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VOLUME 1
OF THE
LOWER ST. JOHNS RIVER BASIN RECONNAISSANCE

HYDROGEOLOGY

by

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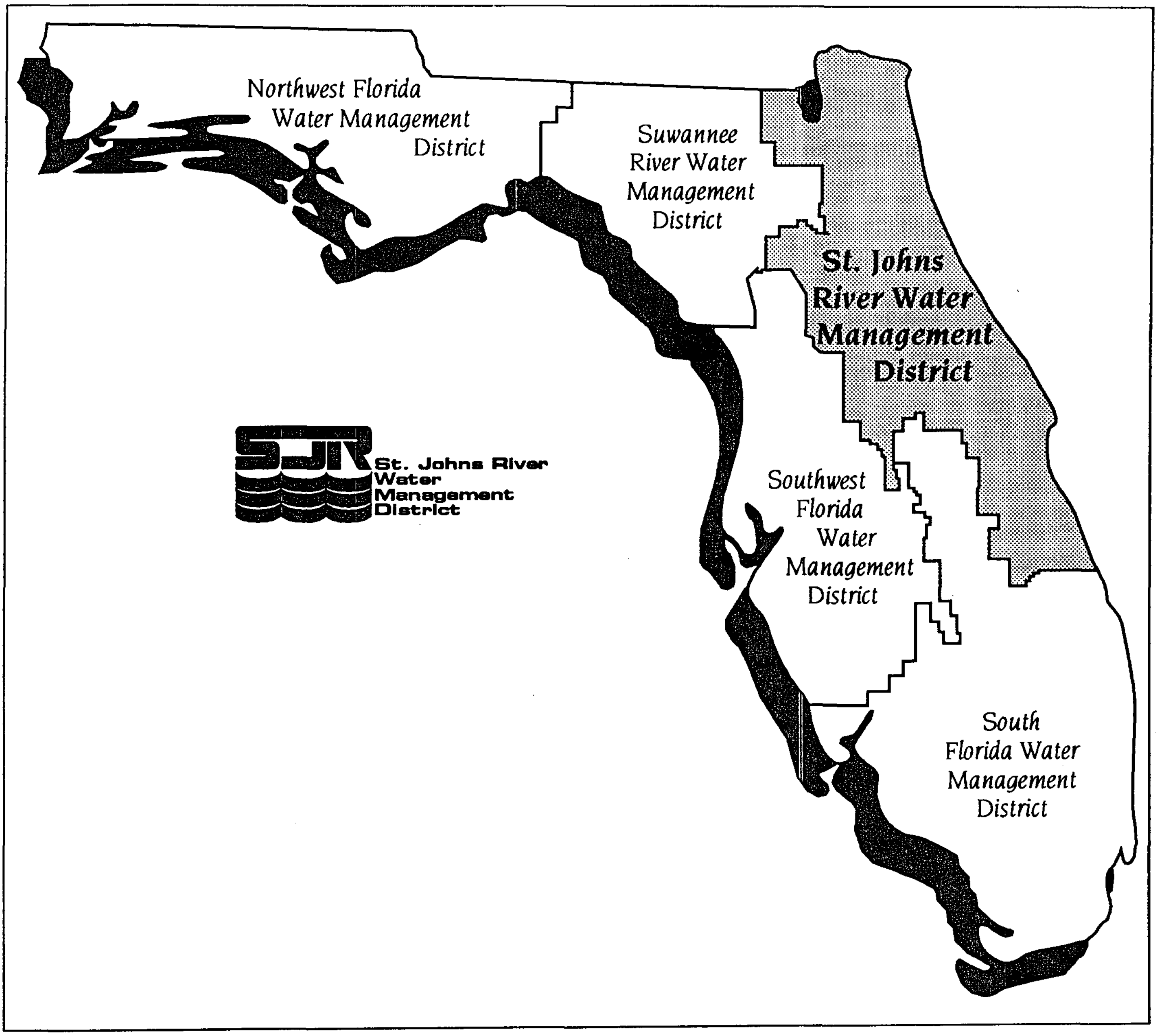

The **St. Johns River Water Management District** (SJRWMD) was created by the Florida Legislature in 1972 to be one of five water management districts in Florida. It includes all or part of 19 counties in northeast Florida. The mission of SJRWMD is to manage water resources to ensure their continued 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.

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ABSTRACT

This report is Volume 1 in a series of reconnaissance reports about the Lower St. Johns River Basin (LSJRB). The lower St. Johns River is the northern part of the St. Johns River from the mouth of the Ocklawaha River in Putnam County to the inlet at the Atlantic Ocean in Duval County. LSJRB includes parts of nine counties in northeast Florida. The reconnaissance reports compile information and make recommendations to help resource managers identify priority needs for research into and management of LSJRB. These reports are part of the research funded under the Surface Water Improvement and Management Act of 1987 (Sections 373.451-4595, *Florida Statutes*).

This volume examines the relationship and influence of the interconnection between the lower St. Johns River and the ground water flow system associated with the river. The mechanisms of this interconnection are spring flow, diffuse upward leakage from the Floridan aquifer system, and seepage from the surficial aquifer system. Ground water within the lower St. Johns River ground water flow system resides in the Floridan, intermediate, and surficial aquifer systems.

Ground water movement within the portion of the Floridan aquifer system that affects LSJRB generally flows eastward. Near Green Cove Springs, the Floridan aquifer system is estimated to lose 46 cubic feet per second (ft^3/sec) to the surficial aquifer system, the intermediate aquifer system, the St. Johns River, or a combination of all three as a result of spring discharge and diffuse upward leakage. In southern Putnam County, 80 ft^3/sec discharges from the Floridan aquifer system to the St. Johns River at Croaker Hole Spring.

In the Floridan aquifer system, moderately saline water containing chloride concentrations between 250 and 1,000 milligrams per liter (mg/L) is present beneath part of the St. Johns River in Putnam County and in southern St. Johns and northern Flagler counties.

The intermediate aquifer system overlies the Floridan aquifer system in portions of Duval, St. Johns, Clay, Putnam, and Flagler counties. Water in the intermediate aquifer system is derived locally either by upward leakage from the underlying Floridan aquifer system or by downward leakage from the overlying surficial aquifer system.

The water table in the surficial aquifer system generally is a subdued reflection of the topography. Water flows away from ridges toward streams, creeks, the St. Johns River, and the coast. Chloride concentrations in the upper 50 feet of the surficial aquifer system are above 1,000 mg/L within 1-4 miles of the coast in Duval, Flagler, and Volusia counties.

INTRODUCTION

This report is Volume 1 in a series of reconnaissance reports about the Lower St. Johns River Basin (LSJRB). This compilation of information and recommendations provides resource managers with a basis for identifying priority needs for future research and actions regarding LSJRB. The reconnaissance reports are part of the research funded under the Surface Water Improvement and Management (SWIM) Act of 1987 (Sections 373.451-4595, *Florida Statutes*).

The SWIM Act declares that many natural surface water systems in Florida have been or are in danger of becoming degraded from point and nonpoint sources of pollution and from the destruction of natural systems. The state's five water management districts, in cooperation with state agencies and local governments, were directed to set priorities for waterbodies of regional or statewide significance and to design plans for surface water improvement and management. Six waterbodies were named for immediate action, including LSJRB.

LSJRB is one of ten surface water basins of the St. Johns River Water Management District (SJRWMD) (Figure 1). LSJRB is located in northeast Florida and represents about 22 percent of the area within the boundaries of SJRWMD. LSJRB extends from the City of De Land, in the south, to the inlet of the St. Johns River at the Atlantic Ocean. LSJRB includes parts of nine counties: Clay, Duval, Flagler, Putnam, St. Johns, Volusia, Alachua, Baker, and Bradford (Figure 2).

The climate of LSJRB is classified as humid subtropical, with an average summer maximum daily temperature of 32.2 degrees Centigrade (°C) (90 degrees Fahrenheit). In the winter, LSJRB experiences below-freezing temperatures an average of 10 to 15 times per year. Average annual rainfall in LSJRB is approximately 132 centimeters (52 inches). A large portion of the annual precipitation falls between June and September when convective activity generates showers and thunderstorms.

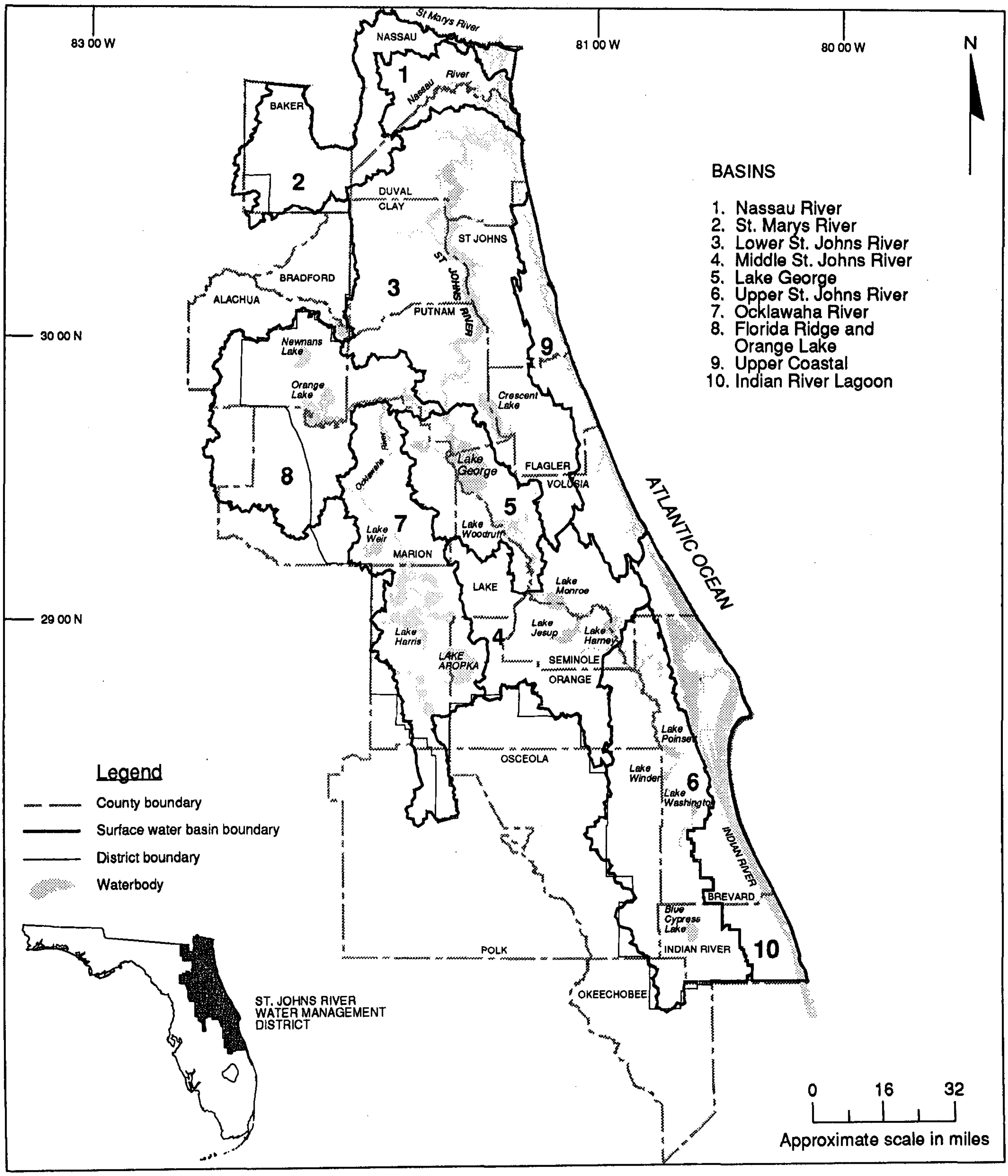

Figure 1. Major surface water basins within the St. Johns River Water Management District

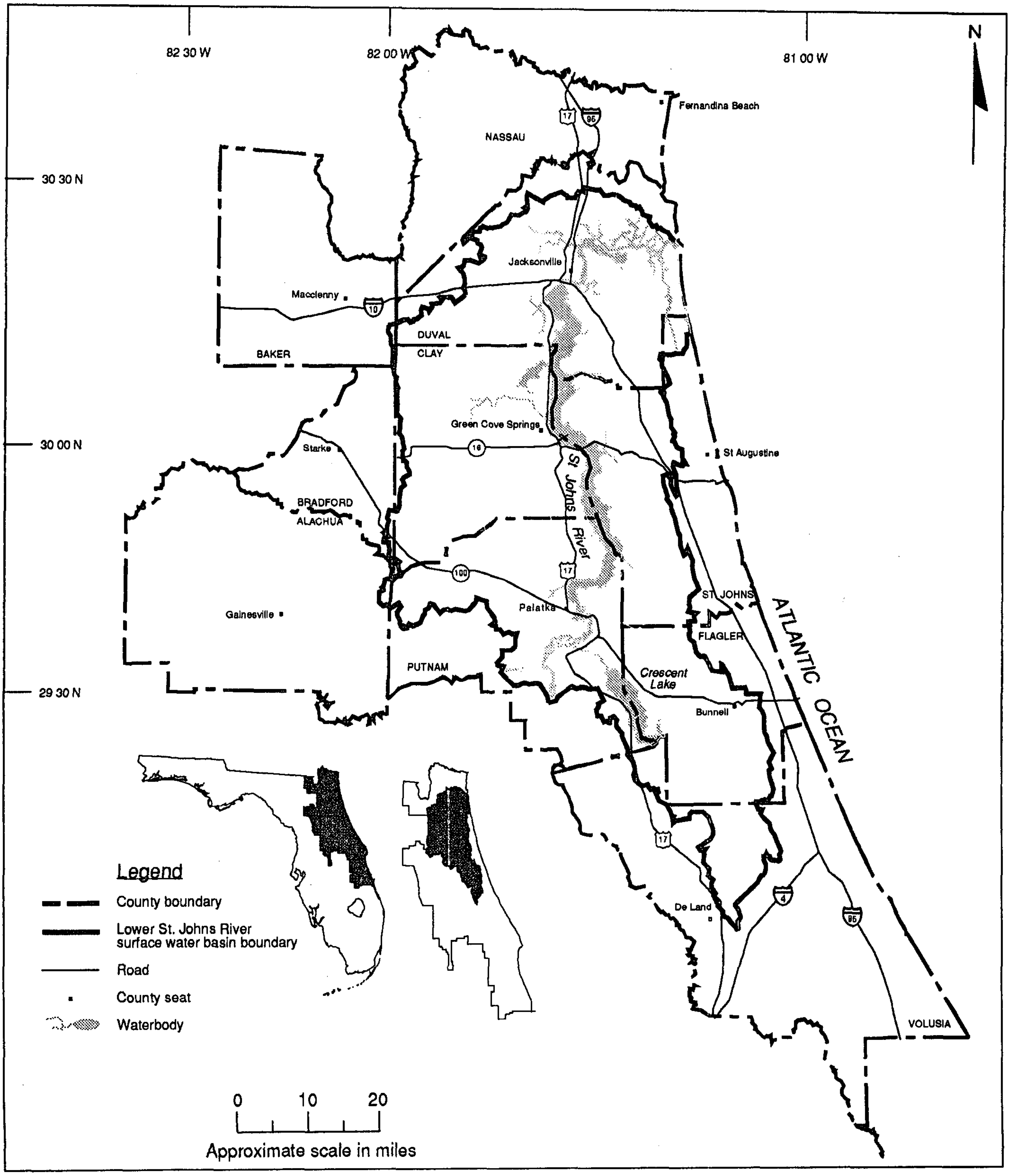

Figure 2. Lower St. Johns River surface water basin

Landscape features within LSJRB are relatively low and flat. Three ridge systems border the drainage area. Surface elevations range from sea level at the inlet to greater than 61 meters (m) (200 feet [ft]) in the western part of LSJRB.

The St. Johns River is an elongated, shallow estuary with an extensive floodplain. The elevation of the St. Johns River at the mouth of the Ocklawaha River is less than 3.0 m (10 ft) above sea level, and the average gradient of the main river channel is only 0.022 meters per kilometer (0.1 ft per mile). Average annual tidal amplitude is 1.5 m (4.9 ft) at the ocean inlet and varies unequally upstream due to channel morphology. Due to the low gradient of the river, however, tides affect the entire LSJRB along with the lower reaches of its tributaries. The mixing of salt water and fresh water has an influence on water quality as well as on the quantity and characteristics of sediments deposited in LSJRB. Water quality conditions for LSJRB range from good in the sparsely populated southern end of the basin to poor in the urban reaches of Jacksonville (Hand and Paulic 1992).

The *Lower St. Johns River Basin reconnaissance report* provides a synthesis of what is known about the condition of the lower St. Johns River and its tributaries from three perspectives: hydrologic, environmental, and socioeconomic. Volume 1, *Hydrogeology,* presents information on the ground water flow system in the basin and its connection to surface waterbodies. Volume 2, *Surface water hydrology,* discusses the surface water system, including hydrologic and hydraulic data collection networks. Volume 3, *Hydrodynamics and salinity of surface water,* describes relationships between river water levels, velocity, flow, storage, and salinity and reviews previous hydrodynamic modeling studies. Volume 4, *Surface water quality,* and Volume 5, *Sediment characteristics and quality,* present details on the levels and trends of chemical contaminants present in the water column and in the bottom sediments. Volume 6, *Biological resources,* describes plant communities and fish, shellfish, and marine animal communities. Volume 7, *Population, land use, and water use,* ties population estimates and projections to land use and residential, commercial, industrial, and agricultural water use.

Volume 8, *Economic values*, discusses the commercial, recreational, and aesthetic values of the river. Finally, Volume 9, *Intergovernmental management*, discusses jurisdictional boundaries, regulatory authorities, and management efforts of governmental agencies, offices, and commissions involved in restoration or protection of water quality and habitat.

This volume, *Hydrogeology*, examines the relationship and influence of the interconnection between the lower St. Johns River and the ground water flow system associated with the river. Different boundaries delineate the ground water flow system and the surface water basin of the lower St. Johns River (Figure 1.1). Under steady-state conditions, ground water does not flow across the ground water flow system boundary. The major differences between the boundaries of the surface water basin and the ground water flow system are in their eastern and southern boundaries. Minor differences also occur in the northern and western boundaries. The lower St. Johns River ground water flow system underlies all of St. Johns County, most of Flagler, Clay, Duval, and Putnam counties, and the northwestern corner of Volusia County. The lower St. Johns River surface water basin, for comparison, does not include eastern St. Johns and Flagler counties or southwestern and southeastern Putnam County but does include a portion of north-central Volusia County. Discussions in this volume only pertain to the ground water flow system. However, for completeness, most of the graphics cover both the surface water basin and the ground water flow system areas.

Information about the interconnection between the ground water and the surface water systems will be used in the development of a hydrodynamic model for the St. Johns River (volume 3 of this reconnaissance series). The model will address such factors as the effect of surface and ground water discharges on the salinity of the river and the fate of nutrients and pollutants in the river.

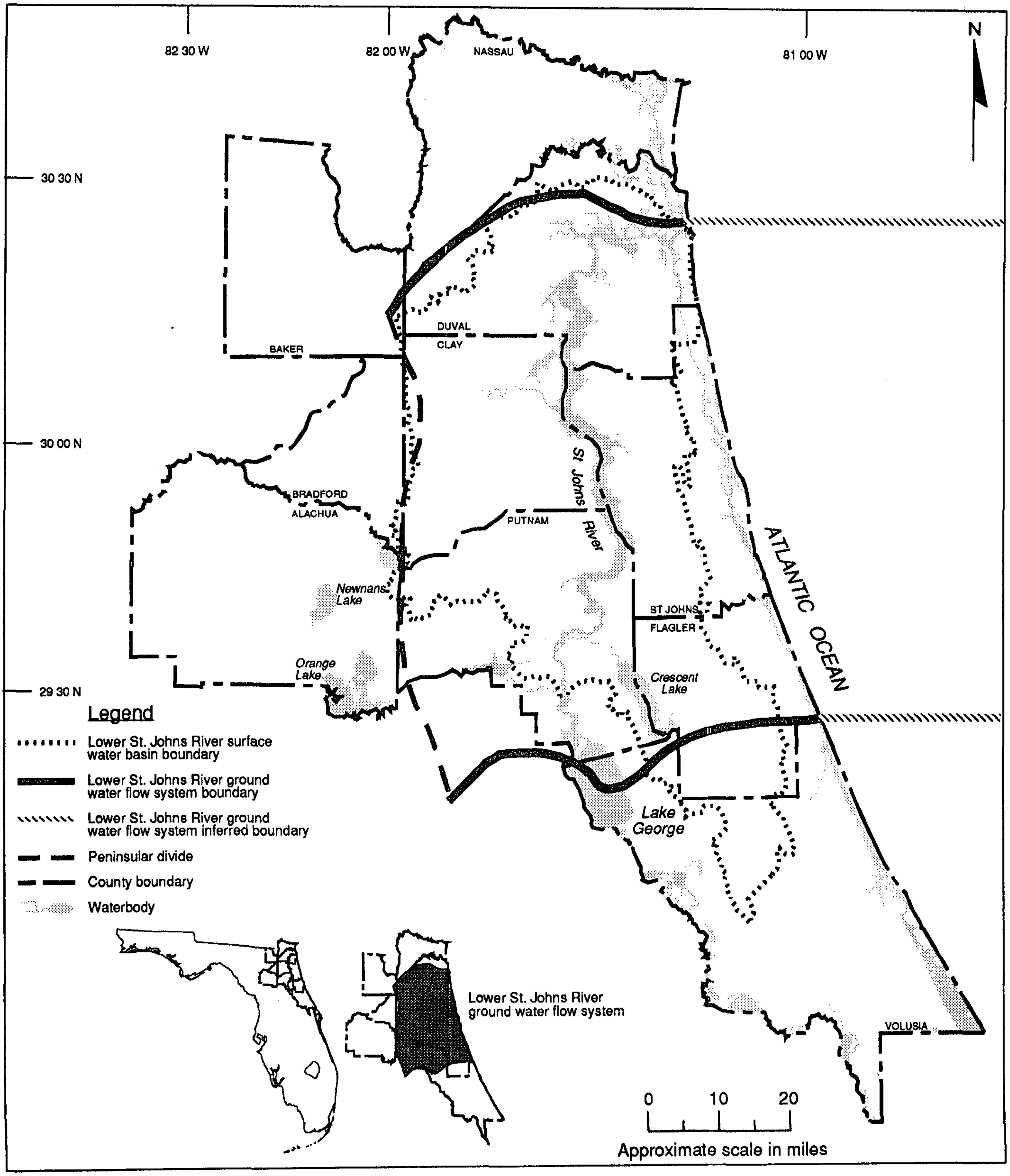

Figure 1.1 The lower St. Johns River ground water flow system and the lower St. Johns River surface water basin

HYDROGEOLOGY

Geology in LSJRB has been discussed in reports by Vernon (1951), Wyrick (1960), Bermes et al. (1963), Clark et al. (1964), Leve (1966), Navoy and Bradner (1987), Snell and Anderson (1970), Spechler and Hampson (1984), and Toth (1990). In general, several thousand feet of sediment overlie the basement complex of granite and other crystalline rocks (Cederstrom et al. 1979, p. 5).

The hydrogeologic framework of the lower St. Johns River ground water flow system consists of three aquifer systems: the Floridan, intermediate, and surficial. The Floridan aquifer system consists of limestone formations from the Paleocene and Eocene epochs (Table 1). The intermediate aquifer system consists of

Table 1. Geologic time scale

Period	Epoch	Time (in million years)
Quarterly	Holocene	0.01
	Pleistocene	1.6
Tertiary	Pliocene	5.3
	Miocene	23.7
	Oligocene	36.6
	Eocene	57.8
	Paleocene	66.4

Miocene deposits of the Hawthorn Group and undifferentiated post-Hawthorn Group sediments. The surficial aquifer system consists of late and post-Miocene surficial deposits.

LIMESTONE

Limestone formations from the Paleocene and Eocene epochs form part of the principal artesian aquifer—the Floridan aquifer system, which is the major source of water in northern Florida. The formations of the Floridan aquifer system include, in order of increasing age, the Ocala, Avon Park, Oldsmar, and the upper part of the Cedar Keys limestones (Table 2 and Figure 1.2).

The formations that comprise the Floridan aquifer system typically vary in depth and thickness throughout the ground water flow system (Figures 1.3 and 1.4). Miller (1986) mapped the thickness and extent of the Floridan aquifer system in Florida and in parts of Georgia, Alabama, and South Carolina. In northern Florida, the limestone formations of the Floridan aquifer system dip and thicken to the northeast (Figure 1.5). In eastern Flagler County, the depth to the top of the Floridan aquifer system is nearly 100 ft below the National Geodetic Vertical Datum (NGVD). The depth to the top increases to 200 ft below NGVD in central St. Johns County and reaches a maximum depth of more than 600 ft below NGVD in Duval County near the St. Johns River. Throughout most of Duval County, the depth to the top of the Floridan aquifer system ranges from 300 ft below NGVD in the western and southern part of the county to 600 ft in the center of the county.

HAWTHORN GROUP

Eocene rocks are overlain by rocks of the Hawthorn Group. The Hawthorn Group consists of early to middle Miocene clay, limestone, and layers of interbedded sand and shell and serves as a confining unit that separates the Floridan aquifer system from the overlying surficial aquifer system (Table 2 and Figure 1.2). The intermediate aquifer system consists of the Hawthorn Group and undifferentiated post-Hawthorn Group sediments. The Hawthorn Group is absent from much of Volusia County and southeastern Flagler and Putnam counties but thickens to the northeast, where it attains a localized maximum thickness of

Table 2. Hydrogeologic framework of the lower St. Johns River ground water flow system (modified from Brown 1984 and Bermes et al. 1963)

Hydrogeologic Unit		Stratigraphy	Approximate Thickness (feet)	Lithology	Hydrogeologic Properties
Surficial aquifer system		Surficial deposits	20 to 175	Discontinuous sand, clay, and shell beds	Sand and shell deposits provide local limited water supplies. Yields moderate to large quantities of water in Duval County and central and eastern Flagler and St. Johns counties and small quantities of water throughout the remainder of the area
Upper confining unit (Intermediate confining unit)		Hawthorn Group	0 to 500	Interbedded phosphatic sand, clay, marl, and limestone	Sand, shell, and limestone deposits provide local, limited water supplies, both artesian and nonartesian. Low-permeability clays serve as the principal confining bed for the Floridan aquifer system below. Important source of water in Clay, Duval, and parts of eastern Flagler and St. Johns counties
Floridan aquifer system	Upper water-bearing zone	Ocala Limestone	0 to 350	Massive fossiliferous chalky to granular marine limestone sequence	Principal source of ground water. High permeability overall. Primary water-producing zone in Flagler, Putnam, and St. Johns counties in the top 50-200 ft of the aquifer
		Avon Park Limestone	60 to 210	Alternating beds of massive granular and chalky limestone and dense dolomites	
	Semi-confining unit				Low-permeability limestone and dolomite
	Middle water-bearing zone		500 to 750		Principal source of ground water
	Semi-confining unit	Oldsmar Limestone	700		Low-permeability limestone and dolomite
	Lower water-bearing zone				Highly permeable; increases in salinity noted
		Cedar Keys Limestone	Unknown	Uppermost appearance of evaporites; dense limestone	Highly mineralized water, very low permeability
Lower confining unit					

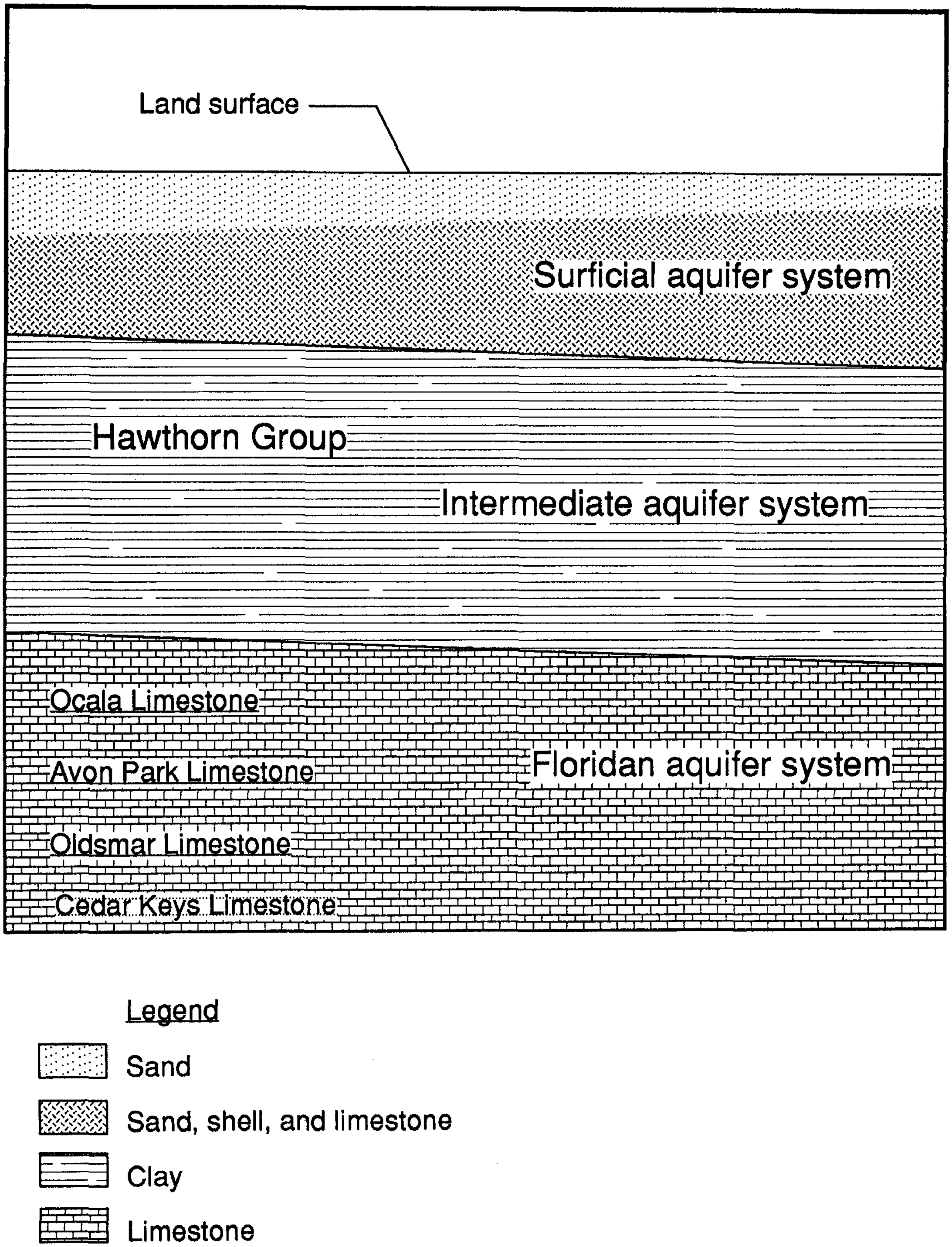

Figure 1.2 **Typical hydrostratigraphic column in the lower St. Johns River ground water flow system**

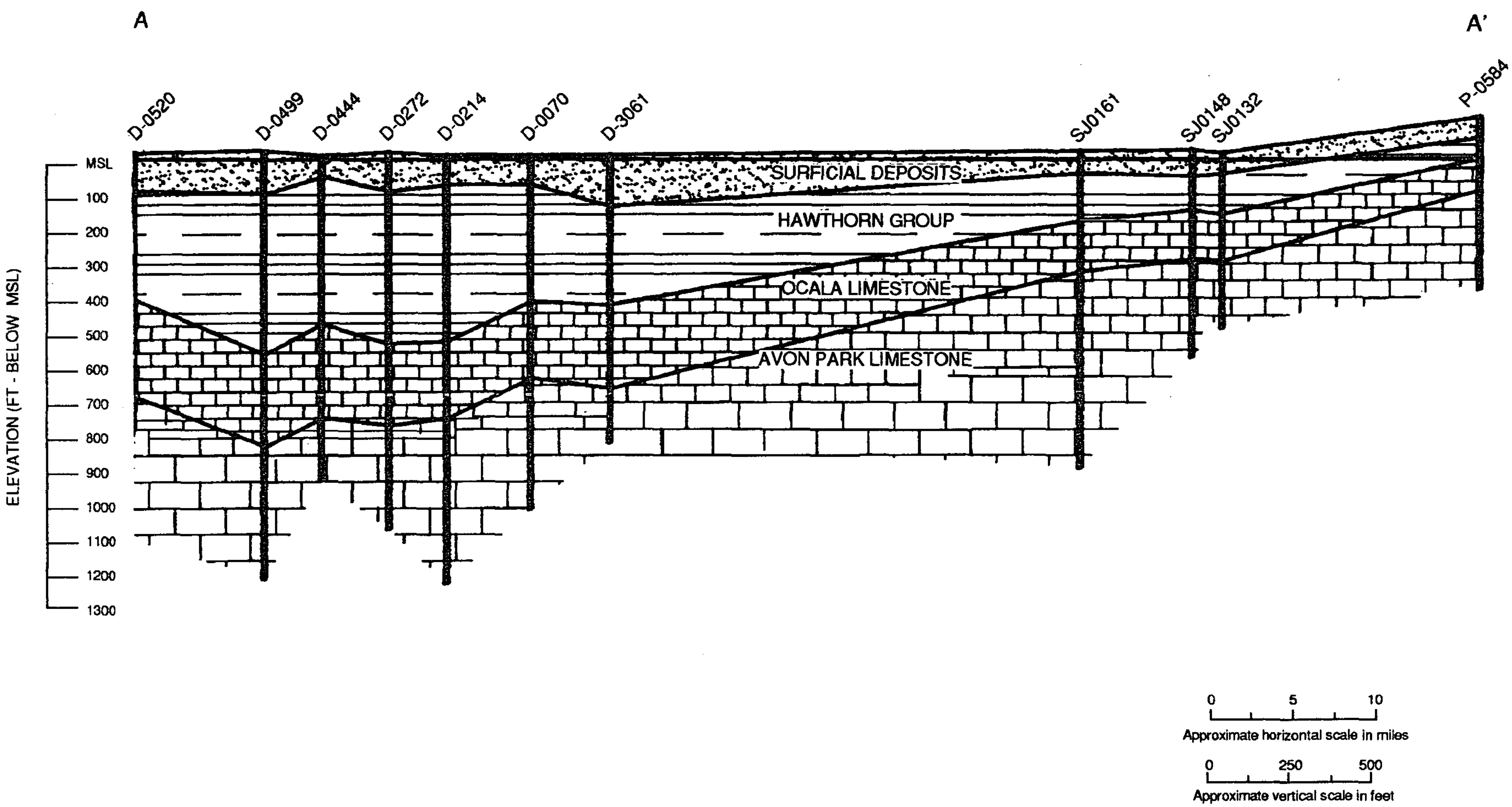

Figure 1.3 Cross section showing geologic structure in the lower St. Johns River ground water flow system

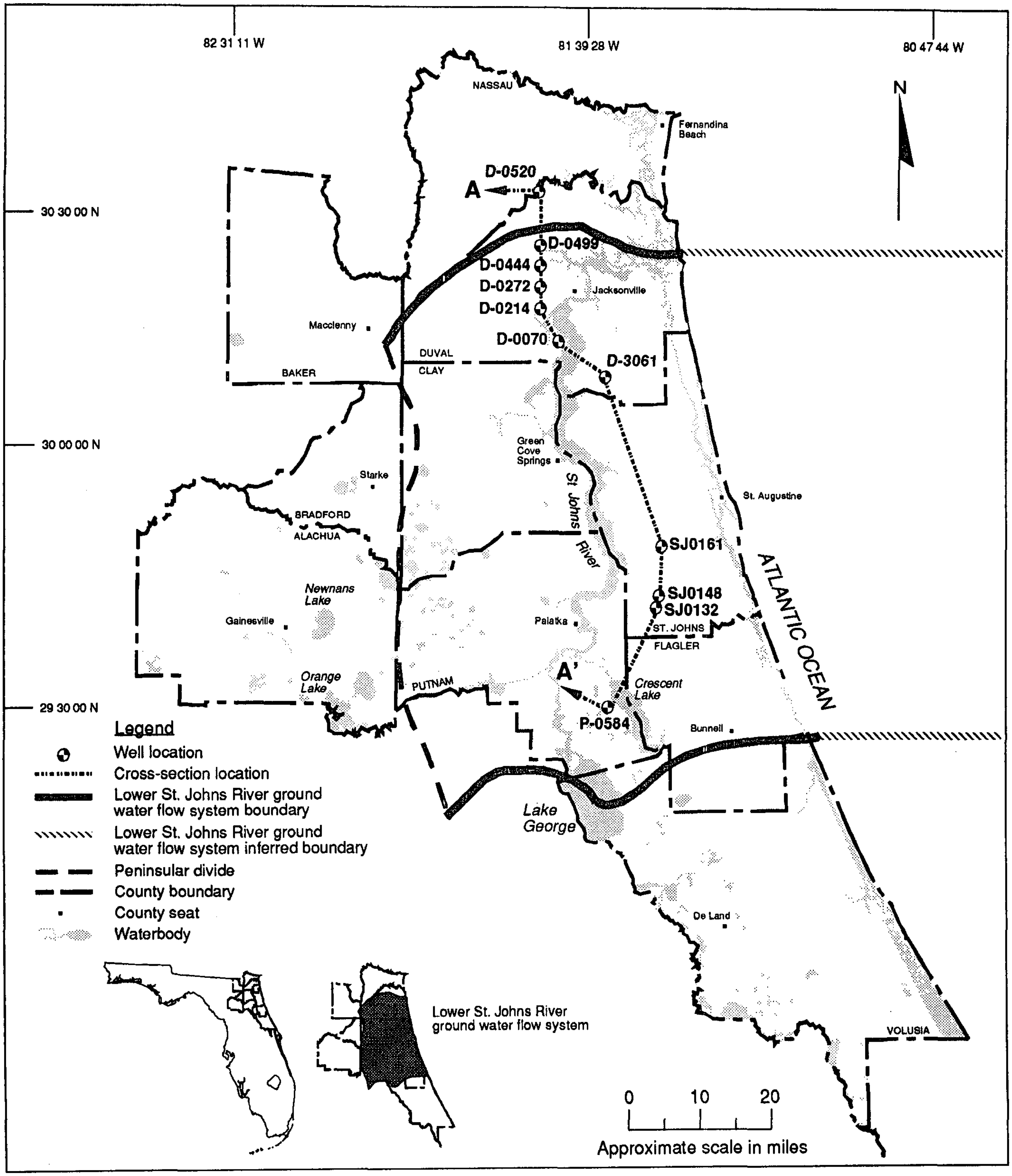

Figure 1.4 Location of cross-section A-A'

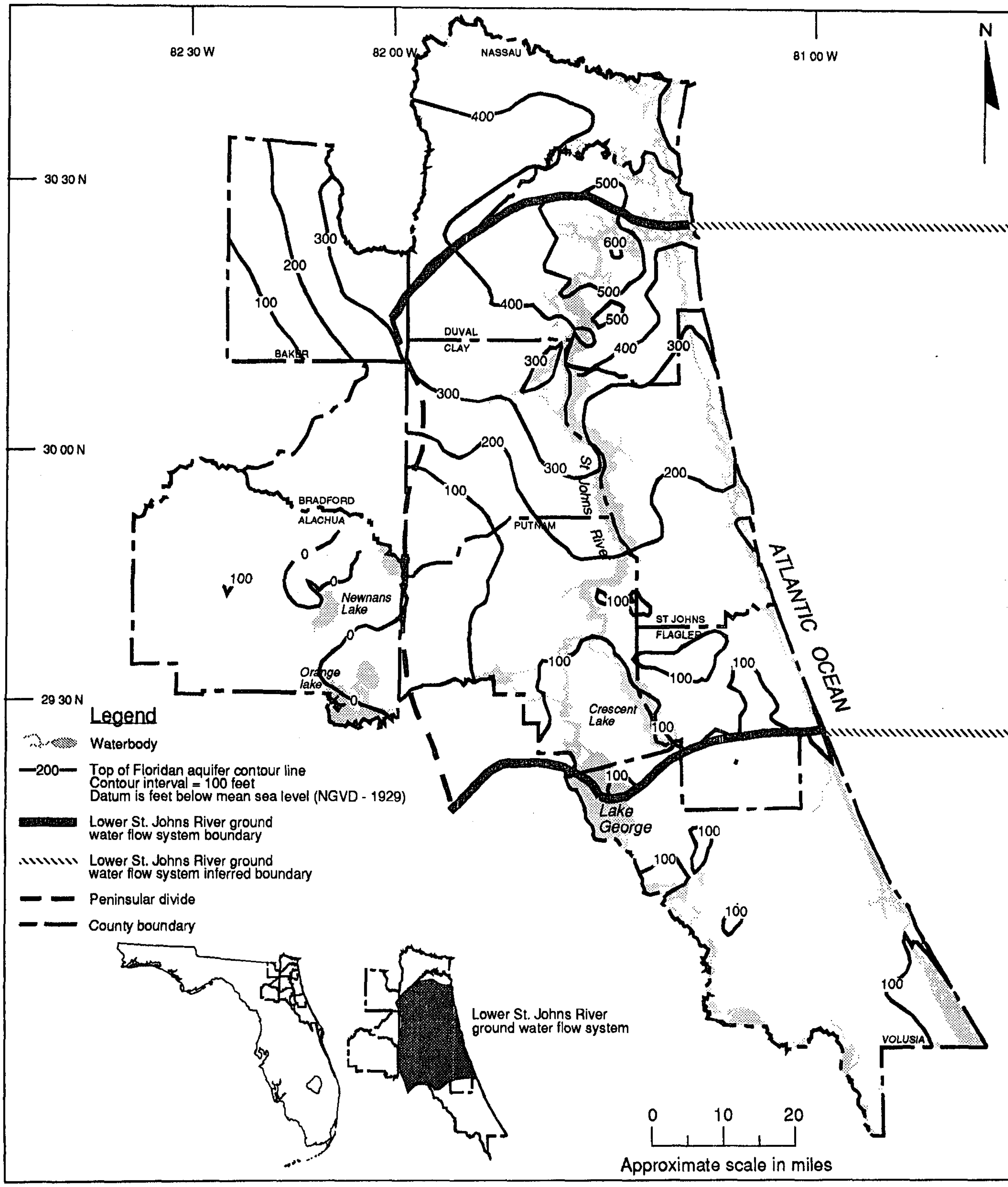

Figure 1.5 **Depth to the top of the limestones of the Floridan aquifer system in the lower St. Johns River ground water flow system**

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT more than 500 ft in central Duval County near the St. Johns River (Figure 1.6).

SURFICIAL DEPOSITS

The surficial aquifer system consists of deposits of extremely variable lithology (clay, sand, coquina, limestone) that overlie the Hawthorn Group (Table 2 and Figure 1.2). Where the Hawthorn Group is absent, the surficial materials rest directly on the Eocene limestone. The thickness of surficial deposits in the lower St. Johns River ground water flow system ranges from less than 50 ft to more than 150 ft (Figure 1.7).

In Duval County, a younger limestone unit occurs at the base of Pliocene or upper Miocene deposits and overlies the Hawthorn Group. This limestone unit generally consists of a soft, friable, cavernous, sandy limestone and ranges from 5 to 40 ft in thickness (Spechler 1982). Along the coast and in the southern part of the county, the limestone becomes discontinuous and grades into medium to coarse sand and shell deposits.

In western Putnam County, the sediments that overlie the Hawthorn Group are non-marine deposits that consist of undifferentiated beds of coarse, poorly sorted sand, kaolin, and variegated sandy clay (the Citronella Formation). These non-marine beds are discontinuous and cannot be differentiated lithologically for any great distance (Bermes et al. 1963).

The sediments that blanket the surface in the lower St. Johns River ground water flow system are from the Pleistocene and Holocene epochs (see Table 1). The Pleistocene deposits consist of fine to medium quartz sand and thin lenses of clay and shell in the eastern part of the area and fine to coarse poorly sorted sand and sandy clay in the western part. Along the coastal islands and inland for approximately 3-10 miles, the Anastasia Formation of the Pleistocene Epoch occurs. The Anastasia Formation primarily consists of shell beds that contain varying amounts of quartz sand, silt, and organic material. The formation extends more than 150 miles south of St. Augustine but rarely extends inland

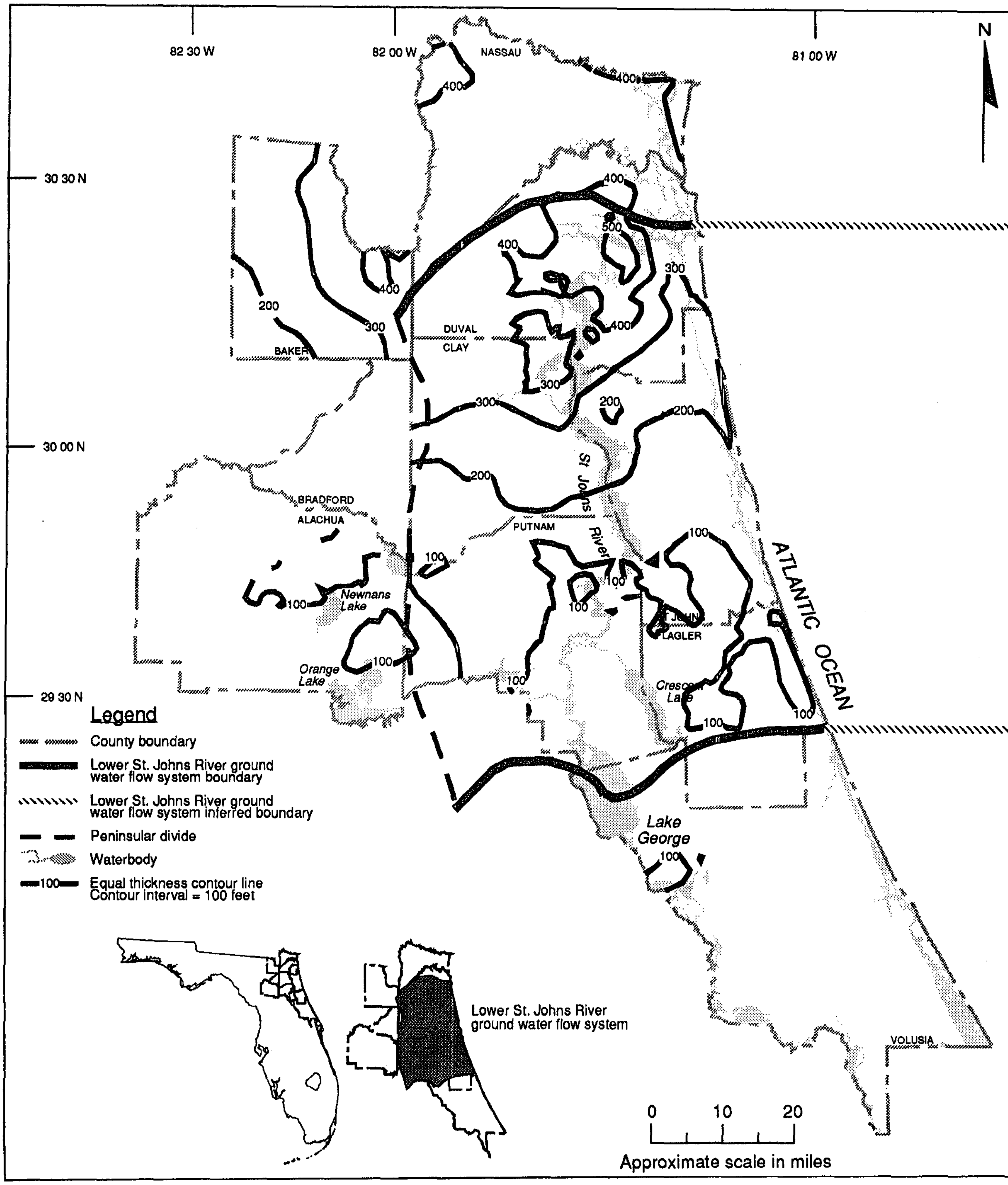

Figure 1.6 Thickness of the Hawthorn Group in the lower St. Johns River ground water flow system

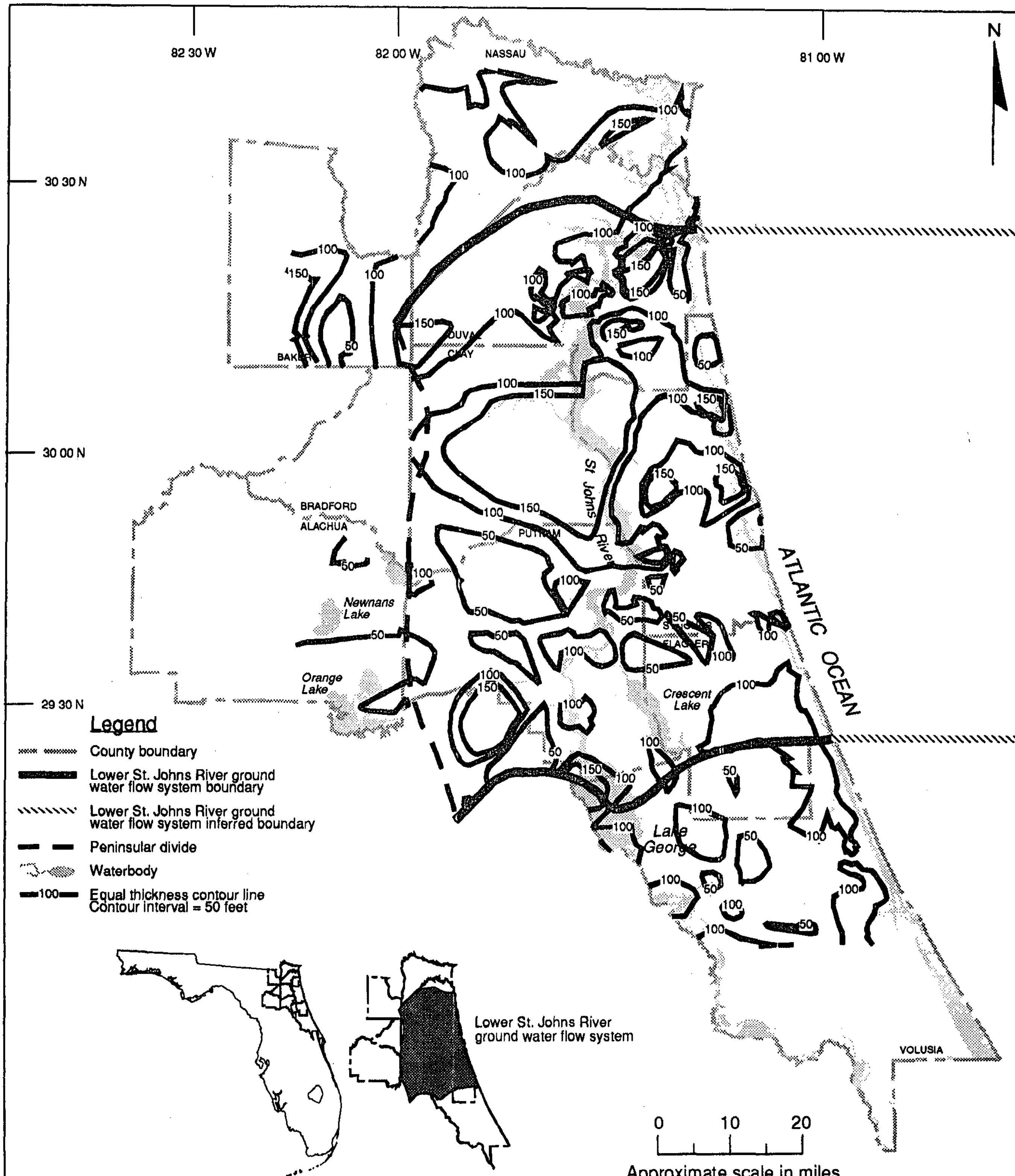

Figure 1.7 **Thickness of surficial deposits in the lower St. Johns River ground water flow system**

beyond the Intracoastal Waterway. Highly variable and undifferentiated Holocene sediments cover the Pleistocene deposits.

AQUIFER SYSTEMS

Aquifers within the lower St. Johns River ground water flow system belong to the Floridan aquifer system, the intermediate aquifer system, or the surficial aquifer system. Each aquifer system has a different influence on river flow. The Floridan aquifer system contributes to river flow directly through spring discharge and indirectly through diffuse upward leakage. The intermediate aquifer system indirectly contributes to river flow through diffuse upward leakage. The surficial aquifer system can discharge directly into the river. Unlike the Floridan and intermediate aquifer systems, the surficial aquifer system is areally in direct contact with the river.

The Floridan aquifer system is the principal artesian aquifer in north Florida and is the one most frequently tapped for water supply. It is tapped for both public supply and domestic self-supply in Duval, St. Johns, Clay, Putnam, Flagler, and Volusia counties (Table 3). Besides public and domestic self-supply, the Floridan aquifer also is used for commercial/industrial self-supply, agricultural irrigation, self-supplied power generation, uncontrolled free-flowing (abandoned artesian) wells, and heating and cooling heat pump units.

Intermediate aquifers occur within the Hawthorn Group or undifferentiated post-Hawthorn sediments and contain limited quantities of potable water. Many domestic water supply wells in Duval, Clay, Flagler, and St. Johns counties tap this source. In Flagler County, the intermediate aquifer system is also tapped for public supply.

The surficial aquifer system is less extensive than the Floridan aquifer system and is tapped when the Floridan aquifer system contains nonpotable water or when the Floridan aquifer system is generally deeper than 200 ft. The surficial aquifer system is tapped as a domestic source of water in Duval, St. Johns, Putnam, Flagler, and Volusia counties and as a public supply source in St. Johns County.

Table 3. Source of water used for public supply and domestic self-supply in the lower St. Johns River surface water basin

County	Public Supply	Domestic Self-supply
Duval	Floridan aquifer system	Floridan aquifer, intermediate aquifer, and surficial aquifer systems
St. Johns	Floridan aquifer and surficial aquifer systems	Floridan aquifer, intermediate aquifer, and surficial aquifer systems
Clay	Floridan aquifer system	Floridan aquifer and intermediate aquifer systems
Putnam	Floridan aquifer system	Floridan aquifer and surficial aquifer systems
Flagler	Floridan aquifer and intermediate aquifer systems	Floridan aquifer, intermediate aquifer, and surficial aquifer systems
Volusia	Floridan aquifer system	Floridan aquifer and surficial aquifer systems

FLORIDAN AQUIFER SYSTEM

In LSJRB, the Floridan aquifer system is composed of an Upper Floridan aquifer and a Lower Floridan aquifer separated by the middle semiconfining unit (Miller 1986). Older and deeper rocks of the Lower Floridan aquifer are not generally tapped by wells in the study area because sufficient water can be obtained from the overlying formations and because the water from deeper rocks is generally more saline.

The primary water-bearing zones in the Floridan aquifer system consist of porous limestone and dolomite. 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 (see Table 2). The upper water-bearing zone consists of the Ocala Limestone and the upper part of the Avon Park Limestone. The thickness of the upper water-bearing zone averages 250 ft at Fort George Island, which is located north of the river near the inlet (Motz 1987). The middle water-bearing zone occurs in the lower part of the Avon Park Limestone and is 575 ft thick at Fort George Island. The lower water-bearing zone occurs in the lower part of the Oldsmar Limestone and is approximately 100 ft thick at Fort George Island (Motz 1987). These zones have been identified at Fernandina Beach, 20 miles north of the lower St. Johns River ground water flow system boundary (Brown 1984). No additional information, however, is available about the thickness of the upper, middle, and lower water-bearing zones beneath the LSJRB boundary. Miller (1986) considered the upper water-bearing zone to be part of the Upper Floridan aquifer. The discussions on the middle and lower water-bearing zones are contained in Miller's (1986) discussion of the Lower Floridan aquifer.

Water within the lower St. Johns River ground water flow system flows from areas of higher hydraulic head to areas of lower hydraulic head in a direction that is generally at right angles to the potentiometric surface contour lines (Figure 1.8). The elevation of the potentiometric surface of the Floridan aquifer system defines the level to which ground water will rise in tightly cased wells that penetrate the aquifer system. The elevation of the potentiometric surface fluctuates both seasonally and yearly. Water within the Floridan aquifer system that affects the lower St. Johns River surface water basin generally flows eastward.

Recharge

Recharge to the Floridan aquifer system is the addition of water to the Upper Floridan aquifer from the overlying surficial aquifer or, more directly, from rainfall in areas where the surficial aquifer is thin or absent and the limestones of the Floridan aquifer are at or near land surface. Recharge to the Upper Floridan aquifer also can occur from the underlying Lower Floridan aquifer. Principal

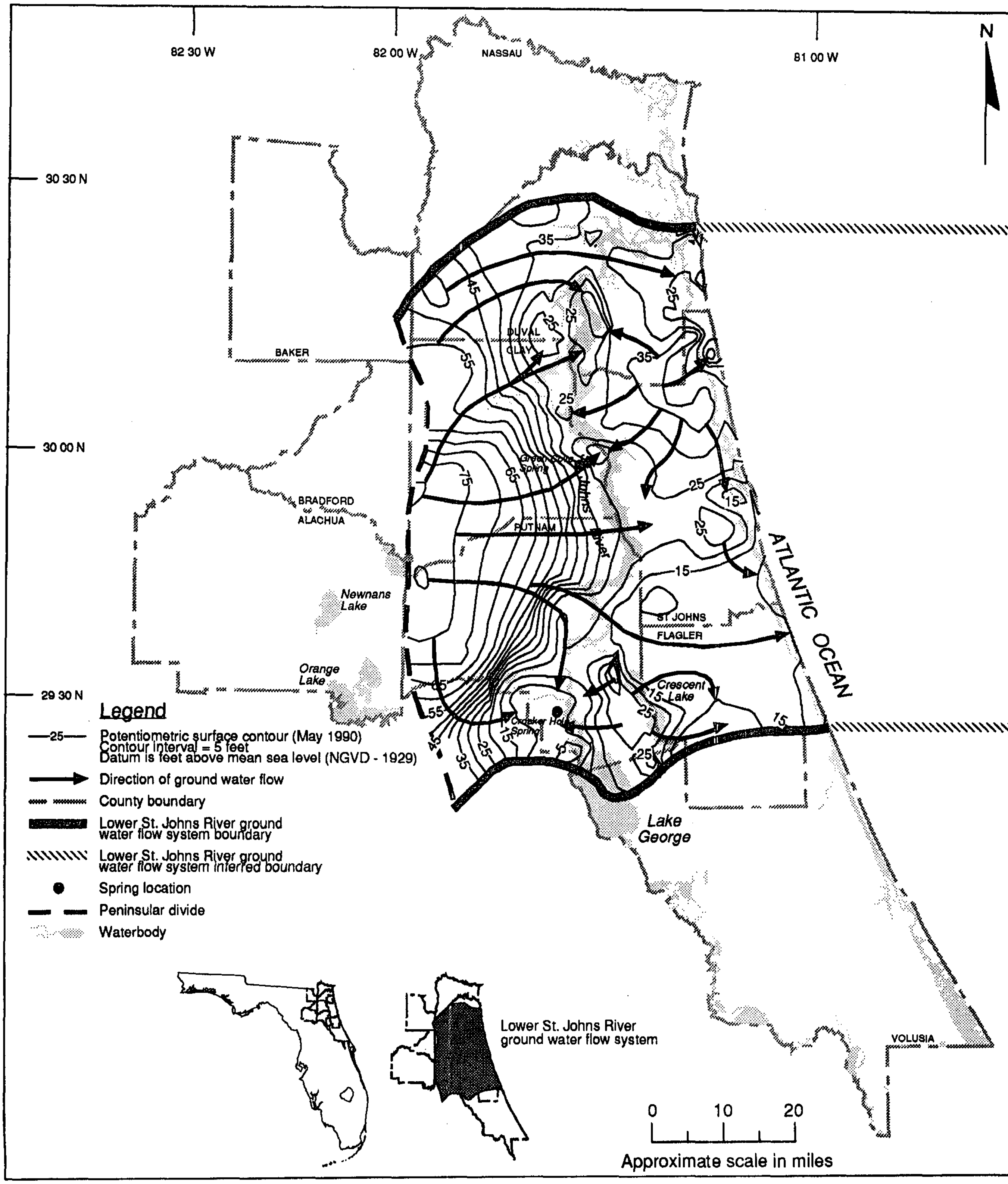

Figure 1.8 **Direction of flow in the Floridan aquifer system of the lower St. Johns River ground water flow system (based on potentiometric surface contours)**

recharge areas for the Floridan aquifer system in the lower St. Johns River ground water flow system and surface water basin occur in southwestern Clay County, northwestern and southeastern Putnam County, and northwestern and west-central Volusia County (Figure 1.9) (Boniol et al. 1993). Areas of recharge of 0-4 or 4-8 inches per year occur in western Duval and Clay counties, western and southeastern Putnam County, northwestern Volusia County, and central St. Johns and Flagler counties.

The lake region of southwestern Clay and northwestern Putnam counties is recognized as an area with a relatively high potential for lake-level decline in response to lowered Floridan aquifer potentiometric levels (Motz and Heaney 1991, 1992). This interconnection is important because these lakes are part of the Etonia Creek chain of lakes that discharges to a tributary of the St. Johns River.

Discharge

Discharge from the Floridan aquifer system can be direct (e.g., wells or springs) or discharge can be indirect or diffuse (e.g., diffuse upward leakage to overlying aquifer systems). Generally, discharge occurs in the eastern portion of LSJRB (see Figure 1.9). Outside LSJRB but within the lower St. Johns River ground water flow system, discharge occurs off-shore in the Atlantic Ocean. Paleosinkholes occur in the St. Johns River near Blount Island (about 8 miles upstream from the mouth of the St. Johns River) (Spechler 1993).

When the elevation of the potentiometric surface of the Floridan aquifer system is higher than the elevation of the water table of the surficial aquifer system, water from the Floridan aquifer system will leak upward to the intermediate aquifer and surficial aquifer systems. When the potentiometric surface of the Floridan aquifer system is higher than land surface, wells drilled into the Floridan aquifer system, unless capped or valved, will flow freely at land surface. In the lower St. Johns River ground water flow system, free-flowing wells can occur in eastern Duval and

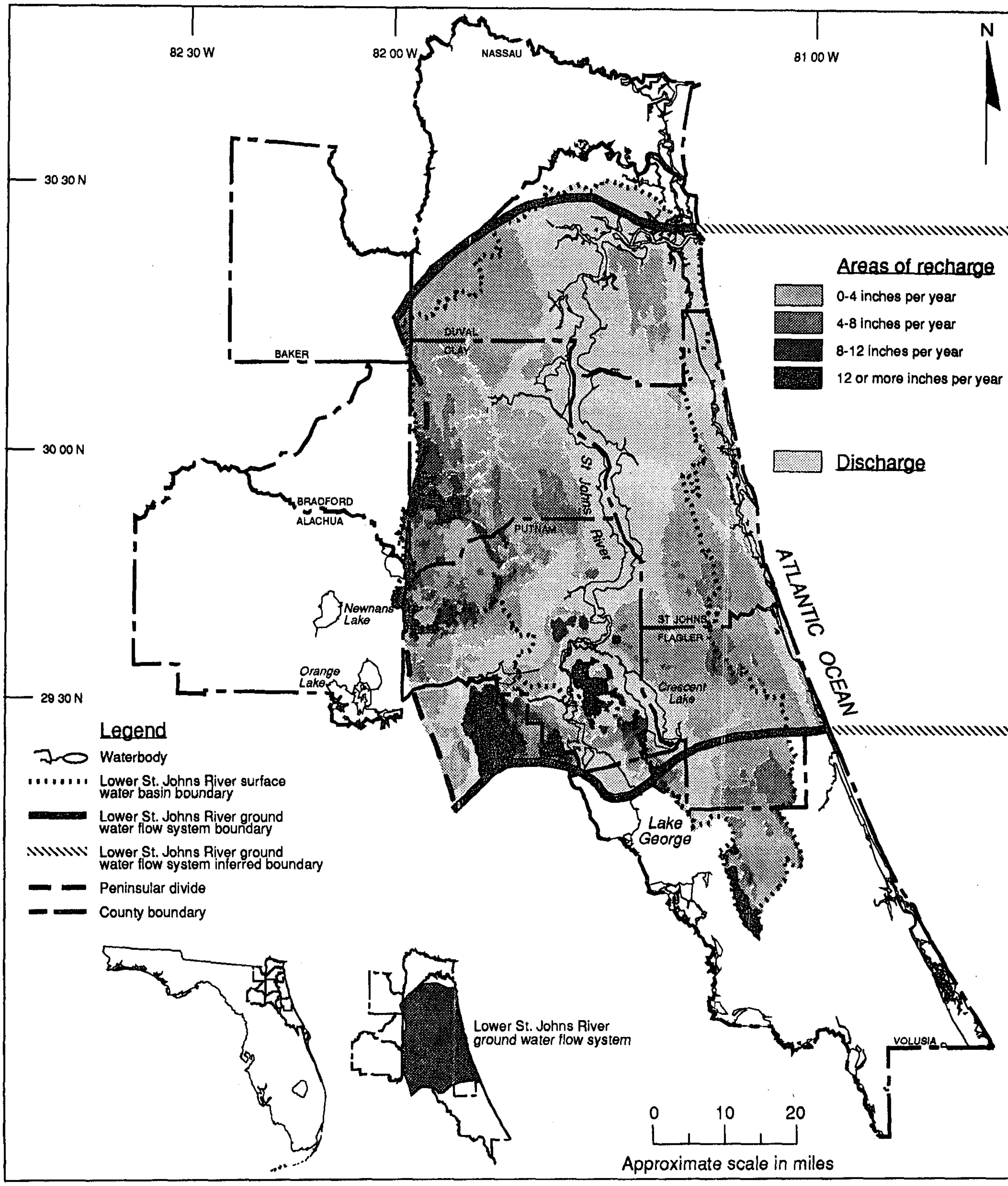

Figure 1.9 Areas of natural recharge and discharge of the Floridan aquifer system in the lower St. Johns River ground water flow system and the lower St. Johns River surface water basin

Putnam counties, northeastern Clay County, and in both eastern and western St. Johns and Flagler counties.

Along the coast south of St. Augustine, the elevation of the potentiometric surface slopes toward the southeast as a result of submarine discharges. Crescent Beach Spring, a submarine spring about 2.5 miles east of Crescent Beach (Figure 1.10), has been described by Stringfield and Cooper (1951, p. 63) and Brooks (1961). Red Snapper Sink is located about 22.5 miles east of Crescent Beach Spring; it is situated in water about 88 ft deep (Rosenau et al. 1977).

Depressions in the elevation of the potentiometric surface generally indicate discharge areas for the Floridan aquifer system (see Figure 1.8). The depression at Green Cove Springs in Clay County is due to a combination of ground water withdrawals from domestic and public supply wells at Green Cove Springs, pumping from irrigation wells just south of the area, and the natural discharge from the spring at Green Cove Springs (Toth 1990). In this area, the Floridan aquifer system loses approximately 46 cubic feet per second (ft^3/sec) to the surficial aquifer system, the intermediate aquifer system, the river, or a combination of all three as a result of spring discharge and diffuse upward leakage (Durden 1991). An unknown part of this discharge of 46 ft^3/sec could be attributed to additional unconfirmed springs discharging in the vicinity of Green Cove Springs.

A depression in the elevation of the potentiometric surface in southern Putnam County is probably due to Floridan aquifer system discharge at Croaker Hole Spring (see Figure 1.8). Croaker Hole Spring is a relatively deep, small-diameter hole in the bottom of the St. Johns River at Little Lake George. Little Lake George is about 5-9 ft deep except in the immediate vicinity of Croaker Hole, where it plunges to a depth of about 48 ft. The discharge of Croaker Hole Spring was about 80 ft^3/sec on September 17, 1981 (Tibbals 1990).

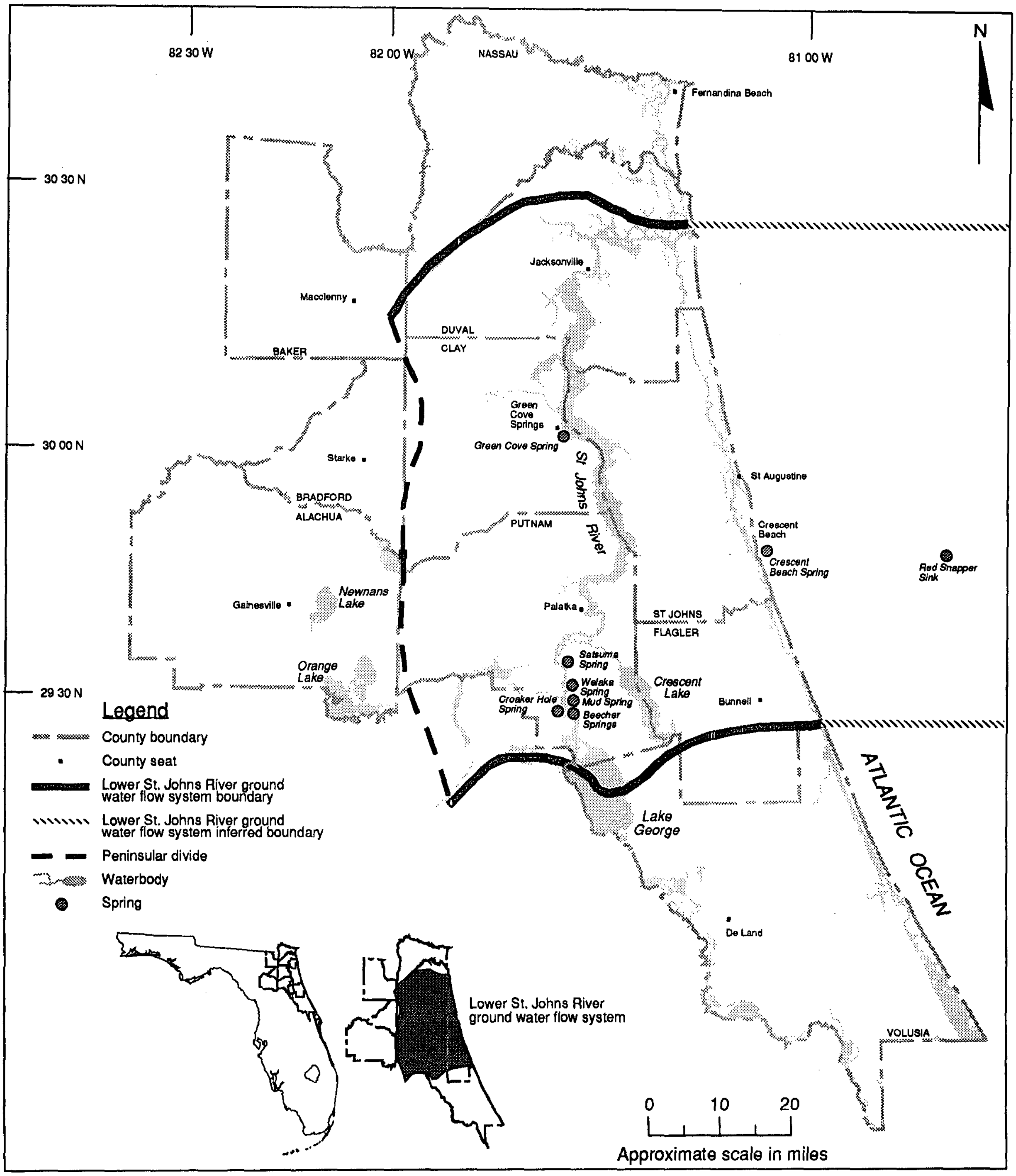

Figure 1.10 Major springs in the lower St. Johns River ground water flow system

Beecher Springs, Welaka Spring, Satsuma Spring, and Mud Spring also occur in southern Putnam County near the St. Johns River (Figure 1.10). The discharge of Beecher Springs was 9 ft^3/sec on April 20, 1972 (Tibbals 1990). The discharge from Welaka Spring was so small that is could not be measured on June 8, 1972. The discharge from Satsuma Spring was 1 ft^3/sec on November 13 and 14, 1980, and the discharge from Mud Spring was 2 ft^3/sec on June 8, 1972 (Tibbals 1990). All of the previous spring discharges are low-flow measurements made during periods of deficient rainfall; therefore, the discharges probably represent a minimum flow for the period 1972-81.

A daily total of approximately 59.5 million gallons per day (mgd)—92 ft^3/sec—of Floridan aquifer system water is discharged into the St. Johns River through these springs (not including Green Cove Spring and the other possible springs in the vicinity of Green Cove Springs). This is a substantial amount of ground water discharged in a day. For comparison, the City of Jacksonville withdrew an average 70.49 mgd from the Floridan aquifer system in 1990 for public supply (Florence 1992). The combined discharge of Floridan aquifer system water to the St. Johns River, however, is a minor amount of the total surface water flow. For comparison, the mean total discharge of the St. Johns River at Palatka and Jacksonville is approximately 5,900 and 7,300 ft^3/sec, respectively (Morris 1993).

The depression in the elevation of the potentiometric surface of the Floridan aquifer system in central and western Flagler County (see Figure 1.8) is probably caused by diffuse upward leakage and possibly by discharge from unconfirmed submerged springs near the southeast side of nearby Crescent Lake. Computer modeling suggests that the rate of diffuse upward leakage in the area is about 16 ft^3/sec (Tibbals 1981).

Several Floridan aquifer system wells discharge water to Etonia Creek near its confluence with Rice Creek, a tributary to the St. Johns River. This ground water, about 17 mgd, is used to support operations of a pulp and paper mill that withdraws water from Rice Creek downstream of the confluence.

The U.S. Geological Survey is conducting a study to estimate the natural discharge and chemical-constituent loading from the Upper Floridan aquifer to the lower St. Johns River in the lower St. Johns River surface water basin. In addition, SJRWMD is developing ground water flow and water quality models to be used as tools for predicting changes in potentiometric levels and water quality in response to changes in rates of ground water withdrawals. These models can be used to predict changes in spring discharge in response to changes in ground water withdrawals.

Quality of Ground Water

Chloride, sulfate, and total dissolved solids (TDS) are common indicators of the presence of saline water in the Floridan aquifer system. These three constituents vary widely in concentrations in the lower St. Johns River ground water flow system, and, in some instances, concentrations of these constituents exceed the public drinking water standards (i.e., chloride—250 milligrams per liter [mg/L], sulfate—250 mg/L, and TDS—500 mg/L). Moderately saline water (chloride and sulfate concentrations between 250 and 1,000 mg/L and TDS concentrations between 500 and 3,000 mg/L) in the Floridan aquifer system enters the overlying surface water system through direct discharge from springs or through diffuse upward leakage.

Chloride. Chloride concentration is a primary indicator of the presence of seawater in ground water. In the lower St. Johns River ground water flow system, chloride concentrations are generally below 50 mg/L in the northern and western part of LSJRB but increase to over 1,000 mg/L in southern Flagler County (Figure 1.11). This information is based on data collected from wells less than 1,400 ft deep. The deepest wells sampled (depths near 1,400 ft) are located in Duval County where chloride concentrations are generally below 50 mg/L. In Volusia County, chloride concentrations are below 250 mg/L in the middle of the county but increase to over 1,000 mg/L in both the eastern and

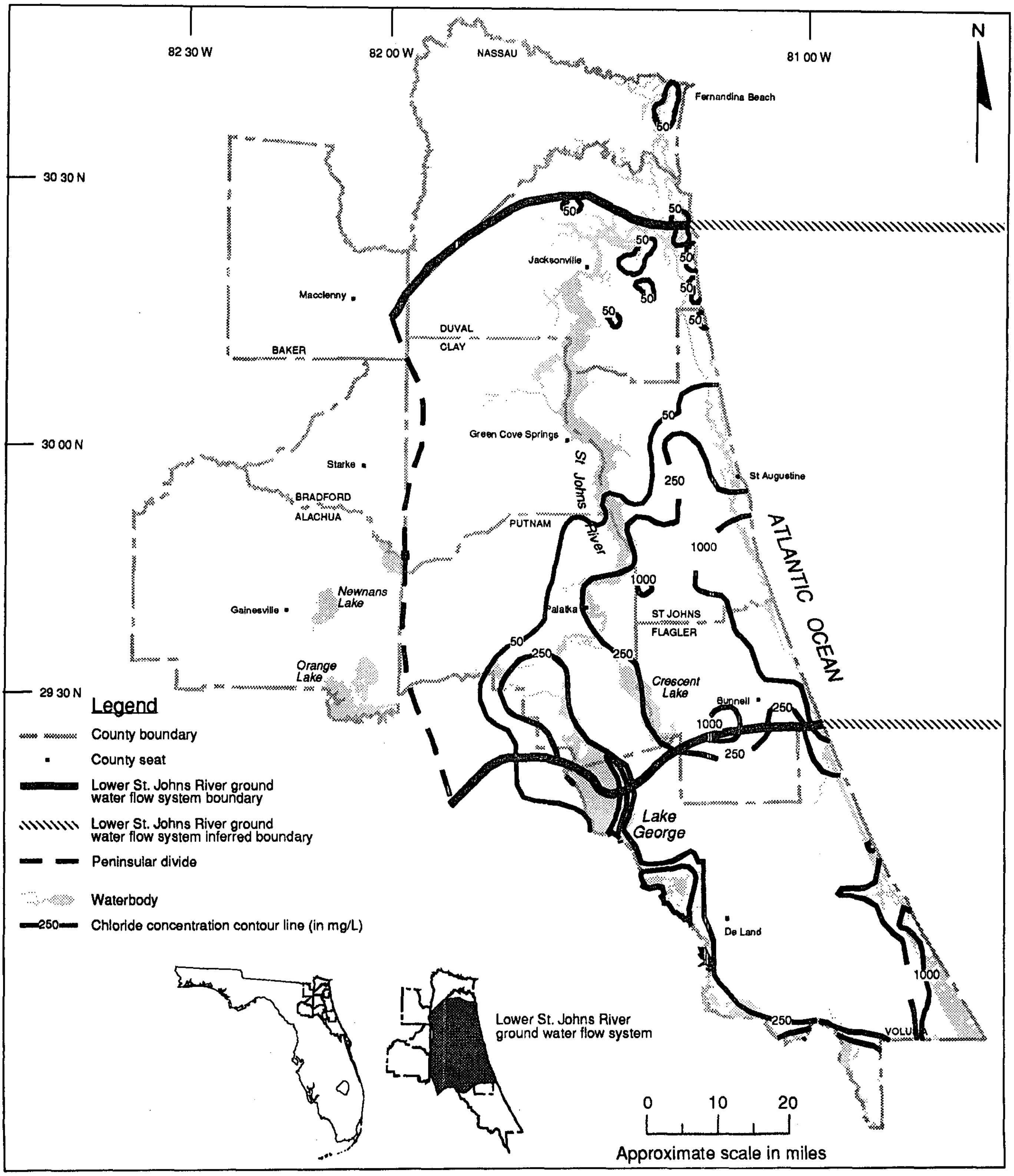

Figure 1.11 **Chloride concentrations in the Upper Floridan aquifer of the lower St. Johns River ground water flow system.** *Data are from 1965 to 1987 for wells less than 1,400 feet deep.*

western portions of the county (along the Atlantic coast and along the St. Johns River).

In the Floridan aquifer system, moderately saline water containing chloride concentrations between 250 and 1,000 mg/L is present beneath part of the St. Johns River in Putnam County and in southern St. Johns and northern Flagler counties. Discharge from hundreds of irrigation wells in southern St. Johns and central Flagler counties seasonally lowers the elevation of the potentiometric surface in the area and causes highly mineralized water to move upward into the production zones of those wells (Bermes et al. 1963). As a result, some wells that yield fresh water during nonpeak irrigation demand months yield moderately saline water during the crop-growing season. Area agricultural drainage districts control irrigation and stormwater runoff that connects with the St. Johns River. SJRWMD currently is analyzing data that will give scientists an idea of the influence of the quality of the ground water pumped for agricultural purposes on the surface water system.

Localized areas where chloride concentrations are above 50 mg/L occur along the coast and near the St. Johns River in Duval and northern St. Johns counties. These areas of higher chlorides are probably due to upward movement of higher chloride waters that exist at depth (Toth 1990). Chloride concentrations above 7,000 mg/L occur in the Lower Floridan aquifer at depths greater than 2,000 ft below mean sea level in the coastal portions of northeast Florida (Leve 1983). Some areas with chloride concentrations above 50 mg/L occur near the north-south faults mapped by Miller in 1982 (Figure 1.12), suggesting that the faults may be the avenue for some of this upward movement. According to Miller (1982), displacements of between 50 and 100 ft may occur along these faults. None of the faults appear to have an effect on ground water flow within the Floridan aquifer system, probably because permeabilities are similar on both sides of the faults. Spechler (1993) speculated that paleokarst features in this area may provide avenues for this upward movement.

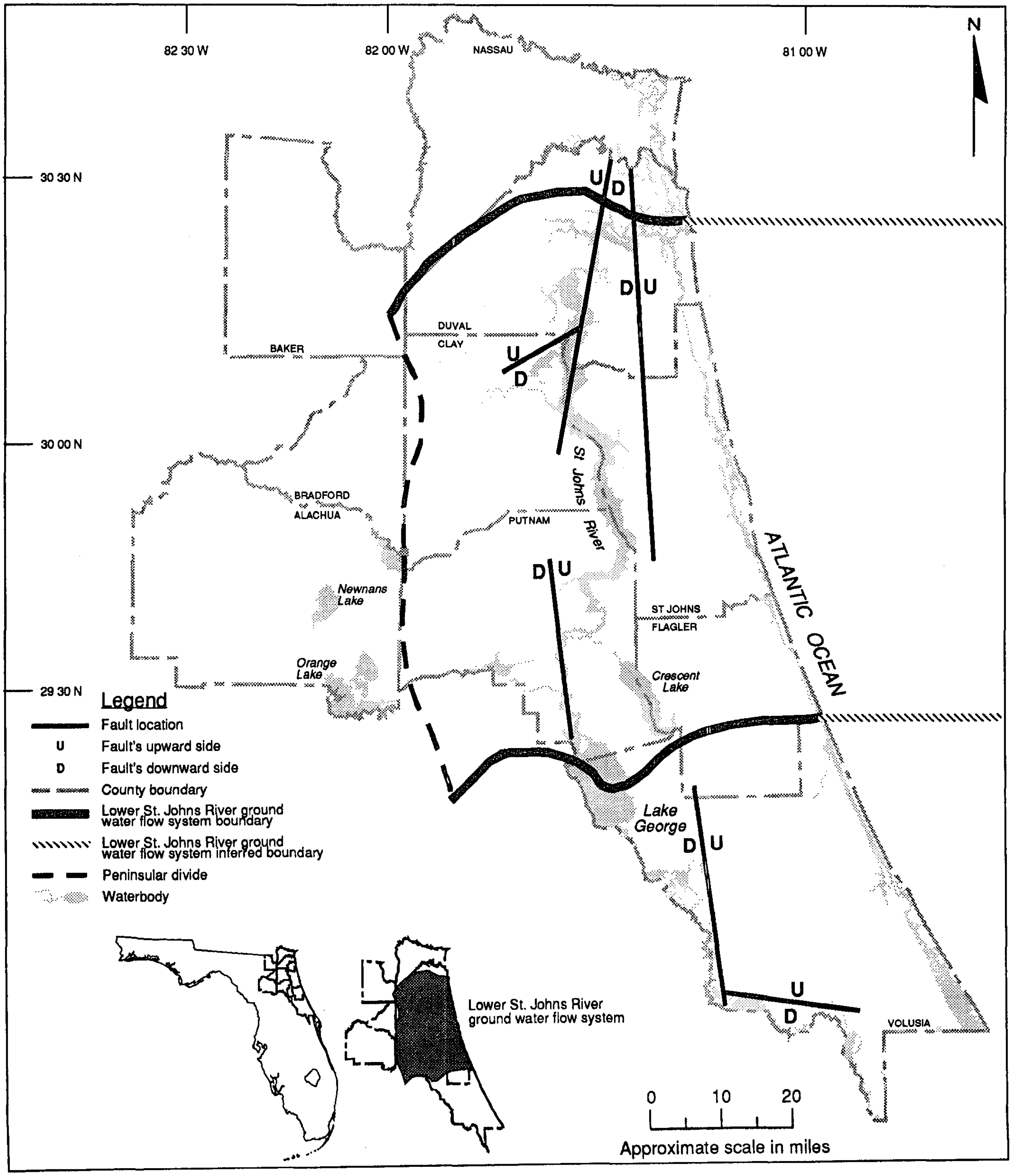

Figure 1.12 **Location of possible faults in the lower St. Johns River ground water flow system**

Source: Miller 1982

In areas of the aquifer where chloride concentrations are greater than 250 mg/L, water also has the relative chemical composition of seawater, connate water, or relict (fossil) seawater. Connate water refers to water of a marine or non-marine origin that has been out of contact with the atmosphere for an appreciable part of geologic time. It is water that was entrapped in the rocks when the rocks were deposited as sediment. Compared to seawater, connate water is enriched in calcium, magnesium, and sulfate. Relict seawater is water that was entrapped in the rocks during a past geologic age when seawater inundated the Florida peninsula, such as occurred during the Pleistocene Epoch. Relict seawater is similar in composition to seawater and can be distinguished from it only by isotopic analysis.

Sulfate. The Upper Floridan aquifer contains sulfate concentrations which vary throughout the lower St. Johns River ground water flow system (Figure 1.13). The source of sulfate in the Floridan aquifer system is dissolution of gypsum and anhydrite, the oxidation of iron sulfides, or the mixing of either relict seawater or connate water with fresher water. The dissolution of sulfur minerals is a slow process and can increase the concentrations of sulfate by a rate of 1-8 mg/L per 100 years (Toth 1990). Sulfate concentrations are generally below 50 mg/L in the western part of the ground water flow system but increase to above 500 mg/L in southern and eastern St. Johns County and northeastern Flagler County. This information is based on data collected from wells less than 1,400 ft deep. The deepest wells sampled (depths near 1,400 ft) are located in Duval County where sulfate concentrations are generally below 250 mg/L. Moderately saline water in the Floridan aquifer system (sulfate concentrations between 250 and 1,000 mg/L) is present in much of St. Johns, northern and southwestern Flagler, northeastern Putnam, and western Volusia counties.

Total dissolved solids. TDS concentrations in the Upper Floridan aquifer also vary dramatically throughout the lower St. Johns River ground water flow system (Figure 1.14). TDS concentration is the sum of all dissolved constituents in ground water. It includes sodium, potassium, calcium, magnesium,

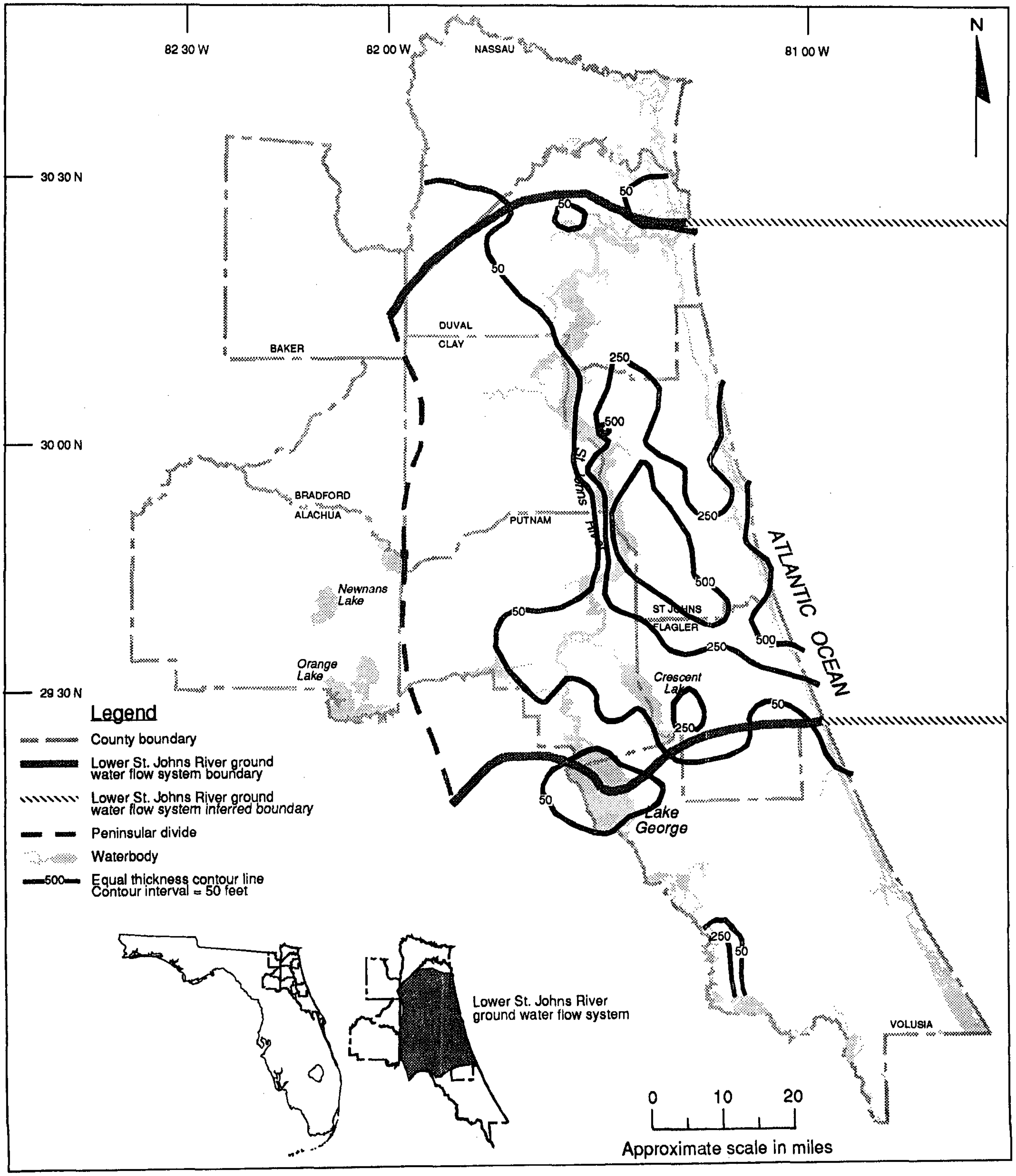

Figure 1.13 **Sulfate concentrations in the Upper Floridan aquifer of the lower St. Johns River ground water flow system**

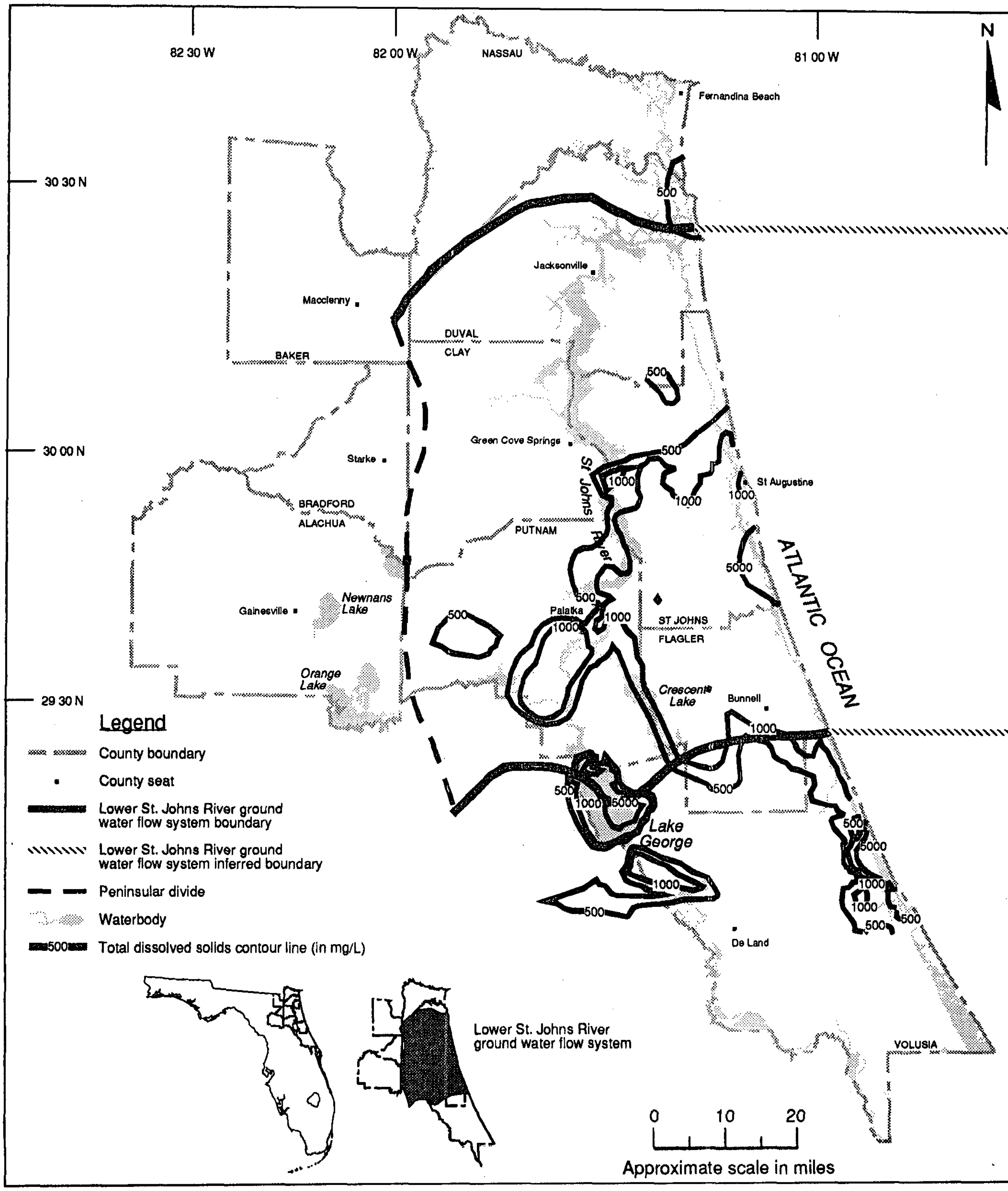

Figure 1.14 **Total dissolved solids in the Upper Floridan aquifer of the lower St. Johns River ground water flow system**

chloride, sulfate, bicarbonate, iron, silica, and other minor components dissolved in water. TDS concentrations are generally below 500 mg/L in the western and northern part of the ground water flow system but increase to above 5,000 mg/L in southeastern St. Johns County and northwestern and eastern Volusia County. This information is based on data collected from wells less than 1,400 ft deep. The deepest wells (depths near 1,400 ft) are located in Duval County, where TDS concentrations are generally below 500 mg/L. Moderately saline water containing TDS concentrations between 500 and 3,000 mg/L in the Floridan aquifer system is present in southern St. Johns, eastern Putnam, most of Flagler, eastern and western Volusia, and northeastern Duval counties.

In addition to measuring TDS from well water, TDS and other water quality parameters can be measured from spring discharge. For example, the quality of ground water discharging from Croaker Hole Spring was measured in 1981. "The temperature and dissolved solids concentration of the spring water were 23°C and 1,430 mg/L, respectively. The temperature and dissolved solids concentration of the river water immediately upstream from the spring were 25°C and 680 mg/L, respectively. The spring water in September was colder, more mineralized, and thus denser than the river water. The denser spring water probably flowed up the spring bore and moved downstream along the bottom of the river" (Tibbals 1990). Chloride and sulfate concentrations of the spring water were 680 and 160 mg/L, respectively; the chloride and sulfate concentrations of the upstream river water were 280 and 84 mg/L, respectively (Tibbals 1990).

INTERMEDIATE AQUIFER SYSTEM

The intermediate aquifer system is not areally extensive, but occurs in portions of Duval, St. Johns, Clay, Putnam, and Flagler counties. It ranges from less than 10 to about 300 ft below mean sea level and varies in thickness from less than 1 to about 15 ft (Bermes et al. 1963).

Intermediate aquifers within the Hawthorn Group or undifferentiated post-Hawthorn sediments are an important source of water in Duval, Clay, and parts of eastern Flagler and St. Johns counties.

More precise information is needed about the geographic location, depth, and thickness of the intermediate aquifer system. More information also is needed about the relationship of the intermediate aquifer system with the overlying surficial aquifer system and the underlying Floridan aquifer system.

Recharge

Intermediate aquifers are recharged from at least two different sources, depending on potentiometric pressures. When potentiometric levels in the surficial aquifer system are greater than those in the intermediate aquifer system, the intermediate aquifer system is recharged by downward leakage from the surficial aquifer system. Similarly, when potentiometric levels in the Floridan aquifer system are greater than those in the overlying intermediate aquifer system, the intermediate aquifer system is recharged by upward leakage from the Floridan aquifer system.

Discharge

Intermediate aquifers discharge to two different sources, depending on potentiometric pressures. When potentiometric levels in the intermediate aquifer system are greater than those in the surficial aquifer system, the intermediate aquifer system loses water by upward leakage to the surficial aquifer system. When potentiometric levels in the intermediate aquifer system are greater than the elevation of the potentiometric surface of the Floridan aquifer system, the intermediate aquifer system loses water by downward leakage to the underlying Floridan aquifer system.

Quality of Ground Water

Chloride, sulfate, and TDS are common indicators of the presence of saline water in the intermediate aquifer system. Where the intermediate aquifer system contains moderately saline water (chloride and sulfate concentrations between 250 and 1,000 mg/L and TDS concentrations between 500 and 3,000 mg/L), the water could enter the overlying surface water system through diffuse upward leakage.

Water in the intermediate aquifer system is derived locally either by upward leakage from the underlying Floridan aquifer system or by downward leakage from the overlying surficial aquifer system. Water quality in the intermediate aquifer system is similar to the water quality in one of the other aquifer systems within the same general area. In the deep intermediate aquifers, the quality of water usually is similar to water in the underlying Floridan aquifer system, and in the shallow intermediate aquifers the quality of water usually is similar to water in the overlying surficial aquifer system (Bermes et al. 1963). Navoy and Bradner (1987) specify chloride and TDS concentrations for the intermediate aquifer in Flagler County. Chloride concentrations ranged from 21 to 1,230 mg/L; TDS concentrations ranged from 356 to 2,016 mg/L. The higher values occurred beneath the barrier island. West of the Intracoastal Waterway, chloride and TDS concentrations were less than 200 mg/L and 704 mg/L, respectively. Little additional information has been published on the chloride, sulfate, or TDS concentrations of the intermediate aquifer in LSJRB. More precise information about the water quality of the intermediate aquifer system needs to be collected.

SURFICIAL AQUIFER SYSTEM

The surficial aquifer system is the principal source of potable water in St. Johns County and an important source of domestic self-supply water in Duval and Flagler counties. In most of Duval County, a limestone unit is the principal water-producing unit in the surficial aquifer system. Water in the surficial aquifer system generally is unconfined. In swampy lowland and flatland areas, the water table is generally at or near land surface throughout most of the year.

The general direction of surficial ground water flow is away from ridges (Bergman 1992). Ridges occur along the coast in Duval, St. Johns, and Flagler counties and in southeastern Putnam County (Bergman 1992). Uplands, or areas of higher land, occur in western Clay and Putnam counties. In these areas, the water table is generally a subdued reflection of the topography, but it can be 10-30 ft below land surface.

More precise information has not been documented or mapped regarding the distribution and thickness of the surficial aquifer system and about the water levels in the surficial aquifer system of the lower St. Johns River ground water flow system. Information regarding water levels in the water table of the surficial aquifer system is particularly lacking. All of this information would be useful to support the development of ground water flow models. Model simulations can estimate the amount of surficial aquifer system water discharging to the lower St. Johns River surface water basin.

Recharge

The surficial aquifer system is recharged by local rainfall, irrigation, some lakes, ditches, streams, septic tank effluent, sewage or stormwater holding pond effluent, and, in areas where the elevation of the potentiometric surface of the Floridan aquifer system is above the water table, upward leakage from the Upper Floridan aquifer. The surficial aquifer system is generally recharged at the ridges and water moves away from the ridges toward the St. Johns River and the coast.

Discharge

Water leaves the surficial aquifer system by seepage to some lakes, ditches, and streams; by evapotranspiration where the water table is at or near land surface; by well withdrawals; and, where the elevation of the potentiometric surface of the Floridan aquifer system is below the elevation of the water table, by downward leakage to the Floridan aquifer system. No quantitative information is available on the flow of water from the surficial aquifer system to the St. Johns River; however, water generally flows toward streams and creeks, the St. Johns River, and the coast (Figure 1.15).

In Duval County, there are interconnections between the St. Johns River and the basal limestone unit of the surficial aquifer system (Spechler and Stone 1983). "Water in the limestone is moving toward and discharging into the St. Johns River. Most of the discharge is occurring along the south side of the river where the potentiometric gradient is steepest" (Spechler and Stone 1983).

Quality of Ground Water

Chloride, sulfate, and TDS are common indicators of the presence of saline water in the surficial aquifer system. Moderately saline water (chloride and sulfate concentrations between 250 and 1,000 mg/L and TDS concentrations between 500 and 3,000 mg/L) in the surficial aquifer system enters the overlying surface water system directly through discharge and indirectly through diffuse upward leakage. Where the surficial aquifer system underlies surface waterbodies containing moderately saline water, this water can enter the surficial aquifer system through downward leakage. During times of excessive rain, the elevation of the water table in the surficial aquifer system can rise, causing septic tanks to malfunction, which can result in the discharge of leachate to the St. Johns River. A situation such as this is known to occur near Palatka on the east side of the St. Johns River.

Where water in the limestone is unconfined in Duval County, saline river water can move naturally through the overlying sediments and into the limestone until a hydraulic equilibrium is reached. Where the limestone adjacent to the river is semiconfined but the limestone in the river channel is breached and when the stage of the river is greater than the potentiometric pressure of water in the limestone unit, saline river water can move through the breached section of the limestone. The location

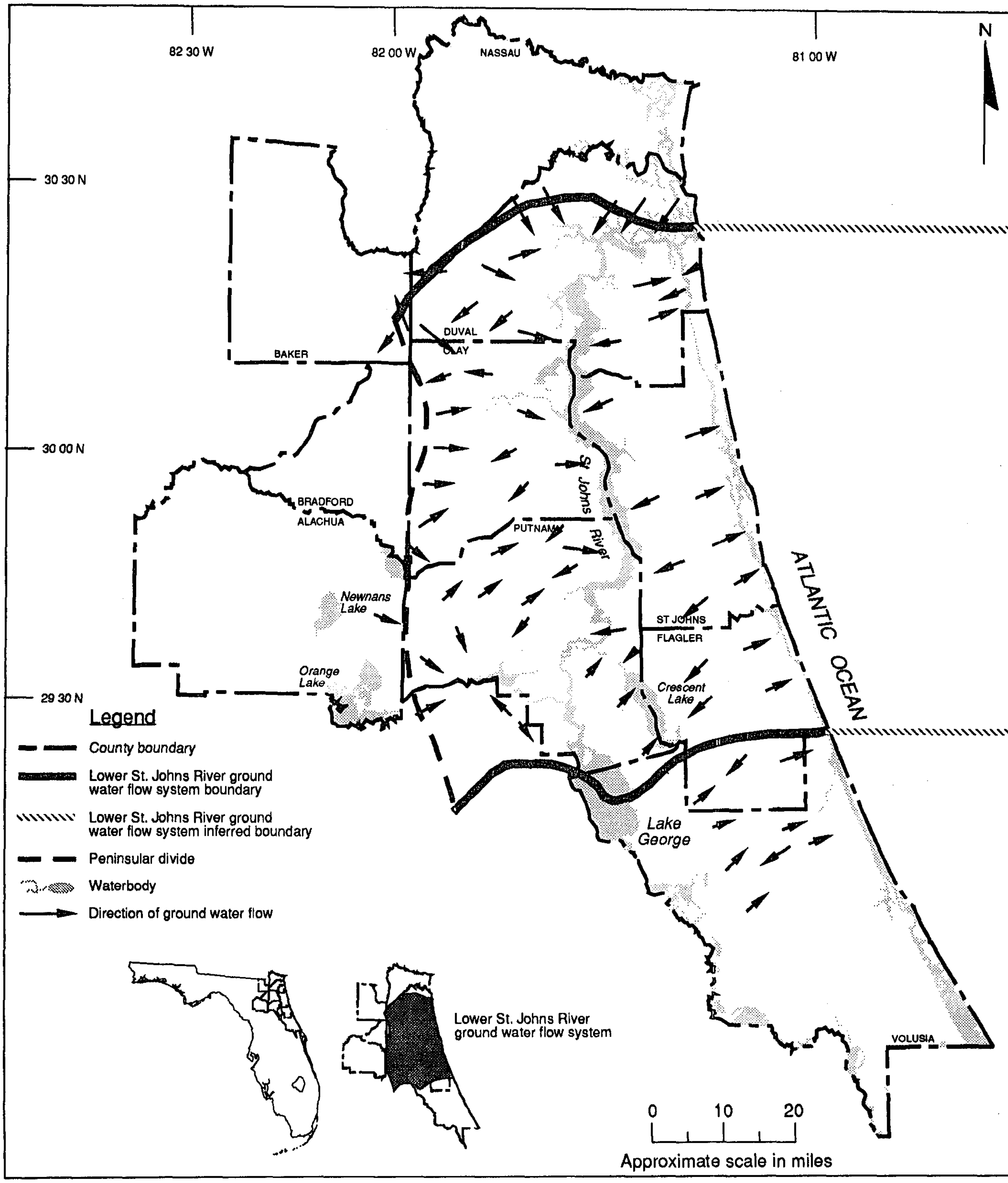

Figure 1.15 **Direction of flow in the surficial aquifer system of the lower St. Johns River ground water flow system**

of the 250-mg/L isochlor is estimated to be less than 1,000 ft from the river (Spechler and Stone 1983); chloride concentrations increase as the river is approached.

Most of the surficial deposits in the lower St. Johns River ground water flow system are greater than 50 ft thick (see Figure 1.7). Chloride concentrations in the upper 50 ft of the surficial aquifer system are generally below 50 mg/L (Figure 1.16). Chloride concentrations in the surficial aquifer system generally increase with depth. Chloride concentrations are above 1,000 mg/L within 1-4 miles of the coast in Duval, Flagler, and Volusia counties. There is not adequate areal coverage to prepare maps of the sulfate or TDS concentrations of the upper 50 ft of the surficial aquifer in LSJRB.

More precise information about the water quality of the surficial aquifer system needs to be collected and documented. There is a paucity of data regarding changes (permanent or seasonal) in water quality at depths. This information would be useful in model simulations, which can estimate the constituent loadings of surficial aquifer system discharge to the lower St. Johns River surface water basin.

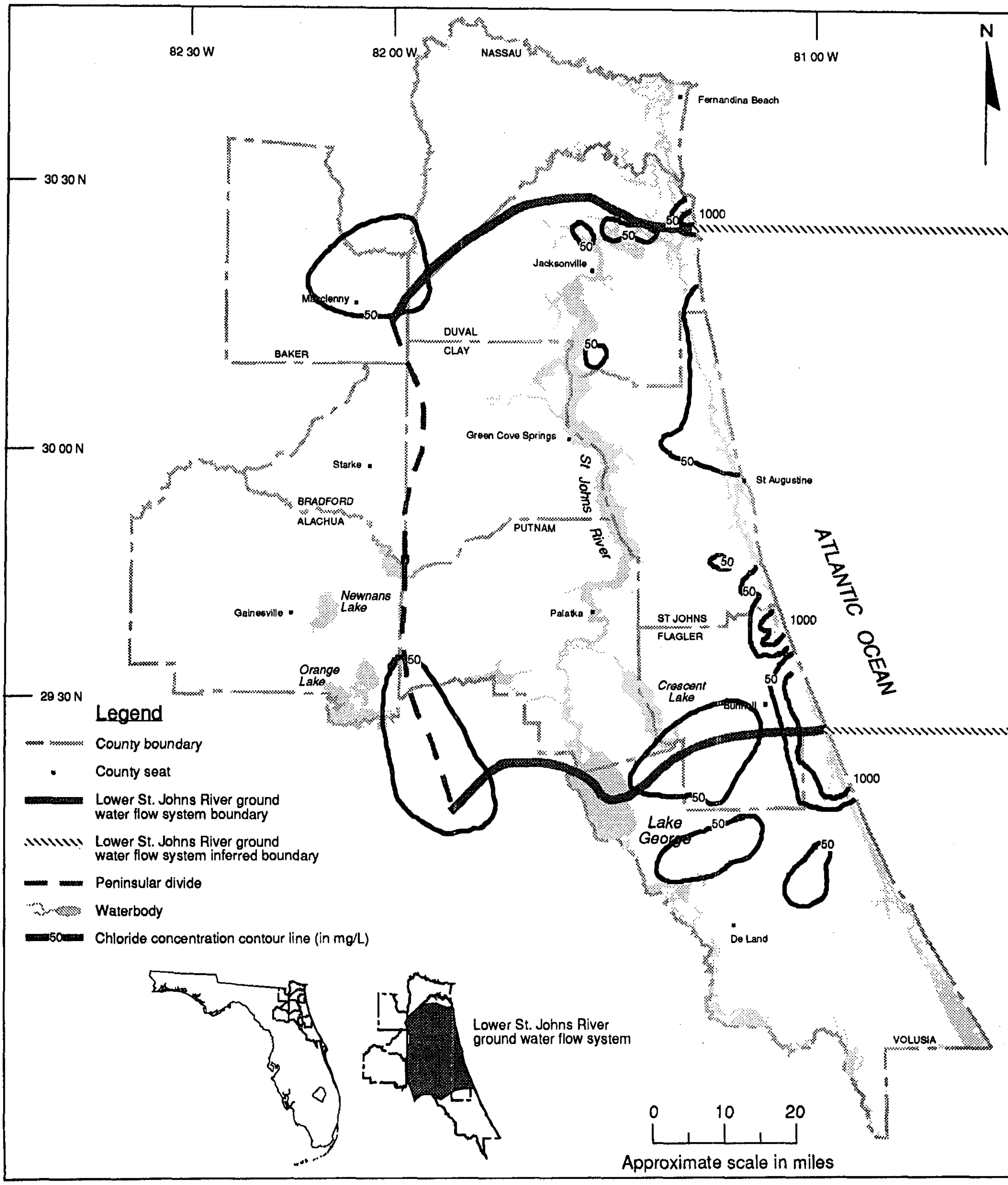

Figure 1.16 **Chloride concentrations in the upper 50 feet of the surficial aquifer system in the lower St. Johns River ground water flow system**

SUMMARY

This volume examines the relationship and influence of the interconnection between the lower St. Johns River and the ground water flow system associated with the river. The mechanisms of this interconnection are spring flow, diffuse upward leakage from the Floridan aquifer and intermediate aquifer systems, and seepage from the surficial aquifer system.

The geology of the lower St. Johns River ground water flow system consists of several thousand feet of Paleocene Epoch and younger aged rocks overlying a basement complex of granite and other crystalline rocks. Limestone formations dip and thicken toward the northeast in northern Florida and form part of the principal artesian aquifer, the Floridan aquifer. The Floridan aquifer system is separated from the overlying surficial aquifer system by the intermediate aquifer system. The intermediate aquifer system consists of Miocene deposits of the Hawthorn Group and undifferentiated post-Hawthorn Group sediments. The Hawthorn Group is absent over the southern portion of the lower St. Johns River ground water flow system, but thickens to the northeast. Deposits of extremely variable lithology overlie the Hawthorn Group and form part of the surficial aquifer system.

The primary water-bearing zones in the Floridan aquifer system consist of porous limestone and dolomite. Massive dolomitic limestone and dolomite beds generally yield little or no water and act as confining units. 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.

Principal recharge areas for the Floridan aquifer system in the lower St. Johns River ground water flow system occur in southwestern Clay County, northwestern and southeastern Putnam County, and northwestern and west-central Volusia County.

Water within the Floridan aquifer system that affects LSJRB generally flows eastward. Discharge from the Floridan aquifer system can be direct (e.g., wells or springs) or discharge can be indirect or diffuse (e.g., diffuse upward leakage to overlying aquifer systems). Discharge areas occur along the eastern portion of LSJRB. Outside LSJRB but within the lower St. Johns River ground water flow system, discharge occurs off-shore in the Atlantic Ocean.

Several depressions occur in the elevation of the potentiometric surface of the Floridan aquifer system in the lower St. Johns River ground water flow system. The depressions signify areas where water is being removed from the Floridan aquifer system by well withdrawals, diffuse upward leakage, or spring discharge. Near Green Cove Springs, the Floridan aquifer system is estimated to lose approximately 46 ft^3/sec to the surficial aquifer system, the intermediate aquifer system, the St. Johns River, or a combination of all three as a result of spring discharge and diffuse upward leakage. In southern Putnam County, 80 ft^3/sec discharges from the Floridan aquifer system to the St. Johns River at Croaker Hole Spring.

In the Floridan aquifer system, chloride concentrations are generally below 50 mg/L in the northern and western part of the lower St. Johns River ground water flow system but increase to over 1,000 mg/L in southern Flagler County. In the Floridan aquifer system, moderately saline water containing chloride concentrations between 250 and 1,000 mg/L is present beneath part of the St. Johns River in Putnam County and in southern St. Johns and northern Flagler counties. In Volusia County, chloride concentrations are below 250 mg/L in the middle of the county but increase to over 1,000 mg/L in both the eastern and western portions of the county (along the Atlantic coast and the St. Johns River).

Sulfate concentrations in the Floridan aquifer are generally below 50 mg/L in the western part of the lower St. Johns River ground water flow system but increase to more than 500 mg/L in southern and eastern St. Johns County and northeastern Flagler

County. Moderately saline water (sulfate concentrations between 250 and 1,000 mg/L) is present in much of St. Johns, northern and southwestern Flagler, northeastern Putnam, and western Volusia counties.

TDS concentrations in the Floridan aquifer are generally below 500 mg/L in the western and northern part of the lower St. Johns River ground water flow system but increase to above 5,000 mg/L in southeastern St. Johns County and northwestern and eastern Volusia County. Moderately saline water (TDS concentrations between 500 and 3,000 mg/L) is present in southern St. Johns, eastern Putnam, most of Flagler, eastern and western Volusia, and northeastern Duval counties.

The intermediate aquifer system is not areally extensive, but occurs in portions of Duval, St. Johns, Clay, Putnam, and Flagler counties. It ranges from less than 10 to about 300 ft below mean sea level and varies in thickness from less than 1 to 15 ft. Water in the intermediate aquifer system is derived locally either by upward leakage from the underlying Floridan aquifer system or by downward leakage from the overlying surficial aquifer system. Water quality in the intermediate aquifer system is similar to the water quality of one of the other aquifer systems within the same general area.

The surficial aquifer system is the principal source of potable water in St. Johns County and an important source of domestic self-supply water in Duval and Flagler counties. Water in the surficial aquifer is unconfined, and the water table is generally a subdued reflection of the topography. The surficial aquifer system is generally recharged at the ridges and water moves away from the ridges toward the St. Johns River and the coast. Water leaves the surficial aquifer system by seepage to some lakes, ditches, and streams; by evapotranspiration where the water table is at or near land surface; by well withdrawals; and, where the elevation of the potentiometric surface of the Floridan aquifer system is below the water table, by downward leakage to the Floridan aquifer system.

In the upper 50 ft of the surficial aquifer system, chloride concentrations are above 1,000 mg/L within 1-4 miles of the coast in Duval, Flagler, and Volusia counties. In Duval County, there is an interconnection between the surficial aquifer system and the St. Johns River.

RECOMMENDATIONS

A review of the available literature indicates a need for additional information about the relationship and influence of the interconnection of the lower St. Johns River ground water flow system with the surface water basin. The following activities, therefore, are recommended.

- Collect more information on the surficial aquifer system. This information should be used to map the distribution, thickness, water levels, and water quality of the surficial aquifer system.

- Quantify discharge to the St. Johns River from the surficial aquifer system. No quantitative information is available on the flow of water from the surficial aquifer system to the St. Johns River.

- Collect more information on the intermediate aquifer system in order to identify geographic locations where surface water may be influenced by the intermediate aquifer system.

- Continue to document the location, flow, and water quality of submerged springs and areas of diffuse upward leakage from the Floridan aquifer system to LSJRB.

- Coordinate with local public health units to identify areas in close proximity to the St. Johns River where there are high concentrations of septic tanks. A determination should be made concerning the potential for these septic tanks to malfunction and discharge undesirable quantities and concentrations of leachate to the surficial aquifer system and the St. Johns River during periods of excessive rain.

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