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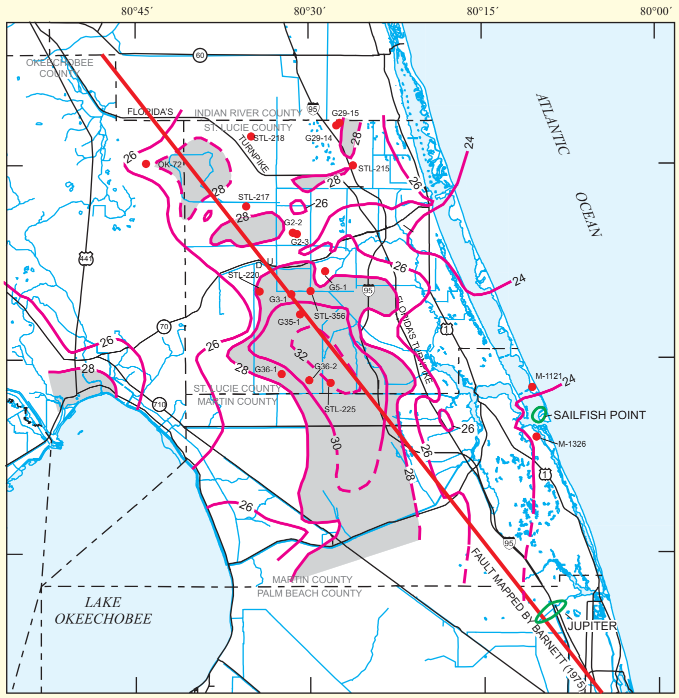
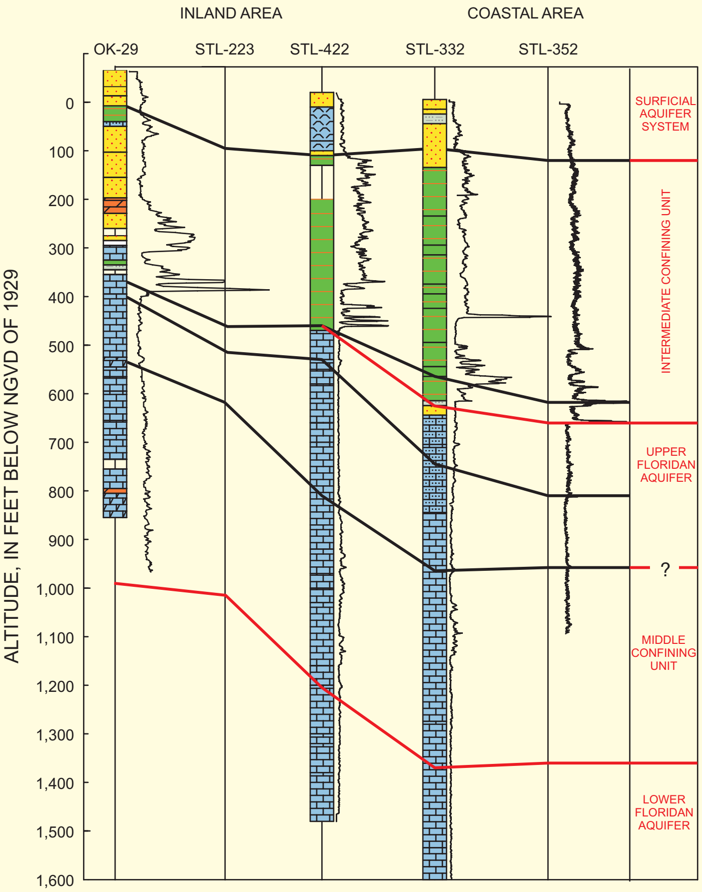
Hydrogeology, Water Quality, and Distribution and Sources of Salinity in the Floridan Aquifer System, Martin and St. Lucie Counties, Florida





Water-Resources Investigations Report 03-4242

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

Prepared in cooperation with the
South Florida Water Management District

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By Ronald S. Reese

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Tallahassee, Florida
2004

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

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Multiply	By	To obtain
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.589	square kilometer
gallon (gal)	3.785	liter
million gallons (Mgal)	3,785	cubic meter
million gallons per day (Mgal/d)	0.04381	cubic meter per second
square feet per day (ft^2/d)	0.09294	square meter per day

Abbreviations and Acronyms used in this report:

mg/L	milligrams per liter
ohm-m	ohm-meter
µm	micrometer
API	American Petroleum Institute
FDEP	Florida Department of Environmental Protection
GWSI	Ground-Water Site Inventory (U.S. Geological Survey database)
NRCS	Natural Resources Conservation Service
PMC	Percent modern carbon
QWDATA	USGS Water Quality Data Base
PDB	Vienna Pee dee Belemnite standard
PMC	Percent modern carbon
RO	Reverse osmosis
SFWMD	South Florida Water Management District
SLAP	Standard Light Antarctic Precipitation
UEC	Upper East Coast
USGS	U.S. Geological Survey
VSMOW	Vienna Standard Mean Ocean Water
WWTP	Wastewater treatment plant

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

$$°C = (°F - 32)/1.8$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 1929); horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Hydrogeology, Water Quality, and Distribution and Sources of Salinity in the Floridan Aquifer System, Martin and St. Lucie Counties, Florida

By Ronald S. Reese

ABSTRACT

The Floridan aquifer system is considered to be a valuable source for agricultural and municipal water supply in Martin and St. Lucie Counties, despite its brackish water. Increased withdrawals, however, could increase salinity and threaten the quality of withdrawn water. The Floridan aquifer system consists of limestone, dolomitic limestone, and dolomite and is divided into three hydrogeologic units: the Upper Floridan aquifer, a middle confining unit, and the Lower Floridan aquifer. An informal geologic unit at the top of the Upper Floridan aquifer, referred to as the basal Hawthorn/Suwannee unit, is bound above by a marker unit in the Hawthorn Group and at its base by the Ocala Limestone; a map of this unit shows an area where substantial eastward thickening begins near the coast. This change in thickness is used to divide the study area into inland and coastal areas.

In the Upper Floridan aquifer, an area of elevated chloride concentration greater than 1,000 milligrams per liter and water temperature greater than 28 degrees Celsius exists in the inland area and trends northwest through north-central Martin County and western St. Lucie County. A structural feature coincides with this area of greater salinity and water temperature; this feature is marked by a previously mapped northwest-trending basement fault and, based on detailed mapping in this study of the structure at the top of the basal Hawthorn/Suwannee unit, an apparent southeast-trending trough. Higher hydraulic head also has been mapped in this northwest-trending area. Another area of high chloride concentration in the Upper Floridan aquifer occurs in the southern part of the coastal area (in eastern Martin County and northeastern Palm Beach County); chloride concentration in this area is more than 2,000 milligrams per liter and is as great as 8,000 milligrams per liter.

A dissolved-solids concentration of less than 10,000 milligrams per liter defines the brackish-water zone in the Floridan aquifer system; the top and base of this zone are present at the top of the aquifer system and within the Lower Floridan aquifer, respectively. The base of the brackish-water zone, which can approximate a brackish-water/saltwater interface, was determined in 13 wells, mostly using resistivity geophysical logs. The depth to the saltwater interface was calculated using the Ghyben-Herzberg approximation and estimated predevelopment hydraulic heads in the Upper Floridan aquifer. In five of six inland area wells, the depth to the base of the brackish-water zone was substantially shallower than the estimated

predevelopment interface (260 feet or greater), whereas in five of seven coastal area wells, the difference was not large (less than about 140 feet). Confining units in the inland area, such as dense dolomite, may prevent an interface from forming at its equilibrium position. Because of head decline, the calculated interface using recent (May 2001) water levels is as much as 640 ft above the base of the brackish water zone (in the northern part of the coastal area).

Isotopic data collected during this study, including deuterium and oxygen-18 ($^{18}O/^{16}O$), the ratio of strontium-87 to strontium-86, and carbon-13 ($^{13}C/^{12}C$) and carbon-14, provide evidence for differences in the Floridan aquifer system ground-water geochemistry and its evolution between inland and coastal areas. Ground water from the inland area tends to be older than water from the coastal area, particularly where inland area water temperature is elevated. Isotopic data together with an anomalous vertical distribution of salinity in the coastal area indicate that the coastal area was invaded with seawater in relatively recent geologic time, and this water has not been completely flushed out by the modern-day flow system.

Upward leakage from the Lower to Upper Floridan aquifer of high salinity water occurs through structural deformities, such as faults or fracture zones or associated dissolution features in the inland area. An upward trend in salinity is indicated in 16 monitoring wells in the inland area, and agricultural withdrawals are probably causing these increases. Most of these wells are located in areas of elevated Upper Floridan aquifer ground-water temperature. Areas of higher water temperature could represent areas of greater potential for increases in salinity. More detailed mapping of the structure of the uppermost geologic units in the aquifer system could better define areas of deformation. Additionally, high potential exists in much of the study area for upward or lateral movement of the saltwater interface because of large declines in hydraulic head since predevelopment. The northern part of the coastal area has the greatest potential for movement; however, upward movement of the interface in the coastal area could be retarded by low vertical permeability. The potential for upward or lateral movement of the interface in the southern part of the coastal area seems to be low, but structural deformation could be present in northeastern Palm Beach County, allowing for localized upward leakage of saltwater.

INTRODUCTION

Rapid urban development has raised concern about increased water use and the potential for degradation of water quality in the Floridan aquifer system in the Upper East Coast (UEC) of southern Florida. The UEC is one of four regional planning areas in the South Florida Water Management District (SFWMD). The UEC Planning Area encompasses about 1,200 mi^2 and includes most of Martin and St. Lucie Counties and a small part of Okeechobee County. Water for urban and agricultural use in the UEC Planning Area comes from surface water, the surficial aquifer system, and the Floridan aquifer system.

The Floridan aquifer system constitutes the Upper Floridan aquifer, a middle confining unit, and the Lower Floridan aquifer. Withdrawal of water from the Floridan aquifer system in urban coastal areas for municipal supply is projected to increase at a much higher rate than withdrawals for irrigation in inland areas (South Florida Water Management District, 1998). Currently, withdrawals in the UEC Planning Area are restricted to artesian flow or pumping rates that do not lower hydraulic head below land surface, but increased urban demand could necessitate increased withdrawals. Most water is withdrawn from the Upper Floridan aquifer, but withdrawals from the Lower Floridan aquifer for public supply have been increasing in recent years. Because of its brackish to saline nature, ground water obtained from the Floridan aquifer system for public supply in the UEC Planning Area is desalinated by the reverse osmosis (RO) method, or blended with freshwater from the surficial aquifer system.

The salinity of the withdrawn Floridan aquifer system ground water can vary sharply, and extended periods of high withdrawals can contribute to the influx of ground water with higher salinity. An understanding of relations between water quality, withdrawal rate, and aquifer hydraulic head is needed by water managers to ensure a sustainable supply of water of adequate quality. Potential sources of higher salinity water in the Floridan aquifer system and mechanisms for the movement of this water include relict seawater, upconing or upward movement of the saltwater interface, lateral encroachment of the saltwater interface along the coast, and upward leakage of saline water through structural deformities or dissolution features. Mechanisms that are occurring or that are most likely to occur need to be identified; an understanding of the hydrogeologic framework and the flow system history will help in this identification. To address these information needs, the

U.S. Geological Survey (USGS), in cooperation with the SFWMD, conducted a study from April 1999 through September 2002. The purpose of this study was to: (1) identify the most likely sources of higher salinity in the Floridan aquifer system, (2) determine how these sources could affect ground-water withdrawals, and (3) identify areas in the UEC Planning Area that are most vulnerable to potential increases in salinity.

Purpose and Scope

The purposes of this report are to: (1) describe the hydrogeologic framework and ground-water flow system in the Floridan aquifer system in the study area; (2) describe relations between salinity, withdrawal rate, and hydraulic head; (3) identify the potential sources of higher salinity water in the aquifer system and discuss potential flow mechanisms and pathways for movement of this water to a production well; and (4) describe areas that have high potential for increasing salinity due to current or increasing ground-water withdrawals. Data are presented for 73 water-quality samples collected from the Floridan aquifer system wells with analysis for major and minor ions, field characteristics, and hydrogen, oxygen, strontium, and carbon isotopes. Hydrogeologic sections and contour maps illustrate the top of the Floridan aquifer system and a key geologic unit contained within it. Additional maps show the spatial distributions of salinity and water temperature and the approximate altitude of the top of saline water.

Description of Study Area

The study area encompasses the UEC Planning Area, Martin and St. Lucie Counties, and parts of Palm Beach and Okeechobee Counties (fig. 1). It is bounded by Indian River County to the north, the Atlantic Ocean to the east, and part of Lake Okeechobee to the west. One deep well (IR-1001) in Indian River County located outside the study area, about 2 mi north of the St. Lucie County boundary, is used for an additional point of control in mapping. Land-surface altitude in the study area ranges from sea level to about 60 ft above NGVD of 1929. A topographic high, referred to as the Osceola Plain (fig. 1), extends southeasterly through eastern Okeechobee County, extreme southwestern St. Lucie County, and into western Martin County. Excluding this topographic high area, land-surface altitude in the study area is less than 35 ft above NGVD of 1929.

Previous Studies

Several studies on the Floridan aquifer system, conducted as part of the Regional Aquifer System Analysis Program of the USGS (USGS Professional Paper 1403 series reports), were used as a basis for this report. The hydrogeologic framework of the Floridan aquifer system was described over its full extent (all of Florida and parts of Georgia, Alabama, and South Carolina) by Miller (1986). The ground-water hydraulics, regional flow, and ground-water development of the Floridan aquifer system were described for this region by Bush and Johnston (1988). Meyer (1989) analyzed the hydrogeology and ground-water movement in southern Florida.

Local hydrogeologic studies conducted in Martin, St. Lucie, and adjacent counties include reports by Lichtler (1960), Brown and Reece (1979), Mooney (1980), Shaw and Trost (1984), Schiner and others (1988), Bradner (1994), Duncan and others (1994), Lukasiewicz and Switanek (1995), Weedman and others (1995), and Reese and Memberg (2000). Areas of anomalously high salinity occurring above the brackish-water/saltwater interface and in the Upper Floridan aquifer were identified in southeastern Florida (Reese, 1994; Reese and Memberg, 2000). Local hydrogeologic data reports include those by Reece and others (1980; 1984) and Lukasiewicz and Smith (1996). Modeling studies of the Floridan aquifer system in the study area, or a portion thereof, were conducted by Bush and Johnston (1988), Tibbals (1990), and Lukasiewicz (1992).

Acknowledgments

The author graciously thanks SFWMD personnel for their assistance in this investigation. The author accompanied Pete Dauenhauer in the field, who provided technical assistance, location maps, and owner contact information for Upper Floridan aquifer monitoring wells that were later sampled. John Cain provided potentiometric head data collected since 1986 from the SFWMD Floridan aquifer system monitoring well network. Simon Sunderland provided additional data on the Floridan aquifer system monitoring well network and data collected from an irrigation well monitoring program run by the Natural Resources Conservation Service (NRCS). Milton Switanek located SFWMD well abandonment geophysical logs in the UEC and had them digitized.

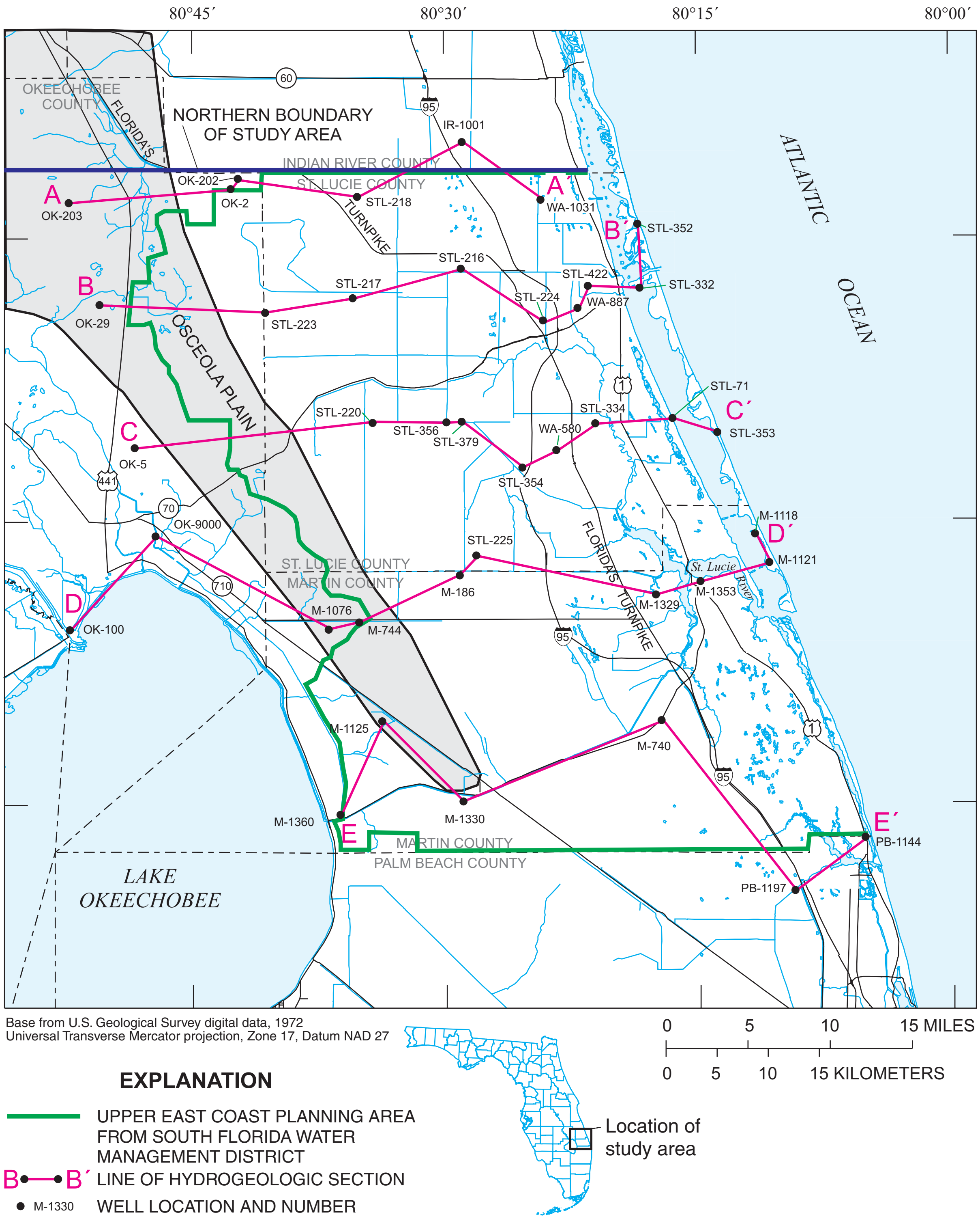


Figure 1. Study area showing lines of hydrogeologic sections.

The author appreciates the assistance of Marion Parsons with the St. Lucie County Soil Conservation Service, as well as water or wastewater treatment plant personnel. Ms. Parsons provided additional information on the NRCS monitoring wells and assisted in the field with sampling several of these wells. Personnel at water and wastewater treatment plants assisted in sampling and provided data on wells operated by their utility. These utilities included Ft. Pierce, Jupiter Water Systems, North Martin County, Port St. Lucie, Stuart, and Tequesta.

METHODS OF EVALUATION AND DATA COLLECTION

This section describes, inventories, and gives the location of wells used in the study. Additionally, the collection and analyses of water-quality data, are discussed. Finally, results of quality-assurance sampling are given.

Inventory of Well Data

Data for all wells used in this study were inventoried and are presented in appendix I; the data include the completed open intervals for each well, if known. The depth of the bottom of casing(s) and the total depth drilled also are included. A completed interval in a well is defined as an interval open to flow. Completed intervals are generally isolated from each other, and from other parts of the borehole, through the use of casing and cement during construction of the well and usually are constructed as open hole in the study area.

Data for most wells used in this investigation are stored in the USGS Ground Water Site Inventory (GWSI) database. Additional information for the wells in GWSI, beyond that provided in appendix I, is available in the database, including land net location (section, township, and range) drilling contractor's name, and owner. The prefixes used for USGS well numbers in GWSI are "M" for Martin County, "OK" for Okeechobee County, "PB" for Palm Beach County, and "STL" for St. Lucie County. Wells not included in GSWI are those from the SFWMD well abandonment program and irrigation wells used in a monitoring program by the NRCS. The SFWMD abandonment wells have numbers with a "WA" prefix instead of a USGS number prefix, and the NRCS wells have a number with a "G" prefix.

Because of the large number of wells used in the study, they were grouped by function or purpose, and their locations are shown on three maps. All wells used for geologic mapping are shown on plate 1. All of the source wells for the water-quality data used are shown on plate 2. Additionally, municipal water wells, wastewater injection wells, aquifer storage and recovery wells, aquifer performance test wells, and Floridan aquifer system monitoring wells operated by the SFWMD and NRCS used in the study are shown in figure 2. Except for the monitoring wells, all the wells in figure 2 are described in table 1, grouped by site name. Wells CS-I1 and CS-M2, also used in the study, are located at the Coral Springs Wastewater Treatment Plant (WWTP) about 40 mi south of the study area and 11 mi west of the coast.

Depth in a well, as used in this report, refers to feet below the measuring point. In most cases, measuring point and land-surface altitudes coincide; however, in some instances, the measuring point lies above land-surface altitude. If measurement of a point in a well is referenced herein to NGVD of 1929, then the phrase "altitude, in feet below NGVD 1929" or simply "feet below NGVD of 1929" is used.

Some of the wells used in this study are located in close proximity to one another (fig. 2). For example, at most wastewater injection system sites, a monitoring well was drilled adjacent to an injection well. Monitoring well MW2-2 (M-1353) at the Stuart WWTP in Martin County is only 70 ft from injection well IW-2 (M-1352). Data collected from injection-monitoring well pairs and other wells drilled in close proximity at a site are treated herein as a single well control point. Thus, well M-1353 (shown in fig. 1) also represents well M-1352 (fig. 2).

Collection and Analyses of Water-Quality Data

A total of 73 water-quality samples were obtained from 50 wells and analyzed for major constituents and field characteristics. These constituents included calcium, magnesium, sodium, potassium, chloride, fluoride, sulfate, bromide, strontium, silica, and dissolved-solids concentration. Specific conductance, pH, water temperature, and alkalinity were measured in the field. Isotopic analyses for the strontium-87 to strontium-86 ratio ($^{87}Sr/^{86}Sr$), hydrogen-2 (deuterium or $^{2}H/^{1}H$), and oxygen-18 ($^{18}O/^{16}O$) were made for 56 samples, and isotopic analyses for carbon-13 ($^{13}C/^{12}C$) and carbon-14 (^{14}C) were made for 38 samples. Results from water-quality analyses were stored in the USGS water-quality database (QWDATA).

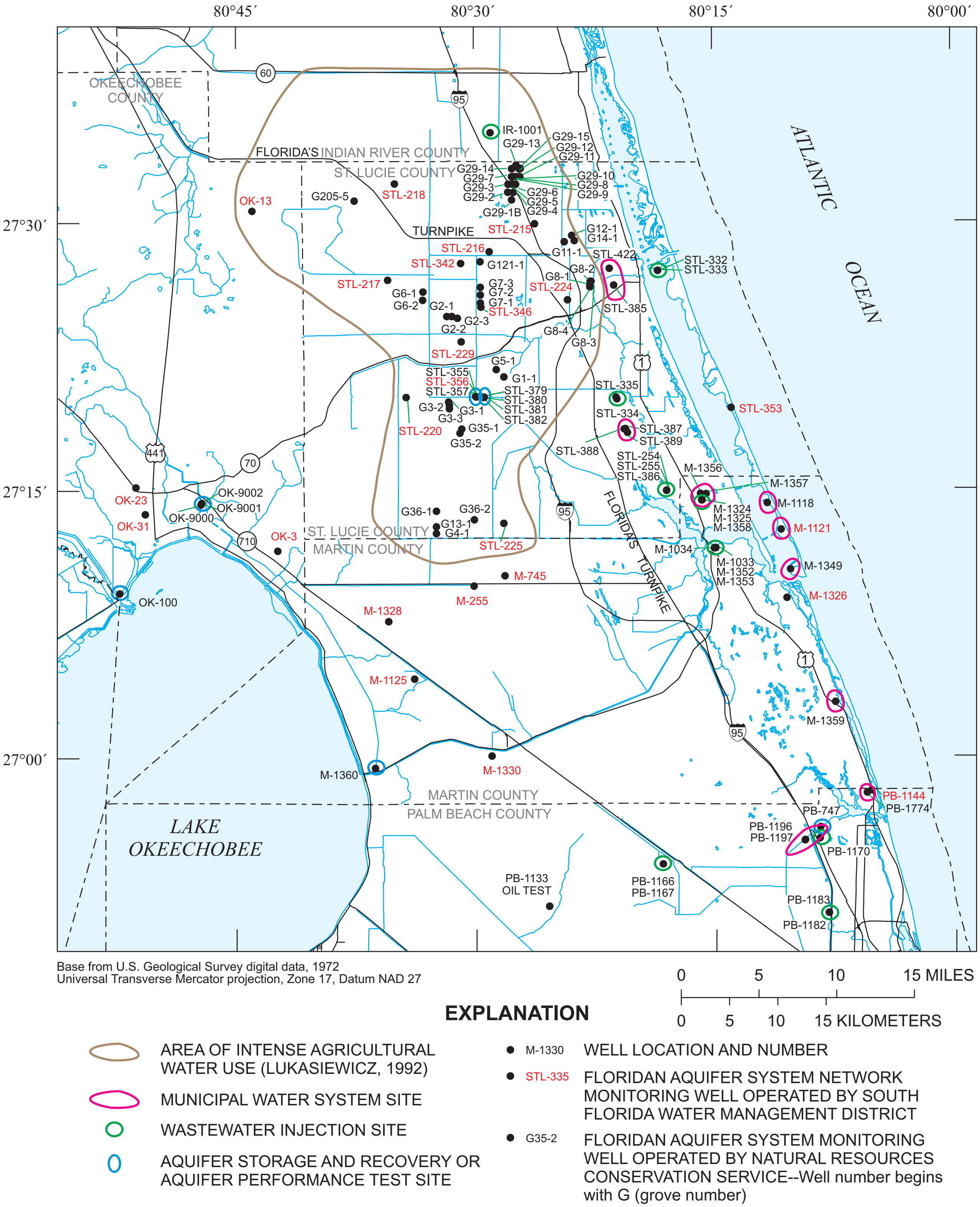


Figure 2. Location of municipal water system wells, wastewater injection wells, aquifer storage and recovery test wells, aquifer performance test wells, and Floridan aquifer system monitoring wells used in the study. Site names are given in table 1.

Table 1. Identification of wells used at municipal water system sites, wastewater injection sites, and aquifer storage and recovery and aquifer performance test sites in the study

[All wells are injection or production wells, unless otherwise noted, and are shown in figure 2. Site name: SFWMD, South Florida Water Management District; FDEP, Florida Department of Environmental Protection. Type of site: APT, aquifer performance test site; ASR, aquifer storage and recovery test site; B, water-supply well used for blending with freshwater; RO, reverse-osmosis municipal water site; WWI, wastewater injection site]

Site name	Type of site	Wells used in study
C-24 Canal (SFWMD)	APT	STL-379[1], STL-380, STL-381[1], STL-382[1]
Fort Pierce Utilities Authority	B	STL-385
Fort Pierce Utilities Authority	RO	STL-422
Fort Pierce Utilities Authority	WWI	STL-332[2], STL-333[3]
Hercules	WWI	IR-1001[2]
Joe's Point	RO	M-1118
Jupiter (FDEP)	ASR	PB-747
Jupiter Water Systems	RO	PB-1196[3], PB-1197
Kissimmee River at Lake Okeechobee (SFWMD)	ASR	OK-100 (test well)
Loxahatchee Environmental Control District	WWI	PB-1170[2,3]
North Martin County Utilities (Jensen Beach)	RO	M-1356, M-1357
North Martin County Utilities (Jensen Beach)	WWI	M-1324[2], M-1325[3], M-1358[2]
North Port St. Lucie Utilities	WWI	STL-334[2], STL-335[3]
Port Mayaca on the St. Lucie Canal (SFWMD)	ASR	M-1360 (test well)
Port St. Lucie Utilities	RO	STL-387[1], STL-388, STL-389
Pratt & Whitney	WWI	PB-1166[2], PB-1167[3]
Radnor	RO	M-1121
Sailfish Point	RO	M-1349
Seacoast Utilities (Palm Beach Gardens)	WWI	PB-1182[2], PB-1183[3]
South Martin Regional Utilities (Hobe Sound)	RO	M-1359
South Port St. Lucie Utilities	WWI	STL-254[2], STL-255[3], STL-386[1]
St. Lucie County (SFWMD)	ASR	STL-355[1], STL-356, STL-357[1]
Stuart	WWI	M-1033[1], M-1034[1,2] M-1352[2], M-1353[1]
Taylor Creek/Nubbin Slough (Lake Okeechobee)	ASR	OK-9000, OK-9001/OK-9002[3]
Tequesta	RO	PB-1774

[1]Single zone monitoring well.
[2]Injection well at wastewater injection site.
[3]Dual zone monitoring well.

Three of the samples were collected from two wells (CS-I1 and CS-M2) located outside the study area in an effort to evaluate an anomalous vertical distribution of salinity considered similar to the distribution in some wells along the coast in the study area.

Field analysis and sampling procedures followed are described by Wilde and Radtke (1998). No less than three well volumes were purged, and specific conductance was monitored to ensure stabilization prior to sampling. Some wells were flowing (left open by the owner) upon arrival at the site for sampling. Most sampled wells were under flowing artesian conditions, making pumping unnecessary. Water temperature was measured in a 2-gal bucket, usually filled rapidly to minimize sample warming or cooling. Sample bottles usually were filled using ¼-in. polyethylene tubing connected to a small wellhead valve separate from the large flow valve. Water samples collected for major ion analyses and $^{87}Sr/^{86}Sr$ were filtered using 0.45-µm Gelman capsule filters, and bottles collected for cation analysis were acidified with nitric acid. Field pH was measured using a flow-through chamber to avoid contact with the atmosphere during the first year of sampling (May to July 2000). During the second year of sampling (July and August 2001), water temperature, specific conductance, dissolved oxygen, and pH were monitored and measured during well purging in a flow cell attached to a water-quality multiprobe instrument. Dissolved oxygen also was checked for stability at a low level (less than 0.5 mg/L) before collecting samples. Alkalinity was measured in the field using the inflection point method by titration with sulfuric acid. Some wells lacked a well-head valve appropriate for sampling through tubing. For these samples, water was collected using a clean 5-gal bucket, and sample bottles were filled from the bucket using a peristaltic pump with silicon tubing.

For deuterium and oxygen-18 analyses, unfiltered samples were collected in glass bottles secured with polyseal cone caps; for isotopic analyses of carbon-13 and carbon-14, a 0.26-gal (1-liter) glass bottle with a septum top was filled with ¼-in. tubing coming from the well. The carbon isotope bottle was flushed (at least two bottle volumes) and filled from the bottom up with the end of the tubing inserted to the bottom of the bottle to prevent interaction with the atmosphere. Immediately after filling the carbon isotope bottle, a capsule of 50-percent ammonium hydroxide was added to fix (precipitate) inorganic carbon, and the bottle was sealed.

Major constituent analyses were performed at the USGS laboratory in Ocala, Fla. Analyses followed methods prescribed by Fishman and Friedman (1989). Charge-balance error for major ions for all samples did not exceed 3 percent, and many were less than 1 percent.

Strontium isotope ratios ($^{87}Sr/^{86}Sr$) were determined at a USGS research laboratory in Menlo Park, Calif., using solid-source mass spectrometry. The ratio of unfractionated strontium-88 (^{88}Sr) to ^{86}Sr, assumed to be 8.37521, is used as an internal standard to correct for stable isotope fractionation, and uncertainties are 2×10^{-5} (T. Bullen, U.S. Geological Survey, written commun., 2000).

The isotopic ratios of deuterium and oxygen-18 were determined at a USGS research laboratory in Reston, Va. Hydrogen isotope analyses were conducted at 30 °C using a hydrogen equilibration technique that measures deuterium activity (Coplen and others, 1991). Oxygen isotope analyses were performed using the carbon dioxide (CO_2) equilibration technique (at 25 °C) of Epstein and Mayeda (1953). Stable isotope ratios of hydrogen are reported relative to Vienna Standard Mean Ocean Water (VSMOW), as delta deuterium (δD) in per mil (parts per thousand), on a scale normalized such that δD = -428 per mil for Standard Light Antarctic Precipitation (SLAP). Stable isotope ratios of oxygen are reported relative to VSMOW, as delta oxygen-18 ($\delta^{18}O$) in per mil, on a scale normalized such that $\delta^{18}O$ = -55.5 per mil for SLAP. The uncertainties of hydrogen and oxygen isotopic analyses are 2 and 0.2 per mil, respectively.

Carbon isotope analyses of dissolved inorganic carbon in samples were performed by Beta Analytical, Inc., in Miami, Fla. Measured carbon-13 ratios ($\delta^{13}C$) were calculated relative to the Vienna Pee dee Belemnite (PDB) standard. Determination of carbon-14 (^{14}C) was by reduction of sample inorganic carbon to graphite and measurement in an accelerator mass spectrometer. The modern reference standard for this measurement was 95 percent of the carbon-14 content of the National Bureau of Standards' Oxalic Acid, and calculations were made using the Libby carbon-14 half life (5,568 years). Measurements of carbon-14 were reported in unnormalized fraction modern carbon and apparent carbon-14 age (years before present with "present" representing A.D. 1950). Analytical error reported by Beta Analytical, Inc., ranged from 0.05 to 0.1 percent modern carbon (PMC) for carbon-14 results and 0.1 per mil for $\delta^{13}C$ results.

Quality Assurance Samples

Two quality assurance blank samples were collected: a blank water sample and an equipment blank. The blank water sample was deionized water poured directly into sample bottles from the deionized water container used to rinse equipment in the field. For the equipment blank, deionized water was pumped through field equipment in contact with the sample (5-gal sample bucket, silicone tubing, a metal threaded fitting used to attach to wells on the end of the tubing, and filter). Analyses of these blank samples for major constituents resulted in virtually all measurements being below the detection limit; the exception being magnesium for the equipment blank, which had a value of 0.002 mg/L. Isotopic analyses of these samples were not conducted, and additional samples for quality assurance of isotopic analyses were not collected.

GEOLOGIC FRAMEWORK

The Floridan aquifer system in southern Florida includes, in ascending order from oldest to youngest, the following geologic units: upper part of the Cedar Keys Formation of Paleocene age, Oldsmar Formation of early Eocene age, Avon Park Formation of middle Eocene age, Ocala Limestone of late Eocene age, and Suwannee Limestone of early Oligocene age (Miller, 1986). The Hawthorn Group overlies the Suwannee Limestone and contains the older Arcadia Formation and the younger Peace River Formation (Scott, 1988). A basal part of the Hawthorn Group also is included in the Floridan aquifer system in this study (fig. 3).

Delineation of the geologic units in the study area began with selected wells in which the boundaries of units were already known based on geophysical logs and lithologic sample descriptions. The gamma-ray log was used to extend these boundaries by correlating between wells; five east-west hydrogeologic sections (figs. 4-8) were constructed to assist in this delineation. Lithologic descriptions, if available, also were used to help determine boundaries. Boundaries were determined for 112 wells (all of which had a gamma-ray log available) in the study area (pl. 1 and app. II). Data presented on the sections for each well include a gamma-ray log curve and lithologic column, if a lithologic description was available.

Geologic Units and Lithology

The Cedar Keys Formation includes dolomite, dolomitic limestone, and anhydrite. The anhydrite is present as thick, massive beds in the lower part of the formation. The Oldsmar Formation consists of micritic limestone and dolomite and is about 1,000 to 1,300 ft thick in the study area (Miller, 1986, pl. 5). The lower 300- to 500-ft section of the Oldsmar Formation, locally called the “Boulder zone” (fig. 3), is predominantly dolomite and contains massively bedded, cavernous or fractured dolomite of high permeability. Zones of similar lithology also can be present in the upper part of the Oldsmar Formation.

The Avon Park Formation consists of micritic to fossiliferous limestone, dolomitic limestone, and dolostone or dolomite (fig. 3). Fine- to medium-grained calcarenite that is moderately to well sorted is present in places. Foraminifera characteristic of the Avon Park Formation are cone-shaped *Dictyoconus* sp. (Duncan and others, 1994). The top of the Avon Park Formation is marked in some places by light-brown, finely crystalline to fossiliferous dolomitic limestone or dolomite thinly interbedded with limestone. A thick interval containing mostly dolomite, but commonly interbedded with limestone, is commonly present in the middle to lower part of the Avon Park Formation.

The Ocala Limestone consists of micritic or chalky limestone, calcarenitic limestone, and coquinoid limestone. The limestone is characterized by abundant large benthic foraminifera, such as *Operculinoides* sp., *Camerina* sp., and *Lepidocyclina* sp. (Peacock, 1983). The presence of these foraminifera aids in distinguishing the Ocala Limestone from the overlying Suwannee Limestone, where present, and the underlying Avon Park Formation.

The Suwannee Limestone of Oligocene age has been interpreted by some investigators to be absent in the study area (Mooney, 1980; Shaw and Trost, 1984; Miller, 1986), whereas others (Lichtler, 1960; Schiner and others, 1988; Lukasiewicz, 1992) have mapped this geologic unit in Martin, St. Lucie, and adjacent counties. The Suwannee Limestone in southwestern Florida predominantly consists of pale-orange to tan, fossiliferous, medium-grained calcarenite with minor amounts of quartz sand and rare-to-absent phosphate mineral grains. Mooney (1980) describes the limestone interval, known as the Suwannee Limestone by others in the study area, as a gray, sandy, calcilutite with minor phosphorite and suggests that this interval may be a basal unit of the Hawthorn Group; however, Mooney (1980) calls it the unnamed limestone unit. Shaw and Trost (1984) place this unit within the Hawthorn Group, at its base, in the eastern part of the study area, and Reese and Memberg (2000) include it in the lower part of the “basal Hawthorn unit.” Based on analysis of a continuous core in Indian River County, this unit is referred to as the “unnamed limestone of early Oligocene age” (Weedman and others, 1995).

Microfossil evidence based on description of drill cuttings that supports facies changes and interfingering between Eocene and Oligocene-aged formations was found in southern Florida (Winston, 1993; 1995). This evidence contradicts the idea that upper boundaries of the Avon Park Formation and Ocala Limestone are represented by an unconformity with deposition of the unit restricted to a certain period of time, such as the Avon Park Formation of middle Eocene age (Miller, 1986, pl. 2).

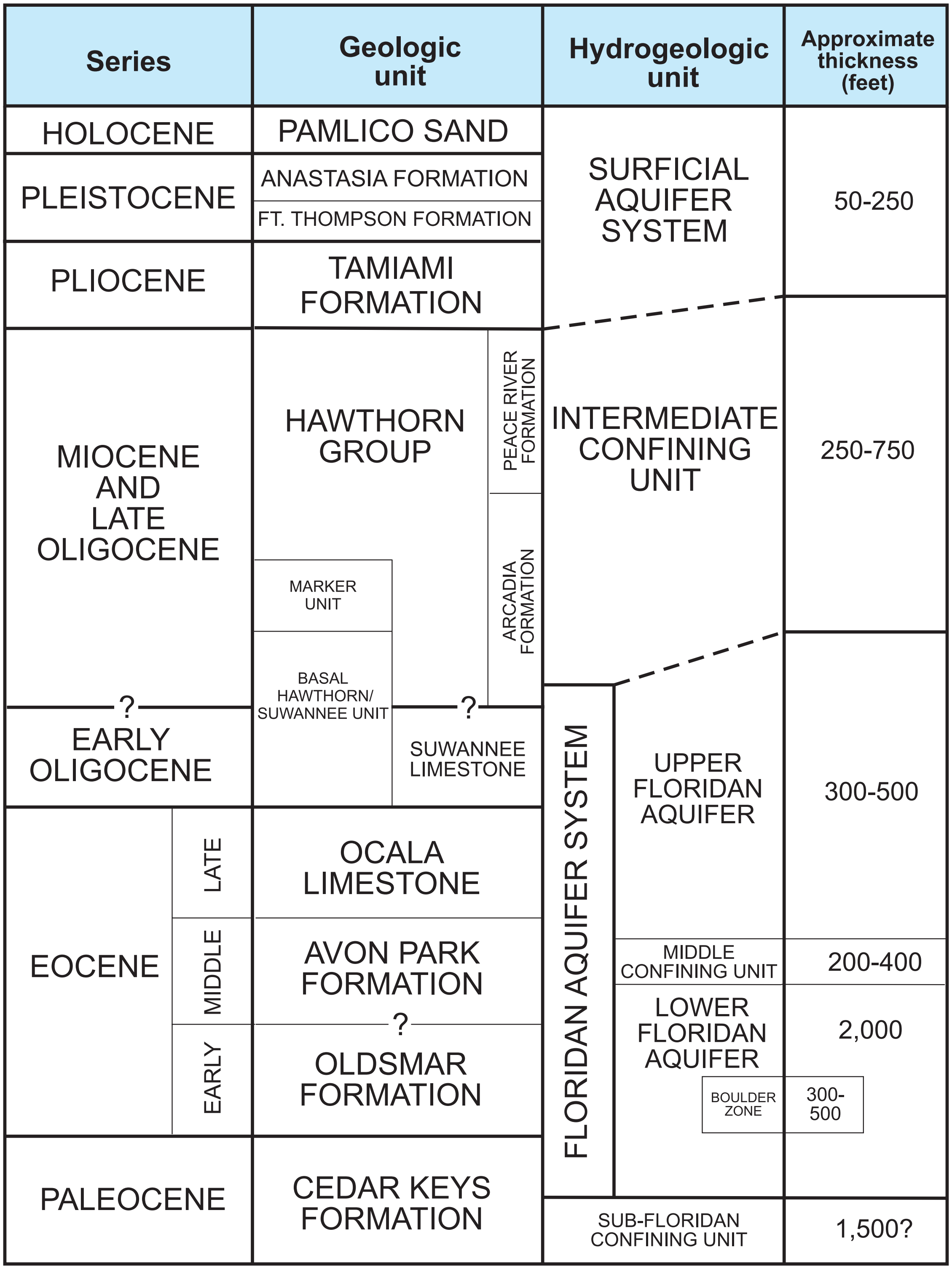


Figure 3. Generalized geology and hydrogeology in Martin and St. Lucie Counties as defined for this study.

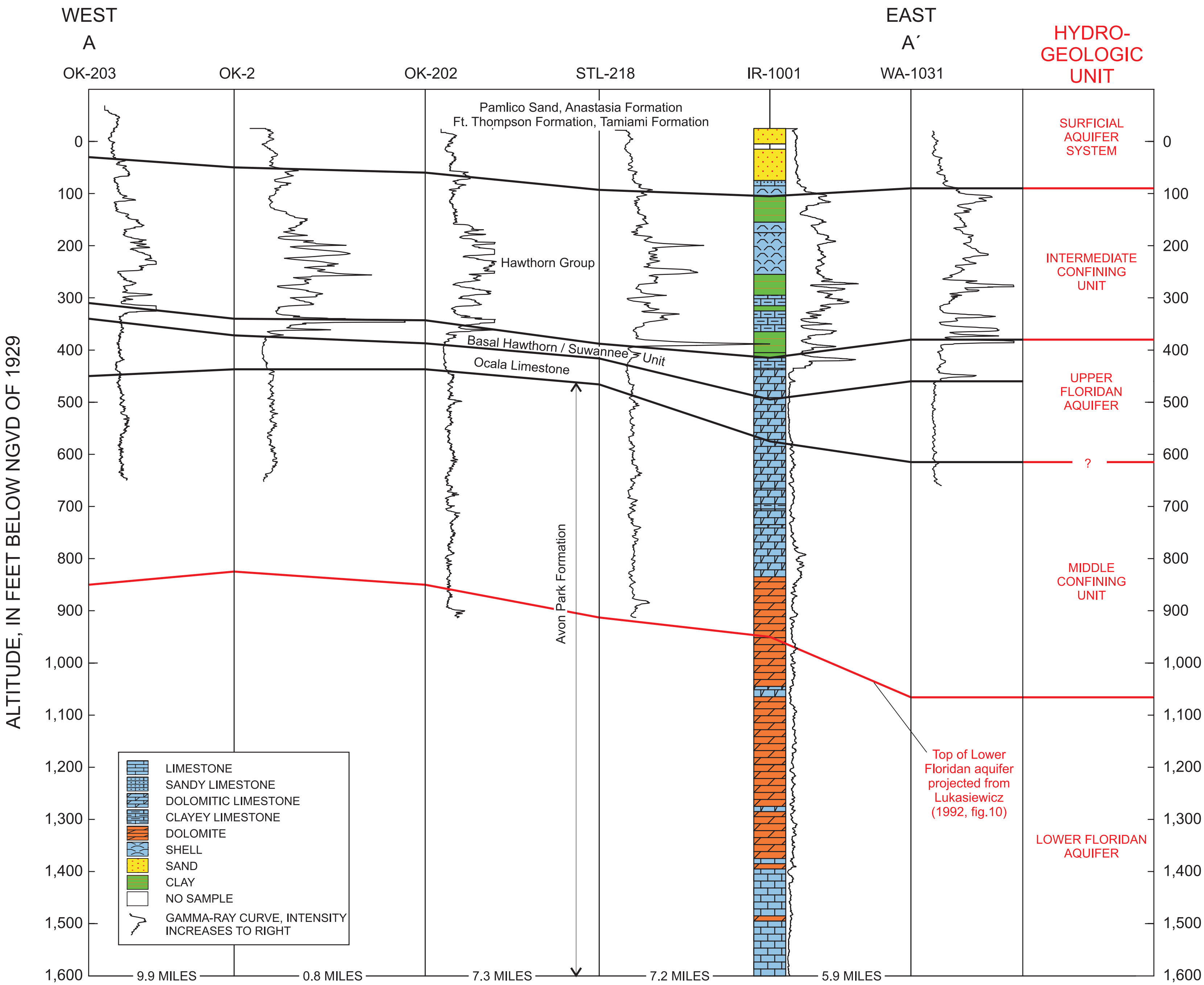


Figure 4. East-west hydrogeologic section A-A′. See figure 1 for trace of section. NGVD of 1929 is National Geodetic Vertical Datum of 1929.

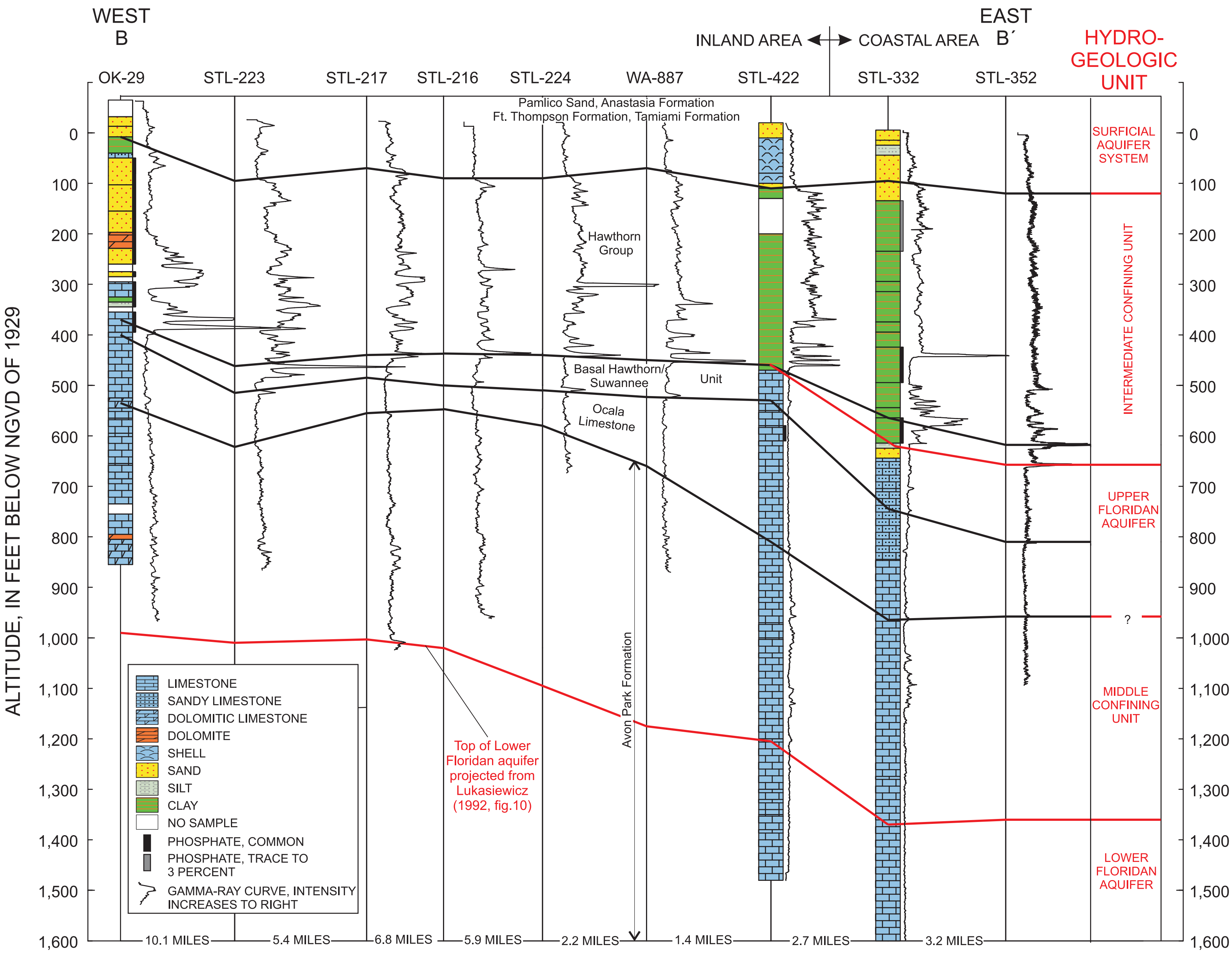


Figure 5. East-west hydrogeologic section B-B′. See figure 1 for trace of section. NGVD of 1929 is National Geodetic Vertical Datum of 1929.

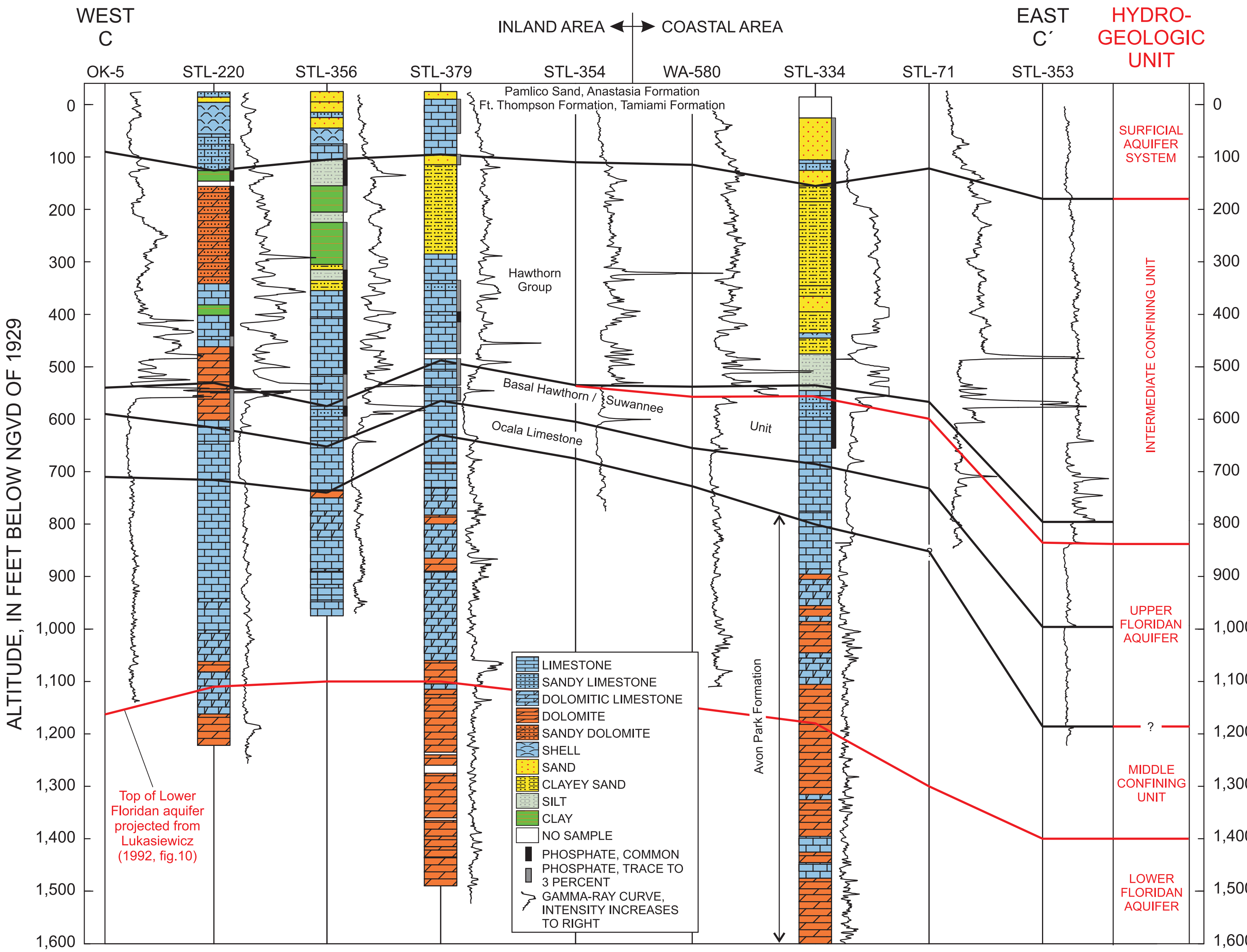


Figure 6. East-west hydrogeologic section C-C′. See figure 1 for trace of section. NGVD of 1929 is National Geodetic Vertical Datum of 1929.

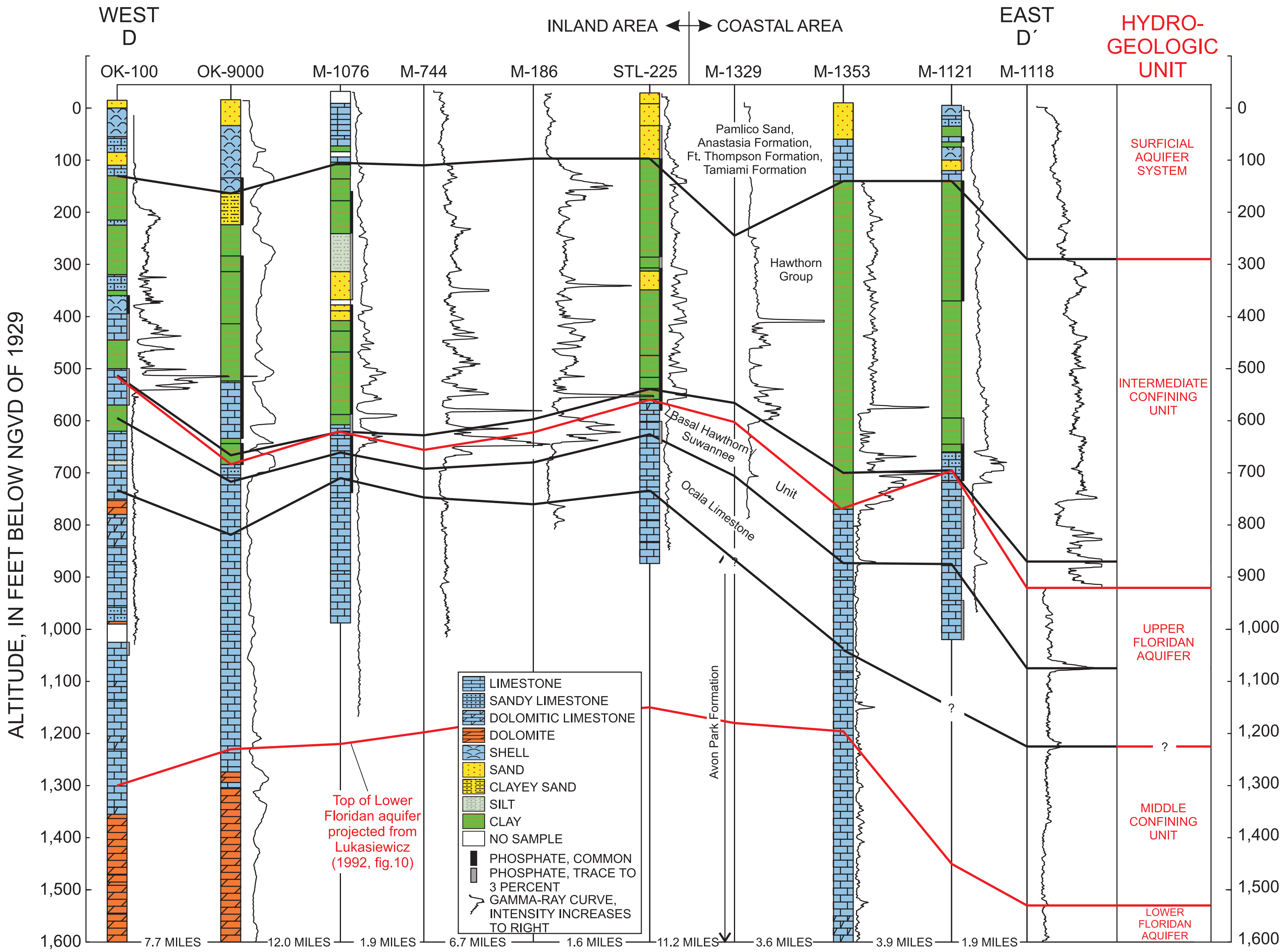


Figure 7. East-west hydrogeologic section D-D′. See figure 1 for trace of section. NGVD of 1929 is National Geodetic Vertical Datum of 1929.

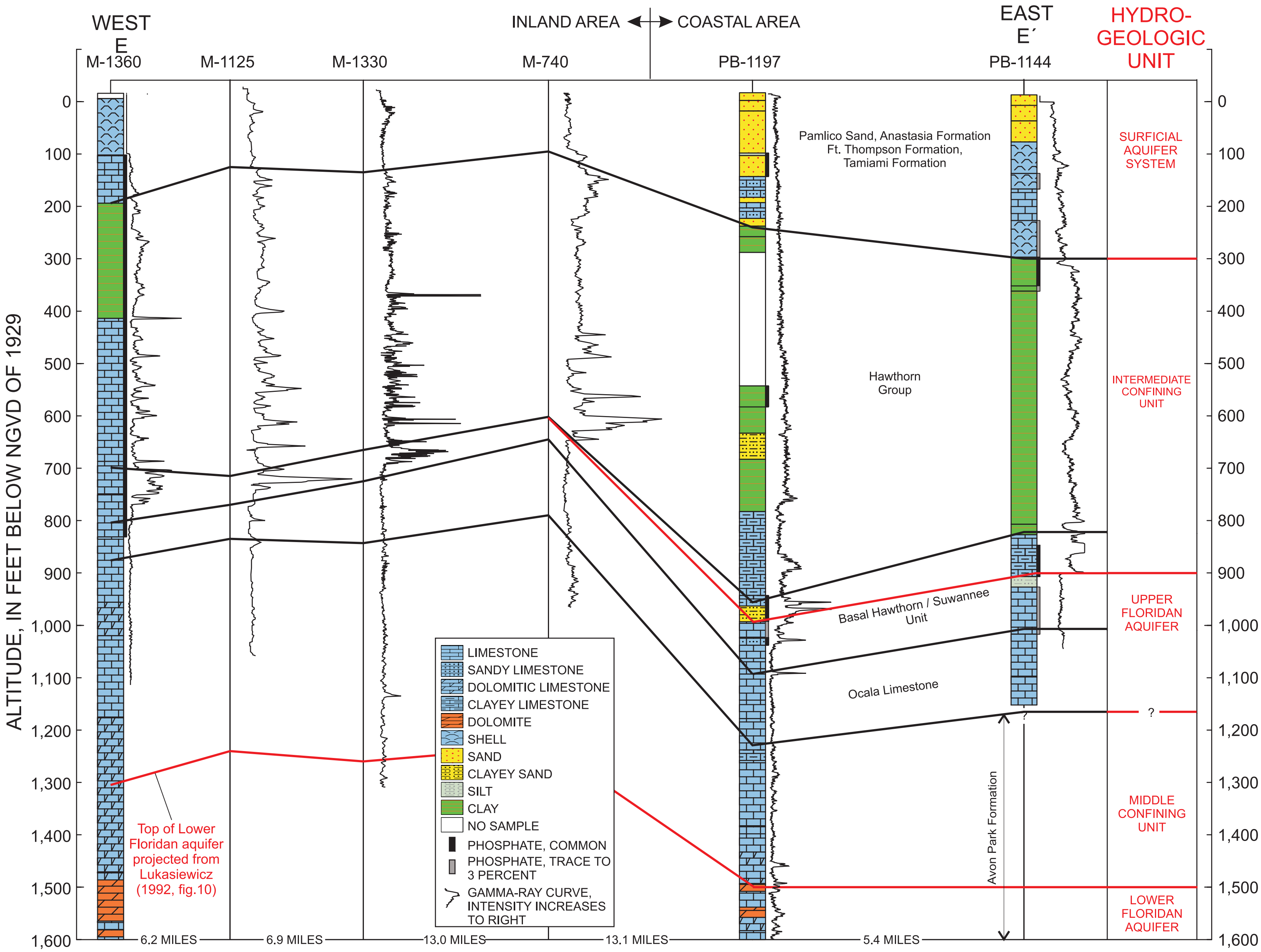


Figure 8. East-west hydrogeologic section E-E′. See figure 1 for trace of section. NGVD of 1929 is National Geodetic Vertical Datum of 1929.

The Hawthorn Group consists of an interbedded sequence of widely varying lithologies and components that includes limestone, dolomite, dolosilt, shell, quartz sand, clay, abundant phosphate grains, and mixtures of these materials. The characteristics that distinguish the Hawthorn Group from underlying units are high and variable siliciclastic and phosphatic content; color, which can be green, olive-gray, or light gray; and gamma-ray log response. Intervals high in phosphate sand or gravel (as thick as 30 ft) are present and have high gamma-ray activity, with peaks of 100 to 200 American Petroleum Institute (API) standard units or more.

This study follows the geologic terminology similar to that proposed by Reese and Memberg (2000); a basal unit is defined as that which underlies a Hawthorn Group marker unit and overlies Eocene-aged limestone. This basal unit is referred to herein as the basal Hawthorn/Suwannee unit (fig. 3). In Reese and Memberg (2000), this unit is referred to as the "basal Hawthorn unit." Gamma-ray log responses indicate that the basal Hawthorn/Suwannee unit can commonly be divided into two intervals. A lower interval has gamma-ray activity similar to, but slightly higher than, the low activity in the underlying Ocala Limestone, and an upper interval has high gamma-ray activity (figs. 4-8). Generally, the lower interval is predominantly limestone, whereas the upper interval includes more clay, silt, sand, and phosphate grains; however, the contact between these two intervals commonly is gradational. The basal Hawthorn/Suwannee unit was defined and mapped in this study because of some similar lithologic characteristics throughout the unit, and because its boundaries can usually be determined with a gamma-ray log. The lower predominantly limestone interval of this unit, near the coast where it thickens and may contain only minor to trace amounts of phosphate grains, could be equivalent to the Suwannee Limestone. An example of this limestone interval is the interval from about 1,050 to 1,110 ft below land surface in well PB-1197 (fig. 9).

The marker unit that overlies the basal Hawthorn/Suwannee unit (fig. 9) is present throughout the study area and correlates with a marker unit west of the study area in Lee, Hendry, and Collier Counties (Reese, 2000) and south in Palm Beach County (Reese and Memberg, 2000). The thickness and characteristic pattern of the marker unit shown by gamma-ray logs remain consistent over large parts of the study area (figs. 4-9). The marker unit commonly consists of micritic limestone, marl, or clay with minor to trace amounts of phosphate grains.

Geologic units that overlie the Hawthorn Group include the Tamiami Formation of Pliocene age, the Fort Thompson Formation and Anastasia Formation of Pleistocene age, and Pamlico Sand of Holocene age (fig. 3). These units or facies within them tend to be discontinuous and difficult to correlate across the study area (Lukasiewicz, 1992).

Structure

Anomalous linear structures (faults, folding, or karst-related dissolution and subsidence) have been mapped by previous workers in the Floridan aquifer system or deeper in the study area (Bermes, 1958; Lichtler, 1960; Barnett, 1975; Black, Crow and Eidsness, Inc., 1975; Schiner and others, 1988; Lukasiewicz, 1992; and Winston, 1995). Most structural features are parallel or subparallel to the coast (fig. 10). The feature mapped by Barnett (1975), however, trends more northwesterly, from northeastern Palm Beach County through western St. Lucie County, and has been interpreted to be a normal fault downthrown to the southwest and part of a network of deep-seated basement faults in peninsular Florida.

A structural feature, mapped by Lukasiewicz (1992), extends along the coast between the mainland and the barrier island chain in St. Lucie and northeastern Martin Counties and was identified on the basis of structure, permeability contrasts across the feature, and study of cores and geophysical logs (fig. 10). The extension of this feature to the north coincides with a feature in Indian River County mapped as a fault by Schiner and others (1988). Mapping of the top of the Floridan aquifer system in Indian River County shows as much as 350 ft of offset, downthrown to the east, along this feature (Schiner and others, 1988). Considerable thickening of the Suwannee Limestone on the downthrown side also is indicated. However, marine seismic profiling of this feature in Indian River County exhibits no obvious displacement of reflectors across it in the section from the upper Avon Park Formation and Ocala Limestone and above. This feature is attributed either to (1) karst-related dissolution and subsidence within the limestone units (without regional faulting), or (2) the presence of a deep-seated fault below the depth of resolution of the seismic profiles (Flocks and others, 2001). Likewise, other linear structures previously mapped as faults or inferred faults in the study area (fig. 10) may not be faults, at least not at the stratigraphic level of the Upper Floridan aquifer and higher.

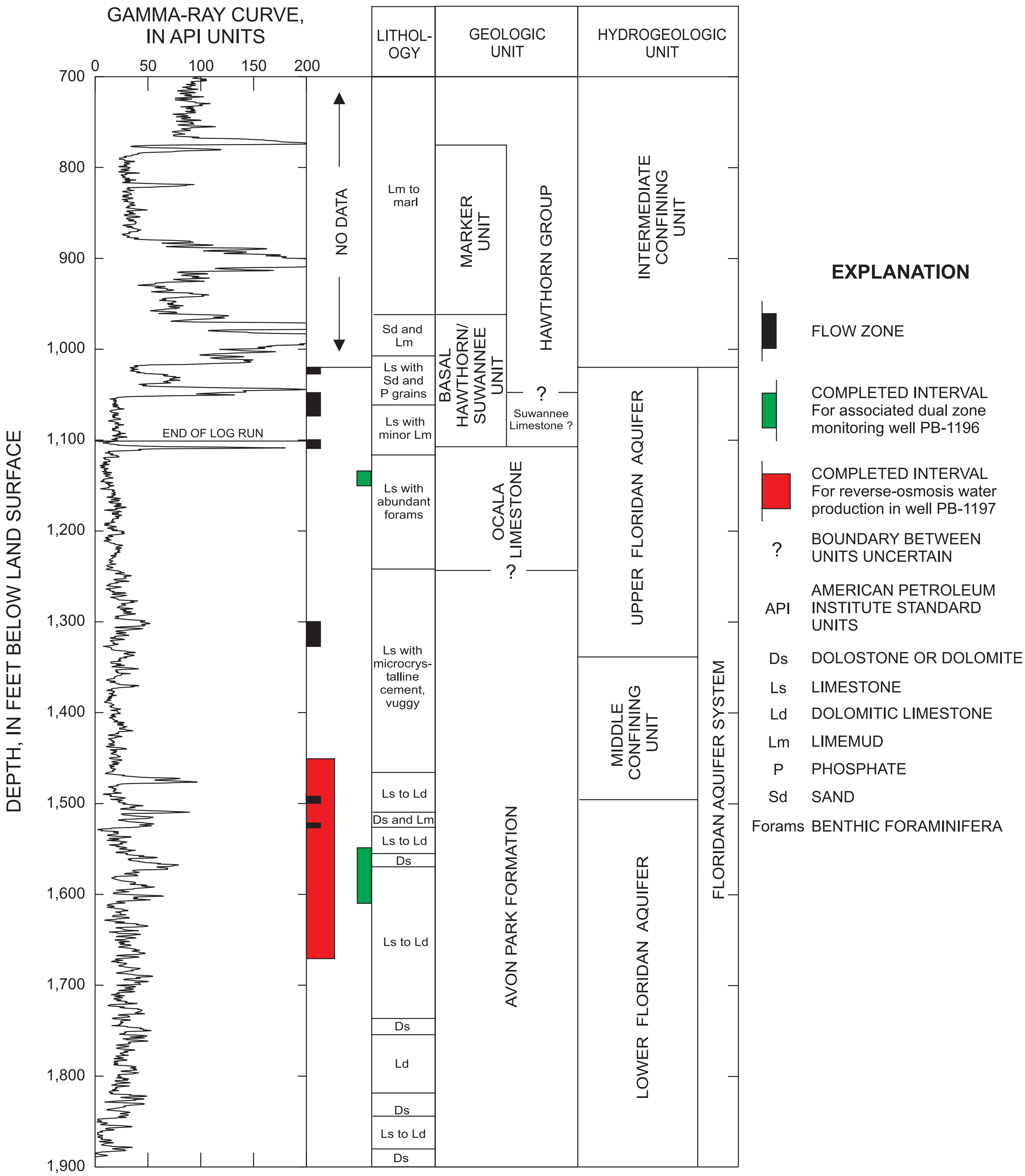


Figure 9. Gamma-ray geophysical log, flow zones, stratigraphy, and hydrogeologic units for well PB-1197 in northeastern Palm Beach County. Flow zones determined from flowmeter and temperature logs and flow measurements while drilling. Well is in the Jupiter water systems Florida aquifer system reverse osmosis well field (fig. 2). Also shows completed intervals for associated monitoring well PB-1196.

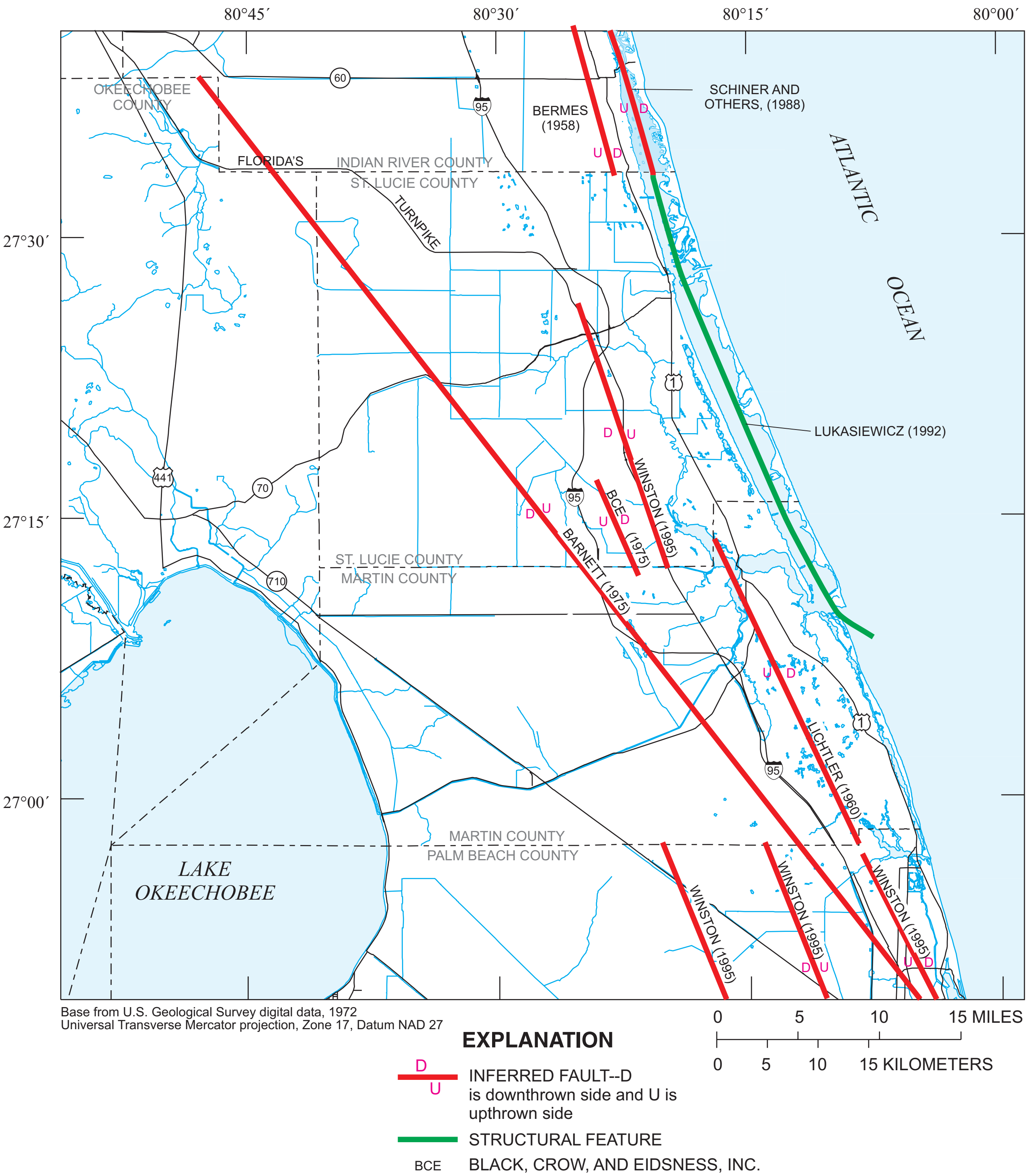


Figure 10. Anomalous linear structures in the study area mapped in previous studies.

The top of the basal Hawthorn/Suwannee unit ranges from as shallow as 310 ft below NGVD of 1929 in the northwestern part of the study area to as deep as 956 ft below NGVD of 1929 in northeastern Palm Beach County (fig. 11). Salient features are a structural high area in central St. Lucie County (where altitude is as high as 408 ft below NGVD of 1929) and low areas along the coast. In places, the top deepens abruptly by 100 to 200 ft between the mainland and the barrier island. Additionally, in south-central St. Lucie County, a southeast-trending trough was mapped, although the top is below the 600-ft contour that defines the trough in only two wells. Abrupt relief along the northern side of this trough is indicated by wells STL-355, STL-356, STL- 379 and WA-1192. The top is deeper in STL-355 than WA-1192 by more than 100 ft over a distance of less than 0.5 mi. This trough roughly coincides in position and trend with the northwest-trending basement fault mapped by Barnett (1975) (fig. 10), and it may have resulted, at least in part, from faulting. An alternate interpretation, however, is that the two wells having altitudes for the top below 600 ft are located in small localized depressions formed by karst-related dissolution and subsidence. Several circular depressions are present on top of the Ocala Limestone based on detailed mapping in northeastern Florida, and these depressions probably are ancient sinkholes caused by dissolution and collapse at depth (Spechler, 1994).

The thickness of the basal Hawthorn/Suwannee unit ranges from 15 ft (well STL-360) in southwestern St. Lucie County to as much as 310 ft (well PB-652) in extreme northeastern Palm Beach County (fig. 12). In the high area on top of the basal Hawthorn/Suwannee unit in central St. Lucie County, the thickness is about 50 to 60 ft. The thickness, however, is more than 100 ft in the eastern part of the study area near the coast. The beginning of this eastward thickening is shown on hydrogeologic section C-C′ (fig. 6) between wells STL-354 and WA-580. The unit does not thicken substantially across the area of abrupt relief along the northern side of the southeast-trending trough on top of the basal Hawthorn/Suwannee unit in south-central St. Lucie County described above.

The 100-ft line of equal thickness that runs subparallel to the coast (fig. 12) marks the beginning of eastward thickening and is used in this report to divide the study area into inland and coastal geographic areas. As described later, this demarcation of the study area tends to coincide with changes in water quality and possible separate flow regimes in the Floridan aquifer system. The coastal area is subdivided further into northern and southern parts, with the southern part representing the area south of the St. Lucie River in eastern Martin and northeastern Palm Beach Counties. The boundary between inland and coastal areas also is shown on four of the hydrogeologic sections (figs. 5-8). The entire extent of hydrogeologic section A-A′ (fig. 4) is in the inland area.

The altitude of the upper surface of the Ocala Limestone (fig. 13) exhibits features similar to the top of the basal Hawthorn/Suwannee unit (fig. 11). The southeast-trending trough in south-central St. Lucie County inferred in figure 11 also is apparent in figure 13. Some eastward thickening of the Ocala Limestone in the vicinity of the 100-ft-thickness contour for the basal Hawthorn/Suwannee unit (fig. 12) also is indicated by the hydrogeologic sections (figs. 4-8).

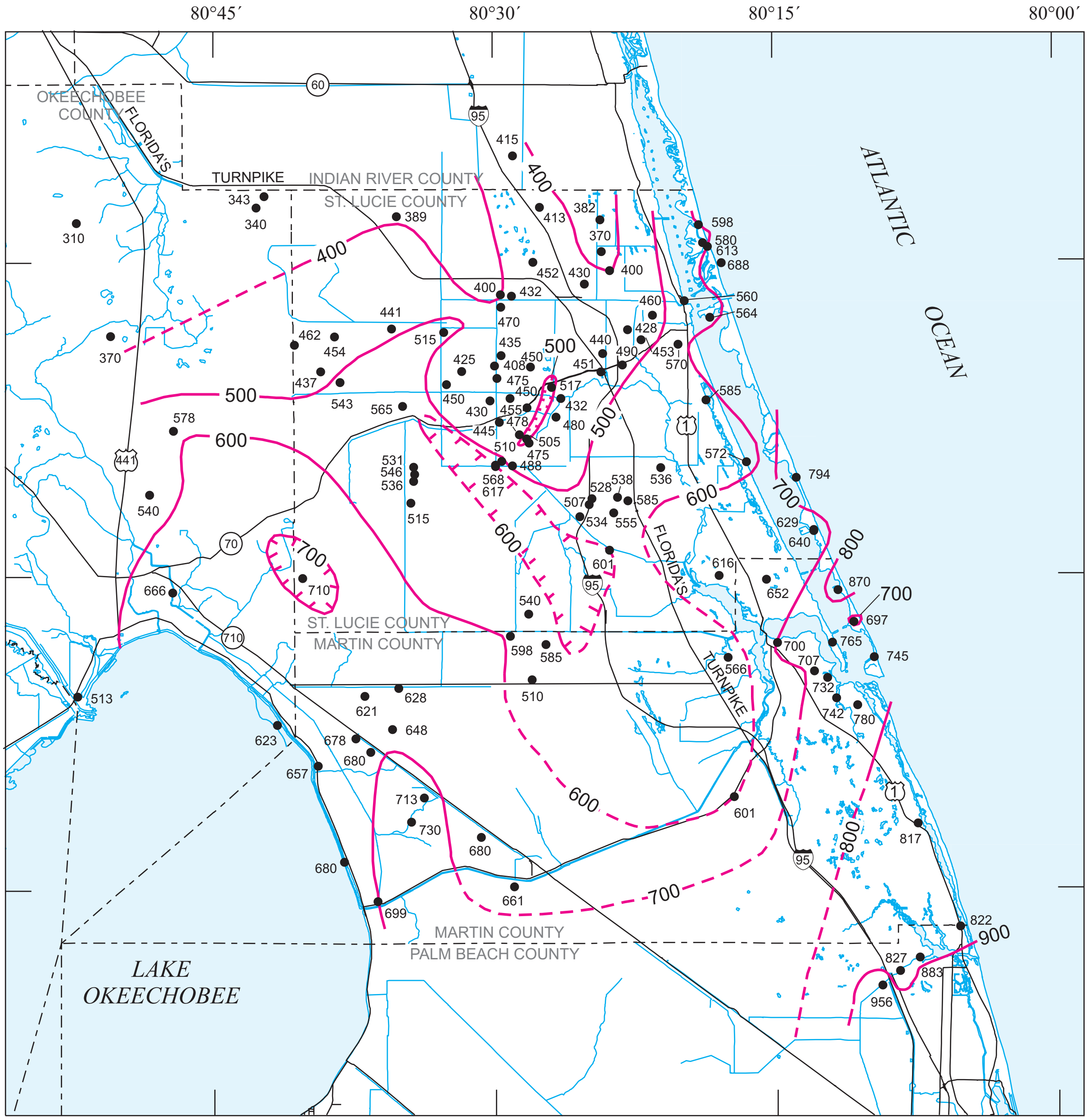
HYDROGEOLOGY

The principal water-bearing units in the study area are the surficial and the Floridan aquifer systems (fig. 3). The two aquifer systems are separated by the intermediate confining unit, which contains sediments of lower permeability. The Floridan aquifer system has two major water-bearing zones, the Upper and Lower Floridan aquifers, which are separated by a less permeable middle confining unit. The base of the Floridan aquifer system is marked by impermeable, massive anhydrite beds of the Cedar Keys Formation.

Surficial Aquifer System

The thickness of the surficial aquifer system varies from less than 50 ft to greater than 250 ft in the study area (Brown and Reece, 1979). The aquifer system consists of quartz sand, silts, clay, shell beds, coquina, calcareous sandstone, and sandy, shelly limestone. The base of the aquifer system commonly is defined where sediments grade from sand into clayey sand or clay; however, basal sediments also can consist of limestone as shown in figure 6.

The surficial aquifer system provides most of the potable water used in the study area (Lukasiewicz, 1992). It is unconfined and receives recharge from rainfall, canals, lakes, reservoirs, irrigation water, and probably some upward leakage from the Floridan aquifer system.



Base from U.S. Geological Survey digital data, 1972
Universal Transverse Mercator projection, Zone 17, Datum NAD 27

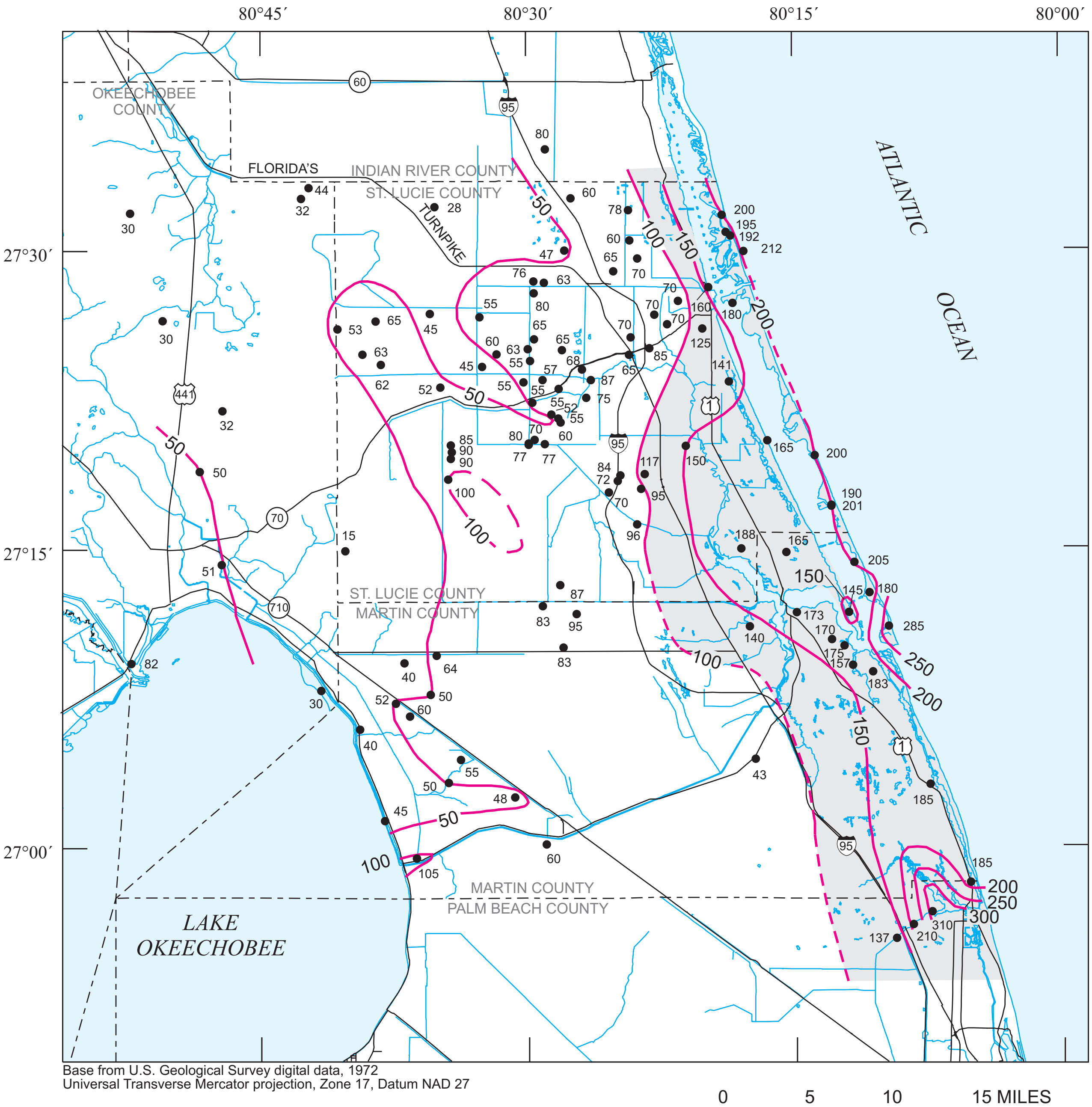
0 5 10 15 MILES
0 5 10 15 KILOMETERS

EXPLANATION

600 — LINE OF EQUAL ALTITUDE OF THE TOP OF THE BASAL HAWTHORN/SUWANNEE UNIT--In feet below NGVD of 1929. Hachures indicate depression. Contour interval is 100 feet. Dashed where approximately located

• 661 WELL LOCATION AND ALTITUDE--Number is altitude of the top of the basal Hawthorn/Suwannee unit, in feet below NGVD of 1929. See plate 1 for local well number

Figure 11. Altitude of the top of the basal Hawthorn/Suwannee unit. NGVD of 1929 is National Geodetic Vertical Datum of 1929.



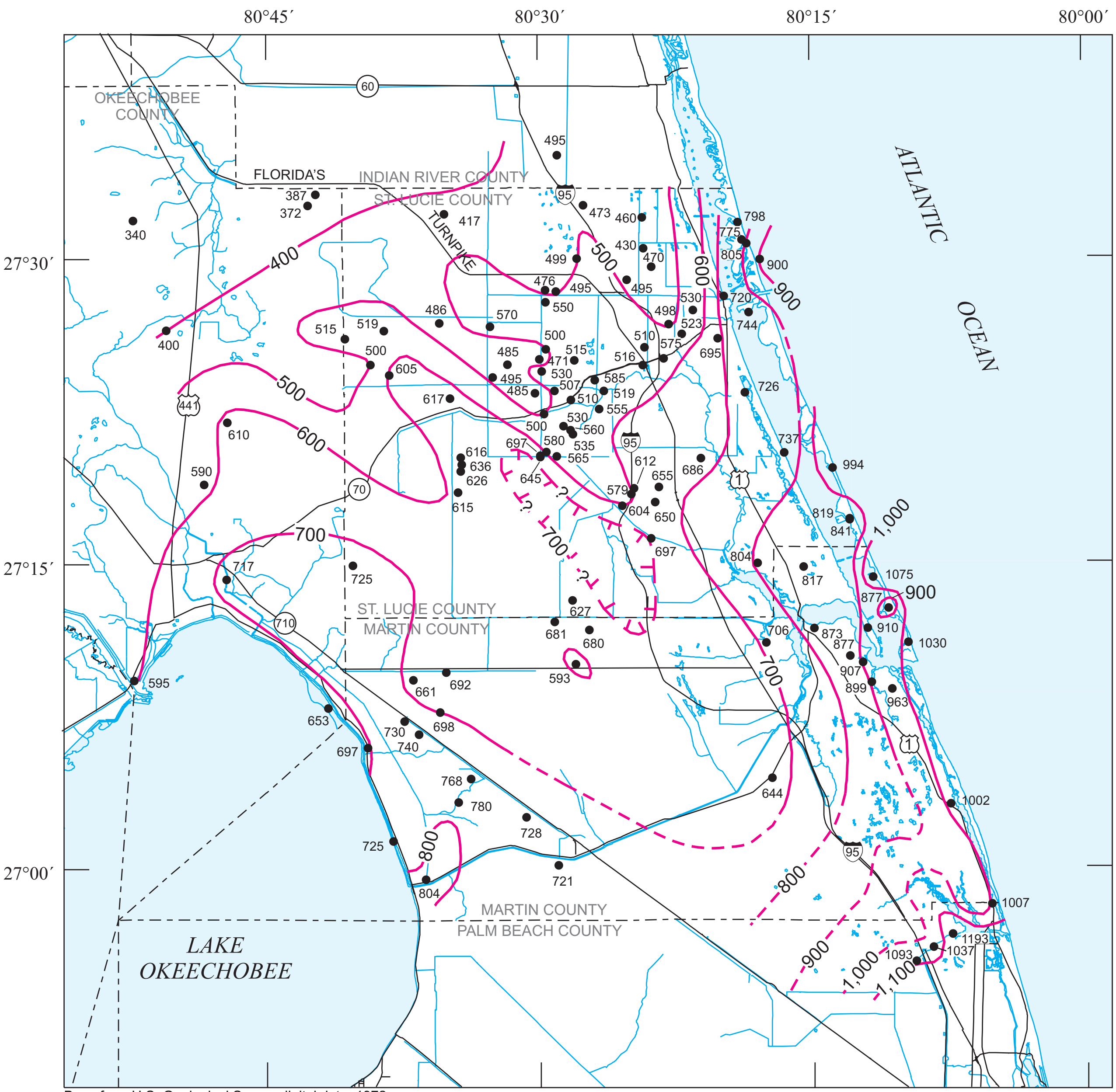
EXPLANATION

COASTAL AREA--Based on 100-foot-thickness contour. Remainder is inland area.

150 LINE OF EQUAL THICKNESS OF BASAL HAWTHORN/SUWANNEE UNIT--Contour interval is 50 feet. Dashed where approximately located

• 60 WELL LOCATION AND THICKNESS--Number is thickness of basal Hawthorn/Suwannee unit, in feet. See plate 1 for local well number

Figure 12. Thickness of the basal Hawthorn/Suwannee unit.



Base from U.S. Geological Survey digital data, 1972
Universal Transverse Mercator projection, Zone 17, Datum NAD 27

0 5 10 15 MILES

0 5 10 15 KILOMETERS

EXPLANATION

— 600 — LINE OF EQUAL ALTITUDE ON THE TOP OF THE OCALA LIMESTONE--In feet below NGVD of 1929. Dashed where approximately located. Hachures indicate depression. Contour interval is 100 feet

● 721 WELL LOCATION AND ALTITUDE--Number is altitude of the top of the Ocala Limestone, in feet below NGVD of 1929. See plate 1 for local well number

Figure 13. Altitude of the top of the Ocala Limestone. NGVD of 1929 is National Geodetic Vertical Datum of 1929.

Intermediate Confining Unit

The intermediate confining unit extends from the base of the surficial aquifer system to the top of the Floridan aquifer system (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986). The top of the confining unit is commonly equivalent to the top of the Hawthorn Group, but can extend into the overlying Tamiami Formation (fig. 3). The lithology of the confining unit is variable and includes fine-grained sediments, such as clay, marl, micritic limestone, and silt, which provide good confinement. The upper contact of the intermediate confining unit ranges from less than 80 ft below NGVD of 1929 in the extreme northwestern part of the study area (northeastern Okeechobee and northwestern St. Lucie Counties) to greater than 200 ft below NGVD of 1929 in extreme southeastern Martin and northeastern Palm Beach Counties (Lukasiewicz, 1992). The minimum and maximum thicknesses of the unit occur in these same areas, being 250 and 750 ft, respectively, and its thickness is 400 to 500 ft in about one-half of Martin and St. Lucie Counties. Permeable water-bearing zones within this unit are not known to exist.

Floridan Aquifer System

The Floridan aquifer system is defined as a vertically continuous sequence of permeable carbonate rocks of Tertiary age that are hydraulically connected in varying degrees, and whose permeability is generally several orders of magnitude greater than that of the rocks bounding the system above and below (Miller, 1986). The Floridan aquifer system in southern Florida predominantly consists of limestone with dolomitic limestone and dolomite common in its lower part (figs. 4-8). This section presents a description of the Floridan aquifer system in the study area, its component aquifers and confining units, and their relation to stratigraphic units.

Upper Floridan Aquifer

In general, the Upper Floridan aquifer is delineated herein on the basis of permeability characteristics, and thus, neither the top nor the base of the Upper Floridan aquifer necessarily conforms to formation or time-stratigraphic boundaries. Ground water occurs under flowing artesian conditions, except in some western parts of the study area where it underlies the Osceola Plain (fig. 1; Bradner, 1994). The top of the Upper Floridan aquifer approximately coincides with the top of the basal Hawthorn/Suwannee unit (fig. 11), except in the coastal area where it lies within this unit at the base of a section with high clay and phosphate grain content (figs. 4-9). The top of the aquifer is as much as 80 ft below the top of the basal Hawthorn/Suwannee unit in the coastal area (fig. 8, well PB-1144). The base of the aquifer can be approximated using the base of the Ocala Limestone (figs. 4-8); however, depending on the occurrence of flow zones, this boundary can occur within the upper part of the Avon Park Formation. The thickness of the Upper Floridan aquifer in the study area is about 500 ft (Lukasiewicz, 1992). Nevertheless, based on only the combined thickness of the basal Hawthorn/Suwannee unit and Ocala Limestone (figs. 4-8), the thickness of the aquifer could be considerably less. The combined thickness of these two units is as low as about 100 ft.

The Upper Floridan aquifer comprises several thin flow zones of high permeability interlayered with thicker zones of lower permeability. Flow zones can be defined in a borehole through utilization of flowmeter, water temperature, and caliper logs. Some of these zones in the Upper Floridan aquifer are areally extensive and seem to coincide with formation boundaries. Three to four producing zones in the Upper Floridan aquifer in the study area were mapped by Brown and Reece (1979). Two areally extensive and mappable flow zones are present at the base of the Suwannee Limestone and Ocala Limestone, respectively (Brown and Reece, 1979; Lukasiewicz, 1992).

The shallowest flow zone of the Upper Floridan aquifer is 90 ft above the base of the basal Hawthorn/Suwannee unit in well PB-1197 in northeastern Palm Beach County, and the top of the Upper Floridan aquifer coincides with the top of this flow zone (fig. 9, 1,020 ft below land surface). The base of the Upper Floridan aquifer is placed at 1,330 ft deep in well PB-1197 near the base of a flow zone.

Transmissivity of the Upper Floridan aquifer was previously mapped in the study area using aquifer performance and specific capacity tests (Lukasiewicz, 1992). Transmissivity varies from 7,000 to greater than 70,000 ft^2/d. A large area with high transmissivity (50,000 to 70,000 ft^2/d) is in northwestern St. Lucie County; the coastal area has transmissivities less than 13,000 ft^2/d.

Middle Confining Unit

The middle confining unit of the Floridan aquifer system lies within the upper part of the Avon Park Formation and principally consists of micritic to fine-grained, fossiliferous limestone of low permeability (fig. 3). Its semiconfining nature in southern Florida is based on aquifer tests conducted within the Upper Floridan aquifer, which often indicate substantial upward leakage (Reese, 2002). The thickness of the middle confining unit ranges from 200 to 400 ft in the study area (Lukasiewicz, 1992).

Lower Floridan Aquifer

In southern Florida, the top of the Lower Floridan aquifer is marked by the shallowest zone of highly transmissive dolomite (Meyer, 1989). Thick confining units separate this permeable zone and the Boulder zone (Miller, 1986). The lithology of these intervening confining units is similar to that of the middle confining unit of the Floridan aquifer system, which predominantly is fine-grained to micritic limestone.

The top of an upper permeable unit of the Lower Floridan aquifer, marking the top of the aquifer and characterized by a flow zone of cavernous dolomite, has been previously mapped (fig. 14; Lukasiewicz, 1992) in the study area. Altitudes of the top of this unit range from 900 ft below NGVD of 1929 in the extreme northwestern part of the study area in northeastern Okeechobee County to greater than 1,400 ft below NGVD of 1929 in southeastern Martin and northeastern Palm Beach County. At the SFWMD test well STL-379 in central St. Lucie County, the top of this unit is at 1,100 ft below NGVD of 1929; here, the upper permeable unit is 400 ft thick, mainly consists of dolomite, and contains two extensive cavernous dolomite flow zones (fig. 6; Lukasiewicz, 1992). The completed interval extending from 1,451 to 1,665 ft below land surface (1,434 to 1,648 ft below NGVD of 1929) at well PB-1197 in northeastern Palm Beach County (fig. 9) is included in the upper permeable unit of the Lower Floridan aquifer as mapped by Lukasiewicz (1992). This productive interval at PB-1197, which mainly consists of limestone and dolomitic limestone, is locally referred to as the middle Floridan aquifer (ViroGroup, 1994).

The upper permeable unit of the Lower Floridan aquifer, as defined by Lukasiewicz (1992), may be poorly developed in the coastal area. For example, a lithologic description for deep injection well M-1352 at the city of Stuart WWTP in northeastern Martin County (fig. 2) indicates limestone with only minor to trace occurrences of dolomite to a depth of 1,920 ft (Montgomery Watson Americas, Inc., 1998). Dolomite is not reported to a depth of at least 1,600 ft below NGVD of 1929 in another well (M-1353) at this site (fig. 7).

Sparse data exist on the transmissivity of the upper permeable unit of the Lower Floridan aquifer because it is penetrated by few wells. Available data, however, indicate that the transmissivity seemed to be higher in the Lower Floridan aquifer than in the Upper Floridan aquifer. Transmissivity of the upper permeable unit of the Lower Floridan aquifer was determined on the basis of multiwell aquifer tests at three sites represented by the following production wells: PB-1197, STL-380, and OK-9000 (fig. 2 and table 1). The transmissivity values (or transmissivity range) at these three sites are 32,000 to 132,000 ft^2/d at well PB-1197 (ViroGroup, 1994), 65,000 ft^2/d at well STL-380 (Lukasiewicz and Smith, 1996), and 590,000 ft^2/d at well OK-9000 (CH_2M Hill, 1989).

The highly transmissive Boulder zone within the lower part of the Lower Floridan aquifer ranges in depth from 2,500 to 3,000 ft below NGVD of 1929 in the study area (Miller, 1986). The thickness of this zone ranges from about 300 to 500 ft.

The lowermost section of the Lower Floridan aquifer extends 500 to 600 ft below the base of the Boulder zone (Miller, 1986, pl. 17) and consists of permeable dolomite or dolomitic limestone of the upper Cedar Keys Formation (fig. 3). The lower boundary of the Lower Floridan aquifer is defined by thick impermeable anhydrite beds in the lower part of the Cedar Keys Formation.

Ground-Water Flow of the Floridan Aquifer System

An understanding of ground-water flow in the Floridan aquifer system, both historical (predevelopment) and current, is necessary in order to know what effect current or increasing withdrawals could have on salinity. In the following discussion, delineation of the flow system is made based on the distribution of hydraulic head, withdrawals, and recharge.

The movement of water in any aquifer generally is perpendicular to potentiometric surface contours. A comparison between predevelopment and current potentiometric surface contours suggests that the direction of ground-water flow in the study area has shifted over time.

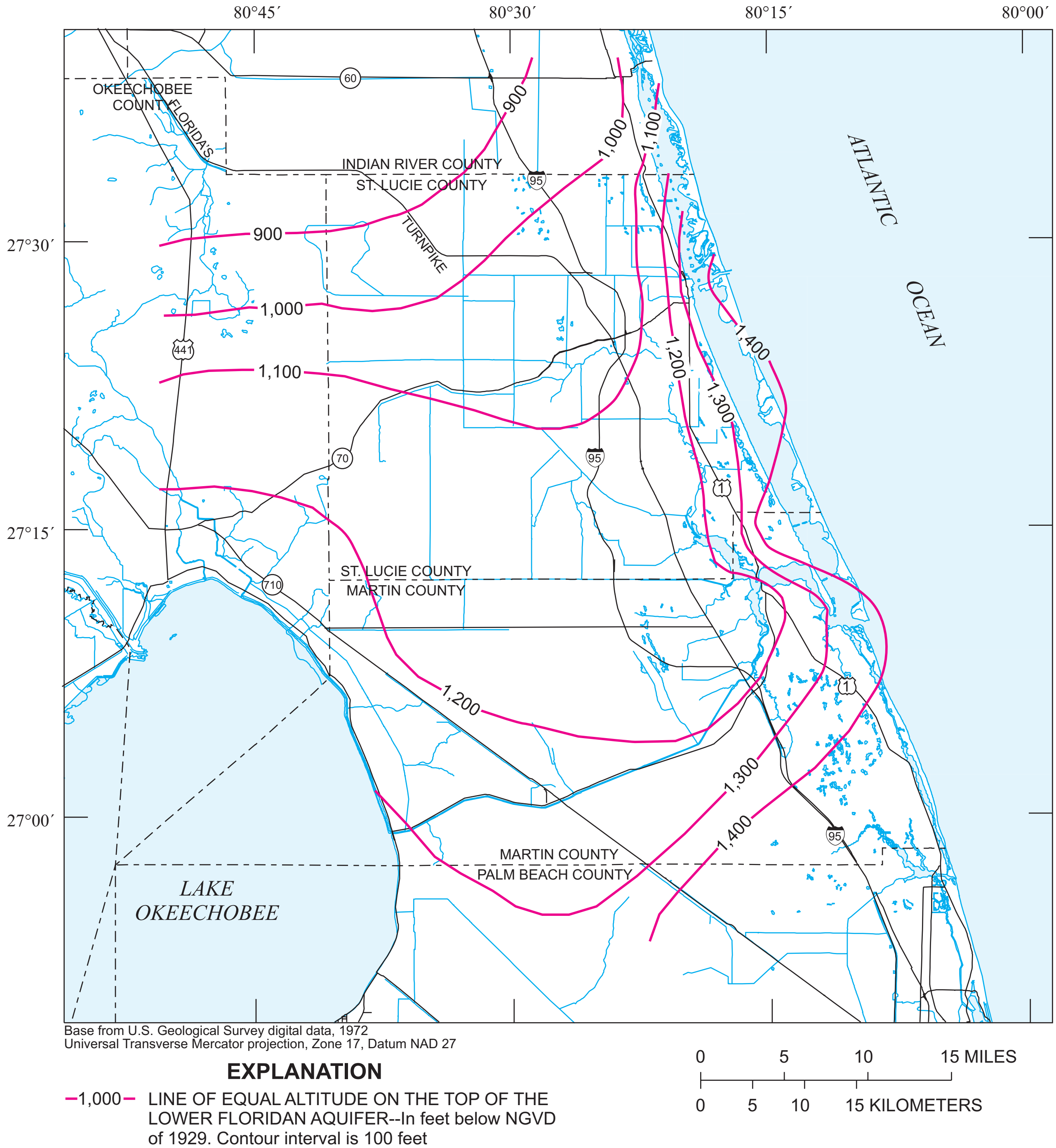


Figure 14. Altitude of the top of the Lower Floridan aquifer (from Lukasiewicz, 1992). NGVD of 1929 is National Geodetic Vertical Datum of 1929.

Potentiometric Surface of the Upper Floridan Aquifer

An estimated predevelopment potentiometric surface for the Upper Floridan aquifer in Florida (Bush and Johnston, 1988, pl. 4) suggests that flow in the study area originally was toward the northeast or east-northeast (fig. 15). However, the May 2001 potentiometric surface indicates that the direction of flow shifted to the north in southern St. Lucie County, southern Okeechobee County, and northern Martin County and to a more easterly direction in northeastern Okeechobee County and northern St. Lucie County (fig. 15). This change in flow direction is attributed to withdrawals from the Upper Floridan aquifer in northern St. Lucie and southern Indian River Counties, the majority of which was used for agricultural purposes (Lukasiewicz, 1992).

Based on the comparison of the two potentiometric surfaces in figure 15, some decline in water level probably has occurred over the entire study area since predevelopment (early 1930's). However, decline in eastern Martin and northeastern Palm Beach Counties has been minimal. Decline in central and northern St. Lucie County and Okeechobee County is greatest and ranges from about 15 to 20 ft. Similar decline (about 16 to 24 ft) between 1934 and 1984 was reported in eastern Indian River County, with most of this decline occurring between 1934 and 1971 (Schiner and others, 1988). Upper Floridan aquifer water levels seemed to stabilize in the study area between 1970 and 1977, as indicated by hydrographs for three wells in Martin County and two wells in St. Lucie County (Brown and Reece, 1979, pl. 3).

Recent data suggest the decline in water levels could be continuing for much of the study area. A SFWMD Floridan aquifer system well network (fig. 2) has been used to monitor water levels since 1986 (Switanek, 1999), and trend analyses of these data were made using linear regression (table 2). Two wells in western Martin County show a water-level increase of 2 to 3 ft. Eight wells in central and northwestern

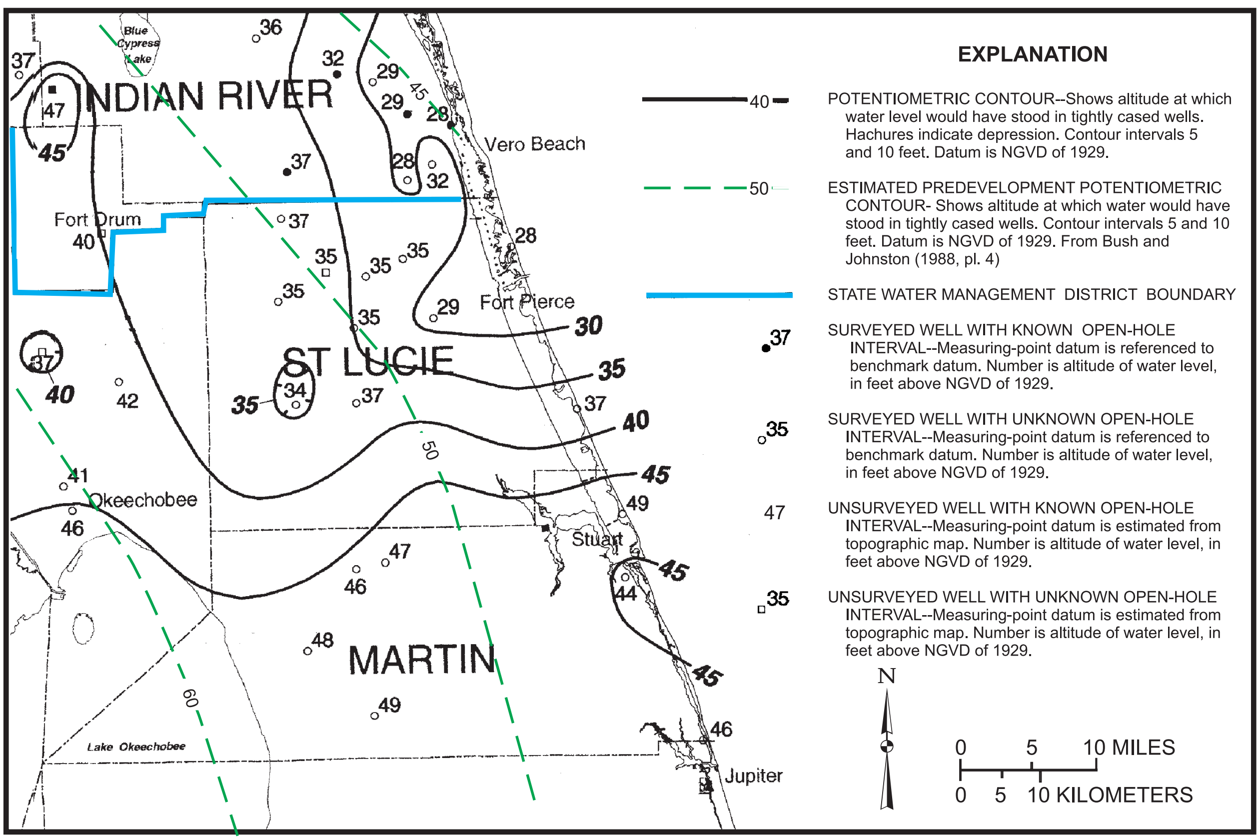


Figure 15. Potentiometric surface of the Upper Floridan aquifer, May 2001 (from Knowles, 2001). Also shown are estimated predevelopment potentiometric contours for the Upper Floridan aquifer (from Bush and Johnston, 1988). NGVD of 1929 is National Geodetic Vertical Datum of 1929.

Table 2. Changes in water level and chloride concentration for South Florida Water Management District ground-water level monitoring network wells completed in the Floridan aquifer system

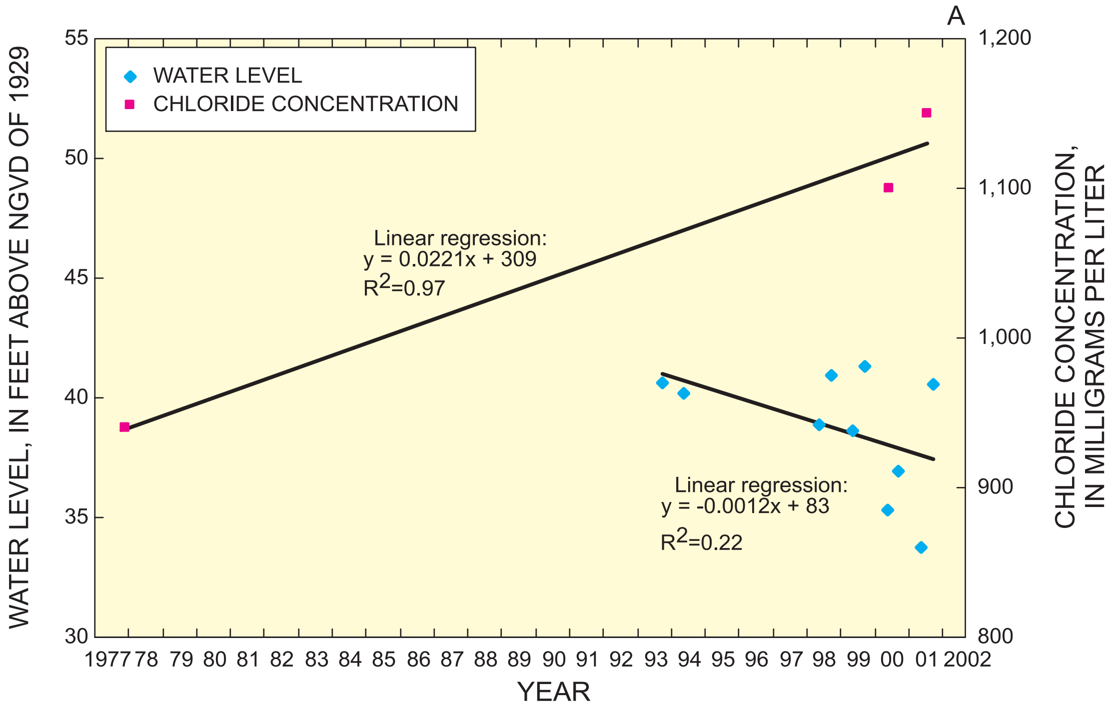
[Well locations are shown in figure 2. For most years, head measurements were made twice a year (wet and dry seasons). SFWMD, South Florida Water Management District; USGS, U.S. Geological Survey; --, inadequate data. All water-quality data used to determine chloride concentration trends are presented in appendix III]

Well number		Period of record for head data	Years of record	Change in head (feet)[1]	Period of record for water sample data	Years of record	Number of samples	Percent change in chloride concentration[1]
USGS	SFWMD							
M-255	MF-2	1991-2001	11	-1	1977-2001	24	4	0
M-745	MF-9	1987-2001	15	None	1990-2001	11	3	-7
M-1121	MF-3	1987-2001	15	-2	1990-2001	11	3	10
M-1125	MF-23	1986-2001	16	None	1977-2000	23	3	0
M-1326	MF-31	1986-2001	16	None	1985-2000	15	4	12
M-1328	MF-33	1986-1998	13	2	1989	1	1	--
M-1330	MF-35	1986-2001	16	3	1990-2001	11	3	1
OK-7	OKF-7	1987-2001	15	-1	1987-1997	10	2	0
OK-13	OKF-13	1987-2000	14	1	1988-2000	12	2	-22
OK-23	OKF-23	1987-2001	15	-2	1987-2000	13	4	0
OK-31	OKF-31	1987-2001	15	1	1984-2001	17	5	-5
OK-72[2]	OKF-72	--	--	--	1990-2001	11	3	207
PB-1144	PBF-1	1986-2001	16	None	1977-2000	23	3	2
STL-215	SLF-3	1986-2001	16	-1	1978-2001	23	4	45
STL-216	SLF-4	1991-2001	11	-2	1978-2000	22	3	-2
STL-217	SLF-9	1992-2001	10	-3	1977-2001	24	8	37
STL-218	SLF-11	1991-2001	11	-2	1978-2000	22	3	34
STL-220	SLF-14	1993-2001	9	-3	1977-2001	24	3	20
STL-224	SLF-21	1987-2001	15	-4	1990-2000	10	4	4
STL-225	SLF-23	1986-1994	9	2	1978-1990	12	2	11
STL-229	SLF-27	1986-2000	15	-3	1977-1990	13	2	1
STL-342	SLF-36	1986-2001	16	-2	1977-2000	23	3	-17
STL-346	SLF-40	1986-2001	16	-2	1990-2000	10	2	2
STL-353	SLF-47	1986-2001	16	1	1988-2000	12	4	-10
STL-356	SLF-50	1986-2001	16	-1	1990-1996	6	2	62

[1]Based on linear regression fit to data.
[2]This well is not part of the monitoring well network, and location is shown on plate 2.

St. Lucie County indicate a water-level decrease of 2 to 4 ft. At one of these eight wells, well STL-220 in west-central St. Lucie County, a 3-ft decrease in water level is indicated during the last 9 years; at another well, STL-224 in central St. Lucie County, a 4-ft decrease occurred during the last 15 years (fig. 16). These decreasing water-level trends could be the result of the 2000-01 drought period in central Florida and the associated decrease in recharge. A plot of the Palmer hydrological drought index for central Florida, the recharge area for the Floridan aquifer system, shows two major long-term drought periods since 1986: 1989-90 and 2000-01 (National Climatic Data Center, 2003). Each of these two drought periods is of similar length and severity. However, data were not collected during the 1989-90 drought period from the Floridan aquifer system monitoring well network. Therefore, the declines indicated for the wells in central and northwestern St. Lucie County are not conclusive.

An upward head gradient within the Floridan aquifer system is most likely prevalent throughout the study area. Water levels of wells completed in the Lower Floridan aquifer in Indian River County are probably at least several feet higher than wells in the Upper Floridan aquifer (Schiner and others, 1988).



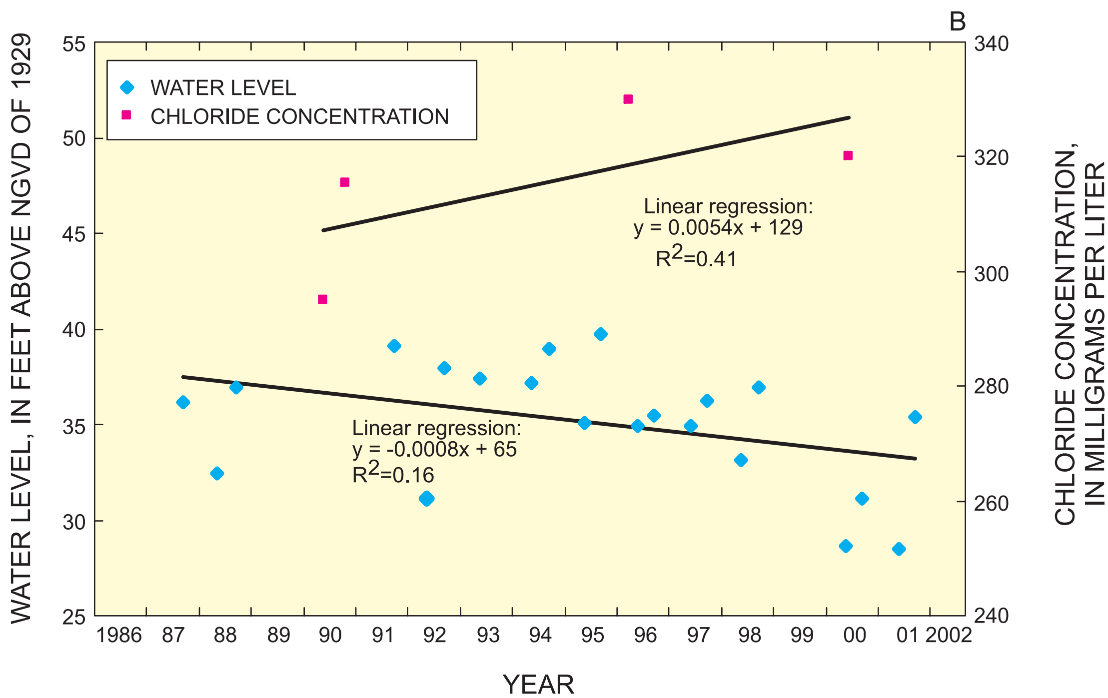


Figure 16. Relations between water level and time and between chloride concentration and time for wells (A) STL-220 and (B) STL-224. Well locations are shown in figure 2. NGVD of 1929 is National Geodetic Vertical Datum of 1929.

Static head measurements were taken during drilling of the open intervals at the Jupiter RO Well Field in northeastern Palm Beach County (Stemle, Andersen, and Associates, Inc., 1998). Generally, the head increased with depth in each well. The open intervals extended from the lower part of the Upper Floridan to the Lower Floridan aquifer. At the Jupiter dual-zone monitoring well PB-1196 (fig. 9), static head measurements taken prior to an aquifer performance test indicated head in the lower zone (Lower Floridan aquifer) was about 4 ft higher than that in the upper zone (Upper Floridan aquifer) (Viro Group, Inc. 1994). Head increase with depth is expected within an area of discharge in a system where deep circulation of meteoric water is occurring.

Ground-Water Withdrawals and Recharge

Municipalities and agriculture are the largest users of Floridan aquifer system ground water in the study area. Most water withdrawn was for agriculture, with the water used for irrigation, primarily of citrus. The area of intense agricultural water use (fig. 2) lies within the inland area, which is bordered by the basal Hawthorn/Suwannee unit 100-ft thickness contour (fig.12). Agricultural well permitting requirements by the SFWMD do not include the reporting of water use; consequently, withdrawals must be estimated.

Agricultural withdrawals from the Floridan aquifer system in the UEC Planning Area were estimated to be 81.8 Mgal/d in March 1990 (Lukasiewicz, 1992). This estimate, based on a survey sent to farm owners, used the number of hours each month that wells were reported to be open and flowing and reported or estimated well capacities. Water use was determined and plotted for model cells, each representing 1 mi^2 for March 1990 (Lukasiewicz, 1992, fig. 22). Water use per square mile within the area of intense agricultural water use (fig. 2) is greatest in central and northern St. Lucie County and southern Indian River County.

Monthly withdrawal data were collected for 45 irrigation wells in the study area over the last 6 years (1996-2001) in a NRCS monitoring program, and these data were summed by water year (fig. 17). A water year starts 3 months ahead of the calendar year, beginning on October 1 and ending on September 30. The NRCS wells are clustered in 16 groves, and all of these groves are located in the area of intense agricultural water use (fig. 2). Withdrawals increased during drought years 2000 and 2001, and for many of the wells surveyed, water used was greatest during this period. Well G29-14 in north-central St. Lucie County is reported to have had the greatest withdrawal in a single year (425 Mgal in the 2001 water year).

Ground-water withdrawals from the Floridan aquifer system for municipal water systems in the study area (fig. 2) also were determined. Municipal well water from the Floridan aquifer system must be treated by RO because of the brackish nature of the water. For each municipal well field, the average daily rate of withdrawal in million gallons per day for a particular year, usually 2000, the number of wells in production, and the aquifer(s) to which the wells are open are given in table 3. Jupiter Water Systems is the largest well field; eight wells were reported to withdraw a combined average rate of 5.2 Mgal/d for the year 2000. All of the well fields that produce at higher rates (greater than 1.0 Mgal/d) have wells open to an interval including both the Upper and Lower Floridan aquifers. The Fort Pierce Utilities and South Martin Regional Utilities Well Fields had not yet been placed into production as of 2001, nor had a newly constructed well at the North Martin County Utilities Well Field as of 2000. The total of the average daily withdrawal rates from municipal well systems was 13.7 Mgal/d (table 3).

Recharge to the Floridan aquifer system occurs to the west and north of the study area in central Florida. Bradner (1994) discusses areas of recharge in central and northern Okeechobee County where the water table is higher than the potentiometric surface of the Upper Floridan aquifer. Model simulations, however, indicate recharge rates in these areas are low, ranging from 0.2 to 1.0 in/yr. Bradner (1994) states:

> *Recharge (into the Upper Floridan aquifer) due to lateral inflow from adjacent areas (around Okeechobee County) probably is small because Upper Floridan aquifer gradients are relatively flat and transmissivities of the Upper Floridan aquifer are relatively low.*

A four-layer model of the Floridan aquifer system has been constructed for the UEC Planning Area (Lukasiewicz, 1992). The surficial aquifer system and Upper Floridan aquifer are represented by the

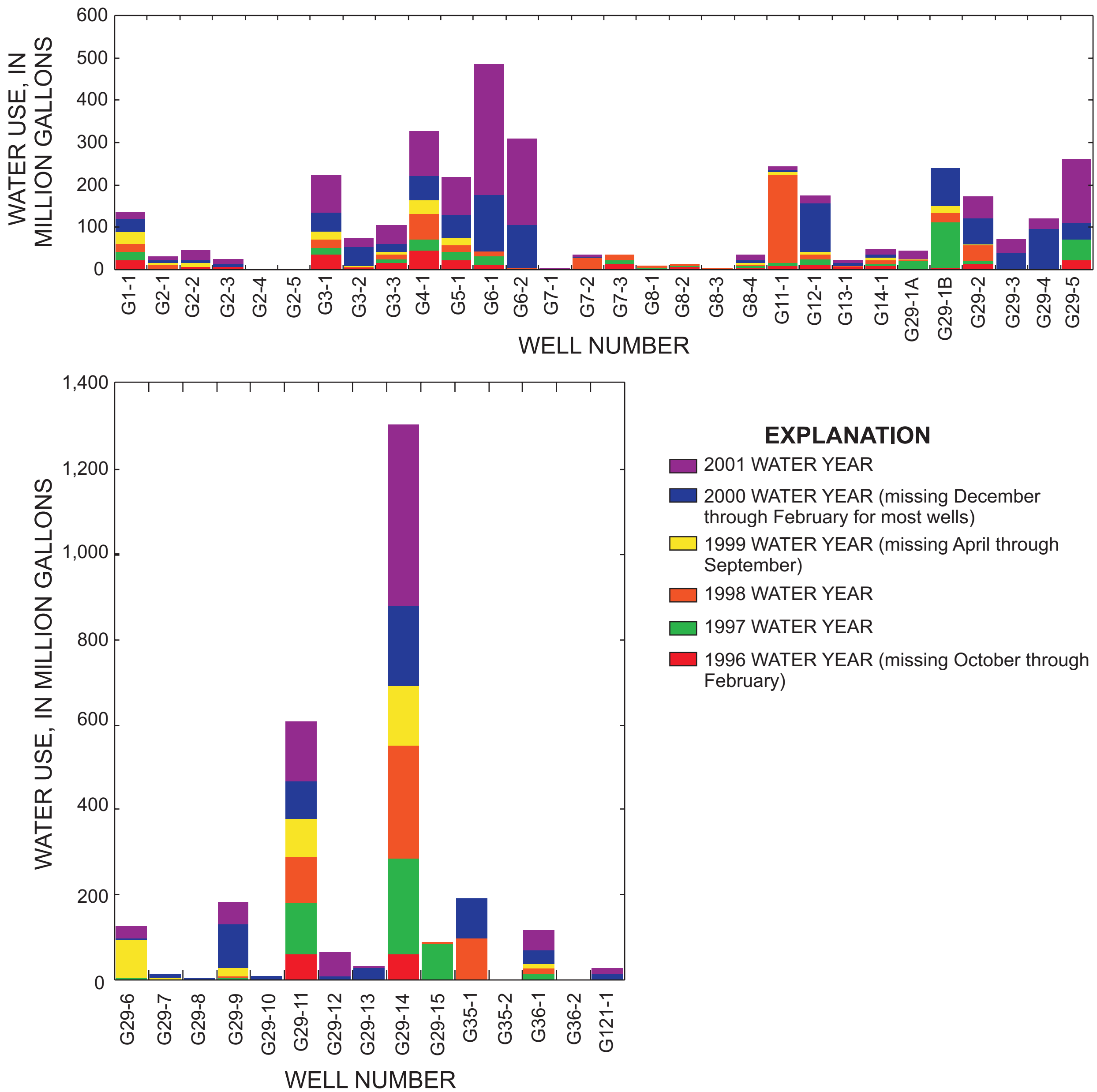


Figure 17. Yearly water withdrawals from Natural Resources Conservation Service monitoring wells in the study area. For wells G35-1, G35-2, G36-1, G36-2, and G121-1, data were not collected for the 1996 water year and for the first 6 months of the 1997 water year. A water year starts 3 months before the calendar year, beginning on October 1 and ending on September 30. Well locations are shown in figure 2.

upper two model layers, and the two cavernous dolomite flow zones of wide areal extent in the upper permeable unit of the Lower Floridan aquifer are represented by the bottom two layers. All withdrawals from the Floridan aquifer system were assumed to come from the Upper Floridan aquifer, and hydraulic heads in the lowermost model layer were treated as a constant head boundary. About 90 percent of the simulated recharge to the Upper Floridan aquifer occurs by leakage from the underlying Lower Floridan aquifer. Under stressed conditions, this result indicates that upward flow in the aquifer system dominates lateral flow.

Table 3. Wells in production at Floridan aquifer system municipal water systems in the study area and their average withdrawals for system and aquifer(s) open

Municipal water system	Number of production wells		Year	Average daily pumpage for year for system (million gallons per day)	Aquifer(s) open in individual wells		
	Total	In use			Upper Floridan	Upper and Lower Floridan	Lower Floridan
Fort Pierce Utilities (blending)	3	2	2000	0.45	X		
Fort Pierce Utilities (reverse osmosis) [1]	6	0	2001	0		X	
Joe's Point	2	1	1992	.03	X		
Jupiter Water System	10	8	2000	5.2		X	X
North Martin County Utilities (Jensen Beach)	4	3	2000	2.5	X	X	
Port St. Lucie Utilities	3	3	2000	3.6		X	
Radnor	2	1	1996	.24	X		
Sailfish Point	2	2	2000	.21	X		
South Martin Regional Utilities (Hobe Sound) [1]	2	0	2001	0		X	
Tequesta	2	2	2001	1.5		X	

[1]Not yet in production.

WATER QUALITY IN THE FLORIDAN AQUIFER SYSTEM

The distribution of salinity and water temperature, isotopic analyses, and recent temporal changes in salinity in the study area are discussed in this section. Water-quality data are available mostly for wells open only in the Upper Floridan aquifer. Some wells, however, including some of those used for irrigation supply, were drilled to greater depths to increase yield and penetrate the Lower Floridan aquifer, and these wells are open to the upper part of the Lower Floridan aquifer in addition to the Upper Floridan aquifer.

Selected water-quality data used in this study and collected from numerous wells tapping the Floridan aquifer system are presented in appendix III. Wells M-1325, OK-9001/OK-9002, PB-1196, STL-255, and STL-335 are dual-zone monitoring wells in which water-quality samples were obtained from both zones. Sources of water-quality data given in appendix III include data collected during this study; from previous research by Lichtler (1960), Reece and others (1980), Lukasiewicz and Switanek (1995), Reese and Memberg (2000); and from consulting reports on deep wastewater injection well systems, previously collected USGS data stored in a USGS water-quality database (QWDATA), NRCS data, well abandonment files from the SFWMD, and Florida Department of Environmental Protection (FDEP) data from the Florida Ground-Water Quality Network Program (Generalized Water Information System database – GWIS3). Major constituent and field characteristic water-quality data collected during this study are presented in appendix IV.

Classification and Characterization of Salinity

A salinity classification scheme based on dissolved-solids concentrations was used for the Floridan aquifer system in the study area. This scheme, modified from Fetter (1988), has three categories:

- Brackish water—Dissolved-solids concentrations range from 1,000 to 10,000 mg/L,
- Moderately saline water—Dissolved-solids concentrations range from 10,000 to 35,000 mg/L, and
- Saline water—Dissolved-solids concentrations range from 35,000 to 100,000 mg/L.

In the scheme by Fetter (1988), saline water has a dissolved-solids concentration range from 10,000 to 100,000 mg/L, and the moderately-saline-water category is not used.

A well-defined relation between chloride and dissolved-solids concentrations in water from the Floridan aquifer system has been established for southeastern Florida (Reese, 1994), allowing these constituents to be interchanged in the characterization of salinity. This relation for the 73 samples collected during this study (fig. 18) is similar to that found by Reese (1994) for Miami-Dade and Broward Counties. In this report, chloride concentration is used to map the distribution of salinity.

The dominant water type present in ground water from the Upper Floridan aquifer in Martin and St. Lucie Counties, based on data plotted on trilinear diagrams, is the sodium-chloride type (Lukasiewicz and Switanek, 1995). Although both counties have sodium-chloride type water, interpretation of these plots by Lukasiewicz and Switanek (1995) based on a classification scheme by Frazee (1982) indicated that ground water from St. Lucie County is connate in nature, whereas Martin County has both connate and lateral intrusion (seawater invasion) signatures. The connate signature has a lower percentage of sodium plus potassium out of the combined major cations (sodium plus potassium, magnesium, and calcium) than the lateral intrusion signature.

Comparison of the sulfate and chloride concentrations for the data collected in this study indicates some enrichment of sulfate as compared to that expected from mixing of freshwater with seawater, but only for samples with chloride concentration less than about 6,000 mg/L (fig. 19). This enrichment probably indicates that some dissolution of gypsum has occurred. Severe depletion of sulfate is evident for most samples with chloride concentration greater than 6,000 mg/L, and this depletion is likely caused by sulfate reduction.

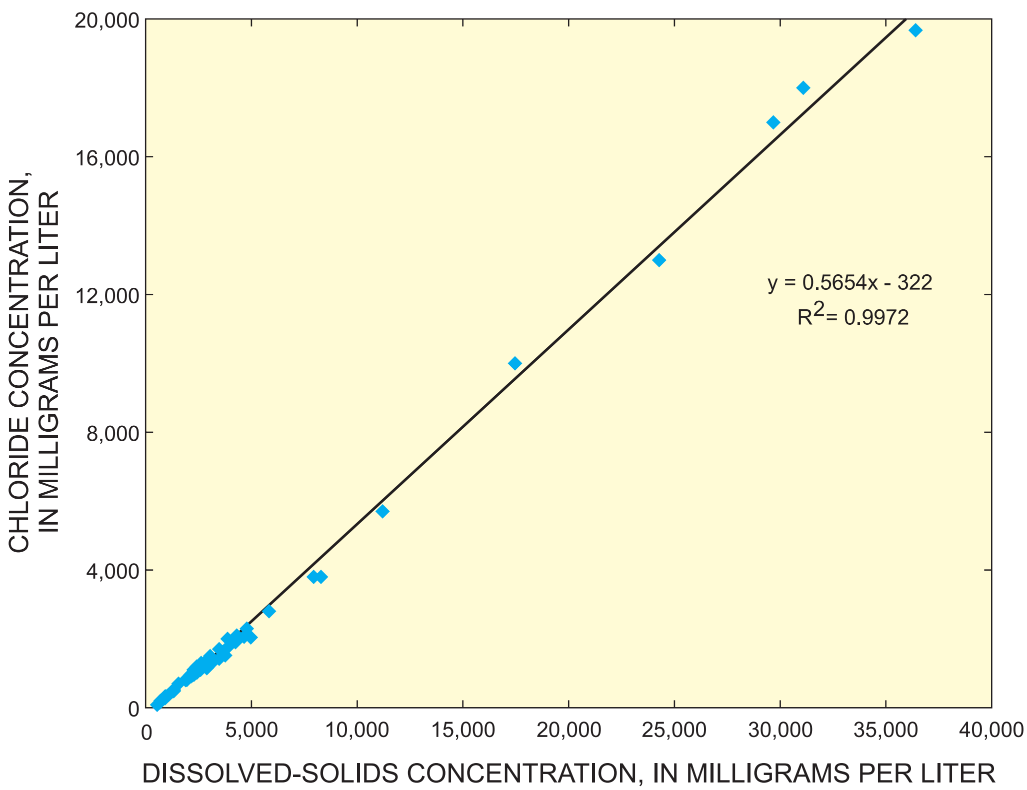


Figure 18. Relation between chloride and dissolved-solids concentrations for samples collected in this study.

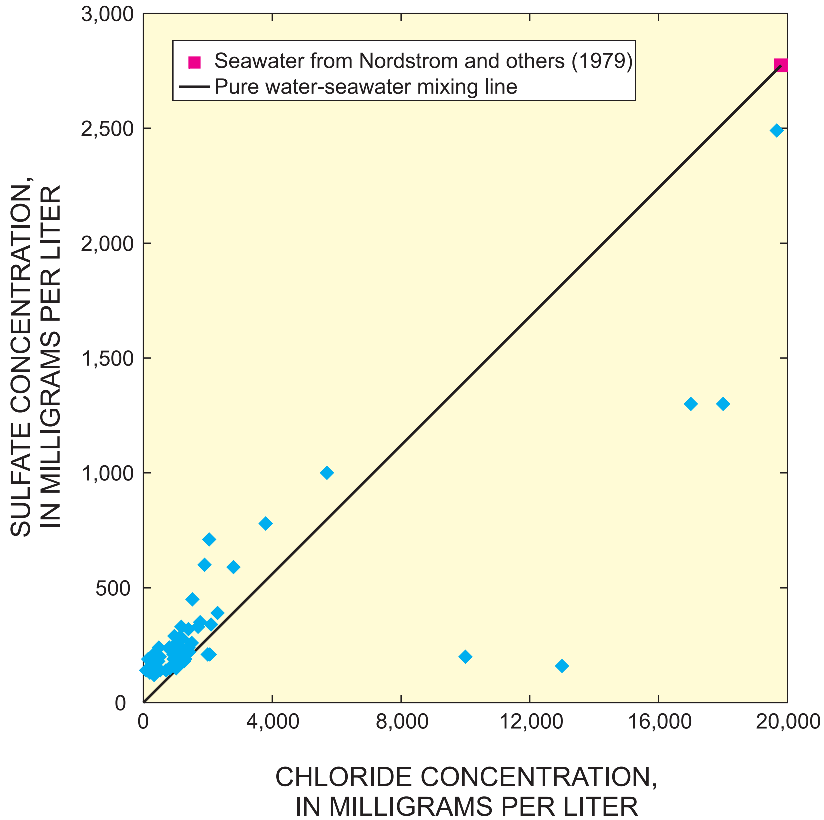


Figure 19. Sulfate and chloride concentrations for samples collected in this study and relation to a pure water-seawater mixing line.

Distribution of Salinity

On the basis of water-quality data and borehole geophysical log responses, the distribution of salinity within the Floridan aquifer system in the study area indicates that the system can be divided into the same three salinity zones, as used in earlier studies of southern Florida (Reese, 1994, 2000; Reese and Memberg, 2000). These zones and their ranges in salinity, in order of increasing depth, are defined as follows:

- Brackish-water zone—Dissolved-solids concentration less than 10,000 mg/L, and chloride concentration less than 5,330 mg/L;
- Salinity transition zone—Dissolved-solids concentration ranging from 10,000 to 35,000 mg/L, and chloride concentration ranging from 5,330 to 19,500 mg/L; and
- Saline-water zone—Dissolved-solids concentration greater than 35,000 mg/L, and chloride concentration greater than 19,500 mg/L.

Salinity increases rapidly with depth in the transition zone. The salinity within the saline-water zone is similar to that of seawater, which has a dissolved-solids concentration of about 36,000 mg/L (Nordstrom and others, 1979) and a chloride concentration of about 19,000 mg/L (Hem, 1989). As will be shown later in this report, the base of the brackish-water zone may or may not approximate a brackish-water/saltwater interface due to density equilibrium (same as a freshwater-saltwater interface).

A linear relation between specific conductance and chloride concentration less than 4,000 mg/L was established using samples collected during this study (fig. 20). The relation was used to estimate chloride concentration in samples for which specific conductance was determined but not chloride concentration (app. III).

In mapping the distribution of salinity in the study area, it was assumed that salinity has not changed substantially since development of the aquifer system began in the 1930's. As will be shown later, salinity in most wells in the study area has changed little during the last 40 to 50 years.

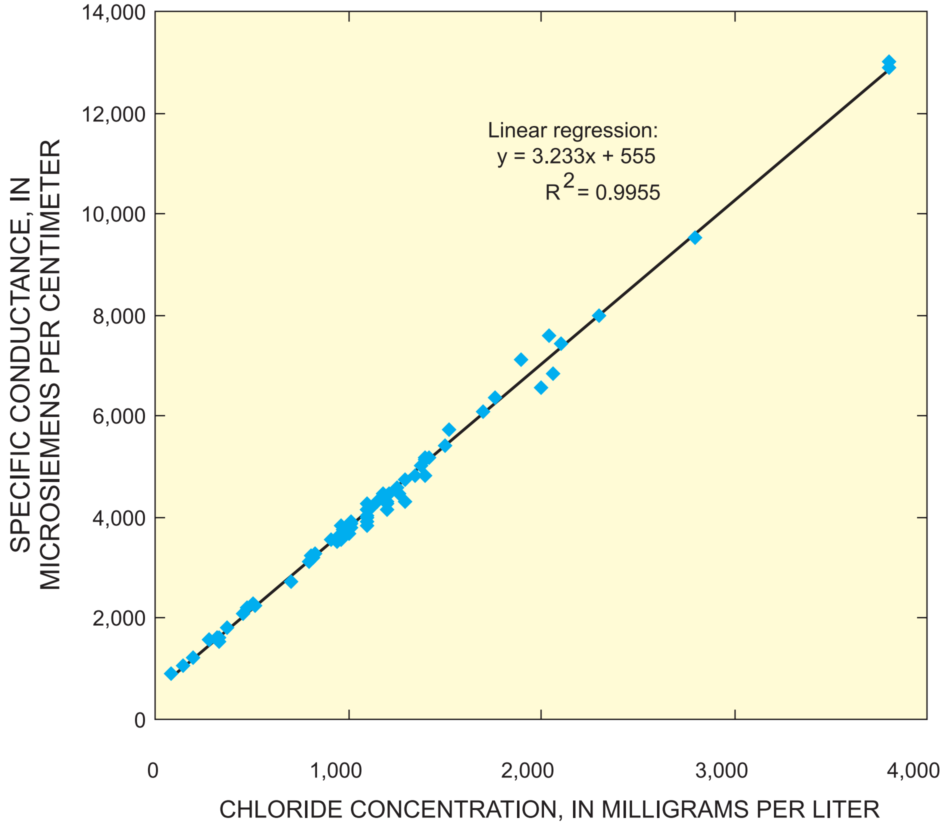


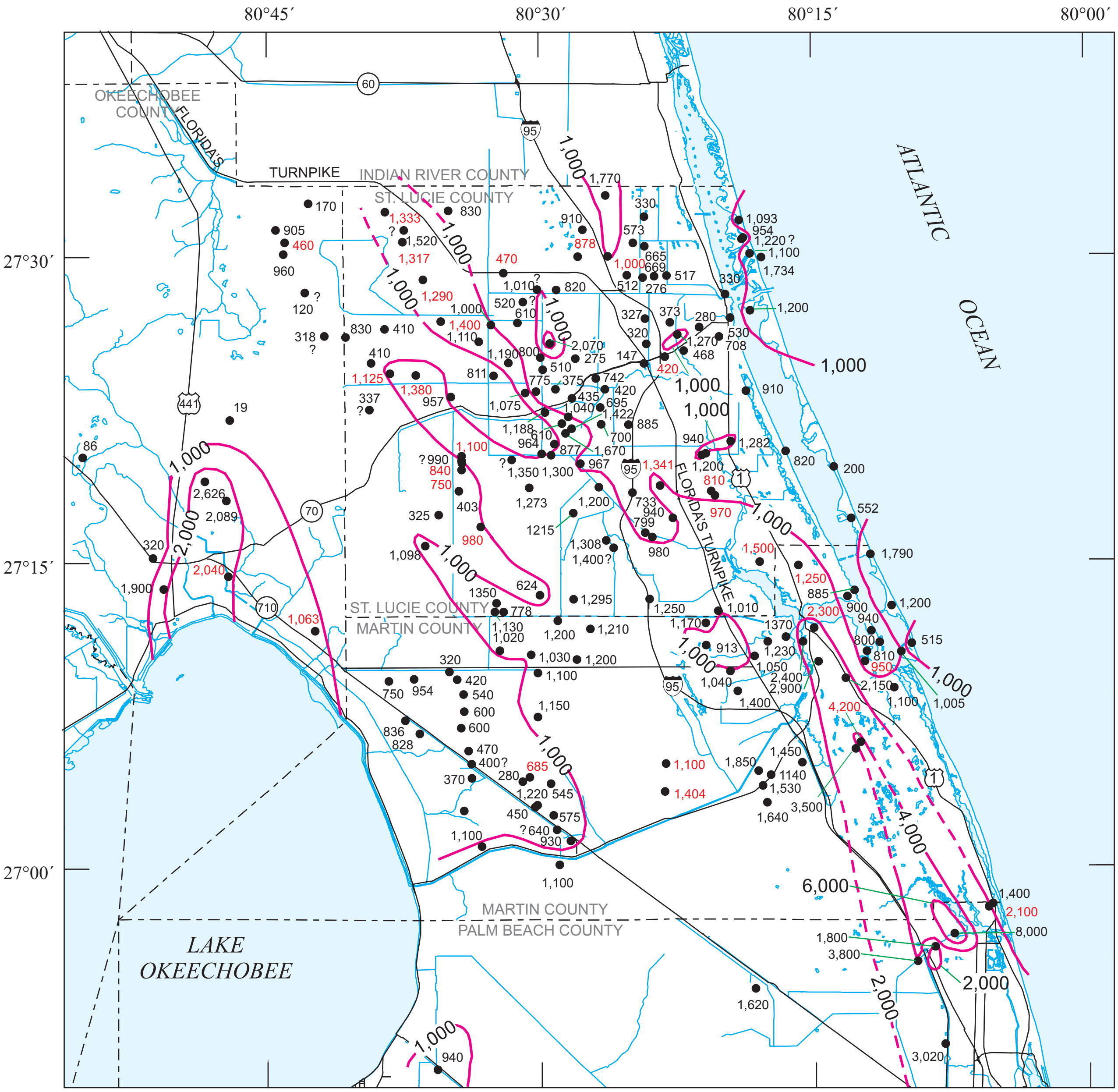
Figure 20. Relation between specific conductance and chloride concentration less than 4,000 milligrams per liter for samples collected during this study.

Upper Floridan Aquifer

The brackish-water zone encompasses the entire Upper Floridan aquifer in the Martin, St. Lucie, Palm Beach, and Okeechobee County study area. Although a number of distinct flow zones are present at various depths in the Upper Floridan aquifer, the salinity of water within the zones does not vary greatly (Lukasiewicz and Switanek, 1995). Salinity does increase with depth between the Upper and Lower Floridan aquifers in Martin and St. Lucie Counties (Lukasiewicz, 1992), Okeechobee County to the west (Bradner, 1994), and Indian River County to the north (Schiner and others, 1988).

The areal distribution of chloride concentration in ground water from the Upper Floridan aquifer varies widely in the study area (fig. 21 and app. III). Figure 21 was constructed using the most recently collected water sample at a specific well, which in many instances, was a sample collected during this study. In some cases, however, the only samples collected for certain wells were those collected as early as the 1940's, especially in Martin County. Chloride concentrations in the study area range from 19 mg/L in Okeechobee County to 8,000 mg/L in northeastern Palm Beach County. Three areas have been identified in which chloride concentrations exceed 1,000 mg/L: (1) an area at the northern end of Lake Okeechobee in Okeechobee County, (2) part of the inland area that extends northwest through north-central Martin County and western St. Lucie County, and (3) part of the coastal area that trends parallel to the coast in Palm Beach County, eastern Martin County, and southeastern St. Lucie County. The maximum chloride concentration in each of these three areas is 2,626, 1,670, and 8,000 mg/L, respectively. Chloride concentration is less than 500 mg/L in large geographic areas in Okeechobee County, northeastern St. Lucie County, and northwestern Martin County.

Some of the wells used to map Upper Floridan aquifer chloride concentration are open to the upper part of the Lower Floridan aquifer (Lukasiewicz, 1992) as well as the Upper Floridan aquifer (fig. 21), and the chloride concentration in water from these wells can be higher than water from only the Upper Floridan aquifer.



Base from U.S. Geological Survey digital data, 1972
Universal Transverse Mercator projection, Zone 17, Datum NAD 27

0 5 10 15 MILES
0 5 10 15 KILOMETERS

EXPLANATION

–1,000– LINE OF EQUAL CHLORIDE CONCENTRATION--In milligrams per liter. Dashed where approximately located. Contour interval is variable

● 940 WELL LOCATION AND CHLORIDE CONCENTRATION--Concentration in milligrams per liter. See plate 2 for local well number. For wells with values shown in red, open interval in well includes an upper part of the Lower Floridan aquifer as mapped by Lukasiewicz (1992) in addition to the Upper Floridan aquifer

Question mark (?) indicates total depth of well is unknown

Figure 21. Distribution of chloride concentration in the Upper Floridan aquifer.

This is because salinity, hydraulic head, and transmissivity can be higher in the Lower Floridan aquifer than in the Upper Floridan aquifer. Some of the northwesterly extensions where chloride concentration is greater than 1,000 mg/L in the inland area in western St. Lucie County (fig. 21) could be due to wells open in the Upper Floridan aquifer that also penetrate the Lower Floridan aquifer. However, many of the wells that are open to both aquifers, particularly in the coastal area, do not contain water with higher chloride concentration when compared to nearby wells open only in the Upper Floridan aquifer.

Lower Floridan Aquifer

Only eight wells in the study area were open only to the Lower Floridan aquifer above the base of the brackish-water zone. These wells, the locations of which are all shown in figure 2, are M-1325 (upper monitoring zone), M-1353, OK-9002, PB-1170 (upper and lower monitoring zones), PB-1182 (packer test), PB-1196 (fig. 9, lower monitoring zone), STL-255 (lower monitoring zone), and STL-380. Chloride concentration in water from these wells (nine samples) ranges from 510 to 3,050 mg/L (app. III). All of these wells, except for OK-9002 and STL-380, are in the coastal area.

Chloride concentration does not increase with depth between the Upper and Lower Floridan aquifers in the coastal area within the brackish-water zone. Chloride concentrations in sampled wells were compared with the depth of the sample in both inland and coastal areas (fig. 22). Only samples collected in this study and only one sample per well or monitoring zone were used. There seems to be no correlation in the coastal area (fig. 22B) between salinity and sample depth; however, some correlation exists in the inland area (fig. 22A). Chloride concentration seems to increase with well depth between the Upper and Lower Floridan aquifers in the inland area.

Reversals (decreases) in salinity with increasing depth between the Upper and Lower Floridan aquifers occur in the coastal area as indicated by monitoring wells that are completed at different depths at the same site. An example is shown by two samples collected from well PB-1196 (Jupiter RO Well Field) on July 17, 2001: chloride concentration was 3,800 mg/L in water from the upper monitoring zone at a depth interval between 1,137 and 1,155 ft below land surface, and 1,760 mg/L from the lower monitoring zone at a depth interval between 1,549 and 1,609 ft below land surface (figs. 9 and 22). Other examples include, from south to north, wells M-1034 (upper monitoring zone) and M-1353 (lower monitoring zone) at the Stuart WWTP site and well STL-255 (upper and lower monitoring zones) at the South Port St. Lucie WWTP site (fig. 22).

Similar reversals in salinity with depth within the brackish-water zone of the Floridan aquifer system were found in areas along the coast in Palm Beach and northern Broward Counties (Reese and Memberg, 2000). An example of this salinity distribution, based on water-quality data and a resistivity geophysical log, is shown in three wells at the Coral Springs WWTP in northeastern Broward County (fig. 23), two of the which (CS-I1 and CS-M2) were sampled as part of this study. The Coral Springs site is classified within the coastal area due to the vertical distribution of salinity, location, and thickness (165 to 235 ft) of the basal Hawthorn/Suwannee unit (Reese and Memberg 2000).

Salinity Zone Boundaries

The two boundaries of the three salinity zones in the Floridan aquifer system, the base of the brackish-water zone and the top of the saline-water zone, were determined in the study area principally using resistivity geophysical logs. The dual-induction resistivity log, the preferred log type for boundary delineation, includes three resistivity curves that are produced by the deep-induction, medium-induction, and shallow-focusing electrode devices all on the same logging tool. These devices are focused to different depths of investigation beyond the borehole wall and record deep, medium, and shallow formation resistivity measurements, respectively.

Calculations of true formation resistivity (using these three resistivity curves and correction charts for borehole and invasion effects) were made for a deep injection well in southeastern Florida in which salty drilling fluid had not invaded the formation (Reese, 1994). The corrections between true formation resistivity and the deep induction resistivity values were shown to be small. Although these calculations were made for a well located in Miami-Dade County south of the study area, lithology and depth are similar to those in the study area. Therefore, it is reasonable to assume that deep-induction resistivity approximates true formation resistivity, provided extensive invasion with salty drilling fluid has not occurred.

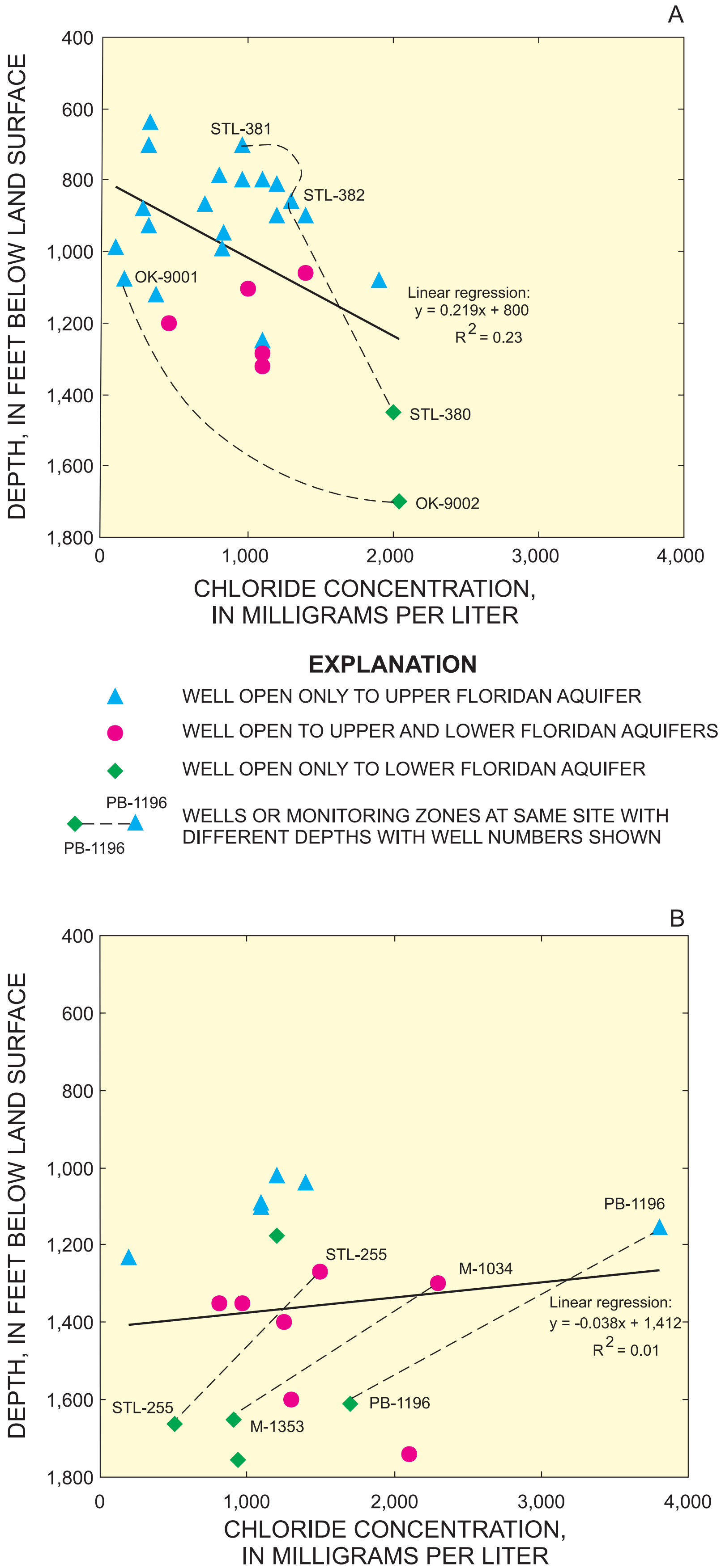


Figure 22. Relation between well depth and chloride concentration less than 4,000 milligrams per liter for (A) inland and (B) coastal areas. Sample depth used is bottom of completed open interval.

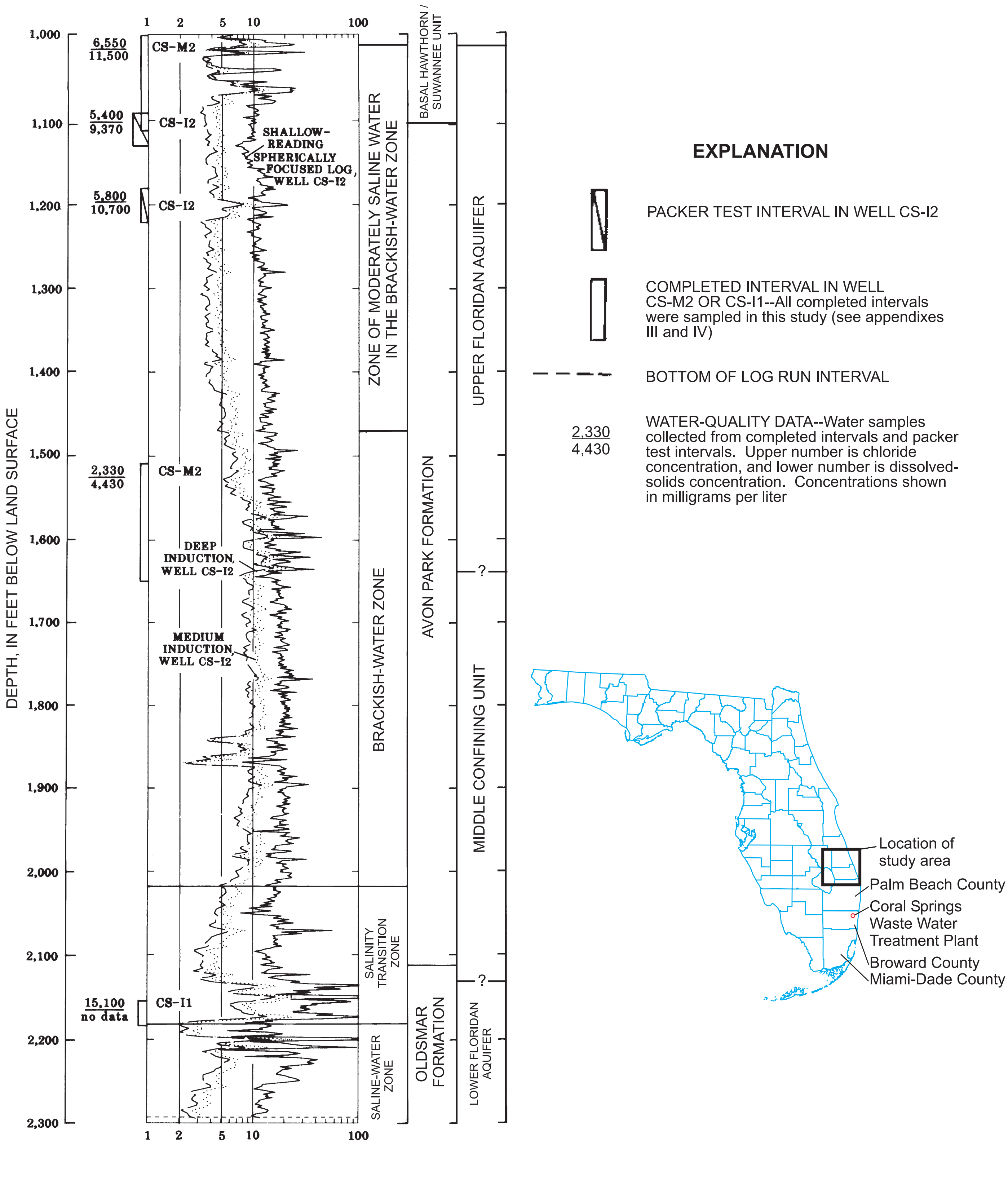


Figure 23. Water-quality data, resistivity geophysical log, salinity zones, and hydrogeologic units for wells at the Coral Springs Wastewater Treatment Plant in northeastern Broward County (modified from Reese, 1994, fig. 14). Wells used at site include CS-I1, CS-I2, and CS-M2. Well CS-I1 is 750 feet south of well CS-I2, and well CS-M2 is 75 feet from well CS-I2.

The formation resistivity, R_o, for limestone was computed using an empirical formula (Archie, 1942) for the two threshold salinity values that define the top and base of the salinity transition zone for expected ranges in porosity, cementation factor, and formation temperature in the study area. The calculated average R_o values used to determine the boundaries are 6 ohm-m for a dissolved-solids concentration of 10,000 mg/L and 2 ohm-m for a dissolved-solids concentration of 35,000 mg/L. These average R_o values were calculated using a porosity of 30 to 35 percent, a cementation factor of 2.0, and a formation temperature of 27 °C. The methodology, relations, and assumptions (Reese, 1994, 2000; Reese and Memberg, 2000) used in this evaluation are believed to be valid for the Floridan aquifer system in all of southern Florida.

The depths of the salinity zone boundaries at the Coral Springs site, based primarily on a resistivity geophysical log, are shown in figure 23. Additionally, these boundaries are shown in well STL-332 at the Fort Pierce Wastewater Treatment Plant in northeastern St. Lucie County (fig. 24).

The approximate depths of the base of the brackish-water zone, and in most cases, the top of the saline-water zone, were determined at 13 wells in the study area (table 4). Three other wells (OK-9001/OK-9002, PB-1197 and STL-379) were drilled to sufficient depths to provide a minimum depth to the base of the brackish-water zone or an estimate of the depth, even though this boundary was not reached. A dual-induction log was used to determine both boundaries at 6 of the 13 wells; this log also was used to determine the top of the saline-water zone at 2 other wells (table 4). Placement of boundaries in all wells were in agreement with water-quality data collected from known intervals (packer test or completed intervals) in a well or at another well at the same site. Only water-quality data from known intervals were used at two wells to determine the base of the brackish-water zone. Use of water-quality data alone is often not as accurate as using geophysical logs to determine salinity zone boundaries because sampled intervals tend to be large, limited in number, or both.

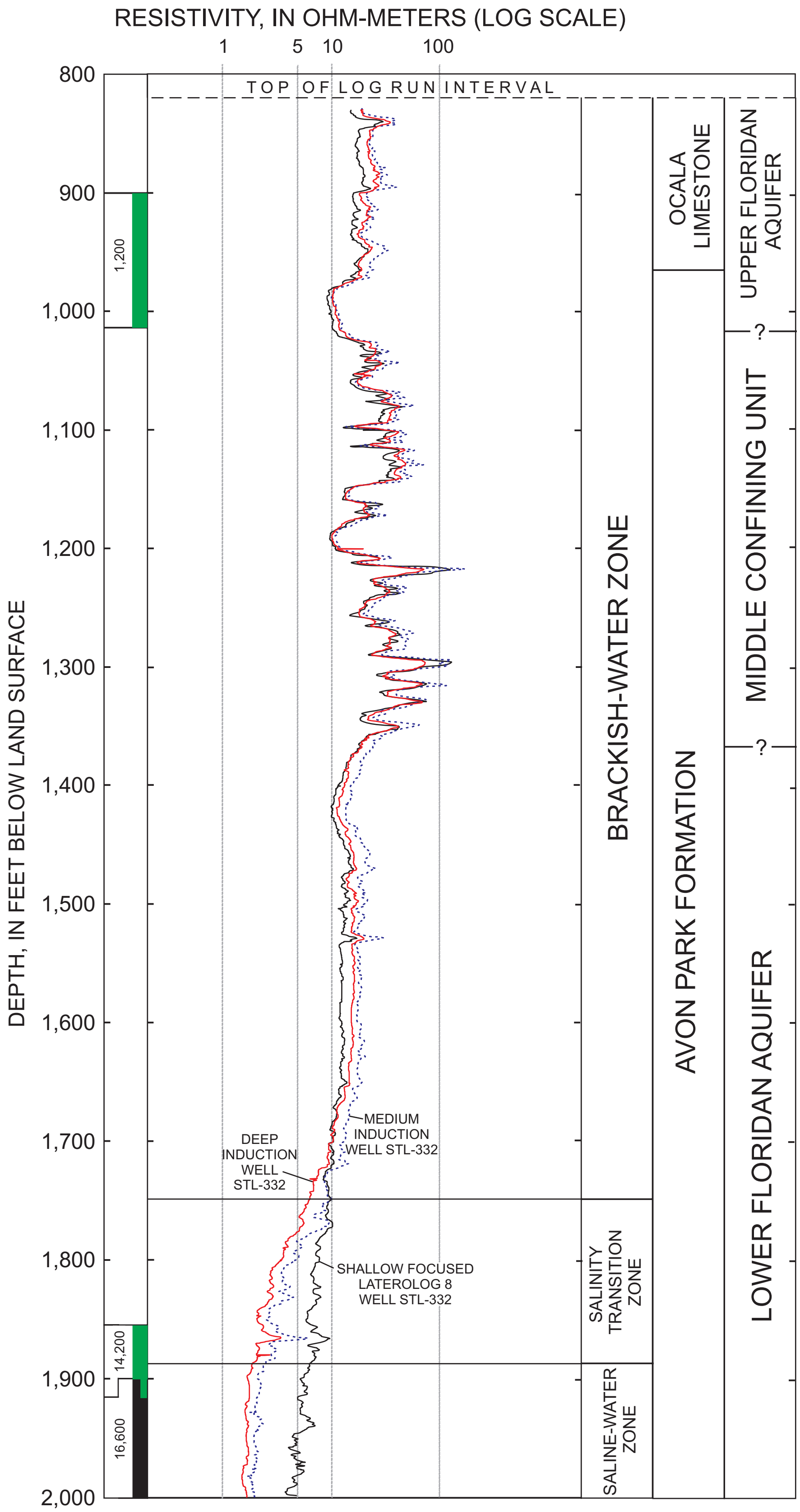
The thickness of the salinity transition zone ranges from 70 to greater than 760 ft and averages about 200 ft thick at seven sites; the thickness was 134 ft or less at four sites (table 4). South of the study area in Miami-Dade and Broward Counties, southeastern Florida, the average thickness of this zone was 143 ft with a range from 60 to 257 ft at 18 wells (Reese, 1994).

In the Martin, St. Lucie, Palm Beach, and Okeechobee County study area, the base of the brackish-water zone lies solely within the Lower Floridan aquifer. The depth to this boundary ranges from 1,525 ft below NGVD of 1929 at well IR-1001 to 2,042 ft below NGVD of 1929 at well PB-1133, both of which are in the inland area (fig. 25). Generally, this boundary is deeper in the coastal area than in the inland area. The boundary is anomalously deep in the southern part of the coastal area where it seems to be greater than 1,900 ft below NGVD of 1929 (fig. 25). At the Coral Springs site, the boundary is 2,017 ft below land surface or 2,004 ft below NGVD of 1929 (fig. 23).

In central St. Lucie County, water samples collected from well STL-379 during drilling by the reverse-air rotary method indicate chloride concentration increases to 3,600 mg/L at a depth of 1,515 ft below NGVD of 1929 (Lukasiewicz and Switanek, 1995). On this basis, the base of the brackish-water zone at this well is estimated to be at a depth ranging from 1,575 to 1,675 ft below NGVD of 1929 (table 4).

A state of equilibrium may exist between the brackish-water and saline-water zones. If so, then the base of the brackish water zone approximates a brackish-water/saltwater interface, and the depth to the base of the brackish-water zone can be estimated using the Ghyben-Herzberg approximation (Bear, 1979). This approximation assumes that pressure at the interface due to the column of overlying freshwater (brackish water) is balanced by the pressure due to a column of saltwater extending up to sea level. In southeastern Florida, south of the study area, the predicted shape of a saltwater interface based on the distribution of hydraulic head and the Ghyben-Herzberg relation generally conforms to the mapped base of the brackish-water zone (Reese, 1994; Reese and Memberg, 2000). The base of the brackish water zone is shallowest along the coast and dips inland to the west or northwest as head increases.

In calculations of the altitudes of a saltwater interface using the Ghyben-Herzberg approximation in the study area, density of water in the Upper Floridan aquifer was estimated using an average chloride concentration of water within the aquifer and by assuming that a linear relation exists between chloride concentration and density from freshwater to seawater (table 5). Two values for head were used in the calculations, estimated predevelopment head (Bush and Johnston, 1988) and head as of May 2001 (fig. 15).



EXPLANATION

PACKER TEST INTERVAL--Interval is from 1,900 to 2,028 feet below land surface in well STL-332

COMPLETED INTERVALS--In monitoring well STL-333

? BOUNDARY BETWEEN UNITS UNCERTAIN

14,200 WATER-QUALITY DATA--Water samples collected from completed and packer test intervals. Number is chloride concentration, in milligrams per liter

Figure 24. Water-quality data, resistivity geophysical log, salinity zones, and hydrogeologic units for twin wells STL-332 and STL-333 at the Fort Pierce Wastewater Treatment Plant in northeastern St. Lucie County. Lithology is limestone with various degrees of cementation throughout the interval shown.

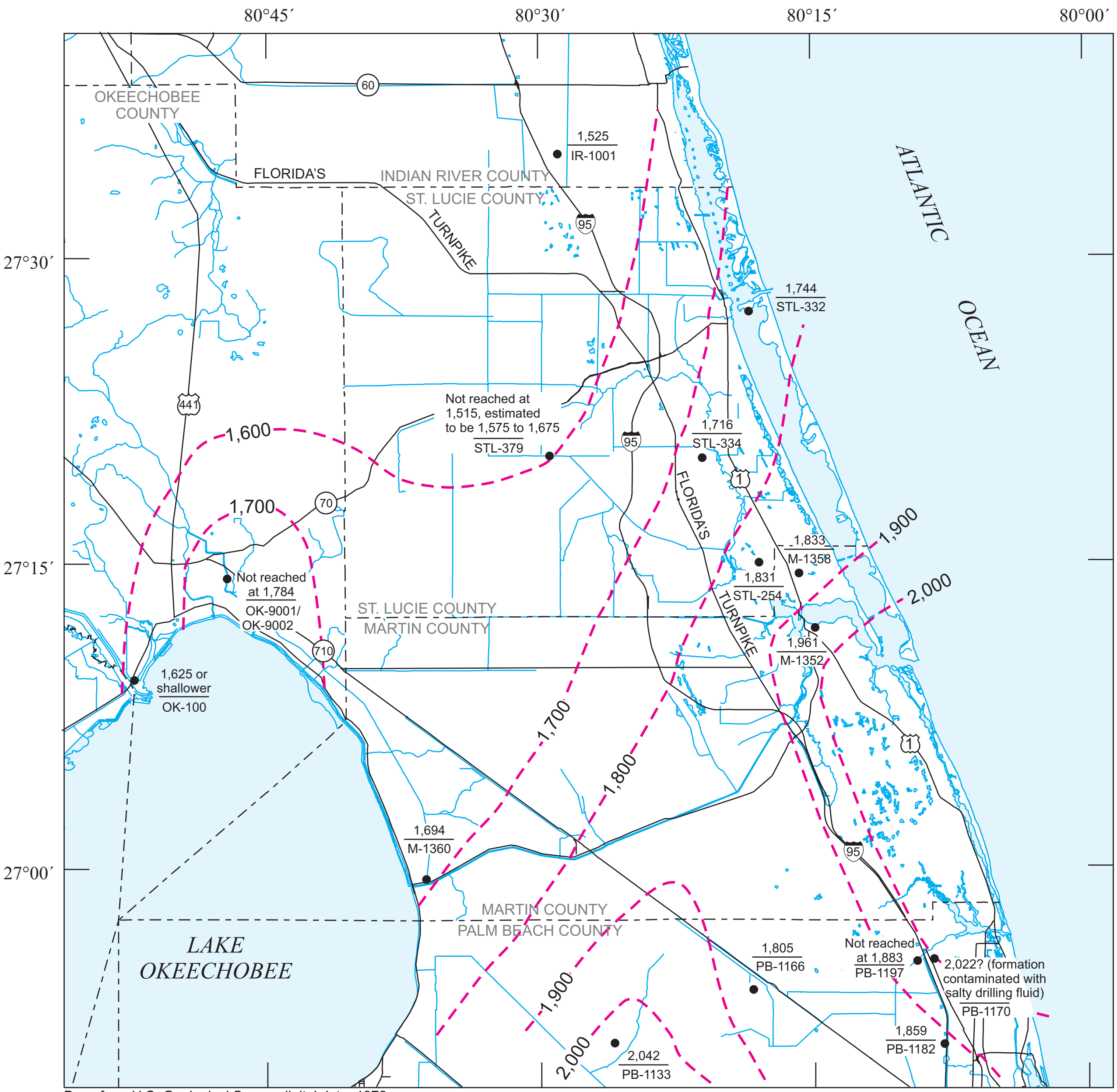
Table 4. Depths to salinity zone boundaries in the Floridan aquifer system as determined in this study

[Depths are below land surface. Annotations: SFWMD, South Florida Water Management District; USGS, U.S. Geological Survey; BWZ, brackish-water zone; STZ, salinity transition zone; SWZ, saline-water zone. Methods: DIL, dual induction geophysical log (deep and medium induction and shallow focusing electrode devices); E, conventional electrical geophysical log (long and short normal devices); SPR, single point resistance geophysical log; completed interval, water-quality data collected from constructed well; DQW, water-quality data collected while drilling by reverse-air rotary method; packer test, water-quality data collected from packer test. Other annotations: ?, Depth uncertain because of formation contamination with salty drilling fluid; NR, not reached; <, less than the value; >, greater than the value]

USGS well number	SFWMD number or other identifier	Total depth (feet)	Land surface elevation (feet)	Depth to base of BWZ (feet)	Depth to top of SWZ (feet)	Thickness of STZ (feet)	Method
IR-1001	Hercules IW-1	3,005	25	1,550	<1,700	<150	For base of BWZ - SPR. DIL for top of SWZ
M-1352	Stuart IW-2	3,252	8.74	1,970	2,040	70	DIL
M-1358	North Martin IW-2	3,350	17.5	1,850	2,045	195	DIL
M-1360	MF-37	2,030	16	1,710	1,885	175	DIL
OK-100	OKF-100	2,030	15	<1,640	NR	NR	Packer test
OK-9001/ OK-9002	Lake Okeechobee ASR monitoring well	1,800	16	NR at 1,800	NR	NR	DQW and completed interval
PB-1133	Permit 235	11,010	38	2,080	2,230	150	E
PB-1166	Pratt & Whitney IW-1	3,310	25	1,830	2,010	180	DQW for base BWZ E for top of SWZ
PB-1170	ENCON IW-1	3,505	18	2,040?	>2,800	>760	DIL
PB-1182	Seacoast IW-1	3,320	21	1,880	2,550	670	Packer test and completed intervals. DIL for top of SWZ
PB-1197	Jupiter RO-5	1,900	17	NR at 1,900	NR	NR	DQW
STL-254	SPSL IW-1	3,418	9.5	1,840	1,916	76	E and packer tests in MW-1A
STL-332	FP IW-1	3,315	6	1,750	1,884	134	DIL
STL-334	NPSL IW-1	3,324	15	1,730	1,835	105	DIL
STL-379	SLF-73	1,540	25	NR, estimated at 1,600 to 1,700	NR	NR	DQW
STL-386	SPSL MW-1A	1,960	9	1,870	Uncertain	Uncertain	E

These heads, recorded as freshwater heads, were corrected using the estimated density of water contained within the Upper Floridan aquifer at each well.

The position of the computed predevelopment Ghyben-Herzberg saltwater interface is comparable to the altitude of the base of the brackish-water zone in some wells and substantially different in other wells (table 5); the difference is 80 ft or less at 5 of 13 wells. In Miami-Dade and Broward Counties of southeastern Florida, this difference was 56 ft or less at five of eight wells (Reese, 1994). Differences between these two numbers can be attributed to the presence of the salinity transition zone rather than a sharp interface, a ground-water flow system that does not conform well to the assumptions of the Ghyben-Herzberg approximation (horizontal flow above the interface and no flow in the saltwater region), and the potential for upward movement of the interface from its predevelopment position in response to regional lowering of head prior to when a well was drilled. Additionally, an error in the estimated average chloride concentration in the Upper Floridan aquifer (table 5) could cause a significant error in the computed predevelopment saltwater interface. For example, decreasing the average chloride concentration in well PB-1182 (table 5) from 3,000 mg/L to 2,000 mg/L lessens the depth of the interface by 104 ft, from 2,087 ft to 1,983 ft below NGVD of 1929, and using the lower chloride concentration in this case gives better agreement of the computed predevelopment saltwater interface with the base of the brackish-water zone.



Base from U.S. Geological Survey digital data, 1972
Universal Transverse Mercator projection, Zone 17, Datum NAD 27

EXPLANATION

- – 1,600 – – LINE OF EQUAL ALTITUDE OF THE BASE OF THE BRACKISH-WATER ZONE--In feet below NGVD of 1929. All contours approximately located. Contour interval is 100 feet
- ● 1,694 / M-1360 DEPTH OF BASE OF BRACKISH-WATER ZONE AND LOCAL WELL NUMBER--Upper number is altitude of base of brackish-water zone, in feet below NGVD of 1929. Lower number is local well number

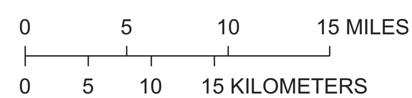


Figure 25. Altitude of the base of the brackish-water zone. NGVD of 1929 is National Geodetic Vertical Datum of 1929.

Table 5. Calculated altitudes of a saltwater interface using the Ghyben-Herzberg approximation and comparison with altitudes of the base of the brackish-water zone

[Well locations are shown in figure 2. BWZ, brackish-water zone; NGVD of 1929, National Geodetic Vertical Datum of 1929; SFWMD, South Florida Water Management District; UFA, Upper Floridan aquifer; USGS, U.S. Geological Survey, NA, Not applicable]

USGS well number	SFWMD or other identifier	Estimated predevelopment head[1] (feet above NGVD of 1929)	Estimated average chloride concentration in UFA (milligrams per liter)	Estimated density of of water in UFA (grams per cubic centimeter)	*a* Corrected predevelopment head (feet above NGVD of 1929)	*b* Ghyben-Herzberg factor[2]	*c (a x b)* Calculated altitude of predevelopment of saltwater interface[3] (feet below NGVD of 1929)	*d* Altitude of base of BWZ[4] (feet below NGVD of 1929)	*(c - d)* Calculated predevelopment saltwater interface minus base of BWZ (feet)	*e* Estimated head May 2001[5] (feet above NGVD of 1929)	*f (b × e)* Calculated May 2001 altitude of saltwater interface (feet below NGVD of 1929)	*(f - d)* Calculated May 2001 saltwater interface minus base of BWZ (feet)
IR-1001	Hercules IW-1	48	1,000	1.0013	47.9	39.267	1,882	1,525	357	32	1,257	-268
M-1352	Stuart IW-2	48	2,300	1.0030	47.9	42.143	2,017	1,961	56	48	2,023	62
M-1358	N.Martin IW-2	48	1,300	1.0017	47.9	39.908	1,912	1,833	80	44	1,756	-77
M-1360	MF-37	59	500	1.0006	59.0	38.191	2,252	1,694	558	49	1,871	177
OK-100	OKF-100	62	Fresh	1.0000	62.0	37.313	2,313	1,625	688	47	1,754	129
PB-1133	Permit 235	54	1,000	1.0013	53.9	39.267	2,118	2,042	76	Unknown	NA	NA
PB-1166	Pratt&Whitney IW-1	51	1,600	1.0021	50.9	40.571	2,065	1,805	260	Unknown	NA	NA
PB-1170	ENCON IW-1	48	2,000	1.0026	47.9	41.430	1,983	2,022	-39	47	1,947	-75
PB-1182	Seacoast	48	3,000	1.0038	47.8	43.643	2,087	1,859	228	47	2,051	192
STL-254	SPSL IW-1	49	1,500	1.0019	48.9	40.237	1,968	1,831	137	43	1,730	-100
STL-332	FP IW-1	46	1,000	1.0013	45.9	39.267	1,804	1,744	59	28	1,099	-645
STL-334	NPSL IW-1	48	1,000	1.0013	47.9	39.267	1,882	1,716	167	36	1,414	-302
STL-379	SLF-73	51	1,000	1.0013	50.9	39.267	2,000	1,575	425	37	1,453	-122

[1]Predevelopment head from Bush and Johnston (1988) recorded as a freshwater head.

[2]Ghyben-Herzberg factor equals $\rho_f/(\rho_s-\rho_f)$, where ρ_f is the density of water in the Upper Floridan aquifer and ρ_s is the density of seawater. Uses 1.0268 grams per cubic centimeter for ρ_s (Parker and others, 1955).

[3]Corrected predevelopment head times Ghyben-Herzberg factor.

[4]Altitude of the base of the brackish-water zone deterined in this study.

[5]May 2001 head from Knowles (2001) recorded as a freshwater head.

In five inland wells, however, the difference between these two depths is greater than what would be expected for these factors; at wells IR-1001, M-1360, OK-100, PB-1166, and STL-379, the altitude of the base of the brackish-water zone was shallower than the calculated predevelopment interface by an amount ranging from 260 ft to 688 ft (table 5).

Formation of a saltwater interface at its equilibrium position in much of the inland area may be prevented by confining units in the Lower Floridan aquifer. Downward movement of fresh to brackish water may be prevented by beds of very low permeability, such as dense dolomite. An alternate theory, however, for explaining this difference is that the hydraulic head in the saline-water zone is substantially greater than zero (sea level), which is assumed in the Ghyben-Herzberg approximation, due to possible heating and expansion of the water in the saline-water zone. Assuming equilibrium, increasing head in the saline-water zone to above sea level would cause the interface to move to a shallower position for the same head in the brackish-water zone.

The anomalous depth of the base of the brackish-water zone in the southern part of the coastal area could be related to the anomalous vertical distribution of salinity in the brackish-water zone in this same area. Anomalously high salinity occurs in this area in the Upper Floridan aquifer (fig. 21), and as previously discussed, there often is a reversal in salinity with depth.

Distribution of Water Temperature

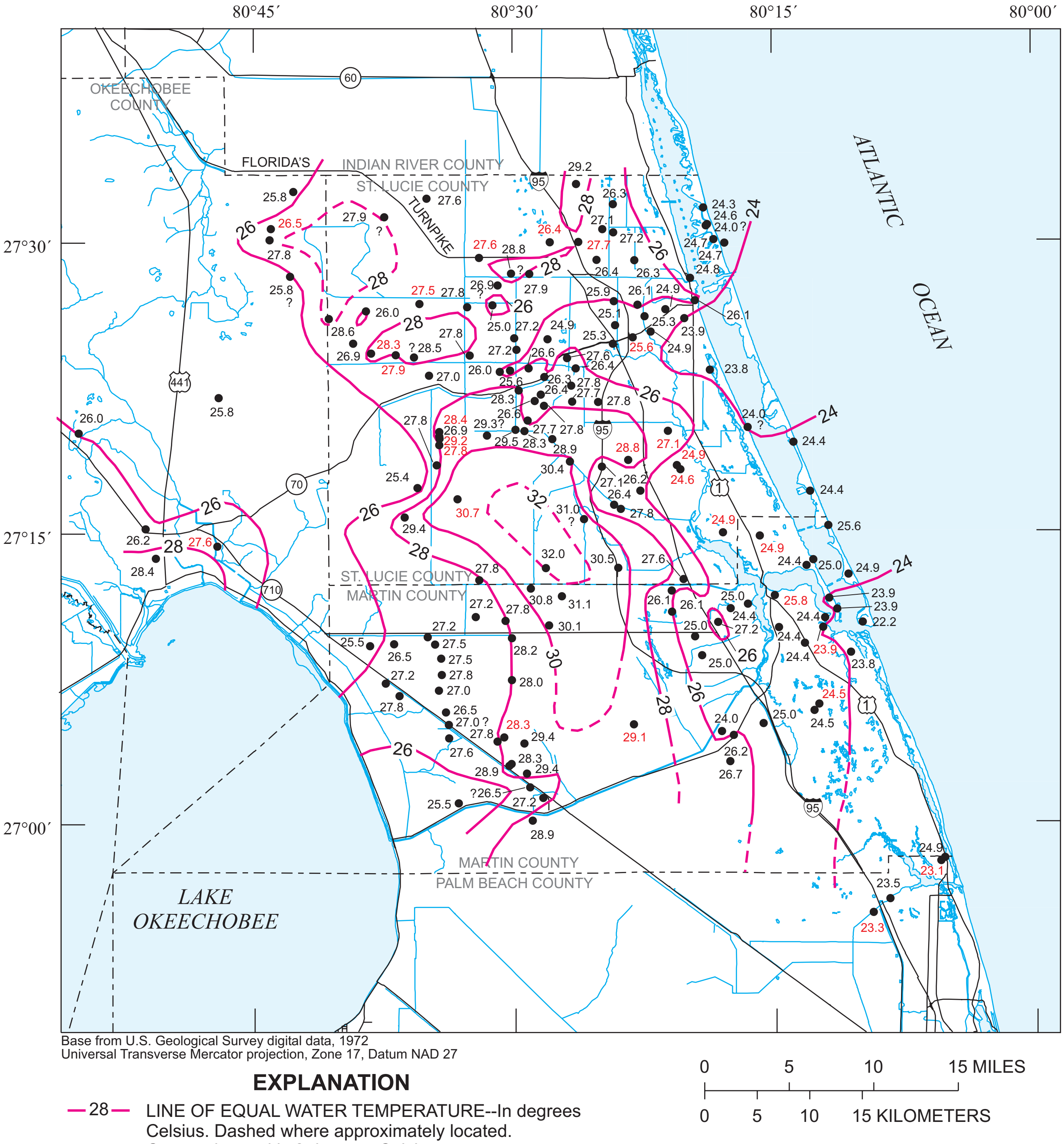
The temperature of ground water withdrawn from the Floridan aquifer system was surveyed in the Martin, St. Lucie, Palm Beach and Okeechobee County study area. For the purpose of this analysis, it is assumed that the change in the temperature of water flowing up a well from the aquifer to the surface is minimal, and that the change is similar between adjacent wells or areas because the depth to the aquifer is similar. The greatest potential error in the latter assumption could be in comparison of areas with a large difference in depth to the top of the Upper Floridan aquifer, such as between north-central Martin County and northeastern Palm Beach County (fig. 11).

The temperature of water withdrawn from the Upper Floridan aquifer varies considerably, ranging from 22.2 °C near the coast in northeastern Martin County to 32.0 °C inland in southern St. Lucie County (fig. 26). An area of high water temperature generally greater than 28 °C trends northwest from central Martin County to northwestern St. Lucie County. Temperatures within this northwest-trending area are greater than 30 °C and up to 32 °C in north-central Martin and south-central St. Lucie Counties. Water temperature in the coastal area is less than 28 °C, except for two small areas with temperatures greater than 28 °C that extend slightly from the inland area into the coastal area (figs. 12 and 26).

Water temperature and sample depth were compared in wells for the Upper and Lower Floridan aquifers (fig. 27), using only samples collected during the course of this study. No correlation exists for wells in the coastal area, whereas in the inland area, a very weak relation of increasing water temperature with depth may exist. Lichtler (1960) indicated a poor correlation of water temperature with depth in the north-central Martin County part of the inland area.

Comparison of the maps showing the distribution of water temperature (fig. 26) and the distribution of chloride concentration (fig. 21) illustrates that the area of high water temperature trending northwest through western St. Lucie County coincides with the northwest-trending area of higher chloride concentration (greater than 1,000 mg/L). Plots of water temperature and chloride concentration using samples collected during this study suggest little correlation exists in the coastal area (fig. 28). A statistically significant correlation, however, has been identified between water temperature and chloride concentration in the inland area ($R^2 = 0.46$).

Meyer (1989) mapped an area of elevated water temperature and salinity in the Upper Floridan aquifer in Martin County and extending northwest through western St. Lucie County. He used this anomaly as evidence in support of upwelling of saline water from the Boulder zone of the Lower Floridan aquifer and mixing with freshwater contained within the Upper Floridan aquifer. In accordance with this interpretation, Kohout (1965) theorized convective movement of ground water in southern Florida because of geothermal heating from below: cold seawater moves inland into the Boulder zone along the southeastern coast, upward through preferential vertical pathways within overlying confining units, and then coastward, mixing within the freshwater flow system in the upper part of the Floridan aquifer system.



EXPLANATION

—28— LINE OF EQUAL WATER TEMPERATURE--In degrees Celsius. Dashed where approximately located. Contour interval is 2 degrees Celsius.

● 28.9 WELL LOCATION AND WATER TEMPERATURE--Temperature in degrees Celsius. See figures 1, 2, or 3 for local well number. For wells with values shown in red, open interval in well includes an upper part of the Lower Floridan aquifer as mapped by Lukasiewicz (1992) in addition to the Upper Floridan aquifer. Question mark (?) indicates total depth of well is unknown

Figure 26. Distribution of water temperature in the Upper Floridan aquifer.

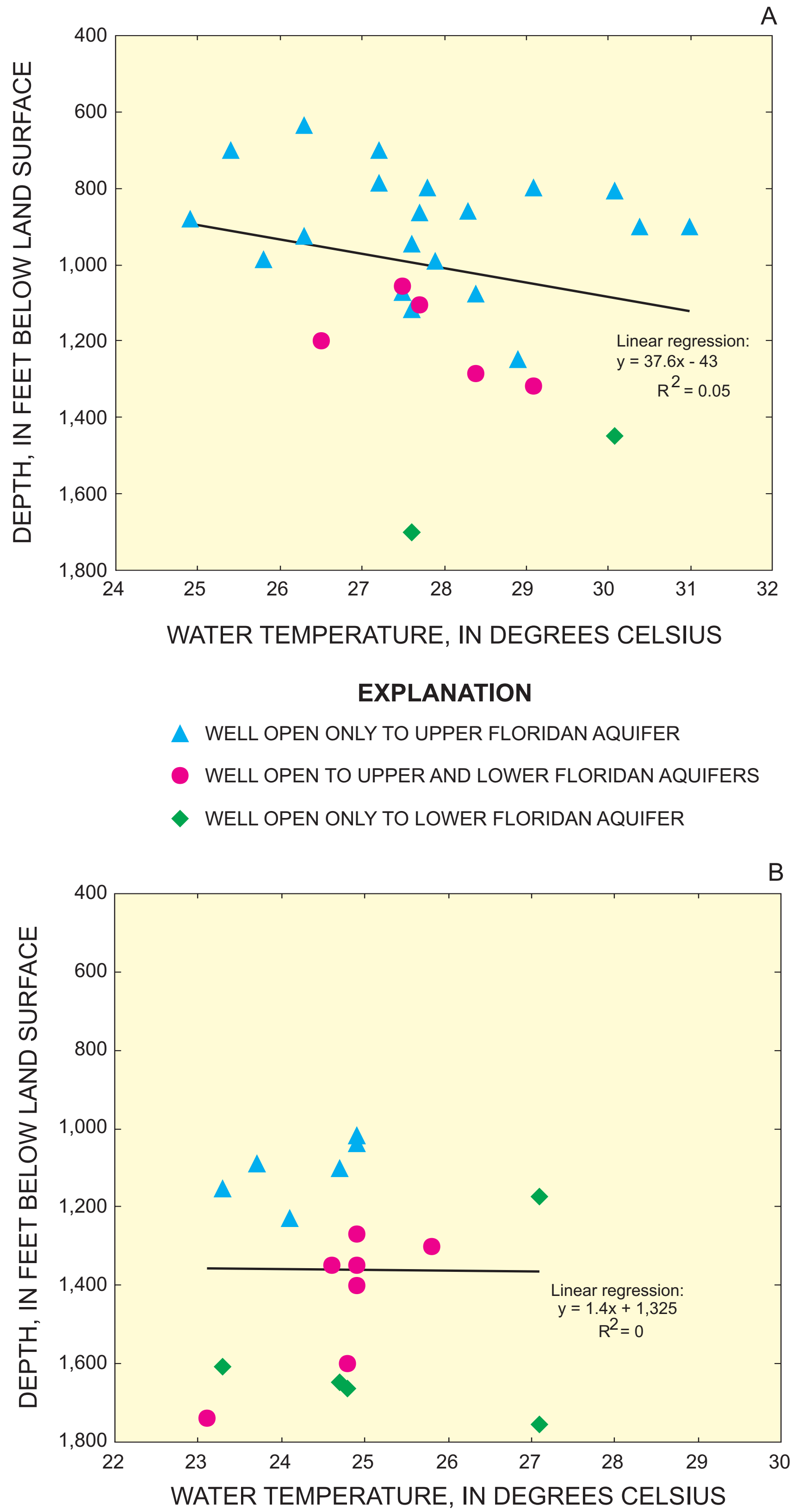


Figure 27. Relation between well depth and water temperature for (A) inland and (B) coastal areas. Depth used is bottom of completed open interval.

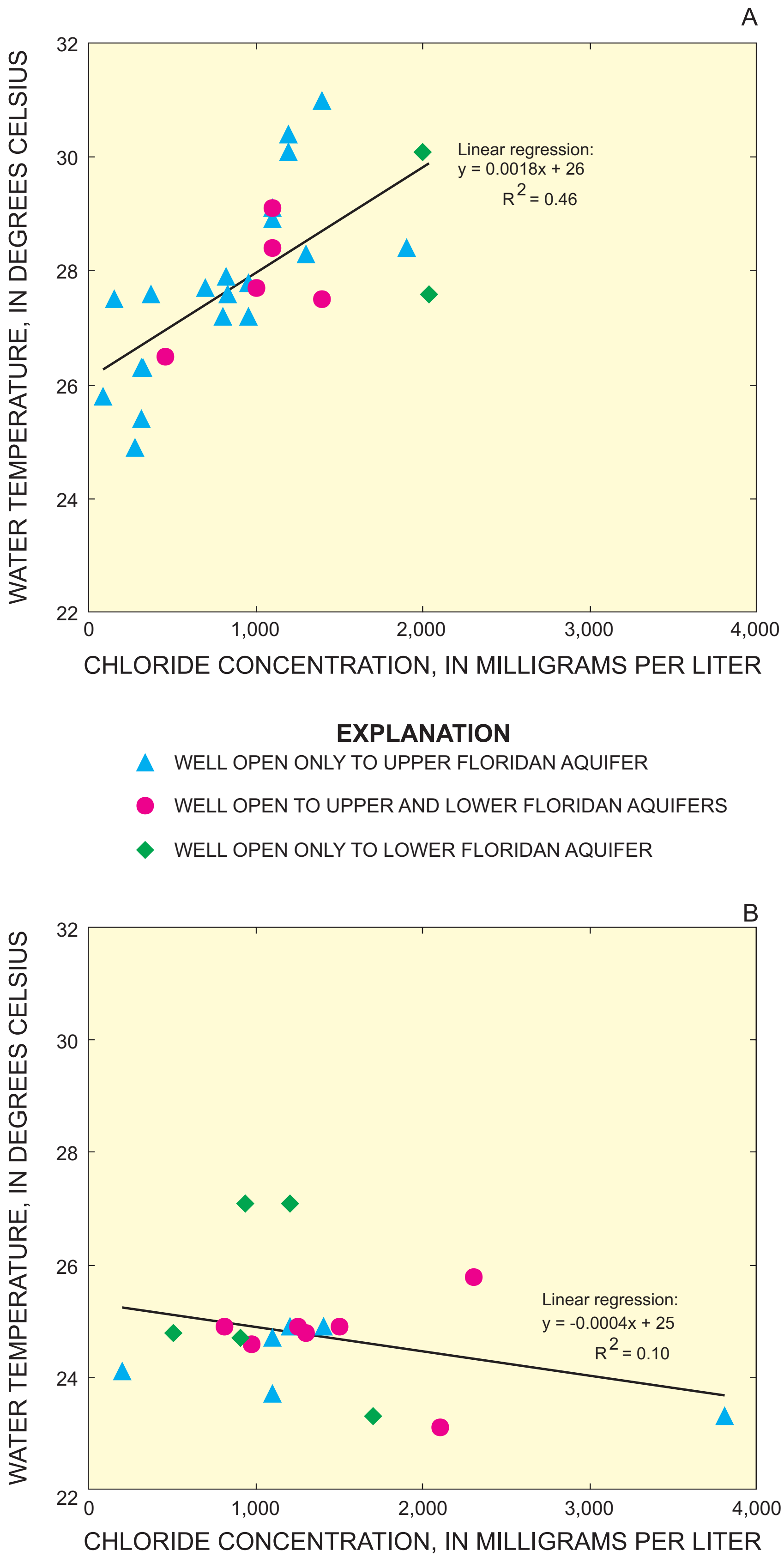


Figure 28. Relation between water temperature and chloride concentration less than 4,000 milligrams per liter for (A) inland and (B) coastal areas. Samples are from completed open intervals in wells.

Localized, warm, upwelling water in the Floridan aquifer system could result in higher hydraulic head than surrounding areas. An area of elevated hydraulic head in the Upper Floridan aquifer for September 1977 is indicated in north-central Martin County and south-central St. Lucie County that extends north-northwest (Brown and Reece, 1979, pl. 2). This area of elevated head (about 4 to 6 ft higher than surrounding areas) roughly coincides with the area of water temperature higher than 30 °C mapped in this study (fig. 26).

Isotopic Analyses

Deuterium (δD), oxygen-18 ($\delta^{18}O$), the strontium-87 to strontium-86 ratio ($^{87}Sr/^{86}Sr$), and stable ($\delta^{13}C$) and radioactive (^{14}C) carbon isotope data were collected during this study, and variations in these constituents were related to factors such as source aquifer, salinity, water temperature, and location (inland or coastal areas). Study of these ground-water isotopic variations can improve understanding of the flow system and the origin and age of water from different areas, water-bearing units, and depths. Isotopic data were collected from 55 completed open intervals in 49 wells (table 6).

Table 6. Isotopic data collected in this study

[Well locations are shown in plate 2. Isotope annotations: $\delta^{18}O$, delta oxygen-18; $\delta^{2}H$, delta deuterium; $^{87}Sr/^{86}Sr$, ratio of strontium-87 to strontium-86; $\delta^{13}C$, delta carbon-13; ^{14}C, carbon-14. Other annotations: DIC, dissolved inorganic carbon; per mil, parts per thousand; PMC, percent modern carbon (unnormalized); BP, before present; --, not determined; ?, unknown]

Local well number	Date	Depth top of open interval (feet below land surface)	Depth bottom of open interval (feet below land surface)	$\delta^{18}O$ (per mil)	$\delta^{2}H$ (per mil)	$^{87}Sr/^{86}Sr$	$\delta^{13}C$ of DIC (per mil)	^{14}C of DIC (as PMC)	^{14}C apparent age (years BP)
CS-I1	09-13-2000	2,153	2,183	0.30	4.7	0.70791	-2.0	5.32	23,570
CS-M2	09-13-2000	1,000	1,110	-.80	-1.8	.70865	-2.2	4.35	25,180
	09-13-2000	1,510	1,653	-1.42	-3.7	.70792	-2.5	4.16	25,530
G3-1	07-26-2001	?	?	-1.51	-4.3	.70777	-4.8	1.70	32,640
G205-5	07-26-2001	?	?	-1.65	-5.6	.70776	-6.6	4.00	25,810
M-255	06-08-2000	300	800	-1.64	-2.9	.70778	--	--	--
	07-24-2001	300	800	--	--	--	-5.6	2.10	30,920
M-745	06-08-2000	360	810	-1.53	-2.9	.70776	--	--	--
	07-24-2001	360	810	--	--	--	-5.7	2.30	30,490
M-1033	07-10-2000	2,027	2,093	.37	5.9	.70787	-.4	2.41	29,910
M-1034	07-10-2000	1,010	1,300	-1.14	-2.1	.70780	-4.2	4.77	24,440
M-1121	07-13-2000	543	1,020	-1.42	-4.4	.70785	--	--	--
	07-18-2001	543	1,020	--	--	--	-3.7	2.10	31,180
M-1125	06-08-2000	456	1,120	-1.81	-4.1	.70781	--	--	--
M-1325	08-30-2001	1,715	1,757	-1.24	-3.5	.70782	-2.1	3.90	26,090
	08-30-2001	2,177	2,212	.50	3.7	.70782	-3.4	10.40	18,220
M-1326	07-10-2000	844	1,091	-1.30	-3.5	.70785	--	--	--
M-1330	06-08-2000	400	1,250	-1.52	-3.6	.70774	--	--	--
	07-17-2001	400	1,250	--	--	--	-3.7	1.60	33,490
M-1347	07-13-2000	400	1,320	-1.44	-5.0	.70781	--	--	--
M-1353	07-10-2000	1,600	1,650	-1.24	-2.9	.70784	-4.8	2.68	29,070
M-1356	08-30-2001	1,165	1,400	-1.22	-2.9	.70777	-2.9	2.30	30,260
OK-13	05-31-2000	600	1,200	-1.53	-4.7	.70780	--	--	--
OK-17	05-31-2000	538	986	-1.39	-4.4	.70777	--	--	--
OK-23	05-31-2000	496	925	-1.80	-6.3	.70777	--	--	--
OK-31	05-31-2000	?	1,079	-1.71	-3.3	.70781	--	--	--
	07-19-2001	?	1,079	-1.80	-6.0	.70777	-3.3	1.60	33,340

Table 6. Isotopic data collected in this study (Continued)

[Well locations are shown in plate 2. Isotope annotations: $\delta^{18}O$, delta oxygen-18; $\delta^{2}H$, delta deuterium; $^{87}Sr/^{86}Sr$, ratio of strontium-87 to strontium-86; $\delta^{13}C$, delta carbon-13; ^{14}C, carbon-14. Other annotations: DIC, dissolved inorganic carbon; per mil, parts per thousand; PMC, percent modern carbon (unnormalized); BP, before present; --, not determined; ?, unknown]

Local well number	Date	Depth top of open interval (feet below land surface)	Depth bottom of open interval (feet below land surface)	$\delta^{18}O$ (per mil)	$\delta^{2}H$ (per mil)	$^{87}Sr/^{86}Sr$	$\delta^{13}C$ of DIC (per mil)	^{14}C of DIC (as PMC)	^{14}C apparent age (years BP)
OK-72	05-31-2000	500	800	-1.65	-3.3	.70776	--	--	--
	07-19-2001	500	800	--	--	--	-3.3	.80	38,420
OK-9001	07-24-2001	990	1,075	-1.98	-7.4	.70777	-2.4	3.00	28,070
OK-9002	07-24-2001	1,275	1,700	-1.69	-5.6	.70776	-6.1	10.80	17,880
PB-1144	07-13-2000	1,020	1,038	-1.36	-3.0	.70791	--	--	--
PB-1196	06-05-2000	1,137	1,155	-1.09	-1.3	.70789	--	--	--
	06-05-2000	1,549	1,609	-1.26	-1.4	.70784	--	--	--
	07-17-2001	1,137	1,155	--	--	--	-1.1	.50	41,900
	07-17-2001	1,549	1,609	--	--	--	-2.5	.80	39,280
PB-1774	08-29-2001	1,120	1,740	-1.19	-3.0	.70791	-2.6	1.00	36,650
STL-215	06-06-2000	310	1,106	-1.52	-2.9	.70781	--	--	--
	07-25-2001	310	1,106	--	--	--	-7.6	2.10	30,860
STL-216	06-01-2000	482	993	-1.46	-2.8	.70780	--	--	--
STL-217	06-01-2000	263	1,058	-1.49	-2.7	.70779	--	--	--
	10-19-2001	263	1,058	--	--	--	-3.9	1.10	36,250
STL-218	06-01-2000	224	946	-1.53	-6.3	.70773	--	--	--
STL-220	06-07-2000	318	1,286	-1.64	-4.6	.70775	--	--	--
	07-18-2001	318	1,286	--	--	--	-5.6	0.90	38,160
STL-224	06-06-2000	156	707	-1.52	-4.0	.70777	--	--	--
STL-255	07-12-2000	898	1,268	-1.27	-2.5	.70779	-4.4	4.62	24,690
	07-12-2000	1,610	1,663	-1.27	-1.9	.70784	-4.3	3.61	26,670
STL-335	07-12-2000	950	1,175	-1.35	-3.6	.70780	-7.4	5.20	23,740
	07-12-2000	1,730	1,800	-.54	-.1	.70782	-.2	1.37	34,490
STL-342	06-01-2000	?	?	-1.46	-5.2	.70780	--	--	--
STL-346	06-01-2000	?	786	-1.56	-3.1	.70780	--	--	--
STL-352	06-06-2000	?	1,100	-1.48	-4.1	.70788	--	--	--
	07-16-2001	?	1,100	--	--	--	-2.4	2.30	30,200
STL-353	06-06-2000	850	1,230	-1.39	-2.8	.70779	--	--	--
STL-375	06-07-2000	420	866	-1.51	-2.6	.70777	--	--	--
STL-376	07-12-2000	?	638	-1.52	-5.0	.70777	--	--	--
	07-25-2001	?	638	--	--	--	-3.6	3.20	27,700
STL-380	06-07-2000	1,070	1,450	-1.45	-3.6	.70778	--	--	--
	07-18-2001	1,070	1,450	--	--	--	-4.6	1.00	36,760
STL-381	06-07-2000	480	700	-1.51	-3.6	.70779	--	--	--
	07-18-2001	480	700	--	--	--	-4.7	1.20	35,300
STL-382	06-07-2000	790	860	-1.49	-3.0	.70775	--	--	--
STL-385	06-15-2000	500	880	-1.57	-4.1	.70780	--	--	--
	07-25-2001	500	880	--	--	--	-3.6	2.80	28,750
STL-386	07-12-2000	1,887	1,960	-.28	3.4	.70785	-.5	1.22	35,400
STL-387	07-11-2000	?	1,600	-1.39	-3.7	.70783	-6.2	4.52	24,870
STL-388	07-11-2000	650	1,350	-1.43	-4.0	.70780	-4.6	2.28	30,360
STL-389	07-11-2000	650	1,350	-1.41	-4.5	.70778	--	--	--
STL-391	07-11-2000	?	900	-1.33	-4.4	.70779	--	--	--
	07-18-2001	?	900	--	--	--	-5.7	1.50	33,620
STL-392	07-11-2000	?	900	-1.39	-3.6	.70783	--	--	--

Deuterium and Oxygen-18

Values of δD and $\delta^{18}O$ for each sample are typically plotted on a diagram, and the distribution of samples is related to a global meteoric water line (Craig, 1961). The position of data relative to this line can indicate important information on waters that have undergone evaporation, recharge during different climatic conditions, and mixing of waters from different sources, such as recharged downgradient ground water and saltwater. Most of the 56 samples from 55 separate open intervals collected in the study area (table 6) fall below the global meteoric water line (fig. 29). Data from the coastal area and the three samples from the Coral Springs WWTP plot along a saltwater mixing line. All six of the points along this line, with $\delta^{18}O$ higher than -1 per mil, have a dissolved-solids concentration exceeding 10,000 mg/L. The extension and intersection of this saltwater mixing line with the global meteoric water line occurs approximately at δD equal to –6.5 per mil and $\delta^{18}O$ equal to –2 per mil; this point compares favorably with isotope data described by Sacks and Tihansky (1996) as fresh "downgradient waters from the Upper Floridan aquifer" in southwestern Florida. Samples from the inland area are isotopically lighter (depleted in deuterium and ^{18}O and values of δD and $\delta^{18}O$ more negative) than samples from the coastal area and plot as a relatively separate nonlinear group. Some inland area data plot close to an extension of the saltwater mixing line fit to the coastal area data, whereas others plot on or near the global meteoric water line. Separation of the data from the two areas indicates that inland area ground water was recharged under different climatic conditions than coastal area ground water or has not mixed with saltwater or both.

Strontium-87/Strontium-86 and Stontium Concentration

Strontium concentration and $^{87}Sr/^{86}Sr$ can be useful indicators of ground-water movement and origin of salinity. The $^{87}Sr/^{86}Sr$ of marine carbonate rocks of Cenozoic age have been measured, and these data have shown strong variation during the late Cenozoic Erathem, providing a high-resolution dating tool during this time (Elderfield, 1986; Howarth and McArthur, 1997). The Floridan aquifer system consists of marine carbonates of Cenozoic age that contain strontium derived from the seawater present during deposition. If the $^{87}Sr/^{86}Sr$ of ground water has equilibrated with the $^{87}Sr/^{86}Sr$ of the rock or sediment containing the water, then the source of the water can be determined, provided the age of potential source rocks are known. The time required for equilibration to occur, however, is uncertain.

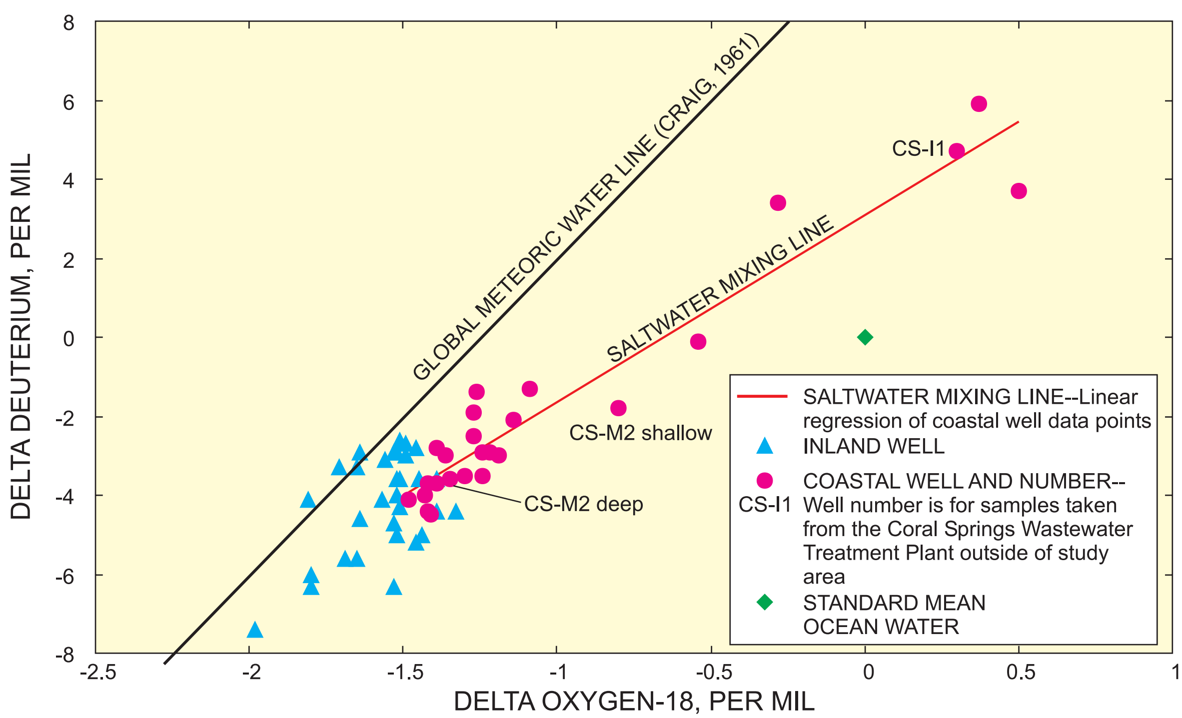


Figure 29. Relation between delta deuterium and delta oxygen-18 in ground water in the study area.

For all of the samples collected in this study (app. IV), strontium concentration was compared to chloride concentration. All water samples had strontium concentrations that plotted considerably above the saltwater mixing line when strontium was graphically compared to chloride concentration (fig. 30). This suggests that dissolution of strontium from the carbonate aquifer matrix represents an important process. Samples from inland area wells generally exhibited a much higher concentration of strontium than coastal area wells, suggesting that inland area waters are older, allowing more time for dissolution.

The $^{87}Sr/^{86}Sr$ ratio was graphically compared to the inverse of strontium concentration and $^{87}Sr/^{86}Sr$ seawater age boundaries (fig. 31). Many of the $^{87}Sr/^{86}Sr$ samples from coastal area wells indicate an early Oligocene seawater age, whereas inland area samples indicate an Eocene seawater age. This result suggests that the basal Hawthorn/Suwannee unit of Oligocene age, which thickens in the coastal area, contributes a greater portion of the water withdrawn in the coastal area wells (as compared to deeper formations) than in the inland area. Many of the samples indicating an early Oligocene age, however, were obtained from wells open exclusively or partially to the Lower Floridan aquifer of Eocene age. A more likely explanation is that Floridan aquifer system ground water in the coastal area may be younger than the host rock because equilibration with the host rock has not yet occurred. Perhaps much of the Floridan aquifer system in the coastal area was invaded with seawater during Pleistocene Epoch high sea-level stands, and flushing out this saline water has been incomplete. Saline water with a $^{87}Sr/^{86}Sr$-derived Oligocene seawater age was collected within the Avon Park Formation of Eocene age near the coast in southwestern Florida. This age is attributed to the mixing of formation water with younger seawater introduced into the Floridan aquifer system (Sacks and Tihansky, 1996).

Stable and Radioactive Carbon Isotopes

Carbon-13 ($\delta^{13}C$) and carbon-14 (^{14}C) of dissolved inorganic carbon are used together to date ground water and gain insight on the evolution of

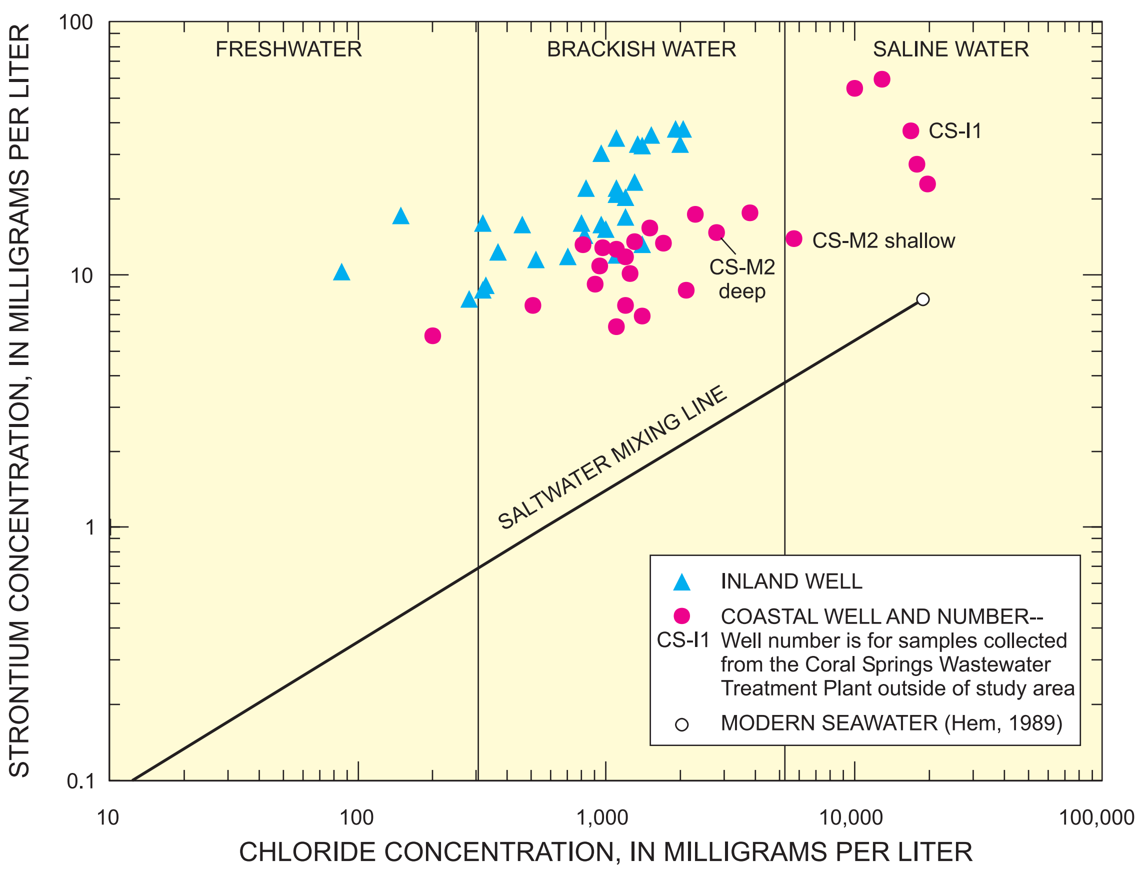


Figure 30. Relation between strontium and chloride concentrations in ground water in the study area.

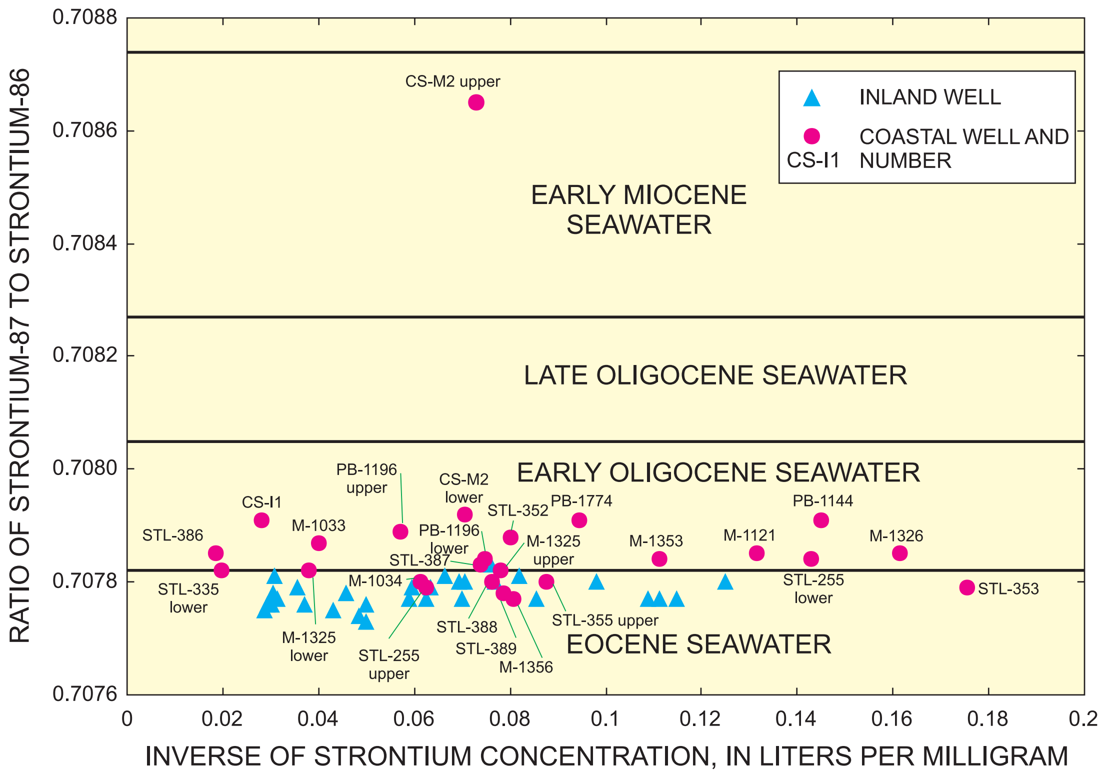


Figure 31. Relation between ratio of strontium-87 to strontium-86 and the inverse of strontium concentration in ground water in the study area.

ground water from recharge areas to confined downgradient areas. A laboratory-derived, apparent carbon-14 age can be adjusted using geochemical models for reactions of the ground water with aquifer minerals. This adjusted sample age is younger that the apparent age due to dissolution of dead carbon (zero ^{14}C) from the carbonate rocks in the Floridan aquifer system during downgradient movement from the recharge area in central Florida. In this study, however, adjusted ages were not determined, and the ages of samples, in terms of PMC, are used in a relative sense to compare the ages of samples. In a study of the intermediate aquifer system in southwestern Florida, adjusted carbon-14 ages were determined for ground-water samples from the intermediate and Floridan aquifer systems (Torres and others, 2001), and a linear correlation between these ages and the apparent ages was evident (L.A. Sacks, U.S.Geological Survey, written commun., 2003). Apparent ages were about 12,000 years older than adjusted ages.

Carbon-13 in ground water evolves to near zero per mil in deeply buried parts of the flow system as a result of confinement and dissolution of isotopically heavy (enriched in ^{13}C) calcite and dolomite. Recently recharged water in the surficial aquifer system has the isotopically light (depleted in ^{13}C) $\delta^{13}C$ signature of soil-zone carbon dioxide (CO_2). Soil-zone CO_2 usually has a $\delta^{13}C$ range of -25 to -20 per mil (Deines and others, 1974). Changes in $\delta^{13}C$ in the confined Upper Floridan aquifer of southwestern Florida is attributed to dissolution or precipitation of dolomite (Sacks and Tihansky, 1996).

The carbon-13 and carbon-14 analysis was performed on 38 samples collected in this study. Unnormalized ^{14}C activity was reported as PMC and apparent age in years before present (table 6). The PMC values range from 0.50 to 10.80, and correspondingly apparent ages range from 41,900 to 17,880 years before present. The $\delta^{13}C$ in the 38 samples range from -7.6 to -0.2 per mil (table 6).

Comparison of $\delta^{13}C$ with PMC indicates that the evolution of ground water in inland and coastal areas is different (fig. 32). Inland area samples tend to group toward low PMC and lighter $\delta^{13}C$ (-8 to-2.5 per mil); grouping is even more concentrated for inland area samples having a water temperature of 28 °C or higher ($\delta^{13}C$ from -6 to -3 per mil). Coastal area samples tend to exhibit wide variability in both $\delta^{13}C$ and PMC.

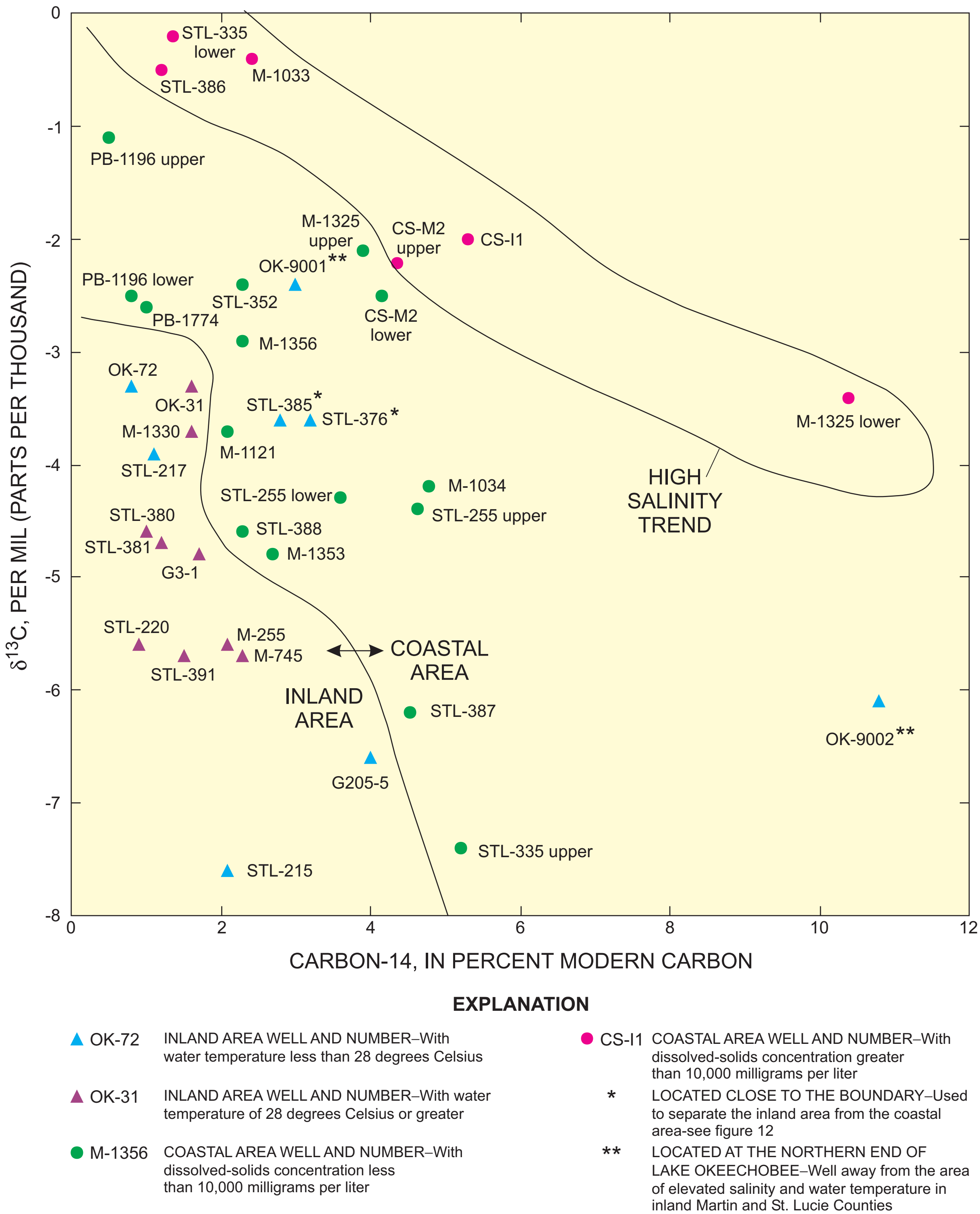


Figure 32. Relation between $\delta^{13}C$ and carbon-14, in percent modern carbon in the study area.

However, samples containing dissolved-solids concentration exceeding 10,000 mg/L group in a separate trend that extends toward 0.0 per mil $\delta^{13}C$ and 0.0 PMC and has $\delta^{13}C$ heavier than -3.5 per mil. The distribution of data indicates that ground water in the inland area has had a greater time of residence than ground water in much of the coastal area, particularly for samples from inland wells having water temperature of 28 °C or higher. Four notable exceptions are samples from wells STL-376, STL-385, OK-9001, and OK-9002. They are inland area samples that plot in the same area as coastal area samples in figure 32. However, both wells STL-376 and STL-385 are located close to the 100-ft thickness contour line for the basal Hawthorn/Suwannee unit used to separate the inland area from the coastal area (pl. 2 and fig. 12), and monitoring well OK-9001/OK-9002 at the northern end of Lake Okeechobee, may be in a different flow regime than most of the inland area. This well is located in a structurally low area (figs. 11 and 13) and well away from the area of elevated salinity and water temperature in inland Martin and St. Lucie Counties (figs. 21 and 26). Of the five samples from the coastal area indicating an older age (less than 2 PMC), two have high salinity (greater than 10,000 mg/L dissolved-solids concentration), and the other three are from northeastern Palm Beach County – the farthest downgradient part of the study area (fig. 15, predevelopment potentiometric contours).

The $\delta^{13}C$ values of inland area ground water could be influenced by dolomite dissolution, if the dolomite that is common in the Lower Floridan aquifer in the inland area formed in a brackish- to saline-water mixing zone associated with a saltwater interface. Some evidence supporting a mixing zone origin for the thick beds of dolomite has been described previously for the Lower Floridan aquifer in Palm Beach County (Reese and Memberg, 2000). Hanshaw and Back (1972) hypothesized that isotopically lighter dolomites in the Floridan aquifer system with $\delta^{13}C$ ranging from –7.5 to –2.8 per mil formed in a saltwater mixing zone; this range is similar to that seen for inland area samples (fig. 32). The trend of coastal area samples with high salinity (greater than 10,000 mg/L dissolved-solids concentration) shown in figure 32 could indicate that dolomite precipitation is occurring in a saltwater mixing zone.

Temporal Changes in Salinity

Few salinity data are available for the study area prior to 1977, and the data that are available indicate minor, if any, change in the salinity of the Upper Floridan aquifer. Lichtler (1960) does not mention any increase in salinity in Martin County. Chloride concentration data indicate salinity in the Upper Floridan aquifer did not change substantially in the UEC Planning Area between 1957 and 1977 (Brown and Reece, 1979). In Indian River County, however, a 22-percent increase on average in chloride concentration was observed between 1951 and 1984 in 26 Floridan aquifer system wells located mostly in the eastern half of the county (Schiner and others, 1988).

Temporal salinity change in the Upper Floridan aquifer was studied at 18 monitoring wells in the UEC Planning Area between 1977 and 1990 (Lukasiewicz and Switanek, 1995). Salinity indicators, including chloride and dissolved-solids concentrations, exhibited change in only 4 of the 18 wells during this period. The increase in salinity indicated was considered to be inconclusive due to limited observations in only a few wells. Only minor seasonal variability in salinity was observed in most wells. At the Sailfish Point Well Field, however, average salinity for two wells increased 15 percent between 1982 and 1992 (table 1 and fig. 2). Combined water use for six wells at this well field for the same period of time increased by 250 percent to greater than 1 Mgal/d (Lukasiewicz and Switanek, 1995).

In this study, additional Floridan aquifer system wells were identified that indicate increasing salinity with time. Based on current and historical water-quality data collected since 1977, salinity has increased substantially in 9 of 24 wells (table 2). All but one of these 24 wells are in the SFWMD Floridan aquifer system monitoring well network. In the nine wells indicating an increase, the increase was from 10 percent to as high as 207 percent based on linear regression. The periods over which these increases occurred ranged from 6 to 24 years. The percent increase and period for two of the wells in table 2, STL-220 and STL-224, was 20 percent over 24 years and 4 percent over 10 years, respectively (fig. 16).

Specific conductance data obtained from the NRCS monitoring program (45 wells in 16 groves since 1996) were used to assess salinity changes. Nine wells located in six groves exhibited a substantial increase in salinity over the last 5 to 6 years (1996-2001). Specific conductance increased by 26 percent in G35-1 as indicated by linear regression (fig. 33) and by

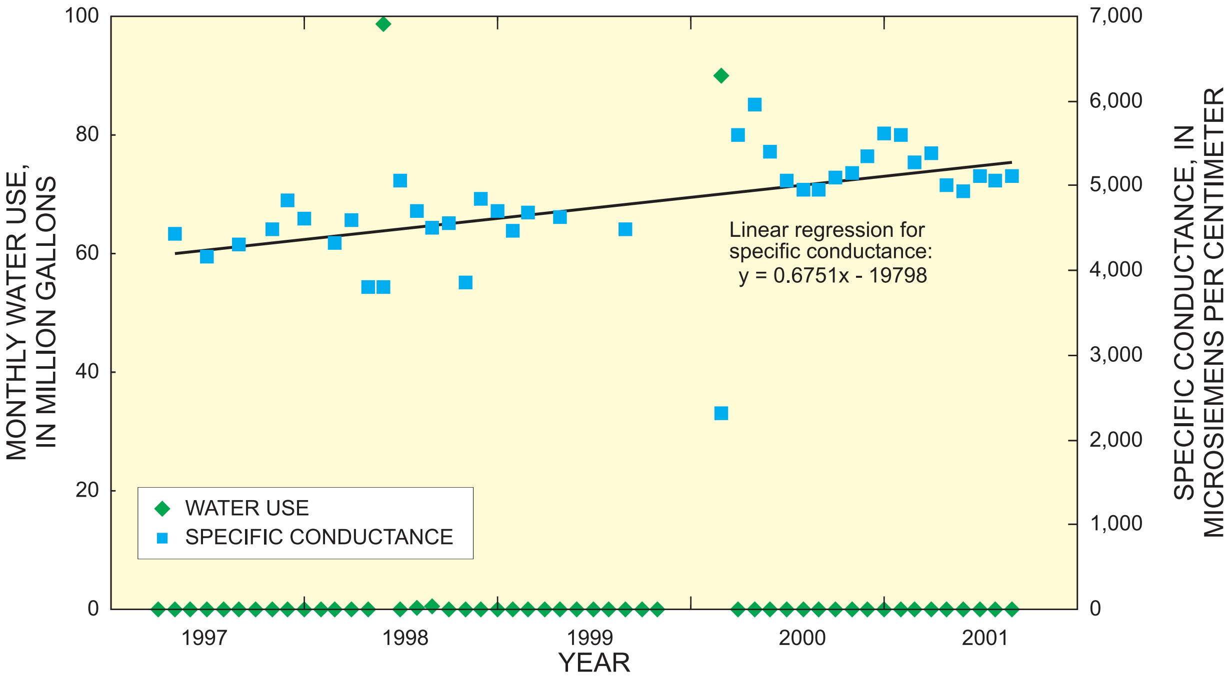


Figure 33. Water-use and specific conductance data for Natural Resources Conservation Service monitoring well G35-1, 1997-2001.

11 to 72 percent for all nine wells. Some of the increase in these nine wells could be due to increased water use in the agricultural area during the 2000 and 2001 water years, as evidenced by the NRCS water-use data (fig. 17).

Production well chloride concentration data from the Jupiter Well Field indicate a temporal increase in salinity. Monthly withdrawals and average chloride concentration in eight wells were evaluated between 1996 and 2001 (fig. 34); average chloride concentration increased 40 percent as indicated by linear regression of the data. Chloride concentration generally seems to correspond to the withdrawal rate; however, chloride concentration can increase during the latter part of the dry season before the withdrawal rate substantially increases. The temporal change in chloride concentration in individual wells is variable. In some wells, such as Jupiter RO-5 (fig. 9, well PB-1197), chloride concentration is not increasing, whereas in other wells the increase in chloride concentration is greater than average. Chloride concentration increased temporarily to 4,000 mg/L in Jupiter RO-2 and RO-3 in June 2000. Available data from other Floridan well fields in the study area did not indicate a substantial increase in salinity with time; although an increase at the Sailfish Point Well Field, as discussed above, was observed between 1982 and 1992 (Lukasiewicz and Switanek, 1995).

All of the wells or well fields that indicate an increase in salinity with time (those from the SFWMD and NRCS monitoring well networks, well OK-72, and the Jupiter and Sailfish Point Well Fields) were compared with the areal distribution of water temperature (fig. 35). Two-thirds of inland area wells are located within an area of higher ground-water temperature (greater than 28 °C).

SOURCES OF SALINITY IN THE FLORIDAN AQUIFER SYSTEM

Four potential sources of high salinity and their origin were evaluated for this study: (1) the presence of incompletely flushed pockets of relict seawater, (2) upconing or upward movement of the saltwater interface, (3) lateral encroachment of the saltwater interface, and (4) upward leakage through structural deformities or dissolution features. Relict seawater involves the occurrence of high salinity ground water in the Upper Floridan aquifer well above the saltwater interface.

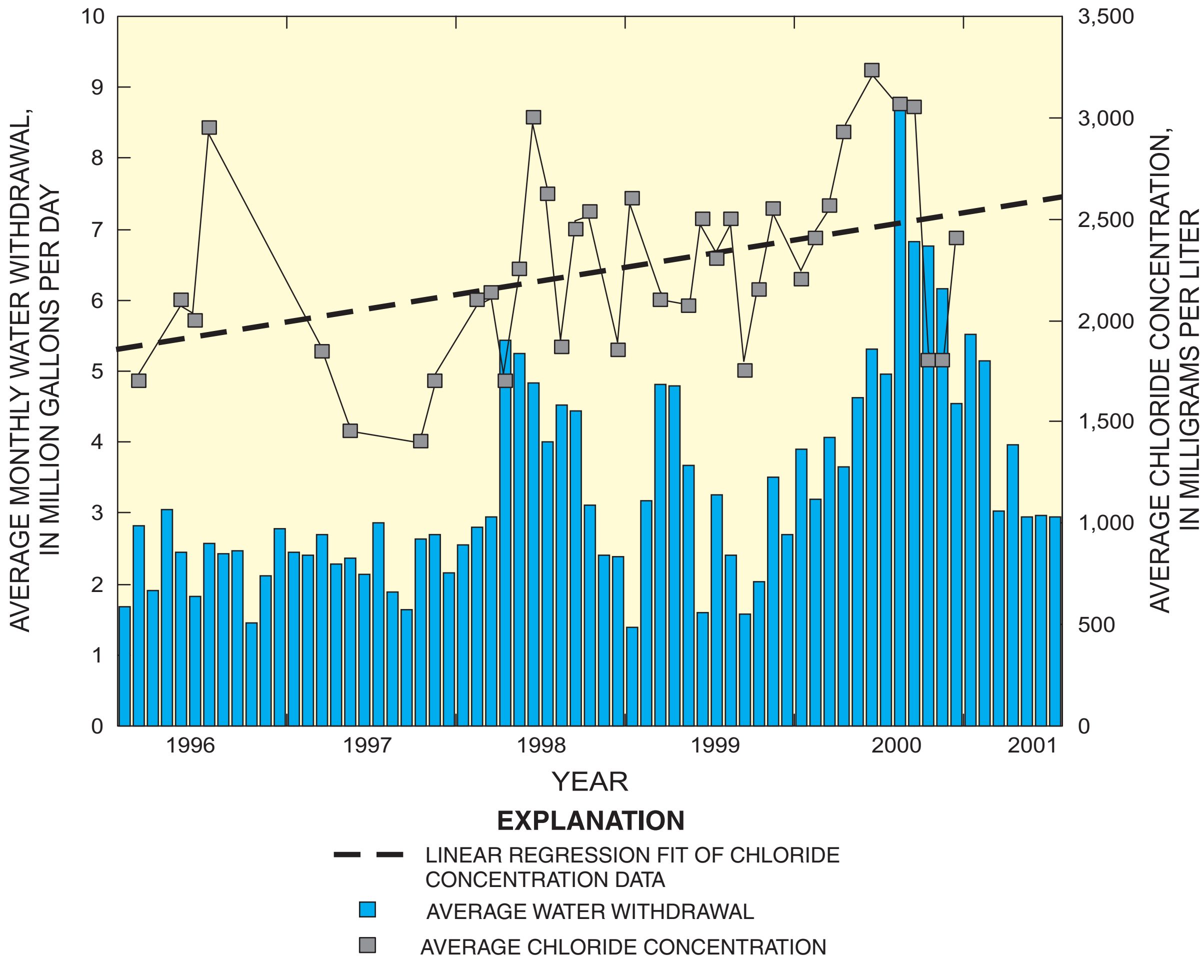


Figure 34. Average monthly total water withdrawals and average chloride concentrations for eight production wells at the Jupiter Well Field, January 1996 to July 2001.

Relict Seawater

High salinity in the Upper Floridan aquifer that occurs in the coastal area could have resulted from the influx of seawater during high sea-level stands in the Pleistocene Epoch. According to this theory, flushing of this saline water by the modern-day fresh ground-water flow system has been incomplete. A similar explanation was used to describe the occurrence of areas of high salinity in the Upper Floridan aquifer in coastal areas of southeastern Florida (Reese, 1994; Reese and Memberg, 2000).

During sea-level rise, the freshwater-saltwater interface in the Floridan aquifer system responded, seeking a new equilibrium position. During adjustment of the interface to a new equilibrium position within or above the Upper Floridan aquifer, lateral invasion of seawater into zones of higher permeability in both the Upper and Lower Floridan aquifers may have occurred. Invasion of the inland area may have been limited not only because of its greater distance from the coast but also because geologic contacts associated with flow zones generally occur at a shallower depth in the inland area than in the coastal area (figs. 5-8, 11, and 13). The reversal in salinity with depth within the brackish-water zone between the Upper Floridan aquifer and upper part of the Lower Floridan aquifer, common in the coastal area, could be explained by greater flushing of saline water from the Lower Floridan aquifer by upgradient recharged water. This greater flushing would have been facilitated by the higher permeability in the Lower Floridan aquifer.

Isotopic data, presented earlier, support saltwater invasion of the coastal area during relatively recent geologic times. Both $^{87}Sr/^{86}Sr$ and ^{14}C data indicate that Floridan aquifer system ground water in the coastal area generally is younger than in the inland area.

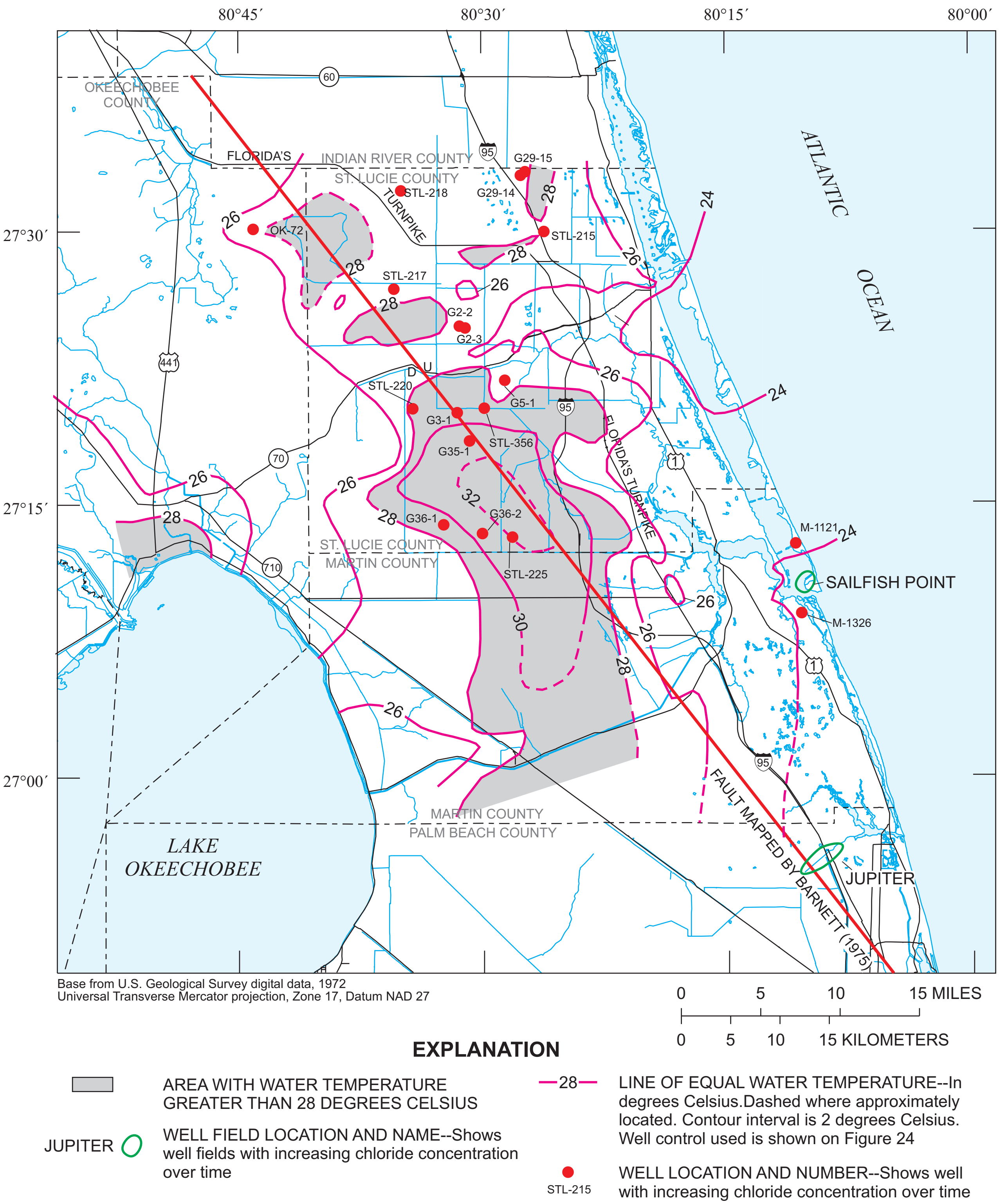


Figure 35. Location of monitoring wells and well fields with increasing salinity over time and distribution of water temperature in the Upper Floridan aquifer.

Apparently, an exception occurs in the southern part of the coastal area in northeastern Palm Beach County near wells PB-1196 and PB-1774. The apparent ^{14}C age for the three samples from these two wells is as old as ground water from the inland area wells (fig. 32). The $^{87}Sr/^{86}Sr$ data, however, still indicate a younger age for ground water from these wells than from inland area wells (fig. 31). An early Oligocene age is indicated even though the open intervals for all three samples are in Eocene-aged rocks (fig. 9, Ocala Limestone and Avon Park Formations).

High salinity water of relict origin in the Upper Floridan aquifer in the coastal area could impact withdrawals through lateral flow. For example, Port St. Lucie Well Field RO production wells STL-388 and STL-389 (fig. 2) are open in both the Upper and Lower Floridan aquifers; movement of higher salinity ground water in the Upper Floridan aquifer from the south or southeast (fig. 21) could result in increased salinity in the production wells. The current direction of Upper Floridan aquifer ground-water flow in the area of this well field is from the south (fig. 15).

Upward Movement of the Saltwater Interface

Diffuse upward movement of the brackish-water/saltwater interface is possible in some parts of the study area. Such movement implies that water in the saline-water zone below the interface is free to move and is open to large-scale circulation. Two ^{14}C samples were collected from the saline-water zone during this study, including (1) the deep monitoring zone of well M-1325 (North Martin County WWTP), and (2) well M-1033 (Stuart WWTP). The PMC was 10.40 for M-1325 and 2.41 for M-1033 (fig. 32). Because the saltwater in the saline-water zone is substantially younger at the North Martin County site than at the Stuart site, the North Martin County site could be more open to ground-water circulation of saltwater from the coast below the interface.

Currently, a large potential for upward movement of the saltwater interface is apparent in some parts of the study area. The depth of the Ghyben-Herzberg saltwater interface also was calculated using May 2001 head data, and the depth of the base of the brackish-water zone was subtracted from these calculated values (table 5). A negative number resulting from this difference indicates wells where currently there is potential for upward movement of the interface. Two inland area wells have a significant negative difference; they are IR-1001 (268 ft) and STL-379 (122 ft). All of the coastal wells, except for M-1352 and PB-1182, have a negative difference, but the two wells with the greatest difference (STL-332 with 645 ft and STL-334 with 302 ft) are in the northern part of the coastal area.

Lateral Encroachment of the Saltwater Interface

Lateral encroachment of the saltwater interface along the coast into the Upper Floridan aquifer is not likely to occur because of the depth of the saltwater interface along the coast and the extent of the aquifer offshore. The submarine outcrop of the top of the Upper Floridan aquifer is estimated to range from 17 to 32 mi offshore in the UEC Planning Area (Lukasiewicz, 1992). However, municipal wells open in the Lower Floridan aquifer (table 3) could experience this problem, particularly in the northern part of the coastal area because: (1) the depth of the saltwater interface is shallower than in the southern part of the coastal area, and (2) the potential for upward (and lateral) movement is much greater based on current head data in the Upper Floridan aquifer.

Upward Leakage through Structural Deformities or Dissolution Features

Upward leakage of water through structural deformities, such as faults and fracture zones or associated dissolution features, is indicated as occurring (or has the potential to occur) in the inland area. The evidence for this leakage comes from multiple sources and includes:

- Coincidence of northwest-trending areas of higher salinity (fig. 21), water temperature (fig. 26), and head (Brown and Reece, 1979) in north-central Martin and western St. Lucie Counties.
- Structural features that coincide with areas of higher salinity and water temperature including a previously mapped, inferred, northwest-trending basement fault (fig. 10) and, based on detailed mapping completed in this study, an apparent southeast-trending trough (figs. 11 and 13).
- Significant correlation of water temperature and chloride concentration in the inland area (fig. 28), but poor to nonexistent correlation of water temperature with depth (fig. 27), suggesting localized upward leakage.

- Simulation of ground-water flow that indicates recharge to the Upper Floridan aquifer is dominated by upward leakage from the Lower Floridan aquifer (Lukasiewicz, 1992).

Upward leaking high-salinity water in the inland area could originate from the upper permeable unit of the Lower Floridan aquifer in the lower part of the brackish-water zone or deeper in the saline-water zone. The older nature of this water is indicated by high concentration of strontium compared to chloride concentration (fig. 30) and old apparent age based on ^{14}C data (fig. 32). The occurrence of "old" ground water does not support the geothermal convection cell theory; Kohout (1965) theorized that the water invading the Boulder zone and leaking upward into the Upper Floridan aquifer is relatively recent seawater.

AREAS OF HIGHEST POTENTIAL FOR INCREASING SALINITY

As withdrawals continue or increase, the Upper Floridan aquifer in the inland area seems to be more susceptible to salinity increase than the coastal area due to: (1) greater apparent structural deformation, (2) higher salinity in the Lower Floridan aquifer relative to the Upper Floridan aquifer, (3) greater water withdrawals, and (4) a Ghyben-Herzberg potential for upward movement of the saltwater interface in some areas (table 5, wells IR-1001 and STL-379). The inland areas that seem to have the highest potential for increasing salinity include:

- Areas of structural deformation as indicated by detailed mapping and high water temperature (figs. 11, 13, and 26),
- Areas of greatest decline in hydraulic head in the Upper Floridan aquifer since predevelopment time (fig. 15 and table 2),
- Areas where agricultural water withdrawals have been, and continue to be, high (figs. 2 and 17; Lukasiewicz, 1992, fig. 22), and
- Areas where monitoring wells have shown salinity to be increasing (fig. 35).

Some of these areas overlap, indicating a greater potential for increasing salinity. Refined geologic and hydrogeologic mapping studies could better identify areas of high potential by detailing areas of deformation. Future mapping efforts could be conducted by using new well control, by geophysical logging of existing wells, and by using surface-geophysical methods such as reflection seismic profiling.

The Lower Floridan aquifer could be affected by increasing salinity in the northern part of the coastal area due to the potential for upward or lateral movement of the saltwater interface. The Fort Pierce and Port St. Lucie Well Fields could be affected by such movement (fig. 2). Both well fields are located near deep injection well sites in eastern St. Lucie County where currently there is potential for substantial upward movement of the saltwater interface due to regional decline in hydraulic head in the Upper Floridan aquifer. The May 2001 Ghyben-Herzberg altitude of the saltwater interface at well STL-332 at the Fort Pierce WWTP is about 1,100 ft below NGVD of 1929 (table 5). This depth is substantially above the base of the open interval at well STL-422 at the nearby Fort Pierce Well Field (1,240 ft below NGVD of 1929).

Depending on lithology, however, upward movement of the saltwater interface in the coastal area could be retarded by low vertical permeability. For example, a resistivity geophysical log and lithologic description of well STL-332 indicate that the lithology from the base of the brackish-water zone at 1,750 ft below land surface up to 1,360 ft is poorly cemented limestone (fig. 24). This limestone is probably fine grained or micritic in nature and of relatively low permeability, which is a lithology common in the Avon Park Formation.

An area of low salinity (less than 1,000 mg/L chloride concentration) was mapped in the Upper Floridan aquifer in northeastern St. Lucie County (fig. 21), and much of this area is within or borders the northern part of the coastal area (fig. 12). Available data did not indicate increasing salinity with time in this area of lower salinity. The low and apparently stable salinity in this area could be related to a low degree of structural deformation, its high structural position (figs. 11 and 13), or distribution of dolomite in the middle confining unit and Lower Floridan aquifer. As previously discussed, dolomite grades out west to east from the inland area to the coastal area (for example, see figs. 5 and 7). Because dolomite is more prone to fracturing than limestone, this loss of dolomite might have prevented the formation of vertical fractures acting as conduits in the middle confining unit and Lower Floridan aquifer in this area.

The potential for increasing salinity in the southern part of the coastal area (fig. 12) due to upward or lateral movement of the saltwater interface seems to be substantially less than in the northern part. In the southern part of the coastal area, the depth to the base of the brackish-water zone is greater, and little change in hydraulic head compared to predevelopment conditions is apparent (fig. 15). Additionally, some evidence was found that indicates low vertical permeability and poor vertical mixing in the lower part of the brackish-water zone and salinity transition zone in the northeastern Palm Beach County part of the coastal area (Reese and Memberg, 2000). This evidence, also found in other coastal areas of Palm Beach County, includes: (1) a base of the brackish-water zone that is deeper than expected given the location of these coastal areas, (2) a thickness of the salinity transition zone that is much greater than normal, and (3) a sulfate concentration of ground water that is depleted relative to chloride concentration, which could be due to prolonged sulfate reduction. Two wells in the southern part of the coastal area, PB-1170 and PB-1182, have a thickness of the salinity transition zone that is 670 ft or greater (table 4).

The increasing salinity at the Jupiter Well Field suggests that upward movement of saltwater can occur locally in the southern part of the coastal area. This upward movement could result from hydraulic head drawdown at the well field due to well field withdrawals and to regional lowering of head in the Upper Floridan aquifer near the end of dry season caused by agricultural withdrawals to the north. Structural deformation may have occurred at the Jupiter site, and upward movement or leakage of saline water could be through localized fractures resulting from this deformation. The basement fault mapped by Barnett (1975) extends to the southeast through or close to the Jupiter site (fig. 35). Additionally, mapping completed in this study indicates deformation could be present. Over 100 ft of offset in the altitude of the top of the basal Hawthorn/Suwannee unit is present between well PB-1197 at the Jupiter Well Field and well PB-652 located only 1.3 mi northeast of well PB-1197 (fig. 11).

SUMMARY

The Floridan aquifer system is considered to be a valuable source for agricultural and municipal water supply in Martin and St. Lucie Counties, despite the brackish nature of its water. Municipal supply withdrawals are increasing, however, and this could threaten the quality of withdrawn water because of increasing salinity. Flow mechanisms that could provide sources of higher salinity water and affect withdrawals need to be identified and described through a better understanding of the hydrogeologic framework and flow system history.

Two geologic units in the Upper Floridan aquifer were mapped using all wells with a gamma-ray geophysical log available. The top of the uppermost unit, referred to as the “basal Hawthorn/Suwannee unit,” approximates the top of the Upper Floridan aquifer and is also the base of a marker unit in the Hawthorn Group; the basal Hawthorn/Suwannee unit includes what has been previously mapped as the Suwannee Limestone along the coast. The top and base of the Ocala Limestone were also determined and the top was mapped. A southeast-trending trough on top of the basal Hawthorn/Suwannee unit and Ocala Limestone is apparent in south-central St. Lucie County. This trough coincides in position and trend with a northwest-trending basement fault previously mapped.

Mapping the thickness of the basal Hawthorn/Suwannee unit indicates an area where substantial eastward thickening begins along the coast. This area is approximately defined by the 100-ft-thickness contour line that runs subparallel to the coast, and this line is used to divide the study area into inland and coastal areas. The unit is as thick as 310 ft in the coastal area and as thin as 15 ft in the inland area. The Ocala Limestone also thickens in the coastal area.

The Floridan aquifer system consists of limestone, dolomitic limestone, and dolomite and is divided into three hydrogeologic units: the Upper Floridan aquifer, a middle confining unit, and the Lower Floridan aquifer. The upper permeable unit of the Lower Floridan aquifer, about 400 ft thick in central St. Lucie County, is composed mostly of dolomite and contains two cavernous dolomite flow zones in the inland area. In the coastal area, however, the unit can contain very little dolomite.

A comparison of the May 2001 Upper Floridan aquifer potentiometric surface with the predevelopment potentiometric surface indicates that decline in heads in eastern Martin and northeastern Palm Beach Counties have been minimal, but the decline indicated in central and northern St. Lucie County and Okeechobee County ranges from about 15 to 20 ft. Apparently, decline has continued during recent years; eight monitoring wells in central and northwestern St. Lucie County indicate a decline of 2 to 4 ft within the last 15 years.

The most intense agricultural water use is in the inland area, whereas all municipal well fields are in the coastal area. Agricultural water use is about 80 to 90 percent of the total use based on a survey conducted in 1990, but municipal water-supply withdrawals are increasing as new wells and well fields are constructed.

All of the municipal well fields that produce at higher rates have wells open to both the Upper and Lower Floridan aquifers or only to the Lower Floridan aquifer.

The distribution of salinity in the Upper Floridan aquifer was mapped using chloride concentration data. One area having an elevated chloride concentration (greater than 1,000 mg/L) exists in the inland area and trends northwest through north-central Martin County and western St. Lucie County. Another area of elevated concentration is in the southern part of the coastal area (eastern Martin County south of the St. Lucie River and northeastern Palm Beach County) where chloride concentration is more than 2,000 mg/L and as great as 8,000 mg/L. Salinity shows a reversal with depth in most of the coastal area, decreasing from the Upper Floridan aquifer to the upper part of the Lower Floridan aquifer. In the inland area, however, salinity is greater in the Lower Floridan aquifer than in the Upper Floridan aquifer.

A dissolved-solids concentration of less than 10,000 mg/L defines the brackish-water zone, the base of which can approximate the brackish-water/saltwater interface in the Floridan aquifer system. Below the brackish-water zone and separated from it by a salinity transition zone is the saline-water zone, within which the dissolved-solids concentration is greater than 35,000 mg/L. The base of the brackish-water zone and top of the saline-water zone, which are present in the Lower Floridan aquifer, were determined at 13 wells, mostly using resistivity geophysical logs. The depth of the base of the brackish-water zone ranged from 1,525 to 2,042 ft below NGVD of 1929; generally, the base increases in depth to the south and east. The depth of the saltwater interface was calculated using the Ghyben-Herzberg approximation and estimated predevelopment hydraulic heads in the Upper Floridan aquifer, and comparisons of this depth to that of the base of the brackish-water zone were made. In five of six inland area wells, the depth to the base of the brackish-water zone was substantially shallower than the calculated predevelopment interface (260 ft or greater), whereas in five of the seven coastal wells, this difference was not great (about 140 ft or less). Confining units in the inland area, such as dense dolomite, may prevent an interface from forming at its equilibrium position.

The temperature of withdrawn water from the Upper Floridan aquifer ranges from as low as 22.2 °C near the coast to as high as 32.0 °C inland. An area of high water temperature (generally greater than 28 °C) trends from central Martin County to the northwest through northwestern St. Lucie County. Correlation of water temperature with well depth is poor to nonexistent, but correlation of water temperature with chloride concentration for data from the inland area gives a statistically significant positive correlation.

Isotopic data collected during this study provide evidence for differences in the Floridan aquifer system ground-water geochemistry and its evolution between inland and coastal areas. In a graphical comparison of isotopic ratios of deuterium and oxygen-18 for 56 samples collected in the study area, samples from the coastal area plot as a somewhat separate group and define a saltwater mixing line. The ratio of strontium-87 to strontium-86 for many of the samples from the coastal area give an apparent source rock age that is younger than the rocks from which the seawater is derived, indicating that the coastal area was intruded with seawater during relatively recent geologic time. A plot of 38 sample analyses for stable and radioactive carbon indicates that water from the inland area is older than water from much of the coastal area, particularly for samples from inland area wells having a water temperature of 28 °C or higher. Exceptions in the coastal area are two samples with high salinity from below the base of the brackish-water zone and samples from the northeastern Palm Beach County part of the coastal area. The strontium-87 to strontium-86 ratio data, however, indicate a younger age for water from the wells in northeastern Palm Beach County than for the inland area. The comparison of strontium concentration to chloride concentration also suggests that inland area water is older than coastal area water.

Potential sources of high salinity include relict seawater, upward or lateral movement of the saltwater interface, and high salinity water leaking upward through structural deformities or dissolution features. Areas of high salinity in the Upper Floridan aquifer that are present in the coastal area could have resulted from the influx of seawater into the Upper Floridan aquifer during high sea-level stands in the Pleistocene Epoch and incomplete flushing by the modern-day ground-water flow system.

High potential exists in much of the study area for upward or lateral movement of the saltwater interface because of large declines in hydraulic head since predevelopment. The depth of the saltwater interface from the Ghyben-Herzberg approximation, calculated using estimated May 2001 water levels in the Upper Floridan aquifer, was compared with the depth to the base of the brackish-water zone determined in this study. Based on two wells, the interface in the inland area in central to northern St. Lucie County has the potential to move up as much as about 270 ft. Based on four wells, the interface in the northern part of the coastal area has a potential to move up as much as 640 ft. Upward movement of the saltwater interface, particularly in the coastal area, however, could be retarded by low vertical permeability. The potential of increasing salinity in the southern part of the coastal area due to upward or lateral movement of the saltwater interface seems to be less than in the northern coastal area because the base of the brackish-water zone is deeper by several hundred feet and postdevelopment declines in head have been minimal.

Upward leakage of high salinity water through structural deformities, such as faults and fracture zones or associated dissolution features, is indicated as occurring (or has the potential to occur) in some inland areas. An upward trend in salinity is indicated in 16 monitoring wells in the inland area, and agricultural withdrawals are probably causing these increases. Most of these 16 wells are located in areas of higher Upper Floridan aquifer ground-water temperature (greater than 28 °C). The upward leakage could originate from the upper permeable unit of the of the Lower Floridan aquifer in the lower part of the brackish-water zone or from deeper in the saline-water zone. The evidence for this leakage comes from multiple sources and includes: (1) coincidence of northwest-trending areas of higher salinity, water temperature, and head in north-central Martin and western St. Lucie Counties; (2) structural features mapped in this study and previously that coincide with the areas of higher salinity and water temperature; (3) correlation of water temperature and chloride concentration in the inland area, but a weak to nonexistent correlation of water temperature with depth, indicating that upward leakage is localized; and (4) groundwater flow modeling conducted in a previous study that indicates recharge to the Upper Floridan aquifer is dominated by upward leakage from the Lower Floridan aquifer.

The Upper Floridan aquifer has the greatest potential for increasing salinity in areas of structural deformation in the inland area. Areas with higher water temperature (greater than 28 °C) seem to indicate greater potential for increasing salinity, and these areas probably correlate with areas of greater deformation based on the correlation of water temperature anomalies with structural features. More detailed mapping of the altitude of the top of the uppermost geologic units comprising the aquifer could better identify areas of greater potential by better defining areas of deformation. This mapping could be done through additional well control, by geophysical logging of existing wells, or by using surface-geophysical methods such as reflection seismic profiling.

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APPENDIX I
Inventory of Wells Used in this Study

Well locations are shown on plates 1 or 2 or in figure 2, except for wells CS-I1 and CS-M2, which are shown in figure 23. Altitude of measuring point commonly is land surface. All depths are below measuring point.

Local well number:

G	Grove
IR	Indian River County
M	Martin County
OK	Okeechobee County
PB	Palm Beach County
STL	St. Lucie County
WA	SFWMD well abandonment program

Other well identifier or owner:

NRCS	National Resources Conservation Service
IW	Wastewater injection well
W	Well number assigned by the Florida Geological Survey
MW	Monitoring well
RO	Reverse-osmosis production well
ASR	Aquifer storage and recovery well
SPSL	South Port St. Lucie
NPSL	North Port St. Lucie
PSL	Port St. Lucie
SFWMD	South Florida Water Management District

ddmmss.s is degrees, minutes, and seconds

Asterisk (*) next to local well number indicates horizontal coordinate information is referenced to the North American Datum of 1983.

Dashes (--) indicate data unknown or not determined.

Appendix I. Inventory of wells used in this study

Local well number	Other well identifier or owner	U.S. Geological Survey site identification number	Latitude (ddmmss.s)	Longitude (ddmmss.s)	Altitude of measuring point (feet)	Depth bottom of casing (feet)	Casing diameter (inches)	Depth drilled (feet)	Depth of completed open interval(s) (feet)	Ending date of construction
CS-I1*	Coral Springs IW-1	261438080154801	261439	801550	13	125	42	3,500	1,193-1,222	05-29-85
						995	34		2,153-2,183	
						2,300	22		3,006-3,500	
						3,006	12.75			
CS-M2*	Coral Springs MW-2	261445080154802	261446.4	801547.7	13	170	24	1,650	1,000-1,110	11-01-89
						1,000	16		1,510-1,650	
						1,510	6.63			
G1-1*	NRCS		272123.5	802807.8	--	296	8	825		--
G2-1*	STL- 394, NRCS	272404080310401	272447.7	803142.4	20	260	6	823		--
G2-2*	NRCS		272447.5	803124.2						
G2-3*	NRCS		272441.4	803102.9						
G2-4*	NRCS		--	--						
G2-5*	NRCS		--	--						
G3-1*	STL- 395, NRCS	272002080313301	272002.2	803133.1	--	--	--	--		--
G3-2*	NRCS		271949.3	803133.4						
G3-3*	NRCS		271937.5	803133.3						
G4-1*	NRCS		271237.6	803224.2	--	--	--	--		--
G5-1*	NRCS		272148.6	802837.2						
G6-1*	NRCS		272610.1	803312.4	--	--	--	--		--
G6-2*	NRCS		272542.1	803312.9						
G7-1*	STL- 401, NRCS	272533080293501	272533.1	802935.8	20	278	8	878		--
G7-2*	NRCS		272559.2	802935.9						
G7-3*	NRCS		272624.9	802935.9						
G8-1*	NRCS		272644.1	802237.7						
G8-2*	NRCS		272644.2	802241.7						
G8-3*	NRCS		272633.8	802242.7						
G8-4*	NRCS		272625.8	802242.2						
G11-1*	NRCS		272857.5	802418.2	--	120	6	893		--
G12-1*	NRCS		272920.7	802346.2	20	345	6	917		--
G13-1*	NRCS		271300.1	803224.4	--	--	--	--		--
G14-1*	NRCS		272901.3	802341.0	--	--	--	--		--

Appendix I. Inventory of wells used in this study (Continued)

Local well number	Other well identifier or owner	U.S. Geological Survey site identification number	Latitude (ddmmss.s)	Longitude (ddmmss.s)	Altitude of measuring point (feet)	Depth bottom of casing (feet)	Casing diameter (inches)	Depth drilled (feet)	Depth of completed open interval(s) (feet)	Ending date of construction
G29-1A*	NRCS		--	--	--	--	--	--	--	--
G29-1B*	NRCS		273119.4	802736.7	--	--	--	--		--
G29-2*	NRCS		273144.3	802750.3						
G29-3*	NRCS		273211.1	802750.[1]						
G29-4*	NRCS		273143.9	802730.4						
G29-5*	NRCS		273211.1	802720.6						
G29-6*	NRCS		273212.6	802735.3						
G29-7*	NRCS		273237.4	802736.0						
G29-8*	STL- 410, NRCS	273237080273001	273237	802730.5	22	278	6	890		--
G29-9*	NRCS		273237.2	802720.2						
G29-10*	NRCS		273237.1	802705.1						
G29-11*	NRCS		273304.7	802703.1						
G29-12*	NRCS		273303.2	802706.7						
G29-13*	NRCS		273303.5	802734.4						
G29-14*	NRCS		273303.6	802735.7						
G29-15*	NRCS		273315.9	802719.8						
G35-1*	NRCS		271829.4	803048.1	--	--	--	--		--
G35-2*	NRCS		271815.5	803053.8						
G36-1*	NRCS		271353.1	803224.4						
G36-2*	NRCS		271323.4	803001.7	--	--	--	--		--
G121-1*	STL- 415, NRCS	272705080293601	272751.8	802936	--	316	6	804		--
G205-5*	STL- 421, NRCS	273119080372601	273119.3	803726.6	--	--	--	--		--
IR-1001	Hercules IW-1	273505080285701	273505	802857	23	116	42	3,005		12-29-78
						462	30			
						1,680	20			
						2,378	10			
M-27		270305080173001	270311	801736	22	430	4	1,000		
M-29		270912080382001	270904	803825	31	--	4	1,100		1924
M-30		270300080301801	270300	803018	41	450	6	1,100		1926
M-32		270306080301201	270306	803012	42	--	4	1,100		1926
M-43		270847080191101	270847	801911	22	--	4	800		--

Appendix I. Inventory of wells used in this study (Continued)

Local well number	Other well identifier or owner	U.S. Geological Survey site identification number	Latitude (ddmmss.s)	Longitude (ddmmss.s)	Altitude of measuring point (feet)	Depth bottom of casing (feet)	Casing diameter (inches)	Depth drilled (feet)	Depth of completed open interval(s) (feet)	Ending date of construction
M-47		270938080193601	270938	801936	21	--	3	500		--
M-64		271522080115001	271520	801152	10	--	4	600		--
M-65		271317080130801	271317	801308	21	--	4	500		--
M-86		271336080124701	271336	801247	10	--	6	1,200		--
M-88		271130080120001	271136	801151	12	--	5	1,180		--
M-95		271102080112301	271102	801123	15	748	5	1,058		--
M-106		271036080120301	271036	801203	11	698	3	1,020		--
M-110	MF-30	271006080121201	271006	801212	7.5	--	6	1,379		--
M-113		270916080131601	270916	801316	17.5	--	5	960		--
M-143		271055080205501	271055	802055	20	272	6	958		05-51
M-145		270428080303701	270428	803037	42	425	6	1,485		01-53
M-146	W-2800	270653080342201	270653	803422	36	437	5	1,155		11-51
M-150		270608080122701	270608	801227	15	740	6	1,315		--
M-168		270507080334801	270507	803348	32	500	5	1,080		1951
M-169		270916080343501	270916	803435	39	500	5	1,080		1951
M-170		270832080341401	270832	803414	38	500	5	1,080		1951
M-171		270742080341201	270742	803412	37	500	5	1,080		1951
M-173		270546080335801	270546	803358	32	500	5	1,080		1951
M-186	MF-1	271208080291001	271208	802910	29	373	5	835		1952
M-189		270409080292701	270409	802927	49	400	8	1,000		1952
M-192		270236080291901	270236	802919	41	400	5	1,000		1948
M-244		270508080154001	270508	801540	14	350	6	900		--
M-254		270725080290201	270725	802902	28	--	5	840		1952
M-255*	MF-2	270935080300001	270940.7	803003.1	28	300	6	800		1949
M-306		270548080124401	270548	801244	15	688	6	1,170		--
M-443		271118080163201	271118	801632	12	275	6	951		1952
M-582		271104080153601	271104	801536	2.5	--	--	700		--
M-602		271200080205601	271200	802056	22	418	6	939		1951
M-655		271116080144601	271116	801446		--	--	--		--
M-657		271122080143101	271122	801431	15	--	4	125		1955
M-740	MF-10	270426080171401	270426	801714	21	240	5.5	990		--

Appendix I. Inventory of wells used in this study (Continued)

Local well number	Other well identifier or owner	U.S. Geological Survey site identification number	Latitude (ddmmss.s)	Longitude (ddmmss.s)	Altitude of measuring point (feet)	Depth bottom of casing (feet)	Casing diameter (inches)	Depth drilled (feet)	Depth of completed open interval(s) (feet)	Ending date of construction
						474	4.25			
M-741		270444080180401	270444	801804	22	500	6	890		--
M-742		270401080175001	270401	801750	21	500	6	1,003		--
M-744	MF-6	270940080350801	270940	803508	35	162	3.5	1,052		--
						400	4.25			
M-745*	MF-9	270941080275901	271015.2	802807.3	30	360	6	810		--
M-747		271041080321401	271041	803214	26	--	6	825		12-55
M-748		271022080181601	271022	801816	16	397	6	773		--
M-841		271004080144601	271004	801446	12	454	4	1,057		--
M-901		270413080305801	270413	803058	38	490	8	1,110		09-56
M-911		270153080290801	270153	802908	37	--	6	1,000		--
M-919		270104080331501	270104	803315	26	636	8	950		08-54
M-920		270249080341301	270249	803413	26	448	5	1,033		--
M-922		270120080282301	270120	802823	36	--	6	800		--
M-926		271105080173201	271105	801732	41	--	6	950		--
M-927		271038080303101	271028	803031	28	--	6	792		--
M-940		271058080093801	271058	800938	13.5	435	6	1,150		05-59
						948	4			
M-1033*	Stuart DMW-1	271146080150202	271146.7	801454.5	10	310	24	3,024	2,027-2,093	04-82
						1,200	16			
						2,027	8.63			
M-1034*	Stuart IW-1	271146080150201	271145.4	801459.2	10	319	36	3,305	1,010-1,300	1974
						1,010	24		2,000-3,011	
						2,000	16		2,670-3,305	
						2,670	10			
M-1076	MF-20	270917080365701	270917	803657	32	450	8	1,200		06-73
M-1118	Well no. 1	271417080113801	271417	801138	5	880	5	1,705	880-1,655	08-79
M-1121*	MF-3	271246080104801	271247.2	801046.9	3	543	8	1,025		--
M-1125*	MF-23	270425080334701	270428.6	803348.1	32	170	5.5	1,119		--
						456	4.25			
M-1127	MF-4	271104080094301	271104	800943	9	658	6	1,525		--

Appendix I. Inventory of wells used in this study (Continued)

Local well number	Other well identifier or owner	U.S. Geological Survey site identification number	Latitude (ddmmss.s)	Longitude (ddmmss.s)	Altitude of measuring point (feet)	Depth bottom of casing (feet)	Casing diameter (inches)	Depth drilled (feet)	Depth of completed open interval(s) (feet)	Ending date of construction
M-1324*	Jensen Beach	271423080154201	271427.4	801544.4	--	62	48	3,505	2,917-3,505	11-07-87
	IW-1					173	38			
						850	30			
						1,683	20			
M-1325*	Jensen Beach	271423080154202	271427.3	801543.8	--	59	24	2,212	1,715-1,757	10-20-87
	MW-1					178	18		2,177-2,212	
						850	12			
M-1326*	MF-31	270847080103801	270857.8	801026.4	13.55	844	6	1,091		--
M-1328	MF-33	270742080352501	270742	803525	35.26	420	--	1,200		--
M-1329	MF-34	271053080172501	271053	801725	12	--	6	800		--
M-1330*	MF-35	270010080290001	270009.1	802858.3	28.94	400	10	1,340	400-1,250	--
M-1331	MF-36B	270907080114501	270907	801145	20	225	6	1,021		--
M-1332	MF-37	270232080304501	270232	803045	20	400	10	1,260		--
M-1335	MF-40, W-5441	270558080392701	270558	803927	18	441	4	1,006		12-06-59
M-1346	MF-51	270344080231201	270344	802312	--	600	10	1,380		--
M-1347*	MF-52	270512080230801	270506.6	802308.2	--	400	10	1,320		--
M-1349	MF-54, well 6	271034080101201	271034	801012	--	300		1,040		--
M-1352*	Stuart IW-2	271146080145401	271146.4	801453.6	8.74	172	54	3,252	2,890-3,252	--
						840	44			
						2,105	34			
						2,890	24			
M-1353*	Stuart MW2-2	271146080145402	271146.4	801453.6	10	175	20	1,650	1,600-1,650	--
						840	14			
						1,600	6.63			
M-1356*	North Martin RO-3	271449080154901	271449.1	801549.7	17	140	16	1,400	1,165-1,400	03-17-98
						202	30			
						1,165	12			
M-1357*	North Martin RO-4	271448080152801	271448.1	801528.4	17.8	140	16	1,375	1,065-1,375	07-21-2000
						199	30			
						893	18			
						1,065	12			

Appendix I. Inventory of wells used in this study (Continued)

Local well number	Other well identifier or owner	U.S. Geological Survey site identification number	Latitude (ddmmss.s)	Longitude (ddmmss.s)	Altitude of measuring point (feet)	Depth bottom of casing (feet)	Casing diameter (inches)	Depth drilled (feet)	Depth of completed open interval(s) (feet)	Ending date of construction
M-1358*	North Martin IW-2	271427080154501	271427.3	801545.3	17.5	179	50	3,350	2,811-3,350	9-27-2001
						858	42			
						2,230	36			
						2,811	20			
						2,830	26			
M-1359	Hobe Sound RO-1	270307080072701	270307	800727	42.8	200	16	1,495	1,228-1,494	11-20-2000
	South Martin					239	30			
						970	18			
						1,228	12			
M-1360*	MF-37	265928080361601	265928.8	803616.5	16	74	24	2,046		10-05-2001
	Port Mayaca ASR					170	18			
	test					765	12			
M-1362	MF-25	270228080325301	270228	803253	28	400	8	1,220		--
M-1363	W-5442	270122080380401	270122	803804	15	--	--	1,012		12-10-59
M-1364	MT-23	270316080342801	270316	803428	25	112	5	1,013		--
						446	4			
M-1365	MF-27	271025080125501	271025	801255	13	600	8	991		--
M-1366	MF-28	271147080115701	271147	801157	25	725	5	1,086	725-1,070	--
OK-1	OKF-1		272815	804254	--	--	--	--		--
OK-2	OKF-2	273238080424201	273238	804242	28	218	6	686		--
OK-3	OKF-3		271140	804222	--	700	--	1,300		--
OK-5	OKF-5	271855080482501	271855	804825	30	440	8	1,180		--
OK-7	OKF-7	272158080470901	272158	804709	61.98	412	--	963		--
OK-13*	OKF-13	273043080440001	273042.8	804356.2	--	600	--	1,200		--
OK-17*	OKF-17	272011080550701	272011	805507	--	538	--	986		--
OK-23	OKF-23	271514080511601	271514	805116	34.44	496	6	925		--
OK-29	OKF-29	272630080503001	272630	805030	65	336	6	1,040		--
OK-31	OKF-31	271343080504001	271343	805040	25.72	--	--	1,079		--
OK-71	OKF-71		273120	804430	--	500	--	800		--
OK-72*	OKF-72	273030080440501	273009	804404	--	500	--	800		--
OK-73	OKF-73		271900	804824	--	500	--	1,000		--

Appendix I. Inventory of wells used in this study (Continued)

Local well number	Other well identifier or owner	U.S. Geological Survey site identification number	Latitude (ddmmss.s)	Longitude (ddmmss.s)	Altitude of measuring point (feet)	Depth bottom of casing (feet)	Casing diameter (inches)	Depth drilled (feet)	Depth of completed open interval(s) (feet)	Ending date of construction
OK-74	OKF-74		271804	804714	--	500	--	1,000		--
OK-100*	OKF-100	270917080521701	270917.4	805216.5	13	80	24	2,048		09-22-2001
	Kissimmee River					207	18			
	ASR test					565	12			
OK-201	W-5405	270755080413701	270755	804137	17.2	266	4	1,008		11-26-59
OK-202	OK0005	273311080421601	273311	804216	25	--	--	939		--
OK-203	OK0006	273154080522001	273154	805220	70	--	--	720		--
OK-9000	Lake Okeechobee ASR1	271416080471101	271416	804711	16	65	42	1,710	1,268-1,710	06-22-88
	ASR-1	271416080471101	271416	804711	16	200	34			
						1,268	24			
OK-9001*	Lake Okeechobee	271421080471001	271420.7	804707.5	16	82	24	1,800	990-1,075	07-22-88
	SMW-1					200	12		1,275-1,700	
						990	6			
						1,270	1.5			
OK-9002*	Lake Okeechobee	271421080471002	271420.7	804707.5	16	1,270	1.5	1,800	1,275-1,700	07-22-88
	DMW-1									
PB-215	S399, field 11	265008080353801	265008	803542	18	850	6	958		--
PB-652		265642080072301	265642	800723	7	826	6	1,385		1939
PB-747*	PB- 733	265604080082601	265606.5	800824.5	13	400	20	1,280		06-74
						990	12			
PB-1133	Permit 235, Amerada	265146080253501	265152	802513	38	1,032	13.38	11,010		
						4,219	9.63			09-01-55
PB-1144*	PBF1	265800080051301	265809.1	800512.4	13	250	12	1,165	1,021-1,038	--
						1,021	6			
PB-1166	Pratt&Whitney IW-1	265404080181701	265404	801817	25	165	40	3,310		04-23-85
						970	30			
						1,865	20			
						2,728	10			
PB-1167	Pratt & Whitney	265404080181702	265404	801817	25	165	24	2,050	1,000-1,237	04-25-85
	MW-1					1,000	16		1,958-2,050	
						1,958	6			
PB-1170	Loxahatchee	265515080082501	265528	800827	18	115	52	3,505	1,501-1,532	01-18-86

Appendix I. Inventory of wells used in this study (Continued)

Local well number	Other well identifier or owner	U.S. Geological Survey site identification number	Latitude (ddmmss.s)	Longitude (ddmmss.s)	Altitude of measuring point (feet)	Depth bottom of casing (feet)	Casing diameter (inches)	Depth drilled (feet)	Depth of completed open interval(s) (feet)	Ending date of construction
	ENCON IW-1					923	44		1,840-1,870	
						1,997	34		2,839-3,505	
						2,839	24			
PB-1182	Seacoast IW-1	265118080075501	265118	800755	20.52	200	54	3,320	2,750-3,320	09-29-88
						990	44			
						2,020	34			
						2,750	24			
PB-1183	Seacoast MW-1	265118080075502	265118	800755	20.23	200	24	2,020	995-1,103	09-29-88
						995	16		1,965-2,020	
						1,965	6.63			
PB-1196	Jupiter DZMW	265522080092401	265522	800924		300	18	1,609	1,137-1,155	08-12-94
						137	10		1,549-1,609	
						1,549	4			
PB-1197	Jupiter RO-5	265523080092301	265523	800923	17	150	16	1,900	1,451-1,665	08-12-94
						1,024	12			
						1,451	8			
PB-1774*	Tequesta RO-1	265801080052901	265801.2	800529.1	14.2	325	30	1,740	1,120-1,740	09-17-96
						1,120	16			
						1,191	16			
STL-47		272645080311201	272645	803112	24	287	5	745		09-51
STL-71	SLF-28	272023080163201	272023	801632	31.38	200	4	883		1953
STL-215*	SLF- 3	272927080261601	272958.3	802610.6	21	310	16	1,106		--
STL-216*	SLF- 4	272823080290201	272825	802902	27.5	482	9.25	993		--
STL-217*	SLF- 9	272650080265001	272650	803525	24	263	10	1,058		--
STL-218*	SLF-11	273212080351101	273214	803459	22.5	224	8	946		--
STL-219	SLF-13	272412080364801	272412	803648	25	344	12	1,238		--
STL-220*	SLF-14	272014080341801	272016	803417.1	24	318	7.75	1,286		--
STL-221	SLF-15	272000080341801	272000	803418	24	--	--	--		--
STL-222	SLF-17	271934080341801	271934	803418	24	320	10	1,286		--
STL-223	SLF-20	272604080404001	272604	804040	28	311	5	896		--
STL-224*	SLF-21	272537080240901	272542	802407	20	156	3.5	707		--

Appendix I. Inventory of wells used in this study (Continued)

Local well number	Other well identifier or owner	U.S. Geological Survey site identification number	Latitude (ddmmss.s)	Longitude (ddmmss.s)	Altitude of measuring point (feet)	Depth bottom of casing (feet)	Casing diameter (inches)	Depth drilled (feet)	Depth of completed open interval(s) (feet)	Ending date of construction
STL-225	SLF-23	271311080281101	271311	802811	28	350	6	894		--
STL-228	SLF-26	272323080183901	272323	801839	2.5	382	3.25	1,000		--
STL-229	SLF-27	272322080304901	272322	803049	22	--	8	900		--
STL-230	SLF-31	271614080235001	271614	802350	23	136	3.5	1,008		--
						818	4			
STL-242	SLF-5, SL00033	273000080275201	273000	802752	12	355	12	1,231		--
STL-243	SLF- 6	272445080241501	272445	802415	18	142	3	596		--
STL-244	SLF- 7	272912080315801	272912	803158	24	257	10	1,040		--
STL-245	SLF-16	271953080341701	271953	803417	28	328	6.5	1,239		--
STL-246	SLF-18	271645080331601	271645	803316	29	330	12	1,240		--
STL-247	SLF-25	273050080185101	273050	801851	2.5	--	4			--
STL-248	SLF-32	271311080240001	271311	802400	27.5	--	4	1,007		--
STL-250	SLF-35	272823080300701	272823	803007	22.5	--	--	--		--
STL-253	SLF-38	272405080354501	272405	803545	24	--	--	--		--
STL-254	SPSL IW-1	271500080175701	271500	801757	9.5	30	54	3,418	2,715-3,418	12-01-82
						175	42			
						840	32			
						1,876	22			
						2,715	12			
STL-255*	SPSL DZMW-1	271500080175702	271500.4	801757.2	9.50	30	34	1,663	898-1,268	12-01-82
						175	24		1,610-1,663	
						898	16			
						1,610	6			
STL-332	Fort Pierce IW-1	272720080182701	272720	801827	5.56	45	60	3,315	2,770-3,315	07-23-92
						180	54			
						810	44			
						1,800	34			
						2,770	24			
STL-333	Fort Pierce MW-1	272720080182702	272720	801827	--	180	26	1,920	900-1,019	--
						900	16		1,850-1,920	
						1,850	6			

Appendix I. Inventory of wells used in this study (Continued)

Local well number	Other well identifier or owner	U.S. Geological Survey site identification number	Latitude (ddmmss.s)	Longitude (ddmmss.s)	Altitude of measuring point (feet)	Depth bottom of casing (feet)	Casing diameter (inches)	Depth drilled (feet)	Depth of completed open interval(s) (feet)	Ending date of construction
STL-334	NPSL IW-1	272009080210301	272009	802103	15	40	54	3,324	2,750-3,324	07-30-87
						195	42			
						850	32			
						1,950	22			
						2,750	12			
STL-335*	NPSL DZMW-1	272009080210302	272014.6	802105.9	--	40	36	1,800	950-1,175	08-09-87
						193	24		1,730-1,800	
						950	16			
						1,730	6.63			
STL-342*	SLF-36	272747080305401	272746	803050	24.5	--	--	--		--
STL-346*	SLF-40	272503080295701	272519	802934	22	--	--	786		--
STL-347	SLF-41	271425080371701	271425	803717	42.71	--	--	1,272		--
STL-348	SLF-42	273054080184701	273054	801847	5	630	6	1,060		--
STL-349	SLF-43	271710080125501	271710	801255	3	650	6	866		--
STL-350	SLF-44	271707080125501	271707	801255	3	620	6	876		--
STL-351	SLF-45	273145080190001	273145	801900	5.27	--	--	1,100		--
STL-352*	SLF-46	273007080182501	273042.5	801830.7	6.71	--	--	1,100		--
STL-353	SLF-47	271938080135201	271938	801352	5.66	850	6	1,230		--
STL-354	SLF-48	271752080252601	271752	802526	26.33	--	--	800		--
STL-355	SLF-49	272019080295501	272019	802955	25.09	560	--	893	560-893	--
STL-356	SLF-50	272017080295301	272017	802953	31.75	600	--	1,000	600-775	--
STL-357	SLF-51	272017080295302	272017	802953	25.56	600	--	775	600-775	--
STL-359	SLF-53	272640080324001	272640	803240	25	330	--	911		--
STL-360	SLF-54	271456080401501	271456	804015	25	450	10	1,304		--
STL-367	SLF-61, Duda 22	271604080262201	271604	802622	--	350	--	695		--
STL-368	SLF-62	271725080281001	271725	802810	--	480	--	935		--
STL-369	SLF-63	272853080362401	272853	803624	--	250	10	1,040		--
STL-370	SLF-64	273044080373101	273044	803731	--	246	10	1,080		--
STL-371	SLF-65, Well 1	273213080382901	273213	803829	--	240	10	1,020		--
STL-373	SLF-67	272230080392101	272230	803921	--	300	6	--		--
STL-374	SLF-68, well 3	272608080414901	272608	804149	--	--	6	--		--

Appendix I. Inventory of wells used in this study (Continued)

Local well number	Other well identifier or owner	U.S. Geological Survey site identification number	Latitude (ddmmss.s)	Longitude (ddmmss.s)	Altitude of measuring point (feet)	Depth bottom of casing (feet)	Casing diameter (inches)	Depth drilled (feet)	Depth of completed open interval(s) (feet)	Ending date of construction
STL-375*	SLF-69	272146080263701	272149.2	802639.3	--	420	--	866		--
STL-376	SLF-70	273157080241301	273157	802413	--	--	--	638		--
STL-377	SLF-71	272055080193001	272055	801930	--	--	--	820		--
STL-379*	SLF-73	272016080292601	272016	802926	25	540	14	1,540	1,070-1,450	07-05-90
	W-16543					1,070	8			
STL-380*	SLF-74	272015080292401	272015.9	802923	--	1,068	8	1,450		--
STL-381*	SLF-75	272015080292402	272015.9	802923	--	480	4	700		--
STL-382*	SLF-76	272015080292403	272015.9	802923	--	790	4	860		--
STL-385*	FB-2	272631080211301	272631.3	802112.9	--	500	12	880		--
STL-386*	SPSL MW-1A	271500080175703	271500.3	801759	9	36	36	1,960	1,887-1,960	11-30-95
						175	24			
						839	16			
						1,887	6.63			
STL-387*	PSL RO DMW	271829080203101	271828.5	802031.2	--	--	--	1,600		--
STL-388*	PSL RO-1	271828080203501	271827.5	802035.1	--	--	--	1,350		--
STL-389*	PSL RO-2	271816080202301	271815.7	802022.9	--	--	--	1,350		--
STL-391*	SLF-62B	271841080264601	271841.3	802646.3	--	480	6	935		--
STL-392*	Duda by pool	271542080255801	271542.4	802558.3	--	--	16	900		--
STL-422*	Fort Pierce FA-8	272727080212801	272727.2	802128.6	20	135	26	1,500	500-1,260	10-19-2000
						500	16			
WA-117	SFWMD		271721	803534	--	--	--	750		--
WA-119	SFWMD		271235	803201	--	--	--	950		--
WA-546	SFWMD		270637	803638	30	442	7.5	1,038		--
WA-547	SFWMD		272308	803453	25	364	6	820		--
WA-561	SFWMD		271835	802251	25	--	--	620		--
WA-562	SFWMD		271825	802455	28	270	5.8	1,018		--
WA-565	SFWMD		271801	802336	25	--	--			--
WA-580	SFWMD		271845	802324	25	476	5.8	1,136		--
WA-582	SFWMD		271841	802445	25	--	--	--		--
WA-611	SFWMD		271710	802242	--	--	--	750		--
WA-612	SFWMD		271627	802414	--	--	--	870		--

Appendix I. Inventory of wells used in this study (Continued)

Local well number	Other well identifier or owner	U.S. Geological Survey site identification number	Latitude (ddmmss.s)	Longitude (ddmmss.s)	Altitude of measuring point (feet)	Depth bottom of casing (feet)	Casing diameter (inches)	Depth drilled (feet)	Depth of completed open interval(s) (feet)	Ending date of construction
WA-625	SFWMD		271236	802014	--	--	--	1,012		--
WA-699	SFWMD		272504	802306	25	376	6	1,156		--
WA-708	SFWMD		272603	802007	10	274	4	957		--
WA-727	SFWMD		273300	802620	--	--	--	1,000		--
WA-815	SFWMD		272658	801930	--	460	8	995		--
WA-820	SFWMD		272329	802624	20	328	8	922		--
WA-823	SFWMD		272827	802937	20	--	--	--		--
WA-825	SFWMD		272534	802233	--	--	--	--		--
WA-829	SFWMD		271951	802746	--	342	5	741		--
WA-875	SFWMD		272427	802949	20	300	4	704		--
WA-877	SFWMD		272645	802249	20	--	--	740		--
WA-878	SFWMD		272410	803192	20	--	--	766		--
WA-879	SFWMD		272610	802225	--	--	--	903		--
WA-887	SFWMD		272616	802206	17	--	--	--		--
WA-1001	SFWMD		272134	802815	20	326	4	829		--
WA-1003	SFWMD		272122	802807	20			822		--
WA-1005	SFWMD		272145	802507	--		4	830		--
WA-1006	SFWMD		272146	802838	20	--	--	930		--
WA-1009	SFWMD		272935	802346	20	--	--			--
WA-1016	SFWMD		272236	802640	20	--	--	876		--
WA-1031	SFWMD		273201	802416	20	--	--			--
WA-1032	SFWMD		272956	801747	20	--	--	1,020		--
WA-1033	SFWMD		273131	802402	--	--	--			--
WA-1082	SFWMD		272330	802908	--	--	--	1,324		--
WA-1083	SFWMD		272303	802813	20	--	--	646		--
WA-1085	SFWMD		272628	803831	20	--	--	784		--
WA-1087	SFWMD		272417	803813	20	--	--	624		--
WA-1107	SFWMD		272208	802826	26	--	--	636		--
WA-1111	SFWMD		272448	803916	25	--	--	1,108		--
WA-1113	SFWMD		272149	802847	--	308	4.9	827		--
WA-1119	SFWMD		272448	803916	25	280	4.9	673		--

Appendix I. Inventory of wells used in this study (Continued)

Local well number	Other well identifier or owner	U.S. Geological Survey site identification number	Latitude (ddmmss.s)	Longitude (ddmmss.s)	Altitude of measuring point (feet)	Depth bottom of casing (feet)	Casing diameter (inches)	Depth drilled (feet)	Depth of completed open interval(s) (feet)	Ending date of construction
WA-1121	SFWMD		272323	803012	--	--	6	798		--
WA-1134	SFWMD		273030	802412	--	--	--	--		--
WA-1136	SFWMD		272222	802942	20	264	--	674		--
WA-1139	SFWMD		273040	802450	20	286	--	987		--
WA-1140	SFWMD		272222	802942	20	290	4	792		--
WA-1143	SFWMD		272905	802511	--	296	5	903		--
WA-1144	SFWMD		271831	803427	20	--	--	--		--
WA-1146	SFWMD		272903	802300	--	330	4	814		--
WA-1147	SFWMD		271144	802716	25	--	--	891		--
WA-1148	SFWMD		270716	803726	--	340	4	742		--
WA-1151	SFWMD		272401	802654	20	352	6	849		--
WA-1155	SFWMD		272657	802371	20	198	5	1,176		--
WA-1158	SFWMD		272522	802204	20	--	--	840		--
WA-1179	SFWMD		272808	801947	--	113	3	700		--
WA-1183	SFWMD		272048	802912	--	376	4	880		--
WA-1186	SFWMD		272030	802935	10	480	6	824		--
WA-1188	SFWMD		272048	802912	--	298	5	628		--
WA-1192	SFWMD		272030	802935	20	--	--	739		--

APPENDIX II
Boundaries of Geologic Units in Selected Wells Penetrating the Floridan Aquifer System as Determined for this Study

Well locations are shown on plate 1. Altitude of measuring point is usually land surface. All depths are below measuring point. Gamma-ray logs were available on all wells and were used in determining tops. Lithologic descriptions were also available for some wells and were used. Dashes (--) indicate well not deep enough or inadequate data available.

Local well number:

G	Grove
IR	Indian River County
M	Martin County
OK	Okeechobee County
PB	Palm Beach County
STL	St. Lucie County
WA	SFWMD well abandonment program

Other well identifier or owner:

NRCS	National Resources Conservation Service
IW	Wastewater injection well
W	Well number assigned by the Florida Geological Survey
MW	Monitoring well
RO	Reverse-osmosis production well
SPSL	South Port St. Lucie
NPSL	North Port St. Lucie
SFWMD	South Florida Water Management District

Appendix II. Boundaries of geologic units in selected wells penetrating the Floridan aquifer system as determined for this study

Local well number	Other well identifier or owner	Altitude of measuring point (feet)	Depth to top of basal Hawthorn/ Suwannee unit (feet)	Depth to top of Ocala Limestone (feet)	Depth to top of Avon Park Formation (feet)	Depth drilled or total depth reached by geophysical log (feet)
G2-1	STL-394, NRCS	20	445	505	580	823
G7-1	STL-401, NRCS	20	455	520	585	878
G29-8	STL-410, NRCS	22	435	495	600	890
G121-1	NRCS	20	490	570	620	917
IR-1001	Hercules IW-1	23	440	520	600	3,005
M-110	MF-30	8	742	917	--	1,349
M-186	MF-1	29	627	710	790	835
M-740	MF-10	21	622	665	810	990
M-744	MF-6	35	663	727	782	1,052
M-745	MF-9	30	540	623	742	880
M-1076	MF-20	32	653	693	742	1,200
M-1118	Well no. 1	5	875	1,080	1,230	1,705
M-1121	MF-3	3	700	880	--	1,025
M-1125	MF-23	32	745	800	865	1,119
M-1127	MF-4	9	755	1,040	1,200	1,525
M-1326	MF-31	14	800	983	--	1,092
M-1328	MF-33	35	680	730	810	1,200
M-1329	MF-34	12	578	718	--	800
M-1330	MF-35	29	690	750	868	1,340
M-1331	MF-36B	20	762	919	--	1,021
M-1332	MF-37	20	700	748	863	1,260
M-1335	MF-40, W-5441	18	675	715	775	1,006
M-1353	Stuart MW2-2	10	710	883	1,050	1,650
M-1357	North Martin RO-4	18	670	835	1,100	1,375
M-1359	Hobe Sound RO-1	43	860	1,045	1,225	1,495
M-1360	MF-37	16	715	820	892	2,046
M-1363	W-5442	15	695	740	775	1,012
M-1364	MT-23	25	755	805	840	1,013
M-1365	MF-27	13	720	890	--	1,000
M-1366	MF-28	25	790	935	--	1,086
OK-2	OKF-2	28	368	400	465	690
OK-5	OKF-5	30	570	620	740	1,181
OK-7	OKF-7	62	638	670	800	963
OK-29	OKF-29	65	435	465	600	1,040
OK-100	OKF-100	13	528	610	748	2,048
OK-201	OE-1	17	640	670	765	1,008
OK-202	OK0005	25	368	412	462	939
OK-203	OK0006	70	380	410	520	720

Appendix II. Boundaries of geologic units in selected wells penetrating the Floridan aquifer system as determined for this study (Continued)

Local well number	Other well identifier or owner	Altitude of measuring point (feet)	Depth to top of basal Hawthorn/ Suwannee unit (feet)	Depth to top of Ocala Limestone (feet)	Depth to top of Avon Park Formation (feet)	Depth drilled or total depth reached by geophysical log (feet)
OK-9000	OKF-77	16	682	733	835	1,710?
PB-652		7	890	1,200	--	1,385
PB-747	PB-733	13	840	1,050	1,200	1,280
PB-1144	PBF-1	13	835	1,020	--	1,165
PB-1197	Jupiter RO-5	17	973	1,110	1,246	1,900
STL-71	SLF-28	31	595	760	880	883
STL-216	SLF-4	28	460	523	570	993
STL-217	SLF-9	24	465	510	580	1,058
STL-218	SLF-11	23	412	440	490	946
STL-220	SLF-14	24	555	640	740	1,286
STL-222	SLF-17	24	560	650	765	1,297
STL-223	SLF-20	28	490	543	650	896
STL-224	SLF-21	20	460	530	600	707
STL-225	SLF-23	28	568	655	763	894
STL-228	SLF-26	3	600	741	875	1,000
STL-230	SLF-31	23	625	721	800	1,030
STL-242	SLF-5	12	475	522	635	1,231
STL-243	SLF-6	18	475	540	--	596
STL-245	SLF-16	28	570	660	773	1,239
STL-332	Fort Pierce IW-1	6	570	750	970	3,315
STL-334	NPSL IW-1	15	550	700	815	3,324
STL-346	SLF-40	22	448	511	575	790
STL-348	SLF-42	5	585	780	945	1,062
STL-349	SLF-43	3	632	822	--	866
STL-350	SLF-44	3	643	844		878
STL-351	SLF-45	5	600	800	918	1,104
STL-352	SLF-46	7	620	812	960	1,100
STL-353	SLF-47	6	800	1,000	1,190	1,230
STL-354	SLF-48	26	560	630	700	800
STL-355	SLF-49	25	639	719	795	894
STL-356	SLF-50	32	600	677	765	1,000
STL-359	SLF-53	25	540	595	665	911
STL-360	SLF-54	25	735	750	865	1,304
STL-379	SLF-73	25	513	590	655	1,540
STL-386	SPSL MW-1A	9	625	813	970	1,960
STL-422	Fort Pierce FA-8	20	480	550	830	1,500
WA-546	SFWMD	30	710	770	810	1,038
WA-547	SFWMD	25	590	642	735	820
WA-561	SFWMD	25	610	--	--	620

Appendix II. Boundaries of geologic units in selected wells penetrating the Floridan aquifer system as determined for this study (Continued)

Local well number	Other well identifier or owner	Altitude of measuring point (feet)	Depth to top of basal Hawthorn/ Suwannee unit (feet)	Depth to top of Ocala Limestone (feet)	Depth to top of Avon Park Formation (feet)	Depth drilled or total depth reached by geophysical log (feet)
WA-562	SFWMD	28	535	607	682	1,018
WA-565	SFWMD	25	580	675	750	763
WA-580	SFWMD	25	563	680	753	1,136
WA-582	SFWMD	25	553	637	702	930
WA-699	SFWMD	25	515	600	662	1,156
WA-708	SFWMD	10	580	705	815	957
WA-820	SFWMD	20	452	539	592	922
WA-823	SFWMD	20	420	496	540	640
WA-875	SFWMD	20	495	550	613	704
WA-877	SFWMD	20	448	518	645	740
WA-878	SFWMD	20	470	515	605	766
WA-887	SFWMD	17	470	540	680	894
WA-1001	SFWMD	20	525	580	650	829
WA-1003	SFWMD	20	495	555	620	822
WA-1006	SFWMD	20	498	550	625	930
WA-1009	SFWMD	20	420	490	590	904
WA-1016	SFWMD	20	500	575	640	876
WA-1031	SFWMD	20	402	480	638	686
WA-1032	SFWMD	20	708	920	--	1,020
WA-1083	SFWMD	20	470	535	583	646
WA-1085	SFWMD	20	470	527	590	784
WA-1087	SFWMD	20	475	530	595	624
WA-1107	SFWMD	26	480	545	--	636
WA-1111	SFWMD	25	568	630	736	1,108
WA-1119	SFWMD	25	462	525	625	673
WA-1136	SFWMD	20	450	505	575	674
WA-1139	SFWMD	20	390	450	550	987
WA-1140	SFWMD	20	465	520	590	792
WA-1144	SFWMD	20	450	515	638	891
WA-1147	SFWMD	25	540	640	745	891
WA-1151	SFWMD	20	605	700	792	849
WA-1155	SFWMD	20	698	750	800	1,176
WA-1158	SFWMD	20	537	605	662	840
WA-1186	SFWMD	10	570	730	--	824
WA-1192	SFWMD	20	530	600	725	739

APPENDIX III
Selected Water-Quality Data Collected from Known Intervals in Wells in the Floridan Aquifer System

Well locations are shown on plate 2, except for wells CS-I1 and CS-M2, which are shown in figure 23. Depths are given in feet below measuring point, which commonly is land surface. Measuring points are given in appendix I. Dashes (--) indicate data unknown or not determined, asterisk (*) indicates under source - packer test, and double asterisk (**) indicates chloride concentration calculated from specific conductance from equation in figure 20.

Local well number:

CS	Coral Springs (Broward County)
G	Grove
M	Martin County
OK	Okeechobee County
PB	Palm Beach County
STL	St. Lucie County
WA	South Florida Water Management District well abandonment program

Source:

1	Lichtler (1960)
2	Reece and others (1980)
3	Lukasiewicz and Switanek (1995)
4	Lukasiewicz and Switanek (1995) - abandonment wells
5	U.S. Geological Survey data collected prior to this study
6	Reese and Memberg (2000)
7	Natural Resources Conservation Service monitoring program
8	Well-construction report from consulting firm
9	Abandonment well files from South Florida Water Management District
10	Ambient network data (GWIS3)
11	Collected during this study
12	Collected by South Florida Water Management District

Appendix III. Selected water-quality data collected from known intervals in wells from the Floridan aquifer system

Local well number	Source	Date	Depth base of casing (feet)	Depth to bottom of open interval or depth of well (feet)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Chloride (milligrams per liter)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)
CS-I1	11	09-13-2000	2,153	2,183	45,900	17,000	29,674	25.9
CS-M2	11	09-13-2000	1,000	1,110	17,770	5,700	11,206	23.3
	11	09-13-2000	1,510	1,653	9,530	2,800	5,830	22.3
G1-1	7	02-29-96	296	825	4,235	1,670	3,269	--
G2-1	7	03-05-96	260	823	3,094	1,190	2,317	--
G3-1	11	07-26-2001	--	--	4,830	1,350	3,210	29.3
G4-1	7	02-29-96	--	--	2,875	1,130	2,051	--
G6-1	7	03-05-96	--	--	2,930	1,110	2,044	--
G7-1	7	02-29-96	278	878	5,240	2,070	3,640	--
G11-1	7	12-98	120	893	1,900	**420	--	--
G13-1	7	02-29-96	--	--	3,532	1,350	2,422	--
G14-1	7	03-05-96	--	--	1,990	669	1,365	--
G29-1B	7	12-98	--	--	3,770	**990	--	--
G35-1	7	12-98	--	--	4,840	**1,300	--	--
G36-2	7	12-98	--	--	2,928	**730	--	--
G205-5	11	07-26-2001	--	--	5,740	1,520	3,760	27.9
M-27	1	07-03-46	430	1,000	--	1,640	--	26.7
M-29	4	--	--	1,100	3,325	750	--	25.5
M-30	5	03-25-58	450	1,100	2,020	450	1,126	28.9
M-32	1	01-25-57	--	1,100	--	1,220	--	28.3
M-43	4	--	--	800	4,800	1,400	--	25.0
M-47	5	06-07-46	--	500	--	--	--	25.0
	5	07-07-46	--	500	3,950	1,040	--	--
M-64	5	07-18-46	--	600	5,990	1,790	--	25.6
M-65	1	07-19-46	--	500	--	890	--	24.4
M-86	5	07-23-46	--	1,200	3,410	885	--	25.0
M-88	5	07-23-46	--	1,180	3,570	940	--	23.9
M-95	5	07-24-46	748	1,060	3,190	800	--	23.9
M-106	5	05-28-57	698	1,020	3,150	**800	1,950	24.4
	1	08-13-46	698	1,020	--	810	--	23.9
M-110	1	08-13-46	--	1,379	--	950	--	23.9
M-113	1	08-13-46	--	960	--	2,150	--	23.9
	1	05-3-57	--	960	--	1,600	--	24.4
M-143	5	10-24-61	272	958	3,780	913	2,110	26.1
M-145	1	02-05-53	425	1,485	--	685	--	28.3
M-146	4	--	437	1,155	2,660	600	--	27.0
M-150	4	--	740	1,315	13,300	4,200	--	24.5
M-168	5	07-16-80	500	1,080	1,830	400	--	27.0
M-169	4	--	500	1,080	2,000	420	--	27.5
M-170	4	--	500	1,080	2,400	540	--	27.5
M-171	1	02-19-53	500	1,080	--	600	--	27.8
M-173	4	--	500	1,080	2,180	470	--	26.5

Appendix III. Selected water-quality data collected from known intervals in wells from the Floridan aquifer system (Continued)

Local well number	Source	Date	Depth base of casing (feet)	Depth to bottom of open interval or depth of well (feet)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Chloride (milligrams per liter)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)
M-186	2	12-30-77	377	837	4,060	1,150	2,480	30.8
	4	--	377	843	4,240	1,200	--	24.0
M-189	1	03-02-53	400	1,000	--	545	--	29.4
M-192	1	04-16-57	400	1,000	--	575	--	29.4
M-244	1	03-23-53	350	960	--	1,450	--	25.0
M-254	4	--	--	840	4,540	1,150	--	28.0
M-255	2	12-30-77	300	800	3,640	1,060	2,300	28.2
	3	05-18-90	300	800	3,920	1,034	2,177	27.8
	11	06-08-2000	300	800	3,920	1,100	2,348	29.1
	11	07-24-2001	300	800	3,930	1,020	2,430	29.2
M-306	4	--	688	1,170	12,000	3,500	--	24.5
M-443	1	04-23-57	275	951	--	1,370	--	24.4
M-582	1	01-10-55	--	700	--	2,400	--	--
M-602	1	11-16-53	418	939	--	1,170	--	26.1
M-740	2	05-24-78	474	993	3,350	1,140	2,570	26.2
M-741	4	--	500	890	6,550	1,850	--	24.0
M-742	1	12-16-55	460	1,003	--	1,530	--	--
M-744	2	05-10-79	400	1,052	1,620	320	1,000	27.2
M-745	3	05-30-90	342	680	4,280	1,288	2,514	29.8
	11	06-08-2000	360	810	4,440	1,200	2,667	30.1
	11	07-24-2001	360	810	4,470	1,210	2,850	30.3
M-747	1	12-16-55	--	825	--	1,020	--	27.2
M-748	1	04-23-57	397	773	--	1,050	--	27.2
M-841	5	09-04-57	454	1,060	9,380	**2,700	6,080	24.4
	1	09-04-57	454	1,057	--	2,900	--	--
M-901	5	05-29-57	490	1,110	1,310	**230	778	27.8
	1	09-21-56	490	1,110	--	280	--	27.8
M-911	5	07-16-80	--	1,000	2,800	640	--	26.5
M-919	4	--	636	950	4,025	1,100	--	25.5
M-920	1	03-07-57	448	1,033	--	490	--	--
M-922	1	03-07-57	--	800	--	930	--	27.2
M-926	1	04-23-57	--	950	--	1,230	--	25.0
M-927	5	10-23-61	--	792	3,870	1,030	2,130	27.8
M-940	5	08-31-59	948	1,150	2,210	515	1,250	--
M-1033	11	07-10-2000	2,027	2,093	46,900	18,000	31,096	26.6
M-1034	11	07-10-2000	1,010	1,300	8,000	2,300	4,784	25.8
M-1076	5	11-18-75	450	1,200	3,900	**1,000	2,030	26.5
M-1121	3	05-31-90	543	980	3,750	1,048	2,153	24.1
	11	07-13-2000	543	1,025	4,330	1,200	2,560	24.9
	11	07-18-2001	543	1,020	4,290	1,100	2,560	24.7
M-1125	2	12-05-77	456	1,119	1,600	390	1,130	26.1
	3	05-17-90	456	1,119	1,760	363	1,025	--
	11	06-08-2000	170	1,119	1,830	370	1,078	27.6

Appendix III. Selected water-quality data collected from known intervals in wells from the Floridan aquifer system (Continued)

Local well number	Source	Date	Depth base of casing (feet)	Depth to bottom of open interval or depth of well (feet)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Chloride (milligrams per liter)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)
M-1324	8	07-30-87	2,917	3,505	44,000	18,800	34,260	--
M-1325	8	10-20-87	1,715	1,757	2,700	904	2,550	25.9
	8	11-10-87	2,177	2,212	44,000	19,740	50,000	25.8
	11	08-30-2001	1,715	1,757	3,600	940	2,100	27.1
	11	08-30-2001	2,177	2,212	52,500	19,670	36,400	26.9
M-1326	3	11-19-85	844	1,091	3,510	930	2,010	24.0
	10	08-02-90	844	1,091	3,940	942	2,145	23.9
	10	07-22-97	844	1,091	4,128	940	--	23.8
	11	07-10-2000	844	1,091	4,050	1,100	2,377	23.7
M-1328	10	10-19-89	420	1,200	701	31	449	24.4
M-1330	3	05-17-90	400	1,250	3,870	1,045	2,132	--
	11	06-08-2000	400	1,250	3,850	1,100	2,266	28.9
	11	07-17-2001	400	1,250	3,870	1,020	2,370	29.4
M-1346	3	05-17-90	400	1,250	5,600	1,404	3,121	--
M-1347	11	06-08-2000	400	1,320	3,990	--	--	28.7
	11	07-13-2000	400	1,320	4,000	1,100	2,393	29.1
M-1349	3	05-31-90	300	1,111	3,710	1,005	2,156	22.2
M-1353	8	09-02-97	1,600	1,650	3,400	730	2,100	29.0
	11	07-10-2000	1,600	1,650	3,540	910	2,148	24.7
M-1356	11	08-30-2001	1,165	1,400	4,570	1,250	2,610	24.9
M-1360	12*	11-13-2001	765	900	2,973	**750	--	27.0
	12*	11-01-2001	1,241	1,288	1,140	**180	--	27.7
	12*	10-30-2001	1,610	1,657	10,161	**2,970	--	28.7
	12*	10-26-2001	1,496	1,543	6,434	**1,820	--	28.0
	12*	10-23-2001	1,782	1,850	33,067	**10,100	--	29.7
	12*	10-16-2001	1,992	2,046	49,941	**15,300	--	30.0
OK-1	2	11-29-77	--	--	830	120	540	25.8
OK-2	2	09-19-78	218	686	880	170	670	25.8
OK-3	3	05-17-90	700	1,300	4,050	1,063	2,321	--
OK-7	10	07-15-87	412	963	532	20	332	24.9
	10	07-23-97	412	963	486	19	--	25.8
OK-13	10	06-27-88	600	1,200	2,330	588	1,364	27.4
	11	05-31-2000	600	1,200	2,090	460	1,238	26.5
OK-17	10	07-16-90	538	986	946	106	444	27.2
	10	07-10-97	538	986	961	100	--	26.0
	11	05-31-2000	538	986	909	86	548	25.8
OK-23	10	07-15-87	496	925	1,647	339	991	26.2
	3	05-17-90	496	925	1,641	322	--	--
	10	07-10-97	496	925	1,671	350	--	26.2
	11	05-31-2000	496	925	1,620	320	982	26.3

Appendix III. Selected water-quality data collected from known intervals in wells from the Floridan aquifer system (Continued)

Local well number	Source	Date	Depth base of casing (feet)	Depth to bottom of open interval or depth of well (feet)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Chloride (milligrams per liter)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)
OK-31	3	09-19-84	--	1,079	1,841	416	1,146	26.4
	10	06-29-88	--	1,079	6,631	1,992	3,993	26.8
	3	05-17-90	--	1,079	7,560	2,306	4,520	--
	11	05-31-2000	--	1,079	7,110	1,900	4,254	28.4
	11	07-19-2001	--	1,079	2,220	480	1,330	27.1
OK-71	3	05-22-90	500	800	3,900	905	2,213	--
OK-72	3	05-22-90	500	800	1,732	358	989	--
	11	05-31-2000	500	800	3,850	960	2,294	27.8
	11	07-19-2001	500	800	4,480	1,180	2,930	27.4
OK-73	3	05-18-90	500	1,000	8,410	2,626	5,170	--
OK-74	3	05-18-90	500	1,000	6,940	2,089	4,186	--
OK-100	12*	12-17-2001	1,640	1,700	20,590	**6,200	Not measured	29.2
	12*	12-14-2001	1,790	1,850	16,696	**4,990	Not measured	33.1
	12*	12-6-2001	1,955	2,030	23,100	**6,970	Not measured	29.3
OK-9000	5	04-17-91	1,270	1,700	--	3,000	7,120	35.0
OK-9001	5	04-17-91	990	1,075	--	210	820	27.5
	11	07-24-2001	990	1,075	1,070	150	676	27.5
OK-9002	5	04-17-91	1,275	1,700	--	2,200	5,230	27.0
	11	07-24-2001	1,275	1,700	7,580	2,040	4,970	27.6
PB-215	5	09-12-41	850	958	3,590	940	--	--
PB-652	6	02-23-73	826	1,385	21,500	**6,500	--	--
PB-747	5	06-19-74	990	1,280	6,400	1,800	4,060	23.5
PB-1144	2	12-5-77	250	1,038	4,370	1,380	3,180	25.9
	3	05-31-90	250	1,038	4,600	1,489	2,600	23.3
	2	12-05-77	250	1,038	4,370	1,380	3,180	25.9
	11	07-13-2000	1,021	1,038	5,130	1,400	3,062	24.9
PB-1167	8	12-07-94	1,000	1,237	--	1,620	2,990	--
PB-1170	8	09-08-94	1,501	1,532	5,130	1,380	2,790	--
	8	09-08-94	1,840	1,870	5,800	1,900	3,610	--
PB-1182	8*	1988	1,814	1,837	8,500	3,050	5,950	--
PB-1183	8	09-29-88	995	1,103	--	3,020	6,280	--
PB-1196	8	09-24-93	1,137	1,155	--	4,000	--	--
	8	09-24-93	1,549	1,609	--	2,020	--	--
	11	06-05-2000	1,137	1,155	12,890	3,800	7,942	23.3
	11	06-05-2000	1,549	1,609	6,110	1,700	3,484	23.3
	11	07-17-2001	1,137	1,155	13,000	3,800	8,290	22.9
	11	07-17-2001	1,549	1,609	6,350	1,760	3,890	23.0
PB-1774	11	08-29-2001	1,120	1,740	7,450	2,100	4,310	23.1
STL-47	5	07-16-80	287	745	2,410	610	--	25.0
STL-71	5	07-16-80	200	883	3,130	820	--	24.0

Appendix III. Selected water-quality data collected from known intervals in wells from the Floridan aquifer system (Continued)

Local well number	Source	Date	Depth base of casing (feet)	Depth to bottom of open interval or depth of well (feet)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Chloride (milligrams per liter)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)
STL-215	2	03-30-78	310	1,106	2,710	690	1,490	27.4
	3	05-23-90	310	1,106	3,450	941	1,893	26.1
	11	06-06-2000	310	1,106	3,680	1,000	2,182	27.7
	11	07-25-2001	310	1,106	3,800	1,020	2,380	28.1
STL-216	2	05-23-78	482	993	2,540	840	1,970	28.2
	3	05-23-90	482	993	3,390	902	1,858	25.0
	11	06-01-2000	482	993	3,220	820	1,900	27.9
STL-217	2	09-26-77	263	1,058	3,530	1,110	2,480	26.9
	2	05-08-79	263	1,058	4,360	1,200	2,600	26.6
	3	11-28-84	256	1,058	5,705	732	2,872	26.4
	10	08-15-88	263	1,058	4,860	1,538	3,247	27.1
	10	10-17-96	263	1,058	5,058	1,700	--	26.8
	11	06-01-2000	263	1,058	5,200	1,400	3,082	27.5
	11	07-19-2001	263	1,058	5,170	1,420	3,480	27.4
	11	10-19-2001	263	1,058	5,010	1,380	3,150	27.4
STL-218	2	01-30-78	224	946	2,650	620	1,500	26.5
	3	05-24-90	224	946	2,830	690	1,648	25.8
	11	06-01-2000	224	946	3,300	830	1,960	27.6
STL-219	2	01-30-78	344	1,238	5,670	1,380	3,370	27.9
STL-220	2	12-01-77	318	1,286	3,200	940	1,990	26.0
	11	06-07-2000	318	1,286	4,150	1,100	2,601	28.4
	11	07-18-2001	318	1,286	4,310	1,150	2,890	28.4
STL-221	2	04-27-77	--	--	--	990	2,200	26.9
STL-222	2	09-20-78	320	1,286	2,090	750	1,820	27.8
STL-223	2	03-28-78	311	896	3,550	830	2,200	28.6
STL-224	2	05-22-78	156	700	1,210	310	930	25.1
	10	10-18-90	156	707	1,383	316	901	25.6
	10	03-20-96	156	707	1,530	330	--	25.1
	11	06-06-2000	156	707	1,610	320	969	25.4
STL-225	2	05-24-78	350	894	3,720	1,170	2,640	32.0
	3	05-30-90	350	894	1,940	1,295	2,437	30.2
STL-228	2	05-09-79	382	958	3,760	910	2,260	23.8
STL-229	2	12-27-77	--	900	3,510	1,060	2,470	26.0
	3	05-23-90	--	900	3,870	1,075	2,224	26.9
STL-230	2	09-29-77	818	1,008	3,470	980	2,190	27.8
STL-242	2	07-27-77	355	1,227	--	610	1,490	27.0
	4	--	355	1,227	3,680	**970	--	26.4
STL-243	4	--	142	596	1,518	**300	--	25.3
STL-244	2	09-26-77	257	1,040	1,890	470	1,050	27.6
STL-245	2	04-27-77	328	1,239	--	840	1,940	29.2
STL-246	2	05-23-78	330	1,240	3,010	980	2,260	30.7
STL-247	2	07-27-77	--	--	--	1,220	2,600	24.0
STL-248	2	09-29-77	--	1,007	4,230	1,250	2,510	30.5

Appendix III. Selected water-quality data collected from known intervals in wells from the Floridan aquifer system (Continued)

Local well number	Source	Date	Depth base of casing (feet)	Depth to bottom of open interval or depth of well (feet)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Chloride (milligrams per liter)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)
STL-250	2	06-29-77	--	--	--	1,010	2,120	28.8
STL-253	2	03-29-77	--	--	--	1,190	2,830	28.5
STL-254	5	11-02-82	2,715	3,418	53,000	20,000	35,300	25.5
STL-255	8	12-09-82	898	1,268	5,100	1,480	2,880	24.4
	8	12-01-82	1,610	1,663	2,530	598	1,360	24.4
	11	07-12-2000	898	1,268	5,430	1,500	3,046	24.9
	11	07-12-2000	1,610	1,663	2,290	510	1,335	24.8
STL-332	8*	09-29-92	1,900	2,028	38,100	16,600	31,500	--
	8	02-01-93	2,770	3,315	…	19,000	36,700	--
STL-333	8	05-24-93	900	1,019	--	1,200	2,130	--
	8	05-24-93	1,850	1,920	--	14,200	25,000	--
STL-334	8	08-18-87	2,750	3,324	50,000	19,400	--	--
STL-335	8	08-30-87	950	1,175	3,400	1,000	2,060	--
	8	08-30-87	1,730	1,800	20,500	9,000	14,900	--
	11	07-12-2000	950	1,175	4,140	1,200	2,425	27.1
	11	07-12-2000	1,730	1,800	27,100	10,000	17,468	27.3
STL-342	2	07-27-77	--	--	--	650	1,470	27.9
	3	05-30-90	--	--	3,220	811	1,851	26.0
	11	06-01-2000	--	--	2,250	520	1,326	26.9
STL-346	3	05-23-90	--	786	2,970	782	1,640	24.0
	11	06-01-2000	--	786	3,130	800	1,888	27.2
STL-348	4	--	630	1,060	3,900	**1,000	--	24.6
STL-350	4	--	620	876	2,712	**670	--	24.4
STL-351	4	--	--	1,100	4,310	**1,200	--	24.3
STL-352	4	--	--	1,100	3,754	**990	--	24.3
	11	06-06-2000	--	1,100	4,170	1,100	2,475	24.7
	11	07-16-2001	--	1,100	4,210	1,120	2,540	24.4
STL-353	3	05-31-90	850	1,230	1,239	243	713	23.7
	10	08-15-88	850	1,230	1,195	208	696	24.3
	10	08-05-93	850	1,230	1,250	216	--	24.4
	11	06-06-2000	850	1,230	1,228	200	701	24.1
STL-355	10	08-31-87	560	893	1,915	964	2,008	29.5
STL-356	3	05-23-90	600	775	1,719	431	911	22.0
	10	03-20-96	600	775	2,570	700	--	28.4
STL-357	10	08-5-93	600	775	3,470	940	1,904	28.6
STL-359	4	--	330	906	--	1,000	--	27.8
STL-367	3	05-25-90	350	695	4,340	1,308	2,334	25.6
STL-368	3	05-25-90	480	935	4,150	1,215	2,251	21.0
STL-369	3	05-30-90	250	1,040	4,390	1,290	2,544	26.0
STL-370	3	05-30-90	246	1,080	5,060	1,317	3,000	26.6
STL-371	3	05-30-90	240	1,020	4,210	1,333	2,602	27.3
STL-373	3	05-24-90	300	--	1,622	337	903	27.2
STL-374	3	05-24-90	--	--	1,618	318	922	26.9

Appendix III. Selected water-quality data collected from known intervals in wells from the Floridan aquifer system (Continued)

Local well number	Source	Date	Depth base of casing (feet)	Depth to bottom of open interval or depth of well (feet)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Chloride (milligrams per liter)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)
STL-375	3	05-23-90	420	866	1,990	679	1,420	25.2
	11	06-07-2000	420	866	2,710	700	1,562	27.7
STL-376	3	05-23-90	--	638	1,611	336	903	25.6
	11	07-12-2000	--	638	1,560	330	917	26.3
	11	07-25-2001	--	638	1,610	330	951	26.9
STL-377	3	05-31-90	--	820	4,550	1,282	2,774	23.0
STL-380	11	06-07-2000	1,070	1,450	6,550	2,000	3,866	30.1
	11	07-18-2001	1,070	1,450	6,860	2,060	4,660	30.7
STL-381	11	06-07-2000	480	700	3,560	960	2,125	27.2
	11	07-18-2001	480	700	3,530	940	2,220	29.0
STL-382	11	06-07-2000	790	860	4,330	1,300	2,634	28.3
STL-385	11	06-15-2000	500	880	1,570	280	918	24.9
	11	07-25-2001	500	880	1,580	280	924	25.0
STL-386	11	07-12-2000	1,887	1,960	35,900	13,000	24,276	24.7
STL-387	11	07-11-2000	?	1,600	4,750	1,300	2,766	24.8
STL-388	11	07-11-2000	650	1,350	3,260	810	1,949	24.9
STL-389	11	07-11-2000	650	1,350	3,750	970	2,207	24.6
STL-391	11	07-11-2000	480	935	4,270	1,200	2,729	30.4
	11	07-18-2001	480	900	4,480	1,260	3,010	29.9
STL-392	11	07-11-2000	--	900	4,810	1,400	3,026	31.0
WA-117	4	--	--	750	1,512	325	--	25.4
WA-119	4	--	--	950	3,138	778	--	27.8
WA-546	9	07-31-85	442	1,038	2,484	828	--	27.8
WA-547	4	08-01-85	364	820	2,870	957	--	27.0
WA-562	9	11-13-85	270	1,018	3,120	733	--	27.1
WA-580	9	01-27-86	476	1,136	5,014	1,341	--	28.8
WA-611	4	--	--	750	3,582	940	--	26.2
WA-612	4	--	--	870	1,590	799	--	26.4
WA-625	4	--	--	1,012	4,060	1,010	--	27.6
WA-699	4	11-25-86	376	1,156	1,910	420	--	25.6
WA-708	4	12-29-86	274	957	1,496	708	--	23.9
WA-727	4	--	--	1,000	6,010	1,770	--	29.2
WA-815	4	06-25-87	460	995	2,982	530	--	26.1
WA-820	4	07-27-87	328	922	1,260	420	--	26.4
WA-829	4	08-05-87	342	741	3,050	967	--	28.9
WA-875	4	08-18-87	300	704	2,080	510	--	27.2
WA-877	9	08-19-87	--	740	1,500	373	--	26.1
WA-878	4	08-25-87	--	766	3,050	811	--	27.8
WA-879	9	08-26-87	--	903	1,270	1,270	--	25.3
WA-1001	9	11-03-87	326	829	2,580	1,422	--	27.8
WA-1005	4	--	--	830	2,975	885	--	27.8
WA-1016	4	--	--	876	2,838	695	--	27.8
WA-1032	4	--	--	1,020	6,270	1,734	--	24.7

Appendix III. Selected water-quality data collected from known intervals in wells from the Floridan aquifer system (Continued)

Local well number	Source	Date	Depth base of casing (feet)	Depth to bottom of open interval or depth of well (feet)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Chloride (milligrams per liter)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)
WA-1082	4	--	--	1,324	4,558	1,098	--	29.4
WA-1083	4	--	--	646	612	275	--	24.9
WA-1085	4	--	--	784	1,780	375	--	26.6
WA-1087	4	--	--	624	2,046	435	--	26.3
WA-1107	4	--	--	636	2,012	410	--	26.0
WA-1111	4	--	--	1,108	4,500	1,125	--	28.3
WA-1113	9	04-14-88	308	827	3,930	1,040	--	26.4
WA-1119	9	04-15-88	280	673	2,052	410	--	26.9
WA-1121	9	05-02-88	--	798	2,774	610	--	26.6
WA-1136	4	05-05-88	264	674	3,110	775	--	25.6
WA-1139	4	05-06-88	286	987	2,764	665	--	27.2
WA-1140	4	05-16-88	290	792	4,500	1,188	--	28.3
WA-1143	9	05-18-88	296	903	2,530	573	--	27.1
WA-1146	9	05-18-88	330	814	2,210	512	--	26.4
WA-1147	4	--	--	891	2,080	403	--	27.8
WA-1148	9	05-20-88	340	742	2,116	517	--	26.3
WA-1151	9	06-07-88	352	849	5,086	1,210	--	31.1
WA-1155	9	06-09-88	198	1,176	3,600	836	--	27.2
WA-1158	4	--	--	840	3,218	742	--	27.6
WA-1179	9	07-19-88	113	700	1,674	327	--	25.9
WA-1183	9	07-20-88	376	880	1,927	468	--	24.9
WA-1186	4	07-20-88	480	824	1,928	330	--	24.8
WA-1188	9	07-21-88	298	628	3,705	877	--	27.7

APPENDIX IV
Major Constituent and Field Characteristic Water-Quality Data Collected from Floridan Aquifer System Wells in this Study

Depths are given in feet below measuring point, which commonly is land surface. Measuring points are given in appendix I.

Annotations:

pH	Field, whole sample, in standard units
SC	Specific conductance, field, in microsiemens per centimeter at 25 degrees Celsius
T	Temperature, in degrees Celsius
Ca	Calcium, dissolved, in milligrams per liter
Mg	Magnesium, dissolved, in milligrams per liter
K	Potassium, dissolved, in milligrams per liter
Na	Sodium, dissolved, in milligrams per liter
Sr	Strontium, dissolved, in milligrams per liter
$CaCO_3$	Alkalinity, dissolved, total, field, in milligrams per liter
ANC	Acid neutralizing capacity, unfiltered, field, in milligrams per liter as $CaCO_3$
Br	Bromide, dissolved, in milligrams per liter
Cl	Chloride, dissolved, in milligrams per liter
F	Fluoride, dissolved, in milligrams per liter
SiO_2	Silica, dissolved, in milligrams per liter
SO_4	Sulfate, dissolved, in milligrams per liter
DS	Dissolved solids, at 180 degrees Celsius, in milligrams per liter

Appendix IV. Major constituent and field parameter water-quality data collected from Floridan aquifer system wells in this study

Local well number	Date	Depth top of open interval (feet)	Depth bottom of open interval (feet)	pH	SC	T	Ca	Mg	K	Na	Sr	$CaCO_3$	ANC	Br	Cl	F	SiO_2	SO_4	DS
CS-I1	09-13-2000	2,153	2,183	7.30	45,900	25.9	460	906	240	9,000	37.002	154.0	--	53.0	17,000	1.10	10	1,300	29,674
CS-M2	09-13-2000	1,000	1,110	7.93	17,770	23.3	240	335	140	3,300	13.872	151.4	--	18.0	5,700	1.10	14	1,000	11,206
	09-13-2000	1,510	1,653	7.74	9,530	22.3	150	195	69	1,400	14.656	122.8	--	9.0	2,800	1.20	11	590	5,830
G3-1	07-26-2001	--	--	7.30	4,830	29.3	164	112	15	640	32.560	144.5	--	6.4	1,350	.50	16	210	3,210
G205-5	07-26-2001	--	--	7.28	5,740	27.9	206	123	19	800	35.500	115.7	--	6.4	1,520	.40	15	450	3,760
M-255	06-8-2000	300	800	7.48	3,920	29.1	110	82	17	540	21.782	140.0	--	3.6	1,100	.62	15	220	2,350
	07-24-2001	300	800	7.38	3,930	29.2	116	85	17	550	21.740	141.8	--	--	1,020	.60	15	220	2,430
M-745	06-8-2000	360	810	7.44	4,440	30.1	130	94	19	630	20.019	141.0	--	3.9	1,200	.62	15	230	2,670
	07-24-2001	360	810	7.35	4,470	30.3	129	95	17	630	19.700	142.9	--	--	1,210	.60	15	230	2,850
M-1033	07-10-2000	2,027	2,093	8.08	46,900	26.6	370	981	320	9,300	27.431	174.0	--	60.0	18,000	.62	8	1,300	31,096
M-1034	07-10-2000	1,010	1,300	7.81	8,000	25.8	110	143	50	1,300	17.312	181.0	--	8.3	2,300	.98	15	390	4,780
M-1121	07-13-2000	543	1,020	7.61	4,330	24.9	90	102	25	650	7.600	166.0	--	4.4	1,200	.81	17	280	2,560
	07-18-2001	543	1,020	7.59	4,290	24.7	92	98	24	640	7.480	169.9	--	--	1,100	.80	16	270	2,560
M-1125	06-8-2000	456	1,120	7.73	1,830	27.6	65	52	9.3	210	12.190	126.0	--	1.4	370	.80	15	200	1,080
M-1325	08-30-2001	1,715	1,757	7.66	3,600	27.1	75	100	20	480	10.780	162.7	--	4.0	940	1.10	15	210	2,100
	08-30-2001	2,177	2,212	7.93	52,500	26.9	415	1270	430	11,230	22.680	141.5	--	83.0	19,670	.50	7	2,490	36,400
M-1326	07-10-2000	844	1,091	7.68	4,050	23.7	86	80	25	600	6.200	191.0	--	4.4	1,100	.94	16	220	2,380
M-1330	06-08-2000	400	1,250	7.42	3,850	28.9	97	80	17	540	20.604	141.0	--	3.9	1,100	.75	15	210	2,270
	07-17-2001	400	1,250	7.49	3,870	29.4	102	84	17	560	20.810	138.9	--	--	1,020	.70	15	220	2,370
M-1347	07-13-2000	400	1,320	7.44	4,000	29.1	110	89	19	580	11.863	164.0	--	4.4	1,100	.75	16	220	2,390
M-1353	07-10-2000	1,600	1,650	7.54	3,540	24.7	82	79	21	520	9.100	161.0	--	3.2	910	.91	16	240	2,150
M-1356	08-30-2001	1,165	1,400	7.34	4,570	24.9	96	102	22	650	10.090	163.4	--	5.1	1,250	.80	14	190	2,610
OK-13	05-31-2000	600	1,200	7.62	2,090	26.5	82	56	7.8	240	15.665	--	137	1.5	460	.84	16	180	1,240
OK-17	05-31-2000	538	986	8.67	909	25.8	16	20	10	130	10.271	--	178	0.2	86	2.20	13	140	548
OK-23	05-31-2000	496	925	7.66	1,620	26.3	56	41	7.8	190	15.907	--	116	0.9	320	.71	15	210	982
OK-31	05-31-2000	--	1,079	7.35	7,110	28.4	230	148	26	1,100	37.608	--	99	6.3	1,900	.36	13	600	4,250
	07-19-2001	--	1,079	7.72	2,220	27.1	70	48	11	300	17.000	105.2	--	2.0	480	.60	14	240	1,330
OK-72	05-31-2000	500	800	7.47	3,850	27.8	140	90	12	500	30.030	--	122	3.0	960	.62	16	290	2,290
	07-19-2001	500	800	7.37	4,480	27.4	165	101	15	600	32.970	111.9	--	--	1,180	.60	16	330	2,930
OK-9001	07-24-2001	990	1,075	7.90	1,070	27.5	51	47	5.5	84	17.000	113.5	--	0.7	150	.70	17	190	676
OK-9002	07-24-2001	1,275	1,700	7.38	7,580	27.6	291	165	26	1,070	37.430	100.9	--	8.3	2,040	.40	13	710	4,970

Appendix IV. Major constituent and field parameter water-quality data collected from Floridan aquifer system wells in this study (Continued)

Local well number	Date	Depth top of open interval (feet)	Depth bottom of open interval (feet)	pH	SC	T	Ca	Mg	K	Na	Sr	$CaCO_3$	ANC	Br	Cl	F	SiO_2	SO_4	DS
PB-1144	07-13-2000	1,020	1,038	7.61	5,130	24.9	100	103	28	800	6.900	164.0	--	5.3	1,400	.86	13	320	3,060
PB-1196	06-05-2000	1,137	1,155	7.88	12,890	23.3	190	256	70	2,300	17.536	160.0	--	13.0	3,800	.79	14	780	7,940
	06-05-2000	1,549	1,609	7.68	6,110	23.3	120	122	36	1,000	13.381	160.0	--	6.1	1,700	.80	15	330	3,480
	07-17-2001	1,137	1,155	7.53	13,000	22.9	190	264	67	2,080	17.460	161.2	--	--	3,800	.80	14	780	8,290
	07-17-2001	1,549	1,609	7.50	6,350	23.0	124	131	36	1,010	13.630	155.1	--	--	1,760	.80	15	350	3,890
PB-1774	08-29-2001	1,120	1,740	7.31	7,450	23.1	151	157	39	1,150	8.700	164.1	--	8.9	2,100	.80	14	340	4,310
STL-215	06-06-2000	310	1,106	7.67	3,680	27.7	120	86	14	470	15.047	160.0	--	3.5	1,000	.52	15	160	2,180
	07-25-2001	310	1,106	7.40	3,800	28.1	124	92	14	500	15.290	147.5	--	--	1,020	.60	15	150	2,380
STL-216	06-01-2000	482	993	7.40	3,220	27.9	110	77	12	410	14.180	--	140	2.6	820	.55	15	150	1,900
STL-217	06-01-2000	263	1,058	7.35	5,200	27.5	160	112	17	730	32.421	--	143	4.8	1,400	.52	17	240	3,080
	07-19-2001	263	1,058	7.34	5,170	27.4	162	110	17	720	30.710	142.5	--	--	1,420	.50	17	220	3,480
	10-19-2001	263	1,058	7.28	5,010	27.4	154	114	16	710	30.450	148.0	--	--	1,380	.50	17	240	3,150
STL-218	06-01-2000	224	946	7.39	3,300	27.6	130	77	11	420	21.781	--	168	2.6	830	.47	15	230	1,960
STL-220	06-07-2000	318	1,286	7.34	4,150	28.4	150	92	13	540	34.700	129.0	--	3.6	1,100	.46	16	280	2,600
	07-18-2001	318	1,286	7.32	4,310	28.4	155	94	14	580	32.860	130.4	--	--	1,150	.50	16	280	2,890
STL-224	06-06-2000	156	707	7.61	1,610	25.4	52	44	10	200	8.700	172.0	--	1.1	320	.87	19	150	969
STL-255	07-12-2000	898	1,268	7.90	5,430	24.9	83	100	32	810	15.290	168.0	--	5.5	1,500	1.10	14	260	3,050
	07-12-2000	1,610	1,663	7.64	2,290	24.8	63	60	14	300	7.500	171.0	--	1.7	510	1.00	15	200	1,340
STL-335	07-12-2000	950	1,175	7.64	4,140	27.1	110	94	20	600	11.738	151.0	--	4.2	1,200	.69	15	210	2,420
STL-335	07-12-2000	1,730	1,800	7.91	27,100	27.3	450	472	140	4,800	54.398	127.0	--	38.0	10,000	.51	14	200	17,468
STL-342	06-01-2000	--	--	7.45	2,250	26.9	77	54	9.8	280	11.387	--	168	1.5	520	.62	17	140	1,330
STL-346	06-01-2000	--	786	7.41	3,130	27.2	110	76	11	390	15.823	--	160	2.7	800	.54	15	150	1,890
STL-352	0606-2000	--	1,100	7.59	4,170	24.7	80	102	30	590	12.511	158.0	--	3.6	1,100	1.40	30	210	2,470
	07-16-2001	--	1,100	7.71	4,210	24.4	82	102	29	600	12.220	159.2	--	--	1,120	1.40	31	210	2,540
STL-353	060-6-2000	850	1,230	7.80	1,230	24.1	37	35	14	150	5.700	161.0	--	0.8	200	1.20	17	130	701
STL-375	060-7-2000	420	866	7.64	2,710	27.7	87	65	11	340	11.762	154.0	--	2.4	700	.67	15	140	1,560
STL-376	07-12-2000	--	638	7.53	1,560	26.3	54	48	9.3	170	9.000	163.0	--	1.2	330	.86	22	120	917
	07-25-2001	--	638	7.53	1,610	26.9	55	49	9.4	190	9.320	173.3	--	--	330	.90	20	130	951
STL-380	06-07-2000	1,070	1,450	7.30	6,550	30.1	220	151	19	880	32.789	135.0	--	7.5	2,000	.46	15	210	3,870
	07-18-2001	1,070	1,450	7.18	6,860	30.7	244	162	19	940	32.520	135.4	--	--	2,060	.50	16	210	4,660

Appendix IV. Major constituent and field parameter water-quality data collected from Floridan aquifer system wells in this study (Continued)

Local well number	Date	Depth top of open interval (feet)	Depth bottom of open interval (feet)	pH	SC	T	Ca	Mg	K	Na	Sr	$CaCO_3$	ANC	Br	Cl	F	SiO_2	SO_4	DS
STL-381	06-07-2000	480	700	7.37	3,560	27.2	110	77	15	470	15.760	144.0	--	3.2	960	.52	16	190	2,130
	07-18-2001	480	700	7.31	3,530	29.0	114	81	15	480	15.490	141.4	--	--	940	.60	16	190	2,220
STL-382	06-07-2000	790	860	7.29	4,330	28.3	150	102	15	560	23.172	140.0	--	4.4	1,300	.50	16	190	2,630
STL-385	06-15-2000	500	880	7.72	1,570	24.9	48	39	13	200	8.000	181.0	--	< 0.05	280	1.00	20	180	918
	07-25-2001	500	880	7.54	1,580	25.0	49	41	13	210	7.950	175.7	--	--	280	1.00	21	170	924
STL-386	07-12-2000	1,887	1,960	7.83	35,900	24.7	530	695	190	6,400	59.420	142.0	--	56.0	13,000	.60	14	160	24,276
STL-387	07-11-2000	--	1,600	7.49	4,750	24.8	110	104	23	670	13.557	151.0	--	5.0	1,300	.81	16	230	2,770
STL-388	07-11-2000	650	1,350	7.54	3,260	24.9	77	69	19	480	13.101	163.0	--	2.7	810	.92	16	240	1,950
STL-389	07-11-2000	650	1,350	7.47	3,750	24.6	93	79	21	550	12.724	156.0	--	3.8	970	.84	16	250	2,210
STL-391	07-11-2000	--	900	7.27	4,270	30.4	140	101	16	590	16.845	144.0	--	4.4	1,200	.58	16	180	2,730
	07-18-2001	--	900	7.24	4,480	29.9	142	101	17	600	17.160	143.5	--	--	1,260	.60	15	180	3,010
STL-392	07-11-2000	--	900	7.21	4,810	31.0	140	102	21	670	13.193	148.0	--	5.0	1,400	.64	16	220	3,030

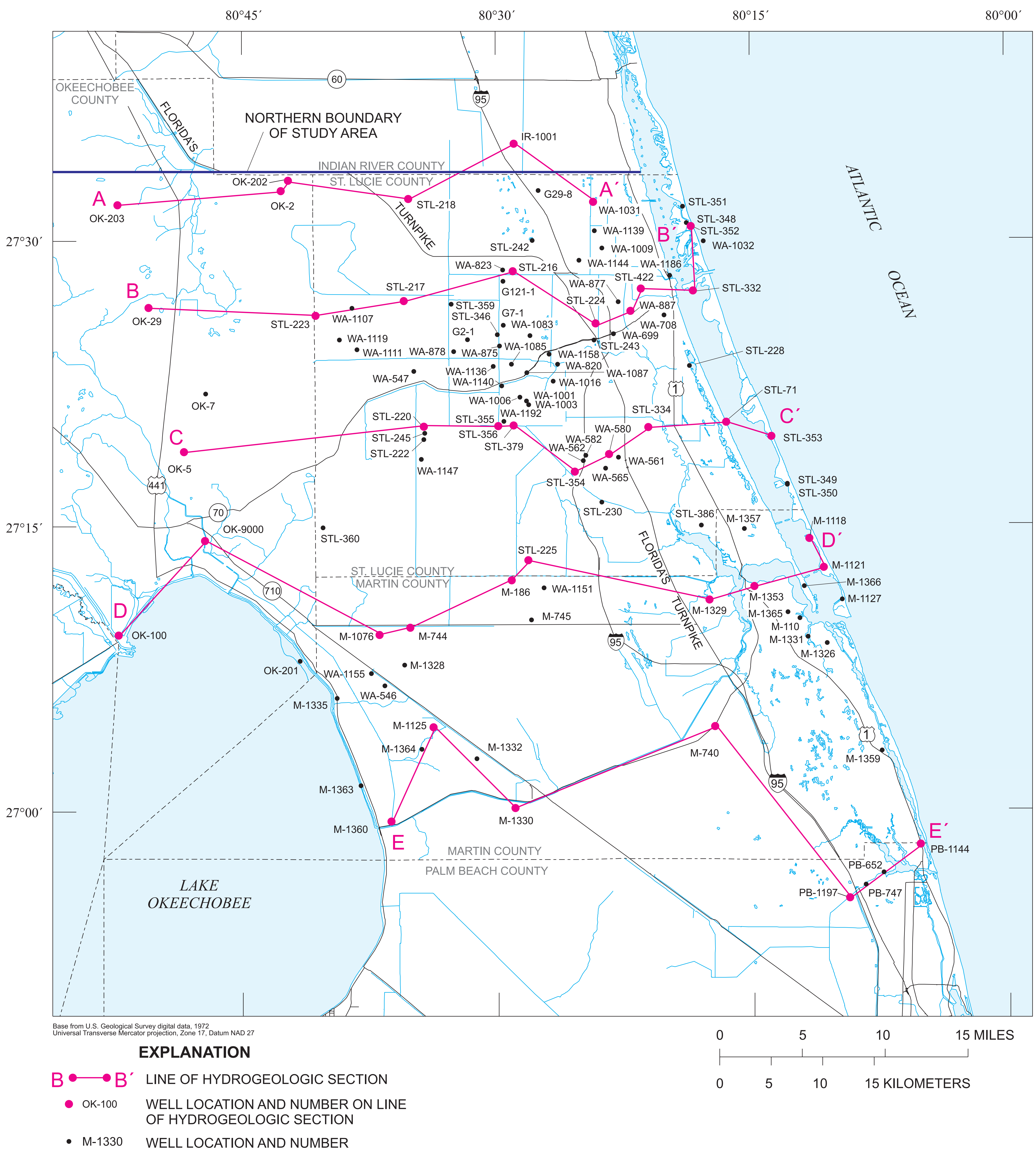

PLATE 1. LOCATION OF WELLS USED FOR GEOLOGIC MAPPING IN THE STUDY AND HYDROGEOLOGIC SECTION LINES

By
Ronald S. Reese
2004

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
SOUTH FLORIDA WATER MANAGEMENT DISTRICT

WATER-RESOURCES INVESTIGATIONS REPORT 03-4242
Location of wells with water-quality data used in the study--PLATE 2
Reese, Ronald S. 2004, Hydrogeology, water quality, and distribution and sources
of salinity in the Florida aquifer system, Martin and St. Lucie Counties, Florida

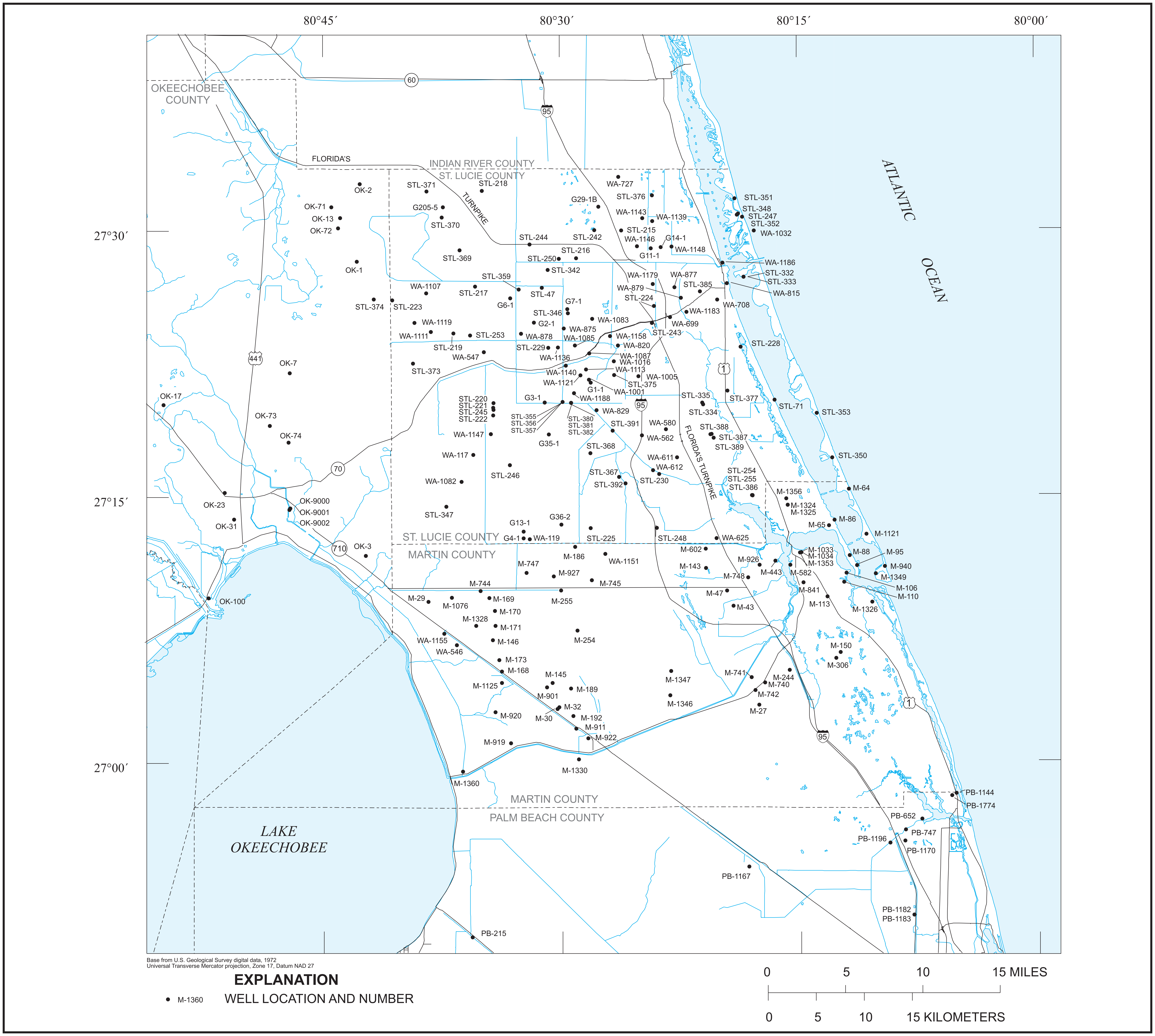

PLATE 2. LOCATION OF WELLS WITH WATER-QUALITY DATA USED IN THE STUDY

By
Ronald S. Reese
2004