SALTWATER INTRUSION AND QUALITY OF WATER IN THE FLORIDAN AQUIFER SYSTEM, NORTHEASTERN FLORIDA

By Rick M. Spechler

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBRIVIATIONS

Multiply	By	To obtain
Length		
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Flow		
million gallons per day	0.04381	cubic meter per second
gallon per minute (gal/min)	0.0630	liter per second
Transmissivity		
foot squared per day (ft^2/d)	0.0929	meter squared per day
Hydraulic conductivity		
foot per day (ft/d)	0.3048	meter per day

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

Equations for temperature conversion between degrees Celsius (°C) and degrees Fahrenheit (°F):

$$°C = 5/9 \times (°F—32)$$
$$°F = (9/5\ °C)+ 32$$

Altitude, as used in this report, refers to distance above or below sea level.

Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness $[(ft^3/d)/ft^2]ft$. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience

Abbreviated water-quality

g/mL = grams per milliliter
mg/L = micrograms per liter
mS/cm at 25 °C = microsiemens per centimeter at 25 °C
mg/L = milligrams per liter

Acronyms

USGS = U.S. Geological Survey
SJRWMD = St. Johns River Water Management District

Saltwater Intrusion and Quality of Water in the Floridan Aquifer System, Northeastern Florida

By Rick M. Spechler

ABSTRACT

Saltwater intrusion into freshwater aquifers has resulted in increased chloride concentrations in water from some wells in northeastern Florida. The principal areas of saltwater intrusion in the Floridan aquifer system in the study area are east-central Duval County, the southern two-thirds of St. Johns County, and along the coast. At least five possible mechanisms of saltwater movement, some more plausible than others, could explain the observed increases in chloride concentration in the upper freshwater zones of the Floridan aquifer. They are (1) the presence of unflushed pockets of relict seawater; (2) lateral movement of the freshwater-saltwater interface off the northeastern Florida coast; (3) upconing of saltwater from deeper, salty zones below pumped wells; (4) upward leakage from deeper, salty water-bearing zones through failed, uncased, or improperly plugged or constructed wells; and (5) upward leakage from salty water-bearing zones through semiconfining units that are thin, or are breached by joints, faults, or collapse features.

Ground-water withdrawals in Duval, Nassau, and St. Johns Counties increased from about 183 to 254 million gallons per day from 1965 to 1988. Approximately 90 percent of the total withdrawal is from the Floridan aquifer system, resulting in long-term declines in the potentiometric surface of the Upper Floridan aquifer of about one-third to three-fourths foot per year. Hydraulic heads in the lower part of the aquifer system are naturally higher than in the upper parts. Declines in head in the upper part have further increased the vertical head difference between zones, increasing the potential for vertical ground-water flow from lower zones of higher head upward through structural deformities, leaky confining beds, and wells, to higher zones of lower head. Lower zones typically have higher chloride concentrations than do upper zones.

Concentrations of chemical constituents in water from the Floridan aquifer system vary both areally and with depth. Chloride concentrations in water in the Upper Floridan aquifer in the study area range from about 4.6 to 3,600 milligrams per liter. Data indicate that in much of the study area, water in the upper zone of the Lower Floridan aquifer generally is slightly more mineralized than water from the overlying Upper Floridan aquifer. Water from the Fernandina permeable zone varies in quality from fresh to saline. Chemical analyses of water from five monitoring wells tapping this zone indicate maximum chloride concentrations of 16,800 milligrams per liter.

The potential for saltwater contamination of the freshwater-bearing zones probably will continue to increase in northeastern Florida as artesian pressure in the upper freshwater zones continues to decline. Implementation of wise water-management strategies could, however, reduce the potential for saltwater intrusion.

INTRODUCTION

The Floridan aquifer system is the major source of ground-water supply in northeastern Florida. In 1965, total ground-water withdrawal in Duval, Nassau, and St. Johns Counties was about 183 Mgal/d. Most of the ground water was withdrawn for commercial/industrial, public-supply, domestic self-supplied, and agricultural irrigation use. By 1988, ground-water withdrawals totaled about 254 Mgal/d, of which approximately 90 percent was from the Floridan aquifer system. The potential effects of increased population growth, industrial expansion, and agricultural irrigation have led to concerns for future availability and quality of the ground-water resources.

The potentiometric surface of the Floridan aquifer system in northeastern Florida has gradually declined at a rate of about one-third to three-fourths foot per year as a result of increased pumping. Associated with this decline in the potentiometric surface has been an increased potential for saltwater intrusion into the freshwater zones of the Floridan aquifer system along the coast. Gradual but continual increases in the chloride concentrations in water from the aquifer system have long been observed in several inland and coastal areas in Duval, Nassau, and St. Johns Counties. The potential for saltwater intrusion is expected to increase as population growth places greater demands on the ground-water resources of northeastern Florida.

In October 1987, the U.S. Geological Survey (USGS), in cooperation with the City of Jacksonville and the St. Johns River Water Management District (SJRWMD), began a study to determine the source, extent, and causes of saltwater intrusion in Duval, Nassau, St. Johns and extreme northeastern Clay Counties (fig. 1). The most intensively studied area was eastern Duval County. The results of this study are intended to help water managers, planners, and others make informed decisions regarding the protection of ground water in the Floridan aquifer system against possible further saltwater intrusion.

Purpose and Scope

This report (1) describes the water quality and delineates the areas where saltwater is present in the various water-bearing zones of the Floridan aquifer system; (2) describes the possible sources and mechanisms of saltwater intrusion into the aquifer; and (3) provides a description of the hydrogeologic framework of the Floridan aquifer system, including the presence of various water-bearing zones and geologic structures such as joints, faults, and solution features that influence the ground-water flow system.

The report includes data that: (1) describe the lithology, depth, thickness, and extent of the Floridan aquifer system in northeastern Florida based on geologic sections, geophysical logs, and geologic and drillers' logs obtained from the files of the U.S. Geological Survey, the St. Johns River Water Management District, and the Florida Geological Survey; (2) describe water levels and water-level declines in the Floridan aquifer system; and (3) describe the water-quality characteristics of the Floridan aquifer system based on chemical analyses of water samples from 223 wells.

Previous Investigations

The geology and hydrology of the study area have been discussed in numerous reports. Much of the geology of the study area has been described by Vernon (1951), Puri (1957), Puri and Vernon (1964), Chen (1965), and Miller (1986). Applin and Applin (1944) described the regional subsurface stratigraphy, paleontology, and structure of Florida and southern Georgia. The ground-water resources of Duval and neighboring counties have been described by Bermes and others (1963), Leve (1966), Bentley (1977b), Frazee and McClaugherty (1979), Brown (1984), and Spechler and Hampson (1984). Reports describing the regional geology, hydrology, and geochemistry of the Floridan aquifer system include those by Stringfield (1966) and various Regional Aquifer-System Analysis (RASA) reports by Miller (1986), Bush and Johnston (1988), Johnston and Bush (1988), Krause and Randolph (1989), Sprinkle (1989), and Tibbals (1990).

Saltwater encroachment in the Floridan aquifer system in southeastern Georgia was studied by Counts and Donsky (1963), Wait (1965), Wait and Gregg (1973), Gregg and Zimmerman (1974), and in northeastern Florida by Cooper (1942, 1944), Bermes and others (1963), Leve (1966), Fairchild and Bentley (1977), Brown (1984), and Toth (1990). Many of the reports by these investigators also discuss the quality of water from the Floridan aquifer system.

Acknowledgments

The author gratefully acknowledges the assistance of Douglas Munch, David Toth, Jeff Davis, and Caroline Mitchell-Silvers, with the St. Johns River Water Management District; Timothy Perkins and Jean Rolke, with the Water Division, City of Jacksonville; Gary Weise, Jim Wieger, William Essex, and Donald Summerfield, with the Groundwater Resource Management Branch, City of Jacksonville.

The author also thanks Ronald Richards, Geis Marine Center, and the Jacksonville Naval Air Station for the use of their docking facilities. Thanks also are extended to Partridge Well Drilling Company and

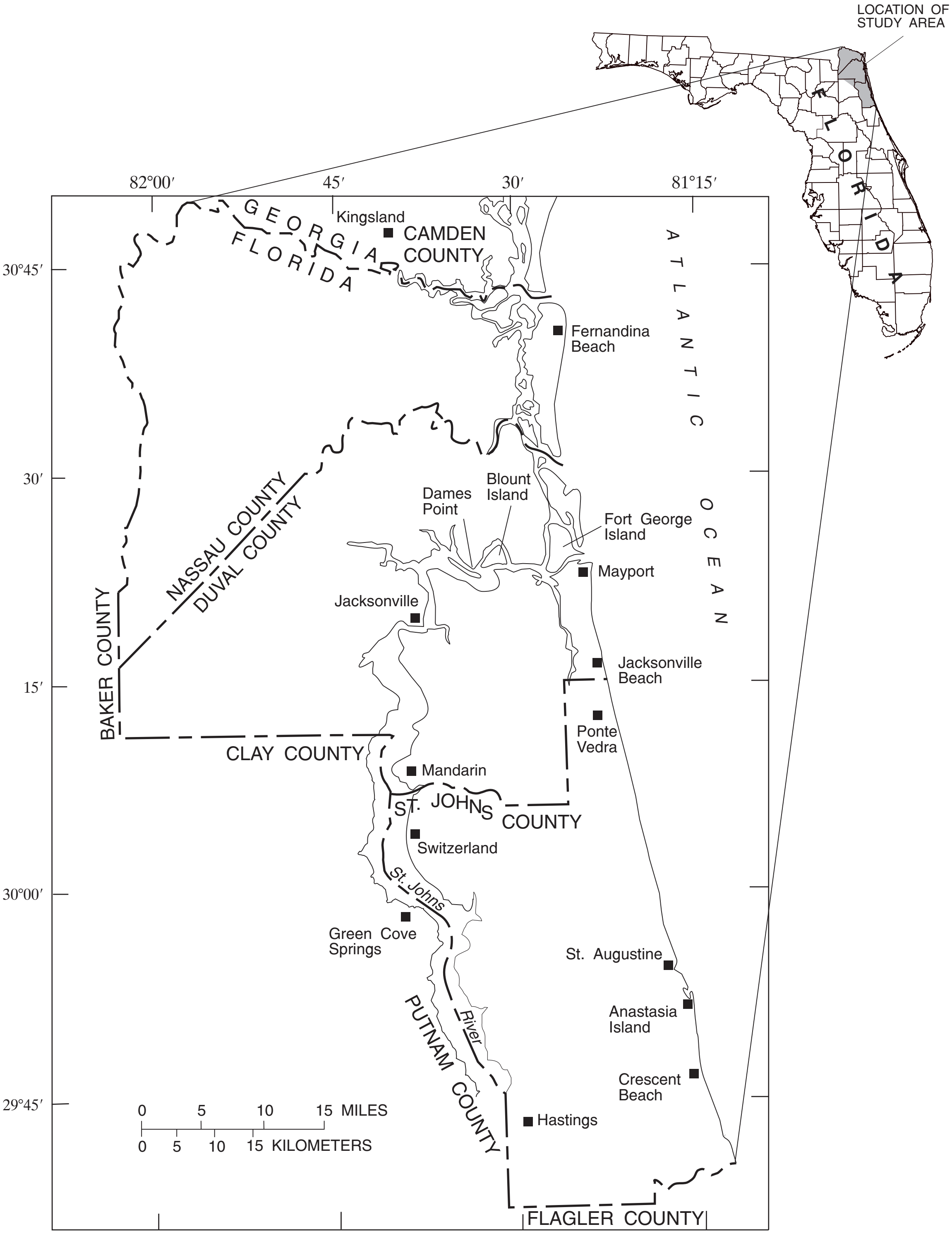

Figure 1. Location of study area.

Freeman Well Drilling Company, who furnished drillers' logs. Appreciation is expressed to the many residents in the area who permitted access to their properties and allowed the sampling of water and measuring of water levels in their wells.

Well-Numbering System

Two well-numbering systems are used in this report. The first, a 15-digit number based on latitude and longitude, is used to identify wells in the U.S. Geological Survey data storage and retrieval systems. The first 6 digits denote the degrees, minutes, and seconds of latitude; the next 7 digits denote degrees, minutes, and seconds of longitude; and the last 2 digits denote a sequential number for a site within a 1-second grid. For example, well 302538081253101 is the first well inventoried at latitude 30°25'38" N, longitude 081° 25'31" W.

The second numbering system is based on local well numbers. Since the 1960's, numbers have been assigned to wells in each county as they were inventoried. An abbreviation for the county where the well was located precedes the well number and thus distinguishes it from a well having the same number in another county. The prefixes, D, N, SJ, and C, indicate a well drilled into the Floridan aquifer system in Duval, Nassau, St. Johns, and Clay Counties, respectively. For example, well D-164 is the 164th well inventoried in Duval County.

Water Use

Ground water is the principal source of water supply in the study area for commercial-industrial self-supplied, public-supply, domestic self-supplied, and agricultural irrigation uses. The major source of ground water is the Floridan aquifer system, though about 10 percent is withdrawn from the surficial aquifer system primarily for domestic self-supplied and some public-supply use. In 1988, ground-water withdrawals in Duval, Nassau, and St. Johns Counties totaled about 254 Mgal/d, which represented an increase of more than 40 percent since 1965. (All data in this section are from R.L. Marella, U.S. Geological Survey, written commun., 1991.)

In 1965, ground-water in Duval County were about 127 Mgal/d. In 1988, withdrawals totaled about 167 Mgal/d (fig. 2) of which nearly 91 percent was from the Floridan aquifer system. Of the total water used, 56 percent was for public supply, 24 percent for commercial-industrial self-supplied, 9 percent for domestic self-supplied, 9 percent for agriculture irrigation, and 2 percent for thermoelectric power generation (fig. 3).

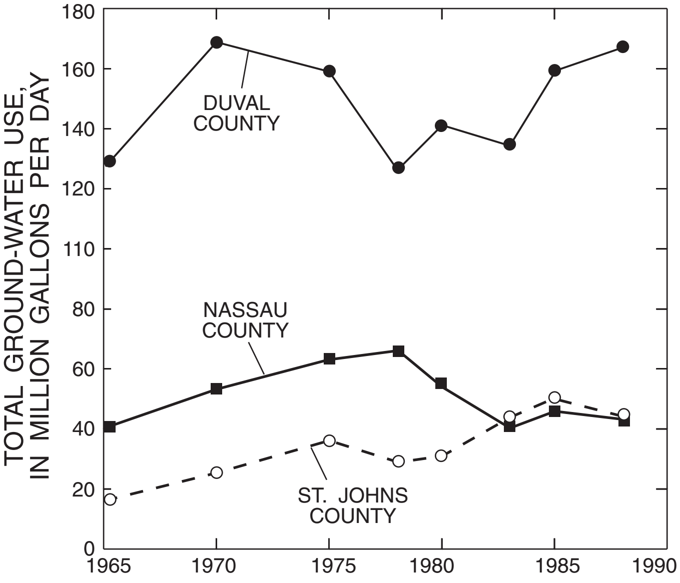

Figure 2. Total ground-water use, 1965-88 (data from R.L. Marella, U.S. Geological Survey, written commun., 1991).

Ground-water withdrawals in Nassau County increased from 40 Mgal/d in 1965 to 66 Mgal/d by 1978 (fig. 2). In 1988, withdrawals reportedly decreased to about 43 Mgal/d, of which about 93 per-cent was from the Floridan aquifer system. About 77 percent of the ground-water withdrawn currently is used for commercial-industrial use, 10 percent for domestic self-supplied use, 8 percent for public supply, and 5 percent for agricultural irrigation use (fig. 3).

Ground-water withdrawals in St. Johns County increased from 16 Mgal/d in 1965 to 44 Mgal/d in 1988 (fig. 2). Approximately 85 percent of the ground water withdrawn in St. Johns County in 1988 was from the Floridan aquifer system. Agricultural irrigation accounted for 78 percent of the water used, most of which occurred around the farming communities in the southwestern part of the county. Most of the irrigation water was withdrawn from the Floridan aquifer system primarily during the growing season. Public-supply and domestic self-supplied ground-water withdrawals accounted for 17 and 5 percent, respectively (fig. 3).

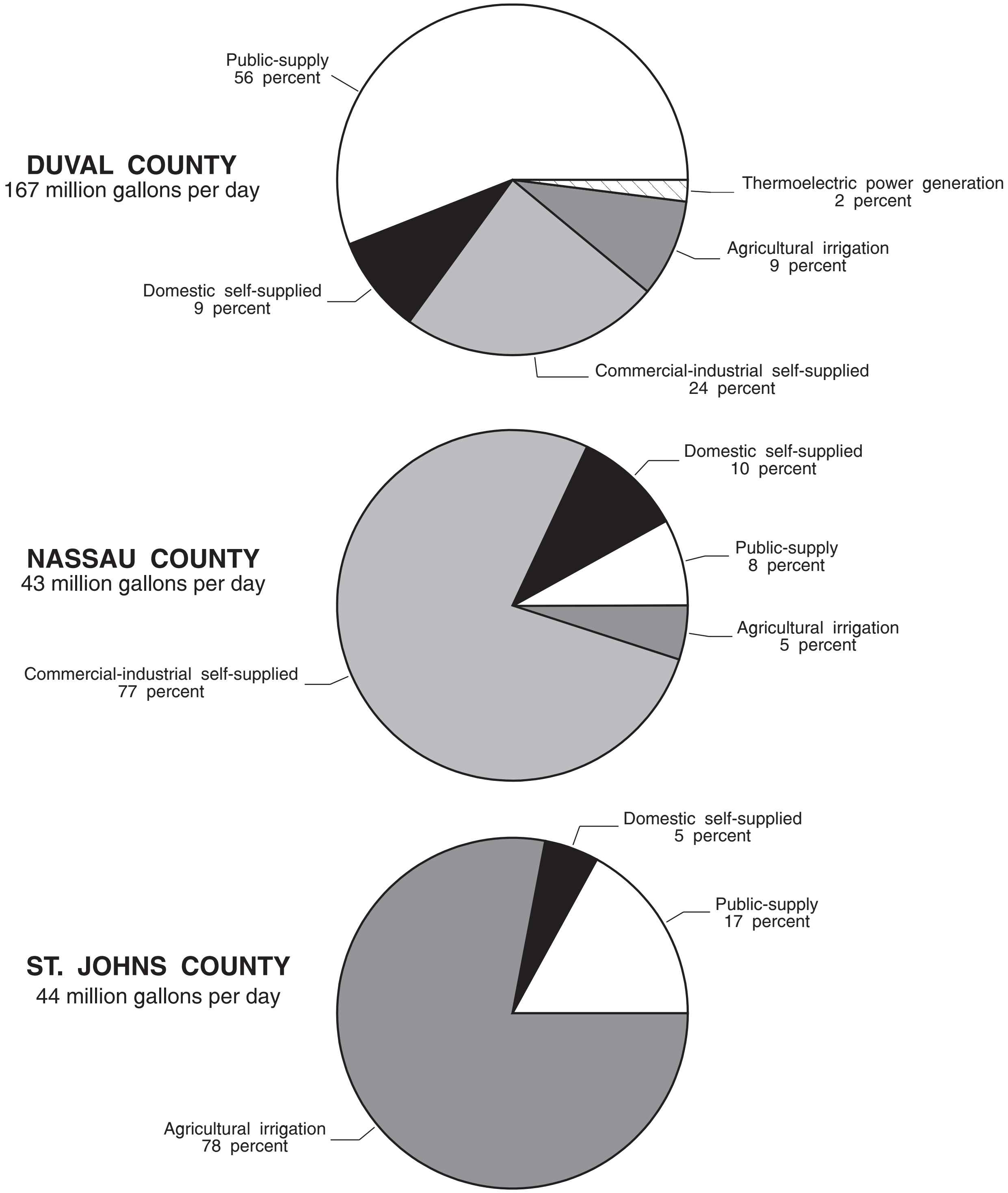

Figure 3. Total ground-water use by category for 1988 (data from R.L. Marella, U.S. Geological Survey, written commun., 1991).

HYDROGEOLOGIC FRAMEWORK

Northeastern Florida is underlain by a thick sequence of marine sedimentary rocks that overlie a basement complex of metamorphic strata. The primary water-bearing sediments are composed of limestone, dolomite, shell, clay, and sand, and range in age from late Paleocene to Holocene.

Descriptions of geologic formations and their hydrogeologic equivalents penetrated by water wells in Duval, Nassau, and St. Johns Counties are given in figure 4. Rocks of the Cedar Keys Formation of late Paleocene age underlie all of the study area. They are overlain in ascending order by the Oldsmar Formation of early Eocene age, the Avon Park Formation of middle Eocene age, the Ocala Limestone of late Eocene age, the Hawthorn Formation of Miocene age, and the undifferentiated deposits of late Miocene to Holocene age. Hydrogeologic sections (locations shown in fig. *5)* based on well data from the files of the U.S. Geological Survey and the St. Johns River Water Management District are shown in figures 6-8. Well information is given in table 1. The altitude and configuration of the top of the Ocala Limestone and Avon Park Formation are shown on plate 1 and figure 9, respectively.

The major structural features within and bordering the study area are the Peninsular Arch, the Ocala Uplift, and the Southeast Georgia Embayment (fig. 10). The study area is on the northwestern flank of the Peninsular Arch, a large anticlinal structure described by Applin (1951). The Peninsular Arch is the dominant subsurface structure in the State and trends south-southeastward and forms the axis of the Florida Peninsula as far south as the latitude of Lake Okeechobee in southern Florida. Applin (1951) concluded that the Peninsular Arch has been a dominant subsurface feature since Paleozoic time, although its present form is due to regional movements during the Mesozoic and Cenozoic eras.

Southwest of the Peninsular Arch is the Ocala Uplift, an anticlinal structure in north-central Florida (Puri and Vernon, 1964). The area of the uplift is approximately 230 mi long and 70 mi wide and generally trends in a northwesterly to southeasterly direction. Vernon (1951) reported that the structure was active from late Eocene to early Miocene time.

The Southeast Georgia Embayment is a synclinal feature that encompasses much of the study area. The basin plunges in an easterly direction beneath southeastern Georgia, northeastern Florida, and the adjacent continental shelf. Herrick and Vorhis (1963) indicated that the basin originated in middle Eocene time and was active intermittently through Miocene time.

Two northward-trending faults have been inferred in the study area (Leve, 1966, p. 20, fig. 5; 1978; 1983, p. 255*)*. The westernmost inferred fault approximately parallels the St. Johns River and extends from north-central Duval County to Green Cove Springs (fig. 10). The easternmost inferred fault extends south from northeastern Duval County to beyond the Duval-St. Johns County line. Other faults have been inferred in areas north and south of the study area. Maslia and Prowell (1988; 1990) mapped several faults in the Brunswick, Ga., area, about 87 mi north of Jacksonville. Two small faults were also inferred by Fairchild (1977, p. 23) west of the St. Johns River in northeastern Clay County. Faults and joints may have an effect on the ground-water system by increasing permeability of the limestone and dolomite.

Several circular depressions are present on the surface of the Ocala Limestone (pl. 1). The top of the Ocala Limestone is a paleokarst plain; the numerous highs and lows present on the surface of the Ocala Limestone are erosion features formed before the deposition of the Hawthorn Formation. Some of the depressions on the surface were formed by sinkhole collapse, the result of dissolution of carbonate material by percolating ground water. Buried collapse features also were discovered beneath the St. Johns River near Dames Point (fig. 10) using marine seismic reflection, and will be discussed later in the report.

<table>
<tr><th>Series</th><th>Stratigraphic unit</th><th>Approximate thickness (feet)</th><th>Lithology</th><th colspan="3">Hydrogeologic unit</th><th>Hydrogeologic properties</th></tr>
<tr><td>Holocene to Upper Miocene</td><td>Undifferentiated surficial deposits</td><td>20 - 120</td><td>Discontinuous sand, clay, shell beds, and limestone</td><td colspan="3">Surficial aquifer system</td><td>Sand, shell, limestone, and coquina deposits provide local water supplies.</td></tr>
<tr><td>Miocene</td><td>Hawthorn Formation</td><td>100 - 500</td><td>Interbedded phosphatic sand, clay, limestone, and dolomite</td><td colspan="3">Intermediate confining unit</td><td>Sand, shell, and carbonate deposits provide limited local water supplies. Low permeability clays serve as the principle confining beds for the Floridan aquifer system below.</td></tr>
<tr><td rowspan="6">Eocene</td><td>Ocala Limestone</td><td>100 - 350</td><td>Massive fossiliferous chalky to granular marine limestone</td><td rowspan="6">Floridan aquifer system</td><td colspan="2">Upper Floridan aquifer</td><td>Principal source of ground water. High permeability overall. Water from some wells shows increasing salinity.</td></tr>
<tr><td rowspan="2">Avon Park Formation</td><td rowspan="2">700 - 1,100</td><td rowspan="5">Alternating beds of massive granular and chalky limestone, and dense dolomite</td><td colspan="2">Middle semiconfining unit</td><td>Low permeability limestone and dolomite.</td></tr>
<tr><td rowspan="4">Lower Floridan aquifer</td><td rowspan="2">Upper zone</td><td rowspan="2">Principal source of ground water. Water from some wells shows increasing salinity.</td></tr>
<tr><td rowspan="3">Oldsmar Formation</td><td rowspan="3">300 - 500</td></tr>
<tr><td>Semiconfining unit</td><td>Low permeability limestone and dolomite.</td></tr>
<tr><td>Fernandina permeable zone</td><td>High permeability; salinity increases with depth.</td></tr>
<tr><td>Paleocene</td><td>Cedar Keys Formation</td><td>about 500</td><td>Uppermost appearance of evaporites; dense limestones</td><td colspan="3">Sub-Floridan confining unit</td><td>Low permability; contains highly saline water.</td></tr>
</table>

Figure 4. General geology and hydrogeology of northeastern Florida.

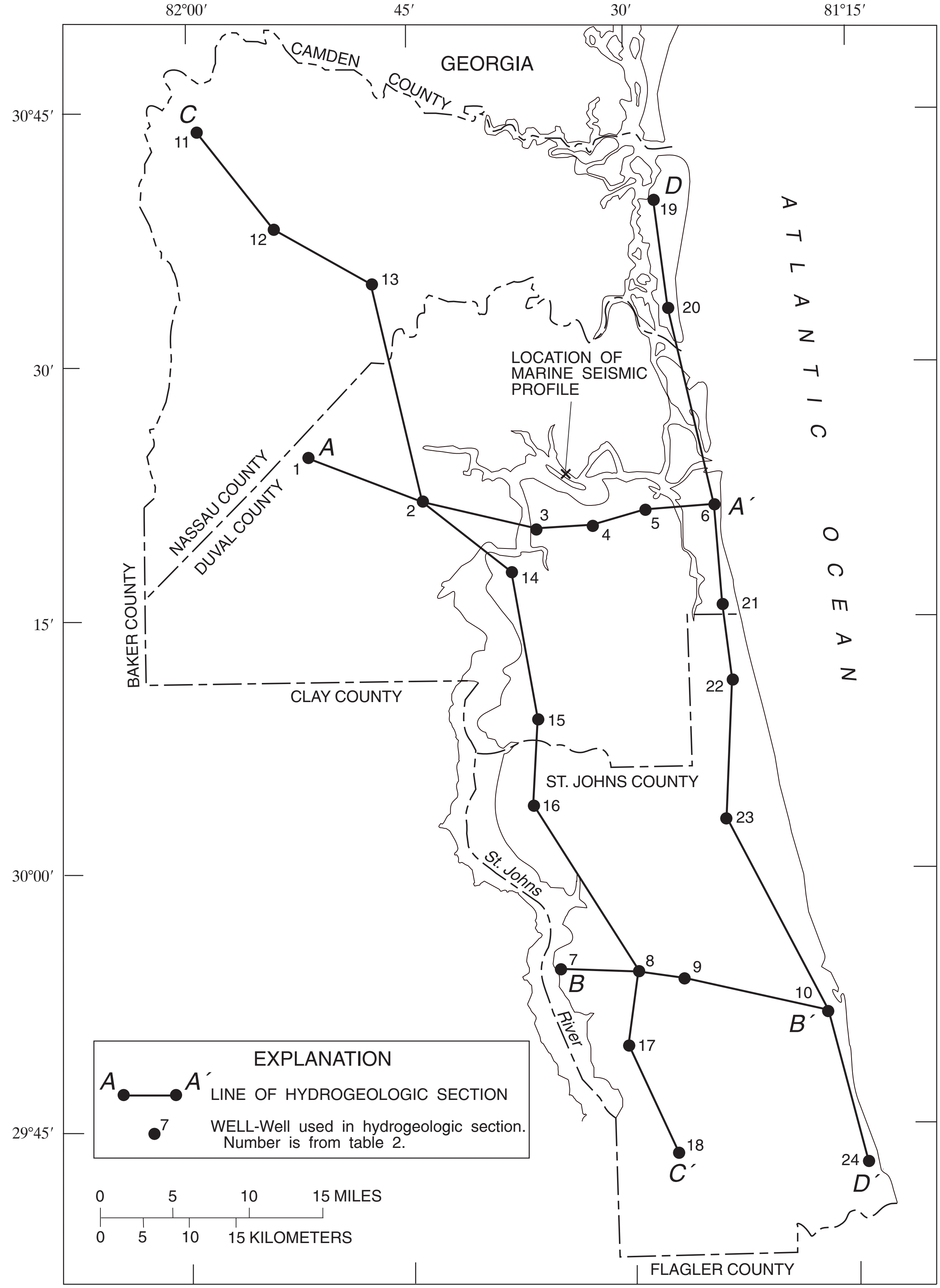

Figure 5. Location of hydrogeologic sections.

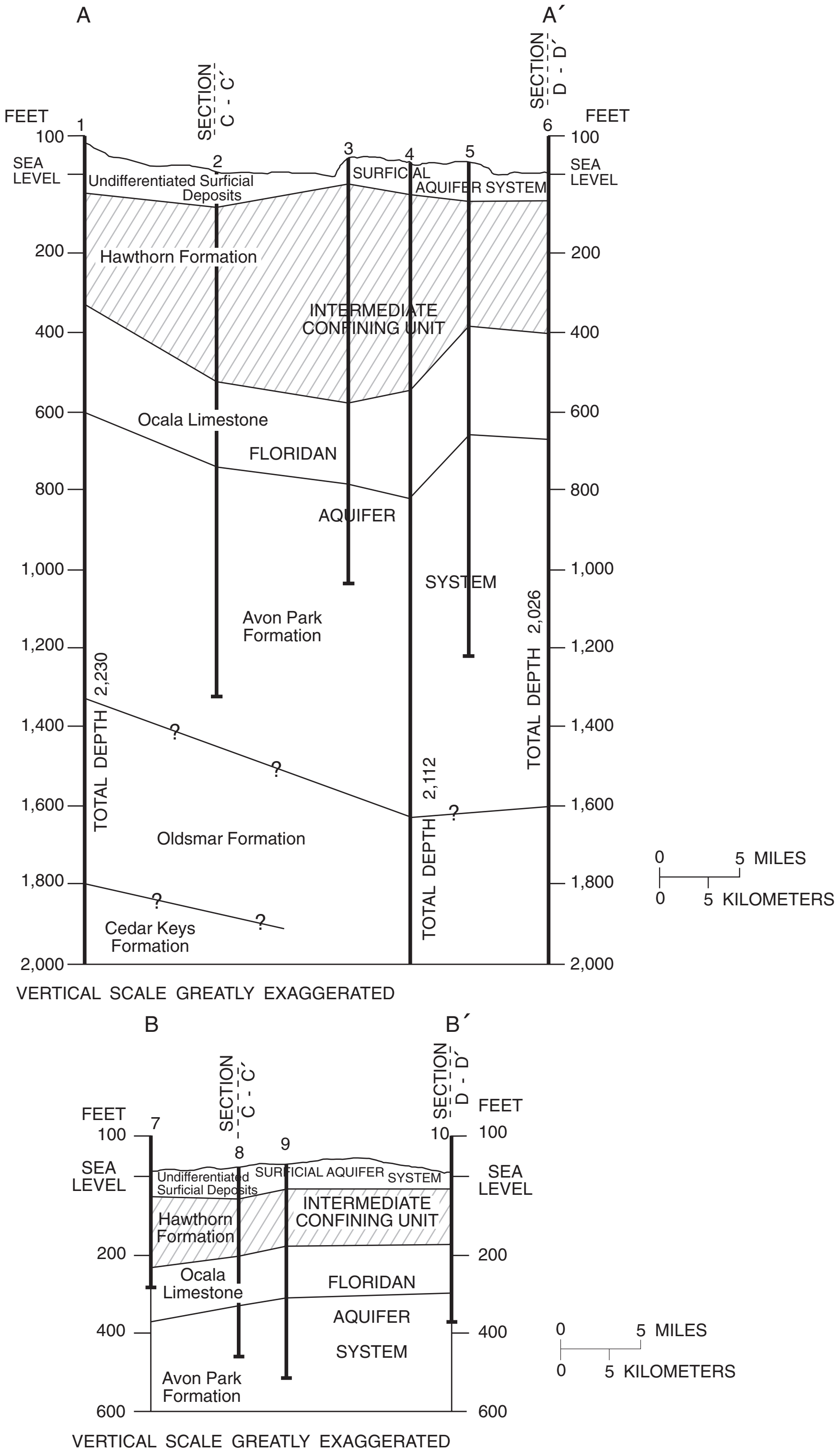

Figure 6. Hydrogeologic sections A-A’ and B-B’ (section lines shown in fig. 5).

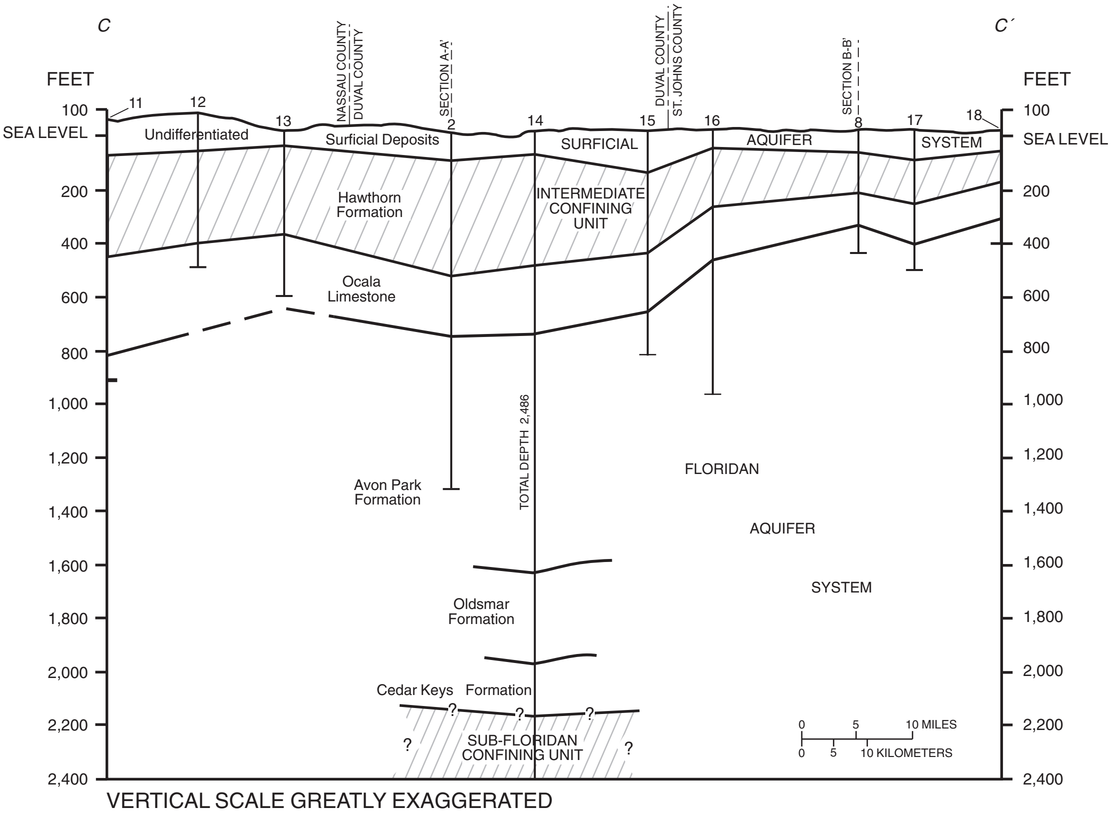

Figure 7. Hydrogeologic section C-C´ (section line shown in fig. 5).

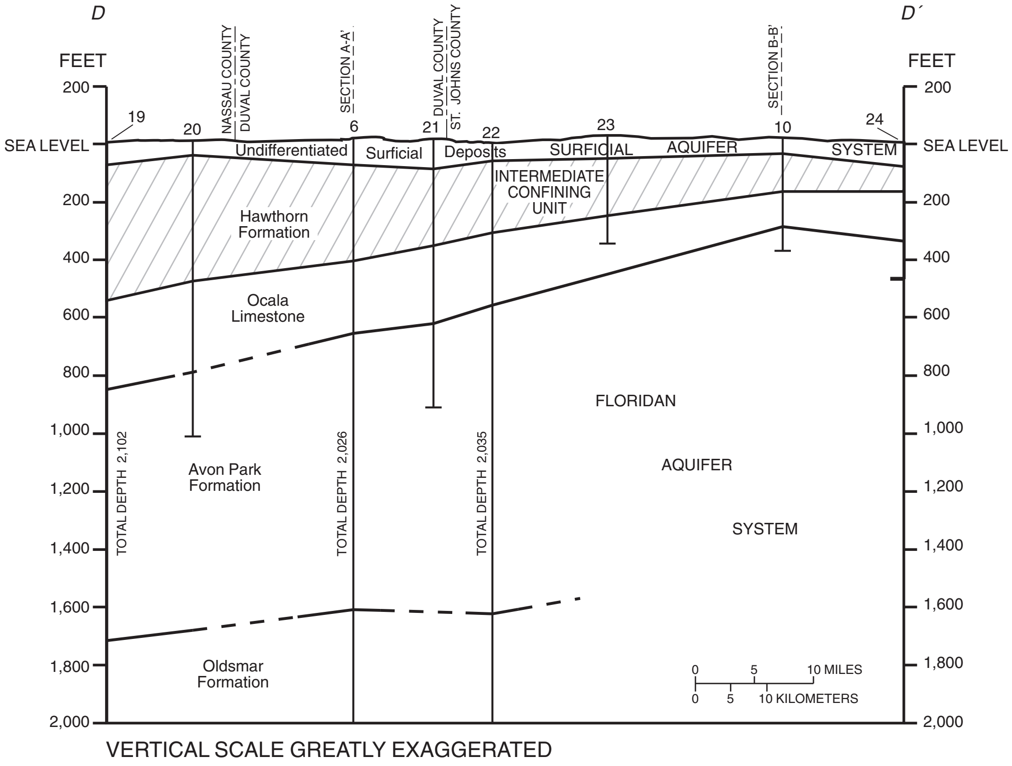

Figure 8. Hydrogeologic section D-D´ (section lines shown in fig. 5).

Table 1. --Wells used for geologic sections

[Agency maintaining well record: USGS, U.S. Geological Survey; and SJRWMD, St. Johns River Water Management District; --, no data]

Well number in figure 5	Site identification number	Agency	Local well number	Depth of well (feet)	Bottom of casing (feet)
1	302416081522602	USGS	D-349	2,230	444
2	302227081435001	USGS	D-592	1,326	1,154
3	302023081361301	USGS	D-266	1,023	579
4	302052081323201	USGS	D-3060	2,112	2,050
5	302134081284803	USGS	D-2363	1,216	454
6	302159081235601	USGS	D-2386	2,026	1,892
7	295454081353101	USGS	--	280	225
8	295427081293101	USGS	SJ-161	464	225
9	295341081263705	USGS	SJ-112E	517	204
10	295200081162301	SJRWMD	--	370	149
11	304409081593801	SJRWMD	--	909	523
12	303746081555701	SJRWMD	--	489	--
13	303348081494301	SJRWMD	--	599	417
14	301817081374902	USGS	D-425B	2,486	2,055
15	300944081362601	SJRWMD	--	825	440
16	300435081381201	USGS	SJ-33	445	278
17	294947081302201	SJRWMD	--	526	152
18	294334081270801	SJRWMD	--	400	150
19	304001081280301	USGS	N-117	2,102	2,000
20	303328081270301	USGS	N-113	1,016	488
21	301614081234201	SJRWMD	--	906	400
22	301132081225801	USGS	SJ-150	2,035	1,980
23	300307081234201	USGS	SJ-99	341	265
24	304300081141701	SJRWMD	--	458	155

HYDROGEOLOGY

Two aquifer systems are present in the study area--the surficial aquifer system and the Floridan aquifer system. The two systems are separated by the clays, silts, and sands of the intermediate confining unit, which includes most of the Hawthorn Formation. The intermediate confining unit contains beds of lower permeability that confine the water in the Floridan aquifer system. The Floridan aquifer system has three major water-bearing zones separated by less-permeable semi-confining units (Brown, 1984). All the geologic units in the study area yield some water to wells, but their water-bearing characteristics differ considerably. The major hydrogeologic units underlying the area, their stratigraphic equivalents, and hydrologic properties are shown in figure 4. A summary of some of the historical nomenclature, as applied to the various water-bearing and confining units, is presented in figure 11.

Surficial Aquifer System

The surficial aquifer system underlies the entire study area and consists of interbedded lenses of sand, shell, clay, and dolomitic limestone. The sediments that compose the surficial aquifer system range from late Miocene to Holocene age. The surficial aquifer system can be described as having two water-producing zones separated by beds of lower permeability. The aquifer system generally is unconfined, but may be semi confined where beds of lower permeability are sufficiently thick and continuous. The uppermost beds of the Hawthorn Formation are hydraulically connected with overlying deposits in most of the area, forming the lowermost part of the surficial aquifer system. The thickness of the surficial aquifer system is variable, ranging from about 20 to 120 ft in the study area.

The physical characteristics of the upper part of the surficial aquifer system are extremely variable. The deposits generally are discontinuous and the lithology

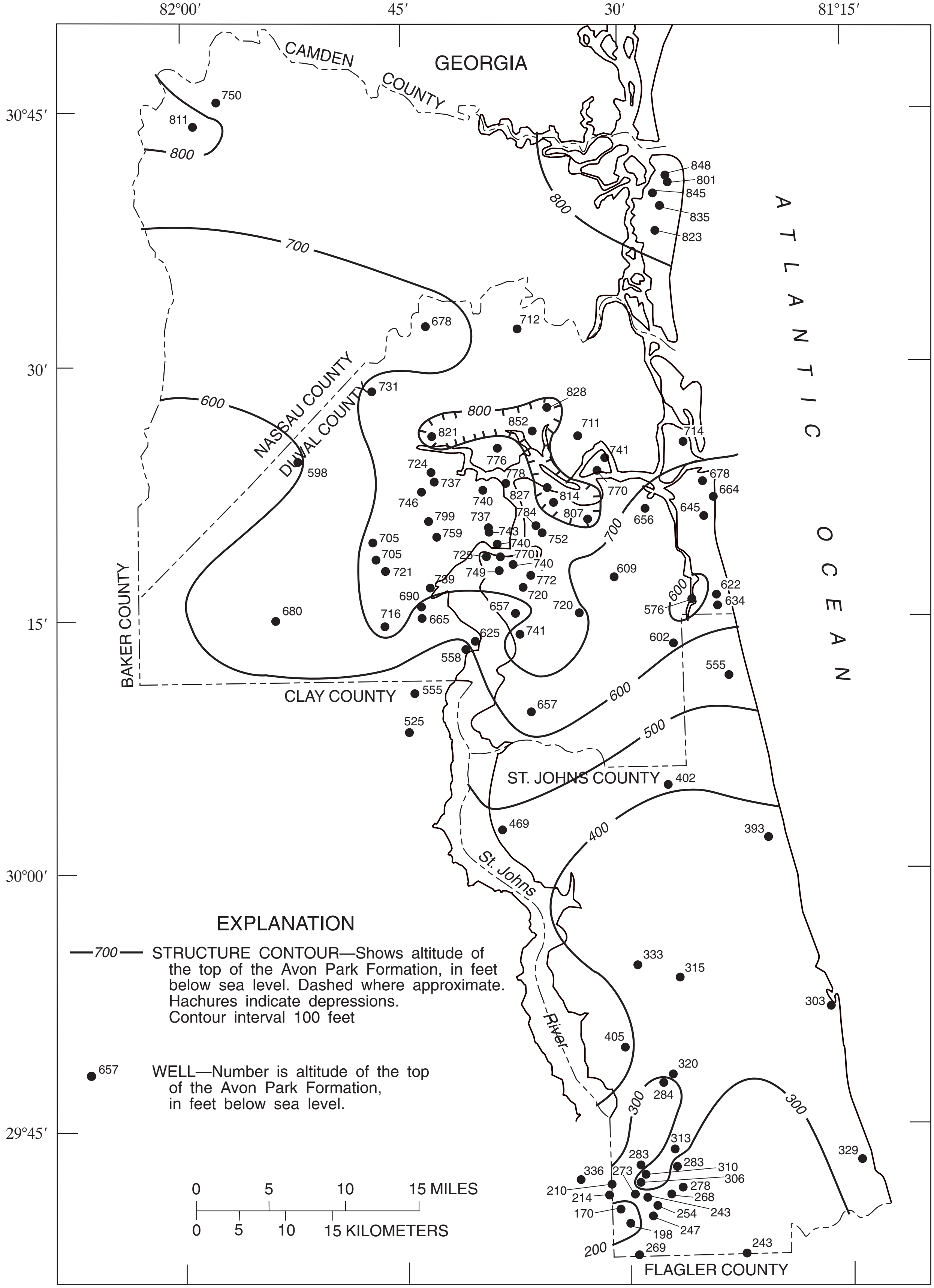

Figure 9. Altitude of the top of the Avon Park Formation.

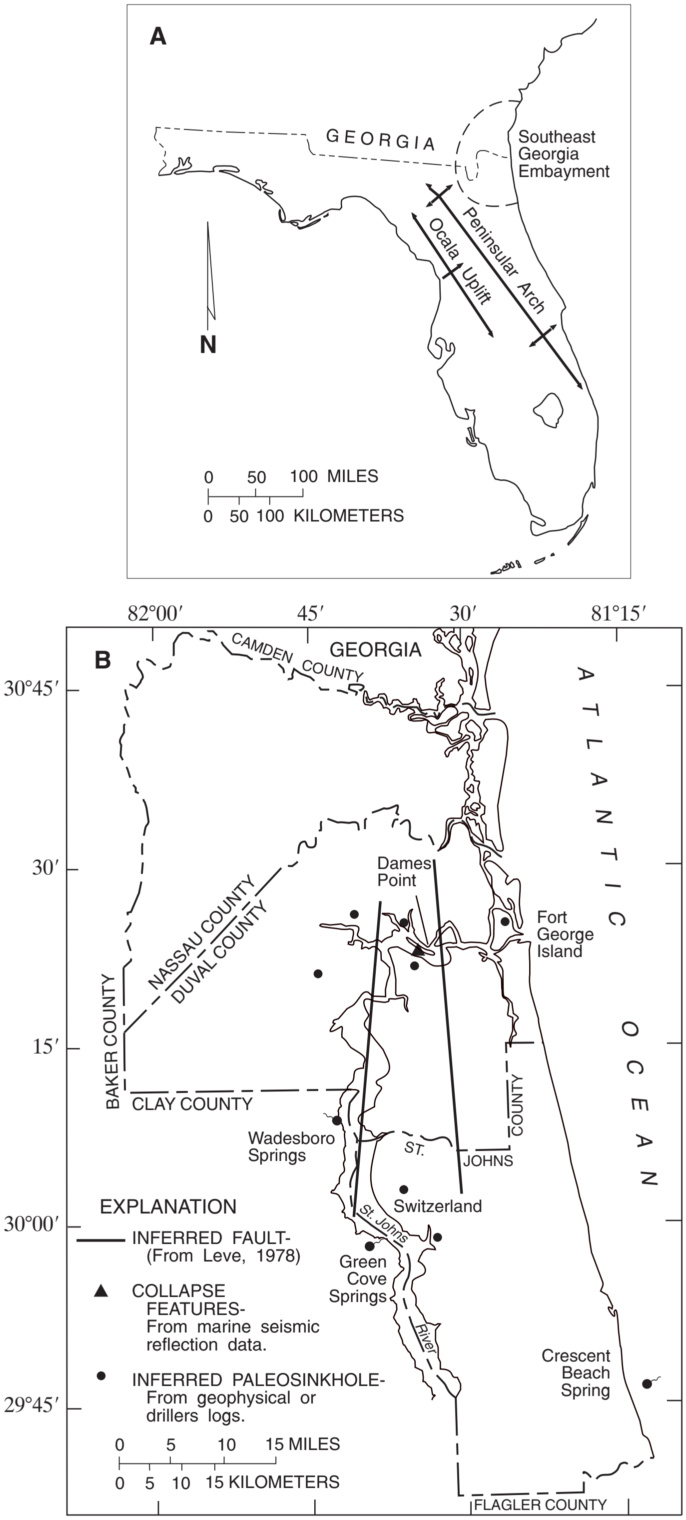

Figure 10. Major structural features in (A) northern Florida and (B) the study area.

<table>
<tr><th>Brown, 1984</th><th colspan="2">Krause and Randolph, 1989</th><th colspan="2">This report</th><th></th></tr>
<tr><td>Surficial aquifer</td><td colspan="2">Surficial aquifer</td><td colspan="2">Surficial aquifer system</td><td></td></tr>
<tr><td>Upper confining unit</td><td colspan="2">Upper confining unit</td><td colspan="2">Intermediate confining unit</td><td></td></tr>
<tr><td>Upper water-bearing zone</td><td colspan="2">Upper Floridan aquifer</td><td colspan="2">Upper Floridan aquifer</td><td rowspan="5">Floridan aquifer system</td></tr>
<tr><td>Upper semiconfining zone</td><td colspan="2">Middle semiconfining unit</td><td colspan="2">Middle semiconfining unit</td></tr>
<tr><td>Middle water-bearing zone</td><td colspan="2">Lower Floridan aquifer</td><td rowspan="3">Lower Floridan aquifer</td><td>Upper zone</td></tr>
<tr><td>Lower semiconfining zone</td><td rowspan="2"></td><td>Lower semiconfining unit</td><td>Semiconfining unit</td></tr>
<tr><td>Lower water-bearing zone</td><td>Fernandina permeable zone</td><td>Fernandina permeable zone</td></tr>
<tr><td>Lower confining unit</td><td colspan="2">Lower confining unit</td><td colspan="2">Sub-Floridan confining unit</td><td></td></tr>
</table>

Figure 11. Summary of historical nomenclature applied to the aquifer systems in the study area.

and texture of the deposits can vary considerably over short distances both vertically and laterally. The deposits primarily consist of fine-to-medium grained sand that locally contain sandy clay and shell beds. In some areas, discontinuous and relatively impermeable beds of reddish-brown hardpan are present within a few feet of the surface. These layers of hardpan are composed of slightly to well-indurated, iron-oxide cemented sand and clay.

Along the coast, shell beds become more common, and in southeastern St. Johns County, limestone composed of cemented shells and quartz sand form a permeable coquina. The coquina and unconsolidated beds of sand and shell extend from St. Augustine southward to Palm Beach County, occurring in a narrow band that parallels the coast. The coquina varies in width and rarely extends inland more than a few miles. Underlying these deposits are interbedded lenses of marine sediments consisting of fine-to-medium sand, shell, and green calcareous silty-clay and clayey sand of Pliocene or late Miocene age. In the lower part of these deposits, a soft-to-hard, cavernous, dolomitic, sandy limestone is present throughout much of Duval and Nassau Counties and in parts of northern St. Johns County. The limestone, together with sand and shell deposits, forms a laterally extensive, relatively continuous, permeable zone, which is the principal water-producing unit in the surficial aquifer system.

In northeastern Duval County, transmissivities of the upper surficial aquifer system average about 800 ft^2/d (Spechler and Stone, 1983, p.9). Transmissivities of the lower part of the surficial aquifer system at 13 sites in Duval County range from 250 to 1,300 ft^2/d (Causey and Phelps, 1978, p. 20.)

In east-central St. Johns County, Hayes (1981, p. 14) reported a transmissivity of approximately 6,500 to 7,000 ft^2/d for sand and shell beds 60 to 100 ft below land surface. An investigation by CH_2M Hill (1979, p. 2-12) reported values ranging from 1,300 to 25,500 ft^2/d. The unusually high value was determined for a shell bed approximately 60 ft thick. Transmissivities estimated from specific-capacity values from five wells in northern Anastasia Island ranged from 1,750 to 18,500 ft^2/d (Geraghty and Miller, Inc., 1976, p. 23).

In western Nassau County, transmissivities ranging from 100 to 950 ft^2/d were reported for the upper part of the surficial aquifer system, and from 200 to 1,000 ft^2/d from zones in the lower part of the aquifer system (Dames and Moore, 1987). In Kingsland, Ga., approximately 15 mi northwest of Fernandina Beach, a transmissivity of about 700 ft^2/d was determined from a zone 60 to 90 ft in depth (Brown, 1984, p. 21).

Heads in the surficial aquifer system vary seasonally and respond to changes in rates of recharge and discharge. Recharge to the aquifer is chiefly by the infiltration of rainfall and seepage from lakes, streams, and marshes. Recharge can also occur by lateral groundwater inflow from adjacent areas and by upward leakage in areas where the head in underlying artesian aquifers is higher than that in the surficial aquifer system. Water is discharged from the surficial aquifer system by evapotranspiration, infiltration into the underlying units where the head in the surficial aquifer system is higher than the potentiometric surface of the underlying artesian aquifers, seepage into surface-water bodies, pumping, and lateral flow to adjacent areas.

The surficial aquifer system provides water for lawn irrigation, heat pumps, and domestic use. Well yields generally range from 10 to 25 gal/min in the upper part of the aquifer and 30 to 100 gal/min in the lower part of the aquifer where permeable limestone and shell beds are present.

Intermediate Confining Unit

The intermediate confining unit underlies the surficial aquifer system and consists primarily of the Hawthorn Formation of Miocene age. The unit consists of interbedded clay, silt, sand, dolomite, and limestone containing abundant amounts of phosphatic sand, granules, and pebbles. Throughout most of northeastern Florida, the clays and silts in the intermediate confining unit serve as an effective confining layer that retards the vertical movement of water between the surficial aquifer system and the Upper Floridan aquifer. Locally, lenses of limestone or permeable sand yield moderate amounts of water to domestic wells. The thickness of the intermediate confining unit ranges from less than 70 ft in extreme southern St. Johns County to more than 500 ft in parts of central Duval County.

Little information is available on the hydraulic properties of the intermediate confining unit in northeastern Florida. Vertical hydraulic conductivities determined by laboratory analysis of cores ranged from 1.5×10^{-2} to 7.8×10^{-7} ft/d; and those determined by extensometer analysis, about 2×10^{-4} ft/d in Baker and Columbia Counties, Fla., approximately 50 mi west of the study area (Miller and others, 1978, p. 95). Franks and Phelps (1979, p. 5) estimated a value for vertical hydraulic conductivity of 1×10^{-3} ft/d in Duval County, based on laboratory analyses of cores from wells. In Brunswick, Ga., vertical hydraulic conductivities of the intermediate confining unit, as determined by laboratory analyses of cores, ranged from 5×10^{-5} ft/d to 1.1 ft/d (Krause and Randolph. 1989, p. 28).

Floridan Aquifer System

The Floridan aquifer system, the principal source of ground water in northeastern Florida, underlies all of Florida, and parts of Alabama, Georgia, and South Carolina. Most reports that describe the hydrogeology of northeastern Florida use the terms “Floridan aquifer” (Parker and others, 1955) or “the principal artesian aquifer’ (Stringfield, 1966) to describe the water-bearing rocks herein referred to as the Floridan aquifer system. Miller (1986, p. B45) defined the Floridan aquifer system as a vertically continuous sequence of carbonate rocks of generally high permeability that are mostly of Tertiary age; the rocks are hydraulically connected in varying degrees, and their permeability generally is one or more orders of magnitude greater than that of rocks bounding the system above and below.

Although the top of the Floridan aquifer system is reported to cross formation and age boundaries, Miller (1986, p. B46) reports that, regionally, the top of the Floridan aquifer system is the Suwannee Limestone, and where absent, the Ocala Limestone. The aquifer ranges from about 1,600 to 1,900 ft in thickness in the study area and includes the following stratigraphic units in descending order: the Ocala Limestone, the Avon Park Formation, the Oldsmar Formation, and the upper part of the Cedar Keys Formation. The lower part of the Avon Park Formation was formerly known as the Lake City Limestone and the upper part, the Avon Park Limestone. Miller (1986), however, redefined the two units and combined them into the Avon Park Formation.

The Floridan aquifer system is divided into two aquifers of relatively high permeability, referred to as the Upper Floridan and the Lower Floridan aquifers. In the study area, the Lower Floridan aquifer is further divided into two water-bearing zones. These aquifers are separated by a less permeable unit that restricts the vertical movement of water.

The Upper Floridan aquifer in the study area corresponds to the Ocala Limestone and, in some areas, also includes the upper part of the Avon Park Formation. The Ocala Limestone is fossiliferous and characterized by high permeability and effective porosity. Permeability has been enhanced by the migration of water along bedding planes, joints, and fractures. The top of the aquifer generally lies at greater depths in the northern part of the study area than in the southern part (pl.1); the altitude at the top of the aquifer ranges from less than 90 ft below sea level in the extreme southwestern part of St. Johns County to more than 600 ft below sea level in several areas in central Duval County. The Upper Floridan ranges in thickness from about 350 to 700 ft (Miller, 1986, pl.. 28).

The middle semi confining unit separates the Upper and Lower Floridan aquifers and is comprised of beds of dense, relatively less-permeable limestone and dolomite of variable thickness and permeability. This unit generally occurs in the upper part of the Avon Park Formation, and ranges in thickness from about 100 to 200 ft (Miller, 1986, p. B57).

The Lower Floridan aquifer which lies beneath the middle semi confining unit, contains two major water-bearing zones (Brown, 1984, p. 15); the middle water-bearing zone and the lower water-bearing zone, referred to in this report as the upper zone of the Lower Floridan and the Fernandina permeable zone, respectively (fig. 11). These zones are separated by another less permeable semiconfining unit.

In most of the study area, the upper zone of the Lower Floridan aquifer consists of approximately the lower two-thirds of the Avon Park Formation which is composed of alternating beds of limestone and dolomite. At Fernandina Beach, the zone is more deeply buried and may include the upper part of the Oldsmar Formation. Permeability within this upper zone is mostly related to secondary porosity developed along bedding planes, joints, and fractures. The upper zone is about 500 ft thick in the Jacksonville area and is about 950 to 1,400 ft below land surface (Krause and Randolph, 1989, p. 22). About half of the water pumped by large municipal and industrial wells in the Jacksonville area is withdrawn from the upper zone of the Lower Floridan aquifer (Krause and Randolph, 1989, p. 22).

The Fernandina permeable zone is a high-permeability unit that lies at the base of the Floridan aquifer system in parts of southeastern Georgia and northeastern Florida (Miller, 1986, B70). The aquifer was first tapped in 1945 by a 2,130-ft deep test well at Fernandina Beach (Brown, 1984, p. 39). In the areas of Fernandina Beach and Jacksonville, the unit is in the lower Oldsmar and upper Cedar Keys Formations (Krause and Randolph, 1989, p. D23). The upper part of the zone consists of limestone that is commonly dolomitized and locally cavernous. Little is known about the extent or thickness of the Fernandina permeable zone. Data from the few wells that have penetrated the zone in the study area indicate that the zone extends over the northern half of St. Johns and all of Duval and Nassau Counties. The thickness of the zone is estimated to range from about 100 ft in the Jacksonville area to more than 500 ft at Brunswick, Ga. (Krause and Randolph, 1989, p. D23).

Hydraulic Characteristics

Variations in transmissivity occur throughout the Upper Floridan aquifer in the study area. Brown (1984, p. 27) reported transmissivities ranging from about 20,000 to 50,000 ft^2/d for the Upper Floridan aquifer in Nassau County and adjacent Camden County, Ga. In Duval County, transmissivities determined from six wells that penetrated less than 550 ft of the aquifer were reported to range from 20,000 to 50,000 ft^2/d (Franks and Phelps, 1979, p. 7). Transmissivities of 31,000 and 49,000 ft^2/d were determined from aquifer tests at Fort George Island in eastern Duval County (Environmental Science and Engineering, Inc., 1985, p. 3-36). Bentley (1977a, p. 37) reported transmissivity values for the Upper Floridan ranging from 1,600 to 88,000 ft^2/d in St. Johns County and eastern Putnam County. The extremely low value was derived from an aquifer test of a well penetrating only 10 ft of aquifer.

Transmissivities resulting from model simulation of the Upper Floridan aquifer system for the study area range from 35,000 to 250,000 ft^2/d (Bush and Johnston, 1988, pl. 2; Tibbals, 1990, p. E36). The higher values derived from the model simulation are thought to reflect the transmissivities of the full thickness of the Upper Floridan aquifer.

The transmissivity of the upper zone of the Lower Floridan aquifer has not been determined by aquifer tests. However, a few values of transmissivity have been determined from aquifer tests of wells open to both the Upper Floridan aquifer and the upper zone of the Lower Floridan aquifer. Franks and Phelps (1979, p. 7) determined transmissivities of 100,000 and 300,000 ft^2/d for two wells that penetrated about 700 ft of the Floridan aquifer system. Bush and Johnston (1988, pl.. 2) reported transmissivities of 130,000 and 200,000 ft^2/d for two wells that penetrated about 700 and 750 ft of aquifer system, respectively. In nearby Clay County, Bentley (1977b, p. 37) determined a transmissivity of 87,000 ft^2/d from one well that penetrated about 850 ft, of the aquifer system. Transmissivities resulting from model simulation to the upper zone of the Lower Floridan aquifer for the study area range from 17,000 to 320,000 ft^2/d (R.E. Krause, U.S. Geological Survey, written commun., 1991).

No aquifer test data are available to calculate the transmissivity of the Fernandina permeable zone. In most of the study area, sufficient water supplies can be obtained from wells completed in the overlying water-bearing zones, which eliminates the need to drill to great depths, even where the Fernandina permeable zone contains potable water. Estimated transmissivity of the zone, based on results of numerical modeling studies, is about 75,000 ft^2/d (R.E. Krause, U.S. Geological Survey, written commun., 1981, referenced by Brown, 1984, p. 29).

The storage coefficient for artesian aquifers usually ranges from about 1.0×10^{-5} to 1.0×10^{-3} (Lohman, 1972). In northeastern Florida and southeastern Georgia, the storage coefficient of the upper 200 to 700 ft of the Floridan aquifer system, as determined from aquifer tests, ranges from 1.5×10^{-4} to 2.1×10^{-2} (Brown, 1984, p. 29).

Ground-Water Flow System

The principal recharge areas to the Floridan aquifer system in northeastern Florida are in southwestern Clay County, eastern Bradford and Alachua Counties, and western Putnam County. Areas in south-central Georgia provide recharge to the northern part of the study area. In recharge areas, the water table is above the potentiometric surface of the Upper Floridan aquifer and water enters the aquifer by downward leakage and through breaches in the intermediate confining unit caused by sinkholes and other features having enhanced permeability. Water is discharged from the Floridan aquifer system by pumping, springs, and upward leakage of water to the surficial aquifer system where the potentiometric surface of the Upper Floridan aquifer is above the water table.

The regional configuration of the potentiometric surface of the Upper Floridan aquifer for September 1989 is shown in figure 12. Ground water moves from recharge areas to discharge areas, in directions perpendicular to the lines of equal head. The potentiometric surface ranges from more than 50 ft above sea level in southwestern Duval County to more than 60 ft below sea level near Fernandina Beach. Positive heads of more than 25 ft extend about 55 mi east of Fernandina Beach (Johnston and others. 1982). The large depression located at Fernandina Beach (fig. 12) is primarily the result of industrial pumping and the depression located south of Ponte Vedra Beach is a result of pumping by public-supply wells and for golf-course irrigation. The depression in the potentiometric surface south of Jacksonville is believed to be caused, in part, by withdrawals from industrial and public-supply wells, and possibly by diffuse upward leakage or undetected spring discharge into the St. Johns River (C.H. Tibbals, U.S. Geological Survey, oral commun., 1991). In the Green Cove Springs area, the depression in the potentiometric surface is the result of a combination of withdrawals from domestic and public-supply wells and pumping for irrigation immediately south of the area. Discharge of water by diffuse upward leakage or from undetected springs in the St. Johns River could also contribute substantially to this depression.

Spring discharge or diffuse upward leakage also may affect the potentiometric surface along the southern coast of St. Johns County. Although a submarine spring 2.5 mi east of Crescent Beach is the only documented offshore spring in the study area (Stringfield and Cooper, 1951a, p. 66), the area offshore between St. Augustine and Brevard County to the south is considered to be an area where springs may be present due to the thinning of the intermediate confining unit. A large sinkhole approximately 26 mi east of Crescent Beach also has been documented; however, no water has been observed discharging into the sea (Wilson, 1991, p. 5).

Long-Term Water-Level Trends

Industrial and agricultural expansion and population growth during the last 50 years in northeastern Florida have resulted in increased water withdrawals from the Floridan aquifer system which subsequently have caused a decline in the potentiometric surface of the Upper Floridan aquifer. Declines in the potentiometric surface for long periods of time, resulting from increased water use or decreased rainfall, are significant because they indicate change in the long-term balance between recharge and discharge. Over time, these changes could shift the natural saltwater-freshwater interface causing more-mineralized water to invade the freshwater aquifers.

Prior to large withdrawals from the Upper Floridan aquifer, the potentiometric surface was mainly controlled by the hydraulic characteristics of the aquifer and the overlying and underlying confining units, the topography and altitude of the recharge areas, and by natural recharge and discharge. Predevelopment hydrologic conditions are considered to be conditions that existed prior to man's influence on the system. In the

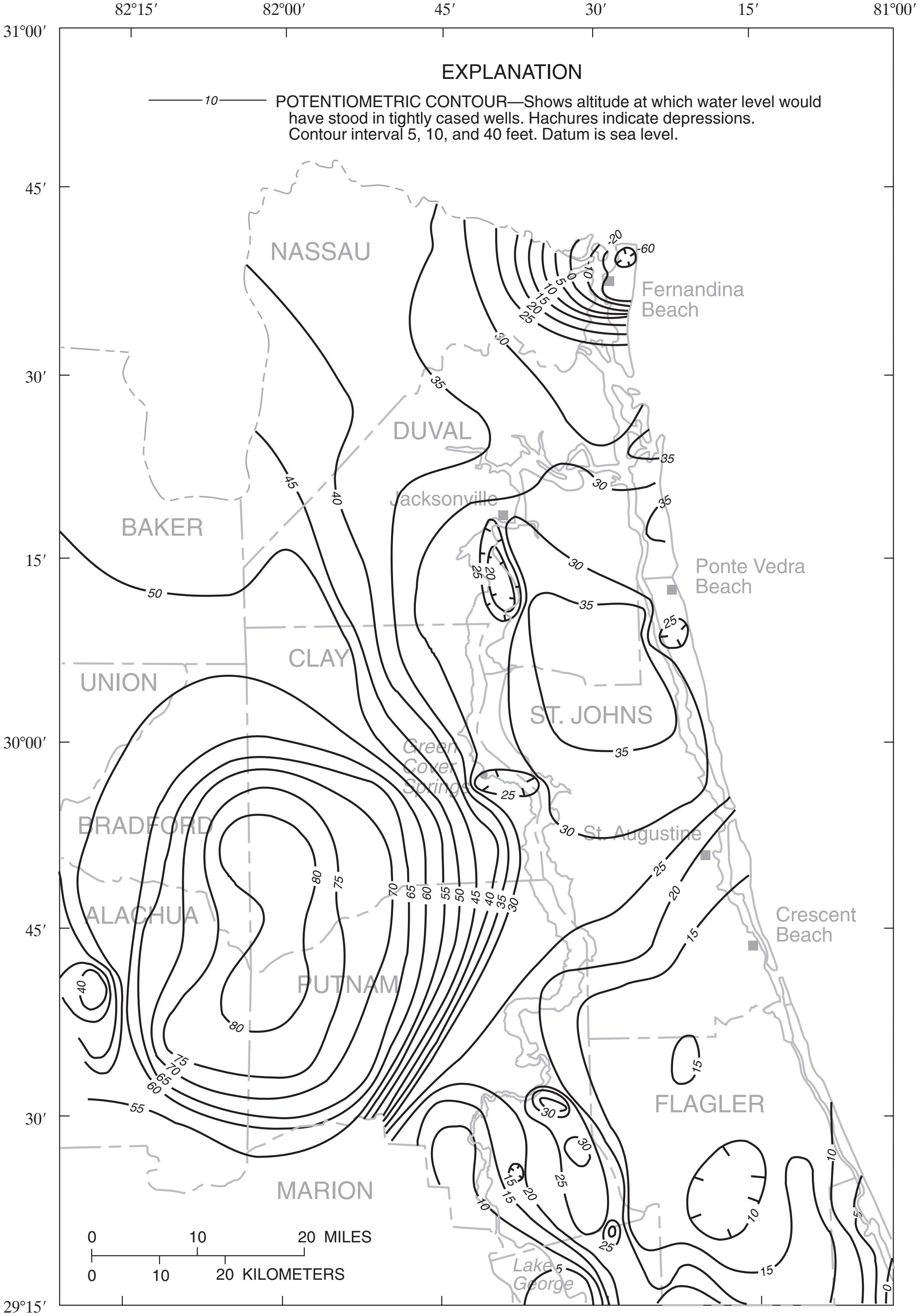

Figure 12. Potentiometric surface of the Upper Floridan aquifer in northeastern Florida, September 1989 (from Burtell, 1990).

study area, the estimated potentiometric surface of the Upper Floridan aquifer prior to develop (about 1880) ranged from about 70 ft above sea level in western Duval and Nassau Counties to about 30 feet above sea level in southern St. Johns County (fig. 13).

Since predevelopment times, the increase in pumping in and near the study area has resulted in a decline of the potentiometric surface. The approximate decline of the potentiometric surface of the Upper Floridan aquifer (fig. 14) is based on the differences between the September 1989 potentiometric map (fig. 12) and the estimated predevelopment potentiometric-surface map (fig. 13). The greatest decline in the potentiometric surface was in northeastern Nassau County where large withdrawals for industrial use have occurred since 1939. Declines of more than 120 ft have occurred near the center of pumping at Fernandina Beach in contrast with 25-ft declines in the western part of the county, an area that is relatively unaffected by pumping. Declines of 10 to 25 ft have occurred in St. Johns County, and 20- to 40-ft declines have occurred in Duval County.

At present, the U.S. Geological Survey and the St. Johns River Water Management District periodically measure water levels from a network of monitoring wells in northeastern Florida. Water-level records for more than 15 years are available for a number of wells tapping various water-bearing zones of the Floridan aquifer system. The locations of some long-term monitoring wells are shown in figure 15. Well information is given in table 2.

Hydrographs of wells tapping the Upper Floridan aquifer and the upper zone of the Lower Floridan aquifer are shown in figures 16 and 17. The hydrographs show seasonal fluctuations and long-term trends of the potentiometric surface. These hydrographs, and others on file, indicate that water-level declines in wells open to the Floridan aquifer system in the study area have averaged about one-third to three-fourth foot per year.

Water level declines are not always the result of deficient rainfall. Tibbals (1990, p. E9) reported that normal to above-average rainfall was recorded at Jacksonville during most of the period from 1943 to 1972. During the same period, declines in water levels were observed in many of the long-term monitoring wells. The decline in water levels probably is the result of increased pumping from the Floridan aquifer system throughout northeastern Florida.

Head Relations

Water levels in wells tapping the Floridan aquifer system vary with depth. Variations in water levels measured in the drill stem and annulus during the construction of three test wells drilled to a depth of 2,000 to 2,100 ft are shown in figure 18. Well locations are shown in figure 15 and well information is listed in table 2. During drilling, water levels measured in the drill stem increased about 3.5 ft from a depth of 770 to 1,628 ft at well D-3060 (Brown and others, 1985, p.49); about 4.5 ft from 600 to 1,209 ft at well D-2386 (Brown and others, 1984, p. 24); and about 9 ft from 548 to 1,790 ft at well SJ- 150 (Brown and others, 1986, p. 22). Water levels slightly decreased from below these depths to the top of the saltwater-bearing zone. Water levels sharply decreased after penetrating the saltwater-bearing zone. The decrease in water levels ranged from about 6 to 38 ft and probably was caused by increased salinities and corresponding densities.

Water-level measurements also were made at selected depth intervals during the construction of test wells N-117 and D-425, which were drilled to 2,102 and 2,486 ft. respectively. Near well N-117, large withdrawals from the Upper Floridan aquifer have formed a deep cone of depression, which has increased the upward gradient below the Upper Floridan aquifer. The water levels in this well in the 568 to 632 ft interval were 68 ft below land surface. When the well was deepened to 1,856 ft, the water level rose 48 ft, to about 20 ft below land surface. However, below this depth, the water level started to decline. When the well was completed at a depth of 2,080 ft. the water level stood at 34 ft below land surface (Brown, 1980, p. 33). Data collected at well D-425 also indicate an upward vertical head gradient through much of the Floridan aquifer system (Leve and Goolsby, 1967, p. 20). Water levels increased more than 12 ft when the well was deepened from 790 ft to about 2,450 ft.

Water-level data presented in figure 18 were not adjusted for density differences between freshwater and the mineralized water in various zones within each well. Corrected for density, water levels in the drill stem probably would be higher in the more brackish zones than in the freshwater zones.

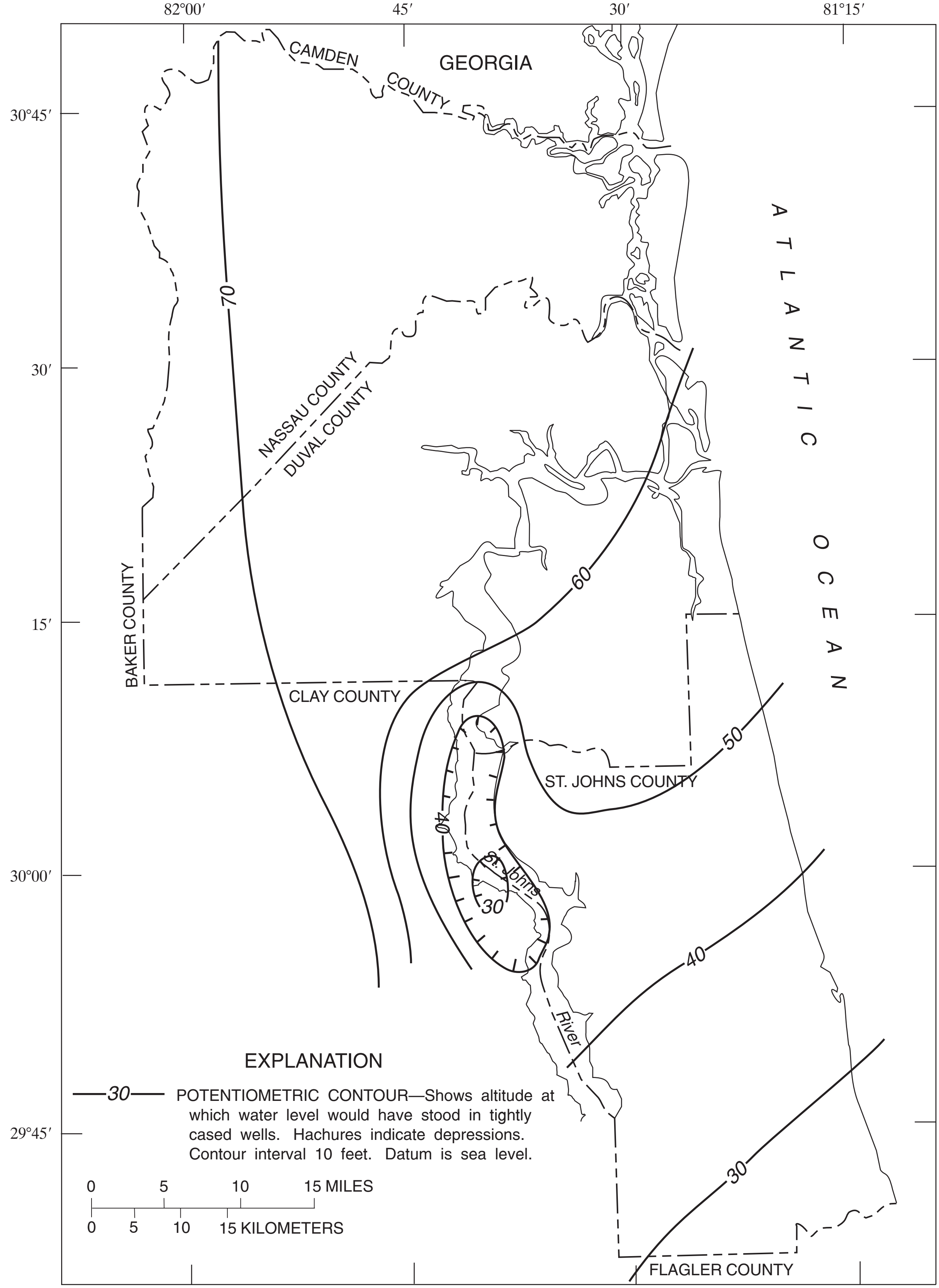

Figure 13. Estimated predevelopment potentiometric surface of the Upper Floridan aquifer (from Johnston and others, 1980).

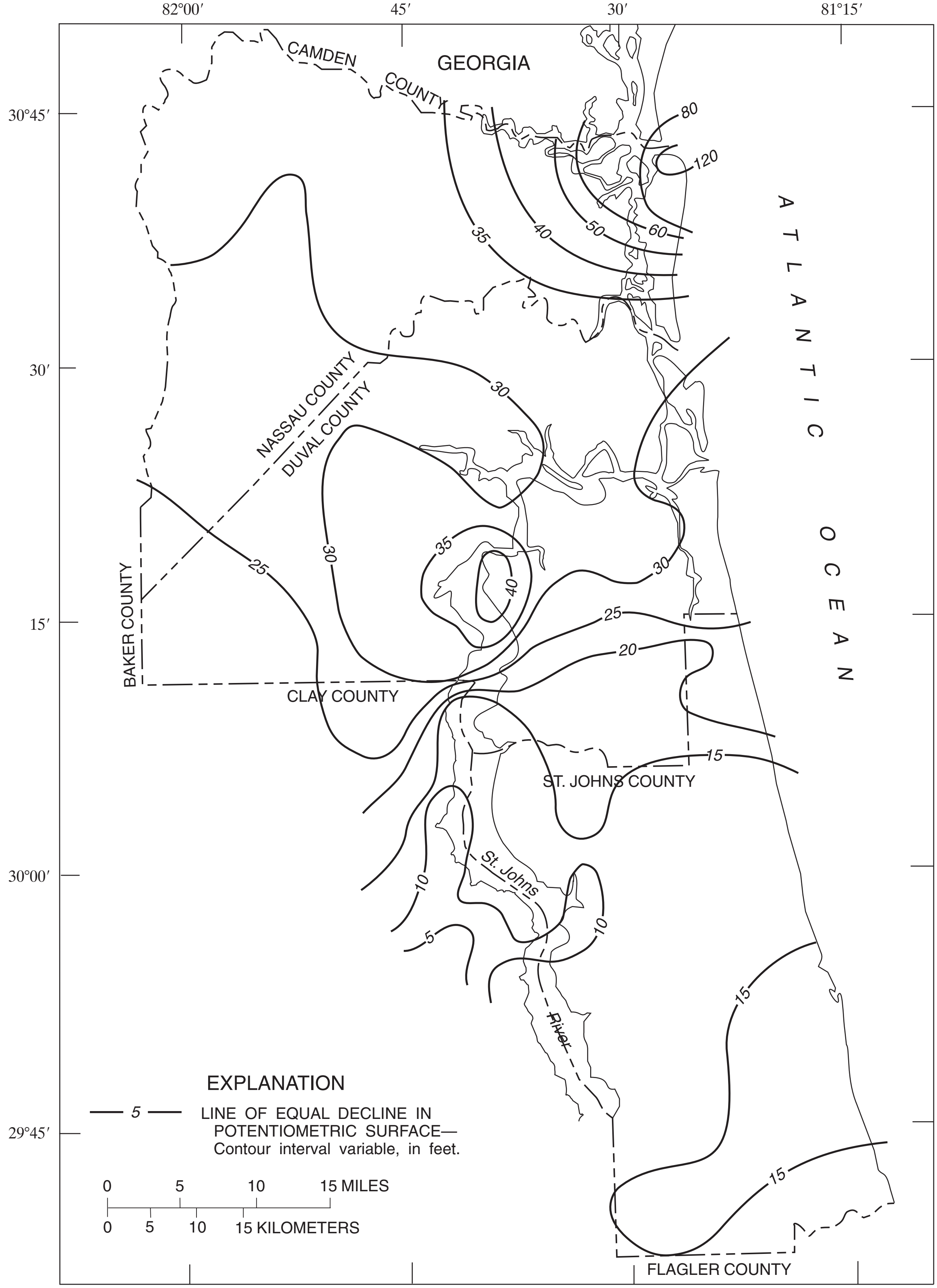

Figure 14. Approximate decline in potentiometric surface of the Upper Floridan aquifer from about 1880 (prior to development) to September 1989.

Table 2. Wells used for graphs showing water levels and chloride concentrations

[Agency maintaining well record: U.S. Geological Survey; --, no data]

Well number in figure 15	Site identification number	Depth of well (feet)	Bottom of casing (feet)
N-2	303519081275301	580	350
N-117	304001081280301	2,102	2,000
D-94	301900081342801	635	520
D-122A	302304081383202	905	571
D-163	302618081261001	707	--
D-164	302538081253101	619	448
D-262	302608081354901	1,237	1,163
D-275	301740081361001	1,234	515
D-360	302243081300401	665	462
D-425B	301817081374902	2,486	2,055
D-450	301604081361501	1,297	1,100
D-484	301704081233401	1,181	357
D-625	302531081253901	458	384
D-665	301758081303901	1,185	422
D-673	302013081353801	814	578
D-913	302557081253101	556	435
D-923	302553081252501	577	434
D-2386	302159081235601	2,026	1,892
D-3060	302052081323201	2,112	2,050
SJ-5	300758081230501	350	--
SJ-150	301132081225801	2,035	1,980

Changes in water levels with depth within the Floridan aquifer system can vary from area to area. None of the deep test wells, with the exception of test wells N-117 and D-425, were near large industrial or public-supply wells. However, in many parts of Duval County, large withdrawals of water from wells tapping the upper water-bearing zones can cause drawdowns in the potentiometric surface, thereby providing optimum conditions for an upward gradient near the wells.

Sub-Floridan Confining Unit

The sub-Floridan confining unit, underlying the Floridan aquifer system, consists of dolomite and limestone deposits impregnated with evaporites (Chen, 1965). These deposits are typically characterized by low permeabilities. The top of the unit generally corresponds to the beginning of the vertically persistent evaporite deposits present in the upper part of the Cedar Keys Formation (Miller, 1986, B46).

Few water wells penetrate the sub-Floridan confining unit and little testing has been done to determine its hydrologic properties. The only data available were reported from test well D-425 drilled in central Duval County. The well, drilled to a depth of 2,486 ft, was completed about 500 ft into the Cedar Keys Formation. A gypsiferous limestone was encountered at about 2,310 ft; however, decreasing permeability was reported in dolomitic limestones at about 2,100 ft (Leve and Goolsby, 1967, p. 19). Fluid velocity logs completed in the test hole indicated little flow of water entering or leaving the borehole below 2,100 ft, and there was practically no increase in flow and pressure at the surface when this zone was penetrated (Leve and Goolsby, 1967, p. 20). Water samples collected from the drill stem indicated little change in chloride concentration until approximately 2,100 ft. where chloride concentrations increased to about 7,700 mg/L near the bottom of the well.

In northwestern Nassau County, an oil well was drilled through the Floridan aquifer system to a depth of 4,817 ft (Cole, 1944, p. 31). A water sample, probably from the sub-Floridan confining unit, was collected at a depth ranging from 2,205 to 2,230 ft. Chemical analysis of the water indicated a chloride concentration of 33,600 mg/L and a dissolved solids concentration of 64,340 mg/L (Cole, 1944, p. 95).

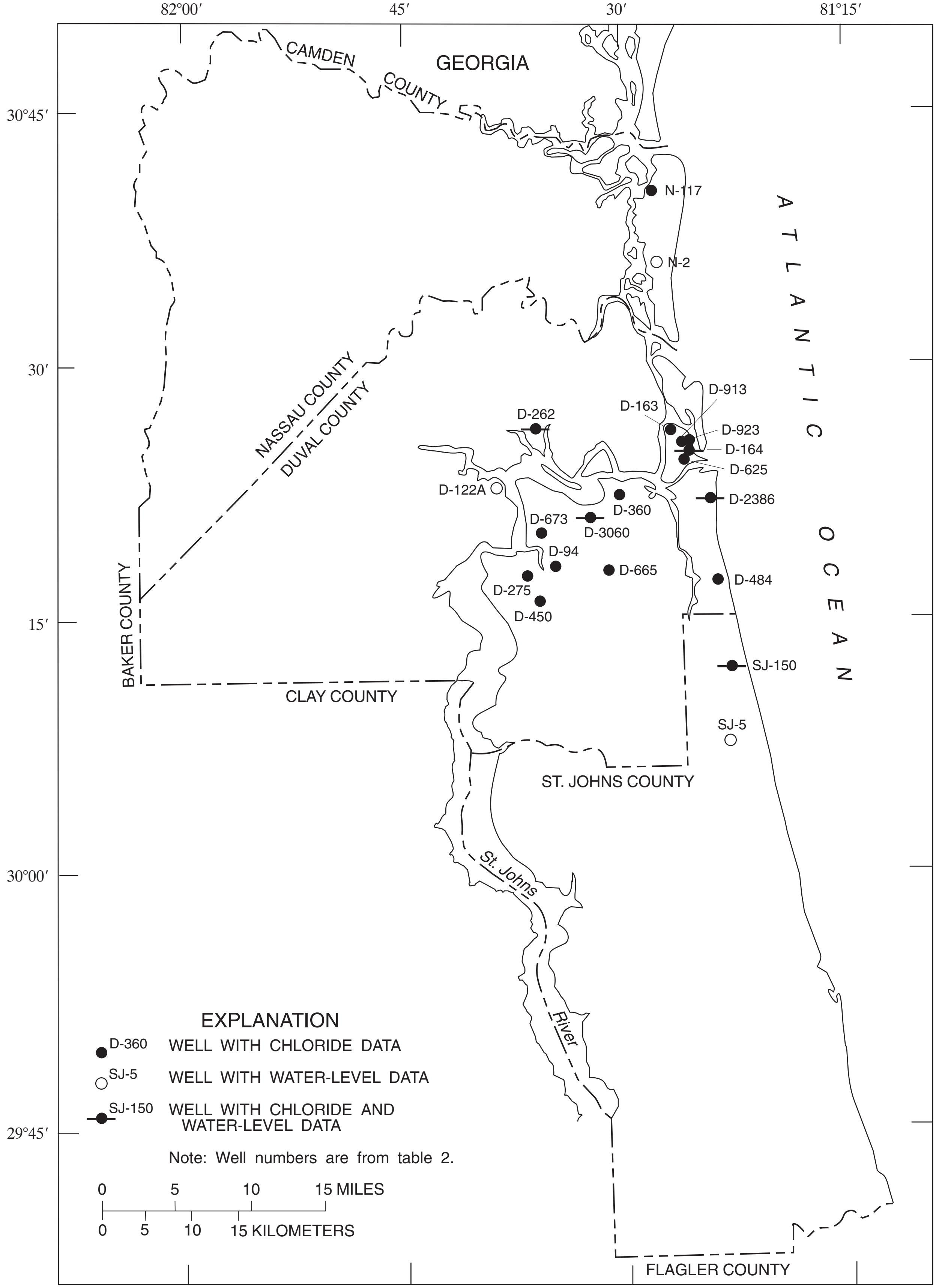

Figure 15. Locations of monitoring wells used for the collection of water-level and chloride-concentration data.

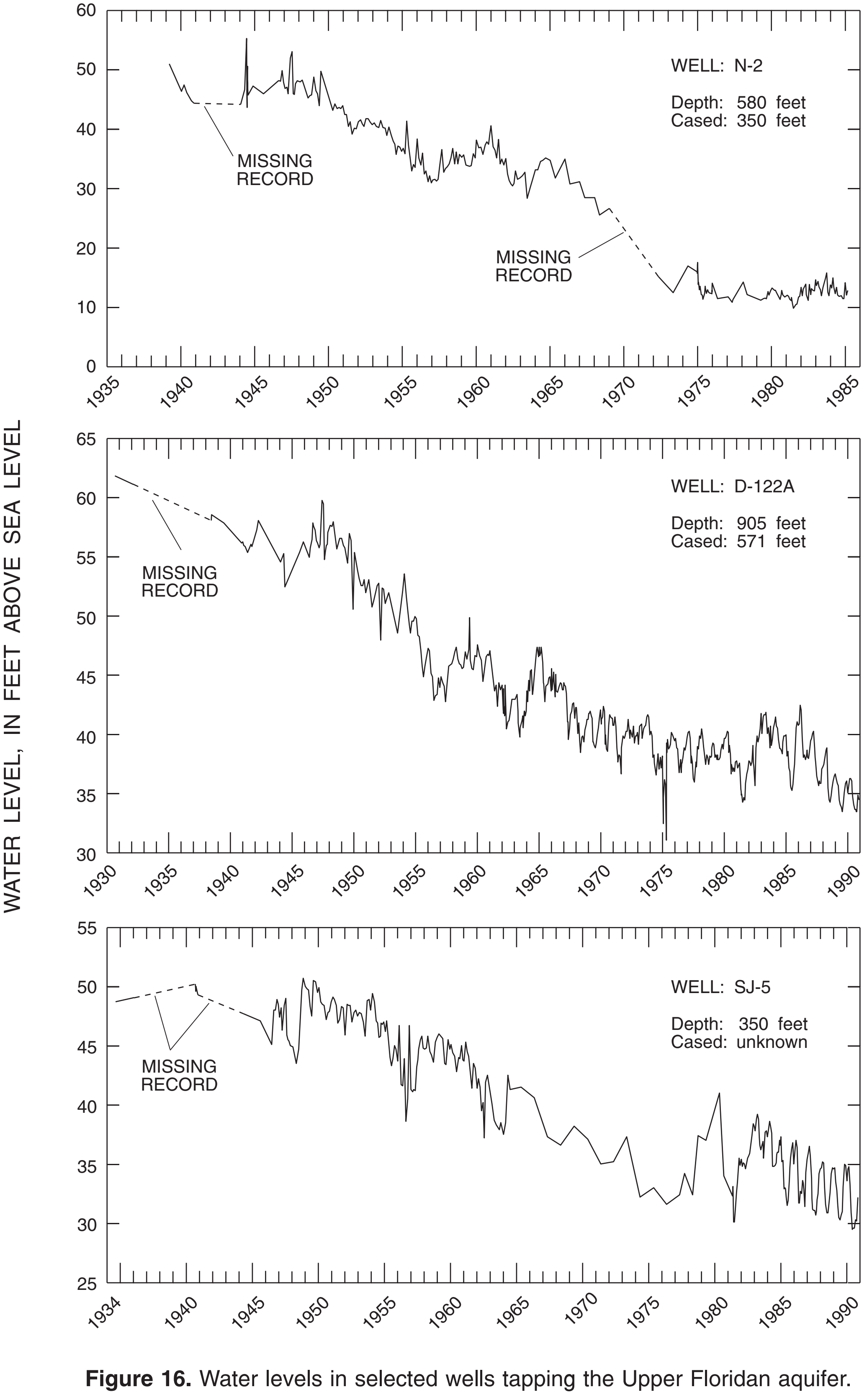

Figure 16. Water levels in selected wells tapping the Upper Floridan aquifer.

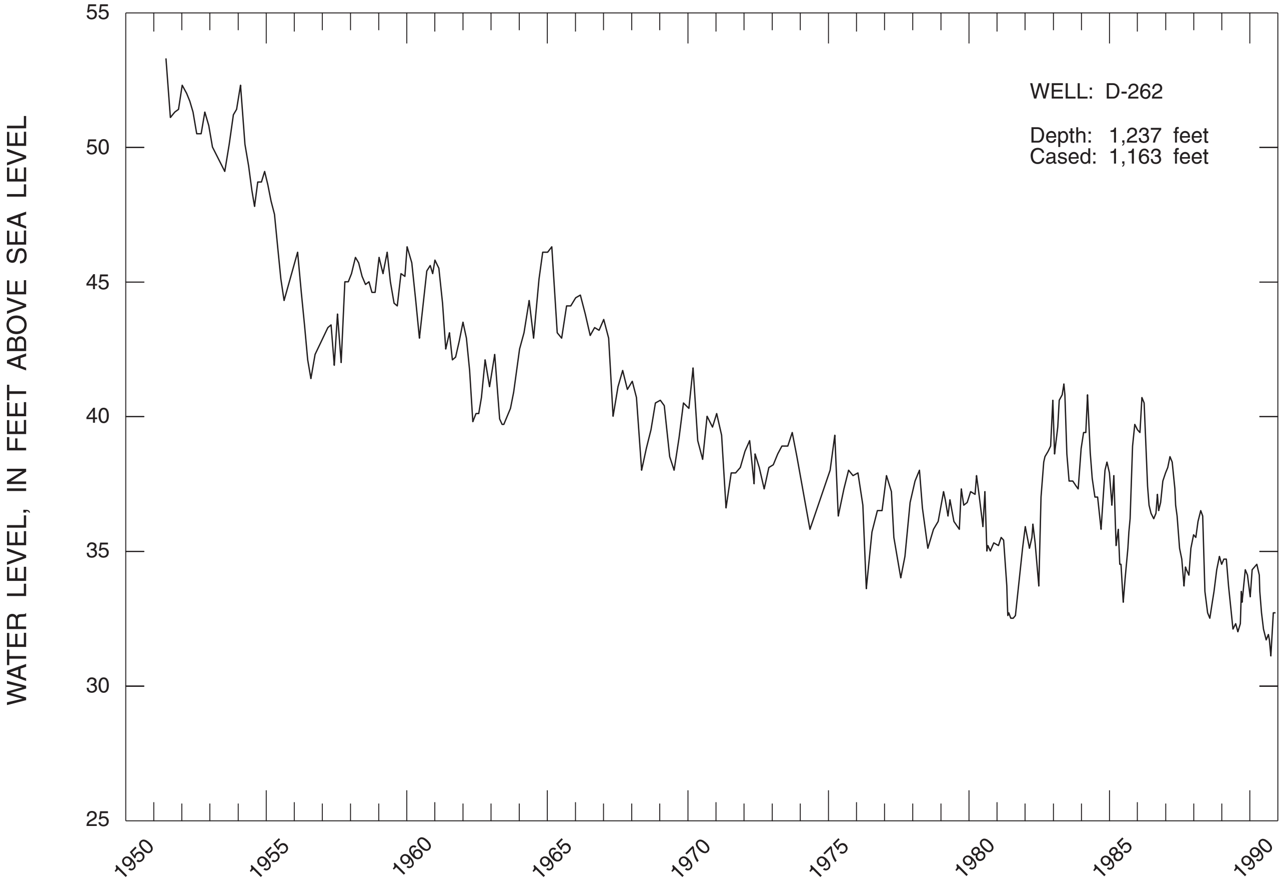

Figure 17. Water levels in well D-262, tapping the upper zone of the Lower Floridan aquifer.

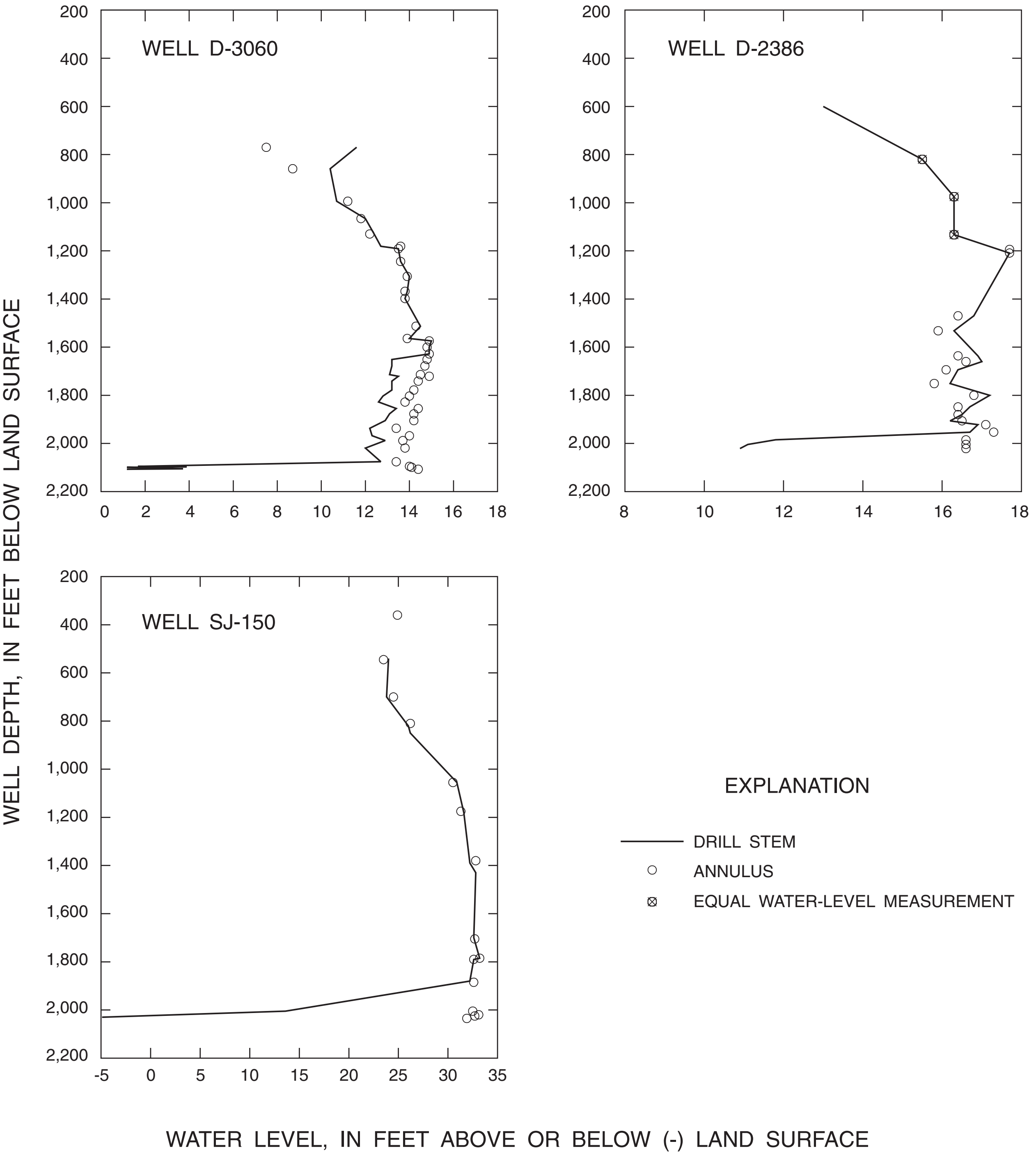

Figure 18. Water levels in drill stem and annulus during drilling of monitoring wells D-3060, D-2386, and SJ-150 (from Brown and others, 1984; 1985; 1986).

QUALITY OF GROUND WATER

The chemical and physical characteristics of ground water in the Floridan aquifer system are affected by many factors. The initial chemical composition of water entering the aquifer, the composition and solubility of rocks with which it comes in contact, and the length of time it remains in contact with these rocks, largely determine the degree of mineralization of the water. Additionally, the quality of the water also can be affected by the mixing of freshwater with seawater, residual seawater, and connate seawater.

The chemical characteristics of water also can determine its suitability for various uses. The Florida Department of Environmental Regulation has established primary drinking-water regulations that establish minimum standards for the quality of drinking water distributed by public water-supply systems (Florida Department of State, 1989). Secondary drinking-water standards, pertaining to the aesthetic qualities of water, set maximum limits for chloride and sulfate concentrations at 250 mg/L.

The concentration of chloride in ground water in northeastern Florida is an important limiting factor for public-supply and agricultural water use. Chloride concentrations are used as an index for determining the quality of water. In this report, water with chloride concentrations of 30 mg/L or more is considered indicative of saltwater intrusion. The limiting concentrations of chloride recommended for plants, animals, and industrial use are shown in figure 19.

Water samples from 1 spring and 223 wells tapping the Floridan aquifer system were analyzed for chemical constituents during 1988-91. The locations of wells sampled are shown in figures 20-22. Of these wells, 21 were sampled in Nassau County, 150 in Duval County, 46 in St. Johns County, and 6 in northeastern Clay County. Results of the chemical analyses are listed in appendix I. Several analyses obtained from the St. Johns River Water Management District are also included in the tables and are so noted.

The wells sampled during this investigation ranged from 198 to 2,486 ft in depth, and represented each of the major water-bearing zones of the Floridan aquifer system (app. II). Although some wells were constructed so that only specific zones could be sampled, most of the wells were cased to the top of the Ocala Limestone and completed as open holes. Because most

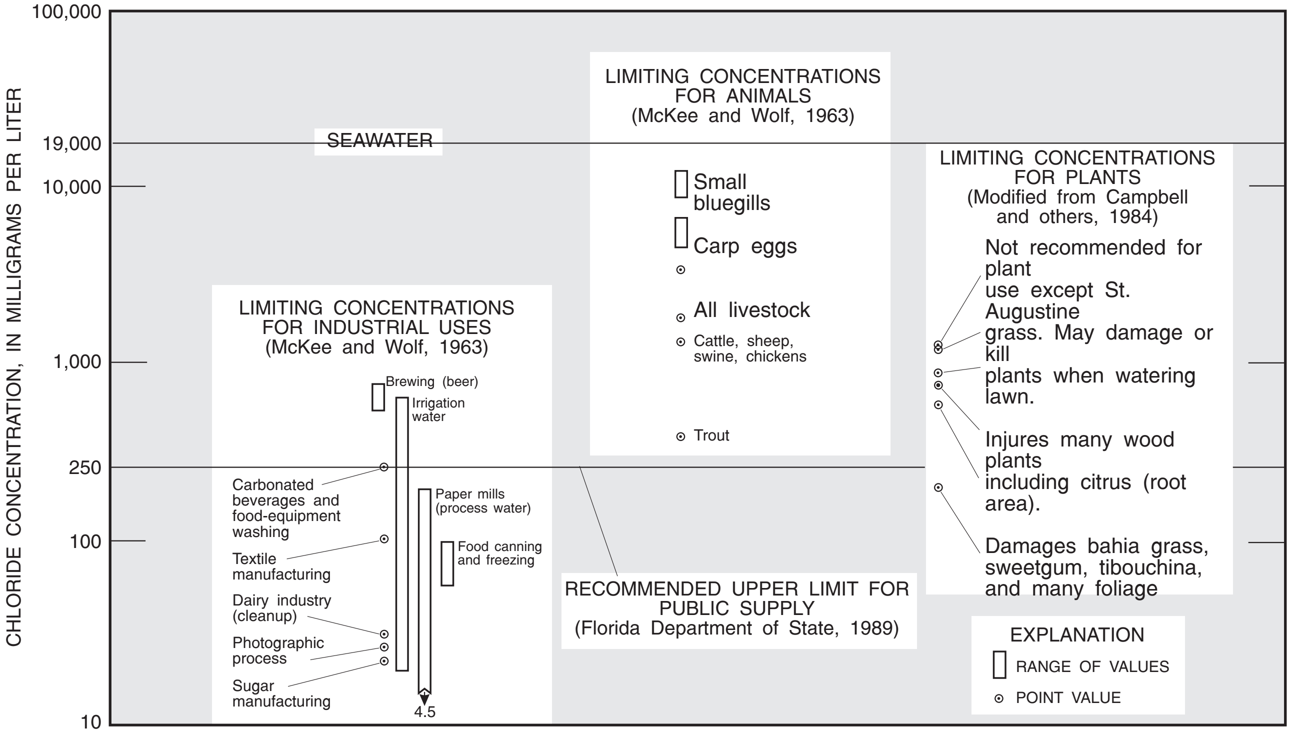

Figure 19. Limiting concentrations of chloride recommended for plants, animals, public supply, and industrial use (modified from Schiner and others, 1988).

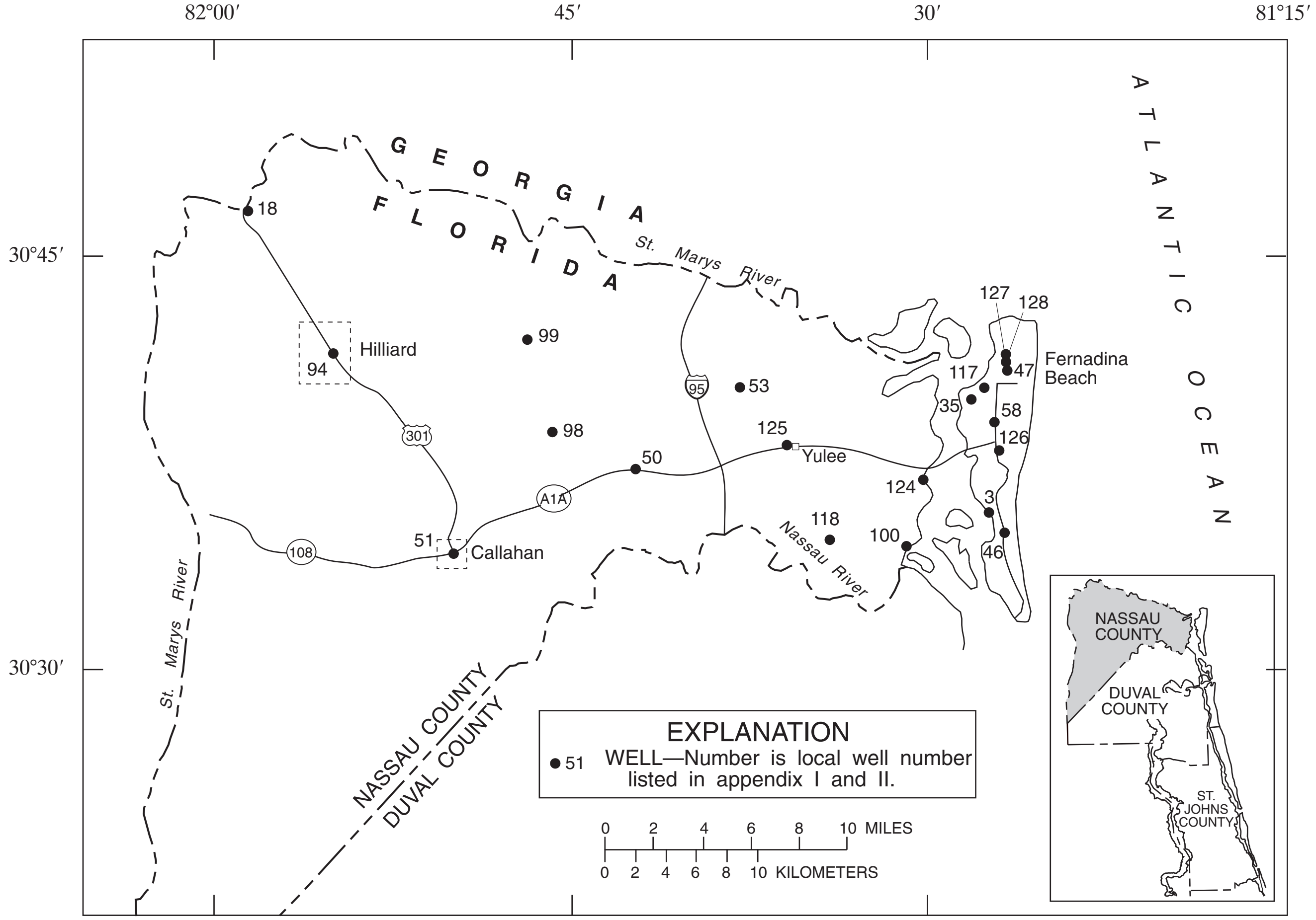

Figure 20. Location of wells sampled in Nassau County.

water samples were collected at the wellhead, the samples are from the open-hole section of the borehole and represent a composite of water from one or more water-producing zones. Relative contributions of water from different zones can vary considerably throughout the study area (Leve, 1966; 1968, p. 24); therefore, it is difficult to determine the water quality of a specific zone if more than one zone is penetrated by a well. Thus, the quality of water sampled from a well depends on which zones are penetrated and the proportion of water derived from each zone. Because the transmissivity and heads of the upper zone of the Lower Floridan aquifer generally are greater than those in the Upper Floridan, it is probable that a water sample collected at the wellhead is mostly representative of water from the upper zone of the Lower Floridan.

Wells Tapping the Upper Floridan Aquifer

Wells tapping the Upper Floridan aquifer penetrate from about 150 to 600 ft of the aquifer, which generally corresponds to the Ocala Limestone and, in some areas, also includes the upper part of the Avon Park Formation. Because most domestic wells that are drilled into the Floridan aquifer system are cased and completed into the Upper Floridan, more information is available on the water quality of the Upper Floridan than for the deeper zones. Of the 223 wells sampled during this investigation, 168 were completed in the Upper Floridan aquifer.

Specific Conductance

The extent of mineralization of water in the Upper Floridan aquifer is indicated by its specific conductance. In the study area, specific conductance of water from the Upper Floridan aquifer ranged from 168 to 12,200 µS/cm (fig. 23 and app. I). The lowest specific conductance values were in the extreme northeastern part of Clay County and the highest values were in southeastern St. Johns County. Generally, specific conductance values increased toward the northeast in Nassau County, toward the east in Duval County, and toward the south in St. Johns County.

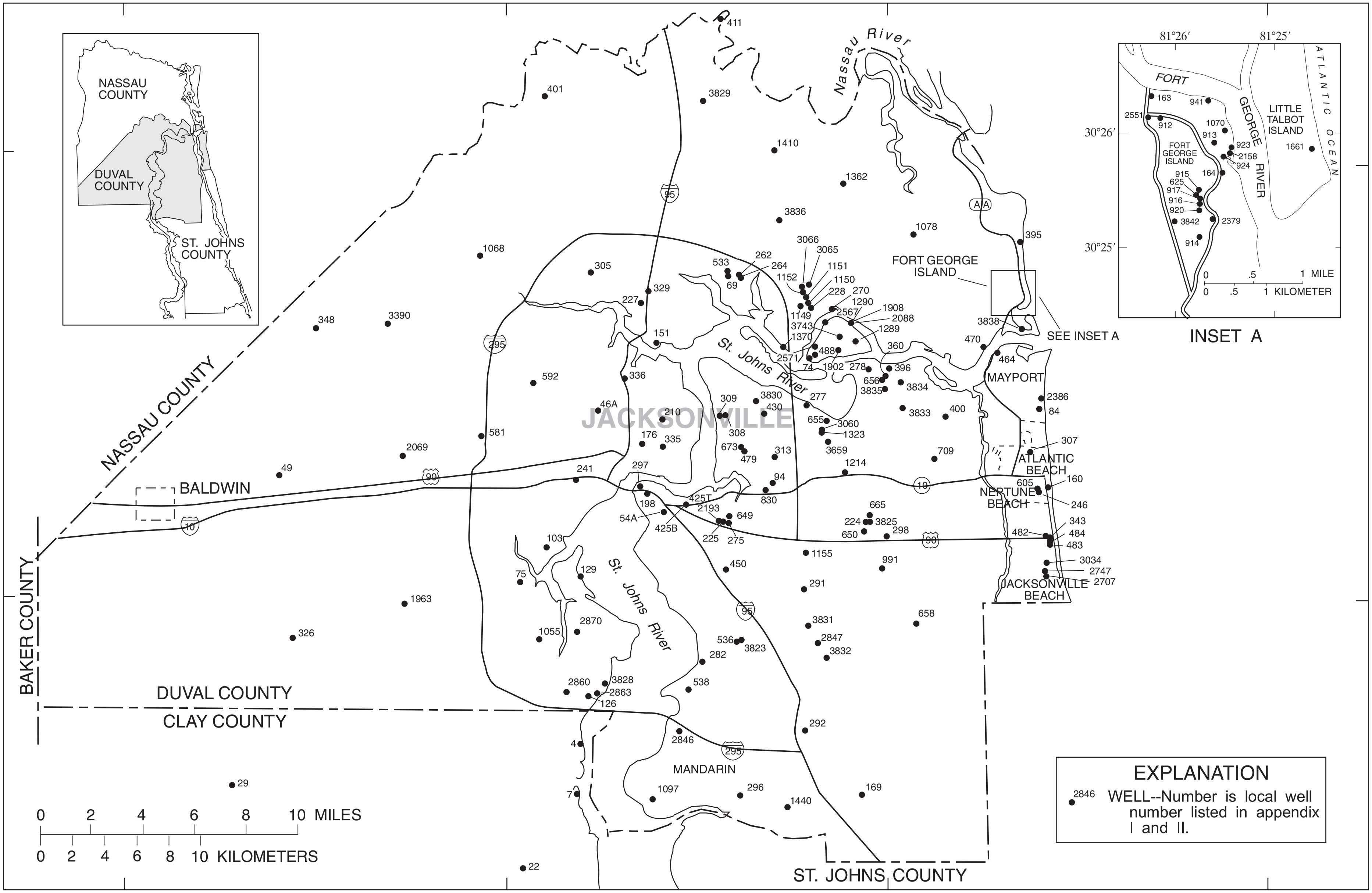

Figure 21. Location of wells sampled in Duval and northern Clay Counties.

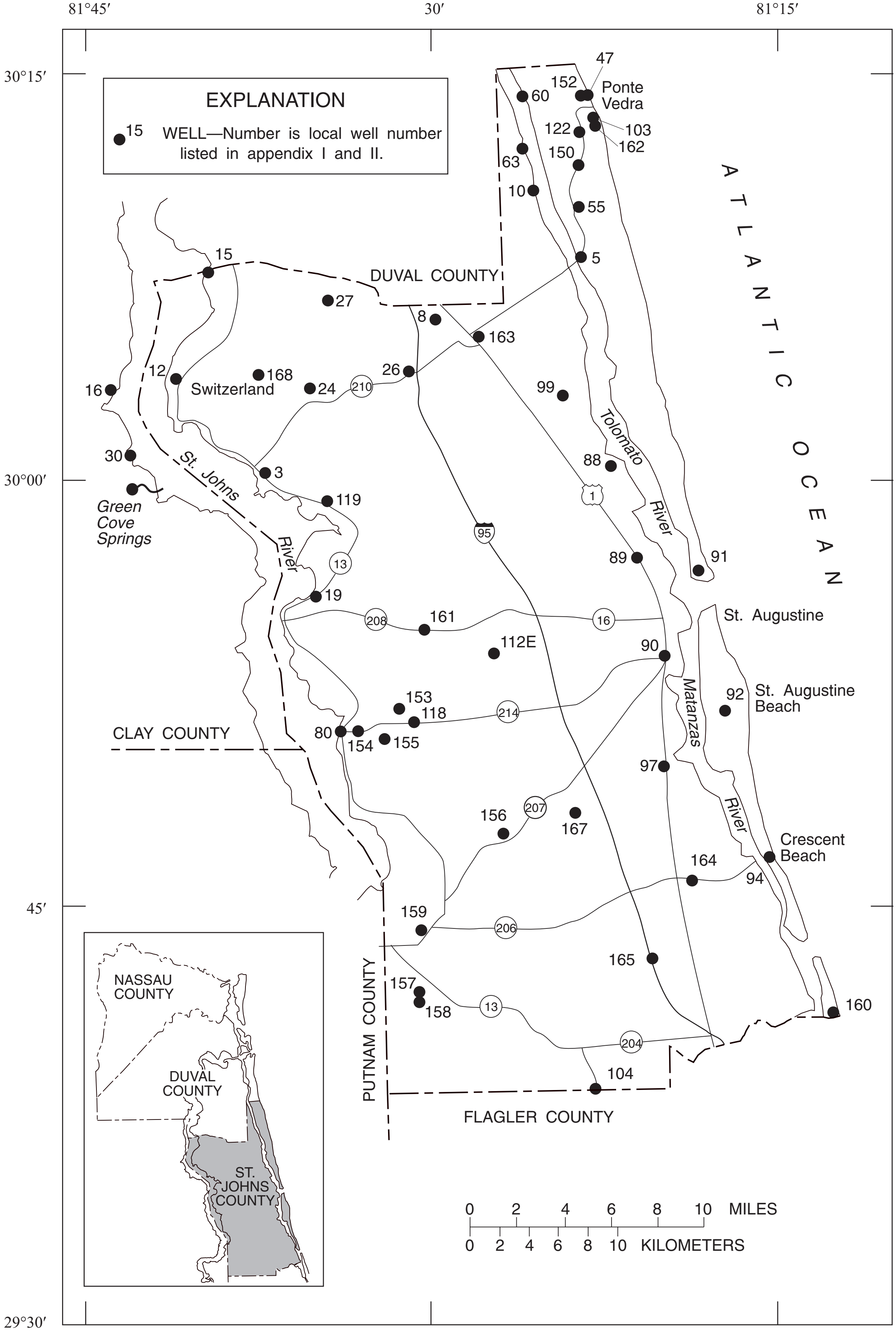

Figure 22. Location of wells sampled in St. Johns and northeastern Clay Counties.

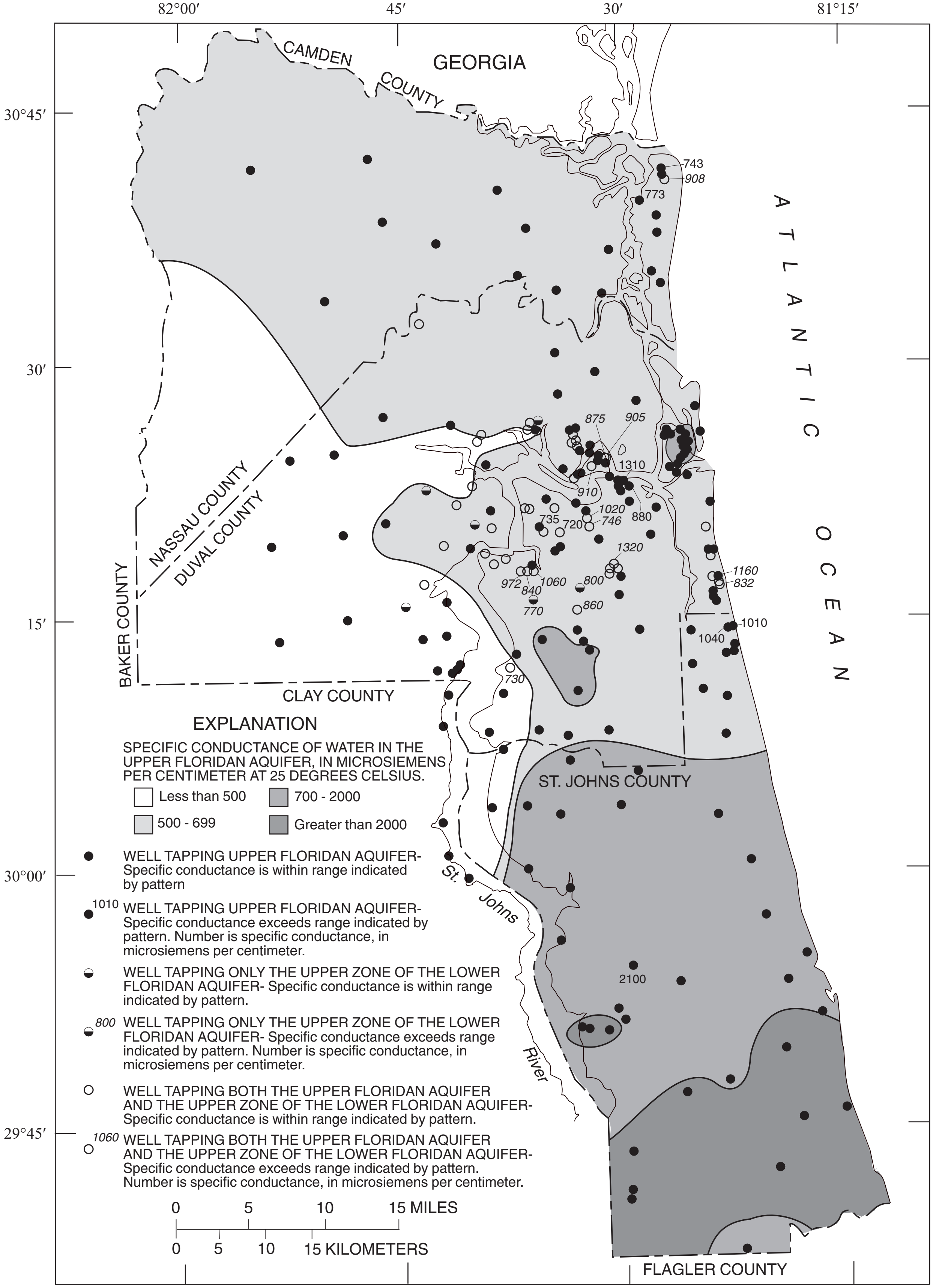

Figure 23. Distribution of specific conductance in water from the Upper Floridan aquifer and in selected wells tapping both the Upper Floridan and the upper zone of the Lower Floridan aquifers.

Sulfate

Concentrations of dissolved sulfate in water from the Upper Floridan range from 5.0 mg/L in northeastern Clay County to more than 1,300 mg/L in west-central St. Johns County (fig. 24 and app. I). In Nassau and Duval Counties, the Upper Floridan aquifer yields water with sulfate concentrations of less than 250 mg/L. However, in all but the extreme northeastern and northwestern parts of St. Johns County, sulfate concentrations commonly exceed the 250 mg/L recommended limit for drinking water (Florida Department of State, 1989).

Possible sources of sulfate include the dissolution of sulfate-bearing minerals, such as gypsum or anhydrite, and the mixing of relict or connate seawater with freshwater. In south-central Duval and north-central St. Johns Counties, where chloride concentrations are low, high sulfate concentrations are not associated with the intrusion of ancient seawater, indicating that sulfate-bearing minerals may be the dominant source of sulfate. Although evaporite deposits have not been observed in the Upper Floridan, gypsum was present in the intergranular pore spaces of the sub-Floridan confining bed in test well D-425 drilled in east-central Duval County (Leve and Goolsby, 1967, p. 19). The possible presence of these minerals in the upper water-bearing zones in northern Florida has been suggested by other investigators (Vernon, 1951; Stringfield, 1966; Miller, 1986; Krause and Randolph, 1989).

In the southern two-thirds of St. Johns County, high sulfate concentrations typically are present in water that also has high chloride concentrations. This indicates that the high concentrations of sulfate could be due, in part, to the mixing of ancient seawater with freshwater. Two trends between sulfate concentrations and sulfate-chloride ratios that can be used to identify the sulfate sources in water samples are shown in figure 25. One trend represents sulfate derived from the mixing of maritime rainfall with seawater and the other represents sulfate derived from the solution of gypsum within the Floridan aquifer system. Figure 25 shows that water having a low sulfate-chloride ratio and a high sulfate concentration is represented by points plotted near the seawater-mixing trend line. Water having a high sulfate-chloride ratio is represented by points plotted near the dissolution of the gypsum-mixing trend line, indicating that gypsum is the major source of sulfate in water in the Floridan aquifer system. Points plotted between these two extremes indicate seawater and gypsum as possible sources of the sulfate in ground water.

Chloride

Chloride in ground water can be derived from several sources, including the dissolution of chloride minerals, contamination, small amounts contributed by rainfall, and by the mixing of connate or relict seawater with fresh ground water. Chloride is the major anion of seawater, which commonly contains concentrations of about 19,000 mg/L. Because chloride ions do not easily enter into oxidation or reduction reactions, do not form important solute complexes with other ions, do not form salts of low solubility, and are poorly absorbed on mineral surfaces (Hem, 1970), the ions can move through aquifers at nearly the same rate as intruding seawater. Therefore, a progressive increase in chloride concentrations in ground water can be a good indication of saltwater intrusion.

Chloride concentrations in water from wells tapping the Upper Floridan aquifer in the study area range from 4.6 to 3,600 mg/L (fig. 26 and app. I). The lowest concentrations are the extreme northeastern part of Clay County, where concentrations generally do not exceed 7 mg/L. In northern Duval and most of Nassau Counties, chloride concentrations typically range from about 20 to 30 mg/L. Chloride concentrations exceeding 30 mg/L occur in parts of Fernandina Beach, northeastern St. Johns County, and east-central and coastal Duval County. Chloride concentrations also exceed 30 mg/L in most of the southern two-thirds of St. Johns County and generally increase toward the south. The highest chloride concentrations occur near the Crescent Beach area, in southeastern St. Johns County.

Ionic Composition

Water-quality analyses of ground water from wells in the study area indicate differences in the ionic composition of water in the Upper Floridan aquifer. The use of trilinear diagrams is one method of graphically displaying the ionic compositions of different water types. Three end-member water types are characterized in the Upper Floridan aquifer: a calcium bicarbonate type, a calcium magnesium sulfate type, and a sodium chloride type (fig. 27).

Calcium bicarbonate type water typically predominates in the recharge areas southeast of the study area. This type water, however, is also present in the Upper Floridan aquifer in parts of western and southeastern Duval County. The water is often low in chloride and dissolved-solids concentrations, indicated by the clustering of data just above the left apex of the diamond-shaped area in figure 27.

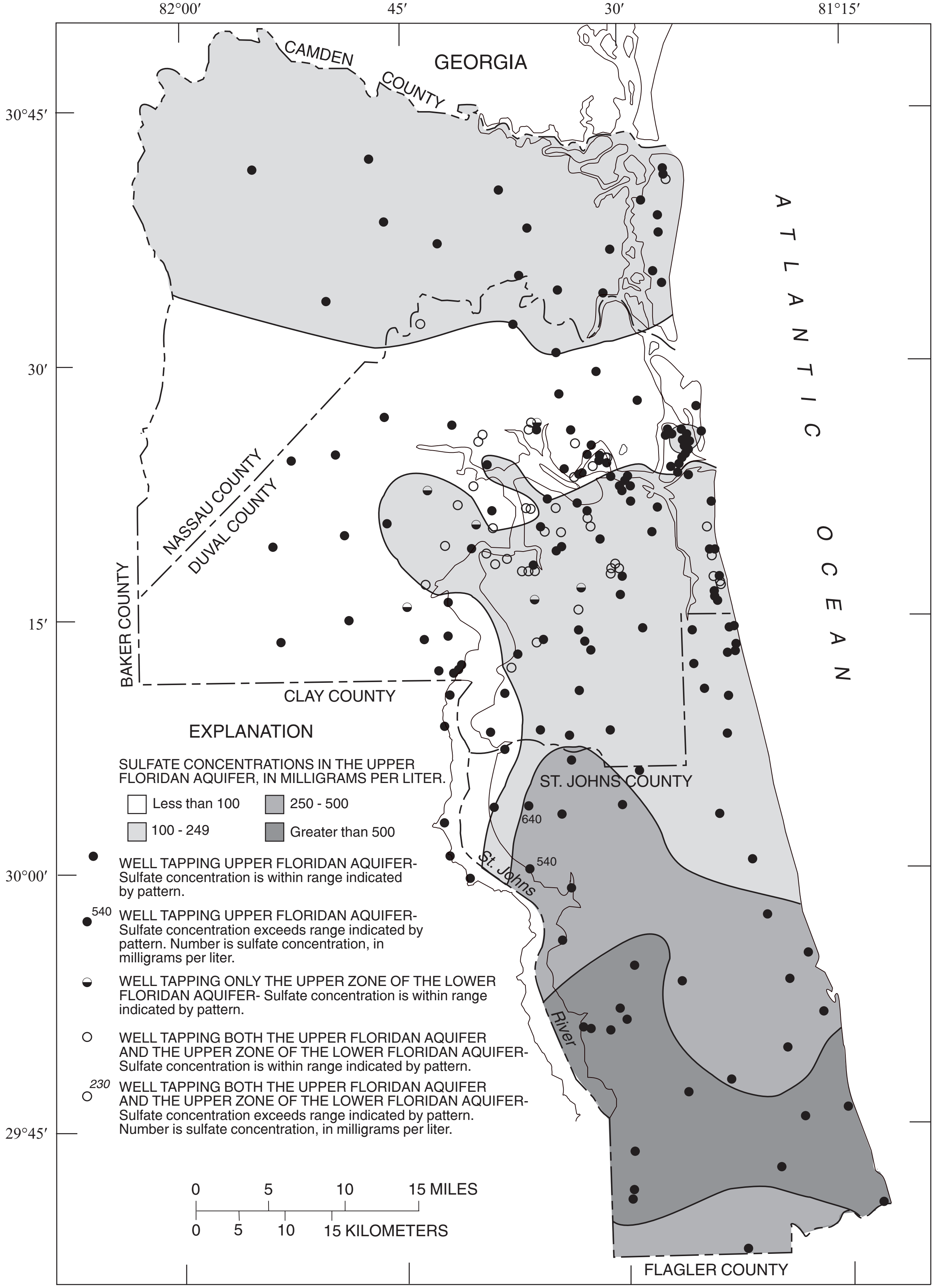

Figure 24. Distribution of sulfate concentrations in water from the Upper Floridan aquifer and in selected wells tapping both the Upper Floridan and the upper zone of the Lower Floridan aquifers.

Calcium magnesium sulfate is the water type generally present in the Upper Floridan aquifer in parts of northern St. Johns County. As water moves down-gradient, the dissolved-solids concentration of the water increases. This increase in mineralization also corresponds to increases in magnesium and sulfate, primarily due to the dissolution of dolomite and gypsum, respectively. The final product is a water type higher in calcium, magnesium, and sulfate, as represented by the clustering of data toward the top of the diamond.

The sodium chloride water type represents the mixing of saltwater with fresh aquifer water. Analyses of sodium chloride water are plotted just above the right apex of the diamond (fig. 27). As saltwater intrudes into the freshwater aquifer, sodium and chloride percentages increase. Analyses of water that plot near the top and right side of the diamond in figure 27 represent a mixture of saltwater and calcium magnesium sulfate water. Sodium chloride type water is predominant in only a few wells in the study area.

Multiaquifer Wells Tapping the Upper Floridan and the Upper Zone of the Lower Floridan Aquifer

Many of the wells drilled in the Floridan aquifer system tap only the Upper Floridan aquifer, such as in the Fernandina Beach area and in the southern two-thirds of St. Johns County where water in the upper zone of the Lower Floridan aquifer is more saline. In Duval County, however, where the water in the upper zone of the Lower Floridan aquifer generally is fresh, wells requiring large yields are sometimes drilled to depths of 1,100 to 1,300 ft and tap both the Upper Floridan and the upper zone of the Lower Floridan aquifer.

Water samples collected from these multiaquifer wells represent composites of water derived from both the Upper Floridan and the upper zone of the Lower Floridan aquifer. Although the relative contribution of water from each zone cannot be determined, multiaquifer wells probably derive much of their yield from the

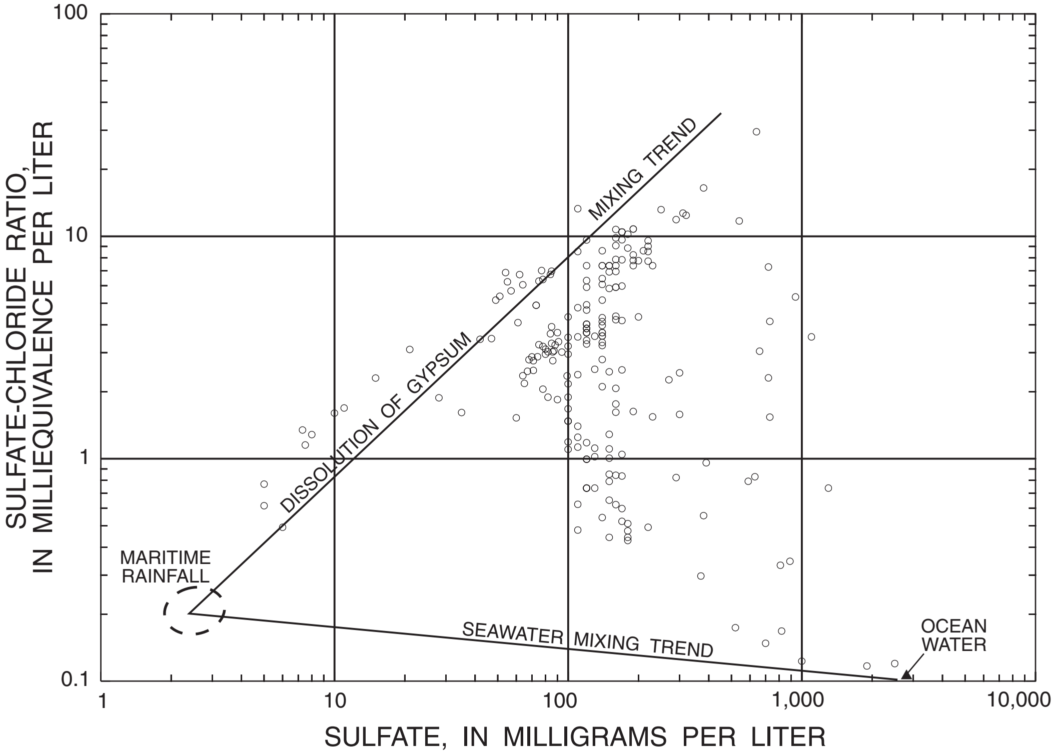

Figure 25. Relation of sulfate-chloride equivalent concentration ration to sulfate concentrations in water from the Floridan aquifer system (modified from Rightmire and others, 1974).

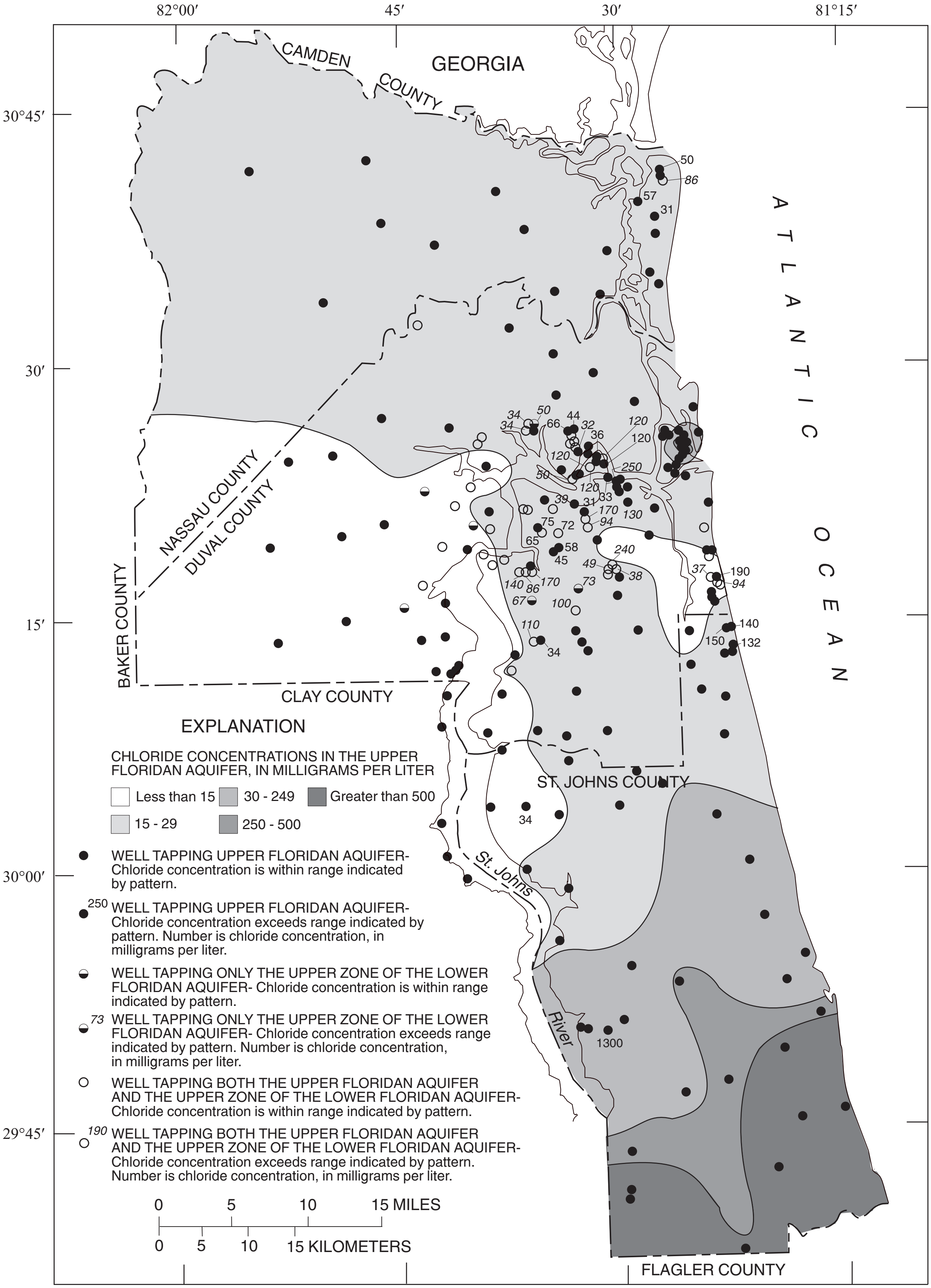

Figure 26. Distribution of chloride concentrations in water from the Upper Floridan aquifer and in selected wells tapping both the Upper Floridan and the upper zone of the Lower Floridan aquifers.

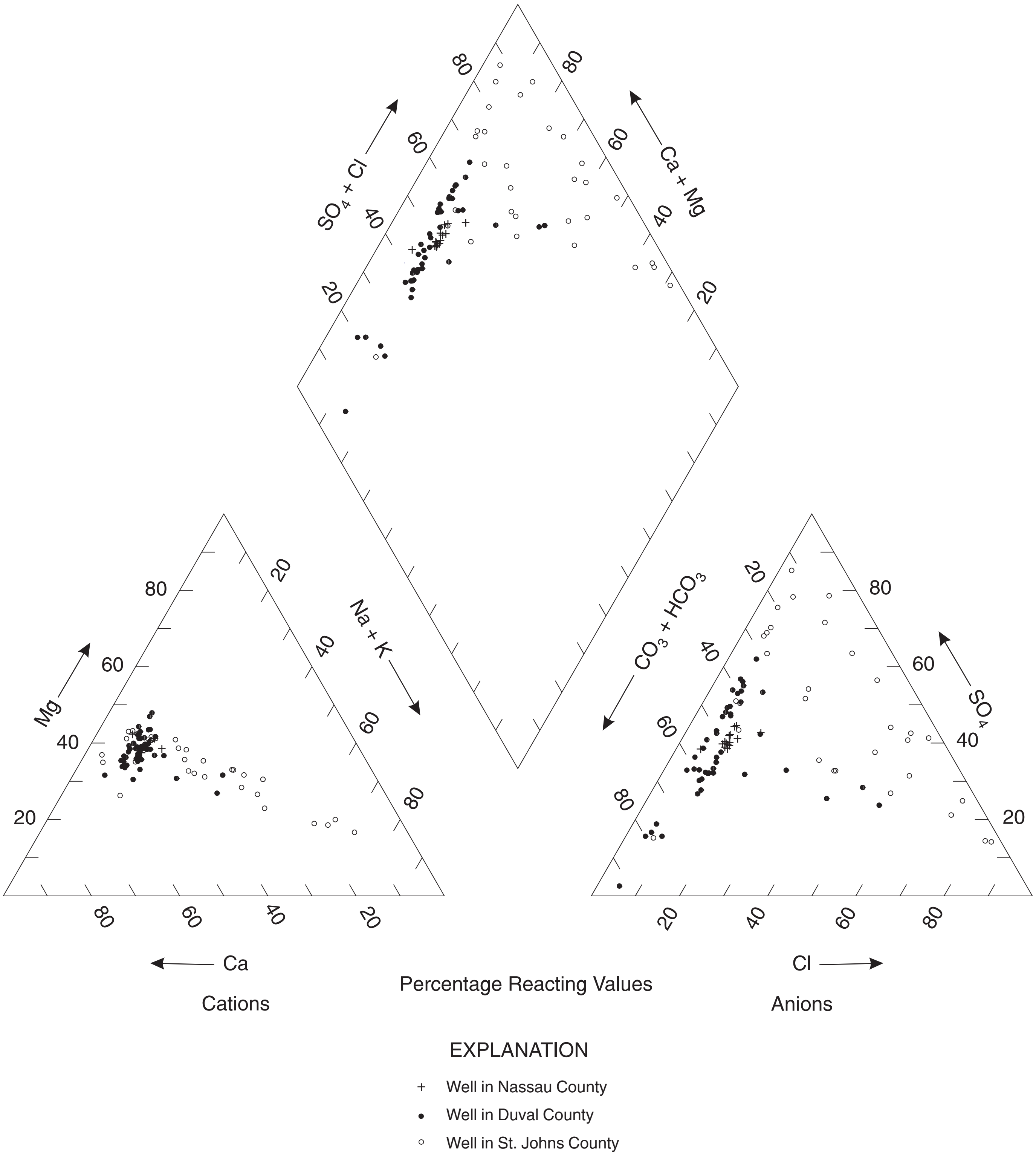

Figure 27. Chemical composition of water from selected wells tapping the Upper Floridan aquifer.

upper zone of the Lower Floridan aquifer. Maps that show the distribution of specific conductance, sulfate, and chloride concentrations in water from 43 wells tapping both the Upper Floridan and the upper zone of upper zone of the Lower Floridan aquifer are shown in figures 23, 24, and 26. Water from wells tapping both zones of the aquifer generally is slightly more mineralized than water from wells tapping only the Upper Floridan. In Duval County, specific conductance values ranged from 460 to 1,320 µS/cm, sulfate concentrations from 70 to 230 mg/L, and chloride concentrations from 9.2 to 240 mg/L (app. I).

A trilinear diagram of the ionic composition of water from selected multiaquifer wells tapping both the Upper Floridan and upper zone of the Lower Floridan aquifers is shown in figure 28. As shown in the figure, some of the water is a calcium bicarbonate type. However, as the water begins to mix, percentages of magnesium and sulfate, and sodium and chloride begin to increase, and the analyses plot more toward the top and right side of the diamond. Because of the lack of data from other parts of the study area and because most of the deeper wells are confined to a relatively small area of Duval County, the differences in the ionic composition of water from multiaquifer wells are not as great as those of water from wells tapping only the Upper Floridan aquifer. If more data were available for Nassau and St. Johns Counties, the trilinear diagrams for the multiaquifer wells and the Upper Floridan aquifer wells probably would be very similar.

Wells Tapping the Upper Zone of the Lower Floridan Aquifer

Within the study area, six wells (all monitoring wells in Duval County) tap primarily the upper zone of the Lower Floridan aquifer. Five of these wells are former public-supply wells, owned by the city of Jacksonville, which were converted to monitoring wells in the mid-1980's. The depths of the city's monitoring range from 1,170 to 1,326 ft; open-hole intervals wells range from 90 to 475 ft. The sixth well in Duval County, D-262, was drilled to a depth of 1,237 ft and cased to 1,163 ft.

The distribution of specific conductance, sulfate, and chloride concentrations from the 6 monitoring wells is shown in figures 23, 24, and 26. Chloride concentrations in water from these wells range from 7.8 to 73 mg/L, sulfate concentrations from 64 to 170 mg/L, and specific conductance from 360 to 800 µS/cm (app. I).

The quality of water from the upper zone of the Lower Floridan aquifer and adjacent overlying and underlying semiconfining units was also determined from water samples collected during drilling of four deep-monitoring wells. The variation in chloride concentrations and specific conductance in water from wells D-3060, D-2386, SJ-150, and N-117 is shown in figures 29 and 30. As the well was drilled, water samples were collected from the drill stem, which terminated near or at the bottom of the drilled hole, and from the annulus. Water samples collected from the drill stem better represent the water quality near the bottom of the borehole. Water samples collected in the annulus represent a composite water sample of the open-hole interval below the surface casing.

Wells Tapping the Fernandina Permeable Zone

The Fernandina permeable zone is the deepest major water-producing zone in the study area. Six monitoring wells in northeastern Florida penetrate this zone. Water analyzed from this zone varies from fresh to saline (Leve and Goolsby, 1966, 1967; Brown, 1980; Brown and others, 1984, 1985, 1986). The water is freshest in the Fernandina permeable zone in the western part of the study area and becomes brackish to saline along the coast. Chloride and sulfate concentrations and specific conductance of water from this zone at five monitoring-well sites are shown in figure 31. The sixth site, located in western Duval County, could not be accurately sampled because the borehole is open throughout the Floridan aquifer system, possibly allowing the mixing of water from different zones. A fluid conductivity log completed in the well in 1970, however, indicated that water from the Fernandina permeable zone is fresh. The highest chloride concentrations in water from the five wells tapping only the Fernandina permeable zone were in a sample from well SJ-150. Chloride concentration at a depth of 2,022 ft in this well was 16,800 mg/L. Specific conductance and sulfate concentrations in water in this well were 44,000 µS/cm and 2,700 mg/L, respectively. Values of selected chemical constituents and physical properties of water samples collected from the five monitoring wells tapping this zone are listed in appendix I. A trilinear diagram, showing ionic compositions of water sampled from the Fernandina permeable zone (fig. 32), indicates that the water type from all but one well (D-425B) was predominately sodium chloride.

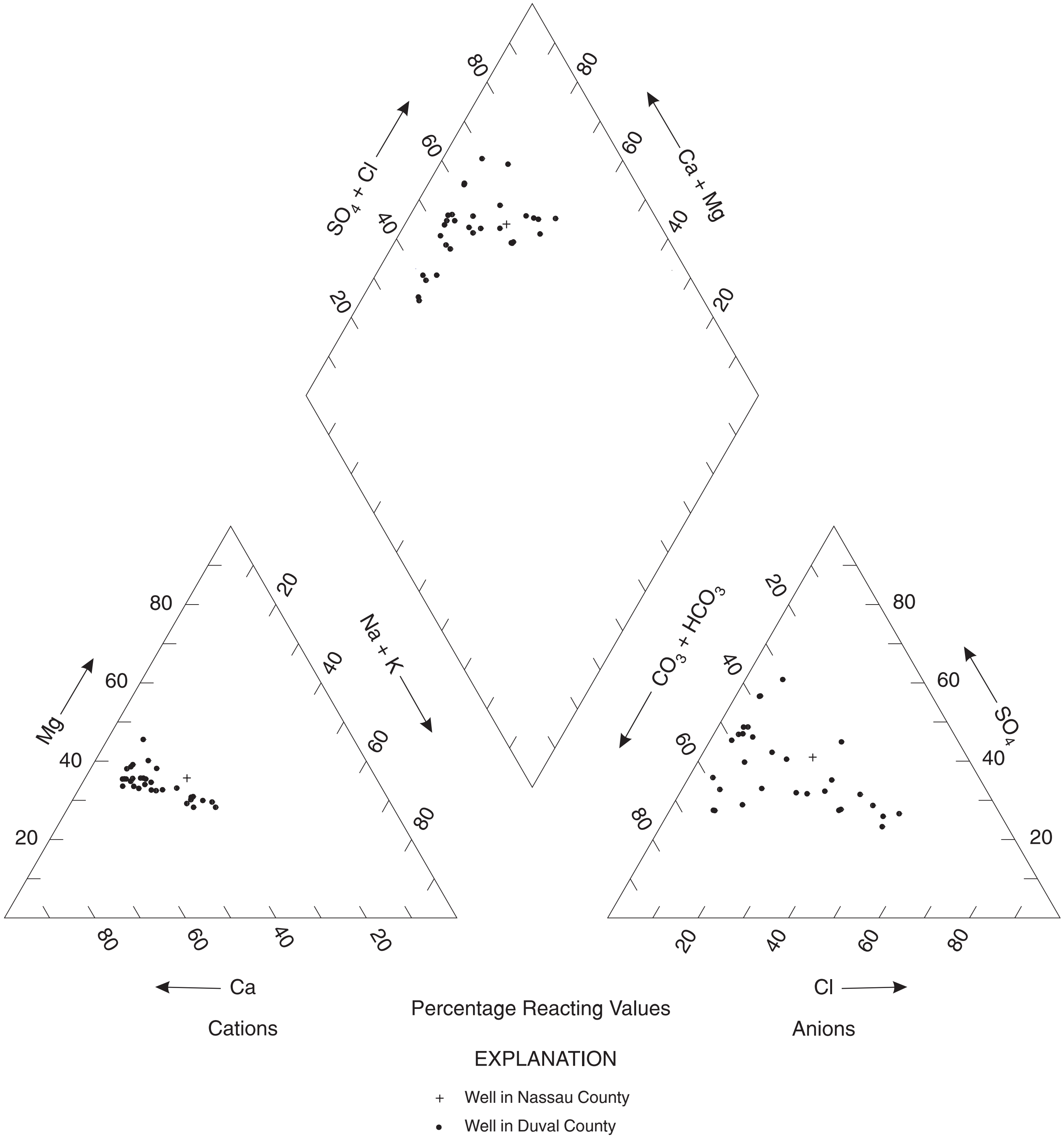

Figure 28. Chemical composition of water from selected wells tapping both the Upper Floridan and the upper zone of the Lower Floridan aquifer.

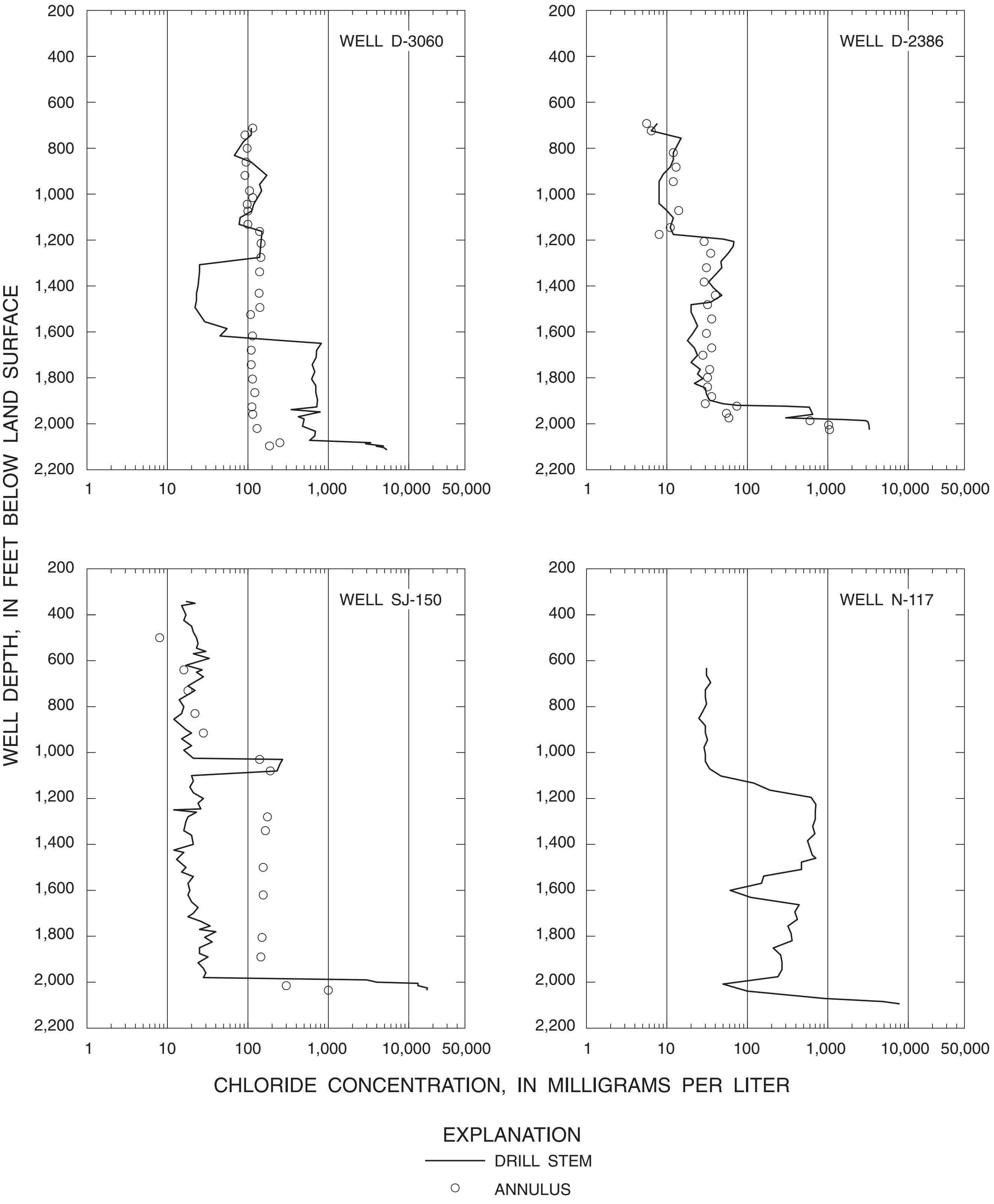

Figure 29. Chloride concentrations in water samples obtained through the drill stem and annulus during drilling of monitoring wells D-3060, D-2386, SJ-150, and N-117 (modified from Brown, 1980, 1984; Brown and others, 1984; 1985; and 1986).

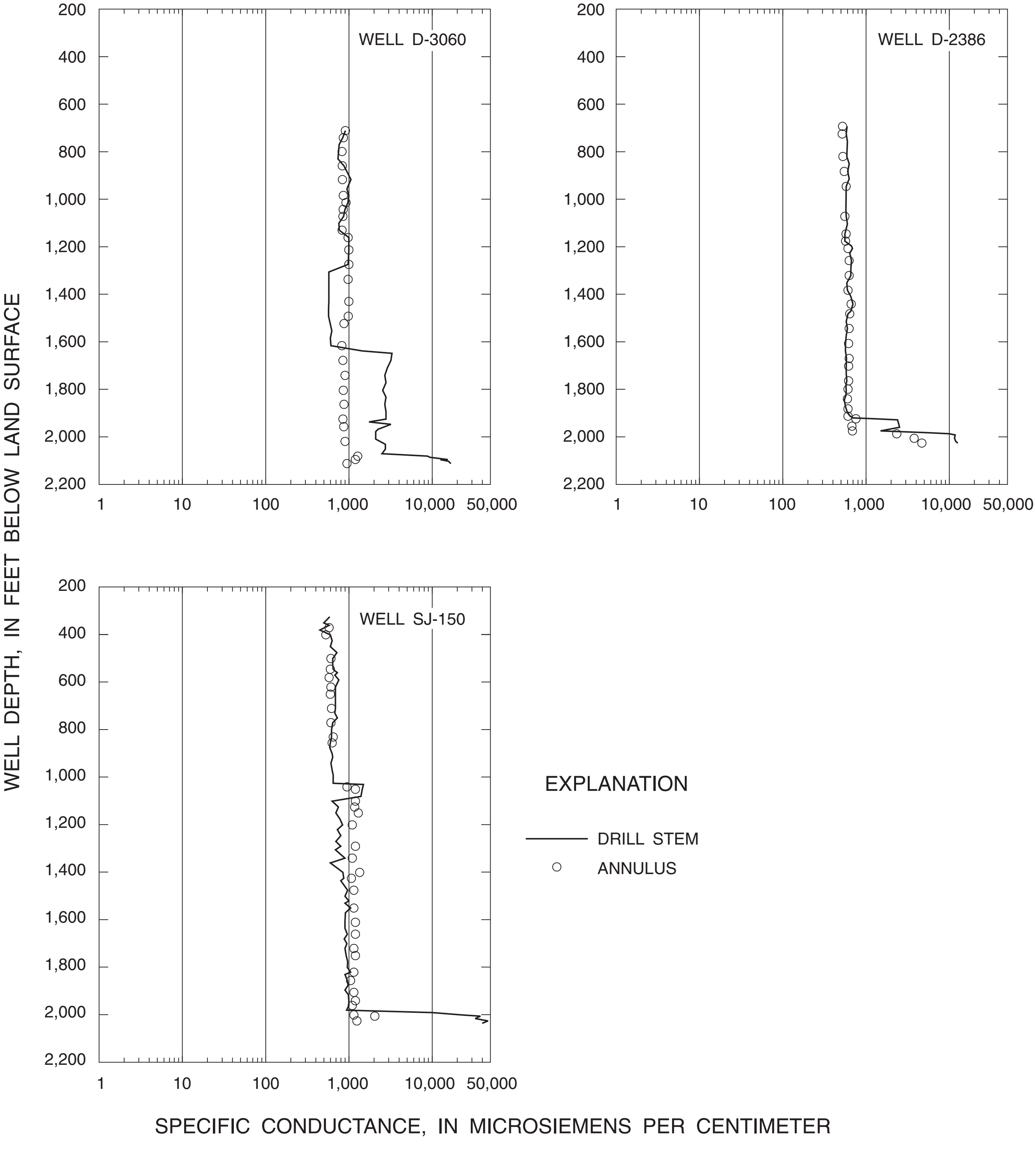

Figure 30. Specific conductance of water samples obtained through the drill stem and annulus during drilling of monitoring wells D-3060, D-2386, and SJ-150 (modified from Brown and others, 1984; 1985; and 1986).

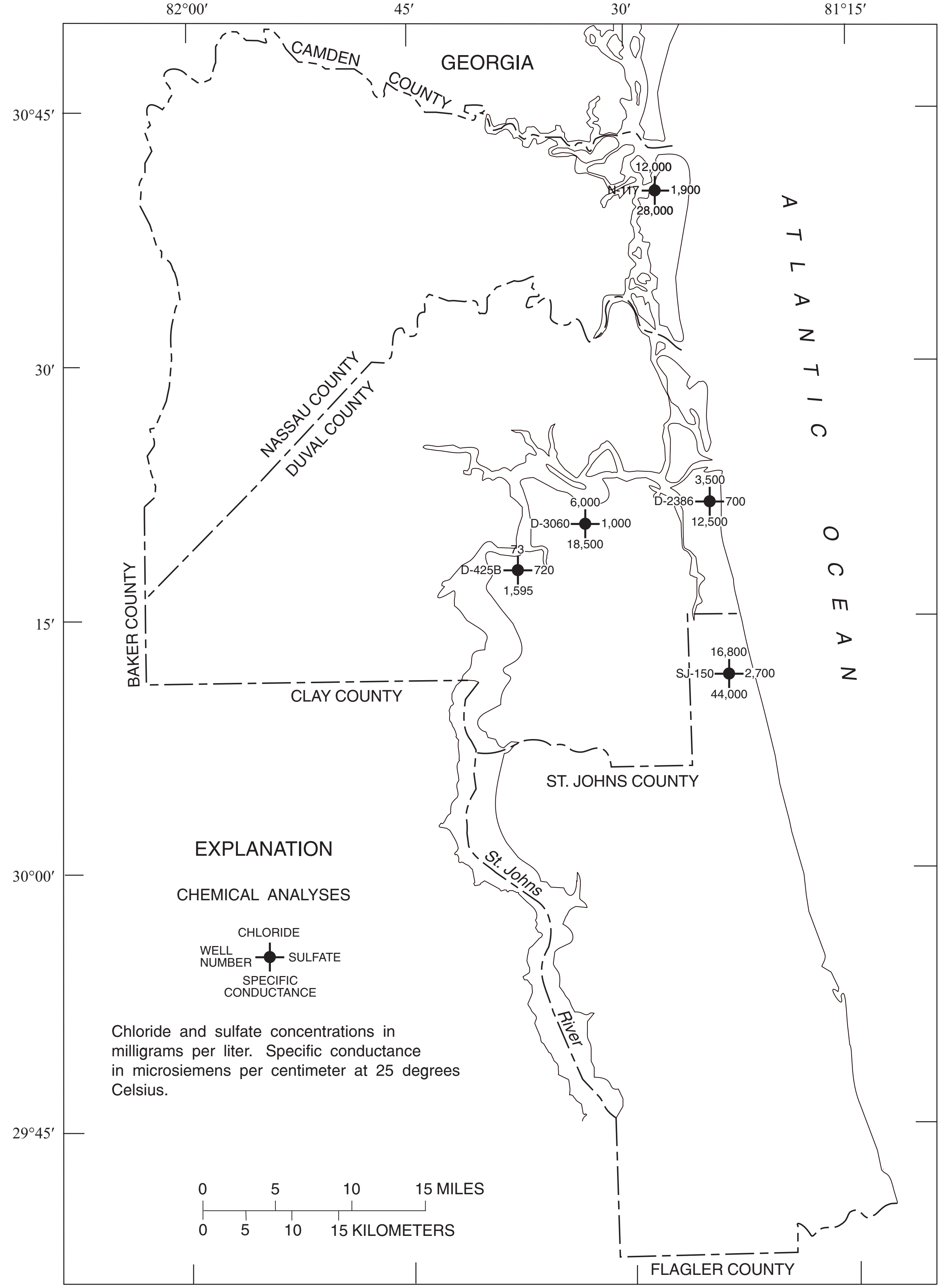

Figure 31. Chemical analyses of water from selected wells tapping the Fernandina permeable zone.

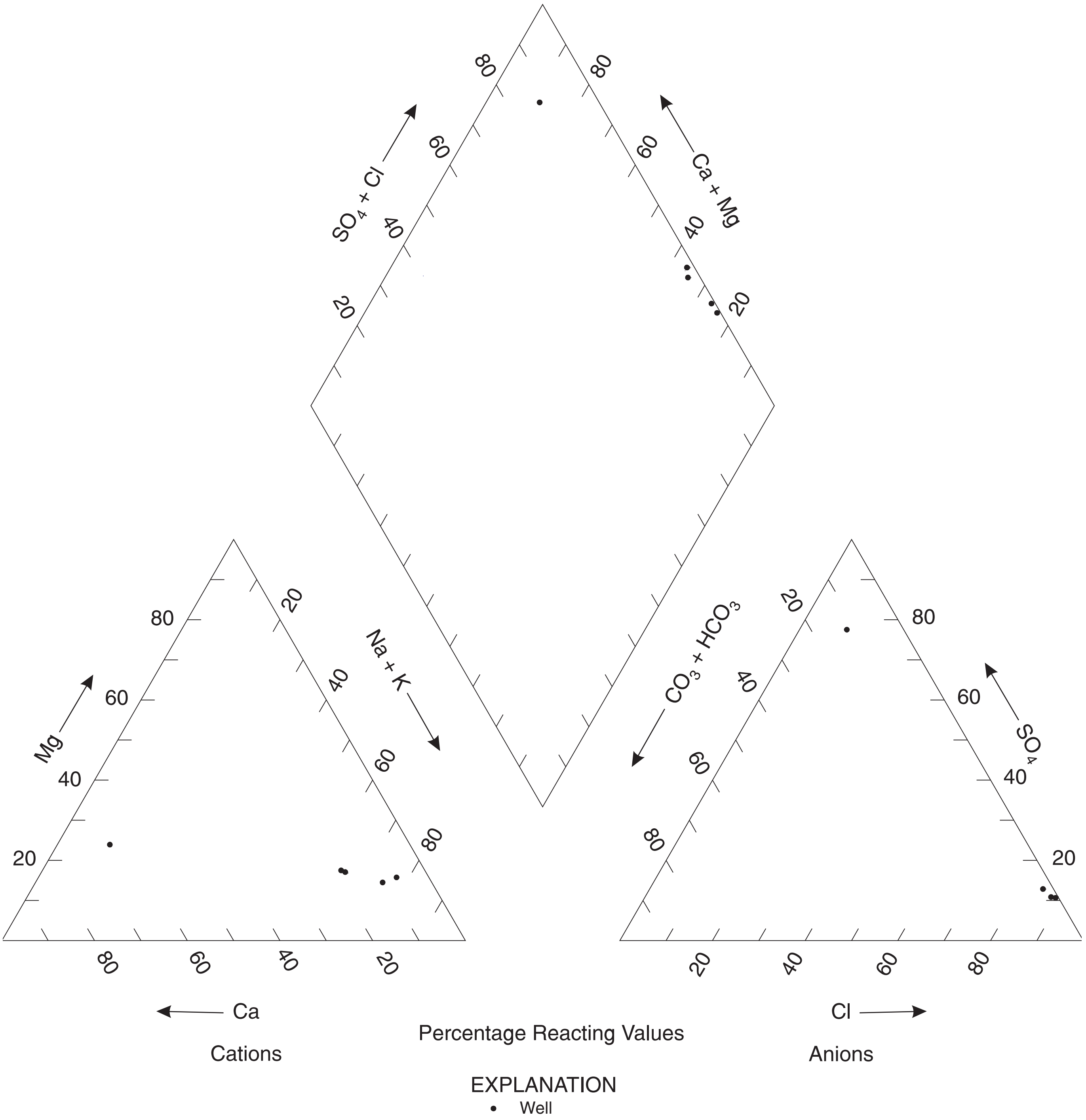

Figure 32. Chemical composition of water from selected wells tapping the Fernandina permeable zone.

Chloride concentrations in water from wells tapping the Fernandina permeable zone collected from the drill stem and annulus during drilling are shown in figure 29. Chloride concentrations in water from the Fernandina permeable zone were considerably higher than those in water from overlying zones. As the monitoring wells were drilled, chloride concentrations in water from the drill stem increased sharply and ranged from a maximum of about 3,300 mg/L at well D-2386 to more than 16,000 mg/L at well SJ-l50. High concentrations of chloride were not present in water from the Fernandina permeable zone at well D-425. Leve and Goolsby (1966, 1967) reported chloride concentrations less than 30 mg/L in water samples from well D-425.

Specific conductance also increased near the top of the Fernandina permeable zone and maximum values reported were 12,700 μS/cm at well D-2386, 16,800 μS/cm at well D-3060, and 46,000 μS/cm at well SJ-150 (fig. 30). Specific conductance in water from well D-425 was less than 700 μS/cm (Leve and Goolsby, 1966, 1967).

SALTWATER INTRUSION AND TRENDS IN CHLORIDE CONCENTRATIONS

Chloride concentrations in ground water as an indicator of saltwater intrusion have been monitored for more than 15 years at a number of wells tapping various water-bearing zones of the Floridan aquifer system. The frequency of data collection varies from well to well. Prior to 1978, water samples were collected and analyzed intermittently; however, many of the wells were sampled as often as one to four times per year from 1978 to 1991.

In parts of Duval County where the water from the Floridan aquifer system contains low chloride concentrations, concentrations of most constituents probably have changed little since the 1930's. However, in areas where the water in the aquifer currently contains chloride concentrations of more than 30 mg/L, the water quality in many of the wells generally has deteriorated over time. Figures 33-35 show several trends in chloride concentrations in water from selected wells tapping various zones of the Floridan aquifer system (see fig. 15 for well locations). Several of the graphs show gradual increases in chloride concentrations. For example, in water from well D-484 (fig. 34), chloride concentrations have increased in a generally stepwise pattern from about 85 mg/L in 1974 to about 180 mg/L in 1990. Other graphs (wells D-673, D-94, and D-262) show little change in chloride concentrations in the early years of record but increasing chloride concentrations during recent years (figs. 33 and 35).

The most interesting trend observed in chloride concentrations in the water from some of the wells (D-360, D-673, D-450, D-665) is the relatively abrupt increase in concentrations since the mid-1980's. From 1975 to about 1984, chloride concentrations in water from wells D-360 and D-673 (fig. 33) either remained constant or increased only slightly. Between 1984 and 1990, however, chloride concentrations in water from well D-360 increased from 210 mg/L to 260 mg/L. In water from well D-673, chloride concentrations increased from 46 mg/L in 1983 to 110 mg/L in 1990. Chloride concentrations increased even more abruptly in water from wells D-450 and D-665 (figs. 34 and 35). Chloride concentrations increased from 26 to 82 mg/L from 1987 to 1990 in well D-450 and from 140 to 480 mg/L from 1984 to 1990 in well D-665. Similar trends have been observed in data from a few other wells, but are not shown in this report.

The trends observed in chloride concentrations in water from some wells sampled in Duval County indicate that saltwater is gradually intruding into the Floridan aquifer system. Whether chloride concentrations in water from these wells will continue to increase is difficult to determine. However, the increase in chloride concentrations observed so far indicates that a further increase in chloride concentrations in water from the Floridan aquifer system is possible and that these elevated chloride concentrations could move downgradient and affect other wells. The abrupt increase in chloride concentrations in water from such wells as D-94 and D-450 also indicate that saltwater can invade areas previously having no evidence of saltwater intrusion. Various mechanisms of saltwater movement explaining the increase in chloride concentrations are discussed in detail in the next section.

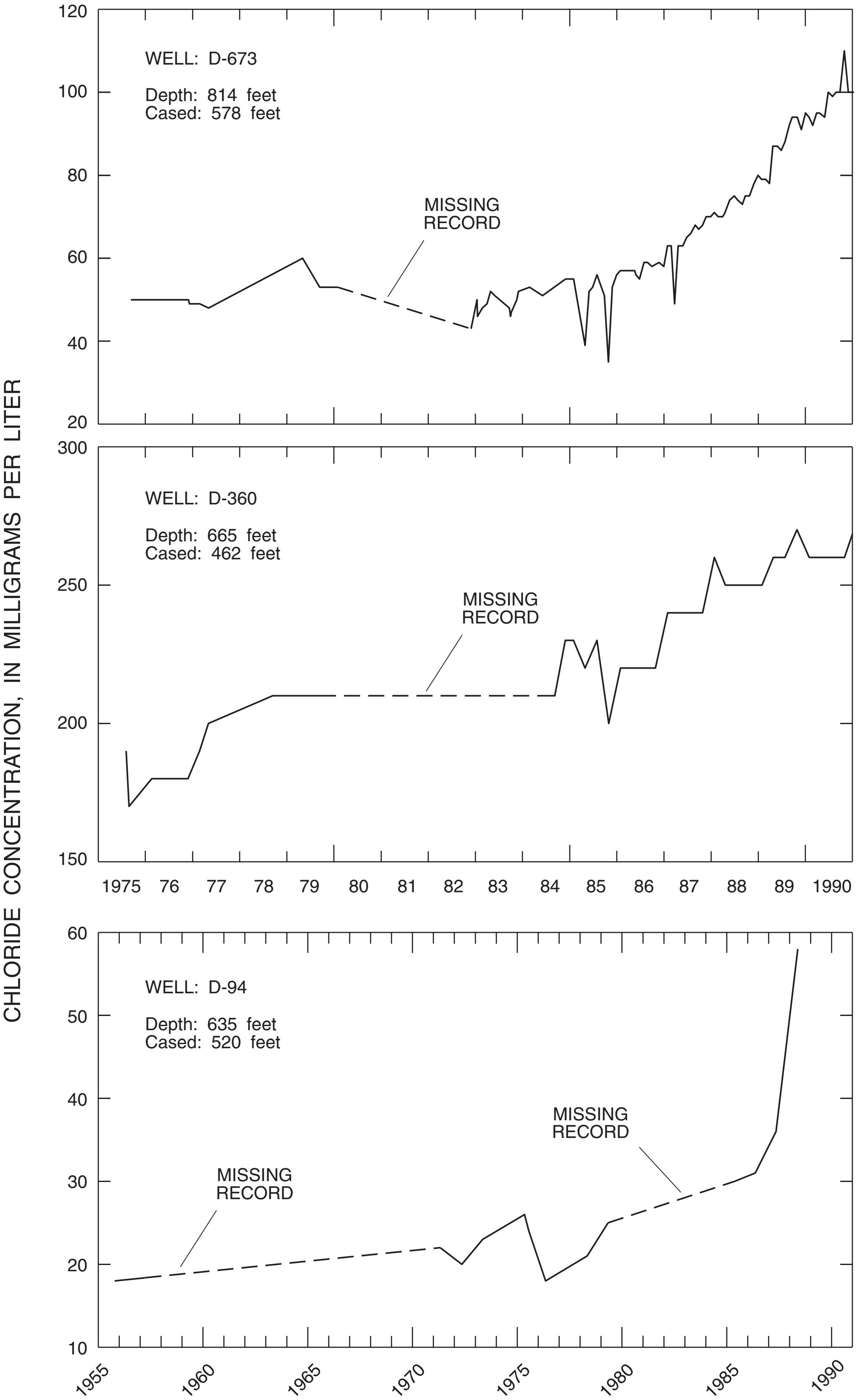

Figure 33. Chloride concentration in water from selected wells tapping the Upper Floridan aquifer.

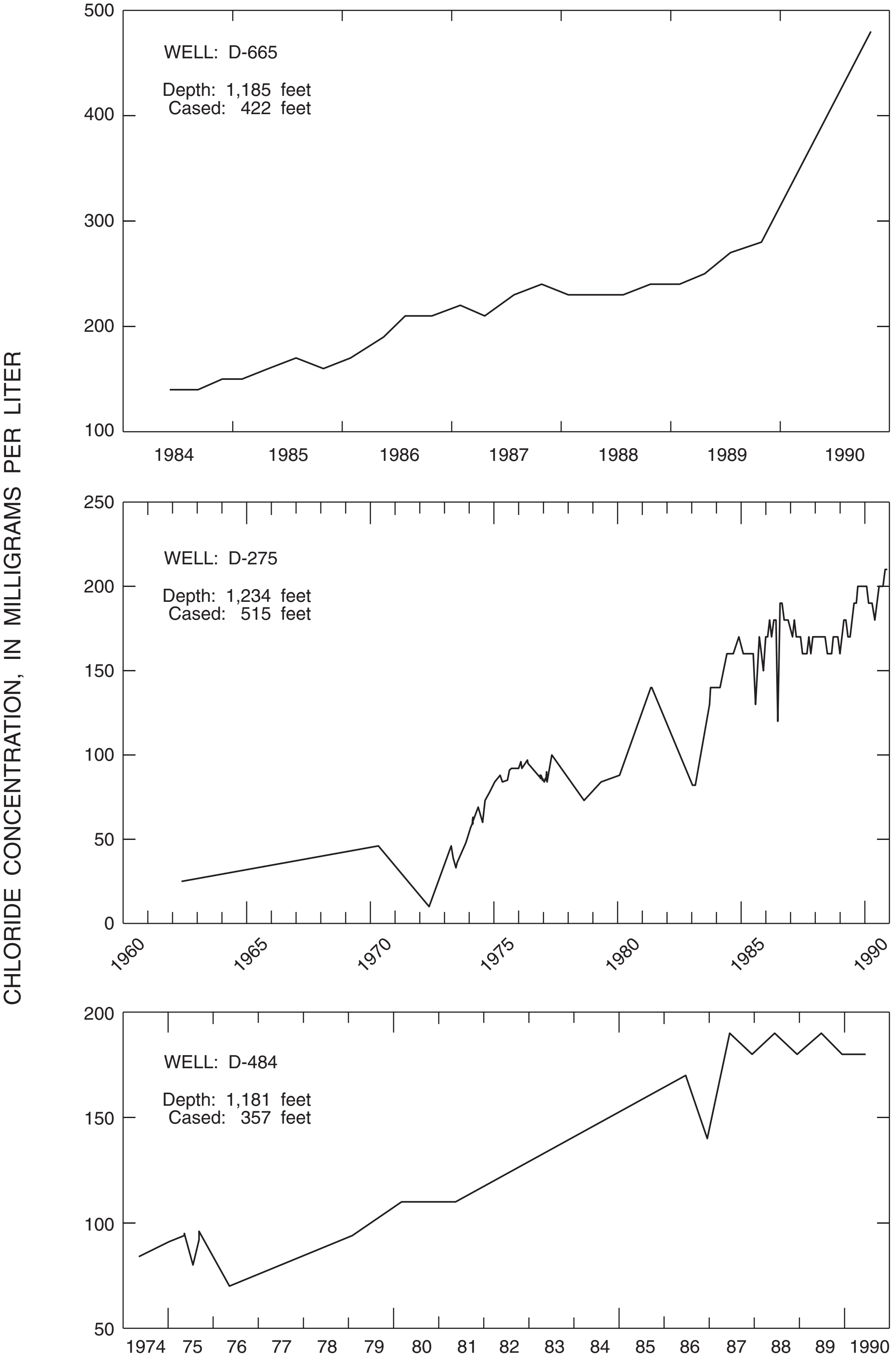

Figure 34. Chloride concentrations in water from selected wells tapping both the Upper Floridan aquifer and the upper zone of the Lower Floridan aquifer.

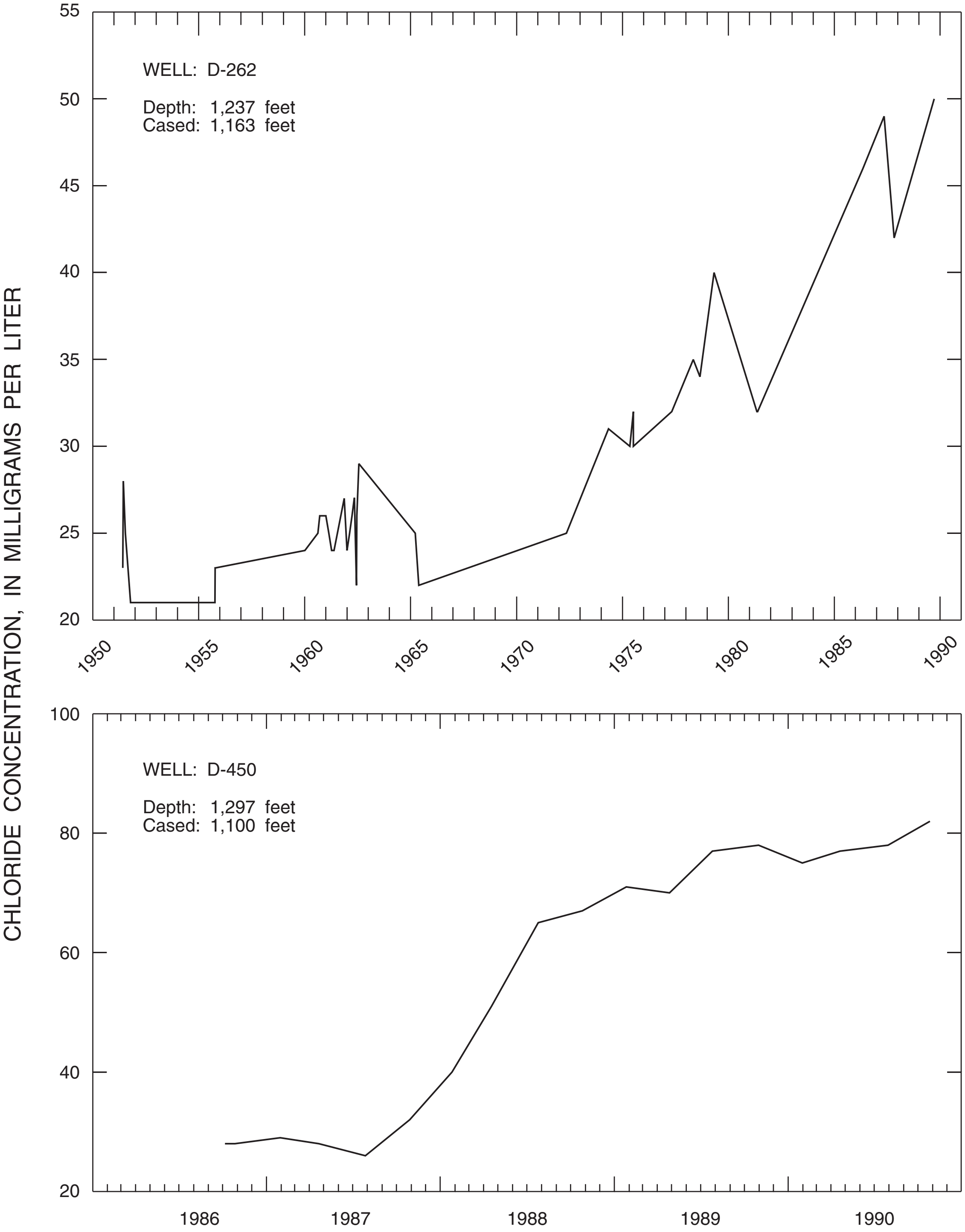

Figure 35. Chloride concentrations in water from selected wells tapping the upper zone of the Lower Floridan aquifer.

MECHANISMS OF SALTWATER INTRUSION

Saltwater intrusion is a potential threat to the quality of ground water in the study area. Chloride concentrations greater than 30 mg/L in water from the Floridan aquifer system were first detected in 1924 in a water sample from a well tapping the Upper Floridan aquifer (well D-625) at Fort George Island (unpublished records from the files of the U.S. Geological Survey). Leve (1966) documented increasing chloride concentrations in other areas of Duval and Nassau Counties from samples collected in the late 1950's and early 1960's. This trend in Duval County was confirmed by Thompson (1982). The few data available prior to 1940 indicate that substantial increases in chloride concentration were not yet a problem in Nassau County. However, as pulp and paper industries began to withdraw large amounts of water from the Floridan aquifer system in 1939, increases in chloride concentrations were documented in the upper water-bearing zones of the Floridan aquifer system.

Five possible mechanisms, some more plausible than others, could explain the movement of saltwater into ground water and the consequent increase in concentrations of chloride in the study area. They are: (1) the presence of unflushed pockets of relict seawater in the aquifer system; (2) lateral movement of the freshwater-saltwater interface off the northeastern coast of Florida; (3) upconing of saltwater from deeper zones of saline water below pumped wells; (4) upward leakage from deeper, saline water-bearing zones through failed, uncased, or improperly plugged or constructed wells; and (5) upward leakage from deeper saline water-bearing zones through semiconfining units that are thin, or are breached by joints, fractures, collapse features, or faults.

Relict Seawater

The presence of unflushed relict seawater could be a source of chloride in some parts of the study area. During the Pleistocene epoch, sea level stood at a much higher level than it does today and the Floridan aquifer system was invaded with seawater. Some of this water may not have been completely flushed from the aquifer. In some parts of the Floridan aquifer system, zones of stagnation or zones of sluggish ground-water flow could be present. Such zones could be of local extent and would be created by regional or local ground-water flow patterns that restricted horizontal or vertical flow in a particular area. If such zones exist, stagnant or sluggish flow would delay the complete flushing of ancient seawater. Stringfield and Cooper (1951a, p. 71) attributed high chloride concentrations observed in southern St. Johns County to relict seawater that had not been flushed from the aquifer. Isolated unflushed pockets of ancient seawater could also explain some of the chloride anomalies observed in Duval County.

Lateral Encroachment

Lateral encroachment of recent seawater into the upper zone of the Lower Floridan and possibly the Upper Floridan aquifers may be possible in southeastern St. Johns County, but can be discounted as a mechanism for elevated chloride concentrations in wells in Nassau, Duval, and northern St. Johns Counties. In Nassau, Duval, and northern St. Johns Counties, water from monitoring wells along the coast typically have low chloride concentrations, and the inferred position of the freshwater-saltwater interface at the top of the Floridan aquifer is miles offshore. If seawater were moving laterally through the Upper Floridan aquifer from outcrops in the Atlantic Ocean, the saltwater would first be detected in wells nearest the coast. Many of the coastal wells drilled to a depth of 700 to 1,200 ft have chloride concentrations below 30 mg/L (fig. 26). Chloride concentrations in water from two deep monitoring wells located along the coast, wells SJ-150 and D-2386 (fig. 29), were less than 30 mg/L down to a depth of about 1,200 ft (except for a 58 ft lens of water containing chloride concentrations of about 270 mg/L beginning at a depth of 1,025 ft in well SJ-150). Chloride concentrations ranged from 6 to 75 mg/L at depths from about 1,200 to 1,900 ft.

Data from abandoned oil wells and exploratory wells were used to estimate the present saltwater-freshwater interface in the Floridan aquifer system off Fernandina Beach (Johnston and others, 1982; Johnston, 1983). Figure 36 shows the inferred position of the saltwater-freshwater interface based on chloride concentrations of water samples and heads obtained from three offshore wells: JOIDES 1-1 (Wait and Leve, 1967, p. A 127), Tenneco lB 427 (Johnston and others, 1982, p. 1), and JOIDES J-2 (Johnston, 1983, p. 243). Applying Hubbert's interface principle (Hubbert, 1940), which states that freshwater is in equilibrium with the underlying saltwater when the depth to which freshwater extends below sea level is approximately

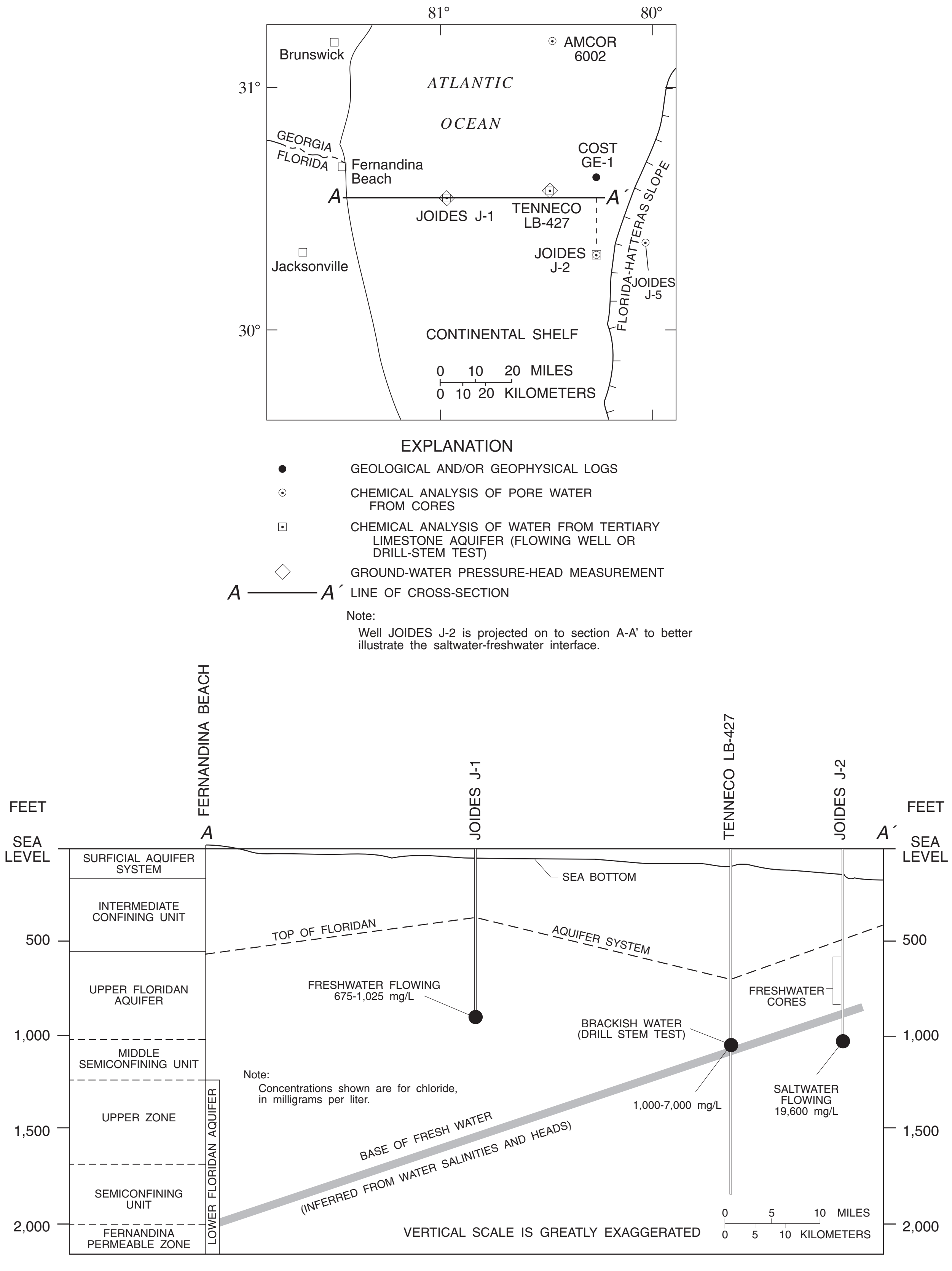

Figure 36. Inferred position of the saltwater-freshwater interface (modified from Johnston and others, 1982; and Brown, 1984).

40 times the altitude of the freshwater head immediately above the interface, Johnston and others (1982, p. 11) calculated the depth to the saltwater-freshwater interface under each well. At JOIDES J-2, more than 60 mi offshore, the interface was estimated to be 900 ft below sea level and increased to more than 2,000 ft below sea level at Fernandina Beach.

Based on recent and predevelopment heads, Johnston and others (1982, p. 12) concluded that pumping primarily in the Fernandina Beach area has resulted in only small head declines in the Upper Floridan aquifer at the JOIDES J-l and Tenneco sites. Although this implies that some movement of the interface has occurred, the offshore heads are high enough to maintain the saltwater-freshwater interface in the Upper Floridan aquifer far offshore in the northern part of the study area. Therefore, the possibility of saltwater from the sea invading the Upper Floridan aquifer along coastal northeastern Florida seems, for now, remote.

Upconing

Upconing of saltwater under a pumping well probably also can be discounted as a mechanism for saltwater intrusion in the study area. Semiconfining units and low values of vertical hydraulic conductivity within the Floridan aquifer system tend to restrict the vertical movement of water. Because of low values of vertical hydraulic conductivity, the saltwater-freshwater interface tends to slowly move in the vertical direction in response to a reduction in the potentiometric surface in the overlying zones. If upconing were occurring, elevated chloride concentrations in water would be areally distributed under cones of depression. Also, the transition zone would be moving upward and chloride concentrations would be expected to increase with depth. Data from several wells indicate otherwise. Fluid resistivity logs and chloride samples collected from several wells having elevated chlorides indicate that less-mineralized water underlies the shallower, higher chloride zone. Chloride concentrations generally increase again with depth, but only slightly until the Fernandina permeable zone is penetrated, at which point chloride concentrations sharply increase.

Upward Leakage Through Wells

Contamination of freshwater zones by saltwater can occur through failed, uncased, or improperly plugged or constructed wells. Wells drilled into or through saltwater can provide a conduit through which saltwater can flow into freshwater zones of the aquifer. In the study area, well construction commonly includes the installation of well casing to the top of the Ocala Limestone which forms the uppermost part of the Floridan aquifer system. After the casing is set, an open hole is drilled until sufficient water is obtained for the required purpose. Thus, several water-producing zones of potentially different water quality may be penetrated. In addition, saltwater from deeper aquifers (under higher artesian pressure) could move up the well bore and enter overlying freshwater zones and then flow laterally through the aquifer. If this were to occur, the increase in chloride concentrations in the freshwater zone would be greatest near the well and decrease with distance from the well.

Careful plugging of wells tapping deeper zones of saline water by cementing from the bottom up can help prevent further contamination of the Floridan aquifer. For example, at well D-464, located in Mayport, a chloride concentration of 670 mg/L was determined from a water sample collected at about 1,200 ft below land surface (unpublished records from the files of the U.S. Geological Survey). Water sampled at the well-head had a maximum chloride concentration of 590 mg/L. After the well was plugged back to a depth of 1,000 ft. the chloride concentration in water at the well-head decreased to 16 mg/L. In the Fernandina Beach area (fig. 1), wells with water having increased chloride concentrations have been plugged back to shallower depths. In one of these wells, chloride concentrations in water at the wellhead decreased from about 1,600 to 50 mg/L after the well was plugged back from 1,826 to 1,100 ft (Brown, 1984, p. 95).

Upward Leakage Through Structural Deformities

The areal and vertical variability of chloride concentrations indicates that isolated geologic features could be responsible for the occurrence and distribution of saltwater in the Floridan aquifer system. Areal distribution of chlorides in water in the study area indicates that the higher-chloride water in the Upper Floridan aquifer and in the upper zone of the Lower Floridan aquifer are somewhat localized and that the lateral extent of those higher chloride concentrations seems to be limited at present. For example, in several well fields, analysis of water from wells drilled to similar depths indicate that chloride concentrations varied from well to well. Chloride concentrations were elevated at some wells, whereas at nearby wells, concentrations did not exceed 30 mg/L.

Saltwater intrusion commonly is associated with a reduction in artesian pressure and, therefore, would be expected to occur in areas where artesian pressure is lowest. However, some wells having elevated chloride concentrations are not in well fields or near major pumping centers that commonly are associated with depressions in the potentiometric surface. Also, in central Duval County, where the potentiometric surface is the lowest in the county (fig. 12), increases in chloride concentrations have not been observed. Fluid resistivity logs in some wells also show zones of more mineralized water layered between zones of fresher water.

The most plausible mechanisms for the movement of higher chloride water into the freshwater zones of the Floridan aquifer system in parts of east-central Duval, eastern Nassau, and northern St. Johns Counties is the upward leakage of saltwater along joints, fractures, collapse features, faults, or other structural deformities. These features can create zones of relatively high vertical hydraulic conductivity through rocks of otherwise low vertical hydraulic conductivity, thereby providing a hydraulic connection between freshwater zones and deeper, more saline zones. Decreasing heads in the shallower freshwater zones of the aquifer can result in an increase in the potential for upward leakage of saltwater through nearly vertical zones of preferential permeability. Once saltwater reaches the freshwater zones, it can move laterally downgradient toward pumping centers (fig. 37).

As previously mentioned, several inferred faults were mapped in or near the study area; two are located in central and east-central Duval County (fig. 10). According to Leve (1983, p. 251), these inferred faults are near areas where relatively high chloride concentrations were detected in water from the upper water-bearing zones of the Floridan aquifer system. Water-quality anomalies may be associated with these inferred faults. Leve (1983) states that geochemical, artesian pressure, and water temperature data indicate that the source of these relatively high chloride concentrations is the Fernandina permeable zone and that faults may have breached the semiconfining beds and allowed the upward movement of saltwater into the shallower, freshwater zones.

Faults are thought to be the cause of the elevated chloride concentrations in water from the Upper Floridan aquifer in the Brunswick, Ga., area (Maslia and Prowell, 1990). Maslia and Prowell reported that four major subsurface faults capable of affecting the flow system of the Upper Floridan aquifer were inferred from structural analysis of geophysical data and from regional fault patterns. The inferred faults breach the nearly impermeable units that, in the Brunswick area, confine the Upper Floridan aquifer from below. Additionally, they provide conduits that allow the upward migration of higher chloride water in response to the lowering of the potentiometric surface in the Upper Floridan aquifer.

As a result of declining artesian pressure, chloride concentrations in water in the Upper Floridan aquifer in the Brunswick, Ga., area have increased significantly since the late 1950’s. Maslia and Prowell (1990, p. 22) reported that in 1962, chloride concentrations in what is equivalent to the upper half of the Upper Floridan were less than 500 mg/L, with the higher concentrations confined to a small area of the city. As groundwater withdrawals increased, chloride concentrations increased and spread to other parts of the city. By 1988, water from the upper part of the Upper Floridan aquifer had chloride concentrations as high as 2,400 mg/L (Maslia and Prowell, 1990, p. 21).

Because of the random distribution of wells yielding water with higher chloride concentrations, large-scale faults, if they exist, may not explain all of the chloride anomalies observed in ground water in northeastern Florida. Evidence indicates that solution-enlarged joints or fractures, and subsequently formed collapse features, might play a substantial role in the distribution of evaluated chloride water in the freshwater zones of the Floridan aquifer system. Marine seismic reflection profiles off the coast of northeastern Florida show solution-deformed limestone of Late Cretaceous to Eocene age (Meisburger and Field, Popenoe and others, 1984). Dissolution and collapse features are widely scattered throughout the area and are expressed as: (1) sinkholes that presently breach the sea floor, (2) sinkholes that breached the sea floor in the past are now filled with sand, and (3) dissolution-collapse structures that originated deep within the section and have caused buckling and folding of overlying Eocene, Oligocene, and to a lesser extent, younger strata (Popenoe and others, 1984). The deep dissolution collapse features seem to originate in the Upper Cretaceous and Paleocene rocks (Popenoe and others 1984). The overlying strata are buckled by the collapse of the deeper rocks causing them to appear folded.

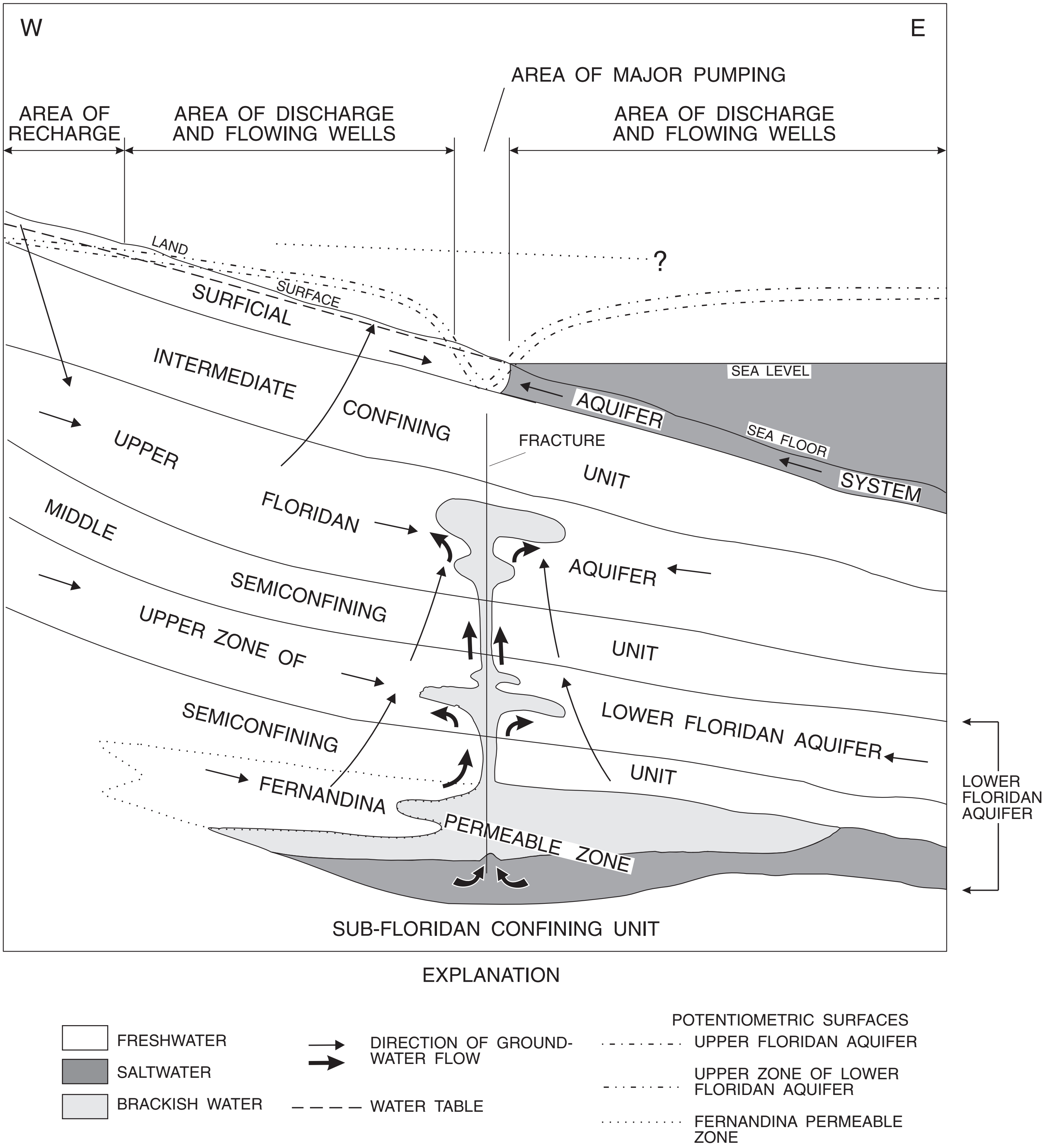

Figure 37. Simplified model of the Floridan aquifer system in northeastern Florida

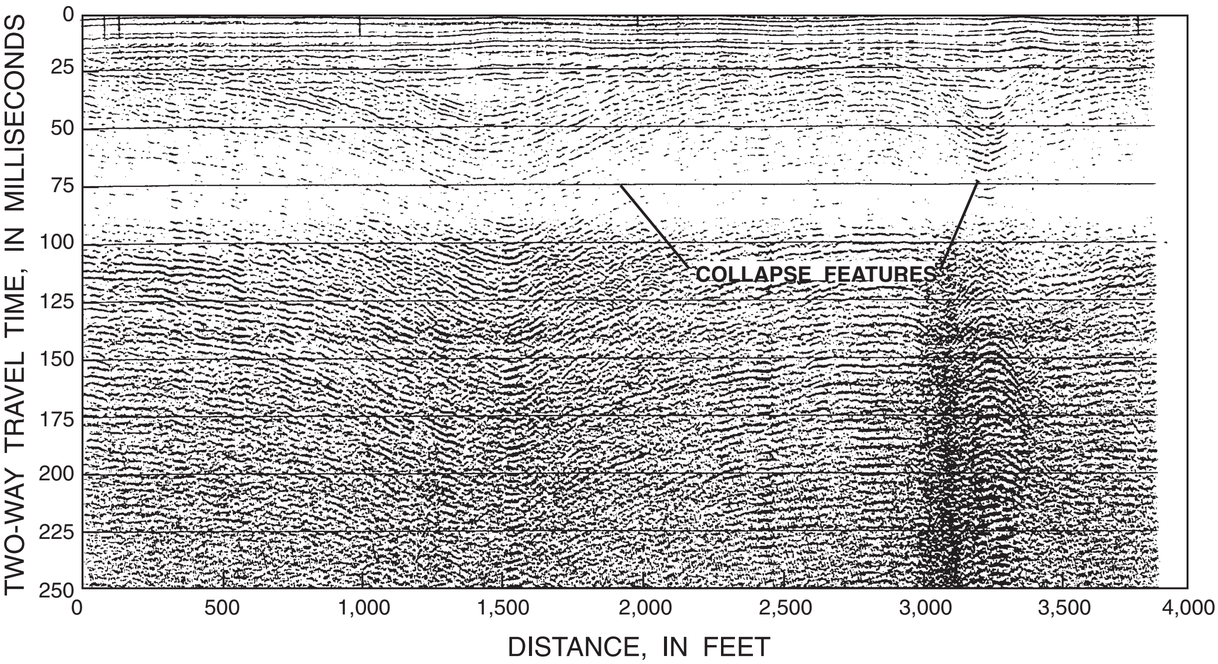

Figure 38. Seismic record showing collapse features along an approximate 4,000-foot section of the St. Johns River near Dames Point in Duval County (location of collapse features shown in figure 10).

According to Popenoe and others (1984), these collapse features are not randomly distributed but are controlled by regional joint patterns, the thickness of the overlying Miocene strata, and by facies of the Upper Cretaceous and Paleocene carbonate platform. Dissolution of Eocene and Oligocene rocks follow fractures caused by deep collapse, and sinkholes propagate toward the surface through the overlying younger strata along these structures.

In 1989, the U.S. Geological Survey ran a series of marine seismic-reflection profiles along the St. Johns River from Blount Island to Mandarin. The purpose of the investigation was to locate subsurface features that might provide information about some of the water-quality anomalies observed throughout the area. The data revealed several collapse features similar to those observed by Popenoe and others (1984). On one seismic transit near Dames Point, two collapse features were discovered only a few hundred feet apart (fig. 38). Additional seismic transits resulted in the discovery of another collapse feature nearby. These collapse features show the downward flexing of reflectors that affect most of the vertical section (to the depth visible on the record) and propagate upward into the overlying Hawthorn Formation, but do not breach the bottom of the St. Johns River. The collapse of the overlying Eocene and Miocene strata is estimated to have resulted in as much as 50 ft of subsidence. Additional seismic transits indicated that the depressions are roughly circular and range from about 500 to 2,000 ft in diameter.

Saline water is present in rocks in much of the Fernandina permeable zone and also may be present in the sub-Floridan confining unit of Paleocene age throughout the study area. If structures observed in the St. Johns River are collapse features and originate in the Upper Cretaceous and Paleocene rocks as proposed by Popenoe and others (1984), then the overlying rocks above these structures are probably highly fractured. Those fractured rocks could breach the semiconfining beds of the Floridan aquifer system and thus provide an effective conduit for saline water to move upward.

Several depressions on the surface of the Ocala Limestone are shown in plate 1. These depressions probably are ancient sinkholes which are probably related to the structures observed offshore. The sinkholes also could be connected to deeper, saline zones. At well SJ-168, located in northwestern St. Johns County, drillers logs show the top of the Ocala Limestone to be more than 200 ft deeper than at nearby wells. Analyses of water from this well indicate that chloride concentrations and temperature were higher than at nearby wells. The chloride concentration in water from this well was 34 mg/L, an indication of some upward leakage of saltwater. The temperature of the water from well SJ-168 was 28.8 °C, a relatively warm temperature generally observed in deeper zones. The elevated temperature is further evidence that vertical mixing is taking place. A temperature log of well SJ-150, located in northeastern St. Johns County shows a typical geothermal gradient with depth (fig. 39). In this well, water temperatures of more than 31 °C were recorded from about 1,500 ft to the bottom of the well (2,035 ft). Similar gradients also were observed in other monitoring wells in Duval and Nassau Counties.

Analyses of water samples collected from 19 wells on Fort George Island indicate that saltwater is present in the Upper Floridan aquifer. Structure-contour maps of the top of the Hawthorn Formation and the top of the Ocala Limestone show a depression of about 55 to 65 ft in the northeastern part of the island (Environmental Science and Engineering, Inc., 1985, p. 3-7). The structural feature is localized and is circular. Potentiometric surface maps of the Upper Floridan aquifer in the area of the island also show that a region of higher artesian pressure is present in the same area as the displaced beds (Environmental Science and Engineering, Inc., 1985). Additionally, chemical and physical characteristics of ground-water samples collected in the area indicate more highly mineralized water near the center of the depression. The distribution of chloride concentrations in water from wells on Fort George Island is shown in figure 40. Chloride concentrations range from 310 mg/L near the northeastern part or the island and decrease to less than 30 mg/L about 3,000 to 4,000 ft away from the inferred structural deformity.

Concentrations of chloride in water from many of the wells tapping the Upper Floridan aquifer on Fort George Island have increased during recent years. A graph showing water-level and chloride data collected at well D-164 since 1930 is shown in figure 41. Long-term data indicates that an inverse relation between water levels and chloride concentrations exists. As water levels declined (about 23 ft in 60 years), chloride concentrations increased from about 63 to 300 mg/L. Concentrations of chloride in water from other selected wells on the island (fig. 42) also have increased, indicating that saltwater may be moving into the Upper Floridan aquifer from zones below.

The increase in regional water use and local withdrawals by golf course and residential users has lowered the head in the Upper Floridan aquifer at Fort George Island.

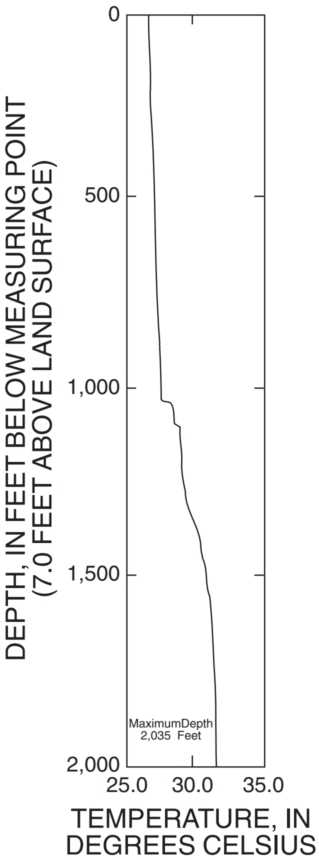

Figure 39. Temperature log of monitoring well SJ-150 (modified from Brown and others, 1986).

Decreased heads in the Upper Floridan aquifer can provide conditions for an upward gradient within the Floridan aquifer system. Available data indicate that saltwater might be moving upward into the Upper Floridan aquifer from a deeper zone along a vertical, or nearly vertical, conduit(s).

WATER MANAGEMENT CONSIDERATIONS

Although northeastern Florida currently has ample freshwater supplies, the potentiometric surface will probably continue to decline and accelerate the intrusion of saltwater as more water is withdrawn from the Floridan aquifer system. However, the rate of saltwater intrusion can be minimized through wise water management practices. Water-management strategies that have been used in other coastal areas to reduce the effects of existing or potential saltwater-intrusion problems include minimizing well depths, installing new well fields in areas where the freshwater thickness is greatest, reducing drawdown in well fields, and plugging deeper parts of selected wells.

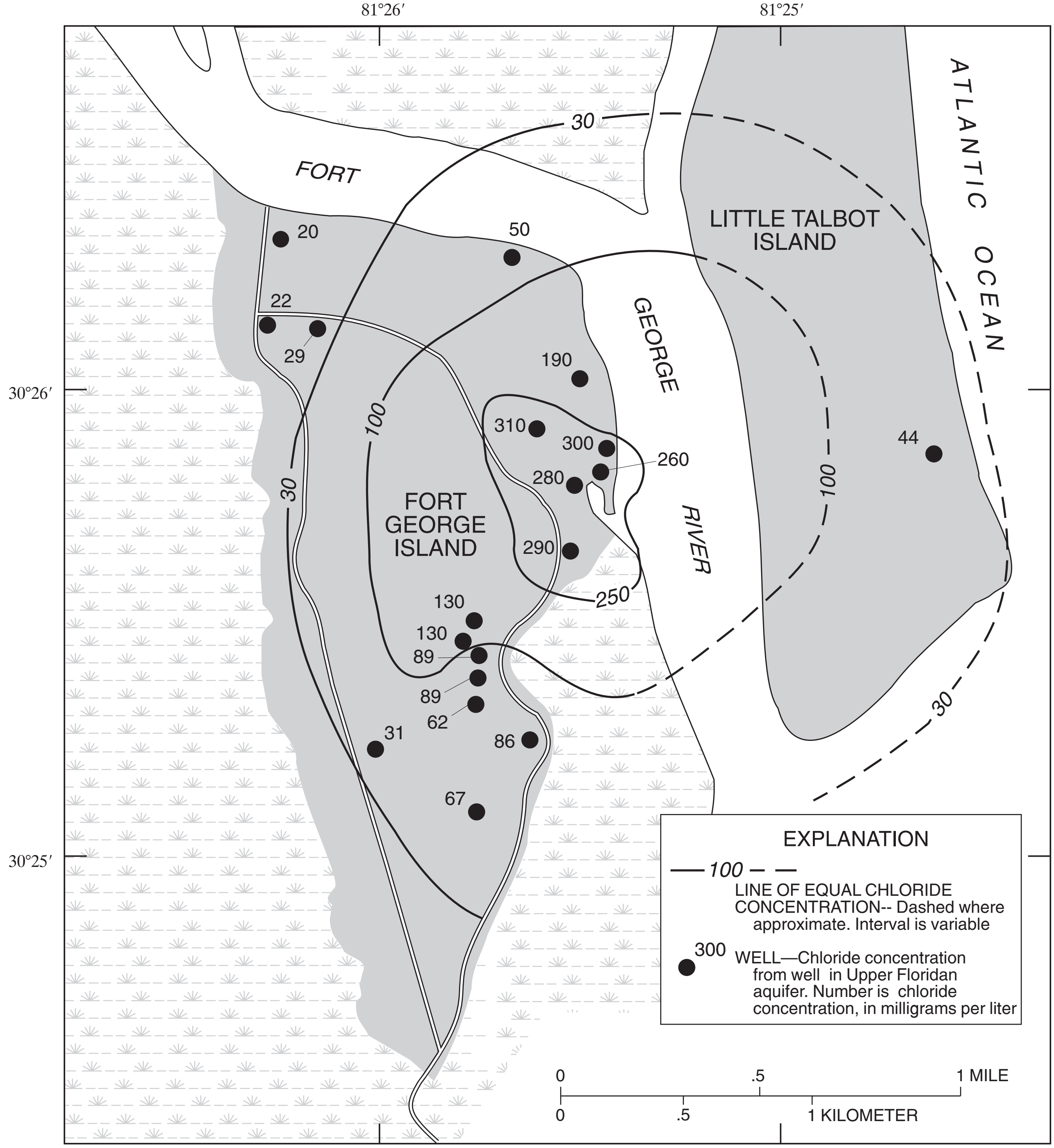

Figure 40. Distribution of chloride concentrations in water from selected wells tapping the Upper Floridan aquifer on Fort George Island.

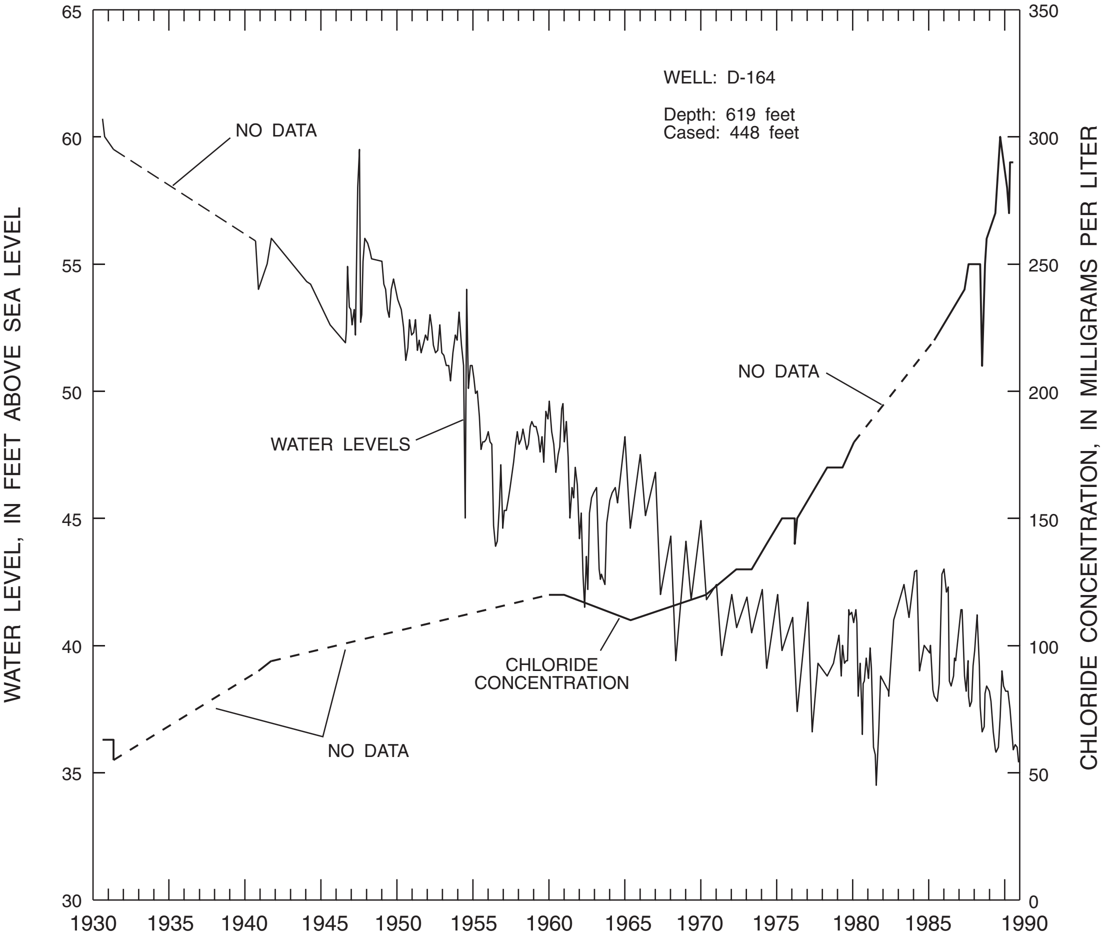

Figure 41. Water levels and chloride concentrations of water in well D-164, tapping the Upper Floridan aquifer, Fort George Island, 1930-90.

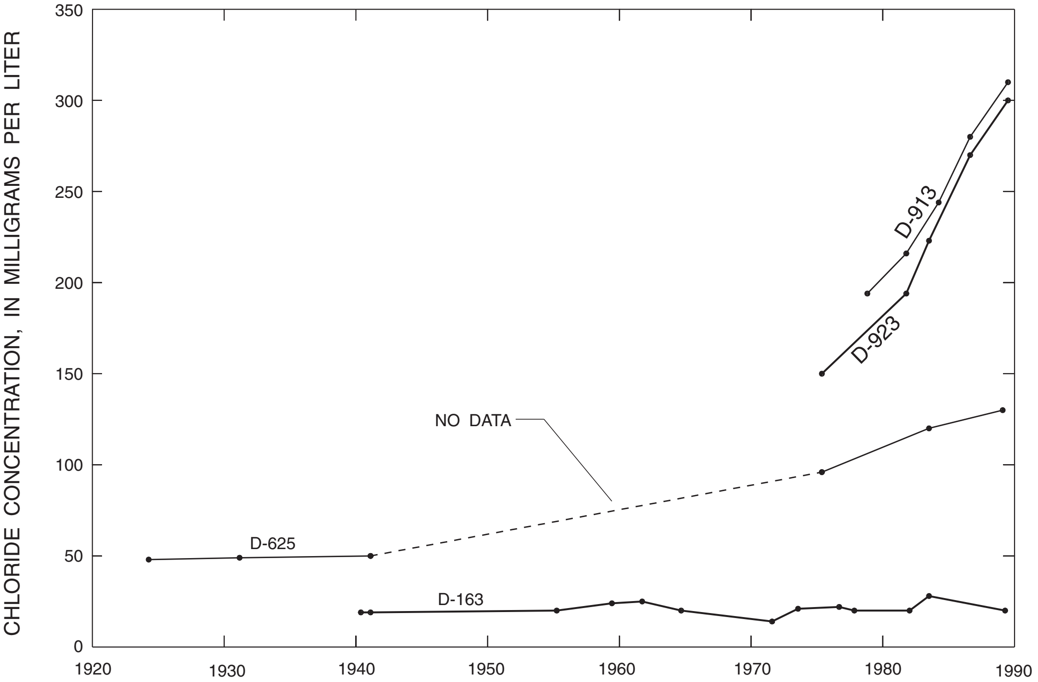

Figure 42. Chloride concentrations in water from selected wells tapping the Upper Floridan aquifer on Fort George Island, 1924-90.

Minimizing well depths can be one of the most effective and simplest methods of reducing the threat of saltwater intrusion. Keeping as much distance as possible between the bottom of the well and the underlying saltwater could slow the upward vertical movement of saltwater. Another effective method can be locating new well fields in areas where the potentiometric surface is high, such as in western Duval County. This would tend to ensure that wells are located in areas of maximum thickness of the freshwater zone. However, if the same geologic features that are causing saltwater to appear in the upper freshwater zones in eastern Duval County also exist in western Duval County, then it is possible that these areas also could experience saltwater intrusion at a later time.

Drawdown reduction is another effective water-management technique. One of the most practical steps in the reduction of drawdown is to increase the horizontal distance between wells in well fields to reduce the cumulative effects of drawdown interference among pumped wells. If an increase in upward leakage of saltwater is a result of head declines in the upper parts of the Floridan aquifer system, it would be desirable to prevent the development of a deep cone of depression in the potentiometric surface. Rotation of pumping among production wells, so that all the individual wells are evenly stressed, also might reduce drawdown.

Many industrial and public-supply wells penetrate more than one water-bearing zone. Wells open to both the freshwater and saltwater zones of the aquifer act as conduits for the movement of saltwater into the freshwater zones. Plugging the deeper parts of the wells that penetrate saline zones could prevent the migration of saltwater through the uncased open hole into other freshwater zones. Deeper parts of several wells in the Mayport and Fernandina Beach areas that had elevated chloride concentrations have been plugged and the wells now pump fresher water.

SUMMARY AND CONCLUSIONS

The Floridan aquifer system is the major source of ground water in Duval, Nassau, and St. Johns Counties. In 1988, ground-water withdrawals totaled about 254 million gallons per day, of which 90 percent was withdrawn from the Floridan aquifer system primarily for industrial, public, domestic, and agricultural supply. Ground-water withdrawals increased more than 40 percent between 1965 and 1988.

The Floridan aquifer system consists primarily of limestone and dolomite of Eocene age. The principal formations of the aquifer are the Ocala Limestone, Avon Park Formation, Oldsmar Formation, and the upper part of the Cedar Keys Formation. The top of the aquifer ranges from less than 90 ft below sea level in the southwestern part of St. Johns County to more than 600 ft below sea level in several areas in central Duval County. Thickness of the aquifer system ranges from about 1,600 to 1,900 ft in the study area.

The Floridan aquifer system is divided into two aquifers of relatively high permeability referred to as the Upper Floridan and Lower Floridan aquifers. These aquifers are separated by the middle semiconfining unit, a less permeable unit that restricts the vertical movement of water. The Lower Floridan aquifer is further divided by another semiconfining unit into two major water-bearing zones within the study area; the upper zone of the Lower Floridan aquifer and the Fernandina permeable zone.

In September 1989, the potentiometric surface of the Upper Floridan aquifer ranged from about 50 ft above sea level in southwestern Duval County to more than 60 ft below sea level near Fernandina Beach. Depressions in the potentiometric surface of the Upper Floridan aquifer in various parts of the study area result from industrial or public-supply pumping, or possibly by diffuse upward leakage or spring discharge into the St. Johns River. Long-term hydrographs of wells tapping the Floridan aquifer system show declines in the potentiometric surface over the study area that range from about one-third to three-fourths foot per year.

Concentrations of chemical constituents in water in the Floridan aquifer system vary both areally and with depth. In Nassau and Duval Counties, most constituent concentrations in the Upper Floridan aquifer meet the Florida Department of Environmental Regulation drinking water standards. In most of St. Johns County, sulfate concentrations generally exceed the recommended 250 mg/L limit for drinking water. In most of the southern part of St. Johns County, saline water is present in the Floridan aquifer and concentrations of several constituents exceed the limits recommended by the Florida Department of Environmental Regulation.

The quality of water in the Upper Floridan aquifer varies considerably in the study area. Specific conductance ranges from 168 to about 12,200 microsiemens per centimeter at 25 degrees Celsius. Generally, specific conductance values increased toward the northeast in Nassau County, toward the east in Duval County, and toward the south in St. Johns County. Within the study area, sulfate concentrations range from 5.0 to 1,300 mg/L and chloride concentrations from 4.6 to 3,600 mg/L. Highest chloride concentrations occur in St. Johns County, where concentrations generally increase toward the south.

Many of the wells drilled into the Floridan aquifer system tap only the Upper Floridan aquifer. However, in Duval County, many industrial and public-supply wells tap both the Upper Floridan and the upper zone of the Lower Floridan aquifers. Data from geophysical logs and from water samples collected from these multiaquifer wells and from deep monitoring wells within the study area indicate that water from the upper zone of the Lower Floridan aquifer generally is slightly more mineralized than water from the overlying Upper Floridan aquifer.

Water from the Fernandina permeable zone ranges from fresh to very saline. The water is freshest in the western part of the study area and is moderately to very saline along the coast. The highest chloride concentration (16,800 mg/L) was in a water sample collected from a deep monitoring well in northeastern St. Johns County (well SJ-150). Specific conductance and sulfate concentrations in water from this well were 44,000 microsiemens per centimeter at 25 degrees Celsius and 2,700 mg/L, respectively.

A potential threat to the quality of ground water in the study area is saltwater intrusion. Elevated chloride concentrations have been observed in wells tapping the Upper Floridan and the upper zone of the Lower Floridan aquifer. In Duval County, increased chloride concentrations in water from some wells indicate that saltwater is gradually intruding into the freshwater zones of the Floridan aquifer system. Currently, the distribution of elevated chloride concentrations in the water indicates that contamination in the Upper Floridan and the upper zone of the Lower Floridan aquifer is somewhat localized, and that the lateral extent seems to be limited, at present.

Five possible mechanisms of saltwater movement, some more plausible than others, could explain the observed increases in chloride concentration in the study area. They are: (1) the presence of unflushed pockets of relict seawater in the aquifer system; (2) lateral movement of the freshwater-saltwater interface within the aquifer off the northeastern Floridan coast; (3) upconing of saltwater from deeper zones of saline water below pumped wells; (4) upward leakage from deeper, saline water-bearing zones through failed, uncased, or improperly plugged or constructed wells; and (5) upward leakage from deeper, saline water-bearing zones through semiconfining units that are thin, or are breached by joints, fractures, collapse features, or faults.

The principal areas of saltwater intrusion in the Floridan aquifer system within the study area are in east-central Duval County, the southern two-thirds of St. Johns County, and along the coast. The high chloride concentrations observed in southern St. Johns County are not man-induced, but probably are the result of the invasion of seawater from previous sea level rises. The most plausible path for the migration of saltwater to the freshwater zones of the Floridan aquifer system in other parts of the study area is by upward leakage along structural deformities, through leaky confining beds, and through wells. Such features can create paths of relatively high vertical conductivity through sediments of relativity low vertical hydraulic conductivity and can provide a hydraulic connection between the freshwater zones and the deeper, more saline zones. Decreasing heads in the shallower, freshwater zones of the aquifer can result in an increase in potential for upward leakage of saltwater through vertical zones of preferential permeability. Saltwater can then move laterally through freshwater zones, moving downgradient toward zones of decreasing head.

Some of the joints or fractures in the Floridan aquifer system seem to be solution enlarged and can form large collapse features. Marine seismic-reflection profiles in the St. Johns River (in Duval County) and off the coast of northeastern Florida, show the presence of collapse features in the Floridan aquifer system. These collapse features probably are not randomly distributed but are controlled by regional joint patterns. The vertical openings apparently penetrate the semiconfining units and may originate deep within the Floridan aquifer system.

The potential for saltwater contamination of the freshwater zones in the Floridan aquifer system probably will tend to increase in northeastern Florida as artesian pressures continue to decline. Possible water-management strategies that might reduce saltwater intrusion into freshwater zones include minimizing well depths, installing new well fields in areas where the freshwater thickness is greatest, reducing drawdowns in well fields and other areas where saltwater intrusion is occurring, and plugging parts of wells that penetrate deeper, saline zones.

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Appendix I

Appendix I. Chemical and physical analyses of water from the Floridan aquifer system in Nassau, Duval, St. Johns, and northeastern Clay Counties

[U, Upper Floridan aquifer well; L, upper zone of Lower Floridan aquifer well; B, well tapping both the Upper Floridan and the upper zone of the Lower Floridan aquifer; F, Fernandina permeable zone well; *, may tap the upper zone of the Lower Floridan aquifer; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °C; g/ml, grams per milliliter; mg/L, milligrams per liter; µg/L, micrograms per liter; --, no data; **, laboratory value]

Local well number	Aquifer	Date	Water temperature (°C)	Specific conductance (µS/cm)	pH (standard units)	Density (g/ml) at 20 °C)	Silica, dissolved (mg/L as SiO_2)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Strontium, dissolved (µg/L as Sr)	Chloride, dissolved (mg/L) as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Alkalinity (mg/L as $CaCO_3$)	Hardness, total (mg/L as $CaCO_3$)	Solids residue at 180 °C, dissolved (mg/L)
Nassau County																		
N-51	U	08-29-88	22.9	605	7.43	--	34	63	29	17	1.8	420	26	120	0.60	160	280	391
N-100	U	08-31-88	23.0	570	7.62	--	32	58	29	16	1.8	520	22	120	.70	154	260	361
N-118	U	05-24-88	22.0	590	--	--	--	--	--	--	--	--	24	120	--	--	--	--
N-46	U	05-23-88	23.0	615	--	--	--	--	--	--	--	--	24	120	--	--	--	--
N-3	U	05-23-88	22.0	610	--	--	--	--	--	--	--	--	23	120	--	--	--	--
N-124	U	08-31-88	21.7	585	7.55	--	33	57	31	17	1.9	560	22	120	.60	157	270	384
N-50	U	09-26-88	22.0	570	7.65	--	33	56	29	17	1.7	500	23	120	.70	155	260	379
N-126	U	08-31-88	22.2	645	7.52	--	33	63	33	19	2.1	600	26	140	.60	164	290	418
N-125	U	08-30-88	24.5	640	8.02	--	33	63	33	18	2.0	570	25	140	.60	164	290	415
N-98	U	09-26-88	23.0	600	7.56	--	33	58	31	18	1.8	570	24	120	.60	160	270	400
N-58	U	10-05-89	24.4	652	7.69	--	33	64	35	21	2.1	660	31	140	.60	163	300	461
N-35	U	10-05-89	25.5	773	--	--	--	--	--	--	--	--	57	160	--	--	--	--
N-117 [a]a/	F	04-27-90	28.5	28,000	7.56	1.020	20	800	700	6,700	180	700	12,000	1,900	.90	148	4,900	24,600
Do. [b]/		05-03-90	30.8	34,000	7.20	--	--	780	750	6,500	210	--	11,800	1,980	.70	71	--	20,400
N-53	U	08-30-88	23.8	685	7.59	--	34	68	35	19	2.0	610	27	160	.60	169	310	449
N-47	B	10-05-89	25.3	908	7.52	--	35	80	42	48	2.8	830	86	190	.80	162	370	629
N-128	U	10-05-89	25.2	743	7.35	--	35	73	38	30	2.3	700	50	170	.70	166	340	522
N-127	U	10-11-88	24.9	690	7.53	--	35	68	35	20	2.2	660	28	160	.60	166	310	451
N-94	U	08-29-88	--	615	7.50	--	35	62	30	18	1.8	480	27	120	.60	163	280	397
N-99	U	09-26-88	23.0	635	7.56	--	34	62	31	19	1.9	530	27	130	.60	167	280	426
N-67	U	05-24-88	22.0	720	--	--	--	--	--	--	--	--	30	170	--	--	--	--
WN-18	U	08-29-88	23.1	670	7.51	--	38	67	33	20	2.1	540	29	140	.60	175	300	445
Duval County																		
D-1440	U	08-23-89	23.7	675	--	--	--	--	--	--	--	--	18	210	--	--	--	--
D-1097	U	05-24-88	23.3	350	8.10	.999	16	31	18	7.4	2.4	2,700	6.8	62	.60	104	150	214
D-296	U	05-24-88	23.3	665	7.95	--	20	61	40	14	3.0	5,200	17	220	.60	117	320	491
D-169	U	06-15-88	24.5	675	7.52	.999	24	71	34	14	2.5	4,400	19	190	.60	145	320	468
D-2846	U	05-24-88	24.4	405	--	--	--	--	--	--	--	--	9.0	78	--	--	--	--
D-292	U	08-23-89	23.9	710	--	--	--	--	--	--	--	--	18	220	--	--	--	--
D-126	U	05-24-88	23.0	350	--	--	--	--	--	--	--	--	7.4	57	--	--	--	--
D-2863	U	01-19-88	23.7	385	7.99	--	18	36	19	6.8	2.2	3,300	8.1	77	.60	105**	170	238

Local well number	Aqui-fer	Date	Water temper-ature (°C)	Spe-cific con-duct-ance (µS/cm)	pH (stand-ard units)	Density (g/ml) at 20 °C)	Silica, dis-solved (mg/L as SiO_2)	Cal-cium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	So-dium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Stron-tium, dis-solved (µg/L as Sr)	Chlo-ride, dis-solved (mg/L) as Cl)	Sul-fate, dis-solved (mg/L as SO_4)	Fluo-ride, dis-solved (mg/L as F)	Alka-linity (mg/L as $CaCO_3$)	Hard-ness, total (mg/L as $CaCO_3$)	Solids residue at 180 °C, dis-solved (mg/L)
<u>Duval County Continued</u>																		
D-2860	U	12-17-87	22.0	360	--	--	16	34	16	7.3	2.0	2,900	6.5	55	.50	108**	150	216
D-538	B	04-18-88	28.2	730	7.62	.999	22	83	37	14	2.8	6,000	23	230	.40	121**	370	544
D-3828	U	01-19-88	25.0	410	7.89	--	18	37	19	7.6	2.2	3,400	8.8	75	.60	112**	170	242
D-282	U	05-24-88	25.0	505	7.98	.999	21	46	27	12	2.7	3,700	12	120	.60	125	230	341
D-3832	U*	08-14-89	27.2	725	--	--	--	--	--	--	--	--	19	220	--	--	--	--
D-2847	U*	09-22-88	--	678	--	--	--	--	--	--	--	--	17	190	--	--	--	--
D-536	B	05-24-88	31.0	1,010	7.54	.999	24	100	42	32	4.3	5,800	110	230	.70	137	430	691
D-3823	U	09-22-88	26.1	727	7.64	.999	23	76	35	17	2.7	4,700	34	200	.80	135	340	500
D-1055	U	05-24-88	22.5	318	--	--	--	--	--	--	--	--	7.0	51	--	--	--	--
D-326	U*	06-20-88	24.7	250	7.86	--	15	27	11	4.3	1.5	1,200	5.0	21	.30	103	110	144
D-2870	U	01-19-88	24.0	366	7.90	--	17	34	18	8.1	2.1	3,100	11	61	.60	114**	160	227
D-3831	U*	08-14-89	25.5	610	7.71	.999	23	62	32	14	2.6	3,400	16	170	1.0	135	290	436
D-658	U	06-28-88	26.0	672	7.78	--	24	74	32	14	2.4	3,700	18	190	.90	137**	320	458
D-1963	U	06-21-88	23.7	450	7.56	--	27	54	18	15	1.6	510	9.0	6.0	.70	229	210	267
D-291	B	07-10-89	29.2	860	7.51	.999	24	83	34	35	2.4	3,700	100	150	.80	145	350	560
D-75	L	10-27-88	25.8	360	7.91	--	18	40	16	6.1	1.8	3,300	7.8	64	.40	112	170	221
D-129	U	05-25-88	22.0	445	--	--	--	--	--	--	--	--	9.0	85	--	--	--	--
D-2707	U	06-14-88	24.5	641	7.68	--	23	62	33	13	2.2	2,200	15	180	.80	126**	290	444
D-2747	U	06-14-88	24.5	637	7.65	--	22	62	34	13	2.3	2,200	13	180	.70	125**	300	436
D-450	L	10-26-88	27.0	770	7.58	.999	25	81	33	24	2.3	3,800	67	160	.70	144	340	514
D-991	U	10-24-88	25.0	595	7.88	--	24	70	27	12	1.8	3,000	15	150	.70	148	290	391
D-3034	U	06-14-88	22.0	617	8.06	--	22	54	37	13	2.3	2,000	12	170	1.1	135**	290	417
D-1155	L	10-24-88	29.0	800	7.62	.999	25	85	34	23	2.3	4,000	73	160	.70	144	360	506
D-103	B	04-18-88	27.1	460	7.83	--	20	48	22	8.1	2.1	3,800	9.5	110	.50	116**	210	302
D-483	B	06-14-88	28.5	832	7.68	--	28	74	33	39	2.3	2,300	94	130	.50	149**	320	532
D-484	B	06-14-88	28.5	1,160	7.38	--	30	90	40	71	2.6	2,400	190	140	.60	146**	390	716
D-343	U	05-23-88	24.5	650	--	--	--	--	--	--	--	--	13	190	--	--	--	--
D-298	U	05-31-88	27.0	580	--	--	--	--	--	--	--	--	16	160	--	--	--	--
D-482	B	06-14-88	27.0	661	7.93	--	27	63	31	21	2.2	2,300	37	140	.70	146**	290	462
D-650	B	12-16-87	26.8	629	--	--	23	67	27	14	1.8	2,700	20	140	.80	141**	280	401
D-275	B	10-27-88	28.0	1,060	7.47	--	26	92	36	65	2.4	3,500	170	150	.60	146	380	636
D-3825	B	02-23-89	--	645	--	--	--	--	--	--	--	--	38	130	--	--	--	--
D-224	B	04-24-90	27.0	695	7.64	--	25	75	30	22	2.1	3,100	49	140	.70	144**	310	476
D-225	B	09-22-88	27.5	840	--	--	--	--	--	--	--	--	86	150	--	--	--	--
D-2193	B	12-15-87	29.1	972	--	--	23	86	34	55	2.3	3,500	140	150	.70	140**	360	613
D-649	U*	04-19-88	25.8	630	7.60	--	24	69	28	13	2.0	3,300	20	160	.80	134**	290	435
D-665	B	10-25-88	26.2	1,320	7.53	.999	26	100	44	94	2.5	4,000	240	170	.70	147	440	756
Do.		10-30-90	--	1,880	--	--	--	--	--	--	--	--	480	--	--	--	--	--

Local well number	Aqui-fer	Date	Water temper-ature (°C)	Spe-cific con-duct-ance (µS/cm)	pH (stand-ard units)	Density (g/ml) at 20 °C)	Silica, dis-solved (mg/L as SiO_2)	Cal-cium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	So-dium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Stron-tium, dis-solved (µg/L as Sr)	Chlo-ride, dis-solved (mg/L) as Cl)	Sul-fate, dis-solved (mg/L as SO_4)	Fluo-ride, dis-solved (mg/L as F)	Alka-linity (mg/L as $CaCO_3$)	Hard-ness, total (mg/L as $CaCO_3$)	Solids residue at 180 °C, dis-solved (mg/L)
Duval County--Continued																		
D-54A	B	10-25-88	27.3	635	7.55	--	22	72	31	11	2.2	4,200	13	190	.70	133	310	424
D-425T	B	10-26-88	29.0	590	7.61	--	24	67	26	11	1.9	3,300	14	140	.70	144	280	382
D-425B a/	F	10-26-88	28.8	1,595	7.47	1.000	25	250	55	50	4.2	7,600	73	720	1.0	123	860	1,320
D-198	B	04-18-88	28.5	560	7.58	--	23	64	25	11	2.0	3,600	14	140	.70	133**	270	388
D-246	B	05-23-88	26.5	600	--	--	--	--	--	--	--	--	28	140	--	--	--	--
D-830	U	08-23-89	26.5	690	7.58	--	25	73	31	21	2.1	3,000	45	150	.70	150	310	497
D-160	U	03-09-90	22.5	610	7.4	--	--	63	32	--	--	--	29	140		422		
D-605	U*	06-16-88	26.0	580	7.66	.999	24	58	33	11	1.9	1,800	15	150	.90	138	280	397
D-94	U	05-23-88	24.0	568	--	--	--	--	--	--	--	--	58	110	--	--	--	--
D-297	U	05-23-88	26.0	586	--	--	--	--	--	--	--	--	12	160	--	--	--	--
D-241	B	10-27-88	29.3	560	7.62	--	23	65	25	10	1.9	3,400	12	140	.60	136	270	368
D-49	U	06-20-88	23.3	350	7.73	--	21	34	16	12	1.9	1,200	11	28	.50	143	150	216
D-1214	U	10-24-88	22.8	545	7.73	--	26	63	23	13	1.8	2,400	15	120	.70	148	250	352
D-709	U	10-24-88	22.1	602	7.52	--	25	70	27	13	2.1	2,500	15	160	.70	151	290	398
D-2069	U	06-20-88	22.2	430	7.73	.999	24	42	21	11	2.3	2,400	11	73	.70	138	190	271
D-313	B	04-19-88	27.5	720	7.56	.999	27	71	28	27	1.8	2,000	72	110	.60	144	290	454
D-479	B	10-25-88	28.1	690	7.56	.999	26	72	28	25	1.8	2,300	65	110	.60	151	300	430
D-307	B	07-06-88	25.5	605	7.83	.999	22	57	34	10	1.9	1,700	12	170	1.0	118**	280	421
D-673	U	10-25-88	28.3	735	7.59	.999	27	76	29	23	1.8	2,400	75	120	.60	150	310	456
D-335	B	10-25-88	28.0	510	7.66	--	27	56	21	13	1.5	1,900	16	85	.70	158	230	319
D-176	L	04-18-88	26.3	625	7.62	--	22	73	27	11	2.0	3,800	12	170	.70	130	300	425
D-3659	B	12-16-91	--	746	--	--	--	--	--	--	--	--	94	120	--	--	--	--
D-581	U	05-25-88	23.0	587	--	--	--	--	--	--	--	--	13	170	--	--	--	--
D-1323	B	06-15-88	27.2	1,020	8.18	.999	23	74	34	66	2.2	2,300	170	110	.50	135	330	618
D-3060 a/	F	04-22-88	29.6	18,500	7.37	1.007	26	650	400	2,700	40	--	6,000	1,000	.40	128**	3,300	12,300
Do. c/		05-08-90	28.9	18,600	7.13	--	--	790	430	3,200	40	--	6,100	1,080	.30	--	--	--
D-210	U	05-23-88	27.0	518	--	--	--	--	--	--	--	--	17	75	--	--	--	--
D-655	U	12-16-91	--	581	--	--	--	--	--	--	--	--	31	120	--	--	--	--
D-308	B	05-23-88	28.0	510	--	--	--	--	--	--	--	--	20	88	--	--	--	--
D-309	B	09-20-88	28.0	550	--	--	--	--	--	--	--	--	20	91	--	--	--	--
D-400	U	05-23-88	24.0	516	--	--	--	--	--	--	--	--	18	120	--	--	--	--
D-430	B	06-15-88	27.5	600	7.60	.999	27	64	24	17	1.7	1,700	39	100	.70	155	260	407
D-46A	B	04-18-88	26.8	550	7.61	--	24	64	23	11	1.7	2,500	9.2	120	.70	137**	260	378
D-84	U	05-23-88	22.5	645	--	--	--	--	--	--	--	--	15	150	--	--	--	--
D-3833	U	08-14-89	25.5	605	7.51	--	25	67	30	13	1.8	2,400	19	150	.80	149	290	435
D-277	U	09-20-88	24.0	572	--	--	--	--	--	--	--	--	16	140	--	--	--	--
D-3830	U	08-17-89	26.2	540	7.66	--	27	61	23	13	1.6	2,000	21	100	.80	154	250	358
D-2386 a/	F	04-21-88	29.6	12,500	7.34	1.004	30	380	240	1,700	26	8,200	3,500	700	.20	137**	1,900	7,380
Do. d/		04-23-90	--	17,000	--	1.008	--	570	400	3,000	68	13,000	5,800	1,030	--	135**	3,100	--

Local well number	Aqui-fer	Date	Water temper-ature (°C)	Spe-cific con-duct-ance (µS/cm)	pH (stand-ard units)	Density (g/ml) at 20 °C)	Silica, dis-solved (mg/L as SiO_2)	Cal-cium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	So-dium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Stron-tium, dis-solved (µg/L as Sr)	Chlo-ride, dis-solved (mg/L) as Cl)	Sul-fate, dis-solved (mg/L as SO_4)	Fluo-ride, dis-solved (mg/L as F)	Alka-linity (mg/L as $CaCO_3$)	Hard-ness, total (mg/L as $CaCO_3$)	Solids residue at 180 °C, dis-solved (mg/L)
Duval County--Continued																		
D-3835	U	08-16-89	--	550	--	--	--	--	--	--	--	--	17	110	--	--	--	--
D-592	L	10-27-88	25.9	585	7.64	--	23	71	25	10	1.6	2,800	11	160	.60	131	280	389
D-3834	U	08-16-89	26.3	880	7.39	--	28	78	32	46	2.0	2,200	130	110	.70	153	330	542
D-656	U	08-16-89	26.1	565	--	--	--	--	--	--	--	--	19	120	--	--	--	--
D-336	B	04-18-88	27.5	485	7.68	--	26	54	21	11	1.5	1,400	9.2	84	.70	143**	220	315
D-360	U	10-25-88	27.0	1,310	7.49	.999	28	96	41	100	2.3	2,600	250	150	.60	151	410	761
D-396	U	05-23-88	25.0	519	--	--	--	--	--	--	--	--	17	100	--	--	--	--
D-278	U	12-11-91	--	591	--	--	--	--	--	--	--	--	33	110	--	--	--	--
D-74	B	07-12-88	27.7	640	--	--	--	--	--	--	--	--	50	100	--	--	--	--
D-488	U	05-25-88	25.0	525	7.62	--	28	56	23	15	1.7	1,400	23	86	.70	157	240	349
D-2571	U	07-12-88	24.5	505	--	--	--	--	--	--	--	--	17	84	--	--	--	--
D-464	U	04-21-88	25.1	565	7.86	--	25	61	28	11	1.7	1,500	17	140	.70	137	270	417
D-1902	B	07-12-88	26.8	910	7.73	--	29	76	32	51	2.0	1,700	120	120	.70	158	320	584
D-1370	U	08-16-89	23.8	505	7.61	--	29	55	23	14	1.5	1,200	19	85	.70	159	230	329
D-470	U	09-19-88	22.5	535	--	--	--	--	--	--	--	--	18	90	--	--	--	--
D-151	U	05-25-88	24.0	545	7.58	--	24	63	23	12	1.7	1,800	14	120	.70	145	250	383
D-1289	U	08-28-89	23.8	505	--	--	--	--	--	--	--	--	20	82	--	--	--	--
D-3743	U	07-12-88	23.0	505	--	--	--	--	--	--	--	--	20	80	--	--	--	--
D-348[e]	U	05-10-90	22.7	387	--	--	--	48	15	6.0	.90	--	9.0	42	.30	225**	--	241
D-3838	U	02-28-90	--	534	--	--	--	--	--	--	--	--	28	78	--	--	--	--
D-2088	B	08-28-89	26.9	905	7.61	.999	30	77	34	53	2.1	1,500	120	120	.80	155	330	551
D-1908	B	08-28-89	26.6	875	7.55	--	30	76	33	51	2.0	1,500	120	120	.80	159	330	541
D-1290	U	07-12-88	23.5	505	7.64	--	29	52	23	13	1.8	870	18	78	.90	163	230	328
D-3390	U	06-21-88	23.2	490	7.58	--	25	46	26	15	1.9	1,100	10	47	.70	198	220	294
D-2567	U	08-28-89	24.3	575	--	--	--	--	--	--	--	--	36	90	--	--	--	--
D-270	U	05-25-88	24.0	510	7.62	--	29	53	23	14	1.6	920	19	80	.60	163	230	341
D-228	U	04-20-88	22.3	510	--	--	--	--	--	--	--	--	25	--	--	--	--	--
D-1149	B	04-20-88	22.5	495	--	--	--	--	--	--	--	--	20	--	--	--	--	--
D-914	U	02-28-90	--	700	--	--	--	--	--	--	--	--	67	100	--	--	--	--
D-1150	B	04-20-88	24.5	550	8.06	.999	31	59	25	17	1.6	820	32	82	.60	164	250	373
D-1151	B	04-20-88	24.2	500	--	--	--	--	--	--	--	--	20	--	--	--	--	--
D-227	B	05-25-88	27.0	495	7.64	--	31	52	22	14	1.6	540	18	70	.50	166	220	318
D-1152	B	04-20-88	24.9	510	--	--	--	--	--	--	--	--	23	--	--	--	--	--
D-916	U	07-27-90	24.0	776	--	--	--	--	--	--	--	--	89	120	--	--	--	--
D-920	U	07-27-90	23.5	660	--	--	--	--	--	--	--	--	62	100	--	--	--	--
D-3842	U	04-19-90	--	555	--	--	--	--	--	--	--	--	31	99	--	--	--	--
D-917	U	07-27-90	24.5	774	--	--	--	--	--	--	--	--	89	120	--	--	--	--

Local well number	Aqui-fer	Date	Water temper-ature (°C)	Spe-cific con-duct-ance (μS/cm)	pH (stand-ard units)	Density (g/ml) at 20 °C)	Silica, dis-solved (mg/L as SiO_2)	Cal-cium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	So-dium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Stron-tium, dis-solved (μg/L as Sr)	Chlo-ride, dis-solved (mg/L) as Cl)	Sul-fate, dis-solved (mg/L as SO_4)	Fluo-ride, dis-solved (mg/L as F)	Alka-linity (mg/L as $CaCO_3$)	Hard-ness, total (mg/L as $CaCO_3$)	Solids residue at 180 °C, dis-solved (mg/L)
Duval County--Continued																		
D-625	U	02-28-90	--	990	--	--	--	--	--	--	--	--	130	130	--	--	--	--
D-915	U	07-27-90	26.0	948	--	--	--	--	--	--	--	--	130	150	--	--	--	--
D-2379	U	02-28-90	--	800	--	--	--	--	--	--	--	--	86	130	--	--	--	--
D-3066	U	12-13-91	--	687	--	--	--	--	--	--	--	--	66	--	--	--	--	--
D-164	U	07-06-88	28.8	1,390	7.45	.999	30	90	50	100	3.2	1,600	210	170	.80	152	430	861
Do.		07-27-90	28.5	1,400	--	--	--	--	--	--	--	--	290	180	--	--	--	--
D-329	B	10-26-88	26.2	510	7.84	--	31	55	23	14	1.5	570	19	71	.60	168	230	324
D-3065	U	12-13-91	--	619	--	--	--	--	--	--	--	--	44	92	--	--	--	--
D-924	U	07-27-90	28.5	1,440	--	--	--	--	--	--	--	--	280	180	--	--	--	--
D-2158	U	07-27-90	28.5	1,360	--	--	--	--	--	--	--	--	260	180	--	--	--	--
D-1661	U	06-16-88	23.2	625	7.66	.999	31	57	28	25	2.0	590	44	100	.50	162	260	444
D-923	U	07-27-90	29.0	1,480	--	--	--	--	--	--	--	--	300	180	--	--	--	--
D-1070	U	07-27-90	28.0	1,150	--	--	--	--	--	--	--	--	190	160	--	--	--	--
D-913	U	02-28-90	--	1,710	--	--	--	--	--	--	--	--	310	180	--	--	--	--
D-69	B	01-22-90	--	596	--	--	--	--	--	--	--	--	34	100	--	--	--	--
D-2551	U	04-19-90	--	483	--	--	--	--	--	--	--	--	22	65	--	--	--	--
D-262	L	09-19-89	25.0	638	--	--	--	--	--	--	--	--	50	100	--	--	--	--
D-264	U	09-19-89	24.0	500	--	--	--	--	--	--	--	--	19	74	--	--	--	--
D-912	U	02-28-90	--	490	--	--	--	--	--	--	--	--	29	60	--	--	--	--
D-941	U	07-27-90	23.0	626	--	--	--	--	--	--	--	--	50	100	--	--	--	--
D-305	U	05-25-88	24.0	500	--	--	--	--	--	--	--	--	18	68	--	--	--	--
D-163	U	04-19-90	--	474	--	--	--	--	--	--	--	--	20	64	--	--	--	--
D-533	B	01-22-90	--	599	--	--	--	--	--	--	--	--	34	110	--	--	--	--
D-1068	U	06-21-88	22.0	550	7.40	--	31	58	25	15	1.6	340	23	94	.60	164	250	370
D-395	U	06-16-88	23.4	485	7.57	--	30	47	23	15	1.9	400	20	67	.50	164	210	334
D-1078	U	06-22-88	23.0	530	7.59	--	30	54	25	14	1.6	430	21	87	.60	163	240	366
D-3836	U	08-16-89	25.0	520	7.86	--	28	50	24	15	1.6	410	21	71	.70	164	220	326
D-1362	U	06-22-88	23.0	520	7.63	--	30	52	25	14	1.4	340	21	86	.60	160	230	353
D-1410	U	06-22-88	22.9	555	7.63	--	31	58	26	15	1.6	350	23	100	.60	162	250	373
D-3829 e/	U	12-08-89	--	--	--	--	--	--	--	--	--	--	25	100	--	--	--	--
D-401	B	06-21-88	26.0	585	7.54	.999	30	57	29	15	1.6	510	23	120	.60	156	260	391
D-411	U	06-22-88	21.5	560	7.92	--	30	58	28	15	1.8	480	23	110	.60	158	260	382
St. Johns County																		
SJ-104 e/	U	12-15-86	24.0	1,550	7.7	--	--	150	107	285	8.8	--	505	380	.50	154	--	--
SJ-160	U	05-16-88	23.2	7,980	7.53	1.002	24	220	180	1,100	30	6,500	2,200	520	.90	132	1,300	4,650
SJ-158	U*	05-09-88	23.6	2,670	7.50	1.000	15	190	120	240	6.3	7,700	560	630	.30	97	980	2,040
SJ-157	U	05-09-88	24.5	7,540	--	--	--	--	--	--	--	--	1,800	810	--	--	--	--
SJ-165	U	10-14-88	22.9	2,750	7.35	1.000	18	170	110	250	9.1	6,600	550	590	.90	119	890	1,800

Local well number	Aqui-fer	Date	Water temper-ature (°C)	Spe-cific con-duct-ance (μS/cm)	pH (stand-ard units)	Density (g/ml) at 20 °C)	Silica, dis-solved (mg/L as SiO_2)	Cal-cium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	So-dium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Stron-tium, dis-solved (μg/L as Sr)	Chlo-ride, dis-solved (mg/L) as Cl)	Sul-fate, dis-solved (mg/L as SO_4)	Fluo-ride, dis-solved (mg/L as F)	Alka-linity (mg/L as $CaCO_3$)	Hard-ness, total (mg/L as $CaCO_3$)	Solids residue at 180 °C, dis-solved (mg/L)
St. Johns County--Continued																		
SJ-159	U	05-09-88	21.4	2,450	7.47	--	16	190	110	160	5.9	8,000	350	730	.50	94	940	1,790
SJ-164	U	10-14-88	24.0	7,680	7.45	1.002	19	260	170	1,100	35	9,600	1,900	890	1.0	127	1,400	4,960
SJ-94	U	05-18-88	22.0	12,200	7.39	1.004	20	300	250	2,000	60	9,500	3,600	820	.90	136	1,800	7,620
SJ-156	U	05-09-88	22.7	2,180	7.45	1.000	18	190	100	120	6.6	8,200	230	720	.60	108	900	1,620
SJ-167	U*	10-14-88	24.8	1,680	7.90	--	26	94	52	160	7.8	4,200	330	220	.80	160	450	1,020
SJ-97	U	05-18-88	24.0	3,850	7.48	1.000	24	140	80	480	16	5,800	920	370	.90	143	690	2,330
SJ-155	U	05-09-88	27.0	6,720	7.46	1.003	16	380	180	700	20	15,000	1,300	1,300	.80	94	1,700	4,380
SJ-154	U*	05-09-88	26.4	2,850	7.39	--	--	--	--	--	--	--	230	1,100	--	--	--	--
SJ-80	U*	05-18-88	24.0	2,220	7.65	1.000	15	220	120	72	4.9	9,600	130	940	.40	85	1,100	1,730
SJ-118	U*	05-18-88	25.0	1,690	--	--	--	--	--	--	--	--	160	660	--	--	--	--
SJ-92	U	05-16-88	22.2	1,990	8.05	.999	18	110	70	140	6.6	5,200	300	390	1.0	93	570	1,220
SJ-153	U	05-09-88	23.7	1,560	--	--	--	--	--	--	--	--	--	720	--	--	--	--
SJ-90	U	05-18-88	25.4	1,250	--	--	--	--	--	--	--	--	140	300	--	--	--	--
SJ-112E	U	10-12-88	23.2	1,550	7.54	.999	23	100	54	140	6.5	5,100	260	290	.80	136	480	991
SJ-161	U	05-18-88	29.3	2,100	7.29	--	21	210	85	55	3.7	11,000	130	730	1.0	120	890	1,450
SJ-91	U	05-16-88	22.6	1,030	7.54	.999	24	90	55	45	4.2	4,400	91	300	1.0	137	460	764
SJ-19	U	05-18-88	22.1	855	7.85	.999	18	87	46	17	3.2	4,700	19	320	.50	115	410	642
SJ-89	U	05-16-88	22.7	1,040	7.53	.999	24	85	50	50	9.4	4,200	88	270	.90	140	420	717
SJ-119	U*	05-19-88	23.3	930	7.53	.999	18	100	52	14	3.1	5,400	17	380	.60	105	470	715
SJ-3	U	05-19-88	29.5	1,290	7.39	.999	18	180	68	12	3.1	7,800	16	640	.60	94	740	1,090
SJ-88	U	05-23-88	23.9	965	7.51	--	27	74	36	64	3.4	2,900	120	170	1.0	153	340	691
SJ-99	U	05-24-88	25.0	915	--	--	--	--	--	--	--	--	110	150	--	--	--	--
SJ-24	U*	05-18-88	24.6	740	7.59	.999	17	75	40	12	2.8	4,000	14	250	.60	103	--	521
SJ-12	U	05-19-88	23.4	210	8.09	.998	12	18	10	5.5	1.6	800	4.8	15	.50	81	87	114
SJ-168	U	08-23-89	28.8	1,230	7.49	.999	19	170	60	15	3.0	7,800	34	540	.90	109	680	999
SJ-26	U	05-19-88	23.3	860	7.56	.999	20	95	46	14	2.9	5,200	18	310	.70	121	430	651
SJ-163 e/	U	07-30-87	--	--	--	--	--	95	25	21	5.4	3,100	21	220	.90	103	--	--
SJ-8	U	05-24-88	23.0	750	--	--	--	--	--	--	--	--	19	200	--	--	--	--
SJ-27	U	09-21-88	23.0	765	--	--	--	--	--	--	--	--	18	290	--	--	--	--
SJ-15	U	09-21-88	23.0	382	--	--	--	--	--	--	--	--	11	73	--	--	--	--
SJ-5	U	05-23-88	23.0	600	7.71	.999	21	49	28	26	3.5	2,400	16	150	1.0	128	240	395
SJ-55	U*	05-23-88	23.3	620	7.62	.999	23	58	32	17	2.8	2,400	20	160	.80	136	280	429
SJ-10	U	05-24-88	23.0	576	--	--	--	--	--	--	--	--	17	160	--	--	--	--
SJ-150 a/	F	04-21-88	--	47,000	7.32	1.022	17	800	1,000	9,400	320	1,300	15,400	2,500	1.2	113**	--	--
Do[f]		05-21-90	29.8	44,000	--	--	--	--	1,300	9,800	370	--	16,800	2,700	.60	125**	--	31,200

Local well number	Aquifer	Date	Water temperature (°C)	Specific conductance (µS/cm)	pH (standard units)	Density (g/ml) at 20 °C)	Silica, dissolved (mg/L as SiO_2)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Strontium, dissolved (µg/L as Sr)	Chloride, dissolved (mg/L) as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Alkalinity (mg/L as $CaCO_3$)	Hardness, total (mg/L as $CaCO_3$)	Solids residue at 180 °C, dissolved (mg/L)
SJ-63	U*	05-24-88	23.0	682	--	--	--	--	--	--	--	--	21	170	--	--	--	--
SJ-122	U	05-23-88	23.7	610	--	--	--	--	--	--	--	--	24	140	--	--	--	--
SJ-162	U	05-23-88	24.5	630	7.64	1.000	26	62	30	18	2.2	2,500	28	140	.80	151	280	433
SJ-103	U	09-18-89	25.5	660	--	--	--	--	--	--	--	--	32	140	--	--	--	--
SJ-60	U	05-24-88	22.0	592	--	--	--	--	--	--	--	--	13	160	--	--	--	--
SJ-152	U*	12-04-89	--	1,040	7.52	--	27	88	42	66	3.0	3,000	150	170	.70	153	400	692
SJ-47	U	05-23-88	29.2	1,010	7.43	.999	28	80	38	55	2.7	2,800	140	160	.70	146	360	630
Northeastern Clay County																		
-- [g]	U	10-30-89	24.9	288	7.77	--	13	29	15	4.6	1.5	1,200	5.8	54	.40	82**	140	181
C-30	U	05-24-88	22.0	185	--	--	--	--	--	--	--	--	4.8	11	--	--	--	--
C-16	U	05-27-88	21.0	168	--	--	--	--	--	--	--	--	4.8	5.0	--	--	--	--
C-22	U	05-24-88	23.0	180	--	--	--	--	--	--	--	--	4.8	7.5	--	--	--	--
C-7	U	05-24-88	23.0	295	--	--	--	--	--	--	--	--	7.0	49	--	--	--	--
C-29	U	05-25-88	21.5	234	--	--	--	--	--	--	--	--	4.6	10	--	--	--	--
C-4	U	05-24-88	29.5	405	--	--	--	--	--	--	--	--	6.1	110	--	--	--	--

a/ Deep monitoring well tapping Fernandina permeable zone.

b/ Point-sample--2,050 feet. Data from St. Johns River Water Management District.

c/ Point-sample--2,100 feet. Data from St. Johns River Water Management District.

d/ Point sample--2,000 feet. Data from St. Johns River Water Management District.

e/ Data from St. Johns River Water Management.

f/ Point-sample--2,022 feet. Data from St. Johns River Water Management District.

g/ Spring.

Appendix II

Appendix II. Records of wells completed in the Floridan aquifer system in Nassau, Duval, St. Johns, and northeastern Clay Counties (well locations shown in figs. 20-22)

[U, Upper Floridan aquifer well; L, upper zone of Lower Floridan aquifer well; B, well tapping both the Upper Floridan and the upper zone of the Lower Floridan aquifer; F, Fernandina permeable zone well; *, may tap the upper zone of the Lower Floridan aquifer; --, no data]

Site identification number	Local well number	Aquifer	Altitude of land surface (feet)	Depth of well (feet)	Bottom of casing (feet)
Nassau County					
303340081500001	N-51	U	19	580	--
303403081311301	N-100	U	12	800	--
303417081342201	N-118	U	10	800	--
303435081271401	N-46	U	15	1,016	492
303518081275001	N-3	U	16	540	--
303634081303201	N-124	U	10	740	480
303658081422601	N-50	U	18	569	--
303739081272701	N-126	U	12	671	566
303754081361301	N-125	U	35	630	510
303819081455701	N-98	U	10	480	--
303840081273501	N-58	U	18	1,000	546
303935081283701	N-35	U	6	1,062	560
304001081280301	N-117	F	5	2,102	2,000
304002081381201	N-53	U	20.22	500	--
304041081270501	N-47	B	26	1,265	555
304057081271001	N-128	U	20	952	550
304116081270901	N-127	U	18	800	584
304118081550301	N-94	U	60	620	310
304150081470301	N-99	U	20	450	--
304317081372301	N-67	U	10	--	--
304640081583801	WN-18	U	20	--	--
Duval County					
300756081335001	D-1440	U	20	500	388
300812081390801	D-1097	U	20	560	440
300820081354001	D-296	U	20	487	--
300824081305401	D-169	U	24	--	--
301032081380401	D-2846	U	15	640	485
301035081330801	D-292	U	25	555	457
301144081413801	D-126	U	16	403	252
301150081411901	D-2863	U	10	514	294
301152081423001	D-2860	U	25	400	--
301157081374301	D-538	B	25	1,000	484
301211081405801	D-3828	U	10	498	298
301255081371001	D-282	U	5	650	--
301305081321901	D-3832	U*	40	1,000	523
301333081324101	D-2847	U*	46	1,000	--
301335081355001	D-536	B	10	1,140	372
301337081354801	D-3823	U	10	750	450
301339081433401	D-1055	U	20	588	492
301339081531203	D-326	U*	80	887	400
301354081420401	D-2870	U	15	400	--
301409081330401	D-3831	U*	55	980	555

Site identification number	Local well number	Aquifer	Altitude of land surface (feet)	Depth of well (feet)	Bottom of casing (feet)
Duval County--Continued					
301415081284801	D-658	U	31	800	--
301450081485001	D-1963	U	20	609	505
301522081331301	D-291	B	60	1,246	535
301537081441901	D-75	L	10	1,295	970
301551081415701	D-129	U	9	600	470
301552081234301	D-2707	U	10	900	400
301604081234601	D-2747	U	10	920	402
301604081361501	D-450	L	22	1,297	1,100
301607081301001	D-991	U	40	885	404
301620081234201	D-3034	U	20	900	400
301639081330802	D-1155	L	50	1,170	1,080
301648081431801	D-103	B	15	1,332	535
301657081233301	D-483	B	8	1,220	372
301704081233401	D-484	B	8	1,181	357
301712081233301	D-343	U	7	650	350
301715081300001	D-298	U	40	--	--
301716081234301	D-482	B	11	1,212	375
301725081305002	D-650	B	40	1,267	416
301740081361001	D-275	B	20	1,234	515
301743081303501	D-3825	B	40	1,097	442
301743081304701	D-224	B	40	1,179	423
301743081362301	D-225	B	20	1,277	547
301744081363301	D-2193	B	20	1,301	549
301752081360501	D-649	U*	20	1,005	534
301758081303901	D-665	B	42	1,185	422
301801081384302	D-54A	B	20	1,348	504
301817081374901	D-425T	B	20	1,895	752
301817081374902	D-425B	F	20	2,486	2,055
301839081392101	D-198	B	10	1,297	552
301846081240201	D-246	B	10	1,212	388
301848081344001	D-830	U	28	695	582
301852081234201	D-160	U	12	585	357
301852081240301	D-605	U*	10	1,050	--
301900081342801	D-94	U	24	635	520
301902081394601	D-297	U	20	760	510
301907081420901	D-241	B	17	1,324	594
301913081534601	D-49	U	90	700	466
301926081313701	D-1214	U	40	540	420
301955081280601	D-709	U	21	523	410
301955081485701	D-2069	U	80	609	525
301957081342301	D-313	B	30	1,150	576
302007081353201	D-479	B	44	1,350	606
302008081242101	D-307	B	9	1,300	407
302013081353801	D-673	U	45	814	578
302015081384501	D-335	B	21	1,286	531
302022081393501	D-176	L	3	1,275	800
302032081321001	D-3659	B	40	1,161	700
302037081455301	D-581	U	25	700	500
302045081323101	D-1323	B	40	1,170	580
302052081323201	D-3060	F	28.44	2,112	2,050

Site identification number	Local well number	Aquifer	Altitude of land surface (feet)	Depth of well (feet)	Bottom of casing (feet)
Duval County--Continued					
302112081384701	D-210	U	21	750	535
302113081322301	D-655	U	13	750	--
302120081361801	D-308	B	47	1,105	703
302120081363001	D-309	B	47	1,300	619
302122081274001	D-400	U	10	490	--
302124081344601	D-430	B	36	1,310	610
302130081411802	D-46A	B	30	1,280	530
302137081240001	D-84	U	9.10	575	--
302138081292301	D-3833	U	35	900	419
302142081330701	D-277	U	10	610	522
302150081350601	D-3830	U	41	--	--
302159081235601	D-2386	F	19	2,026	1,892
302216081300301	D-3835	U	55	650	492
302227081435001	D-592	L	10	1,326	1,154
302232081292901	D-3834	U	30	--	--
302235081301001	D-656	U	25	1,016	460
302236081401501	D-336	B	21	1,303	520
302243081300401	D-360	U	45	665	462
302300081295101	D-396	U	20	700	--
302300081303001	D-278	U	39	1,000	462
302313081330901	D-74	B	5	1,328	586
302317081330401	D-488	U	9	755	560
302323081324801	D-2571	U	10	760	555
302339081254702	D-464	U	7	1,000	427
302342081320601	D-1902	B	5	1,209	515
302344081340101	D-1370	U	10	790	680
302345081261301	D-470	U	6	--	--
302351081390201	D-151	U	6	700	560
302357081311101	D-1289	U	5	580	455
302405081314301	D-3743	U	5	--	--
302416081522601	D-348	U	86	708	416
302422081244401	D-3838	U	10	600	370
302423081312701	D-2088	B	10	1,099	458
302426081312801	D-1908	B	10	1,199	460
302428081313101	D-1290	U	10	550	450
302428081493401	D-3390	U	50	504	399
302432081322301	D-2567	U	10	780	485
302502081321001	D-270	U	5	--	--
302502081330701	D-228	U	10	850	--
302503081332001	D-1149	B	10	1,104	520
302505081254301	D-914	U	12	478	416
302505081331001	D-1150	B	10	1,104	520
302511081331201	D-1151	B	10	1,104	520
302514081393701	D-227	B	15	1,296	570
302519081331501	D-1152	B	10	1,104	520
302520081254301	D-916	U	15	632	451
302524081254401	D-920	U	15	598	357
302527081260601	D-3842	U	40	808	462
302529081254001	D-917	U	15	623	455
302531081253901	D-625	U	15	458	384

Site identification number	Local well number	Aquifer	Altitude of land surface (feet)	Depth of well (feet)	Bottom of casing (feet)
Duval County--Continued					
302532081253701	D-915	U	16	555	443
302535081253701	D-2379	U	14	510	448
302536081331301	D-3066	U	10	750	500
302538081253101	D-164	U	15.71	619	448
302538081392501	D-329	B	20	1,209	545
302545081330901	D-3065	U	10	750	500
302548081252801	D-924	U	17	600	457
302549081252501	D-2158	U	6	560	441
302552081243701	D-1661	U	10	531	451
302553081252501	D-923	U	5	577	434
302555081252701	D-1070	U	6	540	451
302557081253101	D-913	U	20	556	435
302607081361601	D-69	B	16	1,373	612
302608081261401	D-2551	U	10	566	462
302608081354901	D-262	L	16	1,237	1,163
302608081354903	D-264	U	16	700	--
302609081260601	D-912	U	11	484	431
302616081253601	D-941	U	20	608	460
302616081413901	D-305	U	28	700	601
302618081261001	D-163	U	12	707	--
302619081361801	D-533	B	19	1,349	620
302647081460201	D-1068	U	20	560	486
302724081244801	D-395	U	8	--	--
302738081290001	D-1078	U	10	--	--
302805081341701	D-3836	U	25	795	504
302919081314601	D-1362	U	20	590	480
303029081342901	D-1410	U	10	710	--
303209081371801	D-3829	U	29.77	850	450
303216081433301	D-401	B	16	1,100	512
303458081364001	D-411	U	5	1,000	--
St. Johns County					
293729081221201	SJ-104	U	37.93	622	142
294008081125201	SJ-160	U	5	300	160
294049081294301	SJ-158	U*	15	--	--
294111081294301	SJ-157	U	14	480	61
294224081195201	SJ-165	U	35	202	172
294325081294101	SJ-159	U	6	200	153
294518081181401	SJ-164	U	28.05	240	205
294602081151901	SJ-94	U	5	210	100
294701081261201	SJ-156	U	33	280	161
294747081230701	SJ-167	U*	41	--	--
294927081192501	SJ-97	U	5	--	--
295028081311401	SJ-155	U	15	345	238
295040081324801	SJ-154	U*	13	--	--
295040081333201	SJ-80	U*	9	--	--
295105081300401	SJ-118	U*	24	--	--
295132081164801	SJ-92	U	10	248	170
295135081303801	SJ-153	U	22	270	213
295333081191401	SJ-90	U	5	253	105

Site identification number	Local well number	Aquifer	Altitude of land surface (feet)	Depth of well (feet)	Bottom of casing (feet)
St. Johns County--Continued					
295341081263705	SJ-112E	U	33	517	204
295427081293101	SJ-161	U	16	464	225
295502081175401	SJ-91	U	5.09	198	--
295556081342101	SJ-19	U	5	300	--
295713081203401	SJ-89	U	10	350	190
295903081334301	SJ-119	U*	15	--	--
300019081363301	SJ-3	U	22	500	--
300036081213501	SJ-88	U	4	350	155
300307081234201	SJ-99	U	27	341	265
300322081342801	SJ-24	U*	26	600	--
300341081395401	SJ-12	U	15	700	--
300347081363701	SJ-168	U	30	630	590
300354081301201	SJ-26	U	25	362	--
300507081272701	SJ-163	U	62	600	350
300555081290601	SJ-8	U	18	336	240
300632081334301	SJ-27	U	19	388	--
300717081381001	SJ-15	U	8	580	--
300758081230501	SJ-5	U	4.53	350	--
301005081225901	SJ-55	U*	4	1,009	--
301037081243901	SJ-10	U	10	405	348
301132081225801	SJ-150	F	5	2,035	1,980
301212081252401	SJ-63	U*	14	1,000	--
301249081225801	SJ-122	U	12	441	335
301259081222901	SJ-162	U	8	880	364
301304081222701	SJ-103	U	5	857	385
301408081253101	SJ-60	U	6	600	--
301410081225401	SJ-152	U*	11	--	--
301411081224201	SJ-47	U	15	600	--
Northeastern Clay County					
295936081404001 [a]	--	U	10	--	--
300048081414301	C-30	U	10	365	300
300300081422501	C-16	U	10	400	--
300604081441501	C-22	U	10	500	440
300834081421301	C-7	U	5	550	--
300850081552001	C-29	U	40	330	300
301018081415101	C-4	U	10	530	--

[a] Spring.

Link to insert.