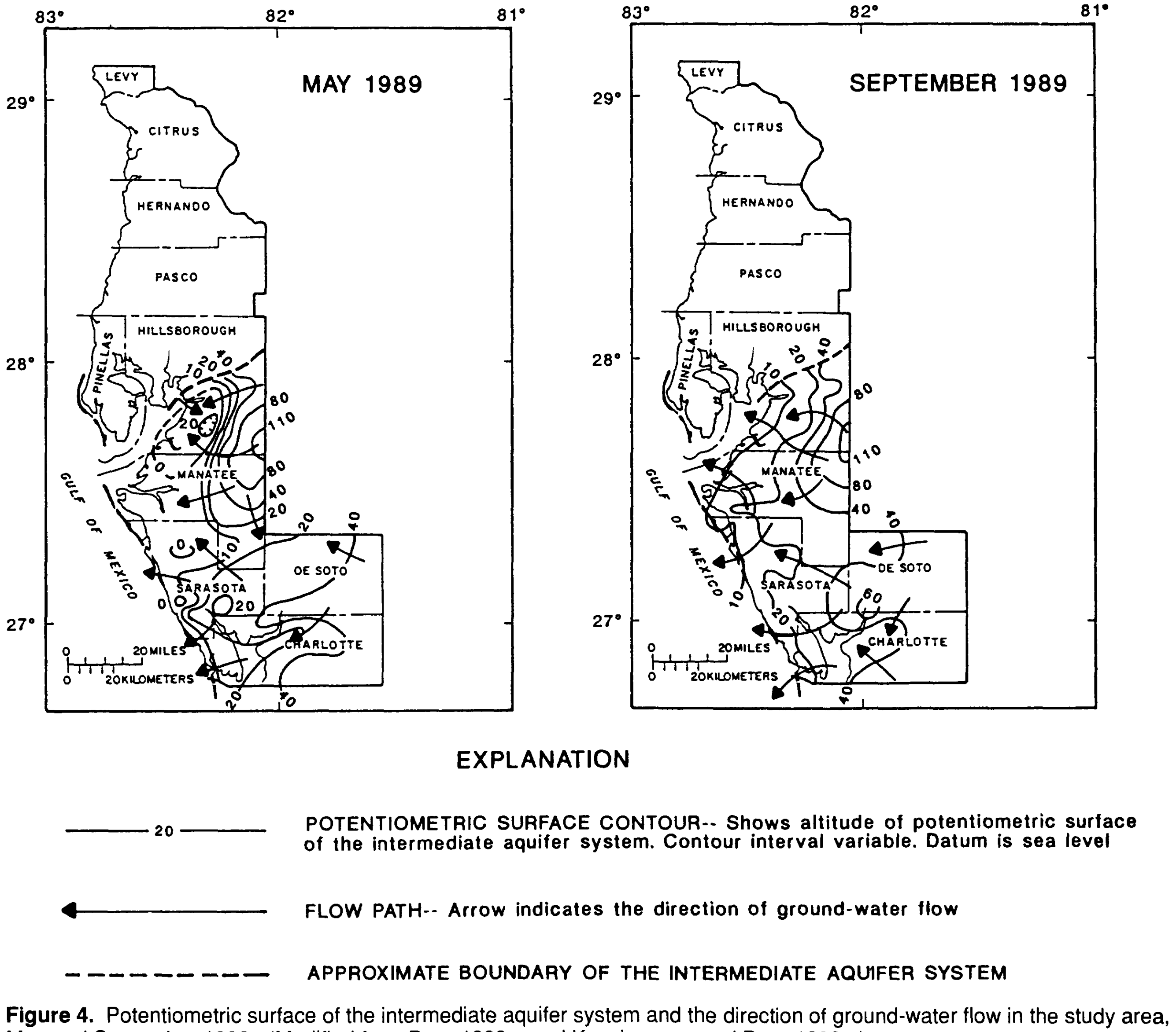


Figure 4. Potentiometric surface of the intermediate aquifer system and the direction of ground-water flow in the study area, May and September 1989. (Modified from Barr, 1989a, and Knochenmus and Barr, 1990a.)

aquifer system also is used as a source of water for irrigation in De Soto, Manatee, and Hillsborough Counties where hundreds of irrigation wells are open to the intermediate aquifer system and the Upper Floridan aquifer.

The Floridan aquifer system is a vertically persistent sequence of Tertiary-age carbonate rocks of generally high permeability that are hydraulically connected in varying degrees and whose permeability is several orders of magnitude greater than that of the rocks that bound the aquifer above and below (Miller, 1986, p. 45). The system consists of the Upper Floridan aquifer, the middle confining unit, the Lower Floridan aquifer, and the sub-Floridan confining unit (fig. 2). The Lower Floridan aquifer generally contains saltwater throughout the study area and is not used as a source of supply. With the exception of some coastal areas and areas in Charlotte and southwestern Sarasota Counties, the Upper Floridan aquifer is the major source of potable water throughout west-central Florida. The Upper Floridan aquifer thickens from north to south, ranging from about 600 ft thick in Levy County to 1,400 ft thick in Sarasota and Charlotte Counties (Miller, 1986, Pl. 28).

Hydrogeologic conditions in the Upper Floridan aquifer in the northern part of the study area are considerably different than conditions in the southern part. Confining units are thin or discontinuous in the northern part, allowing rapid recharge to the underlying limestone. As a result, secondary porosity along bedding planes or fractures in the limestone are highly developed, particularly near the many springs that discharge along the coast. Hydraulic conductivity is much higher in solution-widened channels than in other parts of the aquifer, resulting in a wide range in transmissivity within the aquifer. Transmissivity of the Upper Floridan aquifer in the northern part of the study area is estimated to range from 20,000 ft^2/d in Levy County to more than 800,000 ft^2/d near the Hernando-Citrus County line (Ryder, 1985, pl. 1). In the southern part of the study area, the thicker, more continuous nature of confining units retards the development of large solution channels in limestone; consequently, variation in transmissivity there is not as great and ranges from 20,000 to 300,000 ft^2/d (Ryder, 1985, pl. 1).

The altitude of the potentiometric surface of the Upper Floridan aquifer ranged from about 100 ft above sea level during September 1989 in the east-central part of the study area to more than 20 ft below sea level during May 1989 in Manatee and southern Hillsborough Counties (fig. 5). Head in the Upper Floridan aquifer also fluctuates seasonally. Fluctuations in the northern part of the study area were only about 1 ft between May and September 1989, whereas fluctuations averaged about 20 ft (Knochenmus and Barr, 1990b) in the southern part of the study area.

Direction of ground-water flow in the Upper Floridan aquifer in the study area is generally westward toward the coast and Tampa Bay. A reversal of the gradient in Manatee and southern Hillsborough Counties during the dry season as a result of increased agricultural irrigation, however, results in some ground water flowing from the coast toward the depression created in the potentiometric surface there (fig. 5). The depression in the potentiometric surface in May 1989 was more than 20 ft below sea level. Such depressions can result in lateral intrusion or vertical upconing of saltwater.

SALTWATER-FRESHWATER TRANSITION ZONE

The density difference between saltwater and freshwater in a coastal aquifer causes a wedge of dense saltwater to extend landward and underlie less dense freshwater. The interface between saltwater and freshwater is in dynamic equilibrium and moves in response to ocean tides and variations in aquifer recharge or discharge.

Cooper and others (1964, p. 1) stated that the reciprocating motion of the saltwater front that results from tidal fluctuation and fluctuation in water levels caused by variation in recharge and discharge can create a zone of mixing, commonly referred to as the transition zone. They also discussed that, whenever a transition zone exists, the saltwater is not static, but flows perpetually in a cycle from the sea floor, into the transition zone, and back to the sea. This theory is supported by field evidence and solute-transport modeling simulations (Mahon, 1989, p. 25). This report considers the seaward extent of the transition zone to be where all ground water in a vertical section of the aquifer contains a chloride concentration of 19,000 mg/L or more, which is approximately equal to that of seawater. The landward extent of the transition zone is considered to be where all ground water in a vertical section of the aquifer contains chloride concentrations of 25 mg/L or less (Hickey, 1981, p. 24).

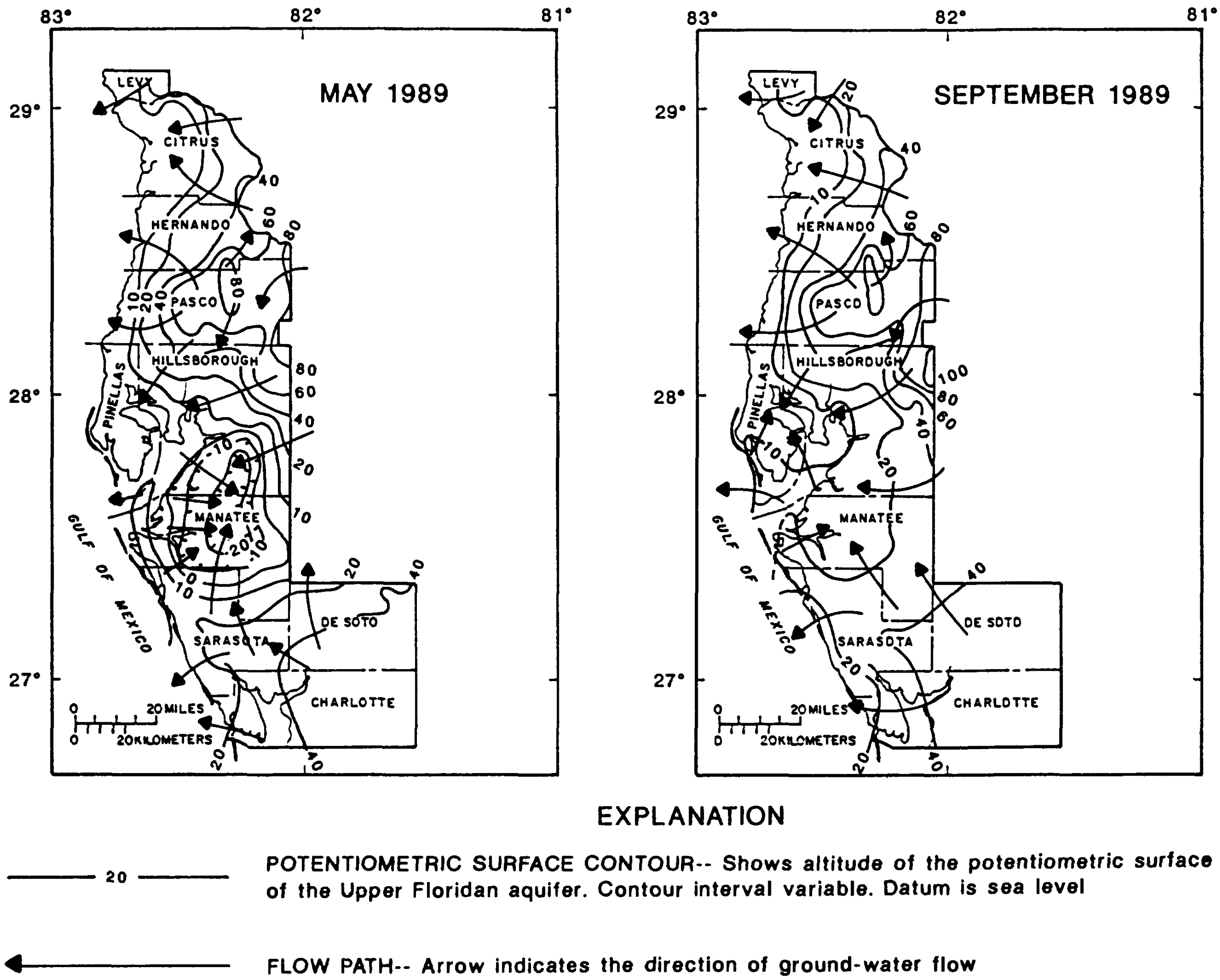


Figure 5. Potentiometric surface of the Upper Floridan aquifer and the direction of ground-water flow in the study area, May and September 1989. (Modified from Barr, 1989b, and Knochenmus and Barr, 1990b.)

Landward movement of saltwater can occur in an aquifer when the freshwater head at or near the coast is lowered. Long-term ground-water withdrawals from the aquifer, reduced recharge, and ground-water discharge to large coastal springs can lower the freshwater head, thereby increasing the potential for saltwater intrusion. The rate and extent of lateral saltwater intrusion are determined by the hydraulic characteristics of the aquifer as well as the net hydraulic gradient (the difference between the freshwater head and the saltwater head). Increased withdrawals from an aquifer also can cause saltwater to enter a freshwater aquifer by vertical intrusion, or upconing, from the deeper leading edge of the saltwater wedge or from lower formations that might contain residual seawater. Upconing also may cause highly mineralized water containing chemical constituents dissolved from evaporite deposits to move into overlying freshwater aquifers.

Configuration of the Transition Zone

This section delineates the landward extent of the saltwater-freshwater transition zone and the position of the 250-mg/L line of equal chloride concentration in the production zones of the intermediate aquifer system and the Upper Floridan aquifer between 1987 and 1990. The 250-mg/L line of equal chloride concentration has been referred to as the saltwater-freshwater interface in a report by Causseaux and Fretwell (1982) and is delineated here because 250 mg/L is the drinking water standard recommended by the Florida Department of Environmental Regulation (1985). Production zones in the intermediate aquifer system and the Upper Floridan aquifer were estimated using driller's completion reports and borehole geophysical logs to determine the average depths of wells in an area.

The transition zone in the intermediate aquifer system extends about 5 mi inland from the coast in west-central Hillsborough County. The zone widens to the south and extends across Sarasota, De Soto, and Charlotte Counties (fig. 6). The 250-mg/L line of equal chloride concentration in the intermediate aquifer system generally parallels the coast from Hillsborough County to southern Sarasota County and then turns southeastward through Charlotte County and northeastward through the southeastern corner of De Soto County (fig. 6).

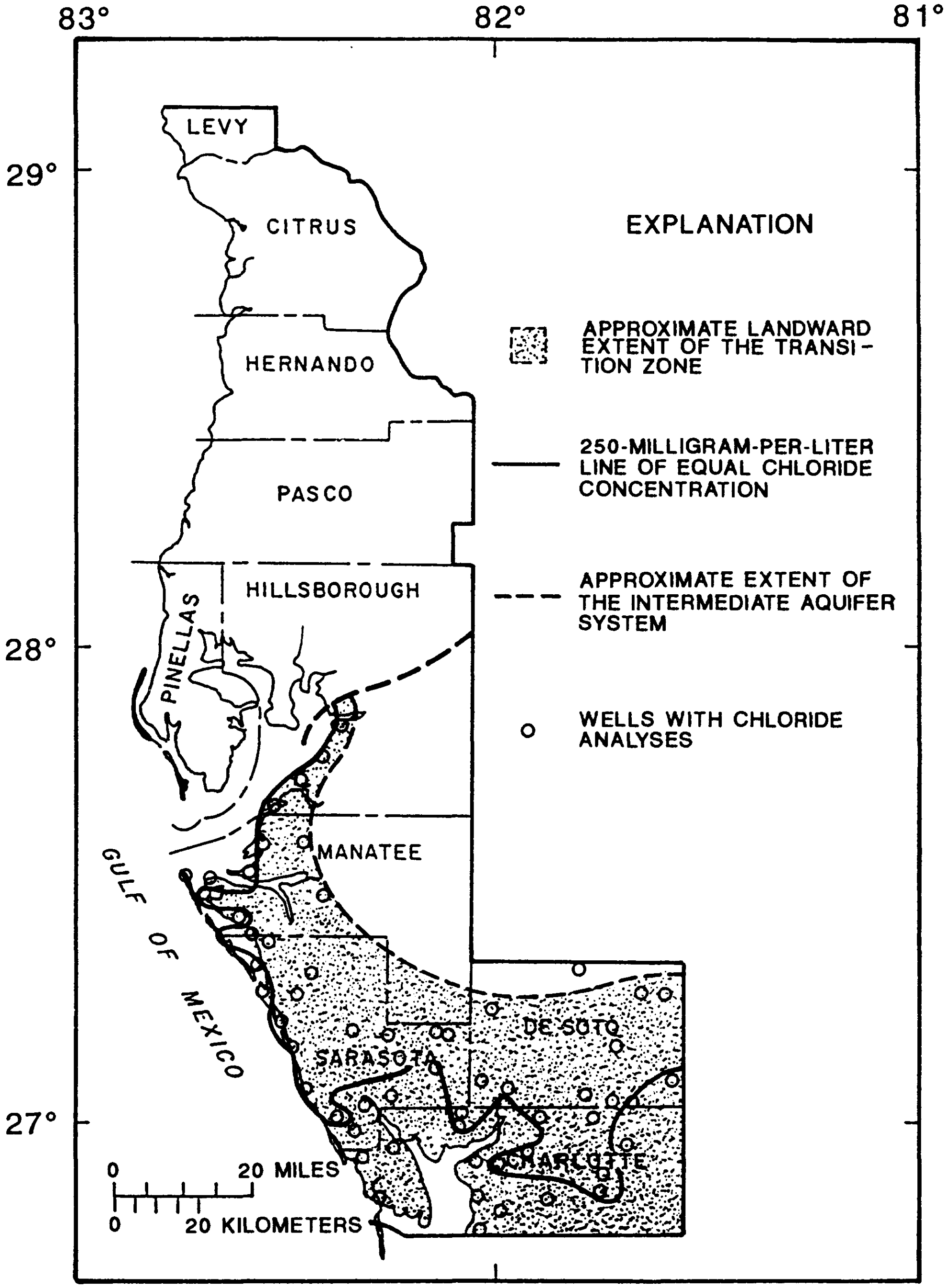


Figure 6. Approximate landward extent of the transition zone and the location of the 250-milligram-per-liter line of equal chloride concentration in the production zone of the intermediate aquifer system, 1987-90.

The transition zone and the 250-mg/L line of equal chloride concentration in the Upper Floridan aquifer extend only a few miles inland from the coast in the northern part of the study area (fig. 7), except in the vicinity of major discharge areas such as the Cross Florida Barge Canal in northern Citrus County and the springs at Crystal River and Homosassa Springs, Chassahowitzka Springs, and Weeki Wachee Springs in southern Citrus and central Hernando Counties (fig. 8). The transition zone extends across all of Pinellas County and extends less than 10 mi inland from the coast through Hillsborough County. The zone widens south of Hillsborough County and extends throughout most of Sarasota and De Soto Counties and

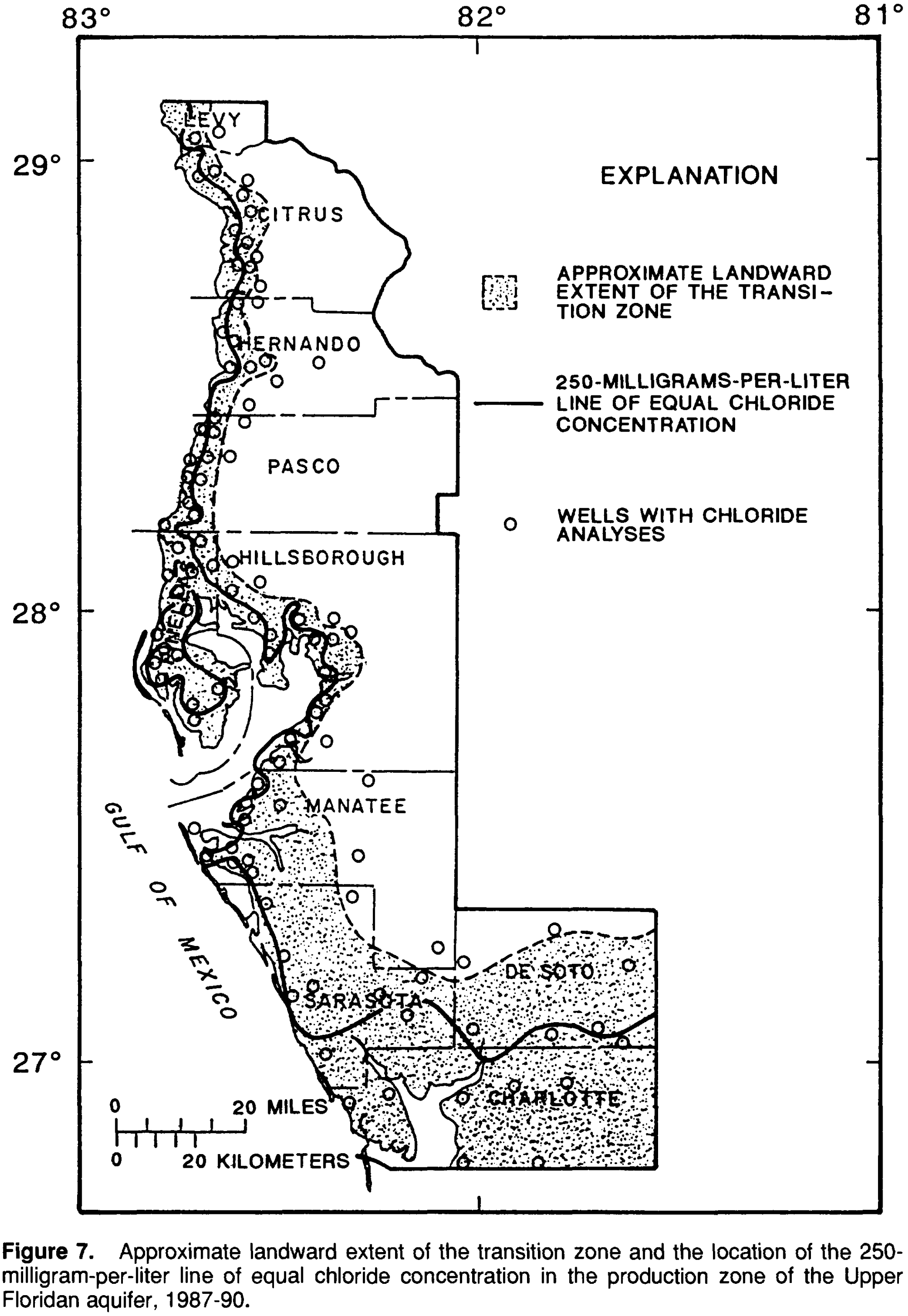


Figure 7. Approximate landward extent of the transition zone and the location of the 250-milligram-per-liter line of equal chloride concentration in the production zone of the Upper Floridan aquifer, 1987-90.

all of Charlotte County. The 250-mg/L line of equal chloride concentration in the Upper Floridan aquifer generally runs parallel to the coast in Pinellas, Hillsborough, Manatee, and most of Sarasota Counties and then turns eastward through southern Sarasota and De Soto Counties (fig. 7).

Water with a chloride concentration of 250 mg/L or less occurs in the intermediate aquifer system near the coast from Hillsborough County to southern Sarasota County and in the Upper Floridan aquifer from Levy County to southern Sarasota County (figs. 6 and 7). The zone of water in the intermediate aquifer

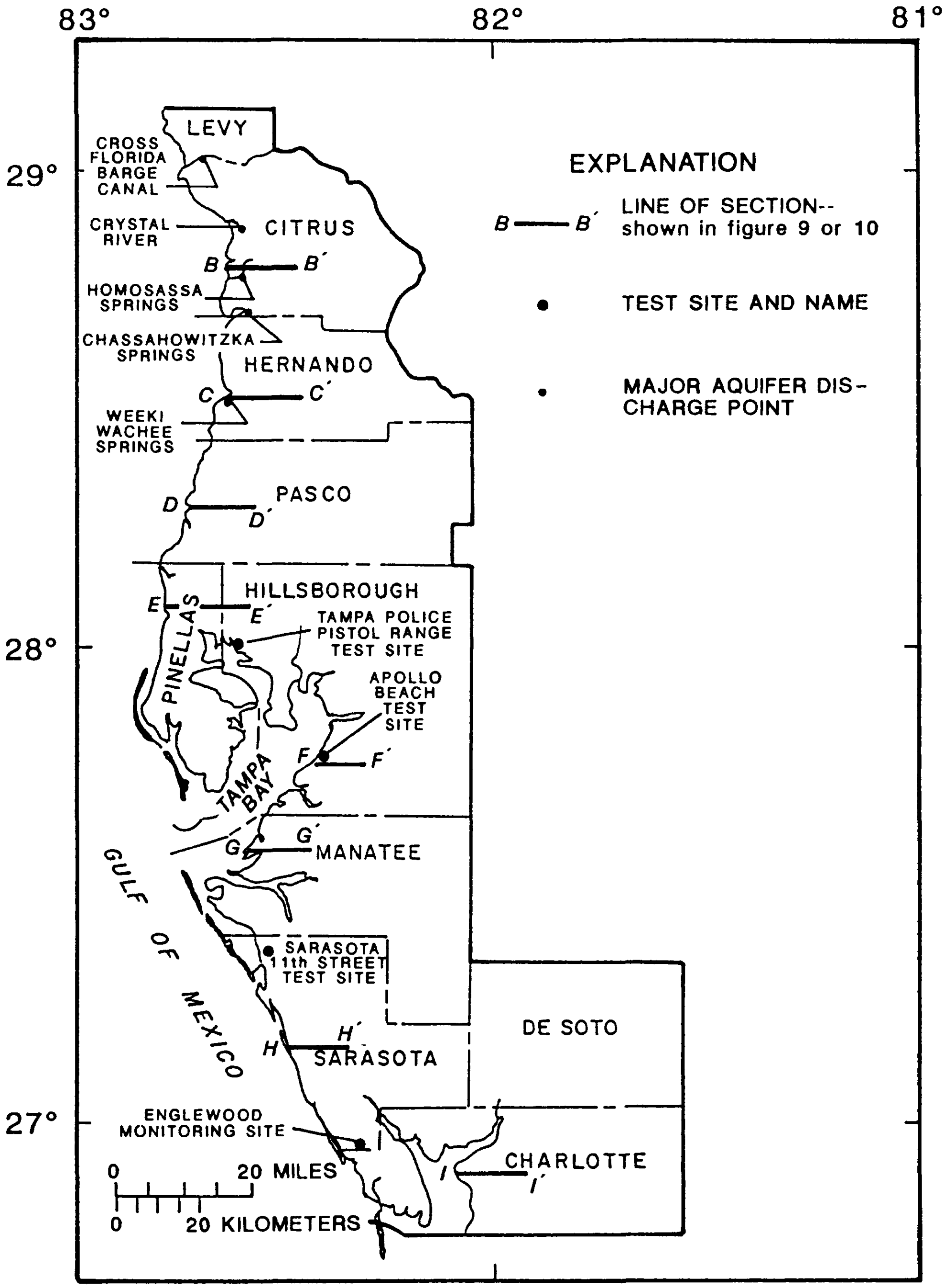


Figure 8. Locations of test sites, major aquifer discharge points in the northern part of the study area, and sections where chloride concentrations were examined in the production zones of the intermediate aquifer system or the Upper Floridan aquifer, 1987-90.

system that contains less than 250 mg/L of chloride extends into central Charlotte County. There are virtually no areas in Charlotte County where the concentration of chloride in water in the Upper Floridan aquifer is less than 250 mg/L (fig. 6 and 7).

Results of chemical analyses of freshwater in the Upper Floridan aquifer in the northern part of the study area indicate the water is predominantly a calcium bicarbonate type that has evolved by dissolution of the aquifer by ground-water recharge. The low

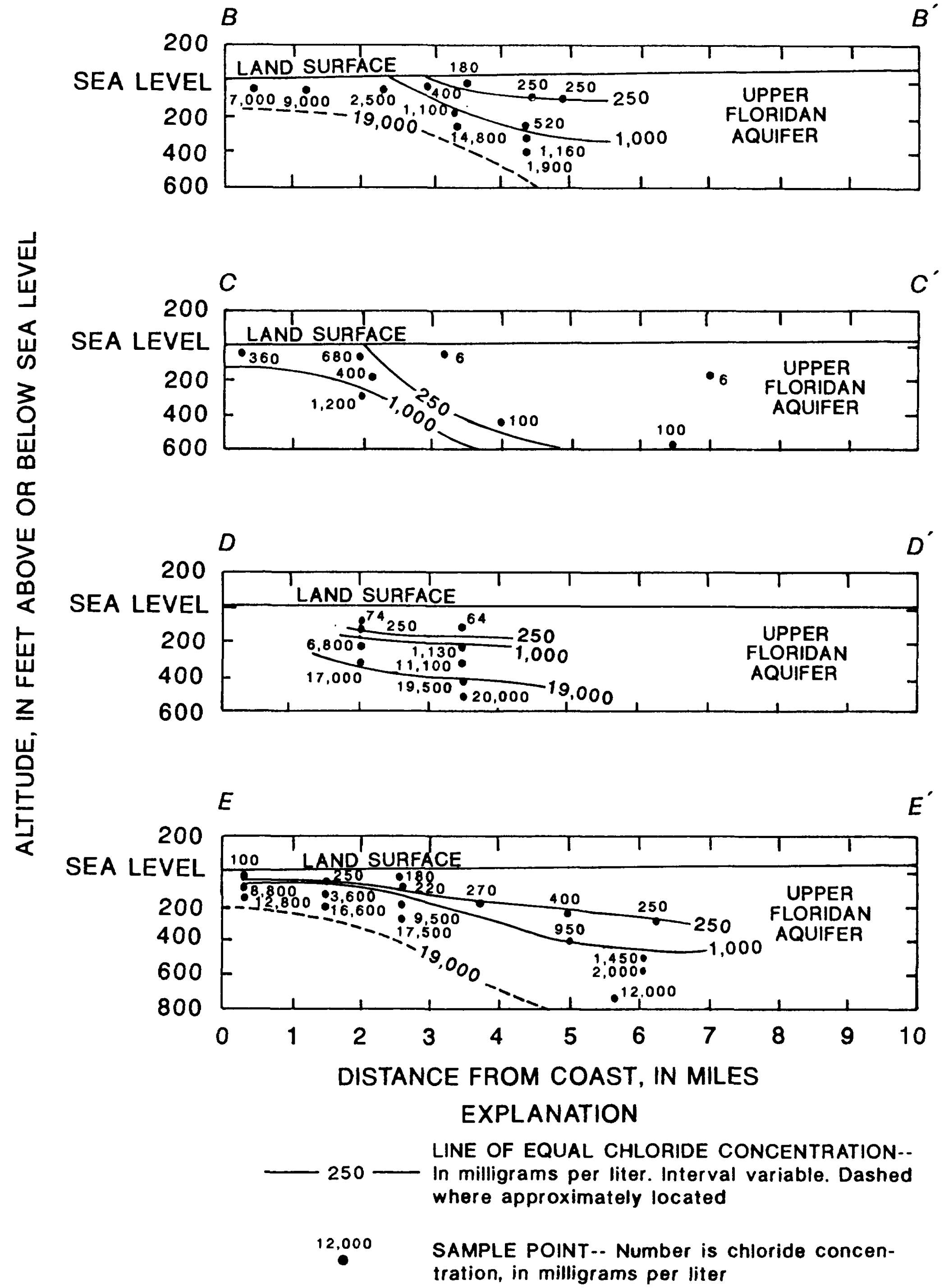


Figure 9. Chloride concentrations in water in the Upper Floridan aquifer along the northern coast of the study area. (Modified from Causseaux and Fretwell, 1983. Lines of sections are shown in fig. 8.)

concentration of chloride in the water indicates that the aquifer has been flushed of residual seawater. Water quality within the transition zone in this area, therefore, reflects a mixture of seawater and freshwater. Specific-conductance and chloride-concentration values in ground water are usually higher toward the coast and increase with depth where the saltwater wedge underlies freshwater. The locations of sections where the stratification of chloride concentration were examined are shown on figure 8. Chloride concentrations in water along selected sections of the northern coastal margin shown on figure 9 demonstrate this point.

Freshwater in the intermediate aquifer system and in the Upper Floridan aquifer in the southern part of the study area generally is a calcium magnesium sulfate type (Steinkampf, 1982), which indicates that this water has evolved from the dissolution of dolomite and gypsum by recharge water. Ground-water in discharge areas near the coast grades to a sodium chloride type, which could be the result of incomplete flushing of residual seawater from the aquifer (Steinkampf, 1982, p. 1) or localized saltwater intrusion. Concentrations of chloride in ground water in section H-H' through central Sarasota County generally are less than 250 mg/L in both aquifers (fig. 10). Results of water-quality analysis (appendix, wells 31-41) indicate that specific-conductance values and sulfate concentrations range between 1,140 and 3,100 μS/cm and 350 and 750 mg/L, respectively, possibly the result of upconing of sulfate-enriched water rather than seawater intrusion into the aquifers.

Water-Quality Changes in Response to Head Fluctuations

The potentiometric surfaces of the intermediate aquifer system and the Upper Floridan aquifer fluctuate in response to seasonal changes in recharge and discharge. The potentiometric surfaces also fluctuate daily in coastal areas, possibly as a result of ocean tide cycles. These fluctuations in water levels may be related to changes in the quality of the water in the aquifers.

Monitoring wells were used to correlate the changes in head and specific conductance resulting from seasonal and tidal fluctuations. Wells open to different hydrogeologic settings were equipped with continuous water-level and specific-conductance recorders. Five monitoring wells with continuous record that extended through at least one wet and one dry season were selected to determine if seasonal and daily (tidal) changes in heads corresponded to changes in specific conductance. Tidal water-level and related specific-conductance data were collected at six additional coastal wells.

The northernmost monitoring well in the study area that has continuous seasonal and tidal water-level data and specific-conductance data is the TR 19-2 well in Hernando County. This well is part of the SWFWMD Regional Observation and Monitor-well Program (ROMP) (fig. 1). At this well site, the limestone that forms the Upper Floridan aquifer is overlain by 5 ft of sand. The surface of the Upper Floridan aquifer is unconfined because the surficial aquifer system or intervening confining units do not exist here. The well is 302 ft deep, has 277 ft of casing, and is open to a 25-ft interval. The well is about 0.5 mi from a saltwater channel.

Daily fluctuation patterns of the potentiometric surface in this Upper Floridan aquifer well indicate the well is tidally affected. Heads fluctuated as much as 2 ft during tidal cycles in May 1989. Corresponding daily specific-conductance data indicated similar fluctuations (fig. 11) that seem to be related to the daily water-level fluctuations. The greatest changes in specific conductance occurred when water-level amplitudes were the greatest. Specific-conductance values ranged from less than 6,000 to more than 17,000 μS/cm.

Water-level and specific-conductance data collected at well TR 19-2 during 1989 indicate that water levels remained fairly constant in the well, varying only about 2 ft during the year (fig. 12). Specific conductance, however, varied greatly, ranging from about 3,000 to more than 18,000 μS/cm. The highest values occurred in May and June and again in November 1989 and may be related to reduced recharge from local rainfall or increased pumping from upgradient wells for irrigation during the dry season.

The second monitoring well to have continuous seasonal and tidal water-level data and specific-conductance data is the TR 12-3 well in northwestern Hillsborough County (fig. 1). At this well site, clay and sandy clay form the intermediate confining unit that separates the surficial aquifer system from the underlying Upper Floridan aquifer. There is no intermediate aquifer system at this site, and the surficial aquifer system is not used as a source of water.

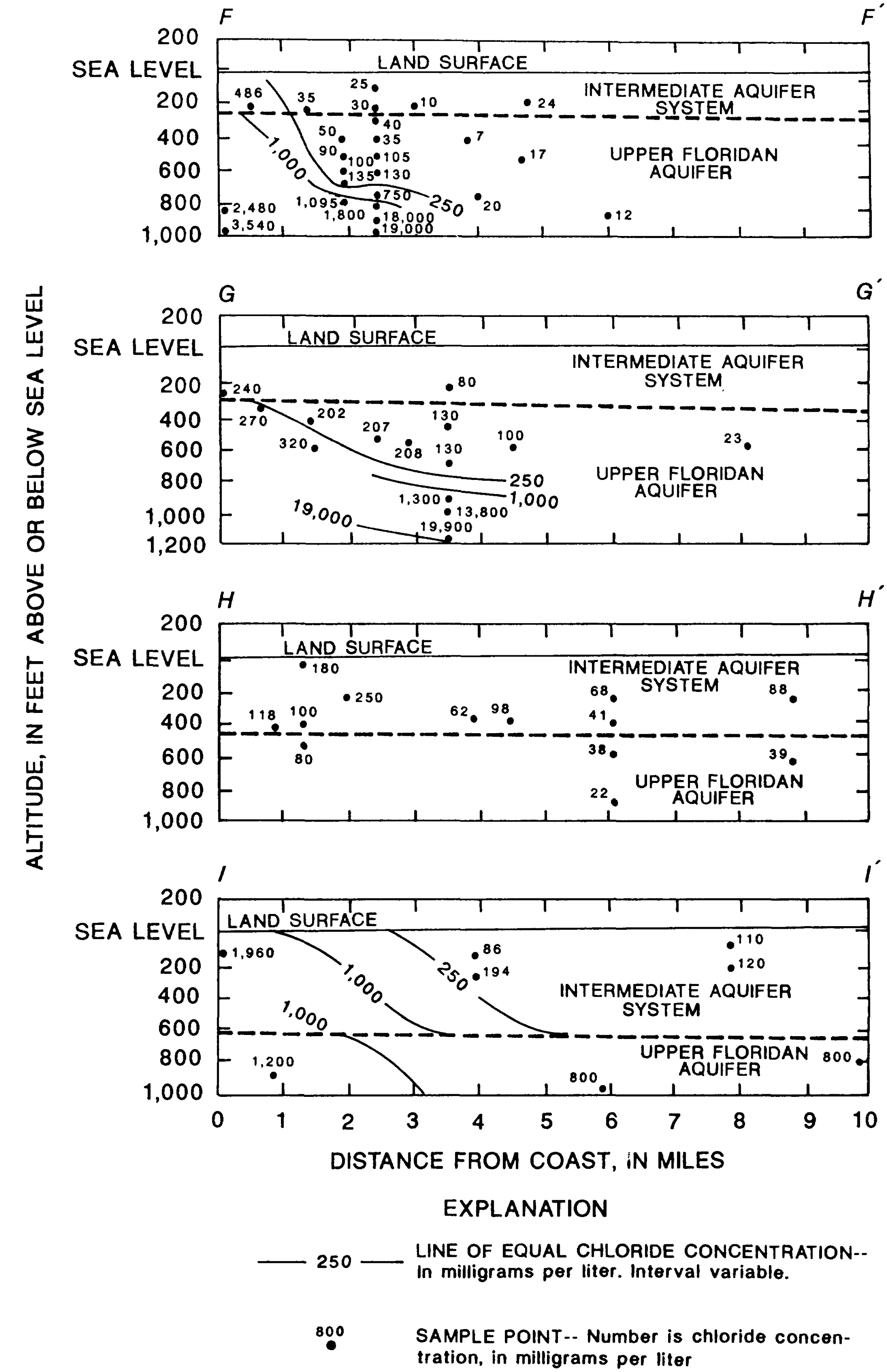


Figure 10. Chloride concentrations in water in the intermediate aquifer system and the Upper Floridan aquifer along the southern coast of the study area. (Modified from Causseaux and Fretwell, 1983. Lines of sections are shown in fig. 8.)

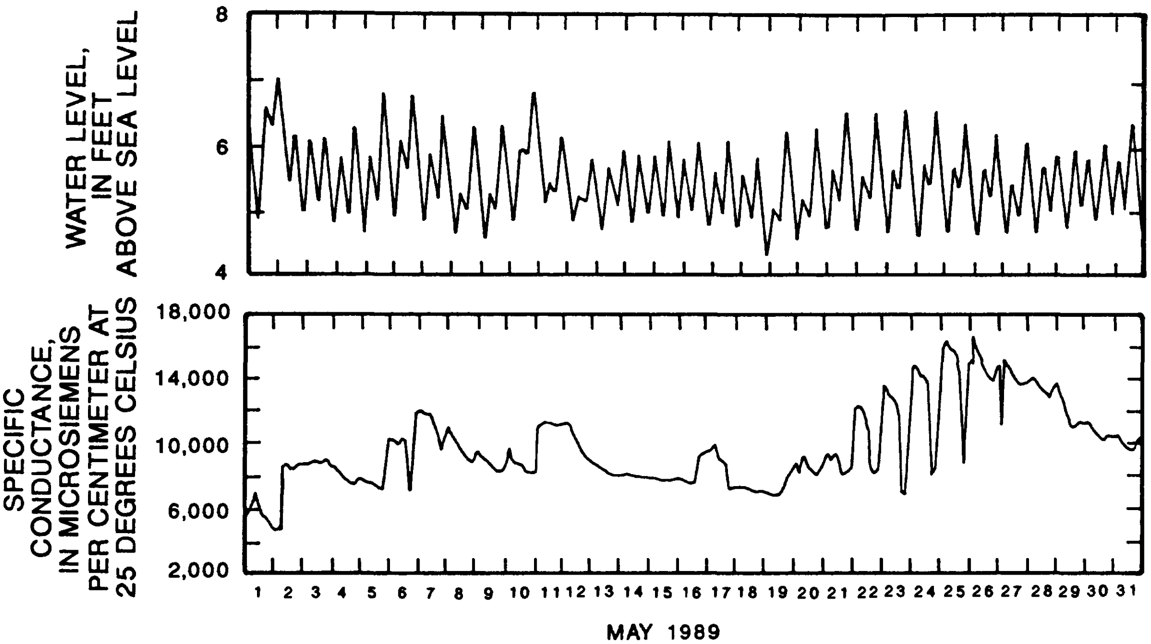


Figure 11. Water levels and specific conductance of water in well TR 19-2, based on hourly measurements, May 1989. (Location of well is shown in fig. 1.)

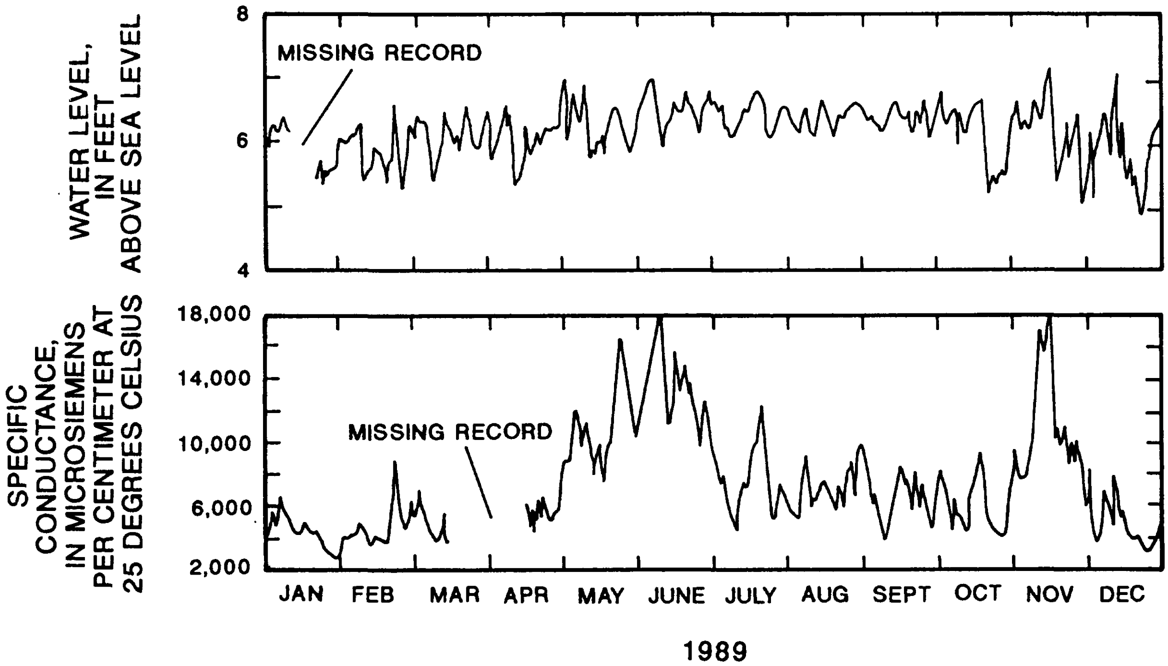


Figure 12. Water levels and specific conductance of water in well TR 19-2, based on maximum daily values, 1989. (Location of well is shown in fig. 1.)

The well is 345 ft deep and has 310 ft of casing. The well is about 3 mi from the coast of Tampa Bay and is in an area of the transition zone where public-supply wells were abandoned because chloride concentrations in the ground water exceeded 250 mg/L.

Data collected during May 1989 (fig. 13) indicate that the potentiometric surface of the Upper Floridan aquifer in this well is tidally influenced. Daily water levels in well TR 12-3 fluctuate about 0.5 ft. Seasonally, the potentiometric surface ranged from a low of about 10 ft above sea level in May 1989 to a high of about 13 ft above sea level in September 1989 (fig. 14). Specific conductance of water from this well indicates that water-level fluctuations from either tidal

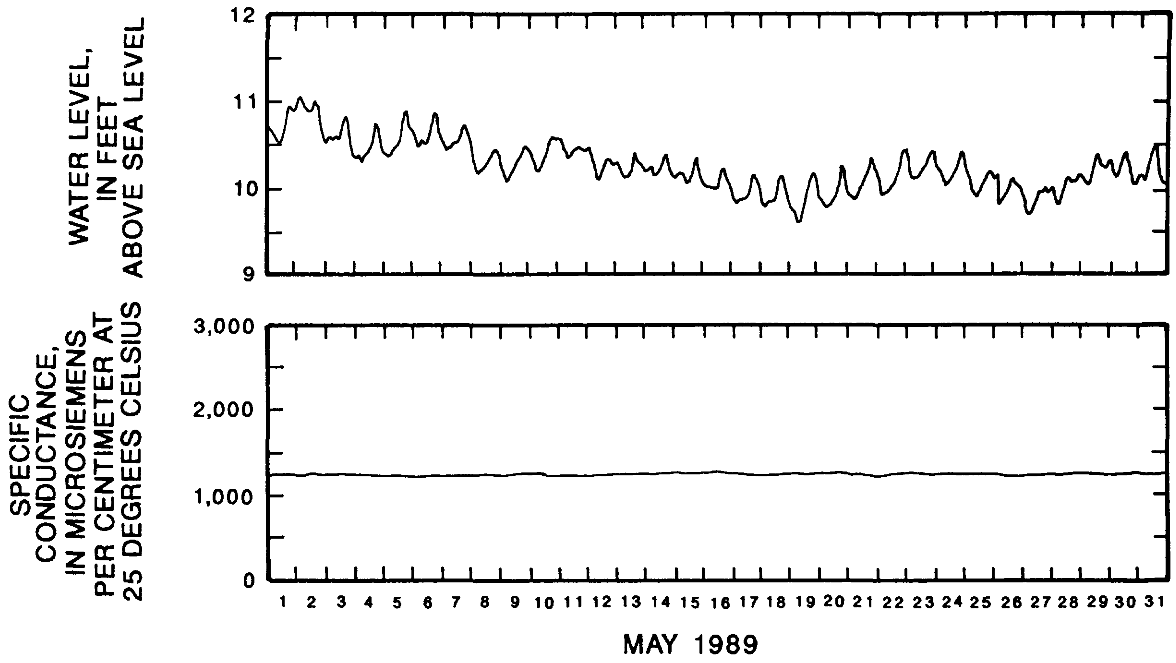


Figure 13. Water levels and specific conductance of water in well TR 12-3, based on hourly measurements, May 1989. (Location of well is shown in fig. 1.)

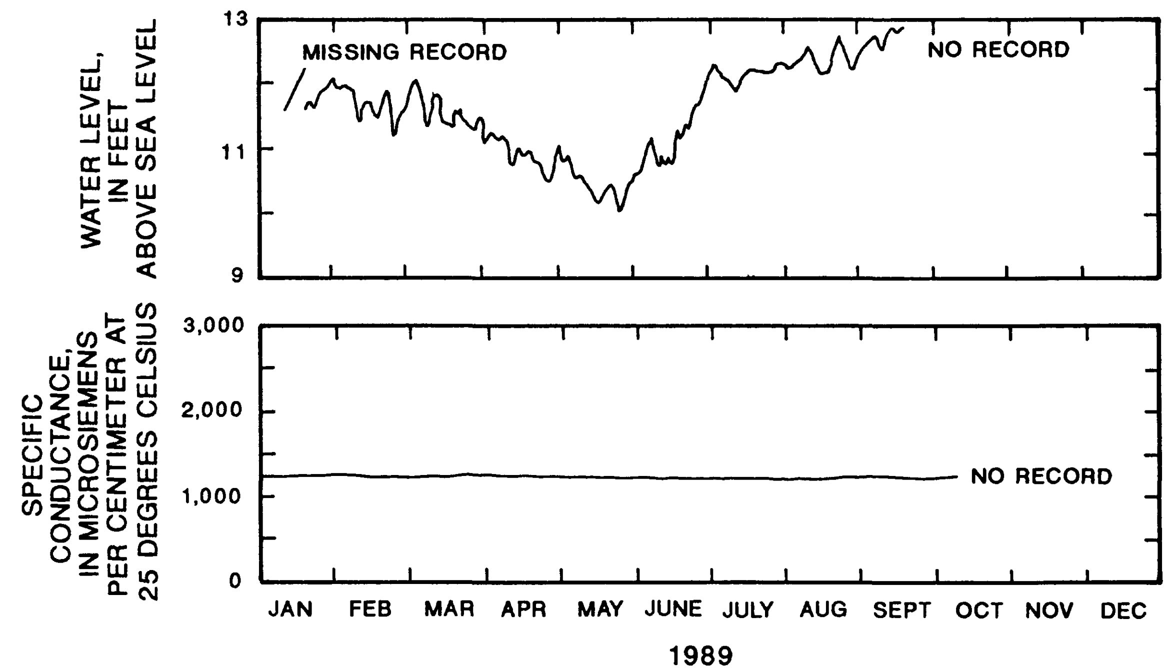


Figure 14. Water levels and specific conductance of water in well TR 12-3, based on maximum daily values, January to October 1989. (Location of well is shown in fig. 1.)

or seasonal influences have little effect on the quality of water in this part of the transition zone.

The third monitoring well to have continuous seasonal and tidal water-level data and specific-conductance data is the TR 10-2 well. It is in west-central Hillsborough County (fig. 1) about 2.5 mi east of Tampa Bay. The monitoring well was completed in the intermediate aquifer system and is 125 ft deep with 115 ft of casing. Water-level and specific-conductance data were collected from December 1987 through July 1988. Water in the underlying Upper Floridan aquifer is highly mineralized (Sutcliffe and Thompson, 1983), is not used as source of supply, and is not monitored. Also, the surficial aquifer system is not monitored because it has limited yield and is not used as a source of supply in this area.

The potentiometric surface of the intermediate aquifer system in well TR 10-2 is tidally influenced; however, water-level data collected during February 1988 (fig. 15) indicated that daily fluctuations were about 0.2 ft. Water levels between December 1987 and July 1988 (fig. 16) ranged from about 6 to 9.5 ft above sea level. Corresponding daily and seasonal specific-conductance data indicate that water quality in the

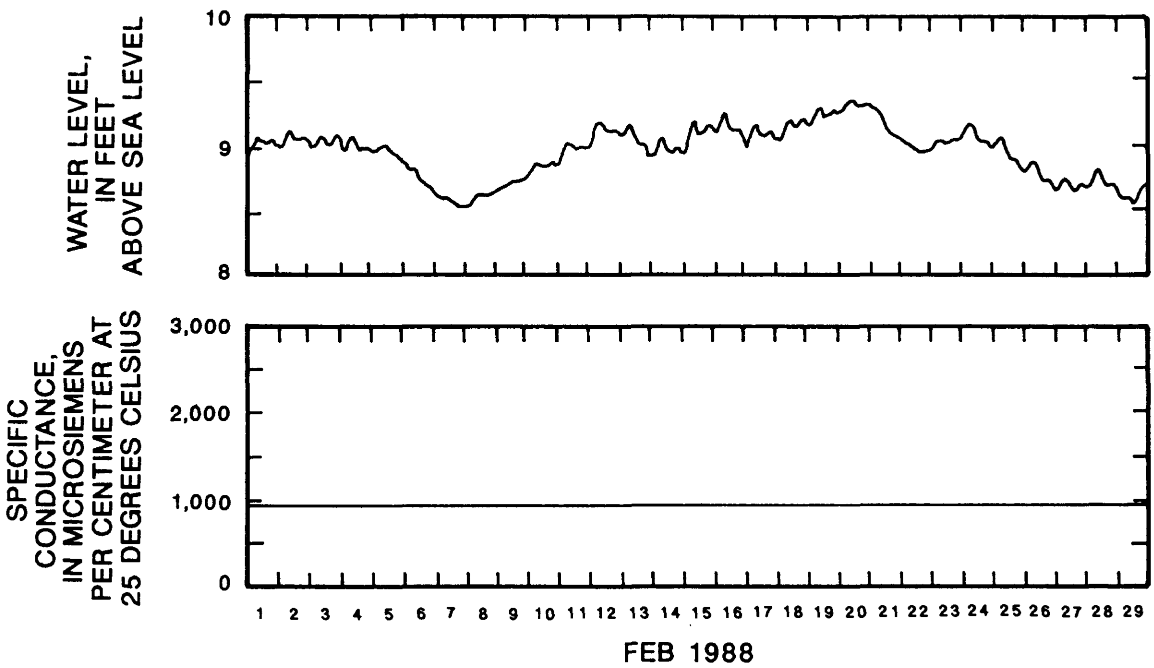


Figure 15. Water levels and specific conductance of water in well TR 10-2, based on hourly measurements, February 1988. (Location of well is shown in fig. 1.)

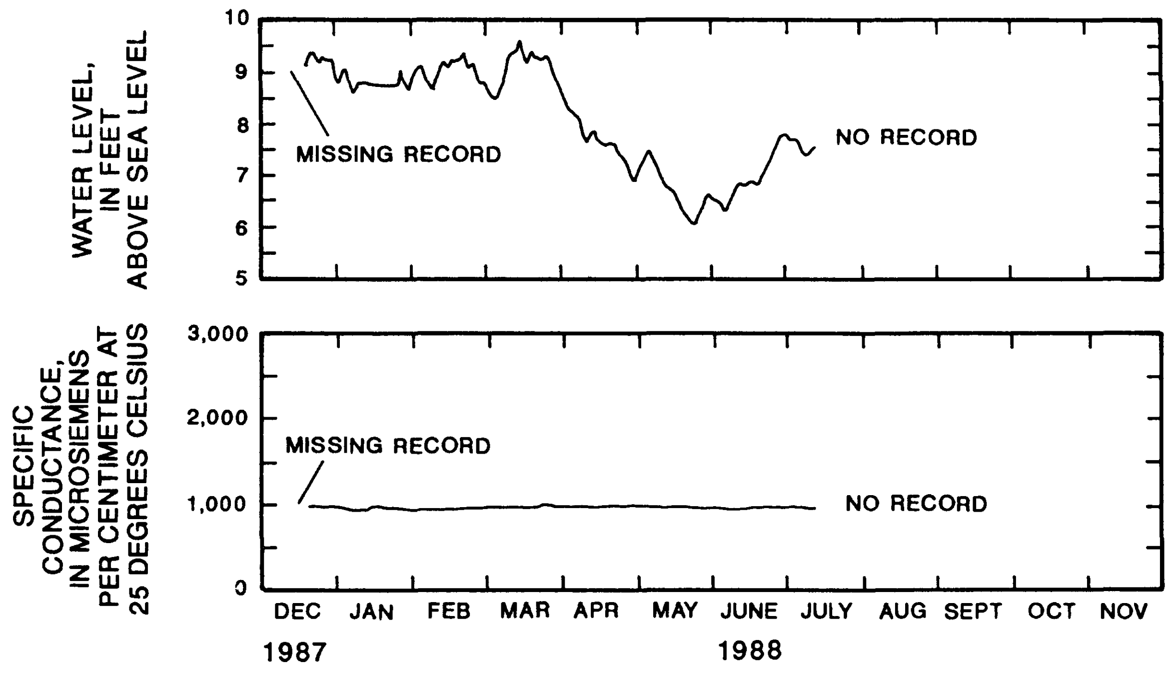


Figure 16. Water levels and specific conductance of water in well TR 10-2, based on maximum daily values, December 1987 to July 1988. (Location of well is shown in fig. 1.)

intermediate aquifer system at this well site is not affected by fluctuations in the potentiometric surface.

The two southernmost monitoring wells to have continuous seasonal and tidal water-level data and specific-conductance data are at Englewood in southwestern Sarasota County (fig. 8). Three aquifer systems exist at this well site. The surficial aquifer system consists of about 25 ft of sand with interbedded clay, marl, and shell fragments and may have multiple water-bearing zones. The surficial aquifer system is used as a source of water supply in the Englewood area. The intermediate aquifer system consists of deposits of Miocene age that form multiple water-bearing units separated by semiconfining units and is approximately 600 ft thick at the well site. Water in some zones of this aquifer system is salty; however, it is used as a source of supply to reverse-osmosis treatment plants. Water in the Floridan aquifer system is highly mineralized, is not used as a source of supply in this area, and is not monitored. Data were collected from February 1989 through May 1990 from a well open to the surficial aquifer system and from August 1987 through May 1990 from a well open to the intermediate aquifer system. The surficial aquifer system well is 15 ft deep with 10 ft of casing and 5 ft of screen. The intermediate aquifer system well is 70 ft deep and has 40 ft of casing.

The surficial aquifer system is unconfined and is not tidally influenced at this well site; however, the aquifer is recharged locally and the water table responds rapidly to rainfall. Water-level data for March 1989 (fig. 17) indicate a 1.5-ft rise in the water table on March 3, apparently the result of 3 days of rainfall between March 1 and 3 that deposited about 3 in. of rain over the area (National Oceanic and Atmospheric Administration, 1989). A rise in the potentiometric surface of the intermediate aquifer system also was observed during this same period, the result of recharge or loading changes from the overlying surficial aquifer system. The potentiometric surface of the upper part of the intermediate aquifer system at this site is confined and is tidally influenced. Daily water-level fluctuations in this well are about 0.5 ft. Seasonal water-level data for 1989 (fig. 18) indicate a high degree of parallelism in both wells, which indicates a good interaquifer connection exists at the well site. Corresponding daily and seasonal specific-conductance data (figs. 17 and 18) indicate that head fluctuations resulting from tides, rainfall, or seasonal wet and dry periods have minimal effect on the specific conductance of the water in either aquifer system. The mean specific conductance for 1989 was 600 μS/cm in the surficial aquifer system and 1,200 μS/cm in the upper part of the intermediate aquifer system.

Six coastal wells were used to supplement data from the long-term monitoring wells and to document the influence of tides on water quality in the intermediate aquifer system and the Upper Floridan aquifer (fig. 19). The wells in Manatee and Sarasota Counties are open to the intermediate aquifer system and the wells in Levy, Citrus, and Pinellas Counties are open to the Upper Floridan aquifer. Data indicate that water levels in all six wells are tidally influenced. The Crystal River deep well is open to the Upper Floridan aquifer and seems to be the only well with a corresponding tidal influence on water quality. The well is 176 ft deep and is completed near the saltwater-freshwater interface.

Data from the long- and short-term monitoring wells indicate that water levels in many coastal wells may be affected by tidal influences. Specific-conductance data, however, indicate water quality in only a small number of wells may be similarly affected.

Chloride Concentration Trends in Ground Water

Concentrations of chloride in ground water have been monitored by the USGS at selected wells along the coastal margins of the SWFWMD for many years. Chloride-concentration trends for samples collected between 1970 and 1990 from 23 of these wells are shown in figures 20 and 21. On each plot, a line that represents the results of a simple linear-regression analysis is superimposed on the data points to indicate possible long-term trends.

Wells 1 through 10 (fig. 20) are open only to the Upper Floridan aquifer. Concentrations of chloride in water samples from wells 1, 2, and 4 in Citrus and Hernando Counties have remained virtually unchanged from 1970 to 1990. Water samples from well 3 in Citrus County, however, had a slight increase in chloride concentration during this period. In Pasco County, chloride concentrations in ground water are increasing at some wells and decreasing at others. The chloride concentration in water samples from well 6 increased from about 8,500 mg/L in 1975 to about 12,000 mg/L in 1987, whereas chloride concentrations in water samples from well 7 decreased from 100 to 50 mg/L during the same time period. This decreasing trend may have resulted from the discontinued use of some coastal public-supply wells. Trends indicate increasing concentrations of chloride in wells in Hernando and Pinellas Counties (fig. 20).

Chloride concentrations in water from 13 wells open to either the intermediate aquifer system or the Upper Floridan aquifer in Hillsborough, Manatee, and Sarasota Counties ranged from 50 to 7,000 mg/L (fig. 21). The concentrations of chloride in water samples from well 11, a 1,120-ft-deep well in northwestern Hillsborough County, increased from 4,000 mg/L in 1983 to about 7,000 mg/L in 1989. Chloride concentrations in water from well 12, a nearby 80-ft-deep well, decreased from 350 to 100 mg/L between 1976 and 1989.

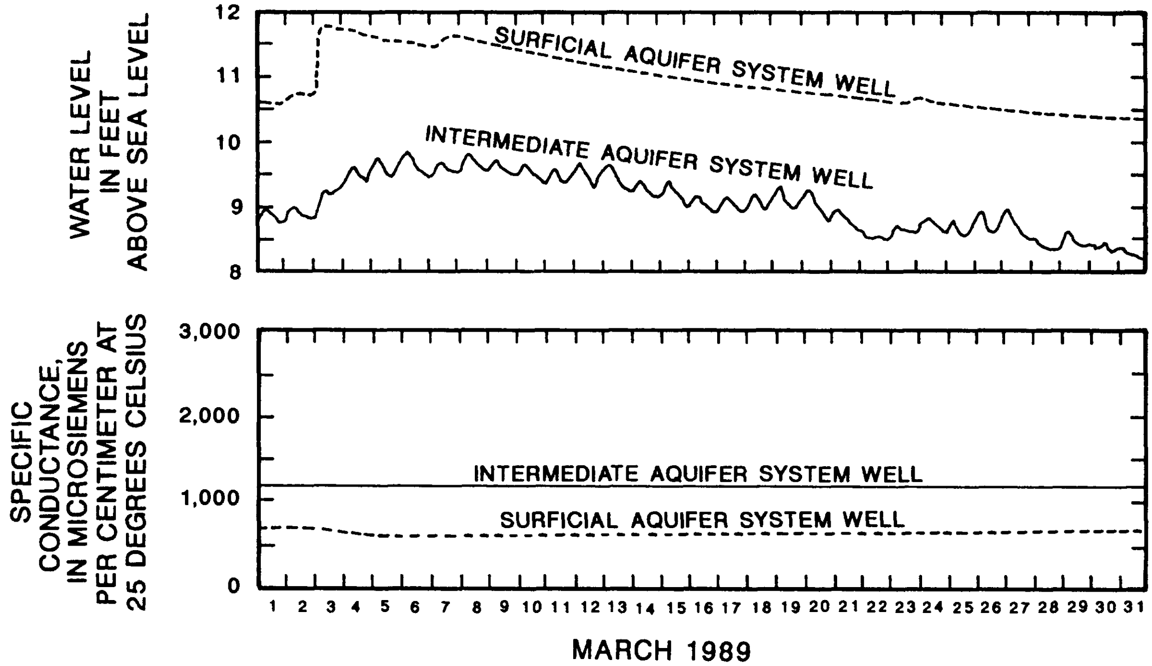


Figure 17. Water levels and specific conductance of water in the surficial and intermediate aquifer system wells at the Englewood site, based on hourly measurements, March 1989. (Locations of wells are shown in fig. 8.)

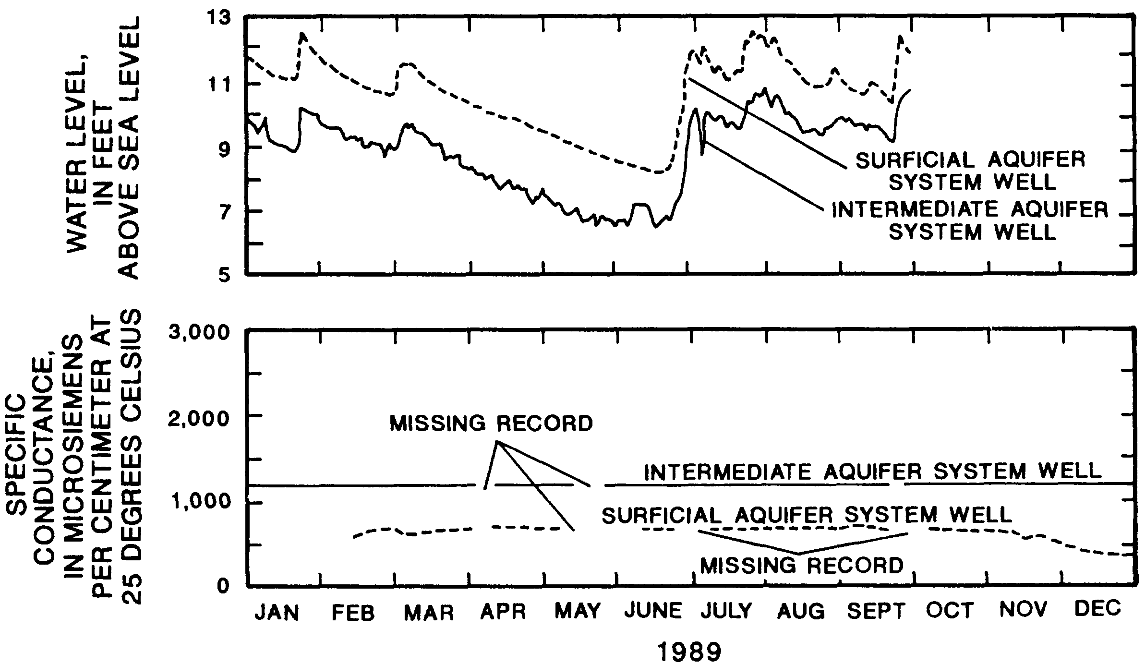
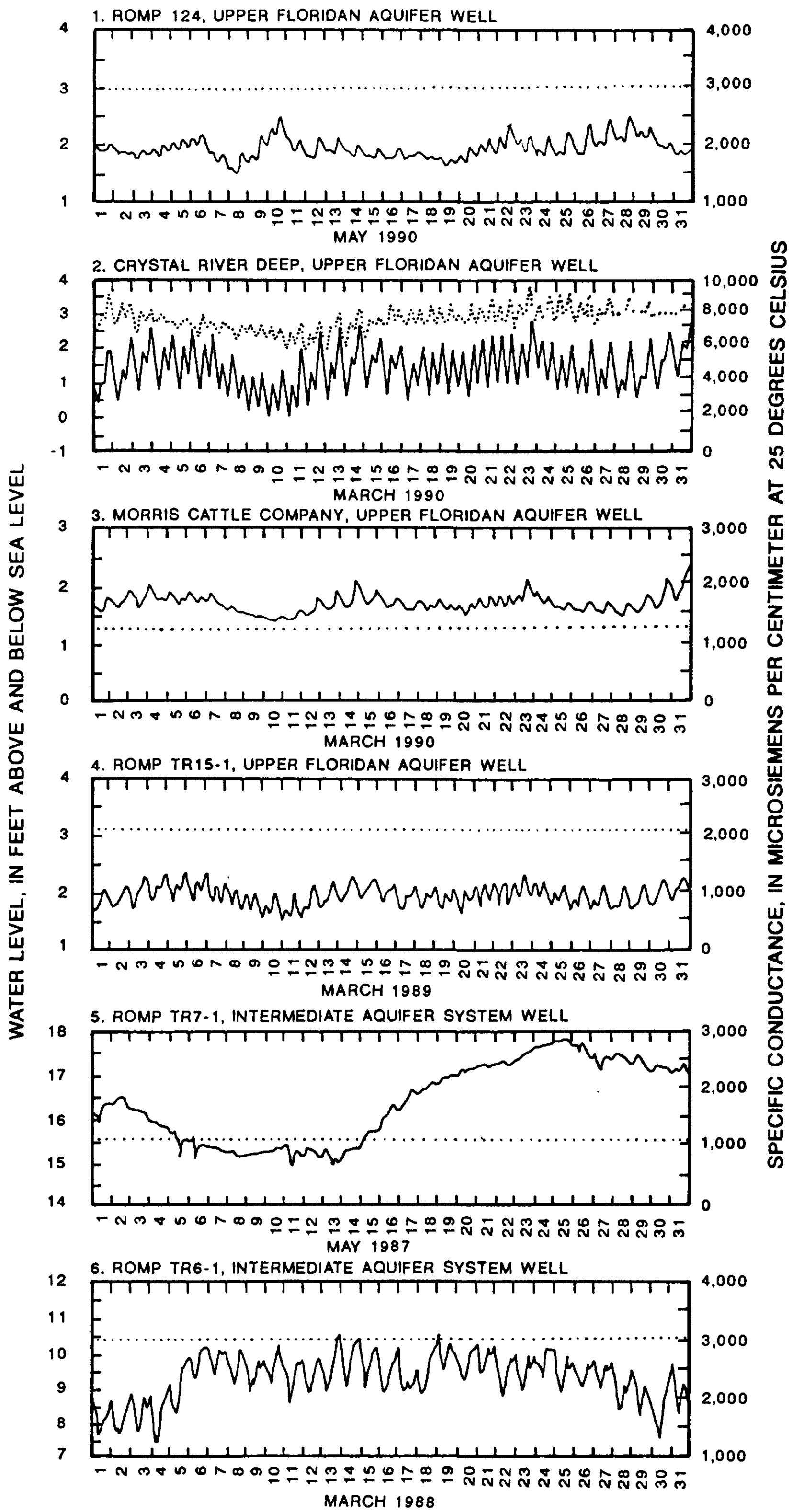


Figure 18. Water levels and specific conductance of water in the surficial and intermediate aquifer system wells at the Englewood site, based on maximum daily values, 1989. (Locations of wells are shown in fig. 8.)



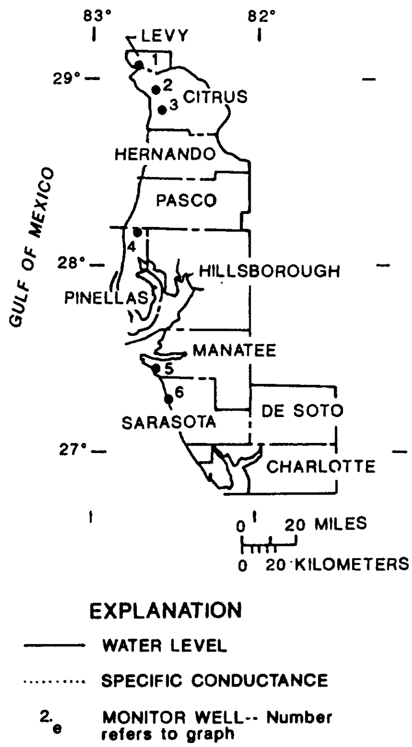


Figure 19. Water levels and specific conductance of water in selected wells, 1987-90.

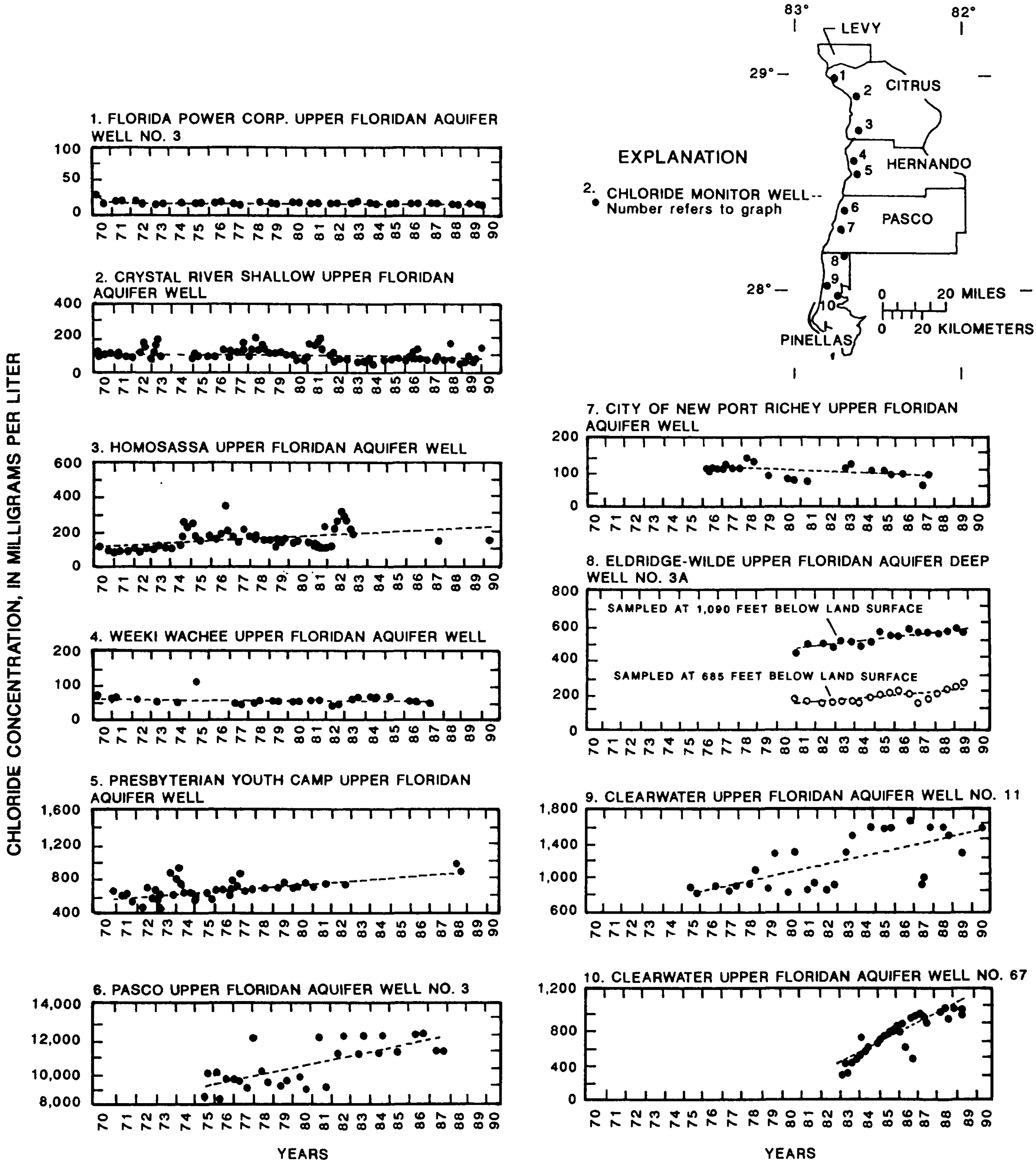


Figure 20. Trends in chloride concentrations in ground water from selected wells along the northern coast of west-central Florida, 1970 to 1990.

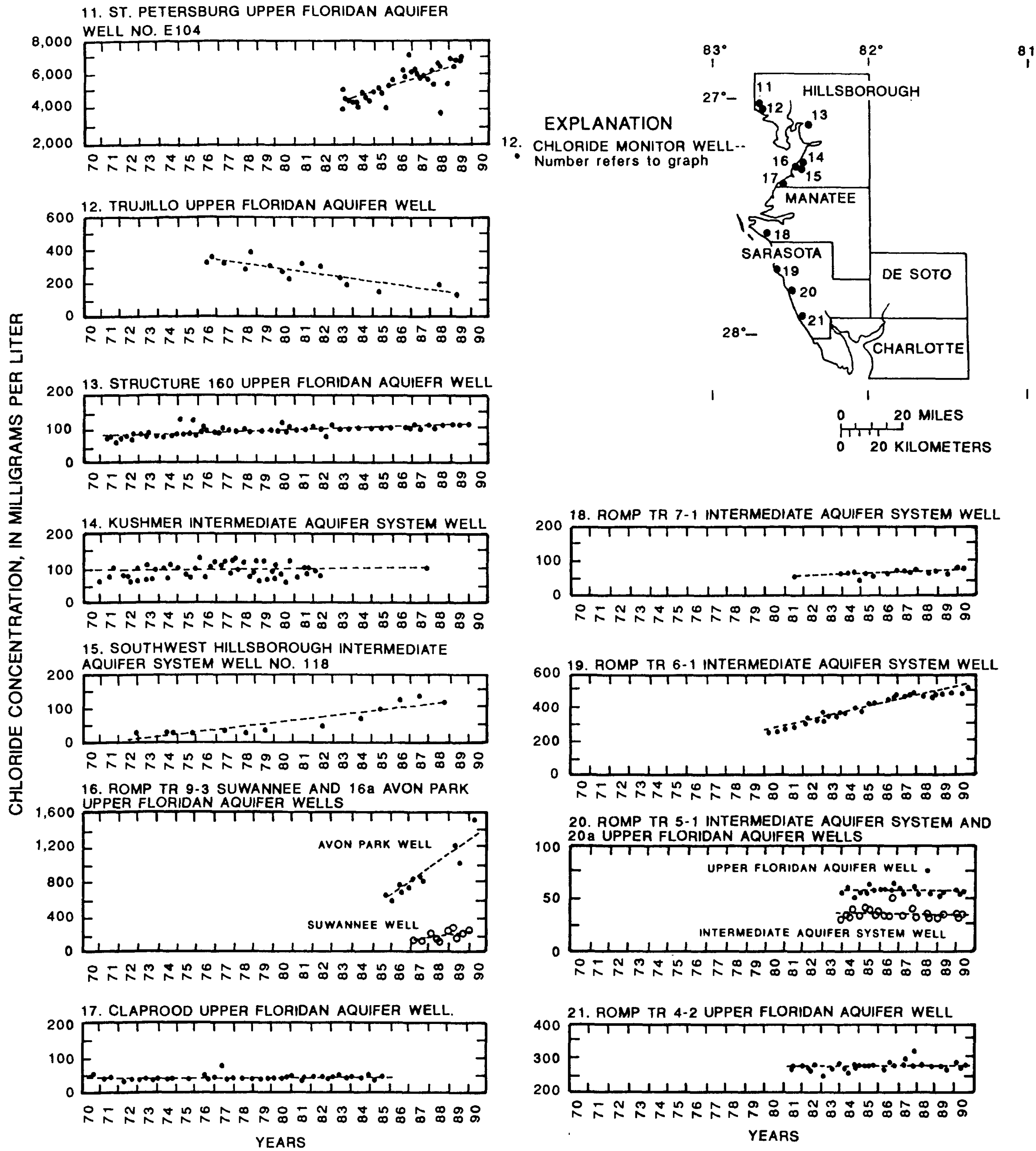


Figure 21. Trends in chloride concentrations in ground water from selected wells along the southern coast of west-central Florida, 1970 to 1990.

Continuing land-use change in this area, which has resulted in less reliance on the upper part of the Upper Floridan aquifer for irrigation and domestic supply, could have resulted in the improvement in water quality in this part of the aquifer. Conversely, heavy pumpage from the well fields north and northeast of this area can be contributing to the increasing trend in chloride concentrations at the edge of the transition zone in the lower part of the Upper Floridan aquifer. Results of analyses of water samples from well 13 in central Hillsborough County indicate a gradual increase in chloride concentration from 50 to 100 mg/L between 1971 and 1990.

Wells 14 and 15 in southern Hillsborough County are open only to the intermediate aquifer system. The concentration of chloride in water samples from well 14 has remained virtually unchanged in 18 years; however, concentrations of chloride in water samples from well 15, about 4 mi south of well 14, have increased. Well 15 is in an agricultural area and localized, extended pumping for irrigation may be contributing to this trend.

Two deeper Upper Floridan aquifer wells, 16 and 16a, are about 2 mi south of well 14. Well 16 is 525 ft deep and is finished in the Suwannee Limestone; well 16a is 779 ft deep and is finished in the Avon Park Limestone. Chloride concentration in water from well 16 has increased from 140 to 250 mg/L from 1987 to 1990, whereas chloride concentration in water from well 16a has increased from about 600 to more than 1,500 mg/L during this same period. Both wells are downgradient of an agricultural area, and saltwater intrusion into the Upper Floridan aquifer as a result of nearby long-term pumping for irrigation may be causing the increased chloride concentrations.

Chloride concentrations in water from wells 17, 18, 20, 20a, and 21 have remained unchanged or have increased only slightly. Chloride concentration in water from well 19, completed in the intermediate aquifer system in northern Sarasota County, has increased from 250 mg/L in 1980 to 500 mg/L in 1990 (fig. 21).

MONITORING THE SALTWATER-FRESHWATER TRANSITION ZONE

Methods used to obtain water samples or to determine the suitability of a well for sampling vary between organizations, individuals, and from site to site. Water samples from transition-zone monitoring wells have been collected by pumping from land surface through a short length of hose or pipe inserted into the casing, by airlift or centrifugal pump through small-diameter drop pipes set to a specific depth, or by grab samples collected from a specific depth using a thief sampler. Additionally, common sampling practices include evacuating three casing volumes or three borehole volumes (casing volume plus volume of water in the open-hole section) of water from the well before collecting the sample, purging the well for some specified period of time, or purging the well until pH, temperature, and specific-conductance values stabilize. Differing well characteristics, such as multiple production zones, length of the open hole section, total depth and casing, and the position of the saltwater-freshwater interface to the bottom of the well, also can affect the results obtained by sampling procedures. Well construction and producing zones in wells selected for monitoring is often not verified before samples are collected. Therefore, tests were designed to document variations in sampling results that might be caused by differing sampling methods or well characteristics.

Sampling Methods and Well Characteristics at Three Test Sites

Wells completed in three different hydrogeologic settings were selected for testing. The tests were conducted at the Tampa Police Pistol Range in northwestern Hillsborough County, at 11th Street and Oregon Avenue in the city of Sarasota, Sarasota County, and at Apollo Beach in southwestern Hillsborough County (fig. 8). The Tampa Police Pistol Range well is representative of wells in the northern part of the study area where the Upper Floridan aquifer is close to land surface and is not overlain by a thick intermediate confining layer or the intermediate aquifer system. The 11th Street and Oregon Avenue well is representative of many wells in the southern part of the study area that are completed only in the intermediate aquifer system. The well at Apollo Beach is representative of many wells in the middle and southern part of the study area that are open to the intermediate aquifer system and the Upper Floridan aquifer.

Existing conditions in each well were assessed by using specific-conductance logs, flowmeter surveys, and continuous water-level and specific-conductance recorders. Specific-conductance profiles identified zones where water quality seemed to change, and flowmeter surveys identified probable flow zones. Flowmeter surveys were conducted in steps, at increasingly higher pumping rates, to document any effects that increased stress might have on the zones contributing water to the well. Probes from the specific-conductance recorder were set at flow zones or zones where water quality changed. Water-level data also were recorded continuously to correlate possible changes in specific conductance with water-level changes.

The first phase of testing consisted of collecting and measuring the specific conductance of ground-water samples through a 0.5-in. polyvinyl chloride pipe placed at depths corresponding to flow zones or zones were water quality changed. This pipe is commonly called a drop pipe. The bottom of the drop pipe was placed at the shallowest depth first, and samples were collected at one, two, and three pipe volumes and then at selected time intervals thereafter. The drop pipe was then lengthened and the procedure was repeated until samples were collected from all zones.

During the second phase of testing, samples were collected by pumping the well from land surface at various rates using centrifugal pumps equipped with short lengths of intake hose inserted into the top of the casing. Samples were collected at one, two, and three casing volumes; one, two, and three borehole volumes; and at selected time intervals thereafter. Pumping rates were increased to increase the stress on the aquifer as the test progressed. Recovery time was allowed between various steps of the test and geophysical logging was conducted periodically throughout the test to document any changes occurring in the well.

Tampa Police Pistol Range Test Site

The first test site was at the Tampa Police Pistol Range in northwestern Hillsborough County (fig. 8). The well at this site was installed by the WCRWSA as a transition-zone monitoring well. The test site lies between Upper Tampa Bay and a public-supply well field that provides water to Hillsborough County residents. Approximately 65 ft of unconsolidated sand, silty sand, peat, and organic rich clay make up the surficial aquifer system and the intermediate confining unit that overlie the Upper Floridan aquifer in this area. The intermediate aquifer system does not exist at the test site. The well is 420 ft deep with 100 ft of casing.

Continuous specific-conductance data collected on June 18 and 19, 1989, indicated some fluctuation in specific conductance with time in this well (fig. 22). Corresponding water-level data were not available. Flow zones, or zones where water quality changed, previously were identified at depths of 110, 230, 270, 325, and 390 ft using borehole-geophysical logs; however, samples were collected only from depths of 110, 230, 325, and 390 ft. The flow zone at a depth of 270 ft was not sampled because water quality did not appear to change between 230 and 325 ft. A specific-conductance log (fig. 23a) was recorded prior to the start of the test on June 20, 1989, at 0600 hours and indicated that specific-conductance values at each of the sampled zones were 850, 945, 1,550, and 1,925 μS/cm, respectively.

The first zone was sampled just below the casing through a 110-ft drop pipe. Specific conductance measured at the start of the test was 890 μS/cm, and,

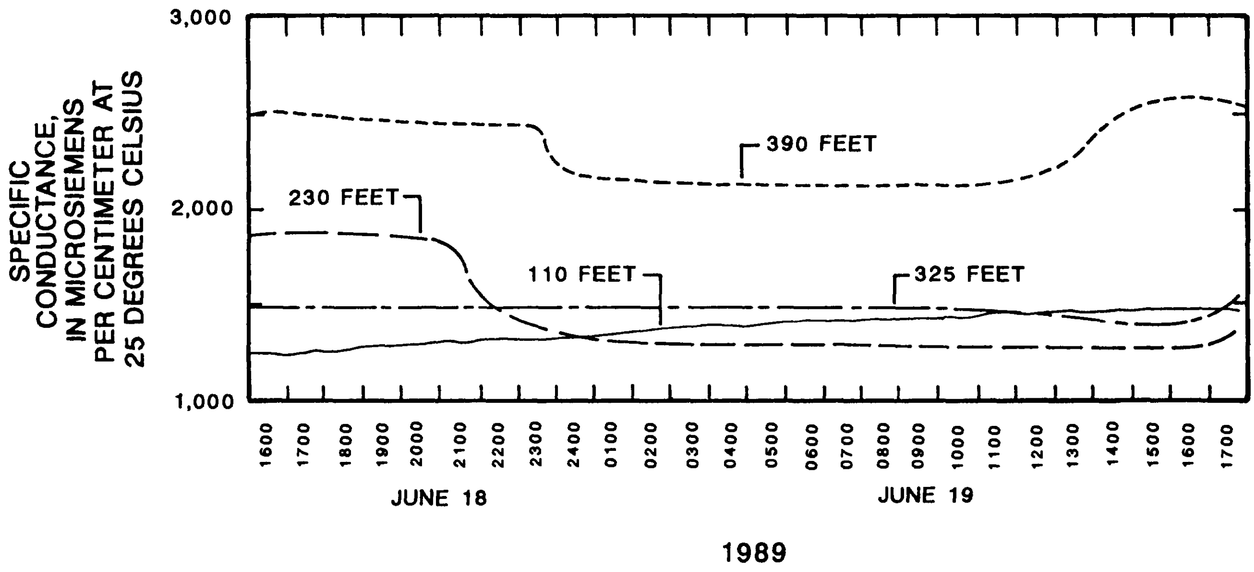


Figure 22. Variation in specific conductance of water at depths of 110, 230, 325, and 390 feet in the Tampa Police Pistol Range test site well, June 18-19, 1989.

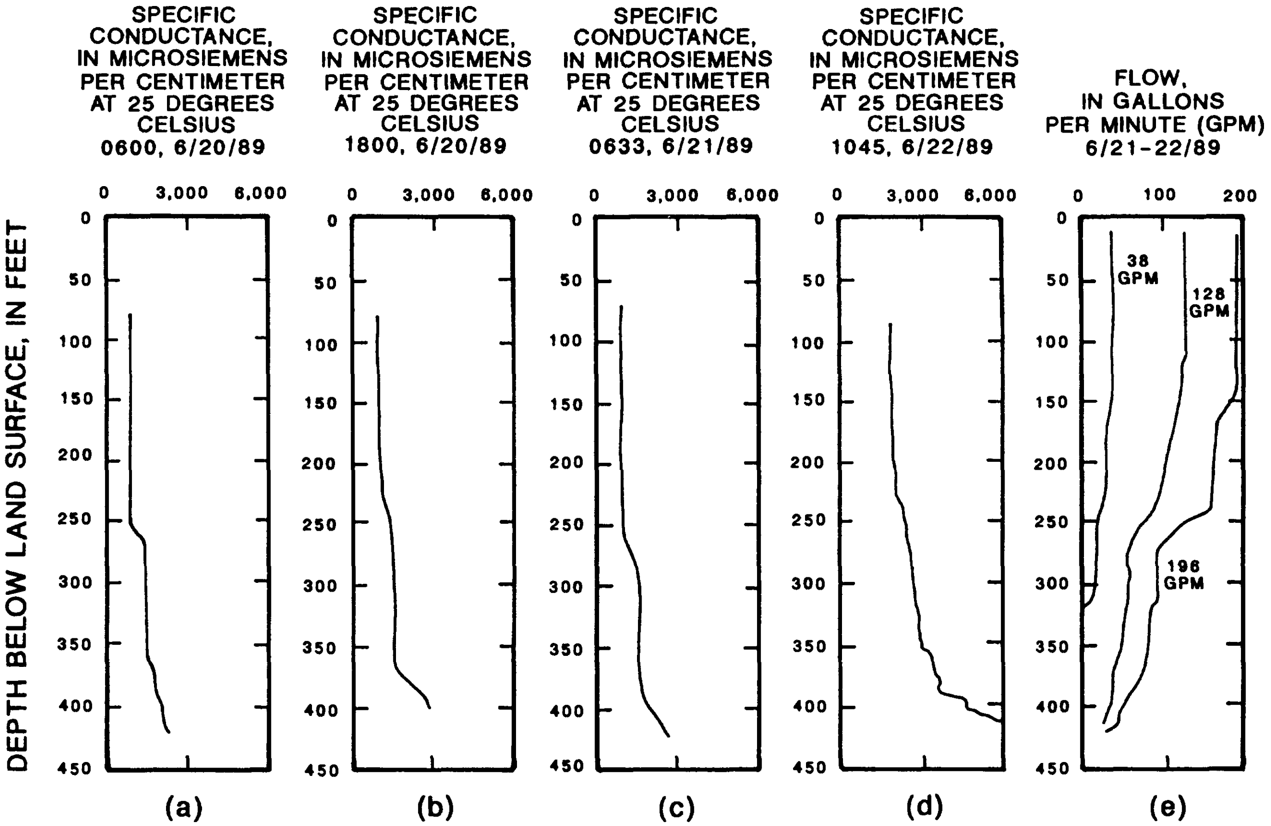


Figure 23. Specific-conductance and flow logs from the well at the Tampa Police Pistol Range test site, June 1989.

after 11 minutes of pumping at a rate of 4.6 gal/min, the specific conductance stabilized at 850 µS/cm. Pumping was terminated after 30 minutes (table 1). Eleven minutes of pumping was approximately equivalent to 50 gal, or 44 drop-pipe volumes, of water, which indicates that some of the water in the borehole also was purged before the ground water was sampled. Water entering the drop pipe probably came from the borehole above and below the bottom of the drop pipe, as well as from the flow zone at a depth of 110 ft. Specific conductance of the samples stabilized when flow paths to the drop pipe stabilized.

The drop pipe was lowered to a depth of 230 ft, and specific conductance measured after 1 minute of pumping was 905 µS/cm. Specific conductance of samples collected during pumping continued to increase slowly, but did not stabilize during 50 minutes of pumping at 3.1 gal/min. Specific conductance was 1,280 µS/cm at the time pumping was terminated. Water entering the drop pipe at this depth seemed to be moving up the borehole from a deeper, more saline zone.

Specific conductance measured at a depth of 325 ft after 2 minutes of pumping was 1,270 µS/cm. At this depth, the specific conductance of the ground-water sample stabilized after one pipe volume at a value of 1,570 µS/cm. The specific conductance remained constant during the 23 minutes of pumping at 2.4 gal/min. Water entering the drop pipe might be representative of the formation at this depth.

Specific conductance of water samples collected from 390 ft remained at 1,970 µS/cm during the first 10 minutes of pumping at 2.1 gal/min, then increased slowly and stabilized at 2,045 µS/cm after the well had been pumped for 23 minutes. At this depth, 23 minutes of pumping is equivalent to approximately 48 gal, or 11 pipe volumes, of water, which indicates that water entering the drop pipe could be moving from another part of the borehole and might not be representative of the formation at this depth.

A specific-conductance log was recorded at the end of this phase of testing on June 20, 1989, at 1800 hours to record changes that had occurred in the well as a result of pumping (fig. 23b). Specific conductance measured with the logging tool at depths of 110 and 325 ft was 850 and 1,570 µS/cm, respectively, and agreed with the pumped samples. A value of 1,125 µS/cm was measured at 230 ft with the logging tool in contrast with the pumped sample from this depth of 1,280 µS/cm. Specific conductance at this depth might have decreased slightly because water was no longer being drawn from lower zones. Specific conductance at a depth of 390 ft was 2,560 μS/cm; however, the pumped sample from this depth stabilized at 2,045 μS/cm. The specific-conductance log shows a sharp increase in specific conductance at depths between 370 and 390 ft. When the well was pumped through a drop pipe, water with a lower specific conductance might have been drawn down the borehole to the bottom of the drop pipe rather than up from the zone below. The drop pipe was removed and the well remained undisturbed overnight.

Table 1. Specific conductance of and chloride concentrations in ground-water samples collected through a drop pipe at the Tampa Police Pistol Range well, June 20, 1989

[gal/min, gallons per minute; μS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; DPV, drop pipe volume; --, no data]

Sampling depth (feet below land surface)	Pumping rate (gal/min)	Pumped volume	Elapsed time (minutes)	Specific conductance (μS/cm)	Chloride concentration (mg/L)
110	4.6	1 DPV	0.25	890	165
		2 DPV	.50	885	159
		3 DPV	.75	870	158
		24 DPV	6	860	150
		44 DPV	11	850	--
		121 DPV	30	850	140
230	3.1	1 DPV	1	905	146
		2 DPV	2.5	1,135	216
		3 DPV	4	1,130	217
		12 DPV	9	1,150	224
		26 DPV	20	1,225	242
		65 DPV	50	1,280	257
325	2.4	1 DPV	2	1,270	250
		2 DPV	5	1,570	339
		3 DPV	7	1,570	343
		8 DPV	11	1,570	340
		16 DPV	23	1,570	341
390	2.1	1 DPV	2	1,575	333
		2 DPV	4	1,970	463
		3 DPV	6	1,970	461
		5 DPV	10	1,970	472
		11 DPV	23	2,045	--
		15 DPV	32	2,045	475
		16 DPV	34	2,045	467

A specific-conductance log recorded the following day, June 21, 1989, before the next phase of testing began indicated that specific conductance in the well had returned to near prepumping conditions (fig. 23c). The well was then pumped at 13, 38, 128, and 131 gal/min using various centrifugal pumps. Samples were collected after each casing volume when pumped at 13 and 38 gal/min. At the higher pumping rates, samples representative of single-casing volumes could not be collected. When pumped at 13 gal/min, specific conductance increased steadily from 875 to 1,620 μS/cm (table 2), but did not stabilize during the 146-minute (equivalent to three borehole volumes) pumping time. The ending specific-conductance value was similar to a value recorded prior to the test at a depth of 230 ft. Specific-conductance values stabilized at 1,610 μS/cm in less than two casing volumes when pumped at 38 gal/min. Pumping rates of 128 and 131 gal/min produced similar results. Specific conductance of the ground water stabilized in less than 5 minutes with values ranging from 1,560 to 1,700 μS/cm. Again, the well was allowed to remain undisturbed overnight.

On June 22, 1989, water quality in the well had again recovered to near prepumping condition. The well was pumped at rates of 170 and 196 gal/min to complete the test (table 2). When pumped at 170 gal/min, specific conductance of the samples increased for about 25 minutes, from 1,185 to 1,650 μS/cm, before stabilizing. At 196 gal/min, specific conductance of the samples stabilized in less than 5 minutes at 1,650 μS/cm. A specific-conductance log recorded at the conclusion of the 196-gal/min test (fig. 23d) indicated specific-conductance values of 1,700, 2,000, 2,850, and 3,700 μS/cm, respectively, at each of the four zones. Water quality below a depth of 390 ft deteriorated rapidly and a specific-conductance value of about 6,000 μS/cm was measured with the logging tool at the bottom of the well (fig. 23d). Under stressed conditions, more saltwater seemed to be entering the well near the bottom, moving up, and mixing with better quality water that was entering higher in the borehole. Flow logs indicated that, at a pumping rate of 38 gal/min, water entered the well at depths between 140 and 320 ft (fig. 23e). At pumping rates of 128 and 196 gal/min, water entered the well along the entire borehole. Most water seemed to enter the well from above 275 ft at all three pumping rates. Specific conductance and corresponding chloride concentrations for selected samples collected during this test are listed in table 2.

Table 2. Specific conductance of and chloride concentrations in ground-water samples collected by pumping through the casing at different rates at the Tampa Police Pistol Range well, June 21-22, 1989

[gal/min, gallons per minute; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; BH, borehole volume (volume of casing plus open hole); CSG, casing volume; --, no data]

Pumping rate (gal/min)	Pumped volume	Elapsed time (minutes)	Specific conductance (µS/cm)	Chloride concentration (mg/L)
13	1 CSG	12	875	143
	2 CSG	24	875	141
	3 CSG	36	870	145
	1 BH	49	1,080	183
	2 BH	97	1,265	251
	3 BH	146	1,620	354
38	1 CSG	4	1,560	--
	2 CSG	8	1,610	361
	--	10	1,610	--
	1 BH	15	1,610	--
128	1 BH	5	1,680	--
	2 BH	10	1,700	--
	3 BH	15	1,650	--
	--	22	1,660	377
	--	30	1,650	--
131	3 CSG	3	1,640	354
	1 BH	5	1,560	343
	2 BH	10	1,620	359
	3 BH	15	1,560	331
	--	20	1,570	339
	--	25	1,590	347
	--	30	1,600	351
170	--	5	1,185	237
	--	10	1,560	337
	--	15	1,595	350
	--	20	1,605	354
	--	25	1,655	369
	--	30	1,650	--
	--	40	1,650	--
196	--	5	1,660	375
	--	10	1,650	375
	--	15	1,650	376

Continuous specific-conductance data were collected at the well from July 20 to September 5, 1989, and continuous water-level data were collected from August 7 to September 5, 1989. The specific-conductance recorder probes were set at depths of 110, 230, 325, and 390 ft. The well was again pumped on August 9, 1989, as part of a routine sampling event by the WCRWSA. Using a centrifugal pump, a water sample was collected after the well was pumped for approximately 15 minutes at a discharge rate of 30 gal/min. The water-level and specific-conductance recorders were left in place during the sampling. Specific conductance before pumping at depths of 110, 230, 325, and 390 ft was 750, 830, 1,190, and 1,780 µS/cm, respectively. At the time the sample was collected, specific conductance in the borehole at each zone was 1,120, 1,530, 2,030, and 2,790 µS/cm, respectively. Specific conductance of the collected sample was 1,140 µS/cm. The sample could be representative of water from the upper part of the borehole, or it could be a composite sample that does not accurately represent the well. The well was not pumped long enough to evacuate the entire borehole or to allow specific conductance to stabilize before the sample was collected. The well was then pumped at a rate of 196 gal/min to record the effects of the added stress and following recovery. Specific conductance stabilized during pumping in about 20 minutes at 1,480, 1,880, 2,320, and 2,950 µS/cm for the four zones. The sample collected at land surface had a specific conductance of 1,480 µS/cm after 40 minutes of pumping, indicating that the sample was a composite with most of the water probably coming from the upper parts of the borehole.

Specific conductance for each zone from July 21 to September 5 and water levels in the well from August 7 to September 5, 1989, are shown in figure 24. Data from the recorders indicate the water level in the well is tidally influenced, and the resulting water-level changes affect specific conductance in the two deeper zones. Water quality in the two upper zones under static conditions does not seem to be affected by tidal water-level fluctuations but is affected by pumping (fig. 24). As a result of the August 9, 1989, pumping event, specific conductance in the upper zone (110 ft) was slower to recover than it was in the lower zones. Inconsistency in water-quality data could result if low stress sampling events are not scheduled to coincide with specific tidal stages. A high-stress sampling event, however, would disrupt the salinity gradient in the well. A specific-conductance plot of samples collected by the WCRWSA from March 1987 through May 1989 is shown in figure 25. The range of specific-conductance values could be attributed to tidal effects, pumping rates, and duration of pumping.

To continue this well as a transition zone monitoring well, the zone near a depth of 230 ft should be monitored instead of the 110-ft zone. A drop pipe constructed to a depth of 230 ft would reduce the time and the size of the pump needed to sample this zone; however, the sample would have to be considered a composite sample because water entering the drop pipe may not be representative of the flow zone at that depth. Stressing the well with a higher volume pump seems to result in upconing of water with high specific conductance. The more this well is pumped, the greater the chance that saltwater will be drawn upward.

City of Sarasota 11th Street and Oregon Avenue Test Site

The second test site was at 11th Street and Oregon Avenue in Sarasota (fig. 8). The well was originally used for public supply, but has been converted to a monitoring well for nearby public-supply wells. The well is 479 ft deep with 43 ft of casing and is open to the intermediate aquifer system. The intermediate aquifer system at the test site is about 500 ft thick (Duerr and others, 1988, p. 11).

A specific-conductance log recorded prior to the start of the test (September 26, 1989) indicated that water-quality changes occurred near a depth of 370 ft and below 415 ft (fig. 26a). A flowmeter survey run while pumping the well at 60 gal/min indicated a major flow zone exists between depths of 370 and 400 ft (fig. 26d). Specific conductance seems to be virtually uniform to a depth of about 370 ft. The zones at 300, 376, and 450 ft, which are above, in, and below the

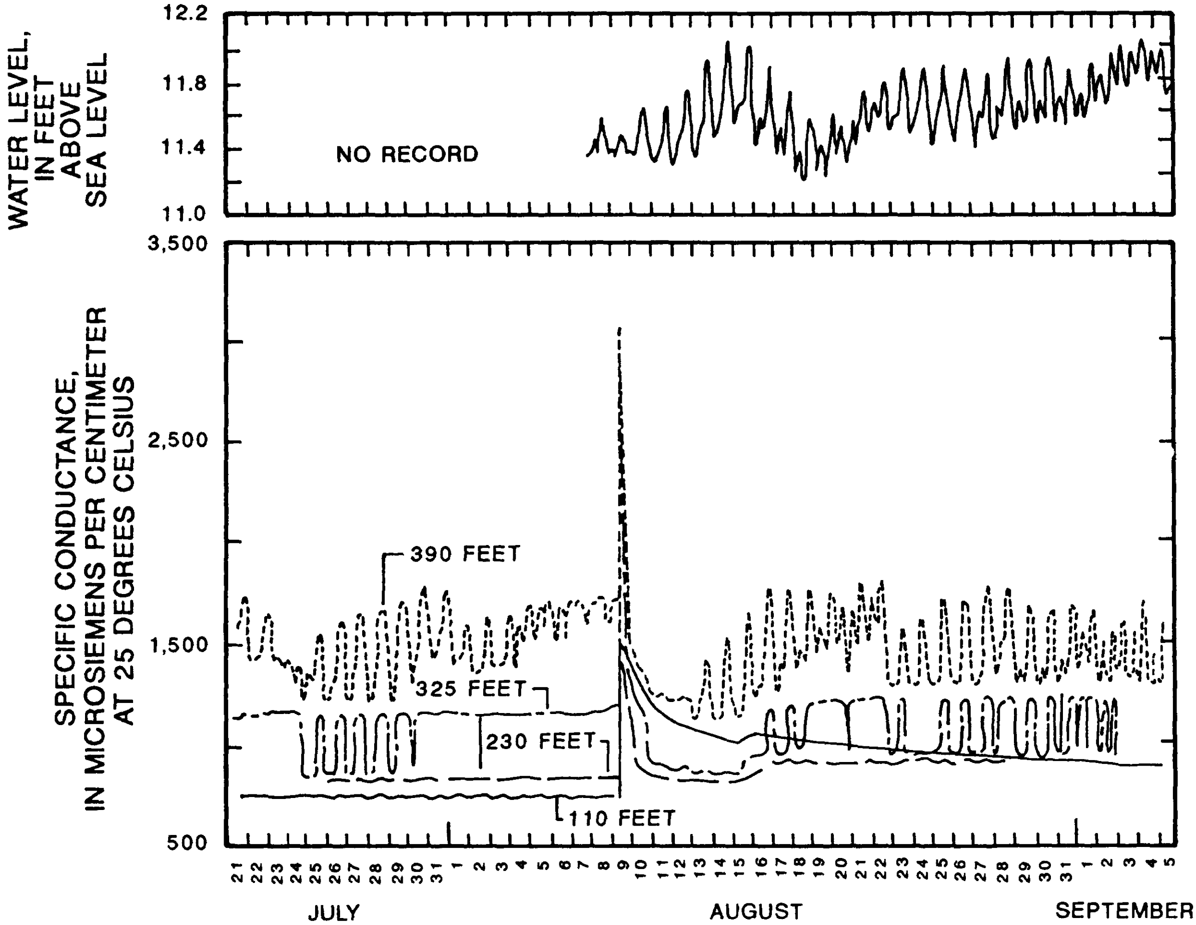


Figure 24. Water levels and specific conductance of water in the well at the Tampa Police Pistol Range test site, July 21 to September 5, 1989.

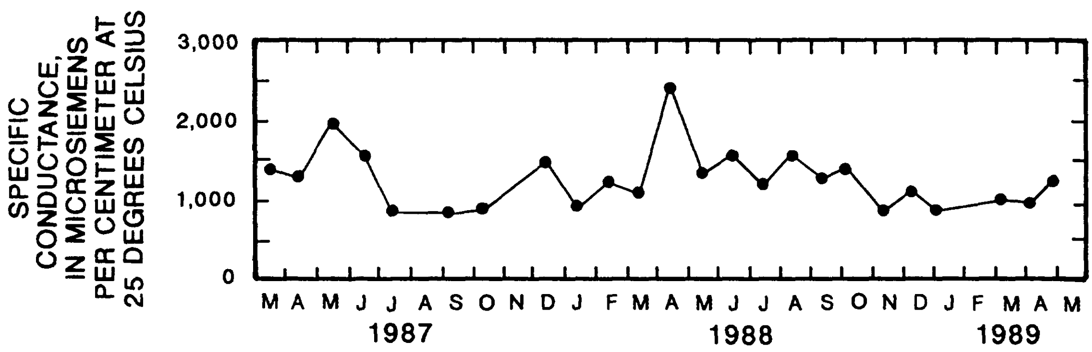


Figure 25. Specific conductance measured in water samples collected from the well at the Tampa Police Pistol Range test site by the West Coast Regional Water Supply Authority, March 1987 to May 1989.

flow zone, were selected for testing. Specific conductance at these depths was 2,400, 2,500, and 3,100 µS/cm, respectively.

The first zone was sampled through a 300-ft drop pipe. Specific conductance measured at the start of the test was 2,400 µS/cm, stabilized at 2,580 µS/cm after 2 minutes of pumping (equivalent to two drop-pipe volumes), and remained stable for 15 minutes until pumping was terminated (table 3). The drop pipe was then lowered into the flow zone at 376 ft. Specific conductance then quickly stabilized at 2,590 µS/cm after pumping for about 3 minutes (two drop-pipe volumes) and remained stable for 15 minutes. When the drop pipe was lowered below the flow zone to a depth of 450 ft, specific conductance of the samples increased from 2,600 µS/cm and stabilized at 3,120 µS/cm after 5 minutes of pumping (equivalent to two drop-pipe volumes). Pumping rates through the drop pipe varied from 2.4 gal/min at 300 ft to 2 gal/min at 450 ft. A specific-conductance log run at the end of the first phase of the test (fig. 26b) indicates that specific conductance in the well had changed little.

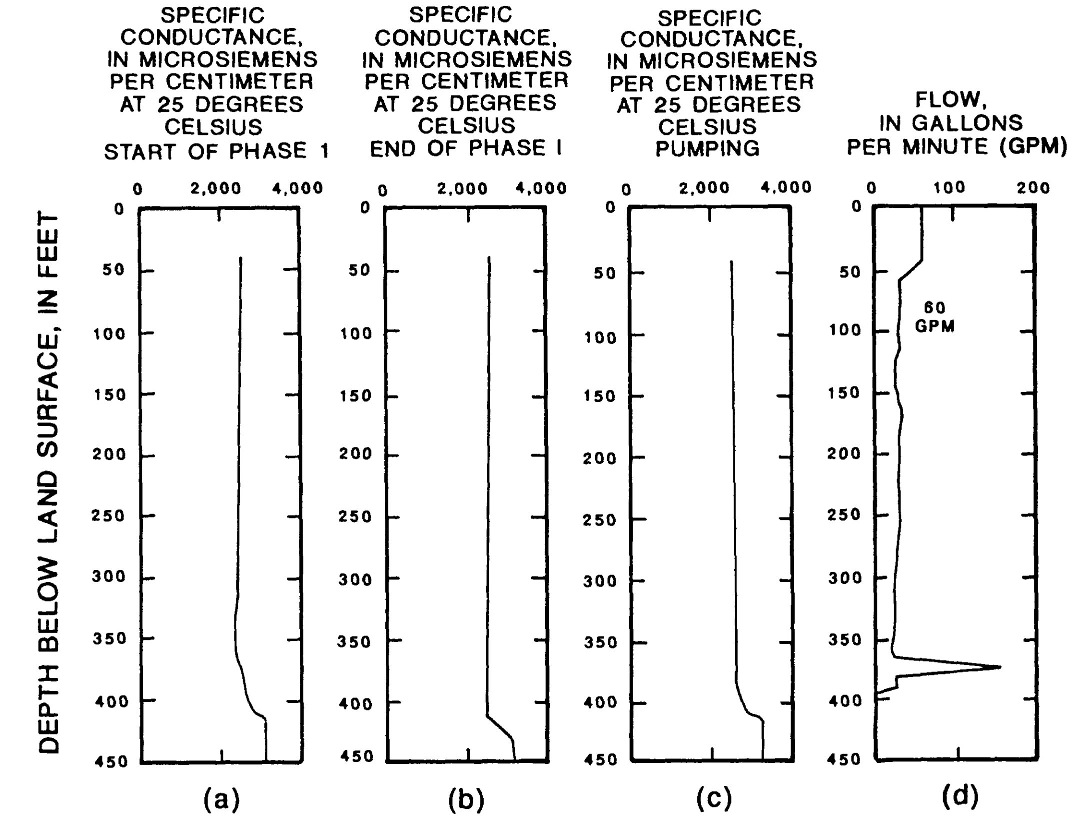


Figure 26. Specific-conductance and flow logs from the well at the city of Sarasota 11th Street and Oregon Avenue test site, September 26, 1989.

Table 3. Specific conductance of and chloride concentrations in ground-water samples collected through a drop pipe at the city of Sarasota 11th Street and Oregon Avenue well, September 26, 1989

[gal/min, gallons per minute; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; DPV, drop pipe volume; --, no data]

Sampling depth (feet below land surface)	Pumping rate (gal/min)	Pumped volume	Elapsed time (minutes)	Specific conduct-ance (µS/cm)	Chloride concen-tration (mg/L)
300	2.4	1 DPV	1	2,560	320
		2 DPV	2	2,580	320
		3 DPV	3	2,580	320
		11 DPV	15	2,580	--
376	2.4	1 DPV	1.5	2,580	320
		2 DPV	3	2,590	320
		3 DPV	3.5	2,590	320
		9 DPV	15	2,590	--
450	2.0	1 DPV	3	2,600	320
		2 DPV	5	3,120	450
		3 DPV	8	3,120	450
		6 DPV	15	3,120	--

The second phase of the test was started without a recovery period because specific conductance in the well bore had not changed significantly. The drop pipe was removed and testing was continued by sampling from land surface using centrifugal pumps. Samples were collected at pumping rates of 11, 35, 45, and 73 gal/min (table 4). At 73 gal/min, the water level was drawn down below the intake hose in 6 minutes. Therefore, higher pumping rates could not be used in this well. Regardless of pumping rates, specific-conductance values stabilized between 2,550 and 2,570 µS/cm in two to three casing volumes indicating that most of the water was entering the borehole at the flow zone. A specific-conductance log that was recorded during pumping (fig. 26c) also indicates that most of the water is entering the well at a depth between 370 and 400 ft.

Continuous specific-conductance and water-level data collected during October 1989 indicated that water levels in the well may be influenced by tidal cycles; however, water levels are also influenced by pumping from nearby production wells. Specific conductance does not seem to be affected by water-level changes regardless of the cause (fig. 27).

Table 4. Specific conductance of and chloride concentrations in ground-water samples collected by pumping through the casing at different rates at the city of Sarasota 11th Street and Oregon Avenue well, September 26, 1989

[gal/min, gallons per minute; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; BH, borehole volume (volume of casing plus open hole; CSG, casing volume; --, no data]

Pumping rate (gal/min)	Pumped volume	Elapsed time (minutes)	Specific conductance (µS/cm)	Chloride concentration (mg/L)
11	1 CSG	10	2,550	320
	2 CSG	20	2,550	310
	3 CSG	30	2,570	320
35	1 CSG	3	2,540	320
	2 CSG	6	2,560	320
	3 CSG	9	2,570	320
	1 BH	34	2,580	320
45	1 BH	30	2,570	320
	2 BH	60	2,570	--
73	1 CSG	2	2,580	320
	1 CSG	3	2,570	320
	2 CSG	5	2,550	320

Although this well has only 43 ft of casing and a large open hole section (436 ft), testing at this well indicated most of the water being pumped is supplied by a short permeable interval of the formation between 370 and 400 ft below land surface (fig. 26d). Variations in sampling methods used at this site had little effect on the water quality of the collected samples; therefore, this well is suitable for monitoring the transition zone in the intermediate aquifer system.

Apollo Beach Test Site

A third test was conducted during November 1989 at a site near Apollo Beach in west-central Hillsborough County (fig. 8). The well at the test site originally was drilled as a public-supply well in the early 1960's, but has not been used since 1982. The well was reported by the Big Bend Utility Company to be 600 ft deep with 80 ft of casing. Borehole geophysical logs run just prior to testing showed the well to be only 324 ft deep with 36 ft of casing. The well is open to the intermediate aquifer system and the Upper Floridan aquifer. Drilling data collected by the SWFWMD from the nearby ROMP TR 9-2 well indicate that the surficial aquifer system overlying the

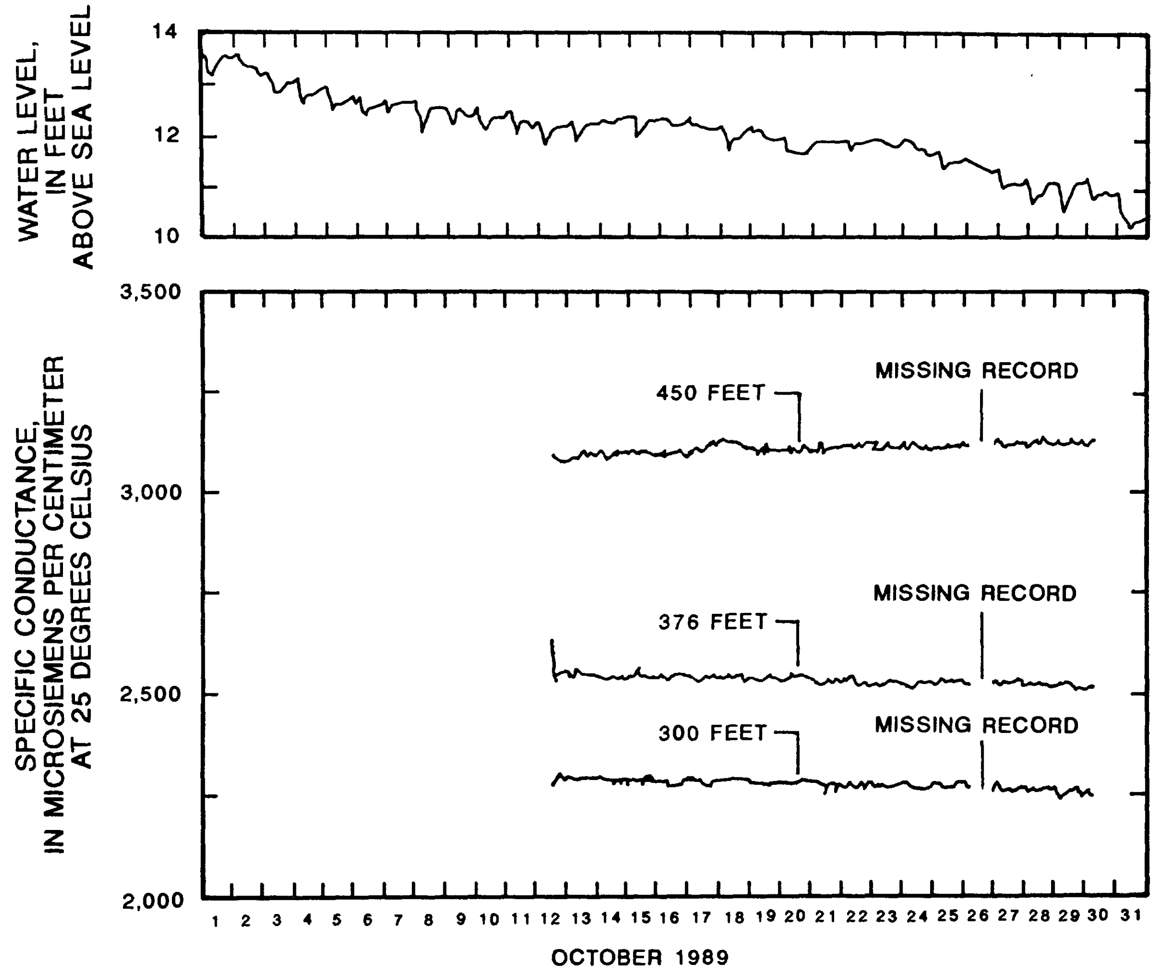


Figure 27. Water levels and specific conductance of water in the well at the city of Sarasota 11th Street and Oregon Avenue test site, October 1989.

intermediate aquifer system is approximately 30 ft thick. The top of the Upper Floridan aquifer is about 269 ft below land surface.

Initial geophysical logs recorded on October 27, 1989, indicated a fairly uniform specific conductance along the entire length of the borehole (fig. 28a), with a mean specific-conductance value of 835 µS/cm. A flowmeter survey that was conducted when this well was pumped at a rate of 157 gal/min indicated most of the water entered the well along the borehole above a depth of 285 ft (fig. 28c). Flow measurements made at a pumping rate of 43 gal/min did not detect any movement below a depth of 75 ft. Based on the flowmeter surveys, the zones at 50, 100, 200, and 300 ft below land surface were selected to be monitored during testing.

On November 8, 1989, a 50-ft drop pipe was installed in the well. Specific conductance measured at the start of the test was 700 µS/cm, but decreased slightly to 690 µS/cm after 9 minutes of pumping (equivalent to three drop-pipe volumes). Specific conductance remained unchanged until pumping was terminated after 15 minutes (table 5). The drop pipe was then lowered to a depth of 100 ft. Specific conductance measured after 5 minutes of pumping (one drop-pipe volume) was 820 µS/cm. This increased slightly to 830 µS/cm after 10 minutes of pumping (two drop-pipe volumes) and remained unchanged until pumping was terminated after 30 minutes. The drop pipe was then lowered to a depth of 200 ft. Specific conductance measured after 1 minute (one drop-pipe volume) was 870 µS/cm. After 3 minutes of pumping, the specific conductance decreased slightly to 830 µS/cm and remained unchanged until pumping was terminated. The specific conductance of a sample collected after 3 minutes (one drop-pipe volume) from a depth of 300 ft was 820 µS/cm. Specific conductance increased slightly to 840 µS/cm after 6 minutes (two drop-pipe volumes) and remained unchanged until pumping was terminated (table 5).

Table 5. Specific conductance of and chloride concentrations in ground-water samples collected through a drop pipe at the Apollo Beach well, November 8, 1989

[gal/min, gallons per minute; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; DPV, drop pipe volume;, --, no data]

Sampling depth (feet below land surface)	Pumping rate (gal/min)	Pumped volume	Elapsed time (minutes)	Specific conductance (µS/cm)	Chloride concentration (mg/L)
50	0.2	1 DPV	3	700	30
		2 DPV	6	700	29
		3 DPV	9	690	29
		5 DPV	15	690	29
100	.2	1 DPV	5	820	33
		2 DPV	10	830	34
		3 DPV	15	830	34
		6 DPV	30	830	--
200	2.4	1 DPV	1	870	36
		2 DPV	2	850	34
		3 DPV	3	830	34
		11 DPV	10	830	34
300	2.0	1 DPV	3	820	32
		2 DPV	6	840	33
		3 DPV	9	840	34
		6 DPV	18	840	--

Table 6. Specific conductance of and chloride concentrations in ground-water samples collected by pumping through the casing at different rates at the Apollo Beach well, November 8, 1989

[gal/min, gallons per minute; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; BH, borehole volume (volume of casing plus open hole); DPV, casing volume; --, no data]

Pumping rate (gal/min)	Pumped volume	Elapsed time (minutes)	Specific conductance (µS/cm)	Chloride concentration (mg/L)
9.5	1 CSG	10	700	30
	2 CSG	20	780	33
	3 CSG	30	810	34
	4 CSG	40	820	34
	5 CSG	50	820	34
47	1 CSG	2	820	34
	2 CSG	4	820	34
	3 CSG	6	830	34
	1 BH	18	830	34
157	2 CSG	2	820	--
	4 CSG	4	820	35
	1 BH	5	830	35
	2 BH	10	830	35
	4 BH	20	830	--
	5 BH	25	830	--

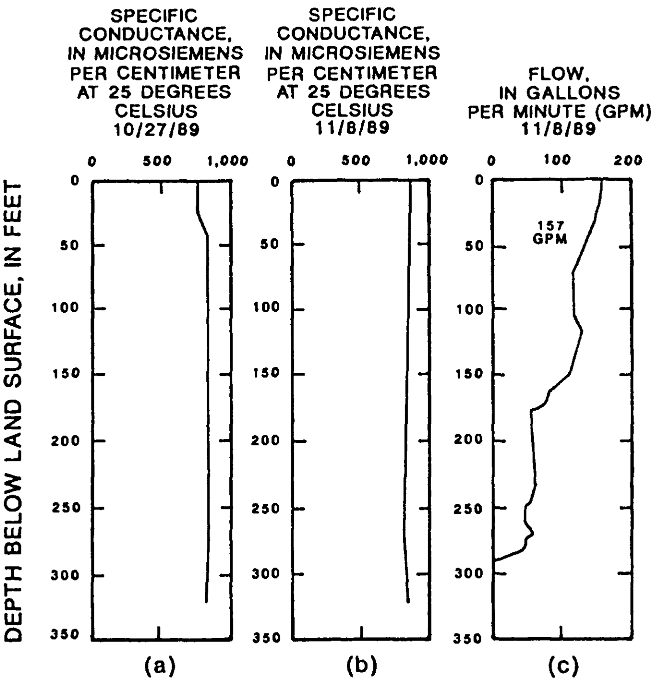


Figure 28. Specific-conductance and flow logs from the well at the Apollo Beach test site.

The second phase of the test was started without a recovery period because specific conductance in this well had not changed significantly. The drop pipe was removed from the well, and testing was continued by pumping at rates of 9.5, 47, and 157 gal/min. When pumped at 9.5 gal/min for 50 minutes (equivalent to five casing volumes), specific conductance in the collected samples stabilized at 820 µS/cm (table 6). At a pumping rate of 47 gal/min, specific-conductance values in collected samples increased slightly after about 6 minutes (three casing volumes) and remained at 830 µS/cm until pumping was terminated. When pumping at 157 gal/min, specific conductance remained at 830 µS/cm after 5 minutes. A specific-conductance log was recorded on November 8, 1989, after testing was completed. The log indicated little change in specific conductance in the well as a result of pumping (fig. 28b).

Continuous water-level data collected during November 1989 indicated the well is affected only slightly by tidal cycles (fig. 29). Continuous specific-conductance data were available only for the first 6 days of November; however, because

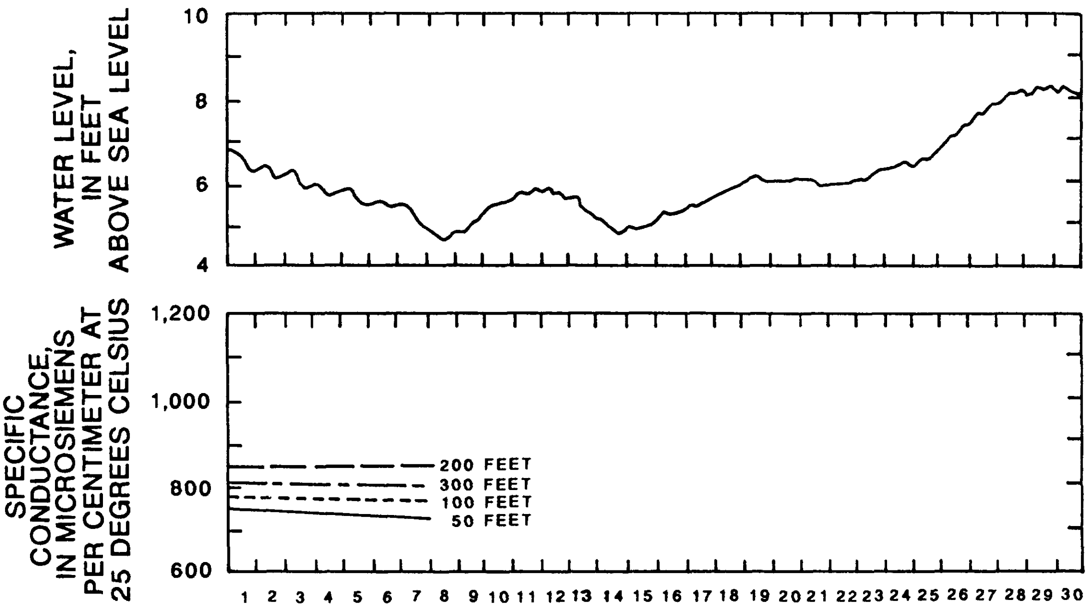


Figure 29. Water levels and specific conductance of water in the well at the Apollo Beach test site, November 1989.

specific conductance remained stable in all four zones, water quality in the well seemed to be unaffected by tidal cycles.

Most of the water withdrawn from the well seemed to come from the intermediate aquifer system, even though the well is open to the intermediate aquifer system and the Upper Floridan aquifer. This well and similarly constructed wells are not good monitoring wells because water-quality changes cannot be linked to specific flow zones or aquifers.

Evaluation of Test-Site Sampling Methods

Many of the wells used to monitor the transition zone are constructed differently; they might have multiple flow zones or have significant water-quality differences between zones, or their levels or water quality are affected by tides. A single sampling method, therefore, might not give consistent water-quality results or guarantee the sample will be representative of a discrete flow zone in an aquifer. Many wells have long open-hole intervals that intersect more than one permeable zone, or the water within the borehole may exhibit tidally related water-quality changes. The concentration of chloride in the transition zone water is vertically stratified; therefore, wells with long open-hole intervals might not yield representative samples of a specific zone. Continuous water-level and specific-conductance recorders, as well as specific-conductance logs and flowmeter surveys, should be used to assess characteristics of the well and the water within it before the well is used to monitor the transition zone. Wells that produce water that has tidally related water-quality changes could be used as monitoring wells only if the variability that may result is controlled by coordinating sampling to a specific tide cycle each time.

Drop pipes can be useful in reducing sampling time in situations where large diameter, deep wells with short open-hole intervals would require large periods of time to evacuate the casing or borehole. Drop pipes are unreliable for collecting water-quality samples from transition-zone monitoring wells with large open-hole intervals or multiple flow zones because of the uncertainty of where water entering the drop pipe might originate.

Wells with long open boreholes might not produce water from the desired interval of the formation when pumped through the casing, or they might produce a composite sample. Transition-zone monitoring wells should be constructed with short open-hole intervals completed to a single specific flow zone of an aquifer within the transition zone. In areas were multiple aquifers or multiple flow zones in an aquifer exist, closely spaced, single wells (nested wells) open to each zone should be constructed to adequately document changes in the entire vertical section of the transition zone at that site. Such wells should then be sampled after purging the well long enough for specific conductance, pH, and temperature to stabilize (Wood, 1976, p. 4).

Transition-Zone Monitoring Network

Wells used to monitor the transition zone in west-central Florida should only be open to small sections of the aquifer or aquifer system because the aquifers often contain multiple water-bearing zones with differing water-quality characteristics. However, few wells that are available as monitoring wells are constructed in this manner. Many wells in the southern counties are open to more than one aquifer, or to more than one water-bearing zone within an aquifer. Wells open to more than one aquifer are not useful for a saltwater monitoring network, but wells open to more than one water-bearing zone within an aquifer can be useful if more suitable wells are not available. Although water samples from these wells are composite samples, water-quality data collected over time could be useful in determining if water quality were changing. In areas where water-quality data from these wells show changing conditions, installation of new monitoring wells open to short, discrete intervals of the aquifer should be considered.

One hundred sixty-three wells at 142 sites were chosen for inclusion in a transition-zone monitoring network. The wells were chosen based on location (spatial distribution within the study area), well construction, present and historical water-quality data, and accessibility to the well. Some of these wells have open-hole sections of more than 100 ft, have multiple flow zones, or have chloride concentrations greater than 250 mg/L. They were included in the network because more suitable wells are not available nearby. The network was divided into primary and secondary monitoring networks to separate the most suitable wells from the less suitable wells. The primary monitoring network (fig. 30) consists of 57 wells at 50 sites (table 7). Seven of these sites have two wells open to either different aquifer systems or different water-bearing zones of a single aquifer. The secondary monitoring network (fig. 31) consists of 106 wells at 92 sites (table 8). Fourteen of these sites have two wells each open to different aquifer systems or different zones within an aquifer. The secondary sites are generally less desirable because chloride concentrations are greater than 250 mg/L or well-construction data are incomplete. These wells were included in the network as backup or interim sites in the event that primary sites became inaccessible or otherwise removed from the network.

Data for the transition-zone monitoring network has been provided to the SWFWMD and the network has been included in their Coastal Ground-Water Quality Monitoring Program under the Ambient Ground-water Quality Monitoring Program. The monitoring network initially was sampled by SWFWMD personnel in March 1991. The results of this sampling were published by the Southwest Florida Water management District (1991). The SWFWMD plans to continue to monitor the network and, following sampling events, to publish the results (Eric Dehaven, Southwest Florida Water Management District, written commun., 1992).

SUMMARY AND CONCLUSIONS

The hydrogeology within the 6,600-mi^2 study area varies considerably. In the north, a thin layer of clastic deposits directly overlies the Floridan aquifer system. A continuous surficial aquifer system in this area is nonexistent, and the Upper Floridan aquifer is unconfined. South of central Pasco County, a clay layer composes the intermediate confining unit that separates the surficial aquifer system from the underlying limestone of the Upper Floridan aquifer. The intermediate confining unit thickens southward, changes lithology, and becomes the intermediate aquifer system. In the southernmost part of the study area, the intermediate aquifer system is a leaky, semiconfined system that is composed of several carbonate water-bearing zones and ranges from about 100 to more than 800 ft thick.

The altitude of the potentiometric surface of the intermediate aquifer system ranges from about 110 ft above sea level in southeastern Hillsborough County to less than 10 ft above sea level near the coast. The underlying Upper Floridan aquifer also thickens from north to south, ranging from about 600 to 1,400 ft thick.

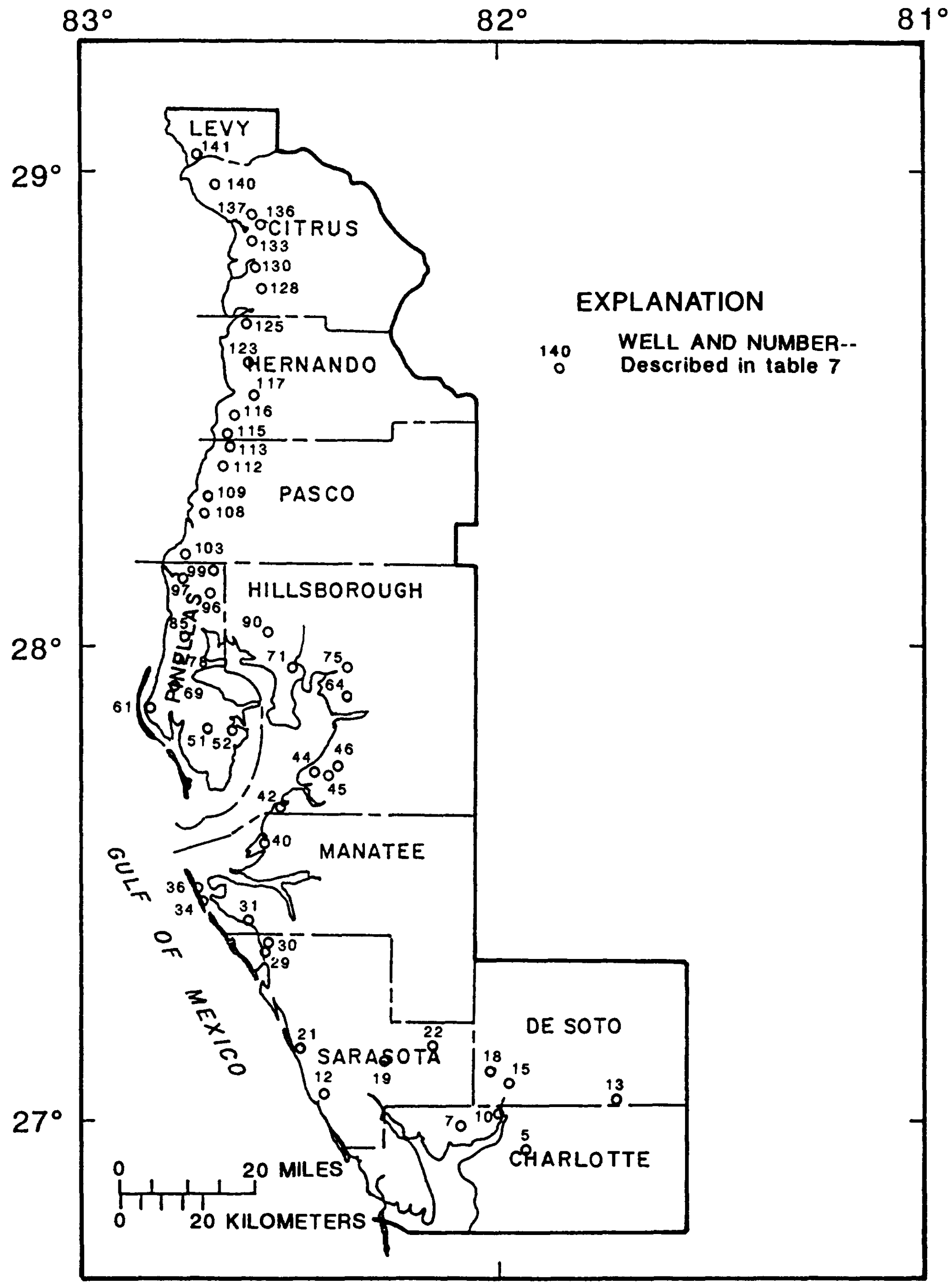


Figure 30. Locations of primary monitoring wells in the transition zone.

The altitude of the potentiometric surface in the Upper Floridan aquifer ranges from about 100 ft above sea level in the east-central part of the study area to more than 20 ft below sea level in areas of southern Hillsborough and northern Manatee Counties during extended periods of pumping for agricultural irrigation.

The density difference between saltwater and freshwater in an aquifer results in a wedge of saltwater that extends landward and that underlies the freshwater. Reciprocating movement of this saltwater wedge and associated cyclic movement along this front creates a mixing or transition zone. The landward extension of the transition zone is considered to be where all water in a vertical section of the aquifer contains chloride concentrations of 25 mg/L or less. The landward extent of the transition zone ranges from near the coast in the northern part of the study area to the eastern boundary of the study area in the southern part.

Table 7. Primary monitoring wells in the transition zone

[Locations of sites are shown in figure 30. ROMP, Regional Observation and Monitor-Well Program; SWNN, Suwannee Limestone; HWTH, Hawthorn Formation; TAMP, Tampa Limestone; OCAL, Ocala Limestone; AVPK, Avon Park Formation; WCRWSA, West Coast Regional Water Supply Authority; #, number; --, no data]

Well number	Identification number	Name	County	Well depth (feet)	Casing depth (feet)	Aquifer or aquifer system
5a	265646081554501	State Highway 74 deep	Charlotte	280	194	Intermediate
5b	265646081554503	State Highway 74 intermediate	Charlotte	75	71	Intermediate
7	265920082045601	Port Charlotte Utilities deep	Charlotte	156	128	Intermediate
10a	270152082002801	ROMP 10 Oligocene-SWNN	Charlotte	917	595	Upper Floridan
10b	270152082002802	ROMP 10 Limestone-TAMP	Charlotte	575	303	Intermediate
12	270240082235701	ROMP TR 4-2 SWNN	Sarasota	475	460	Upper Floridan
13	270246081424301	University of Texas #6	De Soto	408	62	Intermediate
15	270417081575601	Rob Lane (G.V. Russel)	De Soto	411	70	Intermediate
18	270554082003601	General Development South	De Soto	1,411	326	multiple
19	270714082155201	Blackburn (test #18)	Sarasota	351	282	Intermediate
21a	270808082270502	ROMP TR 5-1 SWNN	Sarasota	510	492	Upper Floridan
21b	270808082270503	ROMP TR 5-1 HWTH	Sarasota	289	275	Intermediate
22	270855082090101	VO Ranch #3	Sarasota	350	32	Intermediate
29	272119082325101	Whitaker Bayou	Sarasota	337	54	Intermediate
30	272120082322701	City of Sarasota 21st & RR	Sarasota	557	120	multiple
31	272510082345701	ROMP TR 7-1 deep	Manatee	340	320	Intermediate
34	272731082414601	Anna Maria deep	Manatee	670	280	multiple
36	272818082420301	Bradenton Beach (Don Flor)	Manatee	386	202	Intermediate
40a	273458082324702	ROMP TR 8-1 HWTH	Manatee	326	236	Intermediate
40b	273458082324704	ROMP TR 8-1 SWNN/OCAL	Manatee	867	462	Upper Floridan
42	273843082321501	SW Hillsborough #4B	Hillsborough	600	--	Upper Floridan
44	274421082275401	ROMP TR 9-1 Simmons Park	Hillsborough	288	124	Upper Floridan
45a	274428082251502	ROMP TR 9-3 SWNN	Hillsborough	525	289	Upper Floridan
45b	274428082251503	ROMP TR 9-3 AVPK	Hillsborough	779	764	Upper Floridan
46a	274554082233801	ROMP TR 9-2 Apollo Beach AVPK	Hillsborough	765	725	Upper Floridan
46b	274554082233802	ROMP TR 9-2 Apollo Beach OCAL	Hillsborough	675	625	Upper Floridan
51	274904082423601	Miller (Kenneth City)	Pinellas	251	143	Upper Floridan
52	274910082380401	Shorecrest High School	Pinellas	140	90	Upper Floridan
61	275222082504601	McKay Creek #S3	Pinellas	120	--	Upper Floridan
64	275402082222701	ROMP TR 10-2 deep	Hillsborough	125	115	Upper Floridan
69a	275458082464001	ROMP TR 13-1 OCLA	Pinellas	540	520	Upper Floridan
69b	275458082464001	ROMP TR 13-1 SWNN	Pinellas	264	254	Upper Floridan
71	275631082293801	Messina (305 S. MacDill)	Hillsborough	150	84	Upper Floridan
75	275705082222001	ROMP TR 11-2 SWNN	Hillsborough	315	300	Upper Floridan
78	275739082462601	Clearwater production #18	Pinellas	183	88	Upper Floridan
85	280111082453501	Clearwater #18 (W-4386)	Pinellas	175	76	Upper Floridan
90	280155082340001	WCRWSA RMP 13PZ	Hillsborough	662	612	Upper Floridan
96	280611082412001	Casey Ranch	Pinellas	262	--	Upper Floridan
97	280747082452001	ROMP TR 15-2 deep	Pinellas	54	50	Upper Floridan
99	280846082414301	Pinellas deep #028	Pinellas	740	497	Upper Floridan
103	281128082445501	Tahitian deep #3	Pasco	100	35	Upper Floridan
108	281652082423301	City of Port Richey deep	Pasco	200	104	Upper Floridan
109	281803082420501	San Clemente	Pasco	125	64	Upper Floridan
112	282228082402001	City of Hudson	Pasco	100	47	Upper Floridan
113	282519082394301	M.G. Scheer deep	Pasco	111	50	Upper Floridan
115	282659082391102	ROMP TR 18-2 U. AVPK	Hernando	480	465	Upper Floridan
116	282923082380301	Hernando Beach supply	Hernando	180	--	Upper Floridan
117	283159082345801	Hernando HRS #14	Hernando	67	42	Upper Floridan
123	283529082355801	Weeki Wachee #3	Hernando	140	133	Upper Floridan
125	284130082353501	Betty Jay Spring well	Hernando	--	--	Upper Floridan
128	284551082345301	Homosassa #3	Citrus	99	81	Upper Floridan
130	284803082351701	Norris	Citrus	50	44	Upper Floridan
133	285112082354401	ROMP TR 21-2 deep	Citrus	111	105	Upper Floridan
136	285234082341901	ROMP TR 21-3 Deep	Citrus	252	240	Upper Floridan
137	285421082361601	Crystal River shallow	Citrus	53	3	Upper Floridan
140	285737082413001	Florida Power #2	Citrus	47	42	Upper Floridan
141	290200082432301	ROMP 124 deep (Yankeetown)	Levy	250	200	Upper Floridan

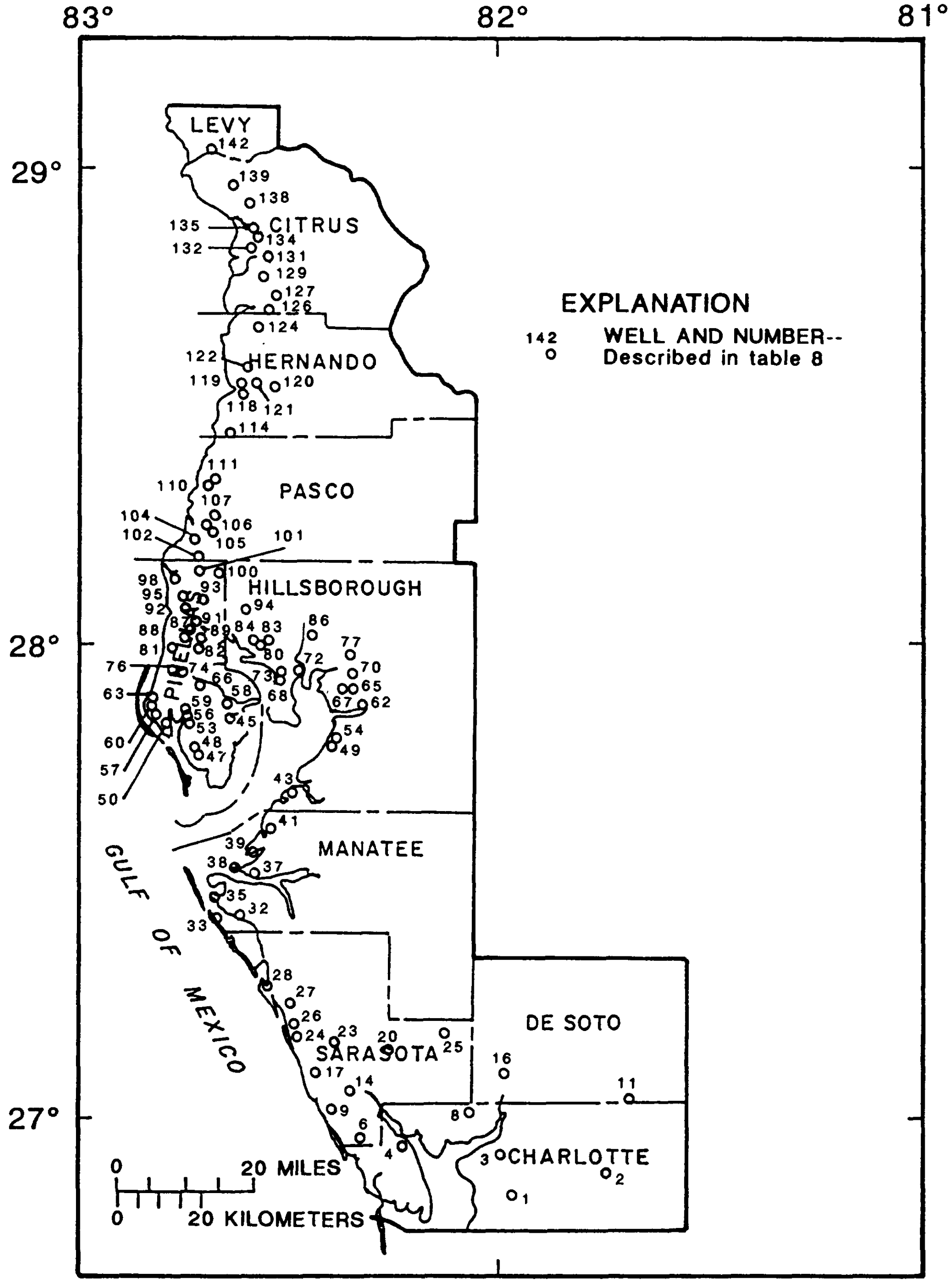


Figure 31. Locations of secondary monitoring wells in the transition zone.

Water quality in the Upper Floridan aquifer in the northern part of the study area indicates that the aquifer has been flushed of residual seawater and that water in the transition zone reflects a simple mixing of freshwater and seawater. Water in both the intermediate aquifer system and the Upper Floridan aquifer that underlies most of the southern part of the study area is more mineralized, which indicates a longer residence time in the aquifers, incomplete flushing of residual seawater, and dissolution of gypsum from deep evaporite beds. Freshwater occurs farther south in the intermediate aquifer system than in the Upper Floridan aquifer.

Linear-regression analyses were run on chloride data from ground water in 24 wells at 21 coastal sites during the period 1970-90 to delineate long-term trends. Concentrations of chloride in samples from 14 wells had increasing trends. Extended pumping for agricultural irrigation or public supply may be contributing to the increasing trend noted in some of these wells. Samples from two wells indicated the concentration of chloride was decreasing slowly. Concentrations of chloride in the eight remaining wells were virtually unchanged.

The effects of seasonal and tidally induced head changes on the quality of water in wells were monitored at four long-term and six short-term sites. Although all wells exhibited daily tidal or seasonal changes to the water levels, only two had related changes in specific conductance. Seasonal and daily data collected at the ROMP TR 19-2 well in Hernando County indicate that a change in the potentiometric surface in the aquifer will result in a change in the specific conductance of the water in the well. The well is used to monitor a short section of the aquifer that is near the saltwater-freshwater interface. At the Crystal River well site, water quality was affected by water-level changes only in the part of the well that is open to the deep zone of the aquifer near the saltwater-freshwater interface.

Three wells were selected to compare the differences in sampling results that might be caused by differing well characteristics or sampling methods. Conditions at each well were assessed prior to testing by using borehole geophysics and continuous water-level and specific-conductance recorders. Probable flow zones and zones where water quality seemed to change were identified. The first phase of testing consisted of sampling from the predetermined zones by pumping through a 1/2-in. polyvinyl chloride drop pipe. The drop pipe was set at the shallowest depth first. Samples were collected at one, two, and three pipe volumes and then at various time intervals thereafter depending on the time necessary for the well to stabilize. The drop pipe was lengthened, and the process was repeated until all zones were sampled. The second phase of the test consisted of pumping the well from land surface at rates up to 196 gal/min. When possible, samples were collected at one, two, and three casing volumes; at one, two, and three well volumes (casing plus open-hole section); and at various time intervals when necessary to allow the well to stabilize. The effects of tidal water-level fluctuations on the quality of water in the well were documented at all sites.

Sampling at the three test wells indicated a single sampling method might not produce the desired results. A sampling method where water is purged at a low rate and samples are collected through a drop pipe in a flow zone does not guarantee consistency or that the sample is representative of the formation at that zone. Drop pipes may be useful in large diameter, deep wells with small open-hole sections, but they are unreliable in wells with large open-hole sections or multiple flow zones. When pumped through the casings, wells with long open boreholes might not produce water from the desired interval of the formation, or they might produce a composite sample. Transition-zone monitoring wells should be constructed with short open boreholes that are completed to a single flow zone of the aquifer within the transition zone. In areas were multiple aquifers or flow zones exist, nested wells should be constructed to monitor the entire vertical section of the transition zone. Monitoring wells should be selected that do not exhibit changes in water quality that are related to tidal water-level changes. In properly constructed monitoring wells, samples should be collected after purging the well sufficiently to allow specific conductance, pH, and temperature to stabilize.

A transition-zone monitoring network consisting of 163 wells at 142 sites was established for this study. There are 50 primary sites with 57 wells. The remaining wells were secondary or backup wells to be used if primary wells became inaccessible. The location, construction, and water-quality data for wells selected for the monitoring network were supplied to the SWFWMD for implementation into a permanent coastal ground-water quality monitoring program under the SWFWMD Ambient Ground-Water Quality Monitoring Program.

Table 8. Secondary monitoring wells in the transition zone

[Locations of sites are shown in figure 30. ROMP, Regional Observation and Monitor-Well Program; SWNN, Suwannee Limestone; HWTH, Hawthorn Formation; TAMP, Tampa Limestone; OCAL, Ocala Limestone; AVPK, Avon Park Formation; WCRWSA, West Coast Regional Water Supply Authority; #, number; --, no data]

Well number	Identification number	Name	County	Well depth (feet)	Casing depth (feet)	Aquifer or aquifer system
1	265004081581901	Herrin Nursery (CH-311)	Charlotte	220	180	Intermediate
2	265321081442601	Babcock Florida Corp. #2126	Charlotte	404	42	Intermediate
3	265504082000601	USGS C-3	Charlotte	205	153	Intermediate
4a	265638082130705	ROMP TR 3-1 L. HWTH	Charlotte	400	380	Intermediate
4b	265638082130706	ROMP TR 3-1 SWNN	Charlotte	620	600	Upper Floridan
6a	265834082202401	Englewood Water District #14	Sarasota	55	44	Intermediate
6b	265834082202402	Englewood Water District #14A	Sarasota	20	10	Surficial
8a	270133082034601	Port Charlotte dp (USGS #6)	Charlotte	350	312	Intermediate
8b	270133082034602	Port Charlotte sh (USGS #7)	Charlotte	89	85	Intermediate
9	270137082235301	Manasota deep #14	Sarasota	305	263	Intermediate
11	270225081415701	University of Texas	De Soto	404	71	Intermediate
14	270401082220501	Plantation (OBS)	Sarasota	176	50	Intermediate
16a	270540082001101	GDU M-2	De Soto	897	605	Upper Floridan
16b	270540082001102	GDU T-2	De Soto	496	393	Intermediate
17a	270542082261801	USGS #35	Sarasota	163	86	Intermediate
17b	270542082261802	USGS #36	Sarasota	68	58	Intermediate
20a	270807082152701	Macarthur Tract 14FS	Sarasota	550	500	Upper Floridan
20b	270807082152702	Macarthur TRact 14GS	Sarasota	300	275	Intermediate
23a	270919082234202	ROMP TR 5-2 U. HWTH	Sarasota	120	100	Intermediate
23b	270919082234205	ROMP TR 5-2 SWNN	Sarasota	700	510	Upper Floridan
24	271035082285901	Southbay Utilities deep	Sarasota	450	220	Intermediate
25	271137082074801	ROMP 18 SWNN	Sarasota	845	505	Upper Floridan
26	271222082295201	Sarasota Historical Society	Sarasota	224	44	Intermediate
27	271450082292601	I.Z. Mann Golf Course	Sarasota	1,200	--	Upper Floridan
28	271717082332601	Martin--Siesta Key	Sarasota	488	300	Intermediate
32a	272558082360601	El Conquistador--North	Manatee	399	49	Intermediate
32b	272558082360602	El Conquistador--South	Manatee	800	--	Upper Floridan
33	272618082411101	Johnson--Longboat Key	Manatee	385	--	Intermediate
35	272807082401501	Manatee Fruit #3	Manatee	492	262	multiple
37	273134082344601	Manatee Fairgrounds	Manatee	273	216	Intermediate
38	273159082373101	Snead's Island	Manatee	525	200	multiple
39	273347082354101	Horse Shoe Loop--Terra Ceia	Manatee	423	22	Upper Floridan
41	273718082315501	Florida Power and Light #1	Manatee	946	104	multiple
43	274114082303701	Claprod	Hillsborough	500	--	Upper Floridan
47	274606082423601	Royal Palm Corp. S-3	Pinellas	285	185	Upper Floridan
48	274652082432201	Diocese of St. Petersburg	Pinellas	354	190	Upper Floridan
49	274837082232901	Kushmer--Adamsville	Hillsborough	145	41	Intermediate
50	274848082461201	War Vets Memorial Park	Pinellas	203	117	Upper Floridan
53	274912082441001	South Cross Bayou S9	Pinellas	150	--	Upper Floridan
54	274928082225501	S.W. Hills #220	Hillsborough	235	--	Upper Floridan
55	274943082380401	Riviera Methodist Church	Pinellas	100	60	Upper Floridan
56	275008082442901	South Cross Bayou S15 (Butler)	Pinellas	146	105	Upper Floridan
57	275022082494001	Webb (Holley)	Pinellas	165	114	Upper Floridan
58	275135082381901	Liberty Baptist Church	Pinellas	115	73	Upper Floridan
59	275138082450301	Bardmoor deep	Pinellas	200	106	Upper Floridan
60	275217082500701	McKay Creek MK1 (Hill)	Pinellas	300	--	Upper Floridan
62	275223082195001	Bradburn	Hillsborough	80	63	Intermediate
63	275241082503901	McKay Creek C-1	Pinellas	210	76	multiple
65	275416082213101	Progress Village	Hillsborough	330	34	multiple
66a	275430082431401	ROMP TR 13-2 L. SWNN	Pinellas	552	530	Upper Floridan
66b	275430082431402	ROMP TR 13-2 U. SWNN	Pinellas	279	269	Upper Floridan
67	275443082224001	James Byrd	Hillsborough	103	--	Upper Floridan
68	275458082310301	Martin Murphey (4317 San Luis)	Hillsborough	205	103	Upper Floridan
70	275611082211701	Seaboard Utilities #8	Hillsborough	302	71	Upper Floridan
72	275634082282201	Pope (108 S. Willow)	Hillsborough	136	63	Upper Floridan

Table 8. Secondary monitoring wells in the transition zone--Continued

[Locations of sites are shown in figure 30. ROMP, Regional Observation and Monitor-Well Program; SWNN, Suwannee Limestone; HWTH, Hawthorn Formation; TAMP, Tampa Limestone; OCAL, Ocala Limestone; AVPK, Avon Park Formation; WCRWSA, West Coast Regional Water Supply Authority; #, number; --, no data]

Well number	Identification number	Name	County	Well depth (feet)	Casing depth (feet)	Aquifer or aquifer system
73	275634082305701	Cleveland & Hubert	Hillsborough	124	--	Upper Floridan
74	275636082450601	Cle-Dun 43 (Guess)	Pinellas	140	--	Upper Floridan
76	275708082465301	McClendon	Pinellas	110	--	Upper Floridan
77	275724082221001	SWFWMD S-160	Hillsborough	240	85	Upper Floridan
79	275828082424201	King--Safety Harbor	Pinellas	140	--	Upper Floridan
80a	275955082335801	Library deep	Hillsborough	180	94	Upper Floridan
80b	275955082335802	Library shallow	Hillsborough	27	--	Surficial
81	280015082471201	Clearwater #23	Pinellas	182	68	Upper Floridan
82	280022082424901	Clearwater #67	Pinellas	297	92	Upper Floridan
83	280034082323701	ROMP TR 12-3 Benjamin Road	Hillsborough	345	310	Upper Floridan
84	280053082350202	Sheldon Road deep	Hillsborough	330	315	Upper Floridan
86	280112082270101	Tourist Club--Sulfur Springs	Hillsborough	318	80	Upper Floridan
87	280118082434501	ROMP TR 14-3 SWNN	Pinellas	319	299	Upper Floridan
88a	280132082452801	ROMP TR 14-2 OCAL	Pinellas	460	440	Upper Floridan
88b	280132082452802	ROMP TR 14-2 TAMP	Pinellas	218	213	Upper Floridan
89	280133082415101	Cle-Dun 5	Pinellas	120	--	Upper Floridan
91	280254082441602	Clearwater #17	Pinellas	405	39	Upper Floridan
92	280405082451901	Duquid	Pinellas	140	80	Upper Floridan
93a	280457082420401	Brooker Creek shallow	Pinellas	90	82	Upper Floridan
93b	280457082420402	Brooker Creek deep	Pinellas	310	300	Upper Floridan
94	280504082365501	St. Petersburg E-102	Pinellas	1,200	697	Upper Floridan
95	280601082460301	810 Bee Pond Road	Pinellas	85	--	Upper Floridan
98	280753082465201	ROMP TR 15-1	Pinellas	87	68	Upper Floridan
100	280904082400302	Eastlake well field #3A deep	Pinellas	1,113	670	Upper Floridan
101	280907082424801	Tarpon Road deep	Pinellas	305	205	Upper Floridan
102	281113082443801	Buena Vista	Pasco	90	--	Upper Floridan
104	281223082442301	Methodist Church	Pasco	37	21	Upper Floridan
105a	281445082414501	Coastal Pasco #11	Pasco	421	401	Upper Floridan
105b	281445082414502	Coastal Pasco #11A	Pasco	108	66	Upper Floridan
106	281512082423401	New Port Richey #142	Pasco	200	120	Upper Floridan
107	281543082421201	City of New Port Richey #8	Pasco	200	120	Upper Floridan
110	281917082420901	ROMP TR 17-1 SWNN	Pasco	139	131	Upper Floridan
111	281948082415301	Withlacoochee Electric #1	Pasco	94	84	Upper Flotidan
114	282600082392601	Magnolia Springs	Hernando	110	--	Upper Floridan
118	282203082370201	Presbyterian Youth Camp	Hernando	75	66	Upper Floridan
119	283243082365701	ROMP TR 19-2 Deep	Hernando	302	277	Upper Floridan
120	283253082322702	WHCWS Monitor #1	Hernando	613	598	Upper Floridan
121	283313082350101	ROMP TR 19-3 AVPK	Hernando	603	440	Upper Floridan
122	283527082365701	Weeki Wachee #2	Hernando	125	123	Upper Floridan
124	284113082352801	Rita Marie Spring	Hernando	72	40	Upper Floridan
126	284317082330601	Chassahowitzka #1	Citrus	176	166	Upper Floridan
127	284457082330302	Sugarmill MZ1	Citrus	358	340	Upper Floridan
129	284720082345801	Homosassa Water District #1	Citrus	86	40	Upper Floridan
131	284939082344701	Baptist Church Pastorium	Citrus	60	--	Upper Floridan
132	285102082361001	Ozello #4	Citrus	75	60	Upper Floridan
134a	285116082351401	Ozello Water Co. #1	Citrus	100	70	Upper Floridan
134b	285116082351402	Ozello Water Co. east #2	Citrus	105	65	Upper Floridan
135	285220082354401	Crystal Shores (condos)	Citrus	129	96	Upper Floridan
138	285508082365701	Indian Waters #1	Citrus	50	40	Upper Floridan
139	285737082400601	Florida Power Corp. #3	Citrus	88	67	Upper Floridan
142	290230082412501	ROMP 125 deep	Levy	280	270	Upper Floridan

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APPENDIX

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APPENDIX--Water-Quality Data for the Transition-Zone Monitoring Wells

[Site locations are shown in figures 30 and 31. Site descriptions are presented in tables 7 and 8. mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, no data]

Site no.	Sample date	Temperature (°C)	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, (mg/L as $CaCO_3$)
1	04-11-84	25.0	1,830	400	150	65	57	240	20	205
2	07-27-88	25.5	760	65	4.2	33	38	53	13	280
	05-18-89	26.0	680	64	3.5	--	--	--	--	--
3	05-18-88	27.0	620	96	10	--	--	--	--	--
	09-21-88	26.0	612	84	8.8	39	20	47	5.9	99
	05-18-89	26.5	580	86	1.8	--	--	--	--	--
4a	05-06-86	26.0	3,300	920	17	110	80	380	14	150
4b	05-06-86	26.0	3,050	610	500	130	84	360	20	144
4c	02-02-86	27.5	2,623	412	468	114	79	265	17	--
5a	10-27-89	24.0	930	110	100	--	--	--	--	--
5b	10-26-89	26.0	887	120	4.5	--	--	--	--	--
6a	09-22-87	--	1,580	320	44	--	--	--	--	--
	05-19-88	--	2,380	550	78	--	--	--	--	--
	09-13-89	24.5	976	130	24	--	--	--	--	--
6b	09-22-87	26.0	174	7.0	8.6	--	--	--	--	--
	09-13-89	25.5	160	5.4	12	--	--	--	--	--
7	10-27-89	24.5	930	220	27	--	--	--	--	--
8a	05-22-87	--	2,930	750	280	--	--	--	--	--
	09-16-87	--	2,950	720	300	--	--	--	--	--
9	09-15-87	25.0	463	59	5.0	--	--	--	--	--
	11-02-87	--	595	56	40	--	--	--	--	--
	09-12-89	25.0	589	--	--	--	--	--	--	--
10a	05-15-87	27.0	1,490	200	370	100	60	120	6.9	121
	09-22-87	27.0	1,550	200	430	--	--	--	--	--
	05-03-89	24.5	1,360	190	370	91	62	110	7.4	96
	11-28-89	27.0	1,540	200	390	110	60	110	7.2	119
10b	05-15-87	27.0	1,700	340	240	--	--	--	--	--
	09-22-87	26.5	1,830	380	270	--	--	--	--	--
	05-03-89	25.0	1,800	360	220	--	--	--	--	--
	11-28-89	26.0	1,900	380	270	--	--	--	--	--
11	09-15-88	28.5	1,400	250	170	70	36	130	4.4	112
12	04-10-87	24.0	2,200	300	730	--	--	--	--	--
	09-21-87	25.5	2,360	320	760	--	--	--	--	--
	06-20-88	28.0	2,120	280	730	--	--	--	--	--
	09-28-88	28.0	2,340	280	750	--	--	--	--	--
	04-13-89	27.0	2,250	270	730	--	--	--	--	--
	12-12-89	27.0	2,200	280	740	--	--	--	--	--
	05-08-90	26.5	2,200	280	750	--	--	--	--	--
13	09-15-88	26.0	795	130	62	68	18	64	3.9	146
14	06-25-81	--	--	320	480	160	76	140	7.9	--
15	09-03-87	27.5	1,280	220	190	88	44	100	4.2	143
	09-12-89	--	980	220	79	--	--	--	--	--
16a	09-12-88	24.5	1,300	68	450	84	56	100	8.3	123
	09-12-89	--	975	83	300	--	--	--	--	--
16b	09-12-88	25.5	1,140	140	230	64	54	76	5.4	141
	09-12-89	--	1,190	140	250	--	--	--	--	--
17a	11-20-87	24.0	1,540	140	520	--	--	--	--	--
	05-16-89	25.0	1,520	130	490	--	--	--	--	--
17b	09-21-87	27.0	1,070	110	150	--	--	--	--	--
	09-12-89	27.0	440	100	21	--	--	--	--	--

APPENDIX--Water-Quality Data for the Transition-Zone Monitoring Wells--Continued

[Site locations are shown in figures 30 and 31. Site descriptions are presented in tables 7 and 8. mg/L, milligrams per liter; μS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, no data]

Site no.	Sample date	Temper-ature (°C)	Specific conduct-ance (μS/cm)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alka-linity, (mg/L as $CaCO_3$)
18	05-17-88	25.5	1,220	160	270	--	--	--	--	--
	05-17-89	27.0	1,490	210	300	--	--	--	--	--
	09-14-89	--	1,490	210	300	--	--	--	--	--
19	05-22-87	25.0	1,520	160	470	--	--	--	--	--
	09-18-87	--	1,700	170	510	--	--	--	--	--
	05-20-88	--	1,680	150	500	--	--	--	--	--
	09-22-88	--	1,350	190	370	--	--	--	--	--
	05-25-89	25.5	1,680	170	540	140	95	78	20	161
20a	05-22-87	26.0	1,400	100	480	--	--	--	--	--
	09-18-87	--	1,430	100	500	--	--	--	--	--
	05-17-88	--	1,380	96	490	--	--	--	--	--
	09-20-88	--	1,420	100	470	--	--	--	--	--
	05-23-89	25.0	1,340	35	480	--	--	--	--	--
20b	05-22-87	24.5	1,360	110	410	--	--	--	--	--
	09-18-87	--	1,210	110	370	--	--	--	--	--
	05-17-88	--	1,390	120	410	--	--	--	--	--
	09-20-88	--	1,400	120	420	--	--	--	--	--
21a	04-10-87	24.5	2,400	56	1,400	--	--	--	--	--
	08-25-87	25.5	2,520	60	1,500	--	--	--	--	--
	06-20-88	28.0	2,450	75	1,400	--	--	--	--	--
21a	09-30-88	28.0	2,490	55	1,500	--	--	--	--	--
	04-19-89	28.0	2,500	56	1,400	--	--	--	--	--
	12-12-89	26.0	2,400	56	1,400	--	--	--	--	--
	05-08-90	26.5	2,350	56	1,400	--	--	--	--	--
21b	04-10-87	26.0	2,230	34	1,200	--	--	--	--	--
	08-25-87	26.0	2,250	40	1,400	--	--	--	--	--
	06-20-88	28.0	2,240	35	1,300	--	--	--	--	--
	09-30-88	27.0	2,250	33	1,300	--	--	--	--	--
	04-19-89	27.0	2,300	35	1,300	--	--	--	--	--
	12-12-89	26.5	2,200	35	1,200	--	--	--	--	--
	05-08-90	26.0	2,200	34	1,200	--	--	--	--	--
22	09-11-90	--	1,820	250	460	--	--	--	--	--
23a	05-06-86	26.0	1,650	54	730	220	76	40	4.9	142
23b	05-07-86	27.0	2,750	41	1,700	520	150	22	3.9	122
	10-06-87	27.5	2,720	44	1,400	480	140	23	3.9	118
24	05-19-87	26.5	3,400	240	1,700	--	--	--	--	--
	09-17-87	26.5	3,400	240	1,700	--	--	--	--	--
	05-18-88	--	3,250	220	1,600	--	--	--	--	--
	09-20-88	--	3,440	250	1,700	--	--	--	--	--
25	09-14-89	25.0	850	33	230	--	--	--	--	--
26	09-15-87	25.5	1,910	43	1,200	--	--	--	--	--
	11-03-87	25.5	2,050	40	1,200	--	--	--	--	--
	05-17-88	25.5	2,150	37	1,100	--	--	--	--	--
	09-20-88	--	2,200	50	1,200	--	--	--	--	--
	05-16-89	25.5	2,100	38	1,200	--	--	--	--	--
27	05-19-87	26.0	2,900	210	1,500	--	--	--	--	--
	09-17-87	25.0	2,750	280	1,400	--	--	--	--	--
	09-20-88	--	2,680	250	1,200	--	--	--	--	--
28	05-19-87	25.5	2,500	280	890	--	--	--	--	--
	09-17-87	25.0	2,450	270	950	--	--	--	--	--

APPENDIX--Water-Quality Data for the Transition-Zone Monitoring Wells--Continued

[Site locations are shown in figures 30 and 31. Site descriptions are presented in tables 7 and 8. mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, no data]

Site no.	Sample date	Temperature (°C)	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, (mg/L as $CaCO_3$)
	05-19-88	--	2,470	270	880	--	--	--	--	--
	09-20-88	24.5	2,320	270	790	--	--	--	--	--
29	11-04-87	25.0	1,080	150	150	--	--	--	--	--
30	05-03-89	28.0	2,000	200	810	--	--	--	--	--
	05-04-90	28.0	2,050	200	820	--	--	--	--	--
31	06-18-87	25.5	1,140	84	350	--	--	--	--	--
	06-16-88	25.0	1,140	85	--	--	--	--	--	--
	05-23-89	27.5	1,140	82	350	100	50	46	5.7	133
	02-13-90	24.5	1,180	100	350	--	--	--	--	--
	04-11-90	25.0	1,200	97	350	--	--	--	--	--
32a	05-29-81	--	1,370	160	--	--	--	--	--	--
32b	05-29-81	--	2,150	340	--	--	--	--	--	--
	09-21-87	27.0	2,400	400	550	--	--	--	--	--
33	06-10-76	25.5	1,230	150	510	150	89	58	12	--
34	05-20-87	--	1,900	200	650	--	--	--	--	--
	09-17-87	--	1,950	200	730	--	--	--	--	--
	05-18-88	--	1,880	200	680	--	--	--	--	--
35	08-24-88	26.5	1,830	230	530	180	86	86	5.6	154
36	08-03-88	26.0	1,460	150	380	130	70	52	6.8	165
37	05-20-87	--	2,350	310	750	--	--	--	--	--
	09-17-87	--	2,080	300	730	--	--	--	--	--
	08-10-89	26.0	2,260	280	740	240	95	120	4.2	130
38	05-20-87	--	2,200	260	700	--	--	--	--	--
	09-17-87	--	2,190	260	740	--	--	--	--	--
	05-18-88	--	2,100	240	700	--	--	--	--	--
	09-21-88	--	2,080	270	660	--	--	--	--	144
39	06-19-87	24.5	1,880	240	530	180	75	110	7.0	137
	09-17-87	--	1,820	230	590	--	--	--	--	--
	05-18-88	--	1,780	220	530	--	--	--	--	--
	09-21-88	--	1,770	210	520	--	--	--	--	--
40a	10-06-89	25.5	1,210	66	410	130	60	40	4.6	142
	06-25-90	24.5	1,160	64	400	120	60	38	4.4	141
41	11-06-87	25.0	3,100	600	610	--	--	--	--	--
42	08-15-90	25.0	1,150	63	380	--	--	--	--	--
43	04-29-85	25.0	1,000	36	--	--	--	--	--	--
	09-16-85	24.0	1,080	44	--	--	--	--	--	--
44	03-09-87	24.0	970	26	380	--	--	--	--	--
	04-15-88	24.5	1,250	23	400	--	--	--	--	--
	09-27-88	25.0	1,170	56	390	--	--	--	--	--
	04-07-89	24.0	978	20	390	--	--	--	--	--
44	05-17-89	24.5	1,060	24	390	--	--	--	--	--
45a	10-09-87	24.0	1,600	120	720	--	--	--	--	--
	09-29-88	25.0	1,890	120	--	--	--	--	--	--
	05-17-89	24.5	2,420	290	920	290	130	81	2.8	130
	10-05-89	26.0	1,990	220	870	--	--	--	--	--
	04-17-90	25.5	2,100	250	--	--	--	--	--	--
45b	10-09-87	26.0	4,400	840	--	--	--	--	--	--
	05-17-89	24.5	5,510	1,200	1,500	590	240	340	4.4	118
	10-05-89	26.0	6,500	1,000	1,500	--	--	--	--	--
	06-29-90	25.5	6,700	1,500	--	--	--	--	--	--

APPENDIX--Water-Quality Data for the Transition-Zone Monitoring Wells--Continued

[Site locations are shown in figures 30 and 31. Site descriptions are presented in tables 7 and 8. mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, no data]

Site no.	Sample date	Temperature (°C)	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, (mg/L as $CaCO_3$)
47	09-18-75	25.3	1,580	360	49	180	27	90	4.7	--
48	09-18-75	24.6	900	140	4.6	110	24	37	--	--
49	09-22-87	24.5	1,420	100	500	--	--	--	--	--
50	09-15-87	--	1,720	420	37	--	--	--	--	--
	06-02-88	--	1,940	450	39	160	52	97	13	185
	09-29-88	24.5	1,940	440	44	--	--	--	--	--
	05-17-89	24.0	1,880	480	41	--	--	--	--	--
51	05-20-87	--	580	72	6.8	--	--	--	--	--
	09-15-87	--	635	87	7.3	--	--	--	--	--
	05-17-89	24.5	700	110	8.9	--	--	--	--	--
52	10-24-78	24.5	--	120	9.1	98	10	39	1.8	--
53	03-10-87	22.0	760	49	--	--	--	--	--	--
	11-02-87	23.0	755	51	--	--	--	--	--	--
	07-27-89	25.0	761	44	--	--	--	--	--	--
54	09-30-88	25.0	2,050	180	700	220	80	100	4.9	144
	09-11-89	--	1,770	200	730	--	--	--	--	--
55	10-19-78	24.6	670	87	11	91	8.3	28	1.7	--
56	09-02-75	--	1,160	210	23	--	--	--	--	--
57	06-02-88	24.5	517	34	--	--	--	--	--	--
	09-29-88	--	492	31	--	--	--	--	--	--
58	10-24-78	24.0	1,400	340	3.6	170	8.1	100	1.2	--
59	05-16-89	24.5	1,670	360	63	--	--	--	--	--
60	04-26-74	24.0	1,700	390	21	120	45	150	2.1	--
61	10-05-78	25.5	--	92	--	--	--	--	--	--
62	05-11-87	25.0	585	61	--	--	--	--	--	--
	06-14-89	25.5	515	47	--	--	--	--	--	--
63	03-09-87	23.0	754	120	--	--	--	--	--	--
	11-02-87	23.0	680	98	--	--	--	--	--	--
64	05-06-87	23.5	948	180	32	--	--	--	--	--
	10-13-87	23.5	909	180	37	--	--	--	--	--
	05-12-88	24.0	980	180	33	--	--	--	--	--
	09-27-88	24.5	1,010	160	31	--	--	--	--	--
	04-07-89	23.5	984	180	32	--	--	--	--	--
65	09-02-76	25.0	1,200	230	30	--	--	--	--	--
66a	04-25-88	24.5	50,700	20,000	--	--	--	--	--	--
	08-22-88	24.5	51,600	20,000	--	--	--	--	--	--
	12-13-88	25.0	52,200	20,000	--	--	--	--	--	--
	01-30-89	25.0	51,700	20,000	--	--	--	--	--	--
	04-06-89	23.5	53,000	18,000	--	--	--	--	--	--
	06-09-89	25.5	53,000	20,000	3,100	--	--	--	--	--
66b	04-25-88	24.5	9,200	2,900	--	--	--	--	--	--
	08-22-88	24.5	9,500	3,100	--	--	--	--	--	--
	12-13-88	24.5	9,500	3,000	--	--	--	--	--	--
	01-30-89	24.0	9,200	3,000	--	--	--	--	--	--
	04-06-89	24.0	9,400	3,000	--	--	--	--	--	--
	06-09-89	24.0	9,400	3,000	60	--	--	--	--	--
67	05-11-87	27.0	1,090	130	--	--	--	--	--	--
	06-17-88	24.5	1,040	130	--	--	--	--	--	--
	06-15-89	24.5	1,020	130	--	--	--	--	--	--
68	09-14-87	--	688	78	9.0	--	--	--	--	--

APPENDIX--Water-Quality Data for the Transition-Zone Monitoring Wells--Continued

[Site locations are shown in figures 30 and 31. Site descriptions are presented in tables 7 and 8. mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, no data]

Site no.	Sample date	Temper-ature (°C)	Specific conduct-ance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alka-linity, (mg/L as $CaCO_3$)
	05-16-88	--	692	76	29	--	--	--	--	--
	09-19-88	--	676	73	12	--	--	--	--	--
69a	06-20-88	24.0	49,800	20,000	--	--	--	--	--	--
	10-13-88	25.0	51,300	17,000	--	--	--	--	--	--
	01-30-89	25.0	51,200	20,000	--	--	--	--	--	--
	06-09-89	25.0	51,100	19,000	3,000	--	--	--	--	--
69b	06-20-88	24.5	1,180	270	--	--	--	--	--	--
	10-13-88	24.0	1,300	300	--	--	--	--	--	--
	01-30-89	24.5	1,290	310	--	--	--	--	--	--
	06-09-89	24.5	1,400	340	20	--	--	--	--	--
70	05-11-87	24.0	1,050	180	87	--	--	--	--	--
	06-17-88	24.0	881	130	--	--	--	--	--	--
	06-15-89	23.5	855	120	63	--	--	--	--	--
71	06-01-88	29.0	558	38	15	86	6.3	20	1.2	222
	09-21-88	--	566	37	19	--	--	--	--	--
	05-16-89	--	561	39	20	--	--	--	--	--
72	05-18-87	--	690	71	18	--	--	--	--	--
	09-14-87	--	595	38	25	--	--	--	--	--
	05-16-88	--	740	96	27	--	--	--	--	--
	09-21-88	--	730	85	19	--	--	--	--	--
73	09-19-88	--	332	13	79	--	--	--	--	--
	05-16-89	--	594	69	59	--	--	--	--	--
74	05-19-87	24.0	461	47	1.0	--	--	--	--	--
	09-14-87	26.0	451	49	--	--	--	--	--	--
	05-17-88	24.5	480	48	.40	--	--	--	--	--
	09-20-88	26.0	499	55	6.7	--	--	--	--	--
	05-16-89	24.0	470	54	--	--	--	--	--	--
75	05-06-87	25.0	1,160	210	140	--	--	--	--	--
	10-08-87	25.0	1,150	200	130	--	--	--	--	--
	04-04-88	24.5	1,190	200	--	--	--	--	--	--
	07-25-88	24.5	1,130	200	--	--	--	--	--	--
	02-06-89	24.5	1,170	260	--	--	--	--	--	--
	05-15-89	24.5	1,160	200	130	100	20	110	3.9	157
76	05-19-87	24.0	581	88	3.4	--	--	--	--	--
	09-15-87	26.0	590	90	8.6	--	--	--	--	--
	05-17-88	24.5	590	82	4.9	--	--	--	--	--
	09-20-88	26.0	590	90	6.7	--	--	--	--	--
	05-16-89	24.5	484	60	--	--	--	--	--	--
	09-12-89	25.0	360	66	.50	--	--	--	--	--
77	05-14-87	24.0	750	100	--	--	--	--	--	--
	09-23-87	24.0	770	100	--	--	--	--	--	--
	05-03-88	24.0	785	100	--	--	--	--	--	--
	08-29-88	27.0	710	110	--	--	--	--	--	--
	05-02-89	26.5	745	110	--	--	--	--	--	--
	09-05-89	30.0	650	110	--	--	--	--	--	--
78	05-19-87	25.0	679	140	--	--	--	--	--	--
	09-15-87	28.0	602	87	12	--	--	--	--	--
	05-17-88	24.5	706	130	8.6	--	--	--	--	--
79	05-17-88	24.5	577	37	63	--	--	--	--	--
	05-16-89	24.5	544	37	--	--	--	--	--	--

APPENDIX--Water-Quality Data for the Transition-Zone Monitoring Wells--Continued

[Site locations are shown in figures 30 and 31. Site descriptions are presented in tables 7 and 8. mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, no data]

Site no.	Sample date	Temperature (°C)	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, (mg/L as $CaCO_3$)
	09-14-89	25.0	555	39	60	--	--	--	--	--
80a	12-01-87	23.0	1,500	340	64	--	--	--	--	--
	09-30-88	24.5	1,440	290	54	110	13	150	3.2	196
80b	09-30-88	25.5	890	140	26	98	6.3	73	2.3	210
81	05-14-87	26.0	690	100	24	--	--	--	--	--
82	05-15-87	23.0	3,280	950	--	--	--	--	--	--
	07-24-87	22.5	2,950	840	--	--	--	--	--	--
	06-17-88	24.0	3,500	1,000	--	--	--	--	--	--
	12-08-88	23.0	3,800	1,000	--	--	--	--	--	--
	01-31-89	24.0	3,650	1,000	--	--	--	--	--	--
	05-02-89	23.5	3,300	940	33	--	--	--	--	--
83	04-20-88	26.5	1,430	300	70	--	--	--	--	--
	06-28-88	25.0	1,380	290	66	--	--	--	--	--
	10-06-88	24.5	1,360	260	64	96	12	130	2.4	184
	06-19-89	25.0	1,280	300	--	--	--	--	--	--
	08-10-89	25.0	1,240	280	--	--	--	--	--	--
84	06-01-87	25.5	8,100	2,300	--	--	--	--	--	--
	10-05-87	24.0	8,000	2,400	420	--	--	--	--	--
	06-28-88	24.0	8,200	2,400	--	--	--	--	--	--
	10-04-88	25.0	8,500	2,400	--	--	--	--	--	--
	05-11-89	25.0	8,250	2,300	450	--	--	--	--	187
85	05-19-87	25.0	630	86	44	--	--	--	--	--
	09-15-87	25.0	643	86	38	--	--	--	--	--
	05-17-88	24.0	681	92	36	--	--	--	--	--
	09-20-88	24.5	725	97	36	--	--	--	--	--
	09-12-89	24.5	685	98	38	--	--	--	--	--
86	06-03-87	24.0	14,500	4,700	--	--	--	--	--	--
	10-06-87	24.0	13,800	4,900	1,000	--	--	--	--	--
	06-29-88	25.0	14,200	4,200	--	--	--	--	--	--
	05-09-89	25.0	9,040	2,600	610	--	--	--	--	--
87	06-17-88	24.0	290	13	--	--	--	--	--	--
	10-03-88	24.5	290	14	--	--	--	--	--	--
	06-06-89	24.5	295	16	1.6	--	--	--	--	--
	10-10-89	24.5	305	18	--	--	--	--	--	--
	04-05-90	24.5	310	19	--	--	--	--	--	--
88a	06-17-88	24.5	30,100	10,000	--	--	--	--	--	--
	10-04-88	24.5	30,000	10,000	--	--	--	--	--	--
	06-06-89	24.5	30,000	10,000	1,400	--	--	--	--	--
	10-10-89	24.5	30,000	11,000	--	--	--	--	--	--
	01-30-90	25.0	30,000	1,100	--	--	--	--	--	--
	04-05-90	25.0	31,000	11,000	--	--	--	--	--	--
88b	06-17-88	24.5	6,000	1,700	--	--	--	--	--	--
	10-04-88	24.5	6,000	1,700	--	--	--	--	--	--
	06-06-89	24.5	5,200	1,500	200	--	--	--	--	--
	01-30-89	24.5	6,800	2,100	--	--	--	--	--	--
	04-05-90	24.5	6,800	2,000	--	--	--	--	--	--
89	05-17-79	25.0	800	130	--	--	--	--	--	--
90	09-21-89	23.9	391	11	1.5	--	--	--	--	--
91	05-19-87	24.0	2,010	510	20	--	--	--	--	--
	09-14-87	24.0	1,990	520	18	--	--	--	--	--

APPENDIX--Water-Quality Data for the Transition-Zone Monitoring Wells--Continued

[Site locations are shown in figures 30 and 31. Site descriptions are presented in tables 7 and 8. mg/L, milligrams per liter; μS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, no data]

Site no.	Sample date	Temperature (°C)	Specific conductance (μS/cm)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, (mg/L as $CaCO_3$)
	05-17-88	24.0	1,980	500	15	--	--	--	--	--
	09-20-88	24.0	2,120	500	37	--	--	--	--	--
	05-16-89	24.5	1,930	500	--	--	--	--	--	--
92	10-01-75	--	705	130	66	73	11	55	--	--
93a	06-09-87	24.0	2,670	760	--	--	--	--	--	--
	10-06-87	24.0	2,600	770	--	--	--	--	--	--
	06-16-88	24.5	2,600	760	--	--	--	--	--	--
	10-07-88	24.0	2,800	800	--	--	--	--	--	--
	02-06-89	25.0	2,900	770	86	--	--	--	--	--
	05-01-89	23.5	2,800	800	62	--	--	--	--	--
93b	06-09-87	25.0	4,860	1,400	--	--	--	--	--	--
	10-06-87	24.0	4,880	1,400	--	--	--	--	--	--
	06-16-88	25.5	4,830	1,400	--	--	--	--	--	--
	10-07-88	24.5	4,830	1,300	--	--	--	--	--	--
	02-06-89	25.0	4,800	1,300	250	--	--	--	--	--
94	06-01-87	26.0	400	9.7	--	--	--	--	--	--
	09-25-87	24.5	445	9.2	--	--	--	--	--	--
	04-21-88	24.5	420	8.8	21	--	--	--	--	--
	02-06-89	24.0	400	11	--	--	--	--	--	--
	05-11-89	24.0	400	11	32	--	--	--	--	191
95	06-23-88	25.5	2,250	620	110	90	32	390	7.5	102
	01-10-89	23.5	2,130	550	100	76	22	310	7.2	102
	05-10-89	25.0	2,810	790	120	94	28	380	8.2	108
	10-04-89	25.5	2,720	740	130	100	31	420	8.0	112
96	09-25-80	--	950	170	--	--	--	--	--	--
97	06-12-87	24.5	910	220	35	--	--	--	--	--
	10-13-87	24.0	720	170	--	--	--	--	--	--
	06-16-88	25.0	820	190	31	--	--	--	--	--
	10-07-88	24.5	830	200	31	--	--	--	--	--
	05-01-89	24.5	820	200	33	43	9.8	96	3.1	60
	10-16-89	24.5	890	200	32	--	--	--	--	--
	04-02-89	24.0	1,000	230	37	--	--	--	--	--
98	06-12-87	24.5	2,020	490	22	--	--	--	--	--
	10-07-88	24.0	2,220	540	20	--	--	--	--	--
	05-02-89	24.0	2,550	620	24	110	36	350	11	281
99	03-09-87	24.5	552	47	--	--	--	--	--	--
	09-21-87	26.0	570	43	--	--	--	--	--	--
	03-10-88	24.0	560	44	--	--	--	--	--	--
	09-19-88	--	547	41	--	--	--	--	--	--
	03-01-89	--	560	30	--	--	--	--	--	--
	08-02-89	24.5	586	44	--	--	--	--	--	--
100	03-09-87	24.5	1,040	140	--	--	--	--	--	--
	09-22-87	26.0	1,240	170	--	--	--	--	--	--
	03-10-88	24.5	1,290	190	--	--	--	--	--	--
	09-19-88	--	1,350	220	--	--	--	--	--	--
	03-02-89	--	1,510	240	--	--	--	--	--	--
	08-01-89	24.0	1,520	260	--	--	--	--	--	--
101	06-08-87	24.5	540	57	--	--	--	--	--	--
	10-05-87	24.5	528	57	--	--	--	--	--	--
	06-16-88	24.5	540	58	--	--	--	--	--	--

APPENDIX--Water-Quality Data for the Transition-Zone Monitoring Wells--Continued

[Site locations are shown in figures 30 and 31. Site descriptions are presented in tables 7 and 8. mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, no data]

Site no.	Sample date	Temperature (°C)	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, (mg/L as $CaCO_3$)
101	10-03-88	24.5	530	55	--	--	--	--	--	--
	05-02-89	24.5	540	56	16	--	--	--	--	--
	10-11-89	25.0	560	58	--	--	--	--	--	--
	04-03-90	24.5	560	58	--	--	--	--	--	--
102	09-09-87	29.5	540	58	23	--	--	--	--	--
103	09-09-87	32.0	710	100	32	--	--	--	--	--
104	09-09-87	29.0	500	42	--	--	--	--	--	--
105a	09-22-81	24.5	2,110	520	--	--	--	--	--	--
106	09-01-71	--	770	292	77	90	16	146	4.6	--
107	05-14-76	--	670	110	--	--	--	--	--	--
108	05-20-87	24.0	550	52	--	--	--	--	--	--
	09-16-87	25.0	688	84	12	--	--	--	--	--
109	04-07-88	25.0	870	130	17	97	4.3	82	3.3	245
110	05-13-87	25.5	3,400	890	100	--	--	--	--	--
	09-04-87	25.5	3,150	860	90	--	--	--	--	--
	04-08-88	24.0	3,650	850	100	--	--	--	--	--
	08-09-88	24.5	3,300	810	100	--	--	--	--	--
	06-13-89	24.5	3,400	880	100	130	41	490	20	236
111	05-20-87	23.0	423	19	4.8	--	--	--	--	--
	09-16-87	25.5	355	30	5.9	--	--	--	--	--
112	02-19-80	23.0	679	110	20	69	6.5	57	1.7	--
113	09-09-87	26.0	750	110	5.3	--	--	--	--	--
114	07-14-88	23.0	332	18	8.3	41	12	7.0	.7	135
115	05-16-89	--	3,5000	9,000	1,900	--	--	--	--	--
116	05-11-88	28.0	350	25	25	45	5.6	13	.6	111
117	09-29-88	23.5	695	100	11	78	2.3	61	.3	189
118	06-25-88	23.0	3,600	1,000	110	140	55	470	10	122
	10-03-88	23.5	3,200	870	110	--	--	--	--	--
119	06-09-87	22.0	3,750	1,100	--	--	--	--	--	--
	09-08-87	24.0	8,500	2,700	390	--	--	--	--	--
	06-24-88	23.5	6,550	2,000	330	--	--	--	--	--
	08-16-88	23.0	4,400	1,300	210	--	--	--	--	--
	06-16-89	23.5	10,100	3,000	460	--	--	--	--	--
	08-11-89	23.5	5,750	1,700	240	--	--	--	--	--
120	05-11-88	25.5	2,550	100	--	--	--	--	--	--
	09-12-89	24.5	2,550	100	--	--	--	--	--	--
121	03-02-82	--	525	18	--	--	--	--	--	--
	04-20-90	--	380	13	--	--	--	--	--	--
122	05-15-85	--	435	51	--	--	--	--	--	--
	05-15-86	--	420	54	--	--	--	--	--	--
123	05-15-86	--	554	58	--	--	--	--	--	--
	09-18-86	--	429	57	--	--	--	--	--	--
	05-27-87	--	370	52	--	--	--	--	--	--
124	07-14-88	21.0	514	13	5.6	78	14	8.6	.5	253
125	01-13-89	23.5	459	25	9.2	56	11	14	.7	171
126	05-15-87	24.5	280	8.8	--	--	--	--	--	--
	09-10-87	24.5	295	7.1	--	--	--	--	--	--
	06-22-88	24.0	269	7.3	--	--	--	--	--	--
	08-18-88	24.0	257	7.0	--	--	--	--	--	--
	07-13-89	23.5	285	8.7	--	--	--	--	--	--

APPENDIX--Water-Quality Data for the Transition-Zone Monitoring Wells--Continued

[Site locations are shown in figures 30 and 31. Site descriptions are presented in tables 7 and 8. mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, no data]

Site no.	Sample date	Temperature (°C)	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, (mg/L as $CaCO_3$)
	09-12-89	23.5	290	7.7	--	--	--	--	--	--
	05-15-90	23.0	323	8.5	--	--	--	--	--	--
	08-21-90	24.5	320	7.2	--	--	--	--	--	--
	11-15-90	24.0	310	8.4	--	--	--	--	--	--
127	09-22-87	24.0	280	7.8	5.5	--	--	--	--	--
128	09-09-87	--	820	160	25	--	--	--	--	--
	04-20-90	--	804	160	28	--	--	--	--	--
129	04-18-90	23.5	366	40	8.9	--	--	--	--	--
130	09-12-85	--	235	11	--	--	--	--	--	--
	06-30-88	23.5	540	95	18	--	--	--	--	--
131	04-18-90	23.0	531	31	6.2	--	--	--	--	--
132	05-21-87	24.5	1,820	460	--	--	--	--	--	--
	09-10-87	24.0	1,550	400	--	--	--	--	--	--
	06-23-88	24.0	1,620	360	--	--	--	--	--	--
	10-19-88	--	1,520	300	--	--	--	--	--	--
	06-15-89	--	1,720	380	25	--	--	--	--	--
	10-12-89	--	1,470	300	16	--	--	--	--	--
133	05-21-87	23.0	1,100	240	56	--	--	--	--	--
	09-10-87	24.0	1,070	240	43	--	--	--	--	--
	06-23-88	24.0	1,100	240	29	--	--	--	--	--
133	08-11-88	23.5	1,120	240	30	--	--	--	--	--
	06-15-89	23.0	1,110	240	30	--	--	--	--	--
	09-13-89	23.5	1,110	240	29	--	--	--	--	--
134a	12-02-75	23.5	371	43	--	--	--	--	--	--
	06-19-80	24.0	328	31	9.6	--	--	--	--	--
134b	12-02-75	23.5	345	35	--	--	--	--	--	--
135	12-03-75	--	520	69	--	--	--	--	--	--
136	05-15-87	26.0	1,680	170	0.4	--	--	--	--	--
	09-10-87	26.0	1,610	130	11	--	--	--	--	--
	06-23-88	26.5	1,550	120	11	--	--	--	--	--
	08-11-88	26.0	1,490	120	11	--	--	--	--	--
	06-15-89	26.0	1,050	120	7.9	--	--	--	--	--
	09-13-89	25.5	1,300	120	8.8	--	--	--	--	--
137	05-15-87	23.0	760	83	--	--	--	--	--	--
	09-10-87	24.5	720	74	--	--	--	--	--	--
	04-07-88	21.0	750	81	21	74	10	42	0.7	207
	10-20-88	21.5	678	66	--	--	--	--	--	--
	06-15-89	21.0	820	110	25	--	--	--	--	--
	10-12-89	21.5	667	60	20	--	--	--	--	--
	06-14-90	21.5	1,290	280	--	--	--	--	--	--
	11-15-90	22.0	750	92	--	--	--	--	--	--
138	05-10-88	23.0	770	100	46	--	--	--	--	--
139	05-19-87	22.0	450	17	--	--	--	--	--	--
	09-10-87	23.0	445	15	--	--	--	--	--	--
	06-23-88	21.5	468	15	--	--	--	--	--	--
	10-20-88	21.5	458	14	--	--	--	--	--	--
	06-15-89	22.0	469	15	2.5	--	--	--	--	--
	10-12-89	22.0	465	16	2.2	--	--	--	--	--
	06-14-90	21.5	462	14	--	--	--	--	--	--
	11-15-90	22.0	452	14	--	--	--	--	--	--

APPENDIX--Water-Quality Data for the Transition-Zone Monitoring Wells--Continued

[Site locations are shown in figures 30 and 31. Site descriptions are presented in tables 7 and 8. mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, no data]

Site no.	Sample date	Temperature (°C)	Specific conductance (µS/cm)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, (mg/L as $CaCO_3$)
140	05-19-87	22.0	1,350	240	--	--	--	--	--	--
	09-10-87	23.0	960	150	--	--	--	--	--	--
	06-23-88	22.0	1,610	280	--	--	--	--	--	--
	10-20-88	21.5	818	76	--	--	--	--	--	--
	06-15-89	22.0	2,170	460	200	--	--	--	--	--
	10-12-89	22.0	928	110	93	--	--	--	--	--
	06-14-90	21.5	3,030	730	--	--	--	--	--	--
	11-15-90	23.5	1,840	370	--	--	--	--	--	--
141	06-05-87	--	3,000	63	1,800	--	--	--	--	--
	11-20-87	--	2,920	60	1,800	--	--	--	--	--
	04-29-88	--	2,930	63	1,700	--	--	--	--	--
	10-19-88	--	2,930	63	1,800	--	--	--	--	--
	07-26-89	27.0	2,780	65	1,800	--	--	--	--	--
142	06-05-87	--	780	10	360	--	--	--	--	--
	09-23-87	--	752	9.4	360	--	--	--	--	--
	03-09-88	--	758	8.0	350	--	--	--	--	--
	10-19-88	--	760	9.8	340	--	--	--	--	--
	05-31-89	--	756	10	340	--	--	--	--	--
	07-26-89	24.5	755	10	350	--	--	--	--	--

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