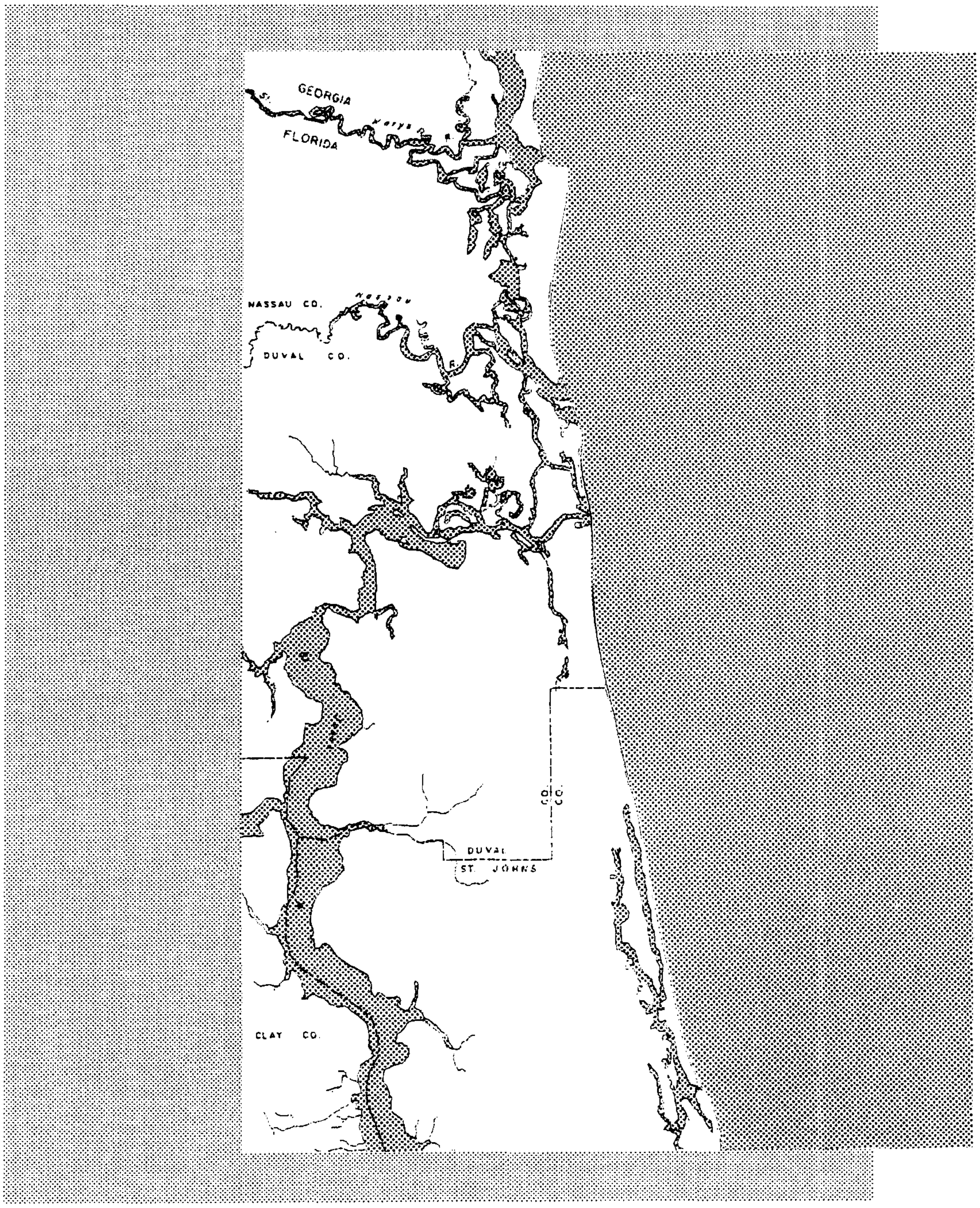
Technical Publication SJ 90-5

Geohydrologic Summary of the Floridan Aquifer in Coastal Areas of Nassau, Duval, and Northeast St. Johns Counties



St. Johns River Water Management District

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GEOHYDROLOGIC SUMMARY OF THE FLORIDAN AQUIFER IN COASTAL AREAS OF NASSAU, DUVAL, AND NORTHERN ST. JOHNS COUNTIES

by

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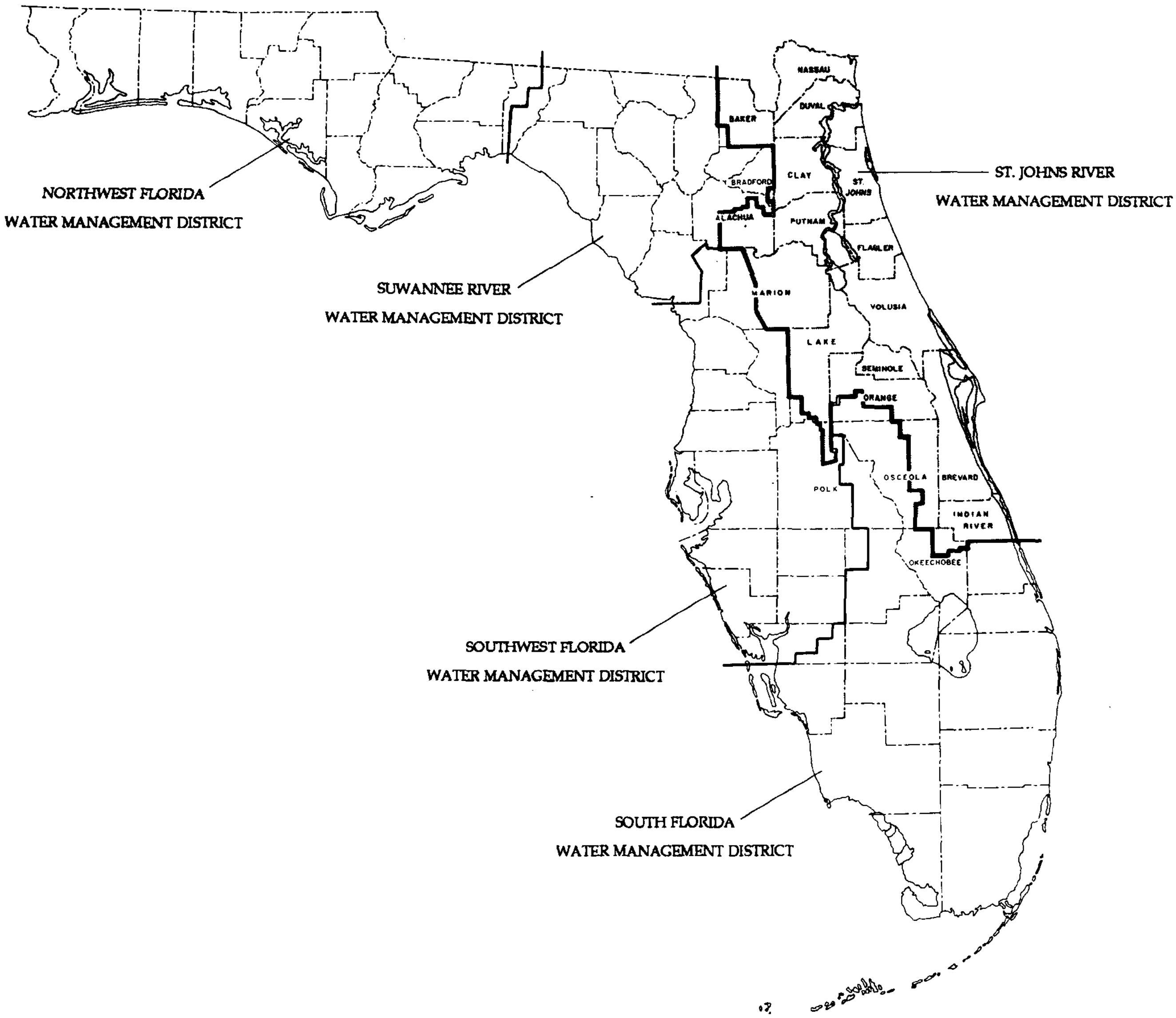
St. Johns River Water Management District
Palatka, Florida

1990



THE ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

The St. Johns River Water Management District (SJRWMD) was created by the Florida Legislature in 1972 to be one of five water management districts in Florida. It includes all or parts of nineteen counties in northeast Florida. The mission of SJRWMD is to manage water resources to insure their continued availability while maximizing environmental and economic benefits. It accomplishes its mission through regulation; applied research; assistance to federal, state, and local governments; operation and maintenance of water control works; and land acquisition and management. Technical reports are published to disseminate information collected by SJRWMD in pursuit of its mission.

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ABSTRACT

The Floridan aquifer is the primary source of water supply in northeast Florida. The effects of increased growth and urbanization along the coast of northeast Florida have raised concerns about the long-term availability of potable ground water supplies. This report presents a preliminary examination of water resource problems, concentrating on the occurrence of saline water in the Floridan aquifer in the coastal areas of Nassau, Duval, and northern St. Johns counties.

Three different water types occur in the study area: low chloride/low sulfate water, which is typical of the background water and occurs in western Nassau and Duval counties; low chloride/high sulfate water, which probably results from mineral dissolution in the aquifer and occurs in southeast Duval and northern St. Johns counties; and high chloride/high sulfate water which occurs along the coast and portions of the St. Johns River. High chloride/high sulfate areas most likely result from the upward movement of high chloride/ high sulfate waters which exist at depth. This high chloride/high sulfate water is under higher artesian pressure than the water above it, thereby providing the potential for upward movement of saline water.

New wellfield development should be avoided in areas where chloride and sulfate concentrations are high because structural weaknesses in confining beds may play a major role in the distribution of high chloride/high sulfate water. These areas occur east of the Intercoastal Waterway along the coast, in a one-mile band on either side of north-south faults mapped by Warren Leve of the U.S. Geological Survey, and in a two-mile band on either side of a line stretching from Fort George Island to the Ortega River in Jacksonville.

INTRODUCTION

The Floridan aquifer is the primary source of water supply in northeast Florida. In coastal portions of Nassau, Duval, and northern St. Johns counties, Floridan aquifer water is withdrawn for public, domestic, industrial, recreational, and irrigation uses. The effects of increased growth and urbanization along the coast of northeast Florida have raised concerns about the long-term availability of potable ground water supplies. Increased ground water withdrawals associated with rapid urbanization can result in undesirable water resource impacts. Because this growth is expected to continue, careful management of existing water supplies is crucial.

This report presents a preliminary examination of water resource problems, concentrating on the occurrence of saline water in the Floridan aquifer in the coastal areas of Nassau, Duval, and northern St. Johns counties (Figure 1). More specifically, the study examined localized occurrences of non-potable water (greater than 250 mg/l of chloride and/or sulfate) in the Floridan aquifer.

PREVIOUS INVESTIGATIONS

The subsurface geology in the study area is described in reports by Vernon (1951), Puri (1957), Puri and Vernon (1964), Chen (1965), Leve (1966, 1968), and Stringfield (1966). Spechler and Hampson (1984) and Bermes et al. (1963) described the ground water resources of St. Johns County. Leve (1966) described the ground water resources of Duval and Nassau counties. Brown (1984) described the ground water resources of eastern Nassau County. The most comprehensive investigation of the ground water resources of coastal northeast Florida was a four-county investigation by Frazee and McClaugherty (1979).

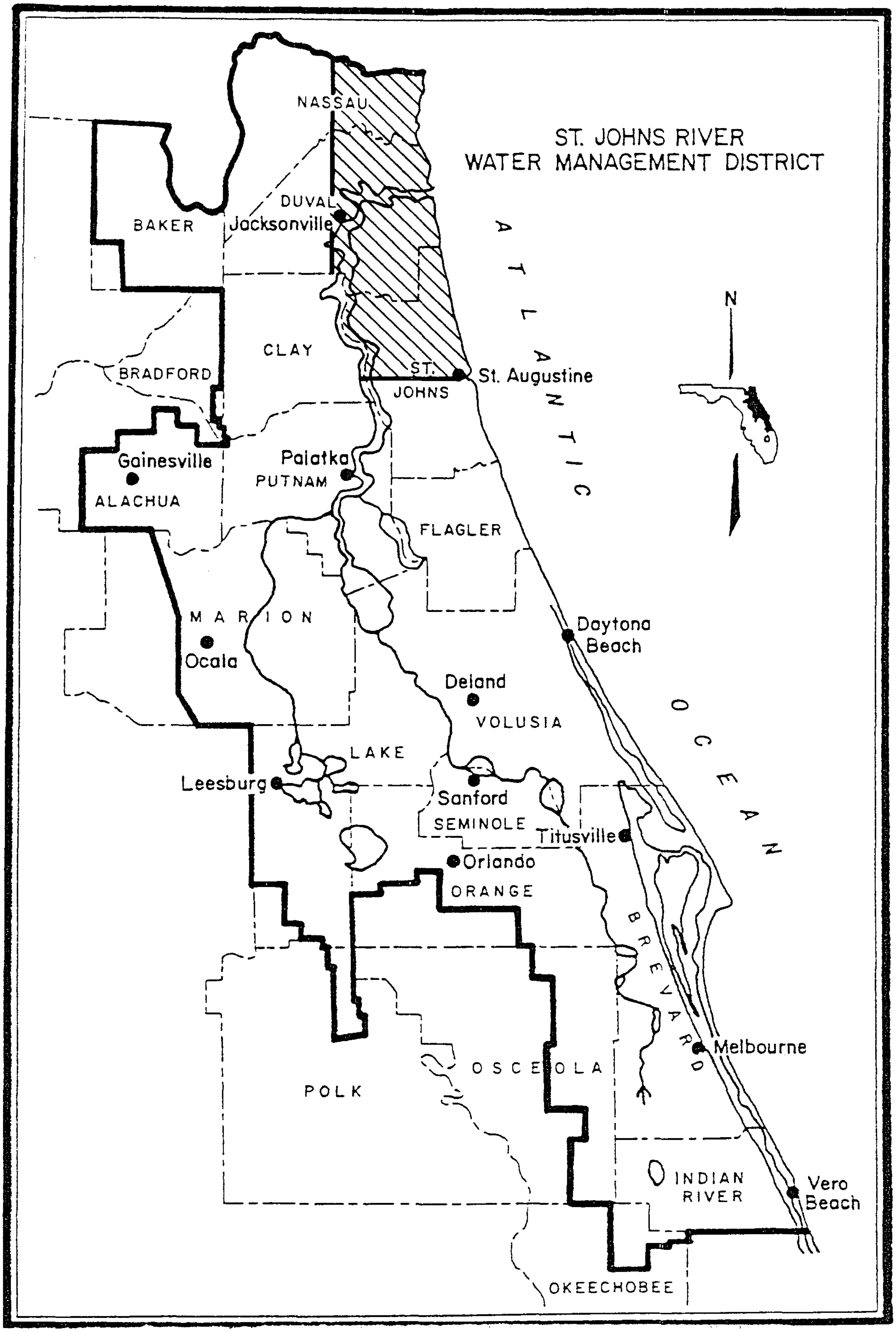


Figure 1. Location of study area within the St. Johns River Water Management District

METHODOLOGY

This investigation relied heavily on previously published data and data collected by local governments in the study area. New geophysical and water quality data were collected to supplement available information using the following methods:

- current and historical ground water data describing well depth, geologic formations penetrated, water quality, and water levels were collected from published sources;
- water quality changes were identified where long-term records were available;
- new wells were inventoried to provide additional water quality coverage;
- depths and thicknesses of various formations, derived from geophysical logs, were plotted by computer to update geologic interpretations and define structural features where possible;
- water quality data were plotted and contoured by computer to identify problem areas; and
- published water use surveys were used to define water use in the area.

DESCRIPTION OF STUDY AREA

The study area is in northeast Florida and includes the coastal areas of Nassau, Duval, and northern St. Johns counties. More specifically, the study area extends from a latitude of 29° 51'N northward to the Florida/Georgia state line and from a longitude of 81° 45'E eastward to the Atlantic Ocean in Duval and Nassau counties and from the St. Johns River to the Atlantic Ocean in St. Johns County (Figure 1). The study area boundaries were defined based on local government interest in the area's ground water resources, projected rapid population growth and the occurrence of potable water in the Floridan aquifer. Immediately south of the study area in southern St. Johns County, water in the Floridan aquifer is non-potable.

In 1980, the population of Nassau County was 32,894; St. Johns County was 51,303; and Duval County was 571,003 (Bureau of Economic and Business Research 1986). The rate of population growth is different in each county. The estimated 1985 population for Nassau County was 39,822; St. Johns County was 68,822; and Duval County was 624,084, (Smith and Sincich 1986). The 1980 population is expected to double by the year 2005 in Nassau County, by 2000 in St. Johns County and by 2020 in Duval County (Smith and Sincich 1988). Approximately

40 percent of the population in Nassau County is located in incorporated areas, generally along the coast. Fernandina Beach is the principal city in this area. Five percent of the population in Duval County is located in the coastal cities of Atlantic Beach, Jacksonville Beach, and Neptune Beach. Jacksonville is the largest metropolitan area in Duval County and had a population of 540,920 in 1980. Nearly 26 percent of the population in St. Johns County is located in incorporated areas along the coast. St. Augustine is the largest metropolitan area in the county and had a population of 11,985 in 1980. Other incorporated coastal communities in St. Johns County are Marineland and St. Augustine Beach.

WATER USE

In 1985 total water use for Nassau, Duval, and St. Johns counties was 46.14, 165.44, and 51.34 million gallons per day (mgd), respectively (Marella 1986). Figure 2 shows 1985 total water use by category for each county.

In Nassau County, 81 percent of total ground water used was withdrawn for industrial supply primarily pulp and paper mills. In Duval County, 51 and 23 percent of total ground water used was withdrawn for public and industrial supply respectively. Water for public and industrial supply in Nassau and Duval counties was withdrawn from the Floridan aquifer.

In St. Johns County, agricultural irrigation comprised about 80 percent of the water use and more than 90 percent of this occurred west of I-95 and south of St. Augustine near Hastings and Elkton. The Floridan aquifer is the source of water used for agricultural irrigation in St. Johns County.

The surficial aquifer system is the major source of public and domestic supply in St. Johns County. However, approximately a third of the water withdrawn for public supply comes from the Floridan aquifer. The Floridan aquifer in the northwestern and southern parts of St. Johns County contains non-potable water.

Between 1980 and 1985, total water use increased by 12 percent in Duval County and 62 percent in St. Johns County. In Nassau County total water use declined about 14 percent during this period due to reduced ground water withdrawals by pulp mills (Figure 3). In the future, total Floridan aquifer water use is expected to increase in each county in response to population growth.

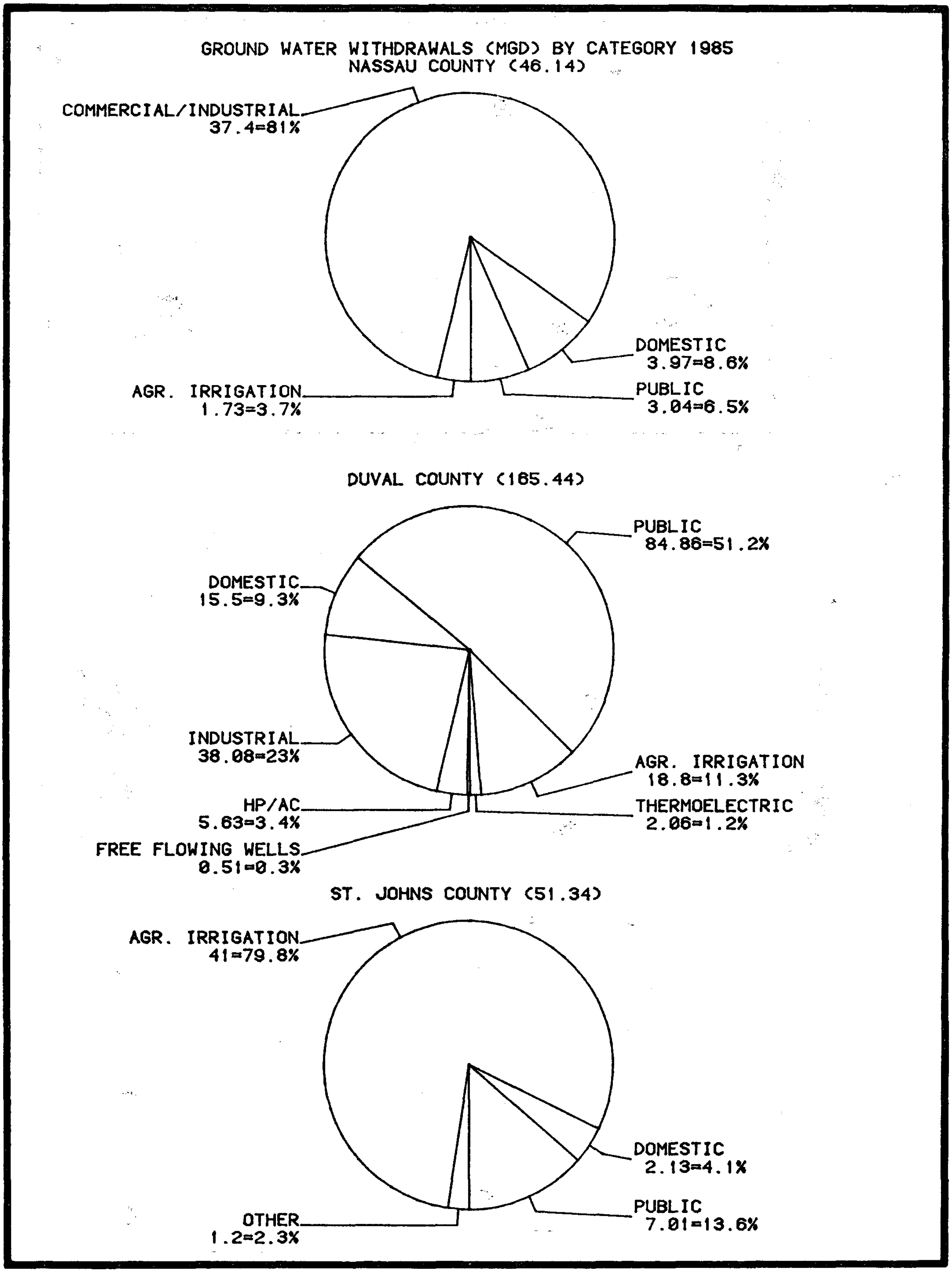


Figure 2. Total ground water use by category for 1985 in Nassau, Duval, and St. Johns counties

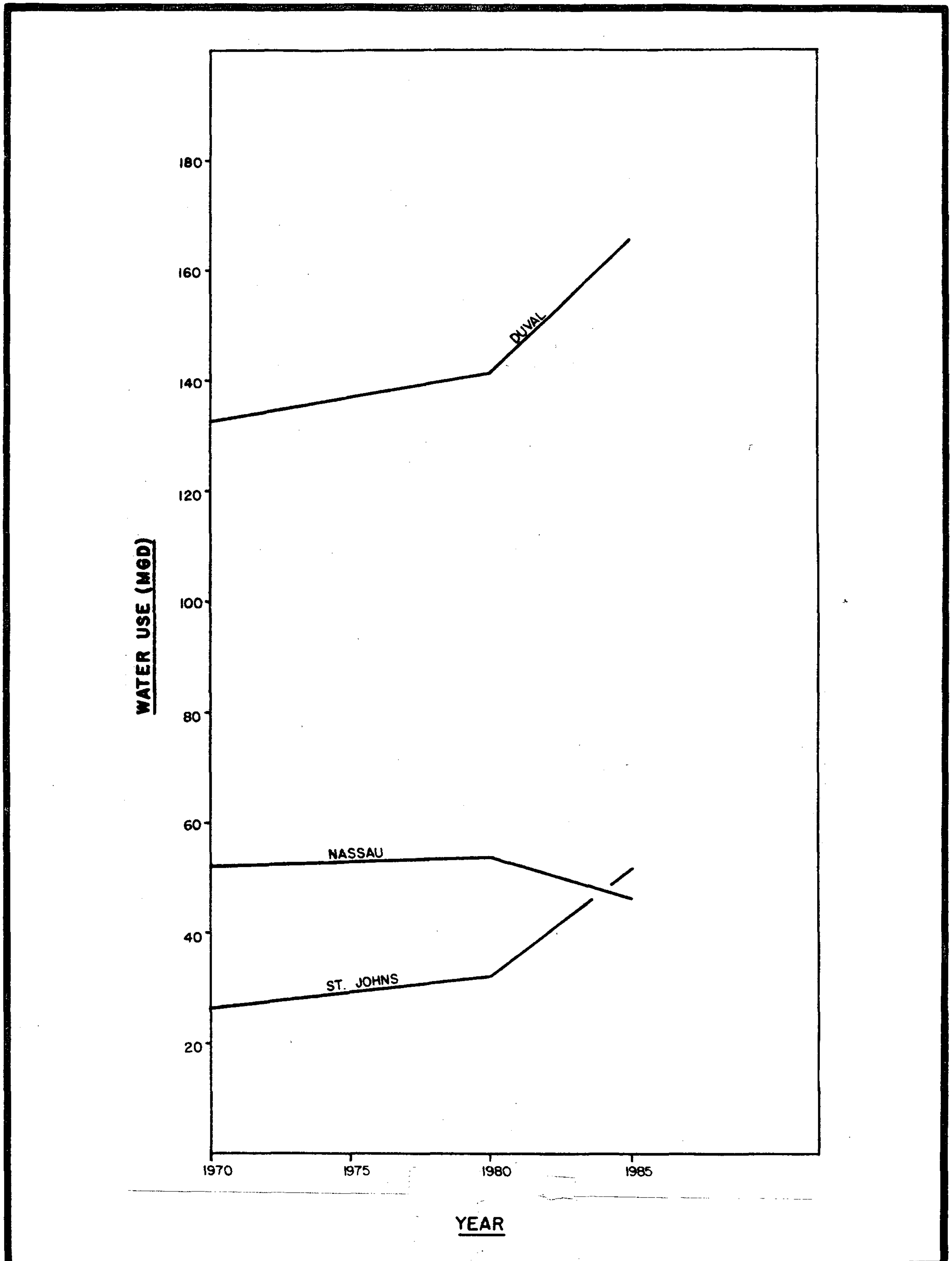


Figure 3. Change in total ground water use between 1970 and 1985 for Nassau, Duval, and St. Johns counties

HYDROGEOLOGIC FRAMEWORK

FLORIDAN AQUIFER

In the study area, the Floridan aquifer consists of alternating beds of porous limestone, massive dolomitic limestone, and dolomite. The Floridan aquifer consists of the Ocala, Avon Park, and Oldsmar limestones (Table 1). These beds dip and thicken to the northeast and are deepest at Fernandina Beach in Nassau County, where the depth to the top of the Ocala, Avon Park, and Oldsmar limestones is near 520, 820, and 1680 ft below msl, respectively (Figure 4). These formations are shallowest at St. Augustine, where the depth to the top of the Ocala Limestone is 180 ft and the top of the Avon Park Limestone is 300 ft below msl. The aquifer is overlain by the Hawthorn Group, which consists of silty clay, clay, and sand beds of Miocene age that range in thickness from 100 ft in St. Johns County to near 500 ft in Nassau County. In the study area, the Hawthorn Group acts as a confining unit for the underlying Floridan aquifer. Figures 5 and 6 show the depth to the top of the Ocala and Avon Park limestones in the study area. Data used to plot these figures were obtained from geophysical logs collected and compiled by the district.

The primary water-bearing zones consist of porous limestone and dolomite. The massive dolomitic limestone and dolomite beds generally yield little or no water and act as confining units (Brown 1984). In northeastern Florida, these relatively impermeable beds restrict the vertical movement of water through the aquifer and separate it into three relatively isolated water-bearing zones (Table 1). The upper water-bearing zone consists of the Ocala Limestone and the upper part of the Avon Park Limestone. It averages 500 ft thick at Fernandina Beach and decreases in thickness to the south. The middle water-bearing zone occurs in the lower part of the Avon Park Limestone and is 500 ft thick at Fernandina Beach. The lower water-bearing zone occurs in the lower part of the Oldsmar Limestone and is 100 ft thick at Fernandina Beach (Brown 1984).

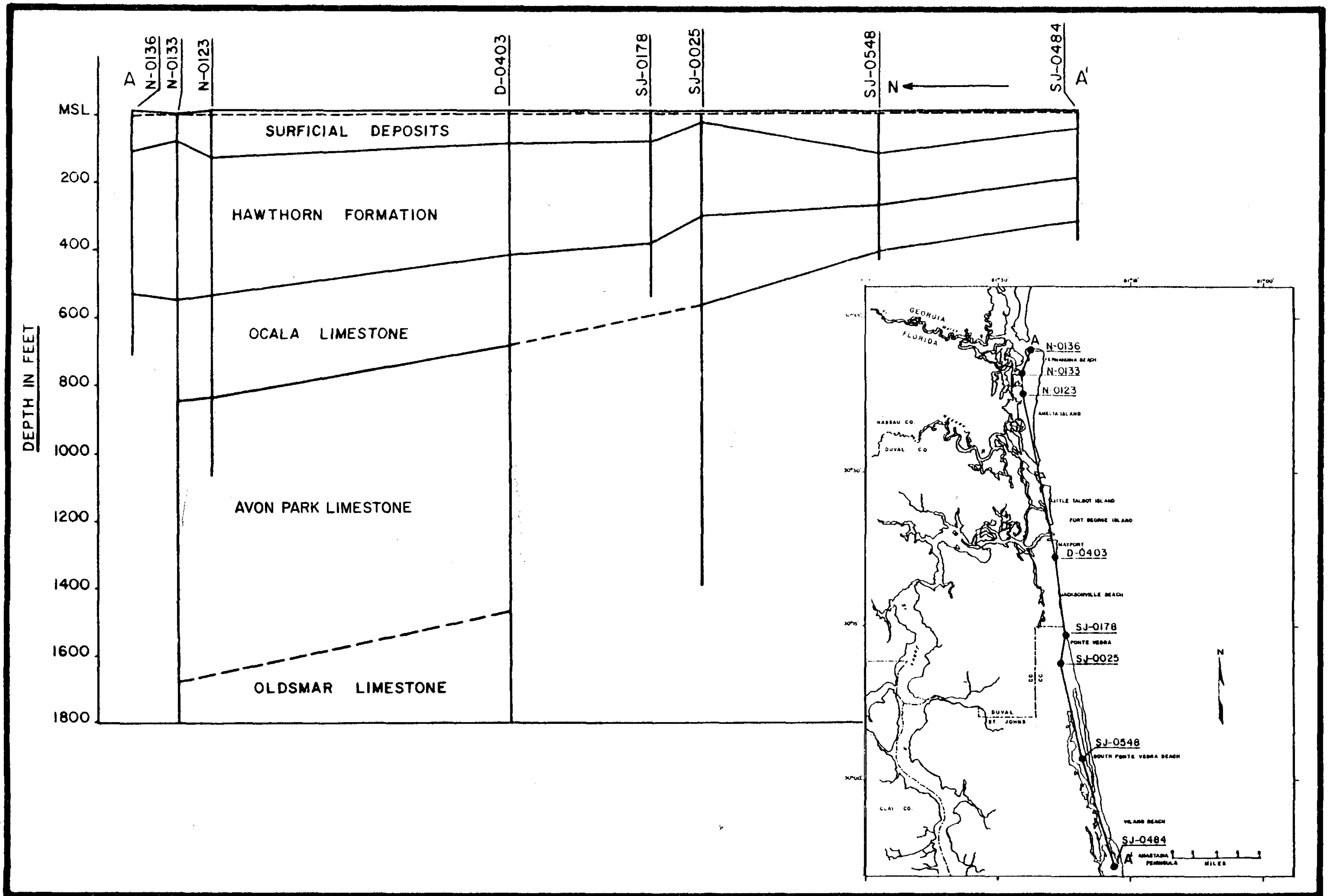


Figure 4. North-south cross section A-A' along the coastal portions of the study area showing regional dip of strata

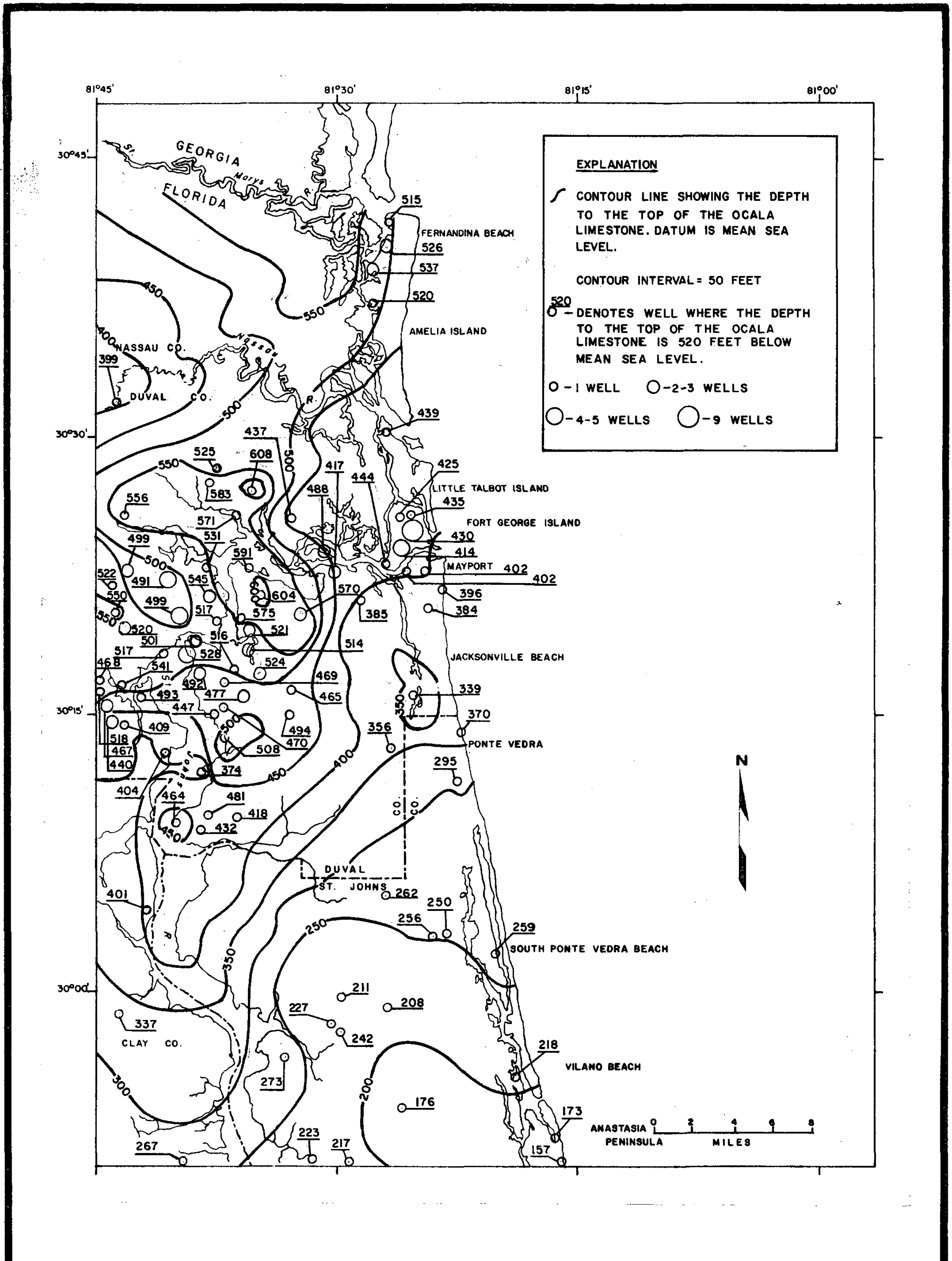


Figure 5. Depth to the top of the Ocala Limestone

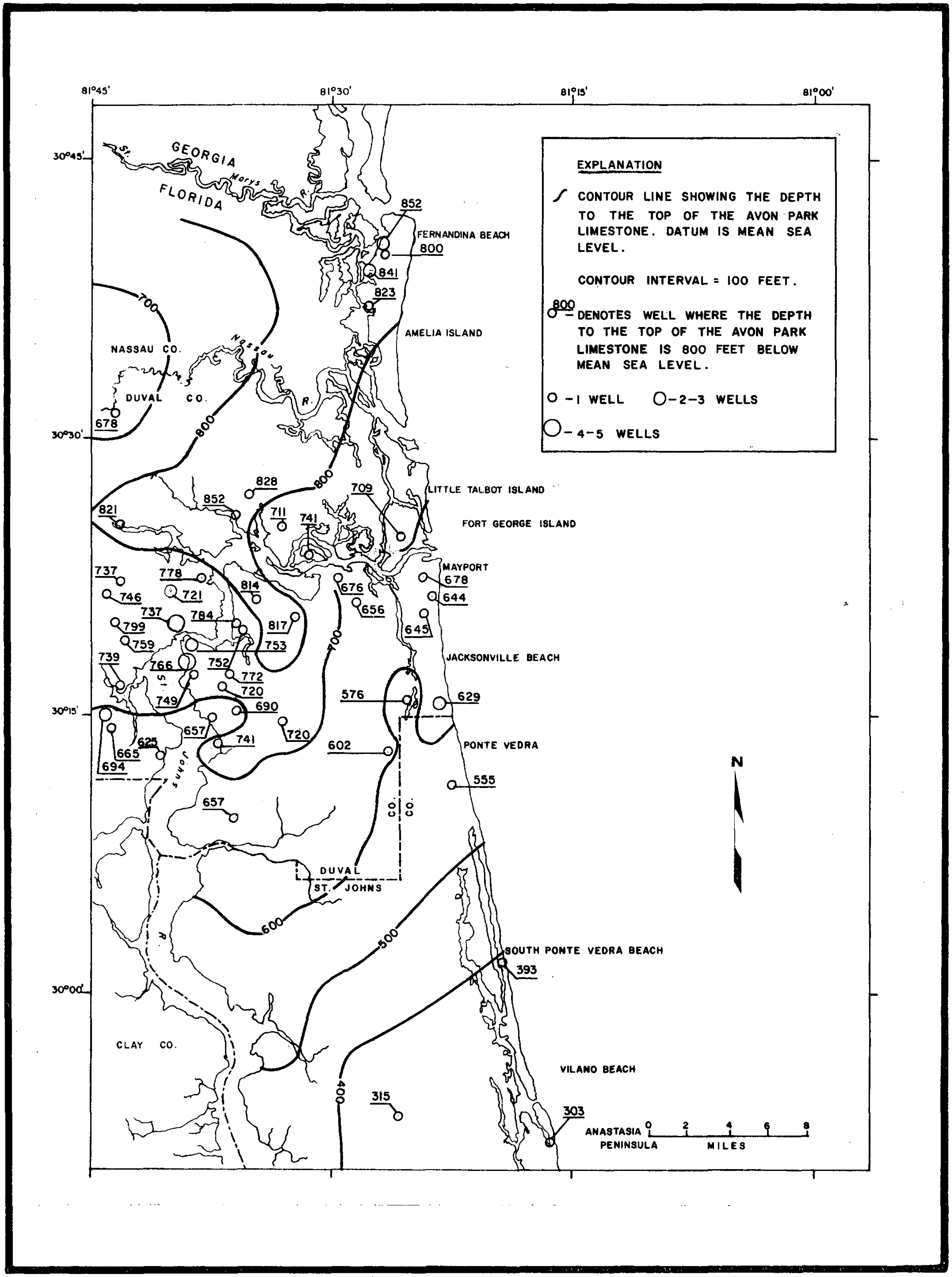


Figure 6. Depth to the top of the Avon Park Limestone

Table 1. Hydrogeologic Framework
(Modified from Brown 1984, p. 15)

HYDROGEOLOGIC UNIT	STRATIGRAPHY		APPROXIMATE THICKNESS (FT)	LITHOLOGY	HYDROLOGIC PROPERTIES
Surficial Aquifer	Surficial Deposits		30 To 140	Discontinuous sand, clay, and shell beds	Sand and shell deposits provide local limited water supplies
Upper Confining Unit	Hawthorn Formation		150 To 500	Interbedded phosphatic sand, clay, marl and limestone	sand, shell, and limestone deposits provide local limited water supplies, both artesian and non-artesian. Low permeability clays serve as the principal confining bed for the Floridan aquifer below.
	Upper Water-Bearing Zone	Ocala Limestone	130 To 350	Massive fossiliferous chalky to granular marine limestone sequence	Principal source of ground water. High permeability overall
	Upper Semiconfining Zone	Avon Park Limestone	60 To 210	Alternating beds of massive granular and chalky limestone, and dense dolomites	Low permeability limestone and dolomite
Floridan Aquifer	Middle Water-Bearing Zone		500 To 750		Principal source of ground water
	Lower Semiconfining Zone	Oldsmar Limestone	700		Low permeability limestone and dolomite
	Lower Water-Bearing Zone				Highly permeable, increases in salinity noted
Lower Confining Unit		Cedar Key Limestone	?	Uppermost appearance of evaporites; dense limestone	Highly mineralized water, very low permeability

GEOLOGIC STRUCTURE

Vernon (1951) mapped numerous fault and joint patterns in the northern portion of the Florida peninsula from surface expressions shown on aerial photographs. Leve (1978) inferred the existence of two concealed faults in the study area from interpretation of geologic descriptions of cores, borings, well cuttings, and geophysical logs. The westernmost fault trends North 10° East and parallels the St. Johns River. The easternmost fault trends North 5° West. Displacement of more than 90 ft occurs along the fault. The faults bound a graben trending north-south. Miller (1982) mapped the location of three faults in the study area (Figure 7). Two of the faults are similar to the faults mapped by Leve (1978). The third fault trends southwest from the westernmost fault of Leve (1978).

AQUIFER TRANSMISSIVITY

Transmissivity is the measure of the rate at which water moves through a unit width of the aquifer under a unit hydraulic gradient. The larger the transmissivity, the faster water moves through the aquifer. Variations in transmissivity occur throughout the Upper Floridan aquifer in the study area. However, quantitative information on transmissivity is sparse. Brown (1984) reviewed the literature and reported transmissivities of about 20,000 to 50,000 ft^2/d for the upper 350 ft of the Floridan aquifer at Fernandina Beach. Franks and Phelps (1979) calculated transmissivities for the upper 700 ft of the Floridan aquifer from more than 20 aquifer tests in Duval County. Their values of transmissivity ranged from 20,000 to 200,000 ft^2/d. Based on considerations of anisotropy, well penetration, and details of the individual pumping tests, they reported an average transmissivity of 80,000 ft^2/d for the upper 700 ft of the Floridan aquifer in Duval County. Bentley (1977) determined transmissivity values of 1,600; 6,800; and 54,000 ft^2/d for three wells penetrating 10, 40, and 325 ft of the Floridan aquifer in northern St. Johns County. The first two calculated transmissivities referenced above are probably low because the pumping wells only penetrated a small portion of the Floridan aquifer (Table 1). Transmissivities generally increase with increases in the thickness of the aquifer penetrated (Bentley 1977).

POTENTIOMETRIC SURFACE

The potentiometric surface is the level to which water will rise in tightly cased wells that penetrate the aquifer. The regional configuration of the potentiometric surface of the upper 500 ft of the Floridan aquifer is shown in Figure 8. The arrows in Figure 8 show

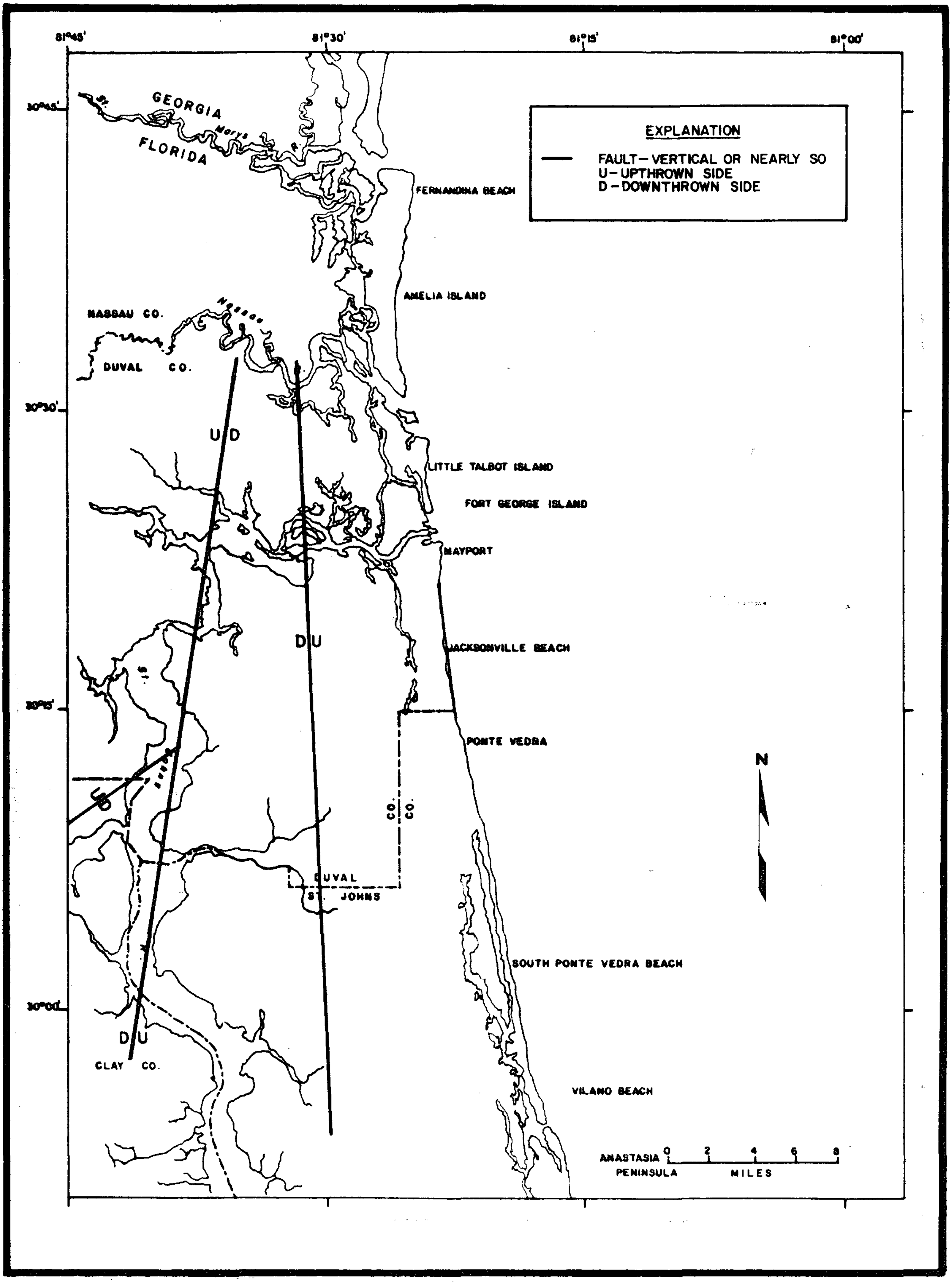


Figure 7. Location of concealed faults in the study area from Miller (1982)

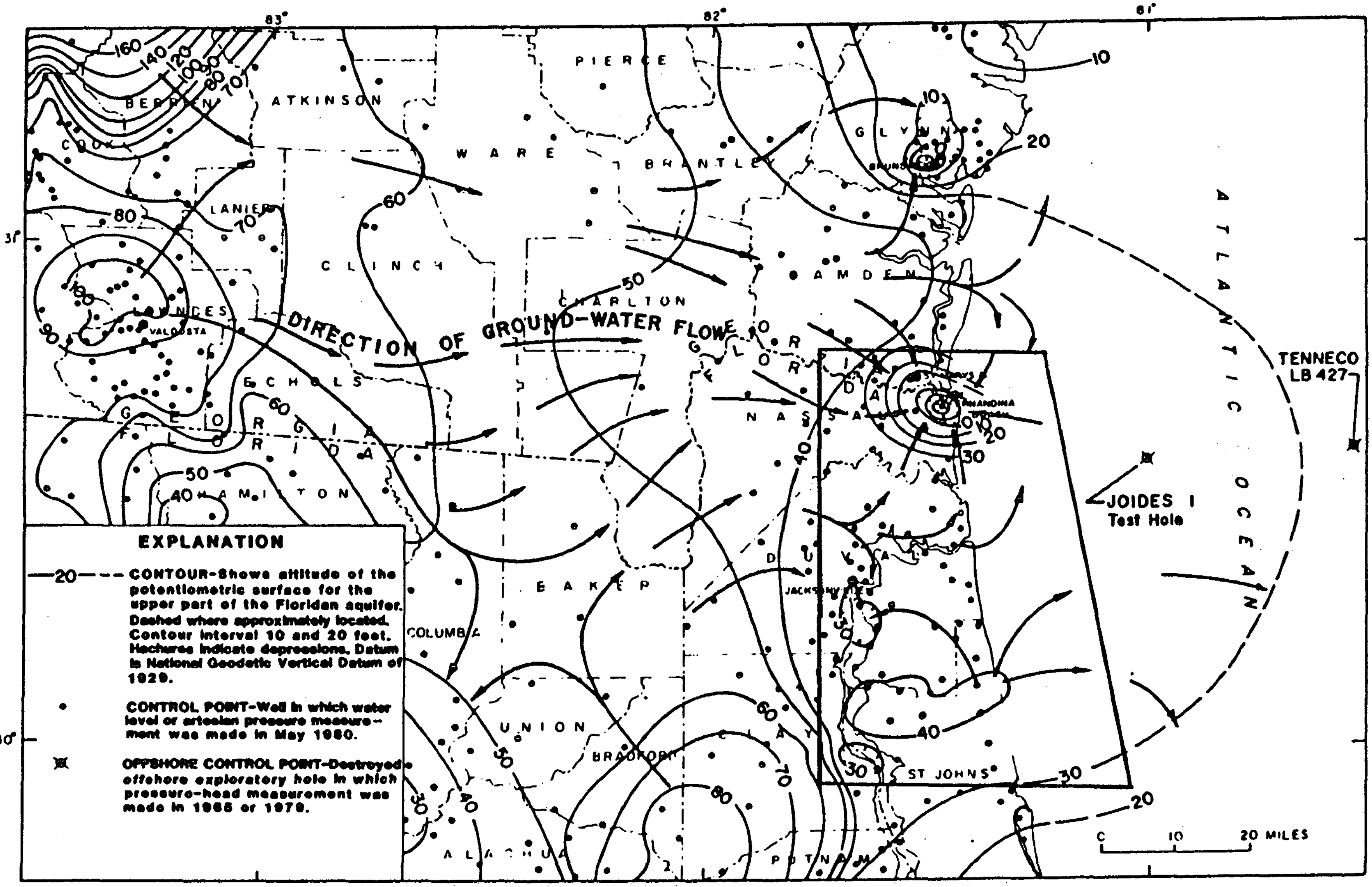


Figure 8. Potentiometric surface of the upper 500 ft of the Floridan aquifer and direction of ground water flow in May 1980 (as reported by Brown 1984). Study area enclosed by box.

the direction of ground water flow in the Floridan aquifer. Ground water flows from areas of high to low potentiometric pressure at right angles to the potentiometric contours. Most of the study area receives ground water flow from the area near Keystone Heights in Clay County. Much of Nassau County receives ground water flow from the potentiometric high centered near Valdosta, Georgia.

The highest potentiometric levels in Figure 8 coincide with areas of greatest potential natural recharge to the Floridan aquifer (Phelps 1984). In these areas, the aquifer is at or near land surface and/or the confining beds overlying the aquifer are thin, absent, or breached. In addition, the water levels in the aquifers in these areas display a net downward gradient. That is, water levels in the surficial aquifer are higher than in the Floridan aquifer.

Recharge occurs wherever the water table is at an elevation above the potentiometric surface of the aquifer. The rate of recharge is dependent upon the difference in water levels between the Floridan and surficial aquifers and the confining characteristics of clays overlying the Floridan aquifer. In the study area, the Hawthorn Group acts as the confining unit for the Floridan aquifer and ranges in thickness from 100 to 500 ft.

In the study area, the potentiometric surface in May 1980 ranged from above 40 ft above msl in the western part to below sea level at Fernandina Beach (Figure 8). Potentiometric elevations of about 30 ft above msl extend more than 50 miles offshore (Johnston et al. 1980).

Depressions in the potentiometric surface shown in Figure 9 generally indicate areas of ground water withdrawal from the Floridan aquifer (Phelps 1984). Such depressions occur at Fernandina Beach in Nassau County, Palm Valley in St. Johns County, and near the San Jose area of Jacksonville in Duval County. Also shown is a depression near Green Cove Springs in Clay County. The marked depression at Fernandina Beach is due to large ground water withdrawals by pulp and paper mills in the area. In May 1977, a period-of-record low water level of 136 ft below msl was observed in this area. The depression near Green Cove Springs is due to natural discharge from springs. The remaining depressions are caused by ground water withdrawals for golf course irrigation and public supply.

When the potentiometric surface is above land surface elevation, wells will flow freely at land surface unless the wells are valved or capped. In the study area, Floridan aquifer wells will generally flow at land surface except in the relatively high topographic areas and near the cone of depression in the potentiometric surface at Fernandina Beach.

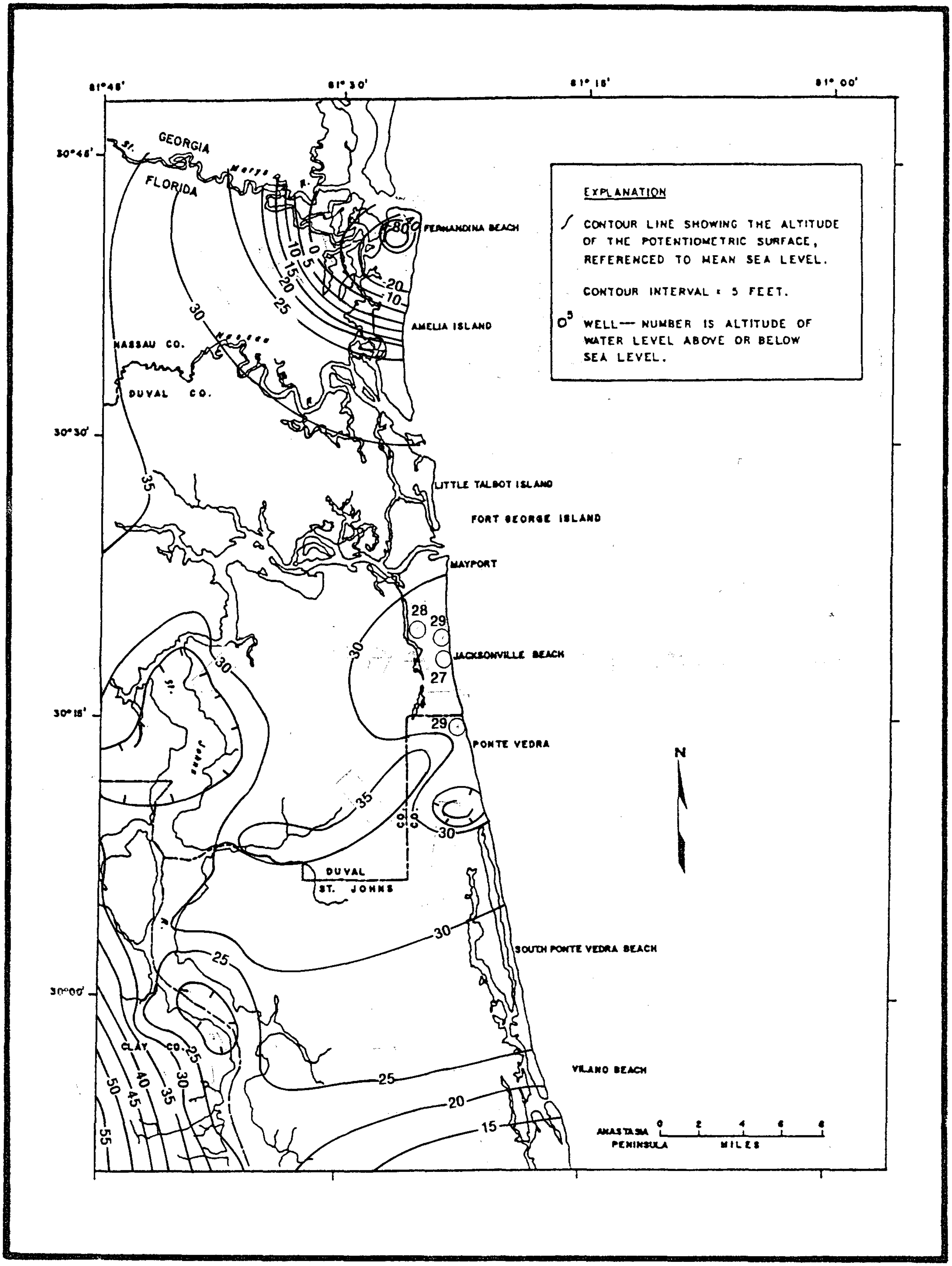


Figure 9. Potentiometric surface of the upper 500 ft of the Floridan aquifer, May 1981 (from Schiner and Hayes 1981).

Seasonal Fluctuations

Seasonal fluctuations of the potentiometric surface occur in response to changes in recharge and discharge. Seasonal and annual fluctuations (1977-1984) for eight selected wells in the study area (Figure 10) are shown in Figure 11. The wells are either located near the coast or along the St. Johns River. The hydrographs reflect typical fluctuations in water levels for each area. Seasonal water level fluctuations are evident in the data, but no net decline is apparent. The relatively low water levels in 1977 and 1981 correspond to periods of below normal rainfall and increased ground water withdrawals. Annual fluctuations of water levels range from less than 4 ft in areas distant from the center of pumpage at Fernandina Beach (N-0002) to more than 40 ft near the center of pumpage (N-0003). The hydrograph for well N-0003, located at Ft. Clinch State Park in Fernandina Beach, shows high frequency water level fluctuations with rapid changes of approximately 30 ft. These fluctuations correlate with the fluctuations in ground water withdrawals for pulp and paper processing. The highest water levels generally occur at the end of every calendar year coinciding with pulp and paper mill shutdowns during the holiday season.

Water levels on the hydrographs shown in Figure 11 range from 15.8 ft above to 34.0 ft below msl in Nassau County, from 42.2 to 24.0 ft above msl in Duval County, and from 41.5 to 17.5 ft above msl in St. Johns County. Annual fluctuations in water levels can be more than 40 ft in Nassau County as stated earlier. In Duval and St. Johns counties, annual fluctuations in water levels have been as high as 10.6 and 11.5 ft respectively.

Long-Term Trends

The estimated potentiometric surface of the Floridan aquifer prior to 1880 (earliest published potentiometric surface records) ranged from about 60-65 ft above msl in the northern part of the study area and 35-40 ft above msl in the southern part (Figure 12). The potentiometric surface in the northern part of the study area declined about 25-30 ft between 1880 and 1980. At Fernandina Beach, the potentiometric surface has declined more than 100 ft as a result of pumpage associated with pulp and paper mill activity. In the southern part of the study area, the potentiometric surface has declined less than 10 ft since 1880.

Potentiometric Surface Relationships

In the study area potentiometric levels generally increase with depth below land surface and are usually 2-4 ft higher in the lower part of the Avon Park Limestone than in the Ocala Limestone. During the construction of a deep monitor well at Hanna Park on the coast in Duval County, water levels measured in the drill stem during drilling operations were 31.0 ft above msl at 600 ft below land surface and increased to 34.3 ft above msl at 975 ft below land

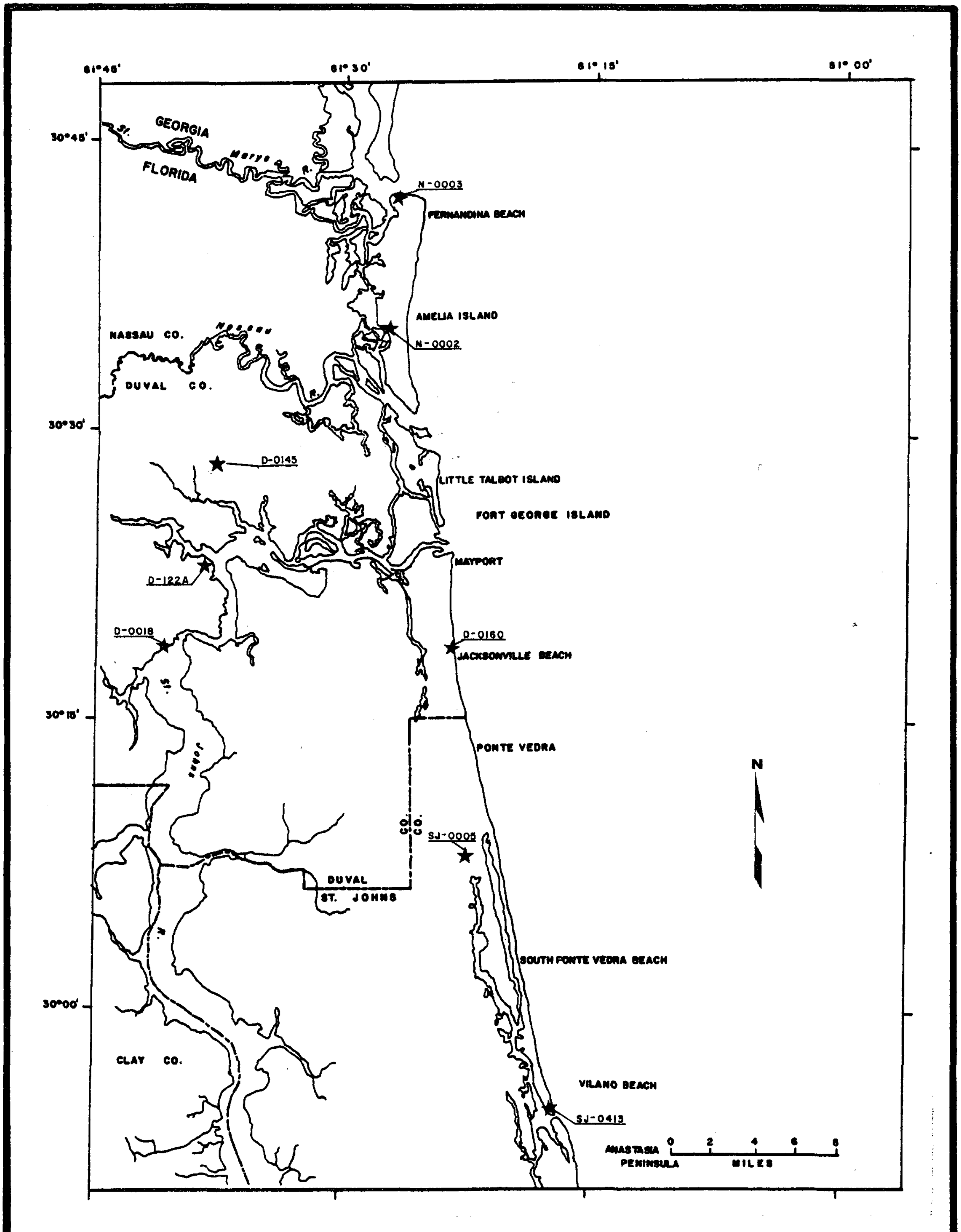


Figure 10. Location of eight selected wells for the hydrographs in Figure 11

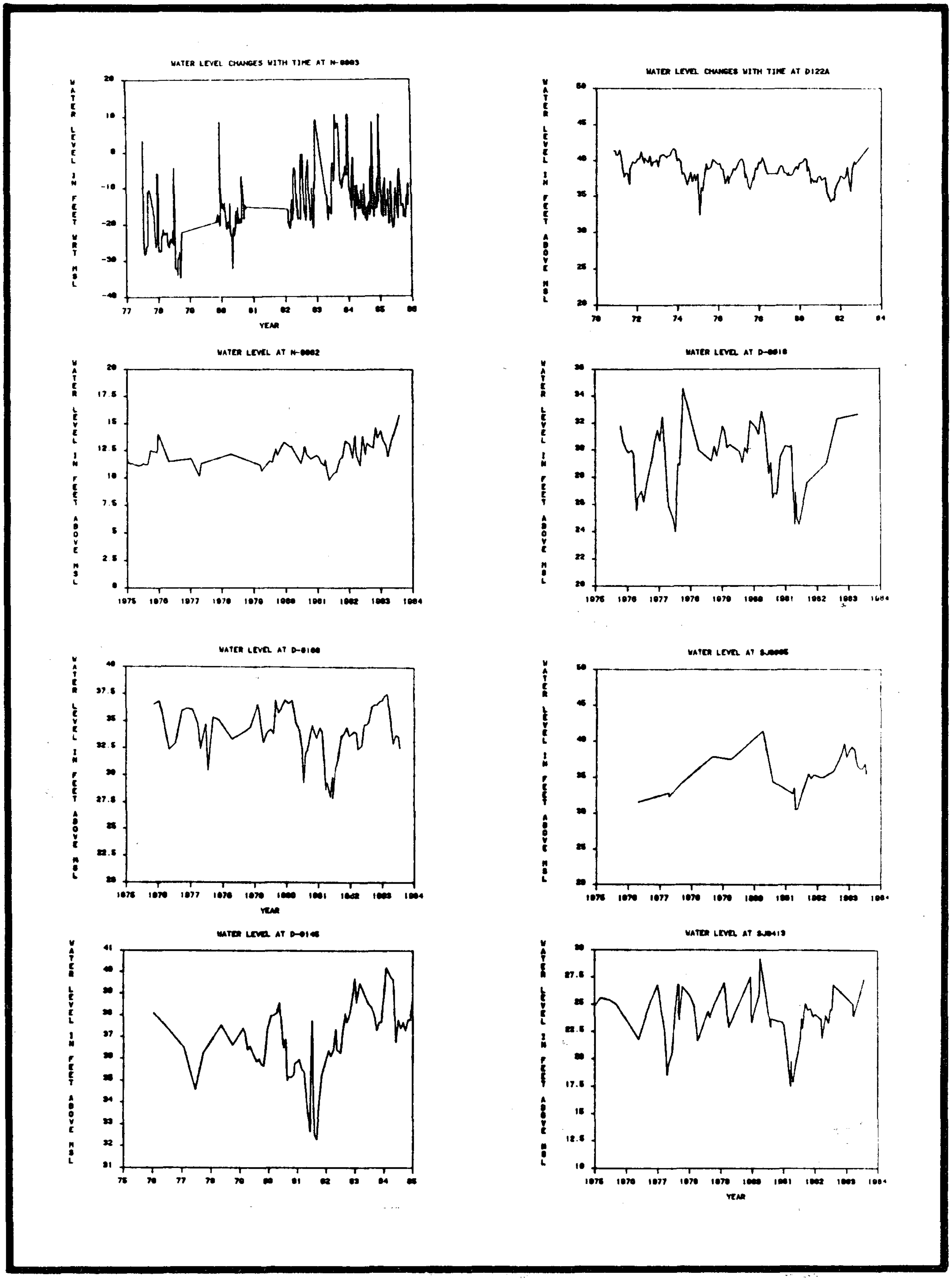


Figure 11. Hydrographs showing seasonal fluctuations in water levels for eight wells in the study area. Well locations are shown in Figure 10.

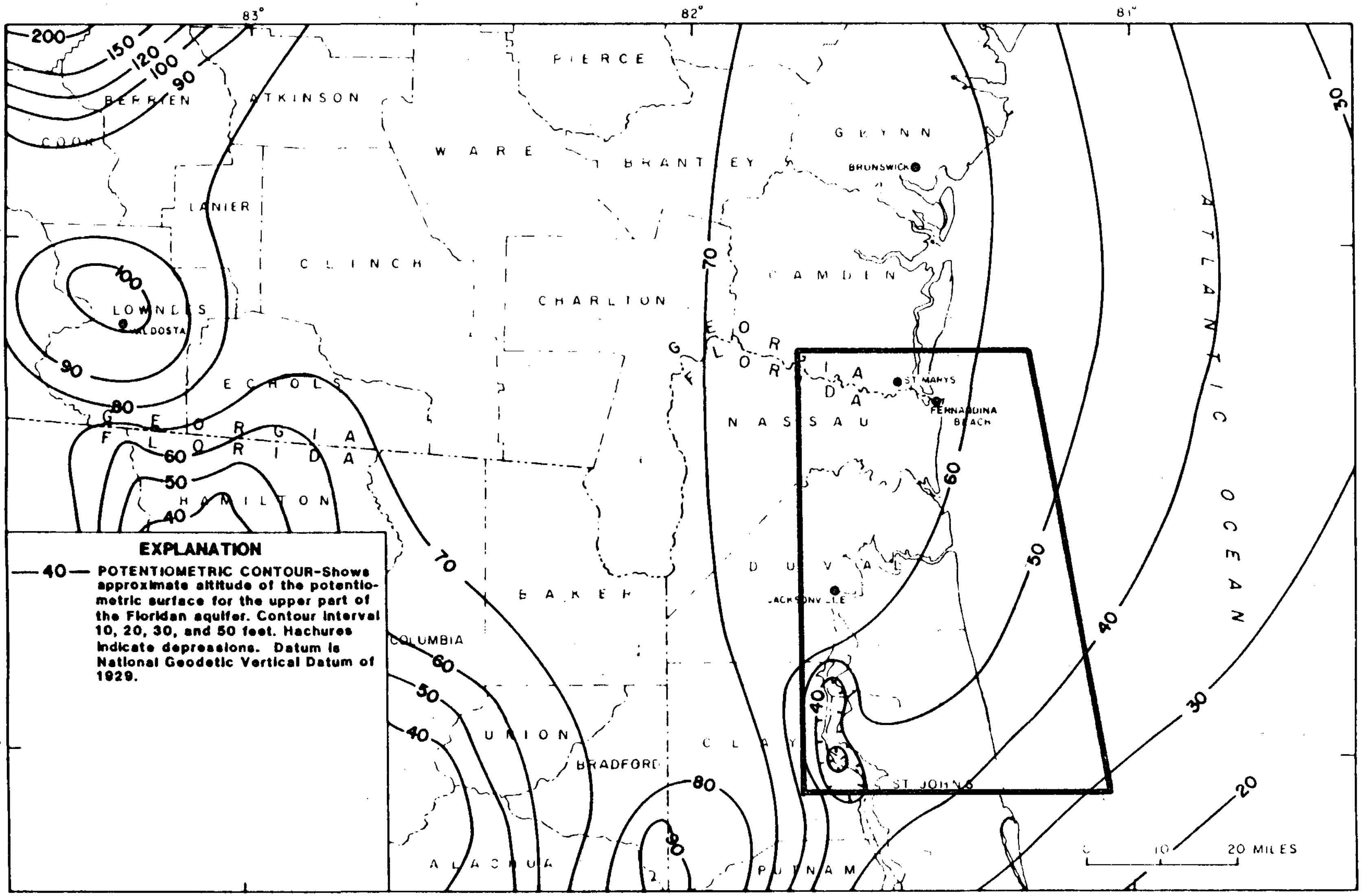


Figure 12. Estimated potentiometric surface of the upper 500 ft of the Floridan aquifer, prior to development, as reported by Brown et al. (1986). Study area is enclosed by box.

surface (Brown et al. 1984). During the construction of similar wells in the Arlington area of Duval County and the Ponte Vedra area of northeast St. Johns County, drill stem water levels were 31.6 ft above msl at a depth of 770 ft below land surface and increased to 34 ft above msl at 1,306 ft below land surface in the Arlington area (Brown et al. 1985). Water levels were 31.0 ft above msl at 548 ft below land surface and increased to 40.0 ft above msl at 1,790 ft below land surface in the Ponte Vedra area (Brown et al. 1986).

In Nassau County, Brown (1984) recognized three major water-bearing zones: upper and middle water-bearing zones at 530-1,000 ft and 1,200-1,700 ft below land surface respectively, and a lower water-bearing zone at 2,000-2,100 ft below land surface. He found that water levels in the middle water-bearing zone at Fernandina Beach were at least 30 ft higher than in the upper water-bearing zone, and that water from the middle zone flowed up the well bore into the upper water-bearing zone. He concluded that the water level in the middle water-bearing zone was probably at or somewhat above mean sea level in the Fernandina Beach area, and he estimated levels to range from 40 to 50 ft above msl elsewhere in his study area. He also concluded that the water level in the lower water-bearing zone must be more than 52 ft above msl.

WATER QUALITY

Ground water contains dissolved minerals that vary in quality and concentration. The mineral content of ground water depends on the quality of water that enters an aquifer as recharge, the solubility and composition of soil and rock material through which the water has passed, and the length of time water is in contact with each material. In coastal areas, salts may also be derived from laterally intruded seawater. In inland areas, the composition of ground water may change due to the mixing of waters of different chemical compositions at depth, where ground water is more mineralized and exists under higher artesian pressure. Wells in the study area contain tens to hundreds of feet of open hole and penetrate several water-producing zones. Hence, water quality is a composite of all producing zones penetrated.

In the study area, the variations in water quality can be sufficiently described by two chemical constituents, chloride and sulfate. Chloride is a conservative ion that does not enter into any chemical reactions. It can be derived from several sources including recharging rainwater, solution of minerals containing chloride, and seawater intrusion. However, increases in chloride usually reflect the latter or a mixing with more saline waters entrapped in limestone formations during Pleistocene time (Stringfield 1966).

Sulfate is derived from the weathering of iron sulfides, solution of sulfur minerals such as gypsum, and/or connate water and seawater.

The U. S. Environmental Protection Agency (EPA) recommends a maximum chloride and sulfate concentration of 250 mg/l for public drinking water. Chloride in concentrations of 300 mg/l or more in combination with sodium gives a salty taste to water and increases the corrosiveness of water. High sulfate concentrations may cause severe scaling problems in pipes and boilers. In drinking water, high sulfate concentrations may produce undesirable laxative effects.

Chloride Concentration

Chloride concentrations in the Floridan aquifer in the study area are generally less than 50 mg/l. Figure 13 (a-f) shows chloride concentrations in water from Floridan aquifer wells in the study area for six different time periods: (a) 1960-1969; (b) 1970-1973; (c) 1974-1975; (d) 1976-1977; (e) 1978-1979; (f) post 1979. In each of these figures, wells are grouped on the basis of chloride concentration. Most of the wells sampled had a depth less than 1500 ft below land surface. Only eight wells had depths greater than 1500 ft. Their depths ranged between 1690 and 2230 ft below land surface. Because the number of wells sampled and the frequency of sampling varied throughout the period of available data, the data are best used to indicate general water quality conditions and should not be used as the sole basis for defining water quality trends. However, chloride concentrations above 50 mg/l have occurred throughout the period of available data in coastal areas and along the St. Johns River.

Areas where chloride concentrations were greater than 50 mg/l between 1960 and 1984 occur along the coast and near the north-south trending faults described by Leve in 1978 and Miller in 1980 (Figure 14). The occurrence of high chlorides concentrated along these faults suggests that these faults may be the mechanism for upward movement of more mineralized water from deeper zones within the Floridan aquifer. Areas of high chloride concentration also lie along a northeast-southwest trending line from Fort George Island to the Ortega River in Jacksonville. This line may define a fracture or zone of weakness within the Floridan aquifer system. Adequate data are not available to verify this.

Sulfate Concentration

Sulfate concentrations in the Floridan aquifer in the study area are generally less than 150 mg/l. Figures 15a and 15b show sulfate concentrations in water from Floridan aquifer wells in the study area for two different time periods: (a) 1975-1979 and (b) 1980-1984. The number of wells sampled and the frequency of sampling varied throughout the period. Most of the wells sampled had depths less than 1500 ft. Only six wells had depths greater than 1500 ft. Their depths ranged between 1690 and 2230 ft below land surface. Areas where sulfate concentrations are greater than 150 mg/l occur at

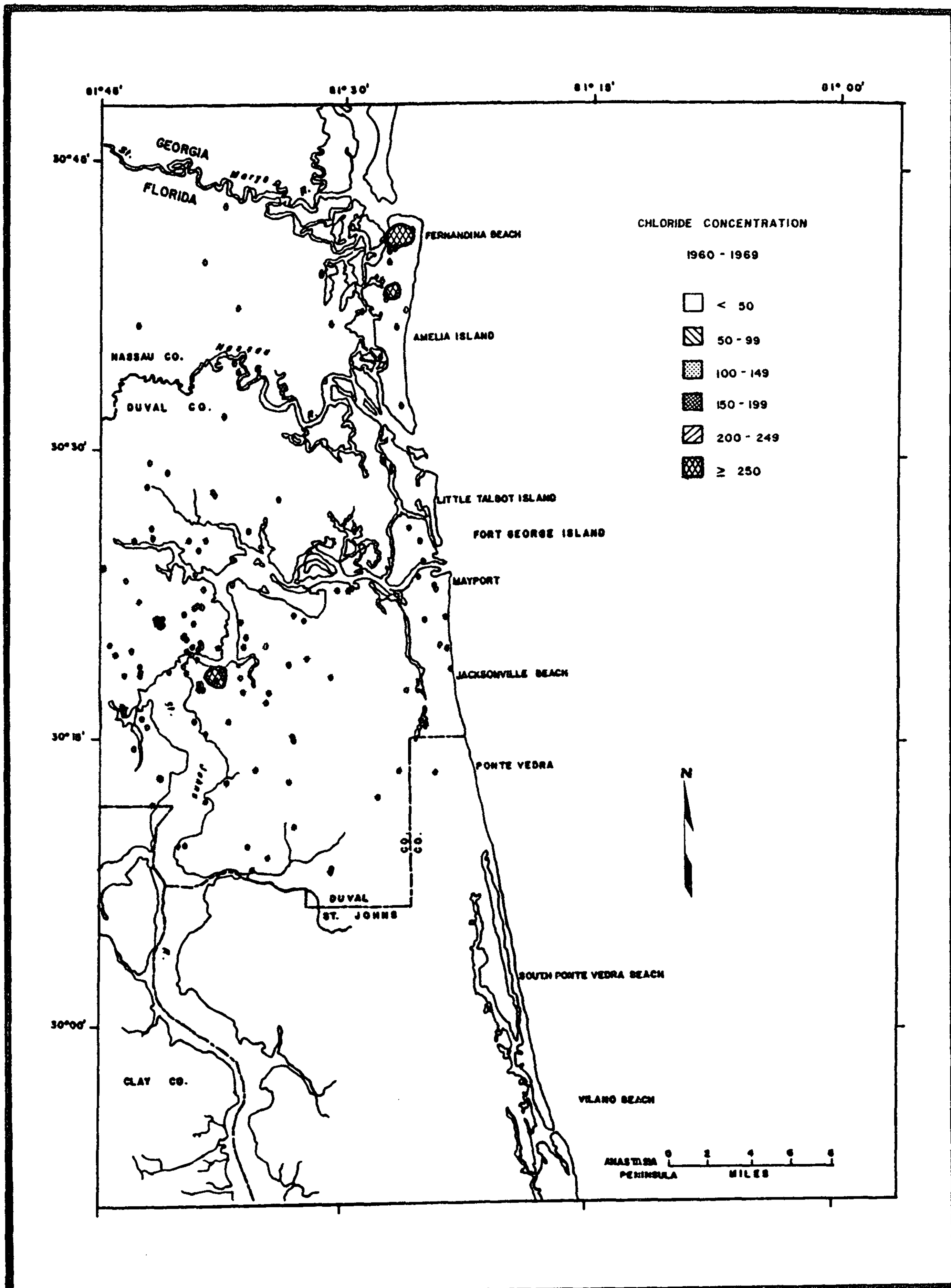


Figure 13a. Chloride concentration (in mg/l) in water from the Floridan aquifer for samples collected between 1960 and 1969

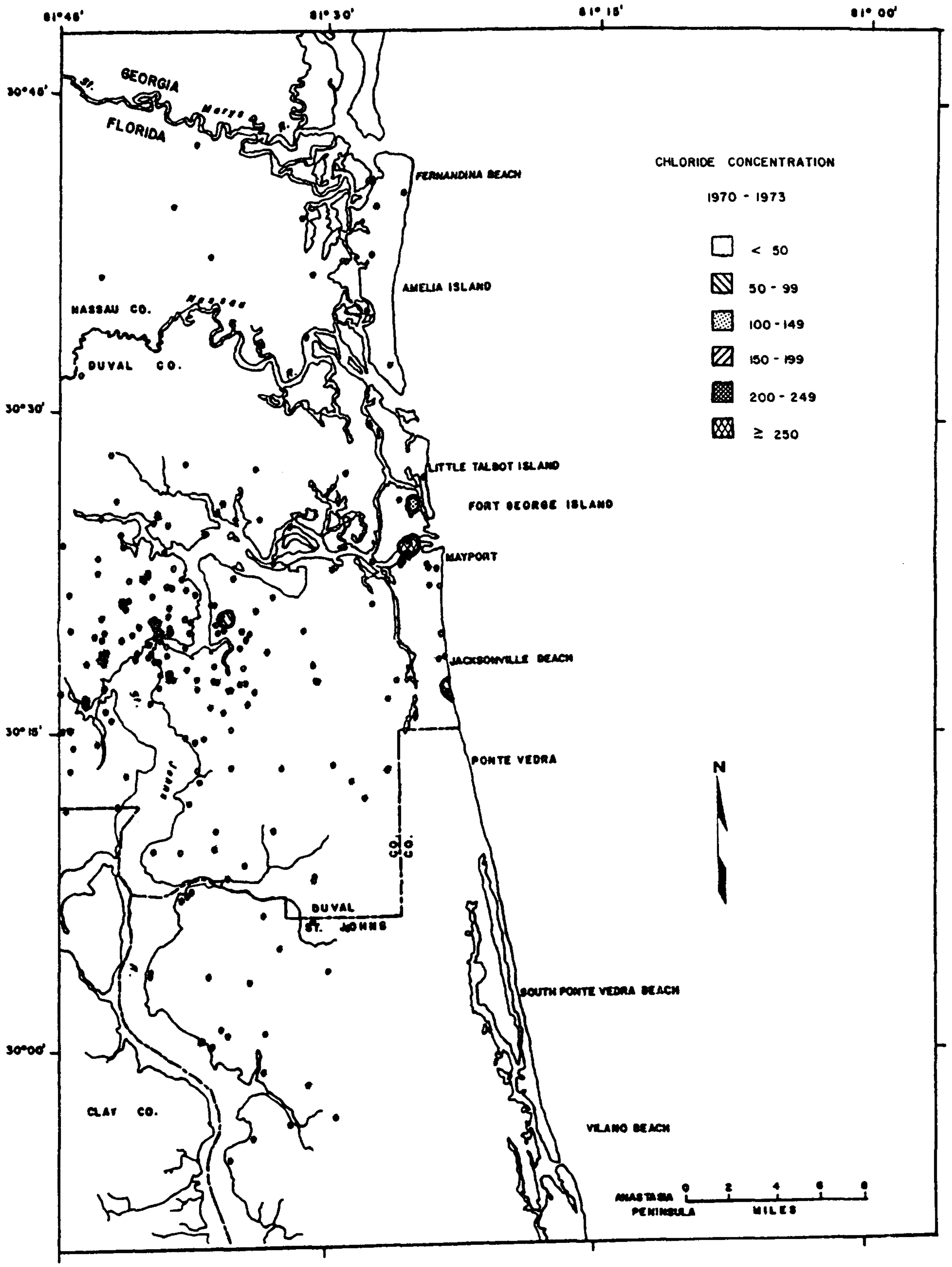


Figure 13b. Chloride concentration (in mg/l) in water from the Floridan aquifer for samples collected between 1970 and 1973

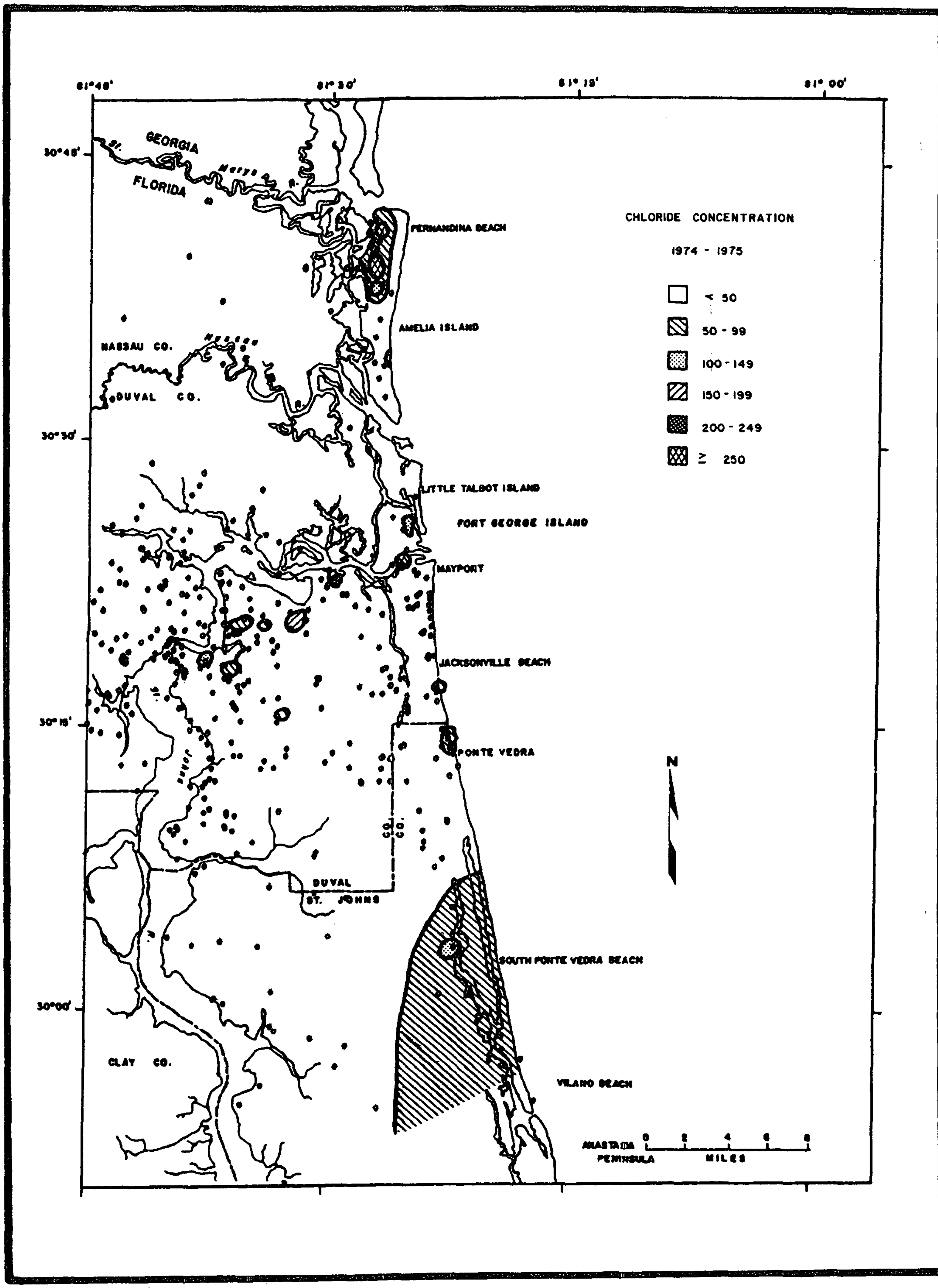


Figure 13c. Chloride concentration (in mg/l) in water from the Floridan aquifer for samples collected between 1974 and 1975

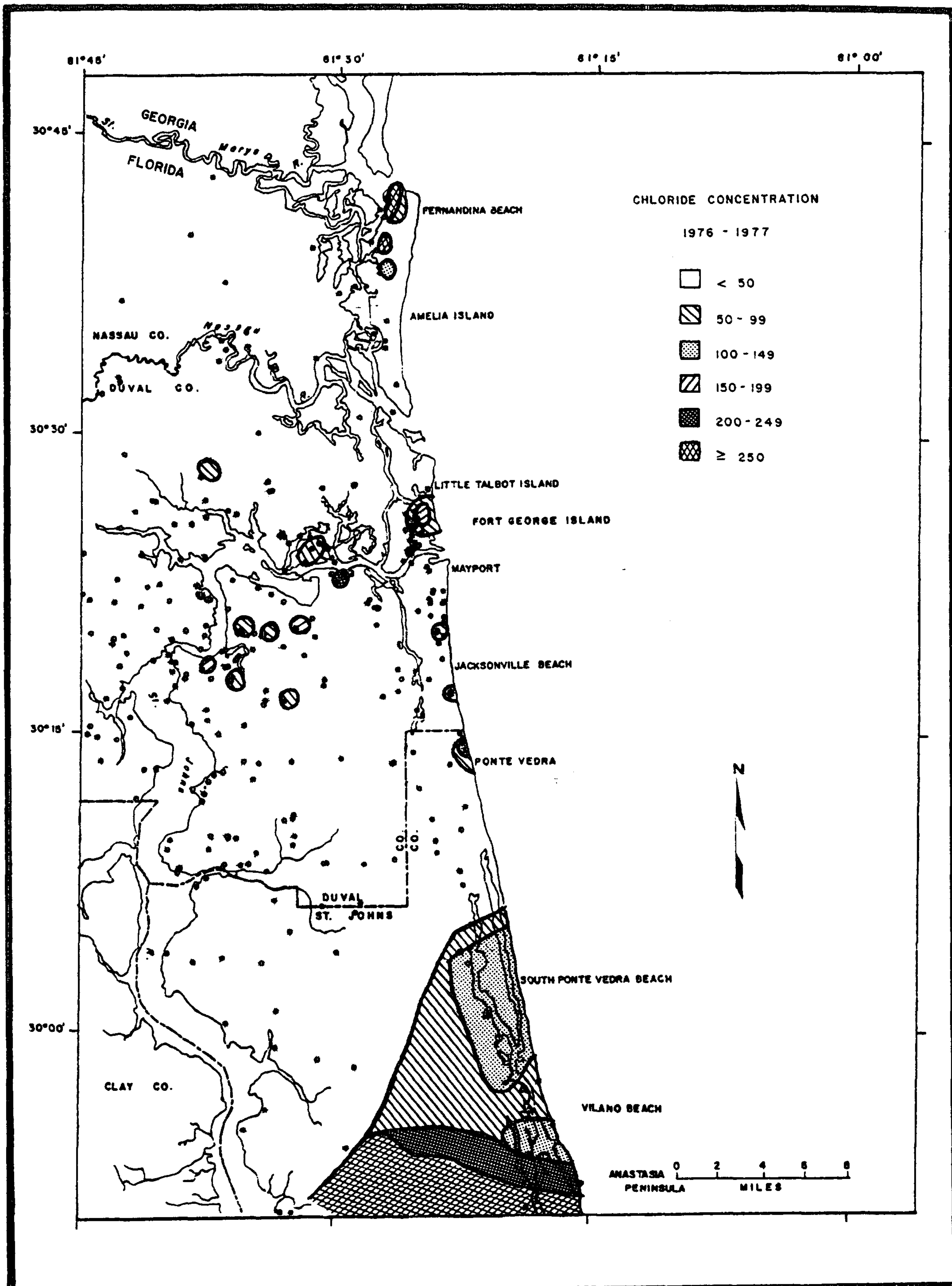


Figure 13d. Chloride concentration (in mg/l) in water from the Floridan aquifer for samples collected between 1976 and 1977

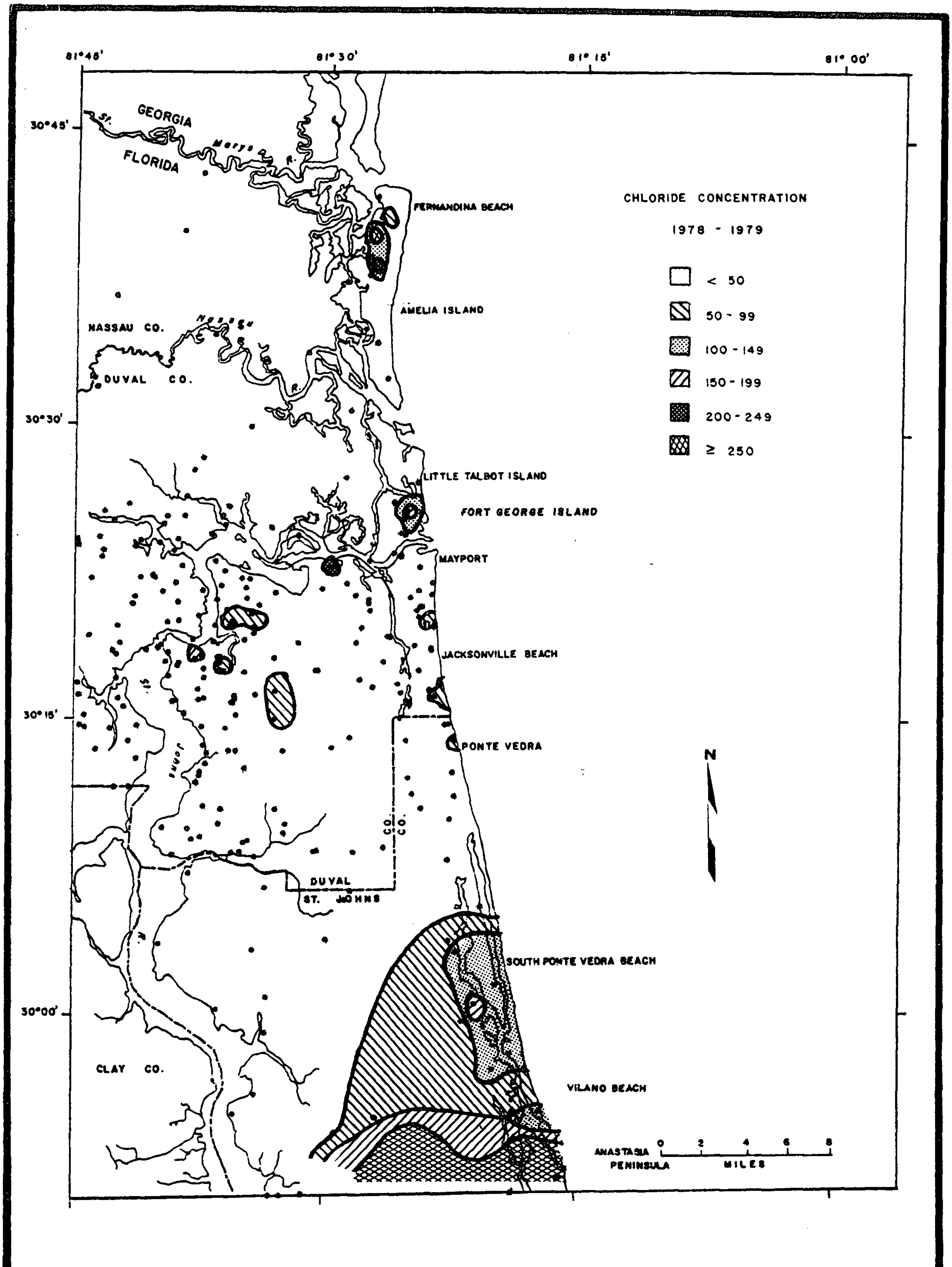


Figure 13e. Chloride concentration (in mg/l) in water from the Floridan aquifer for samples collected between 1978 and 1979

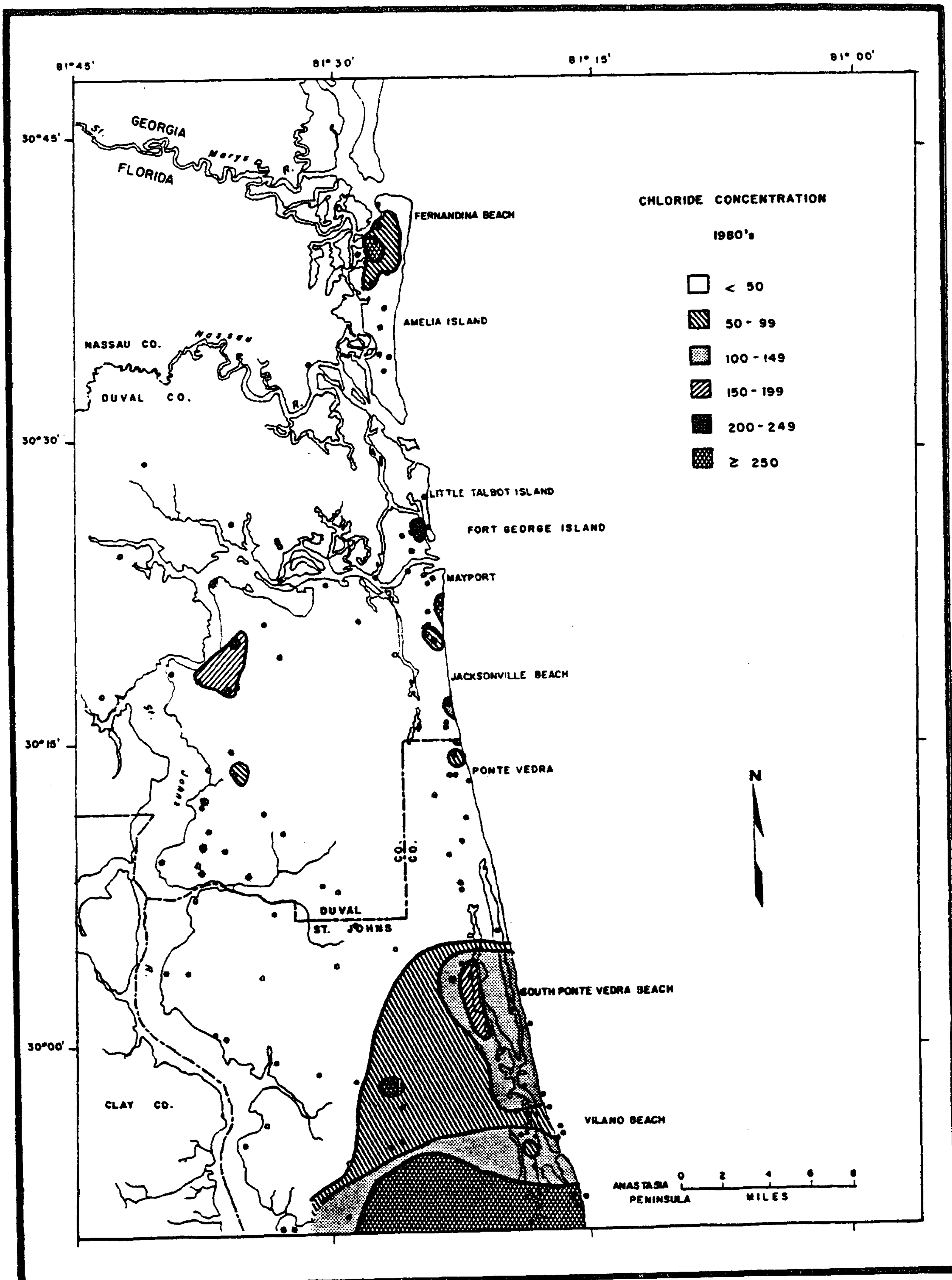


Figure 13f. Chloride concentration (in mg/l) in water from the Floridan aquifer for samples collected after 1979

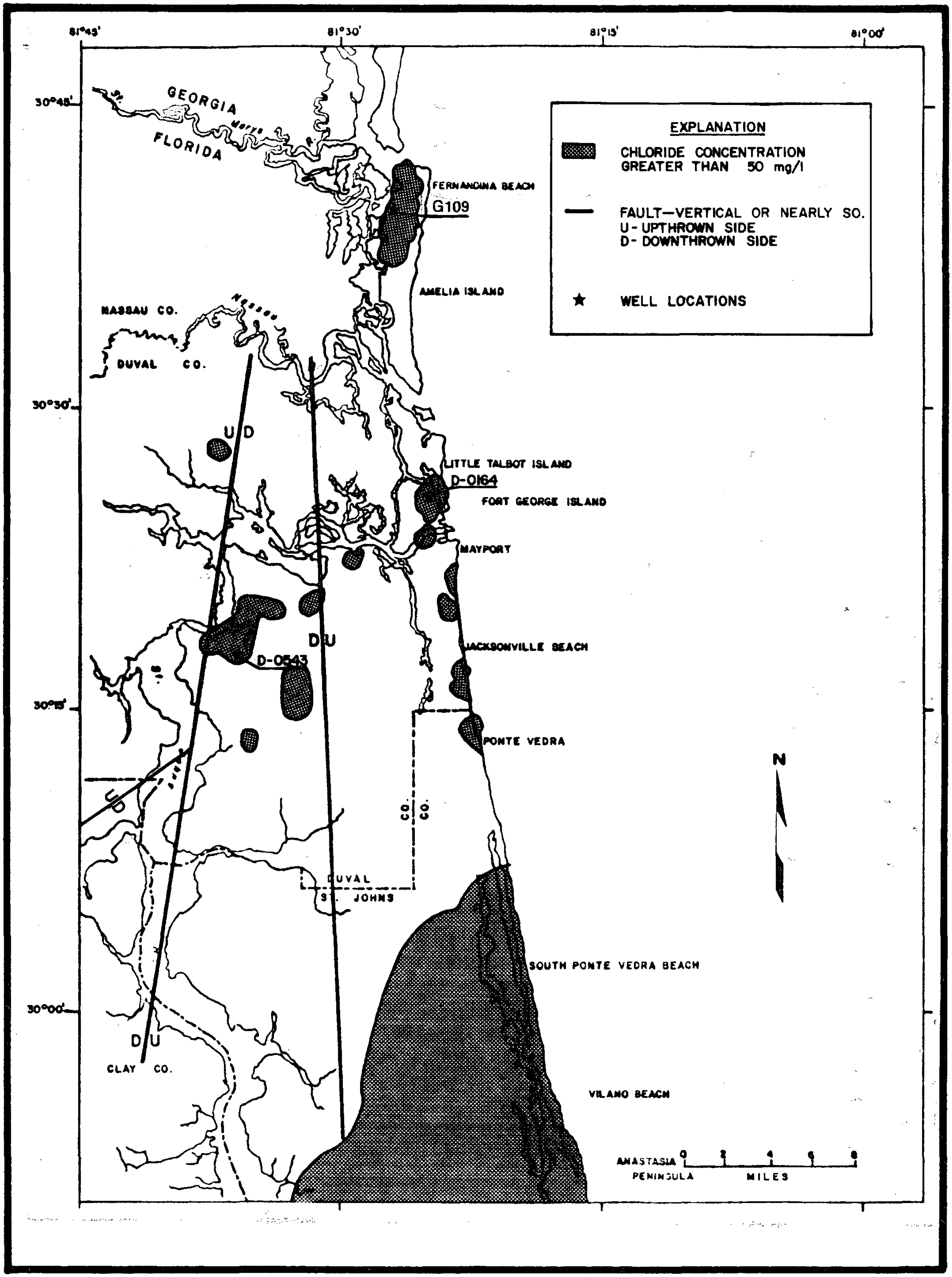


Figure 14. Areas where chloride concentration was greater than 50 mg/l between 1960 and 1984. Fault locations are from Miller (1982).

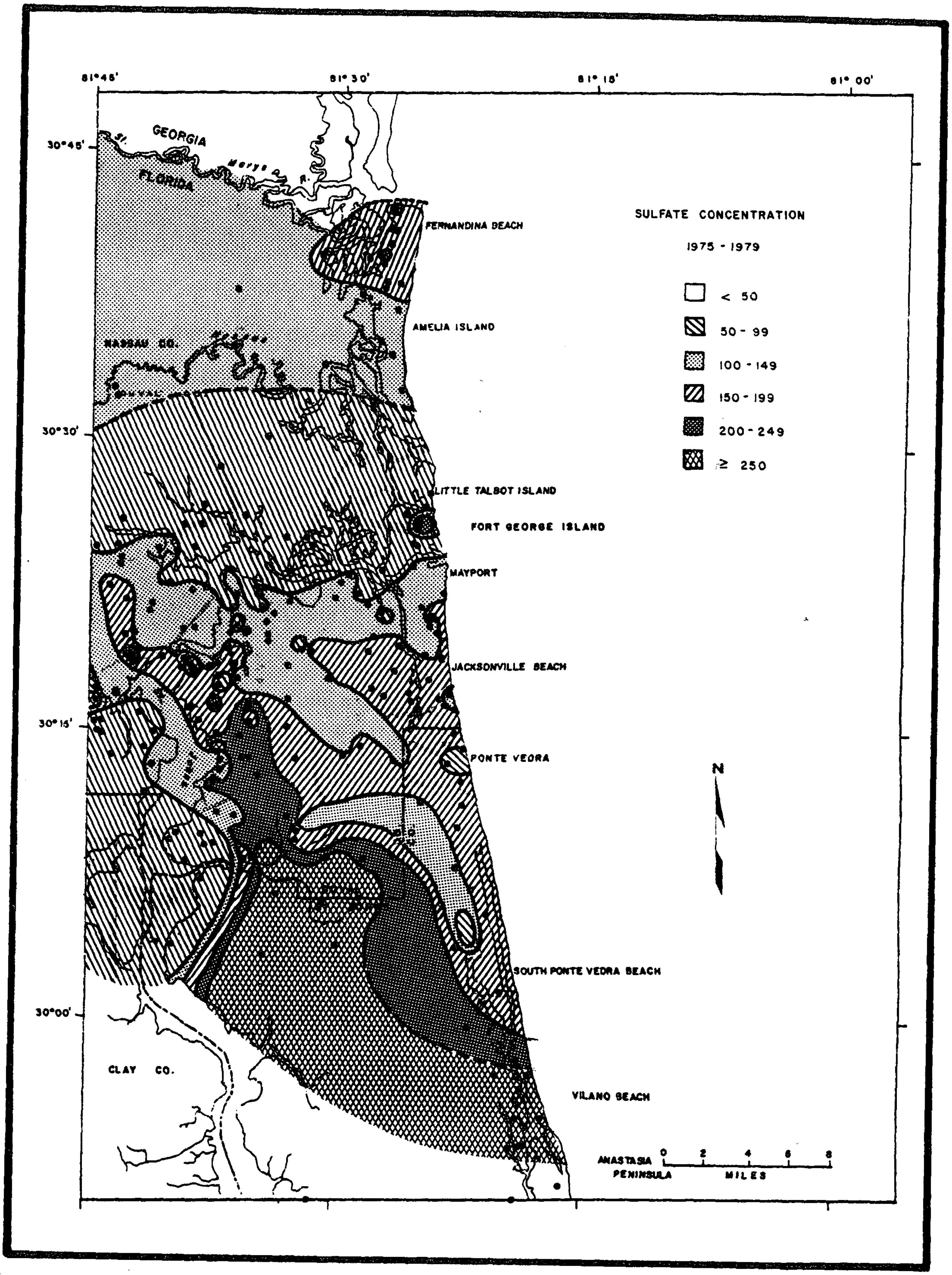


Figure 15a. Sulfate concentration (in mg/l) in water from the Floridan aquifer for samples collected from 1975 to 1979

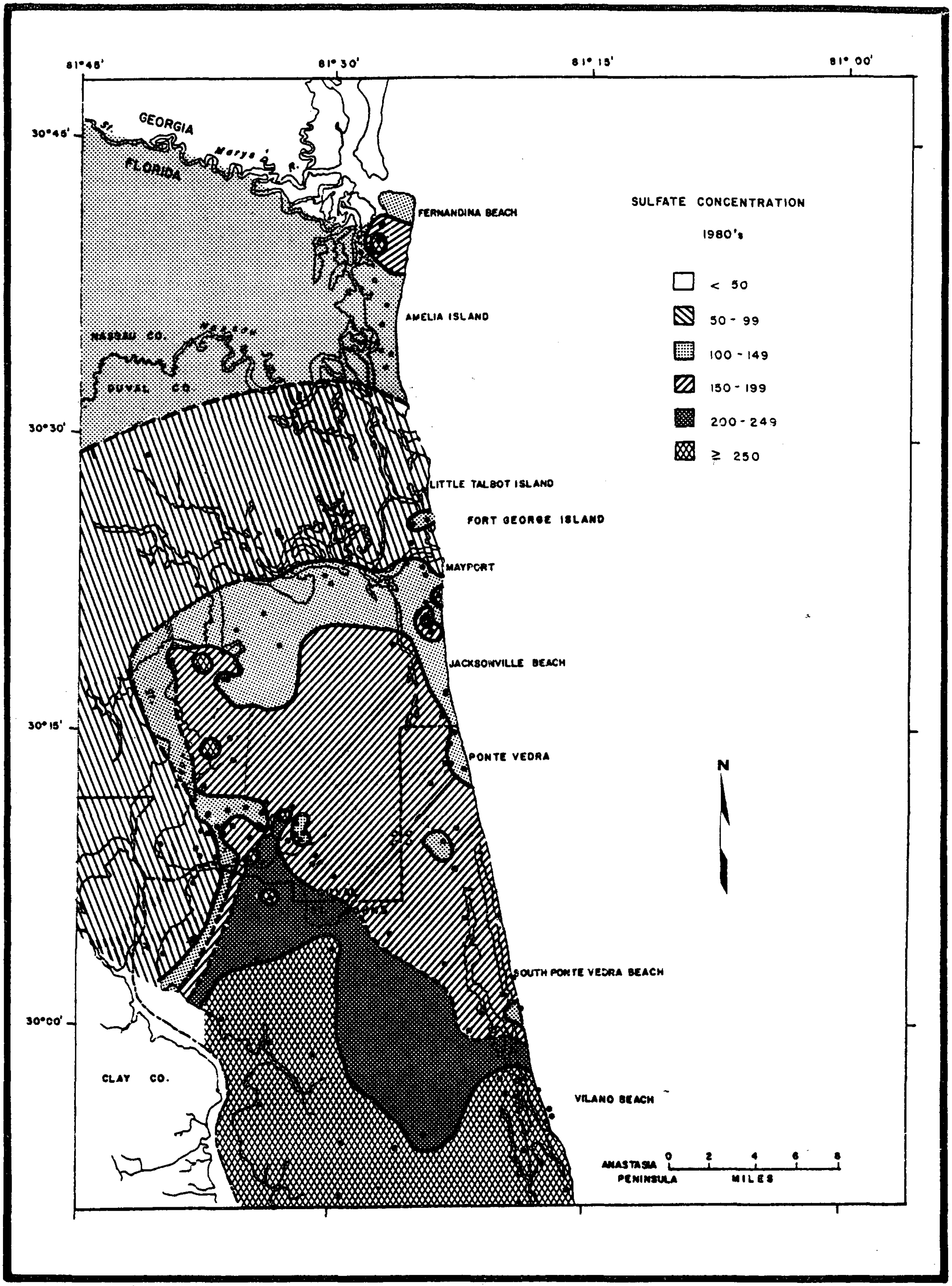


Figure 15b. Sulfate concentration (in mg/l) in water from the Floridan aquifer for samples collected from 1980 to 1984

Fernandina Beach, south Jacksonville, Hanna Park, the St. Augustine area, and in a large area of western St. Johns County (Figures 15a and b).

Chloride and Sulfate Concentrations

Chloride and sulfate occur in varying concentrations in the ground water in the study area. In eastern Nassau and northeastern Duval counties, chloride concentration in the Floridan aquifer is generally below 50 mg/l and sulfate concentration below 150 mg/l. In isolated areas, however, higher chloride and sulfate concentrations have occurred. In this report chloride and sulfate concentrations greater than 100 mg/l are considered significant.

Analysis of existing data indicates three ways in which chloride and sulfate occur in combination with one another: low chloride/low sulfate; low chloride/high sulfate; and high chloride/high sulfate (Figure 16). For the purposes of this report, chloride levels less than 50 mg/l were considered low and levels greater than 100 mg/l were considered high. Sulfate levels were considered high if they were greater than 150 mg/l, unless chloride levels were high, in which case sulfate levels greater than 100 mg/l were considered high.

Low chloride/low sulfate waters occur where the recharge areas of the aquifer and the ground water along the flow path contain low concentrations of chloride and sulfate minerals, where the aquifer transmissivity is high, and where little or no mixing with more saline waters (such as connate water or seawater) has occurred. In the study area, ground water with low chloride/low sulfate concentrations occurs throughout much of northern and western Duval County and western Nassau County.

Ground water with low chloride/high sulfate concentrations occurs in areas where the aquifer is enriched in sulfate minerals and where the aquifer transmissivity is low. The presence of high concentrations of sulfate in this water is influenced by local dissolution of sulfur minerals in combination with low aquifer transmissivity. Ground water with low chloride/high sulfate concentrations occurs in southeast Duval and northern St. Johns County.

High concentrations of both chloride and sulfate occur in areas that are strongly influenced by intruded seawater or connate water. Both seawater and connate waters contain high concentrations of chloride and sulfate. High chloride/high sulfate concentrations in ground water occur in localized areas along the coast and along the St. Johns River in Duval County.

Increases in sulfate concentration depend on the rate of gypsum dissolution, which is typically slow. Throughout the study area, ground water in the upper 1000 ft of the Floridan aquifer is undersaturated with respect to gypsum, a common sulfur-bearing mineral

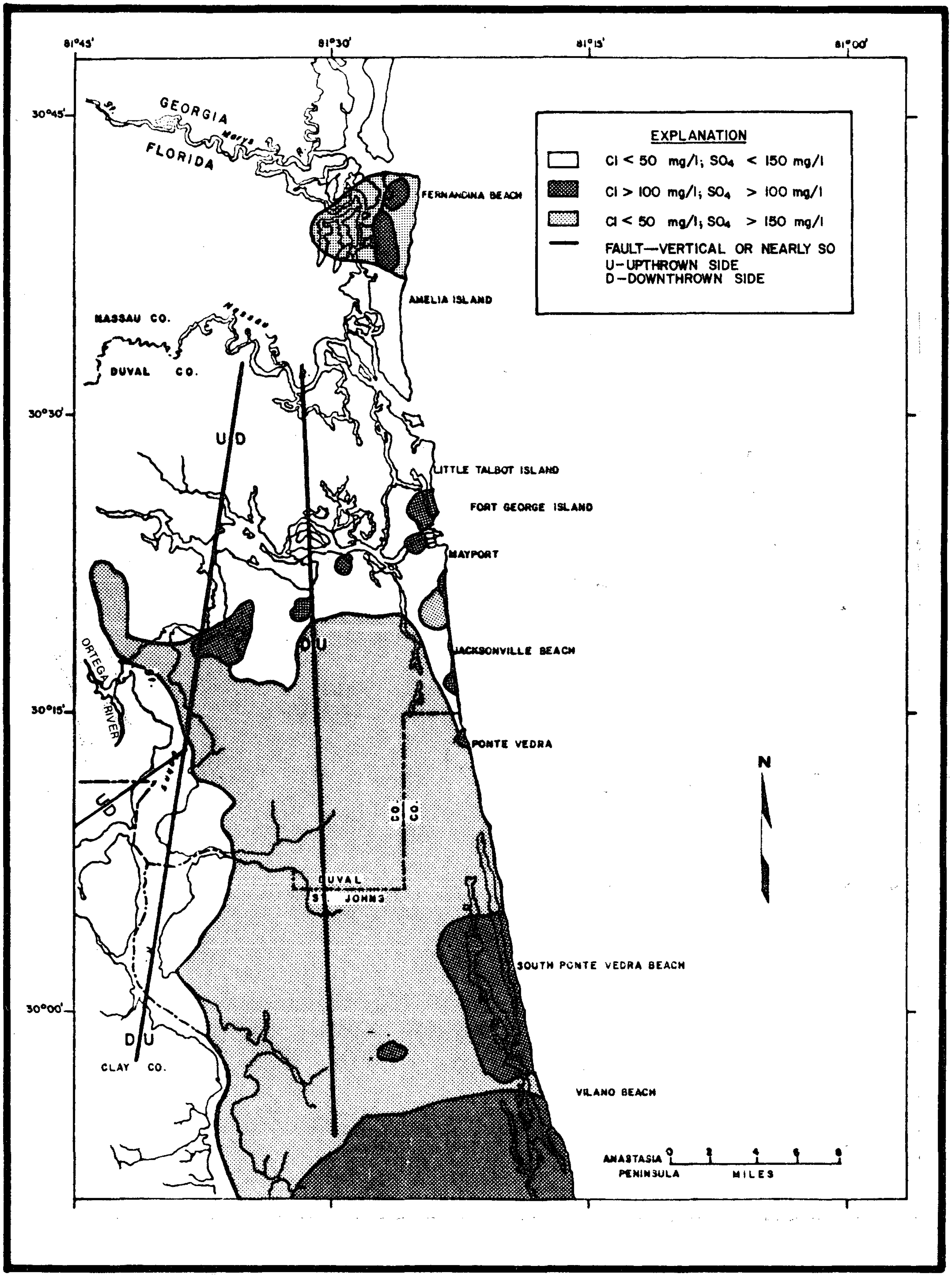


Figure 16. Locations of three different water types. Fault locations are from Miller (1982).

in limestone. In the low chloride/high sulfate area of southeastern Duval and northern St. Johns counties, the average concentration of calcium and sulfate is 78 and 230 mg/l respectively, the ground water temperature is approximately 25°C, and the ionic strength is approximately 0.01 moles per liter (mol/l). Ionic strength is defined as half the sum of the product of the concentration of every ion in solution in mol/l and the square of its charge. Dissolution of gypsum by ground water with an ionic strength of .01 mol/l and a temperature of 25°C could increase the sulfate concentration by an additional 391 mg/l before the ground water becomes saturated with respect to gypsum. This calculation assumes that gypsum dissolution is not accompanied by the dissolution of limestone and that sufficient gypsum is present in the limestone to reach aqueous equilibrium. If limestone also dissolves or insufficient gypsum is present in the limestone to reach aqueous equilibrium, the sulfate concentration will increase by less than 391 mg/l.

However, the increase in sulfate concentration is limited by the rate of mineral dissolution. The rates of mineral-to-water reactions are generally very slow. As a consequence, little information is available on them. Plummer (1977) examined observed changes in water chemistry in part of the Floridan aquifer in central Florida. Through the use of mass balance relationships and mass transfer calculations, he derived rate constants for several reactions that simulated the observed water chemistry. His derived rate constants represent a first step toward obtaining kinetic information on mineral-to-water reactions from field data. Those rate constants are used here to obtain an order of magnitude for mineral dissolution. Using the derived rates for gypsum dissolution, sulfate concentration could increase at a rate of 1-8 mg/l per 100 years as a result of the dissolution of gypsum. Because of this slow rate of gypsum dissolution, the sulfate concentration in the low chloride/high sulfate areas could not be expected to worsen to a very large degree during the next century.

The occurrence of chloride and sulfate concentrations greater than 100 mg/l in the Floridan aquifer in the study area is probably the result of upward movement of water with higher chloride and sulfate concentrations from lower levels of the Floridan aquifer. Chloride concentrations above 7,000 mg/l occur at depths greater than 1,800 ft below mean sea level in the coastal portions of northeast Florida. This saline water is under higher artesian pressure than water above it (Leve 1983). Higher artesian pressure in the lower water-bearing zone provides the potential for upward movement of saline water. Faults or other structural features which breach confining units may serve as pathways for upward movement. Increased withdrawals from the upper and middle water-bearing zones increase the potential for upward movement of water from the lower water-bearing zone.

Ground Water Quality Trends

Wells from three of the areas with high chloride/high sulfate concentrations were selected to demonstrate how chloride and sulfate concentrations have changed with time. The wells are G109 located in Fernandina Beach, D-0543 located along the St. Johns River in Duval County (Lovegrove), and D-0164 located on Fort George Island (Figure 14). In each well, high chloride concentrations coincide with high sulfate concentrations, and the wells show a general increase in chloride and sulfate concentrations with time.

At G109 in Fernandina Beach (Figure 17a) the average chloride concentration increased from 126 to 253 mg/l between 1975 and 1982. The average sulfate concentration increased from 240 to 270 mg/l between 1978 and 1982. Well G109 has an open bore hole from 535 to 1,700 ft and penetrates both the upper and middle water-bearing zones of the Floridan aquifer.

At D-0543 in Duval County (Lovegrove) (Figure 17b) the chloride concentration increased from 25 to 180 mg/l between 1962 and 1982, but decreased to 82 mg/l in 1983. The sulfate concentration increased from 105 to 140 mg/l between 1975 and 1980. Well D-0543 is 1234 ft deep and is cased to 515 ft. It penetrates the upper and the top of the middle water-bearing zones of the Floridan aquifer.

At D-0164 on Fort George Island (Figure 17c) chloride concentrations increased from 63 to 210 mg/l between 1930 and 1982. The sulfate concentrations increased from 128 to 170 mg/l between 1930 and 1980. From 1930 to 1972 the chloride concentration increased at a rate of 1.5 mg/l/yr. In 1972 the chloride concentration was 128 mg/l, and it increased linearly from 1972 to 1982 at a rate of 7.3 mg/l per year. If this rate continues, the chloride concentration may exceed 250 mg/l by 1990.

Water levels in D-0164 on Fort George Island decreased linearly from 60.6 ft msl in 1930 to 40.9 ft msl in 1973. Between 1973 and 1984 water levels fluctuated above and below approximately 40 ft msl, but no net decline occurred. Hence, increases in chloride concentration coincided with decreasing water levels before 1972. After that date, chloride concentration continued to increase, but water levels remained approximately constant. Well D-0164 is 619 ft deep and is cased to 448 ft below land surface. It is a monitor well completed in the upper water-bearing zone of the Floridan aquifer.

The increase in chloride and sulfate concentrations in these wells represents the vertical migration of saline water from the deeper zones of the aquifer through fractures or through wells which were not back-plugged adequately. At Fernandina Beach, many pulp and paper mill supply wells penetrating both the upper and middle water-bearing zones have been back-plugged to the bottom of the upper water-bearing zone in order to prevent upward migration of more saline water from the middle and lower water-bearing zones to the upper water-bearing zone. These wells when originally drilled probably penetrated saline water in the middle water-bearing zone.

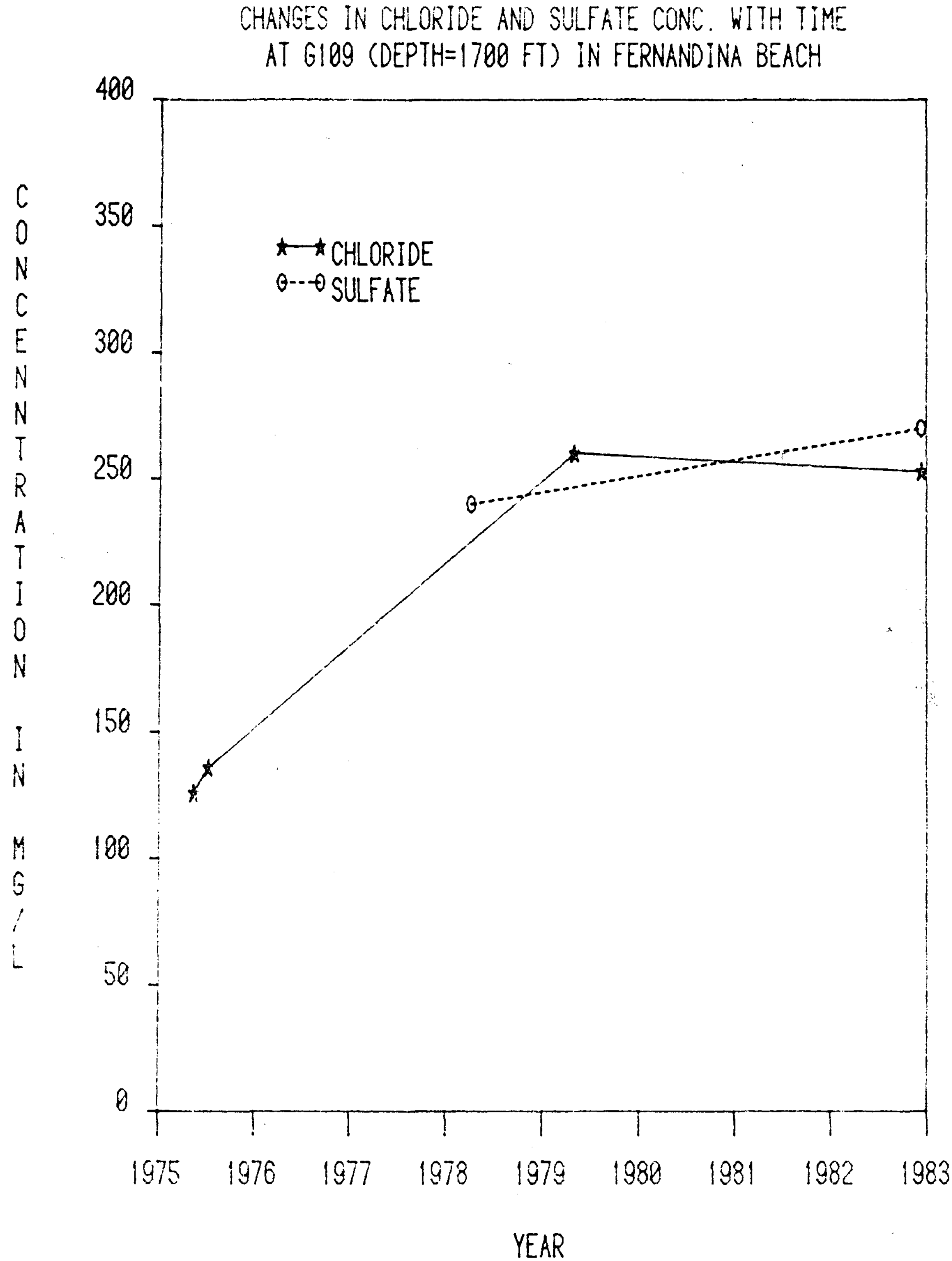


Figure 17a. Changes in chloride and sulfate concentrations over time at well G109 in Fernandina Beach

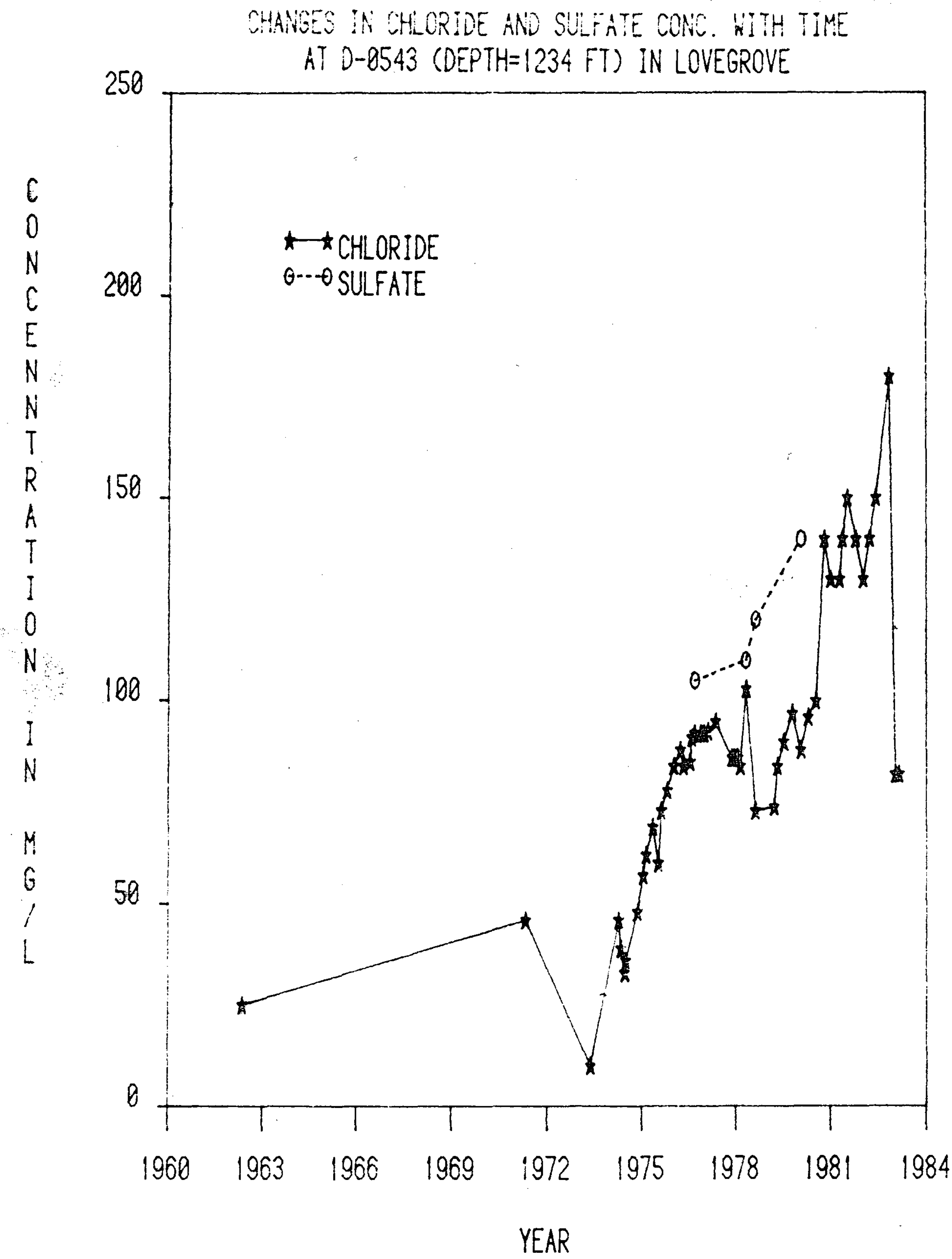
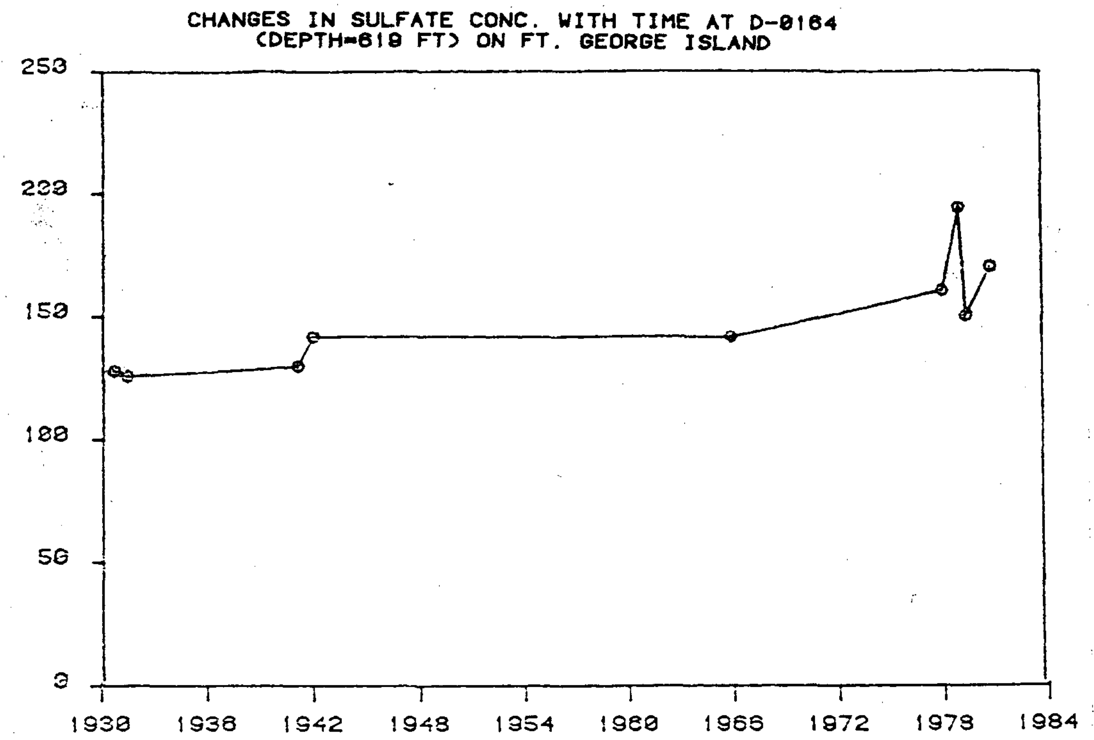


Figure 17b. Changes in chloride and sulfate concentrations over time at well D-0543 in Lovegrove



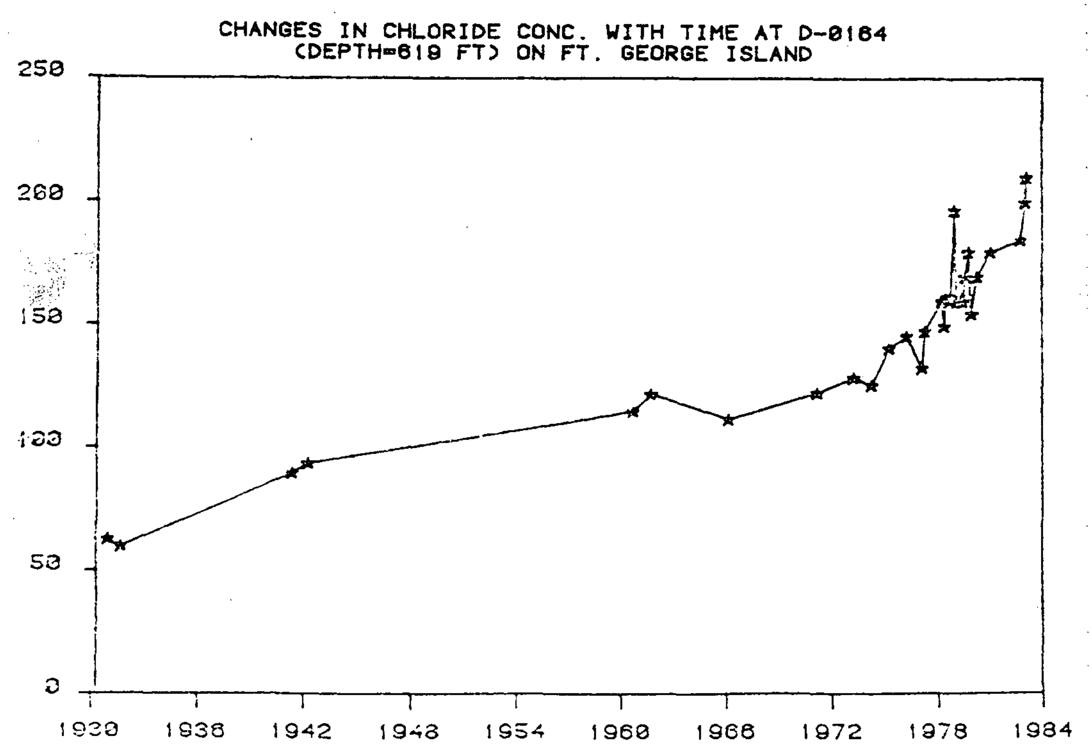


Figure 17c. Changes in chloride and sulfate concentrations over time at well D-0164 on Fort George Island

Mineralized water is moving into the upper water-bearing zone in the northeast part of Fort George Island (Environmental Science and Engineering 1985). Geochemical, potentiometric, and temperature maps indicate that an area of higher hydraulic head, higher temperature, and higher chemical concentrations exists in the upper water-bearing zone in the northeast part of the island, where D-0164 is located. Geophysical logs and geologic cross-sections indicate that the geologic units are displaced downward 60-70 ft in this area. This anomaly is localized and has the shape of a circular or elliptical feature. This leads to the conclusion that the mineralized water is moving upward into the upper water-bearing zone from a deeper zone along a vertical or nearly vertical conduit. The conduit apparently penetrates the confining beds between the lower and middle water-bearing zones and between the middle and upper water-bearing zones.

The mechanism that causes saline water to move upward from the lower water-bearing zone to overlying units is the higher artesian pressure in the lower unit as compared to the pressure in the overlying units. Regional pumping from the upper and middle water-bearing zones has resulted in the hydraulic heads in these units being lower than the hydraulic head in the lower water-bearing zone, causing enough head difference for water to move upward from the lower water-bearing zone. For example, between 1973 and 1984, water levels fluctuated above and below approximately 40 ft msl in D-0164 on Fort George Island. At Hanna Park, located 4 miles southeast of Fort George Island, the equivalent freshwater head in the lower water-bearing zone of the Floridan aquifer was approximately 45 ft above msl in July, 1982 (Brown et al. 1984). Assuming that the lower water-bearing zone at Fort George Island has approximately the same hydraulic head as at Hanna Park, then there is sufficient head difference between the lower water-bearing zone and the overlying zones to result in upward flow from the lower water-bearing zone.

Well D-0164 on Fort George Island is a monitor well and is not pumped. Pumpage from nearby irrigation wells at the golf course and industrial and public supply wells in Jacksonville may aid this upward movement by lowering water levels in the upper and middle water-bearing zones.

Insufficient data has been collected from wells in this study area to distinguish whether connate or laterally intruded seawater is the source of higher chloride and sulfate water. Laterally intruded seawater and connate water may be distinguished by differing concentrations of sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), bicarbonate (HCO_3), chloride (Cl), and sulfate (SO_4). Water compositions can be plotted using a Piper trilinear diagram (Frazee 1981).

WATER MANAGEMENT CONSIDERATIONS

TEST AREAS

Presently SJRWMD requires site-specific ground water evaluations in the Duval County and St. Johns County area to support consumptive use permit (CUP) applications. In this report, areas and test procedures for site-specific ground water evaluations have been identified based on the presence of chloride/sulfate associations. In many of these areas, the permitting staff already requires extensive aquifer tests to satisfy CUP applications.

Areas of high chloride and sulfate concentrations in the upper and middle water-bearing zones of the Floridan aquifer occur along the coast and along the St. Johns River (Figure 16). Some of these areas occur where there is heavy pumping from the Floridan aquifer and may be caused by weaknesses in the lower confining units of the Floridan aquifer, which allow saline waters to move upward from the lower water-bearing zone. Other areas may occur due to natural weaknesses in the lower confining units of the Floridan aquifer.

The saline waters in the lower water-bearing zone have a higher artesian pressure than waters in overlying zones. This pressure differential provides the driving force for this upward movement. Wellfield withdrawals in high chloride/high sulfate areas increase the pressure differentials further and may lead to degradation of water quality with time. Development of dependable supplies of ground water in high chloride/high sulfate areas requires extensive testing and careful planning and management of withdrawal facilities to prevent contamination.

Well depth, well spacing, the magnitude of wellfield withdrawals, and wellfield location are all important factors to be considered in the planning and management of withdrawal facilities. Because fractures or weaknesses in confining beds may play a major role in the distribution of high chloride and sulfate concentrations, wellfield development in areas with known structural weakness should be avoided. Areas where increased withdrawals would significantly impact the potentiometric surface should also be avoided. Alternatively, withdrawals should be adjusted so as to minimize potentiometric declines.

In the high chloride/high sulfate concentration areas, detailed pump tests should be conducted for proposed new withdrawals greater than or equal to 100,000 gallons per day (gpd) average annual pumpage per square mile where any or all of the following conditions exist:

- o there is a lack of water quality data with depth;
- o there are no geophysical logs;
- o there are no data on the aquifer properties within a square mile area of the proposed withdrawal site; or
- o current permitted withdrawals within one square mile of the proposed withdrawal site are in excess of 100,000 gpd.

High chloride/high sulfate concentration areas occur east of the Intercoastal Waterway along the coast, within a one-mile band on either side of the north-south faults mapped by Miller (1982), and within a two-mile band on either side of a line stretching from Fort George Island to the Ortega River in Jacksonville (Figure 16).

While sulfate concentration may increase somewhat in the low chloride/high sulfate areas, increases will be slow and will be limited by the slow rate of dissolution of sulfur minerals. However, detailed pump tests should also be conducted for proposed new withdrawals greater than or equal to 100,000 gpd in southeast Duval and northwest St. Johns counties. These areas are either currently experiencing or are projected to experience rapid urban development and population growth during the next 20 years. Chloride concentrations are less than 50 mg/l, but sulfate concentrations are greater than 150 mg/l in these areas.

Finally, detailed pump tests should be conducted for every proposed new withdrawal in the remainder of the study area for withdrawals that exceed 1500 gpm or approximately 2.1 mgd per square mile. Withdrawals of this magnitude will produce a drawdown of at least 2.2 ft in observation wells 1000 ft away and 1.3 ft in wells 5000 ft away from the pumping well. These drawdowns were calculated using an average transmissivity for the upper 700 ft of the Floridan aquifer in Duval County of 80,000 ft^2/d and a leakance of 0.0003 $gpd/ft^2/ft$ (Franks and Phelps 1979). In areas where the transmissivity is half this value, the drawdowns will be approximately doubled.

When proposed production well depths are in excess of 1000 ft in Nassau and Duval counties and in excess of 400 ft in St. Johns County, the well should be drilled by the reverse-air rotary method and water samples collected every 10 ft for the determination of chloride and sulfate concentrations. Geophysical logs should be run during construction of the production well. Logs should include a minimum of the following types of tests: electric, caliper, natural gamma, temperature, acoustic velocity, and flow. Additional areas of high chloride concentrations could be identified and mapped by these drilling activities.

ADDITIONAL STUDIES

Additional investigations are needed to comprehend the causes and mechanisms of increases in chloride and sulfate concentrations with time. The linear alignment of high chloride areas between Fort George Island and the Ortega River in Duval County and its relationship to concealed faults and fractures needs further investigation.

The USGS is currently in the second year (1989) of a four year investigation to delineate areas where saline water occurs in the various water-bearing zones of the Floridan aquifer system and possibly permeable zones deeper than the Floridan in Duval and coastal portions of Nassau and St. Johns counties, and to provide a redefined conceptual model of the hydrogeologic framework of the Floridan aquifer system in northeast Florida. This description of the hydrogeologic framework of the Floridan aquifer system will include the hydrologic properties of the various water-bearing zones and semi-confining units; the occurrence of saline water in the various zones of the aquifer and its source; geologic structures such as faults, fractures, and solution features and their significance to the ground water flow system and the occurrence of saline water.

The district is in the second year of a two-year investigation collecting and summarizing information concerning the hydrogeology and water quality of the Floridan, intermediate, and surficial aquifer systems in the Lower St. Johns ground water basin. The basin includes all of Duval, St. Johns, Flagler, Clay, Putnam, and portions of northeast Marion counties. This investigation is designed to identify potential problems and data deficiencies in northeast Florida.

Past studies (Brown et al. 1984, 1985) have examined the change in chloride concentration with depth. Few investigators have measured sulfate concentrations as a function of depth. At least one additional deep-monitor well should be drilled in the low chloride/ high sulfate area of southeast Duval and northwest St. Johns counties. The well should be drilled by the reverse-air method with water samples collected every 10 ft for the determination of chloride and sulfate concentration. The well should be drilled to a depth adequate to encounter saline water.

To detect the occurrence of saline water and to identify its source, it is recommended that a water quality monitoring network be established and water samples analyzed for Ca, Mg, Na, K, HCO3, Cl, and SO4. It is also recommended that the existing SJRWMD and USGS monitoring networks be maintained. The USGS, in cooperation with the City of Jacksonville, is monitoring water levels and water quality in five wells in the middle water-bearing zone of the Floridan aquifer in Duval County.

To assist in the evaluation of proposed ground water withdrawals associated with development, it is recommended that a flow and solute transport model be developed for northeast Florida. The model can be used to test the relationship between increasing ground water withdrawals and concentrations of chloride and sulfate.

SUMMARY AND CONCLUSIONS

In northeastern Florida, the Floridan aquifer consists of three relatively isolated water-bearing zones separated by relatively impermeable beds which restrict the vertical movement of water through the aquifer. The upper and middle water-bearing zones occur at 530-1,000 and 1,200-1,700 ft below land surface respectively in Nassau County. The lower water-bearing zone occurs at 2,000-2,100 ft below land surface and contains saline water (Brown 1984). Depths to the water-bearing zones in Duval and Nassau County are similar, but because the aquifers dip to the northeast, these depths are shallower in St. Johns County.

Depressions in the potentiometric surface of the Floridan aquifer occur at Palm Valley in St. Johns County, near the San Jose area of Jacksonville in Duval County, at Fernandina Beach in Nassau County, and near Green Cove Springs in Clay County (see Figure 9). The depression near Green Cove Springs is due to natural spring discharge from the Floridan aquifer. The depression at Fernandina Beach is associated with large withdrawals by pulp and paper mills. The remaining depressions are caused by ground water withdrawals for golf course irrigation and public supply. The potentiometric surface for May 1980 in the northern part of the study area is estimated to have declined about 25 to 30 ft since 1880.

In the study area, three different water types occur: the background "fresh" or "recent" water which is comparatively low in chloride and sulfate concentration which occurs in western Nassau and Duval counties; low chloride/high sulfate water which occurs in southeast Duval and northern St. Johns counties and probably results from mineral dissolution within the aquifer; and high chloride/high sulfate water which occurs along the coast and portions of the St. Johns River.

Chloride and sulfate concentrations have increased with time in the Fernandina Beach, Lovegrove, and Fort George Island areas. These increases are most likely a result of upward movement of high chloride/high sulfate waters which exist at depth. This high chloride/high sulfate water is under higher artesian pressure than the water above it (Leve 1983). Higher artesian pressure in the lower water-bearing zone provides the potential for upward movement of saline water.

Because structural weaknesses in confining beds may play a major role in the distribution of the occurrence of high chloride/ high sulfate water, areas where chloride and sulfate concentrations are already high should be avoided for new wellfield development. These areas occur east of the Intercoastal Waterway along the coast, within a one-mile band on either side of the north-south faults mapped by Miller (1982), and within a two-mile band on either side of a line stretching from Fort George Island to the Ortega River in Jacksonville (Figure 16).

Areas where increased withdrawals would significantly impact the potentiometric surface should also be avoided.

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