# Estimated Discharge and Chemical-Constituent Loading from the Upper Floridan Aquifer to the Lower St. Johns River, Northeastern Florida, 1990-91

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## CONVERSION FACTORS VERTICAL DATUM, AND ADDITIONAL ABBREVIATIONS

| Multiply | By | To obtain |
|---:|:---:|---|
| | **Length** | |
| inch (in.) | 25.4 | millimeter |
| feet (ft) | 0.3048 | meters |
| miles (mi) | 1.609 | kilometers |
| | **Area** | |
| square miles ($mi^2$) | 2.590 | square kilometers |
| | **Flow** | |
| cubic feet per second ($ft^3/s$) | 0.02832 | cubic meters per second |
| inch per year (in/yr) | 25.4 | millimeters per year |
| | **Mass** | |
| tons per year per square miles [$(ton/yr)/mi^2$] | .3503 | megagrams per year per square kilometers |
| ton per year (ton/yr) | .9072 | megagrams per year |
| | **Leakance** | |
| feet per day per feet [(ft/d)/ft] | 1.000 | meters per day per meter |

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

×C = 5/9 x (×°F - 32)

×F = (9/5 °C) + 32

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

### Additional abbreviations

| | |
|---|---|
| µS/cm | microsiemens per centimeter at 25 degrees Celsius (25 ×°C) |
| mg/L | milligrams per liter |

### Acronyms

| | |
|---|---|
| RASA | Regional Aquifer-System Analysis |
| USGS | U.S. Geological Survey |

# Estimated Discharge and Chemical-Constituent Loading from the Upper Floridan Aquifer to the Lower St. Johns River, Northeastern Florida, 1990-91

Rick M. Spechler

## Abstract

The lower St. Johns River, a 101-mile long segment of the St. Johns River, begins at the confluence of the Ocklawaha River and ends where the river discharges into the Atlantic Ocean at Mayport. The St. Johns River is affected by tides as far upstream as Lake George, 106 miles from the mouth. Saltwater from the ocean advances inland during each incoming tide and recedes during each outgoing tide. The chemical quality of the lower St. Johns River is highly variable primarily because of the inflow of saltwater from the ocean, and in some areas, from the discharge of mineralized ground water.

Three hydrogeologic units are present in the study area: the surficial aquifer system, the intermediate confining unit, and the Floridan aquifer system. The surficial aquifer system overlies the intermediate confining unit and consists of deposits containing sand, clay, shell, and some limestone and dolomite. The intermediate confining unit underlies all of the study area and retards the vertical movement of water between the surficial aquifer system and the Floridan aquifer system. The intermediate confining unit consists of beds of relatively low permeability sediments that vary in thickness and areal extent and can be breached by sinkholes, fractures, and other openings. The Floridan aquifer system primarily consists of limestone and dolomite.

The quality of water in the Upper Floridan aquifer varies throughout the study area. Dissolved solids in water range from about 100 to more than 5,000 milligrams per liter. Chloride and sulfate concentrations in water from the Upper Floridan aquifer range from about 4 to 3,700 milligrams per liter and from 1 to 1,300 milligrams per liter, respectively.

The rate of leakage through the intermediate confining unit is controlled by the leakance coefficient of the intermediate confining unit and by the head difference between the Upper Floridan aquifer and the surficial aquifer system. The total ground-water discharge from the Upper Floridan aquifer to the St. Johns River within the lower St. Johns River drainage basin, based on the potentiometric surface of the Upper Floridan aquifer in September 1990, was estimated to be 86 cubic feet per second. Total estimated ground-water discharge to the lower St. Johns River in September 1991, when heads in the Upper Floridan aquifer averaged about 4 feet higher than in 1990, was 133 cubic feet per second.

The load of dissolved-solids that discharged from the Upper Floridan aquifer into the lower St. Johns River on the basis of September 1990 heads is estimated to be 47,000 tons per year. Estimated chloride and sulfate loads are 18,000 and 9,500 tons per year, respectively. Dissolved-solids, chloride, and sulfate loads discharging into the lower St. Johns River are estimated to be 81,000, 39,000, and 15,000 tons per year, respectively, on the basis of September 1991 heads.

## INTRODUCTION

Few data are available on the quantity of water from the Upper Floridan aquifer that discharges to the lower St. Johns River. This lack of data has caused difficulty for various State regulatory agencies in implementing management plans to control point and nonpoint sources of effluent discharged to the lower St. Johns River. For example, chloride and sulfate usually are present in effluent and ground water entering the river from the Upper Floridan aquifer. It is probable that in some areas of the lower St. Johns

River, ground-water discharge from the Upper Floridan aquifer could be more mineralized than the riverwater. Therefore, it is possible that some constituent loads to the river contributed by ground-water discharge from the Upper Floridan aquifer are greater than those contributed by manmade sources.

The U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers, began a study in 1992 to estimate the quantity and quality of Upper Floridan aquifer discharge to the lower St. Johns River. Information about the quantity and quality of ground-water discharge can be used by agencies concerned with evaluating point and nonpoint discharge to the St. Johns River. This information also can be used to assess the potential effects of urbanization on the quality of the river water.

### Purpose and Scope

This report describes the quantity and quality of ground-water discharge to the lower St. Johns River from the Upper Floridan aquifer. A short overview of the geology and hydrology of the study area includes maps constructed from geophysical logs, and geologic and driller logs.

Potentiometric-surface maps of the Upper Floridan aquifer published in recent reports depict heads in the aquifer for September 1990 and September 1991. The information contained in these maps is the basis for simulating and evaluating ground-water discharge from the Upper Floridan aquifer to the surficial aquifer and to the St. Johns River using existing subregional RASA ground-water flow models.

Water-quality data from recent reports were used to map the distribution of dissolved solids, chloride, and sulfate in water in the Upper Floridan aquifer. The quality of ground-water discharge is reported in terms of loads of these constituents using the simulated discharge values. Total constituent loads in water discharging from the Upper Floridan aquifer are estimated in zones along the lower St. Johns River drainage basin.

### Previous Investigations

The study area has been described in numerous statewide and regional hydrologic and geologic investigations, and in several reports specifically about Duval, St. Johns, Clay, and Putnam Counties. Regional reports describing the geology, hydrology and geochemistry of the Floridan aquifer system include Stringfield (1966), and various RASA reports by Miller (1986), Bush and Johnston (1988), Johnston and Bush (1988), Krause and Randolph (1989), Sprinkle (1989), and Tibbals (1990).

The geology of the study area has been described in reports by Vernon (1951), Puri (1957), Puri and Vernon (1964), and Chen (1965). Ground-water resources were described by Bermes and others (1963), Clark and others (1964), Leve (1966), Bentley (1977b), Frazee and McClaugherty (1979), and Spechler and Hampson (1984).

The quality of water from the Floridan aquifer system in northeastern Florida was described in reports by Cooper (1942, 1944), Bermes and others (1963), Leve (1966), Fairchild (1972), Fairchild and Bentley (1977), Munch and others (1979), Brown (1984), Toth (1990), and Spechler (1994). Some of these reports discuss the intrusion of saltwater into the Floridan aquifer system.

Anderson and Goolsby (1973) describe in detail the physical and chemical characteristics of the water in the lower St. Johns River. Spechler and Stone (1983) evaluated the interconnection between the St. Johns River and the surficial aquifer system along a 25-mi section of the channel east of Jacksonville, but the discussion did not include the evaluation of discharge from the Upper Floridan aquifer. The U.S. Army Corps of Engineers has prepared many internal reports on several aspects of the lower St. Johns River; however, many primarily pertain to navigational improvements along the channel.

## LOWER ST. JOHNS RIVER DRAINAGE BASIN

The study area encompasses the drainage basin known as the lower St. Johns River basin (fig. 1). The lower St. Johns River drainage basin is approximately 2,600 $mi^2$ in area and consists of the 101-mi long section of the St. Johns River (herein referred to as the lower St. Johns River) that begins at the confluence with the Ocklawaha River and ends where the St. Johns River discharges into the Atlantic Ocean at Mayport.

Basin land peripheral to the lower St. Johns River is drained by 12 major tributaries. The river also receives surface runoff and drainage from minor tributaries within its own hydrologic subbasin.

Landscape features within the lower St. Johns River basin are relatively low and flat. Three ridge systems border the drainage area. Land surface altitudes range from sea level to greater than 200 ft in the western part of the basin.

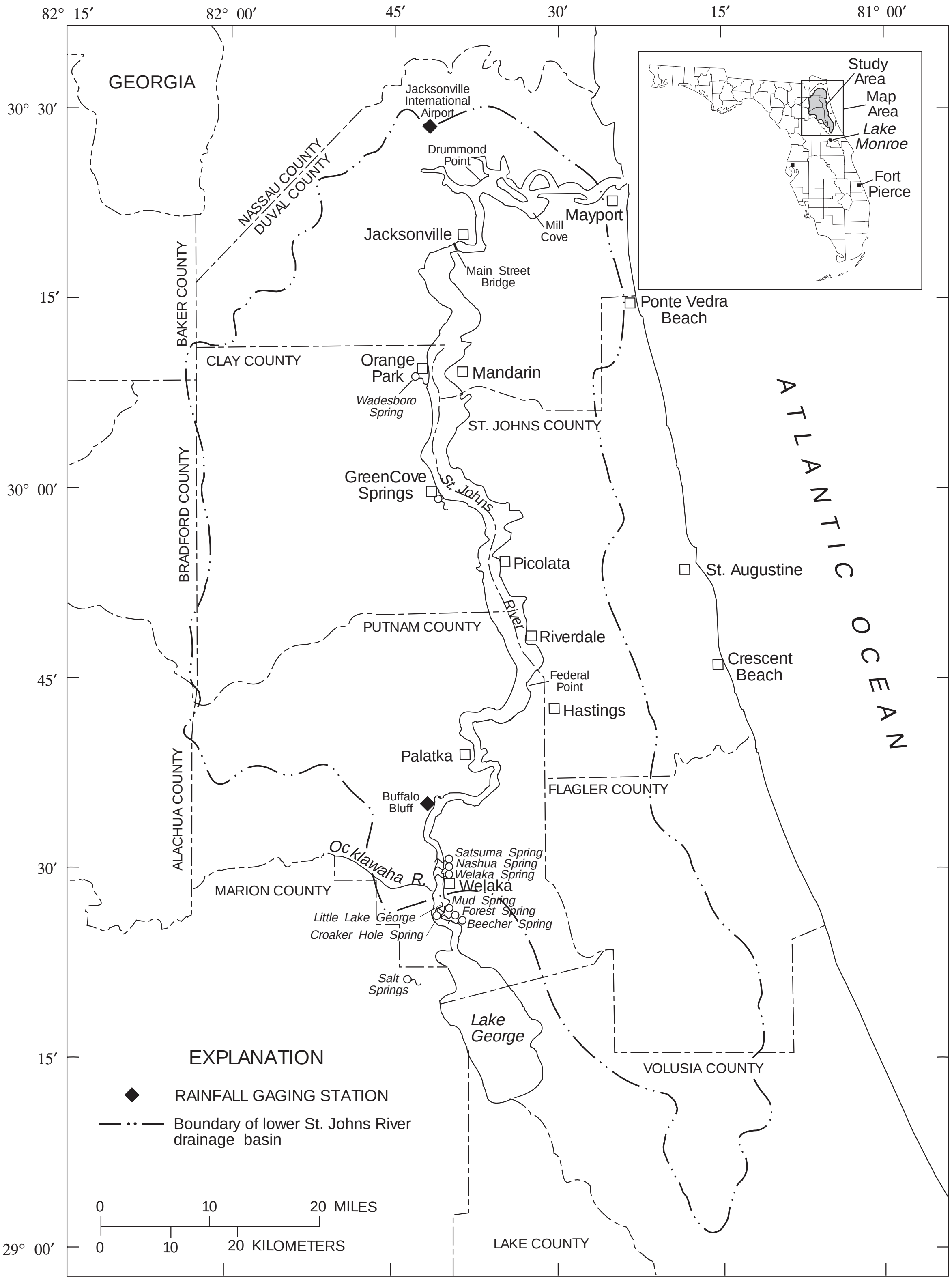


**Figure 1.** Location of study area.

## Description of the Lower St. Johns River

The headwaters of the St. Johns River occurs near Ft. Pierce, more that 300 mi from its mouth. The river flows on a generally northward course to Jacksonville and then eastward to the ocean. In the study area, the St. Johns River passes through four counties that include most of the northeastern part of the state.

From the confluence with the Ocklawaha River to Palatka, the lower St. Johns River generally ranges in width from about 600 ft to one-half mile. In the reach from Palatka to Jacksonville, the river widens and ranges from about l to 3 mi. From Jacksonville to the mouth of the river at Mayport, the width of the river ranges from about 1,250 ft at the Main Street Bridge to more than 2 mi at Mill Cove.

Navigation is one of the primary uses of the St. Johns River. A navigational channel in the river, maintained by the U.S. Army Corps of Engineers, is about 12 ft deep and 100 ft wide from the Ocklawaha River to Palatka; about 13 ft deep and 200 ft wide from Palatka to Jacksonville; and about 40 ft deep and 400 to 900 ft wide from Jacksonville to the ocean. Scouring by river currents near some bridge pilings has deepened the channel to more than 90 ft.

The St. Johns River is affected by tides as far upstream as Lake George, about 106 mi from the mouth. Occasionally, combined wind and tidal effects can influence river stages and flow as far as Lake Monroe, about 161 mi upstream (Anderson and Goolsby, 1973, p. 9). The tidal range averages about 4.9 ft at the mouth of the river and varies unequally upstream because of channel geometry. Normal tidal range is about 1.2 ft at Jacksonville and about 0.7 ft at Orange Park; from Orange Park southward, the amplitude of the tidal wave increases gradually to about 1.2 ft at Palatka; and from Palatka to Lake George, the amplitude again decreases and approaches zero near the outlet of Lake George.

Because of the tidal nature of the river, accurate measurements of streamflow are difficult to obtain and subject to error. Therefore, ground- water discharge to the lower St. Johns River cannot be quantified by the standard technique of making multiple streamflow measurements under low-flow conditions and computing ground-water discharge by determining differences in discharge between measurement sites. Discharge records for several sites along the river are, at best, poor. Net discharges above the mouth of the Ocklawaha River and at the Atlantic Ocean near Mayport are estimated to be 4,000 and 8,300 $ft^3/s$, respectively (Snell and Anderson, 1970, p. 35, 44). Average discharge at Palatka during 12 years of record is estimated at 6,000 $ft^3/s$ (U.S. Geological Survey, 1983, p. 124). The average discharge of the St. Johns River at the Main St. Bridge in Jacksonville is estimated (from 22 years of record) to be 5,700 $ft^3/s$ (U.S. Geological Survey, 1992, p. 132).

## Geologic Framework

The study area is underlain by a thick sequence of sedimentary rocks that overlie a basement complex of metamorphic rocks. Major stratigraphic units and corresponding hydrogeologic units in northeastern Florida include sedimentary rocks ranging in age from late Paleocene to Holocene (fig. 2). Stratigraphic units of interest, in ascending order are: Cedar Keys Formation of late Paleocene age, the Oldsmar Formation of early Eocene age, the Avon Park Formation of middle Eocene age, the Ocala Limestone of late Eocene age, the Hawthorn Formation of Miocene age, and the undifferentiated deposits of late Miocene to Holocene age.

Subsurface structures (such as collapse features and related fractures, joints, and faults) can play a significant role in the quantity and quality of ground water discharging from the Upper Floridan aquifer to the lower St. Johns River. Previous investigators have inferred the presence of several faults within the study area. Leve (1978, 1983, p. 255) postulated two generally northward-trending faults located primarily in Duval County. The easternmost inferred fault extends from northeastern Duval County south to a few miles beyond the Duval-St. Johns County boundary. The westernmost inferred fault approximately follows the St. Johns River and extends from north-central Duval County south toward Green Cove Springs in Clay County. Fairchild (1977, p. 23) inferred the presence of two smaller faults just west of the St. Johns River in extreme northeastern Clay County. A northsouth fault near Lake George in southern Putnam County was inferred by Bermes and others (1963, fig. 8) and extends northward into north-central Putnam County.

Circular depressions are present on the surface of the Ocala Limestone (Spechler, 1994). Some of the depressions could be erosional features formed before the Hawthorn Formation was deposited. However, some were formed by sinkhole collapse caused by the gradual dissolution of the underlying carbonate materials. Recent marine seismic-reflection investigations

| Series | | Stratigraphic unit | General lithology | Hydrogeologic unit | | | Hydrogeologic properties |
|---|---|---|---|---|---|---|---|
| Holocene to Upper Miocene | | Undifferentiated surficial deposits | Discontinuous sand, clay, shell beds, and limestone | Surficial aquifer system | | | Sand, shell, limestone, and coquina deposits provide local water supplies. |
| Miocene | | Hawthorn Formation | Interbedded phosphatic sand, clay, limestone, and dolomite | Intermediate confining unit | | | Sand, shell, and carbonate deposits provide limited local water supplies. Low permeability clays serve as the principle confining beds for the Floridan aquifer system below. |
| Eocene | Upper | Ocala Limestone | Massive fossiliferous chalky to granular marine limestone | Floridan aquifer system | Upper Floridan aquifer | | Principal source of ground water. High permeability overall. |
| | Middle | Avon Park Formation | Alternating beds of massive granular and chalky limestone, and dense dolomite | | Middle semiconfining unit | | Low permeability limestone and dolomite. |
| | | | | | Lower Floridan aquifer | Upper zone | Principal source of ground water. |
| | Lower | Oldsmar Formation | | | | Semiconfining unit | Low permeability limestone and dolomite. |
| | | | | | | Fernandina permeable zone | High permeability; salinity increases with depth. |
| Paleocene | | Cedar Keys Formation | Uppermost appearance of evaporites; dense limestones | Sub-Floridan confining unit | | | Contains highly saline water; low permeability. |

**Figure 2.** Generalized geology and hydrogeology of northeastern Florida (modified from Spechler, 1994).

along the St. Johns River in Duval County (Spechler, l994) and in south-central Florida (Snyder and others, 1989) reveal buried collapse features that originated in the rocks of the Floridan aquifer system. Marine seismic-reflection profiles collected off the coast of northeastern Florida also show the presence of these buried collapse features (Meisburger and Field, 1976; and Popenoe and others, 1984).

## Hydrogeology

Two aquifer systems are present in the study area- - the surficial aquifer system and the Floridan aquifer system. The two systems are separated by the intermediate confining unit, which includes most of the Hawthorn Formation. The intermediate confining unit contains beds of lower permeability sediments that confine the water in the Floridan aquifer system. In the northern part of the study area, the Floridan aquifer system has three major water-bearing zones (the Upper Floridan aquifer, the upper zone of the Lower Floridan aquifer, and the Fernandina permeable zone) separated by less permeable semiconfining units. The major hydrogeologic units underlying the study area, their stratigraphic equivalent, and hydrogeologic properties are shown in figure 2.

The uppermost water-bearing unit is the surficial aquifer system. It primarily is composed of deposits of sand, clay, shell, and some limestone and dolomite of Holocene to upper Miocene age (fig. 2). The thickness of the surficial aquifer system is highly variable, ranging from about 20 to 160 ft throughout the study area.

The depth to the water table in the surficial aquifer system generally is less than 5 ft. In areas of higher relief, such as in the western part of the study area, the water table can be more than 15 ft below land surface. In areas of poor drainage and low topographic relief, the water table can be less than 1 ft below land surface. The water table fluctuates seasonally and varies within about a 5-ft range. Maximum depth to water occurs during the spring and early summer months. Water levels generally recover during the wet summer months and reach their annual high in September or October.

The surficial aquifer system yields small to moderate amounts of water to wells and is an important source of water supply in those areas where the Floridan aquifer system water is too highly mineralized for use. In the areas where the Floridan aquifer system is less mineralized, the surficial aquifer system is used only to supply small amounts of water for domestic and irrigation use.

The intermediate confining unit, which underlies the surficial aquifer system, primarily consists of the Hawthorn Formation of Miocene age. However, in the extreme southern part of the area where the Hawthorn Formation is thin or absent, other deposits of Miocene age or younger can act as a confining unit. The intermediate confining unit consists of interbedded clay, silt, sand, limestone, and dolomite. The thickness of the intermediate confining unit varies considerably: it ranges from 0 in southern Flagler and northern Volusia Counties where it is absent, to more than 500 ft in the central part of Duval County (fig. 3). The intermediate confining unit also can be locally breached by sinkholes where it is relatively thin, or by other openings that serve to connect the Floridan aquifer system directly with the river.

The Floridan aquifer system is a vertically continuous sequence of Tertiary-age carbonate rocks of generally high permeability that are hydraulically connected to each other in varying degrees (Miller, 1986, B45). The aquifer system consists of rock units which vary in age from late Paleocene to Eocene. The Floridan aquifer system ranges in thickness from 1,500 to 2,000 ft and underlies all of the study area. It is the principal source of municipal, industrial and agricultural water supply for most of northeastern Florida. The top of the Floridan aquifer system ranges from less than 50 ft below sea level in the extreme southern part of the study area to more than 550 ft below sea level in parts of central Duval County (fig. 4).

The Floridan aquifer system in northeastern Florida is divided into the Upper Floridan aquifer and the Lower Floridan aquifer (fig. 2) which are separated by the a zone of lower permeability (Miller, 1986, p. B45). Two major water-bearing zones exist within the Lower Floridan: the upper zone of the Lower Floridan aquifer and the Fernandina permeable zone. These zones are separated by another less permeable semiconfining unit. The Fernandina permeable zone is thought to be absent in the southern part of the study area (Miller, 1986, p. B72). In this study, however, only hydrogeologic and chemical data obtained from the Upper Floridan aquifer are presented.

The principal recharge area of the Upper Floridan aquifer is in the western part of the study area. In this area, water enters the Floridan aquifer system by several means: by downward leakage where the water table is above the potentiometric surface of the Upper Floridan aquifer; through sinkholes and other features having enhanced permeability; and by lateral inflow from adjacent areas. Areas of discharge are present along the coast and throughout the lower St. Johns River basin (fig. 5). Discharge from the Floridan aquifer system is by diffuse upward leakage in areas where the potentiometric surface of the Floridan aquifer system is above the water table, by pumping and flowing wells, by springs, and by lateral outflow.

## Potentiometric Surface of the Upper Floridan Aquifer

The potentiometric surfaces of the Upper Floridan aquifer for September 1990 and 1991 were selected for the estimate of discharge from the Upper Floridan aquifer to the lower St. Johns River. Ground-water levels in much of northeastern Florida were at or near record lows in September 1990 (fig. 6). Rainfall during this period was about 21 in. below normal at the Jacksonville International Airport and about 12 in. below normal at Federal Point near Palatka (National Oceanic and Atmospheric Administration, 1990) (fig. 1). Water levels in September 1991 (fig. 7) were about 2 to 6 ft higher than in September 1990 because of near-record rainfall in northeastern Florida. Rainfall was about 22 in. above normal at Jacksonville International Airport and about 17 in. above normal at Federal Point (National Oceanic and Atmospheric Administration, 1991).

The altitude of the potentiometric surface of the Upper Floridan aquifer ranged from about 75 ft above sea level in the western parts of Clay and Putnam Counties to less than 10 ft above sea level in the southern part of Flagler County in September 1990 (fig. 6),

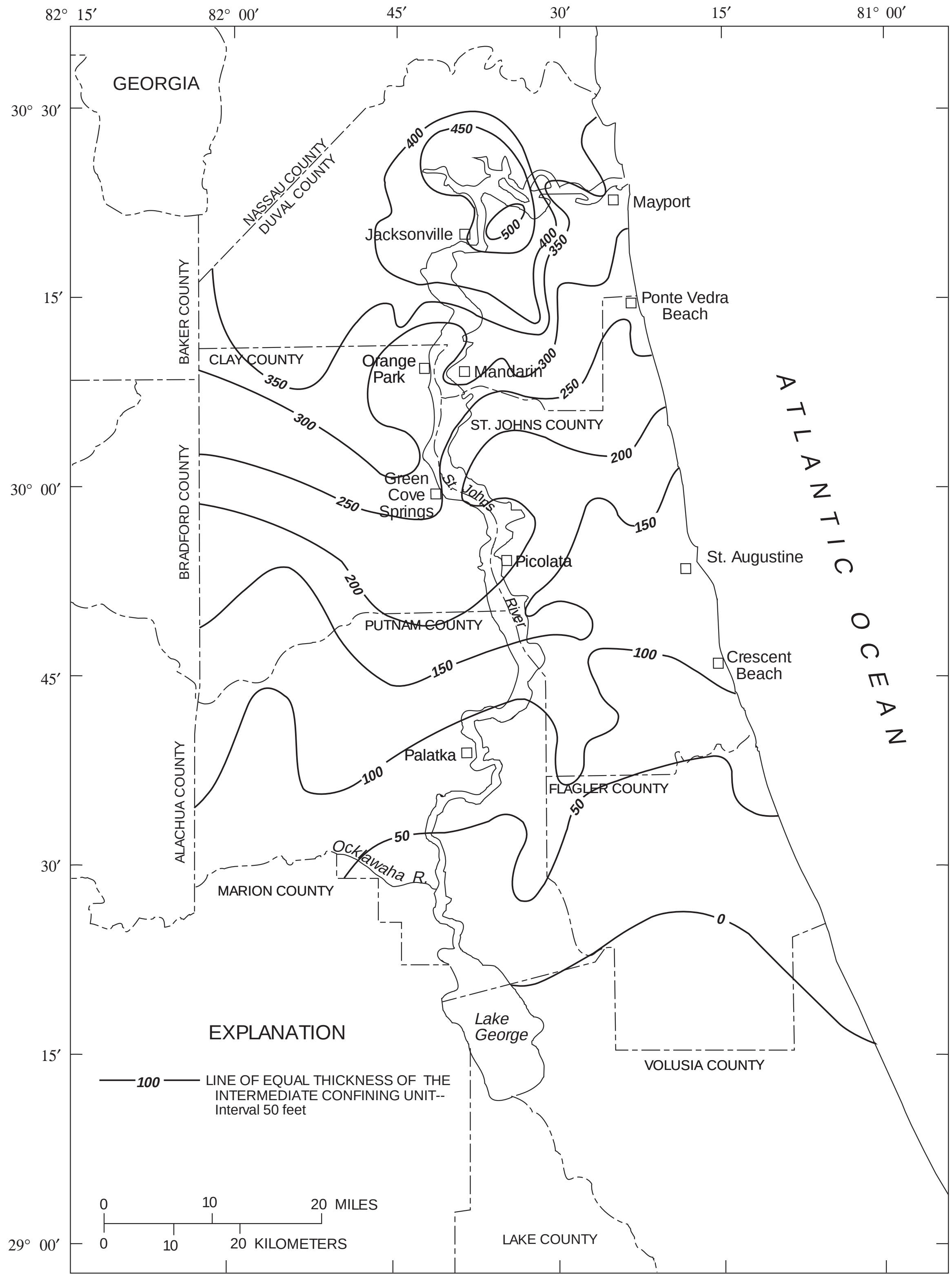


**Figure 3.** Generalized thickness of the intermediate confining unit (data from Scott and others, 1991, and files of the U.S. Geological Survey and St. Johns River Water Management District).

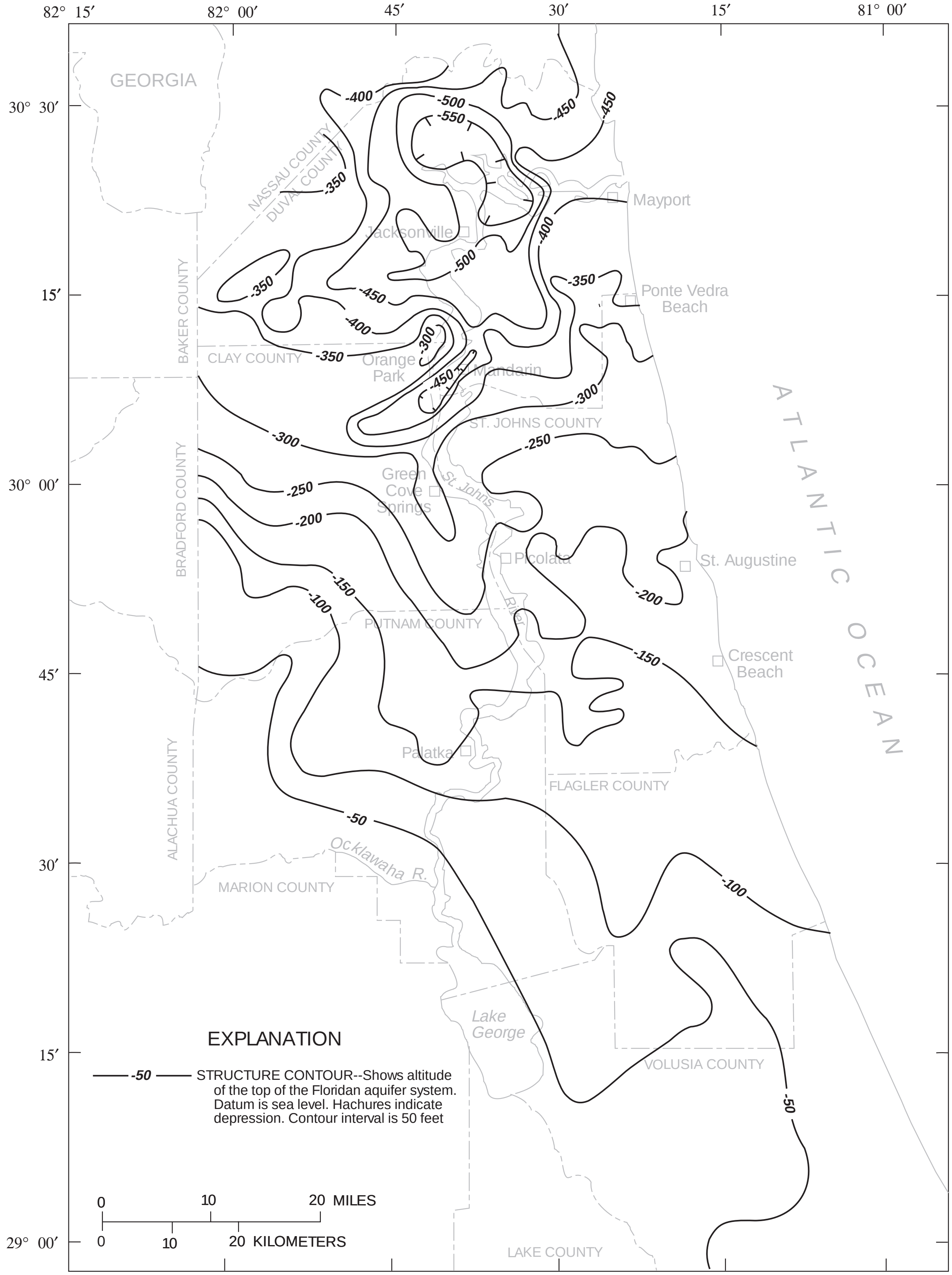


**Figure 4.** Altitude of the top of the Floridan aquifer system (modified from Scott and others, 1991; and Spechler, 1994).

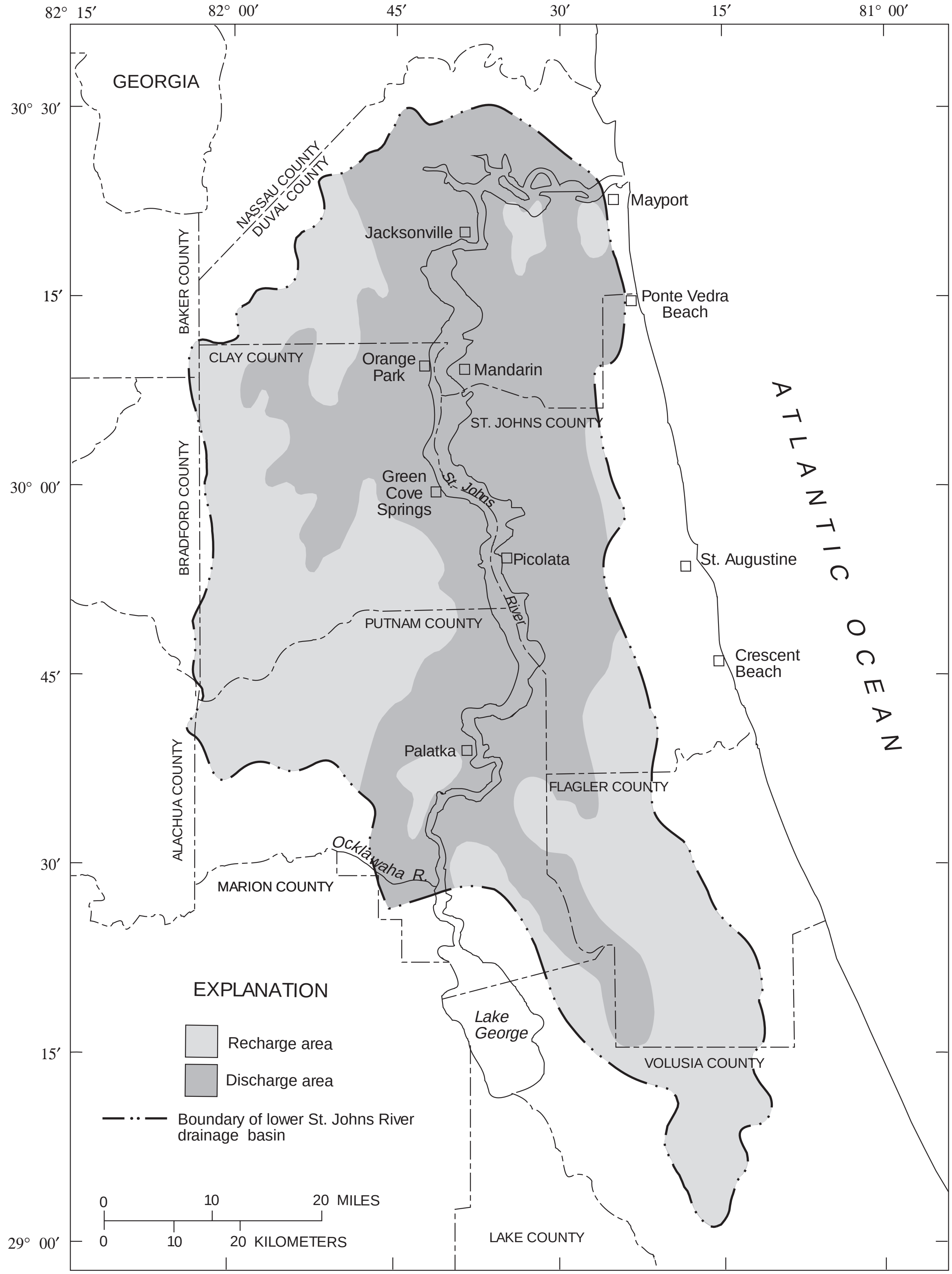


**Figure 5.** Approximate extent of natural recharge and discharge areas in the Upper Floridan aquifer (from Phelps, 1984).

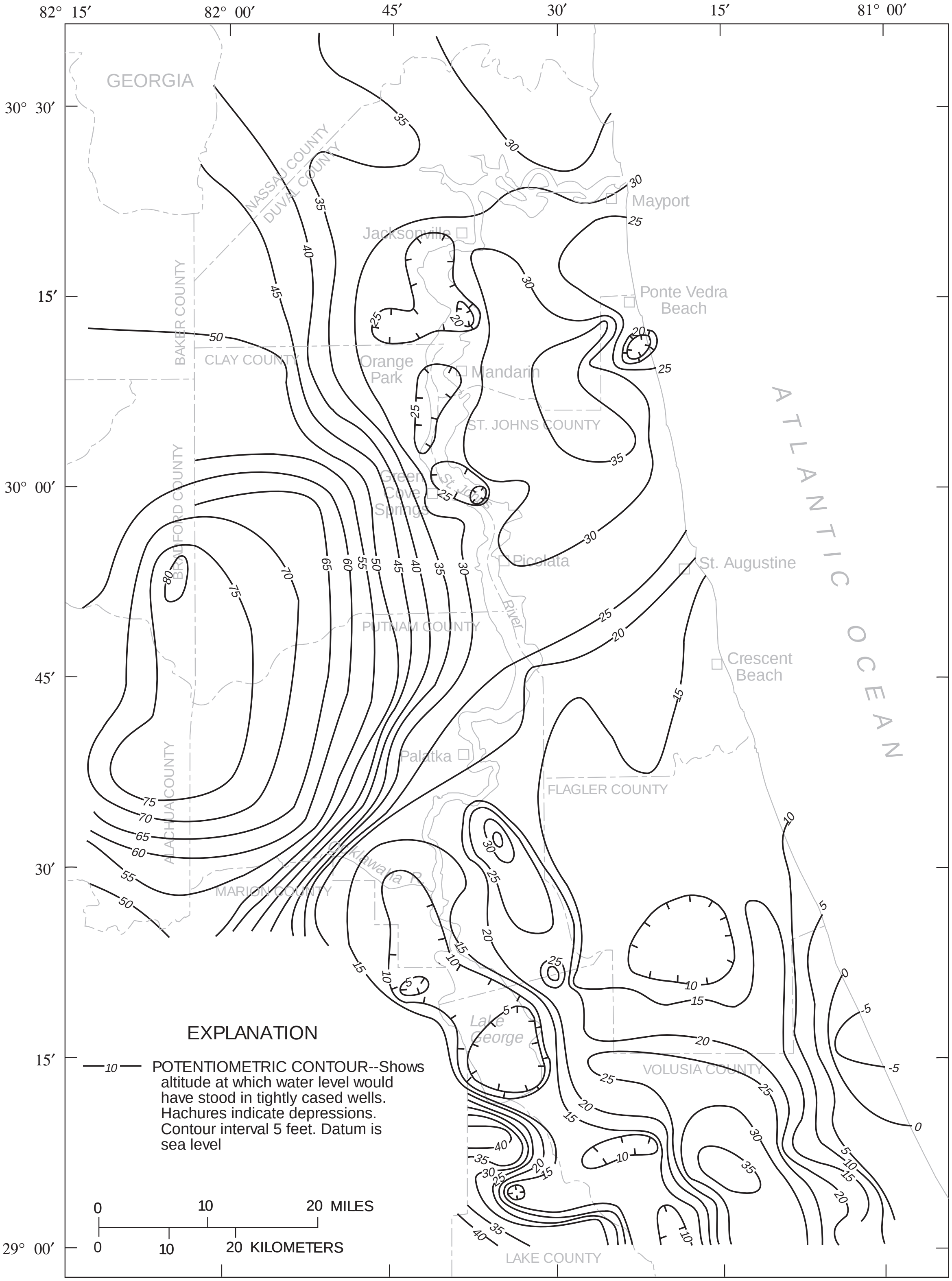


**Figure 6.** Potentiometric surface of the Upper Floridan aquifer, September 1990 (modified from Spechler and others, 1991).

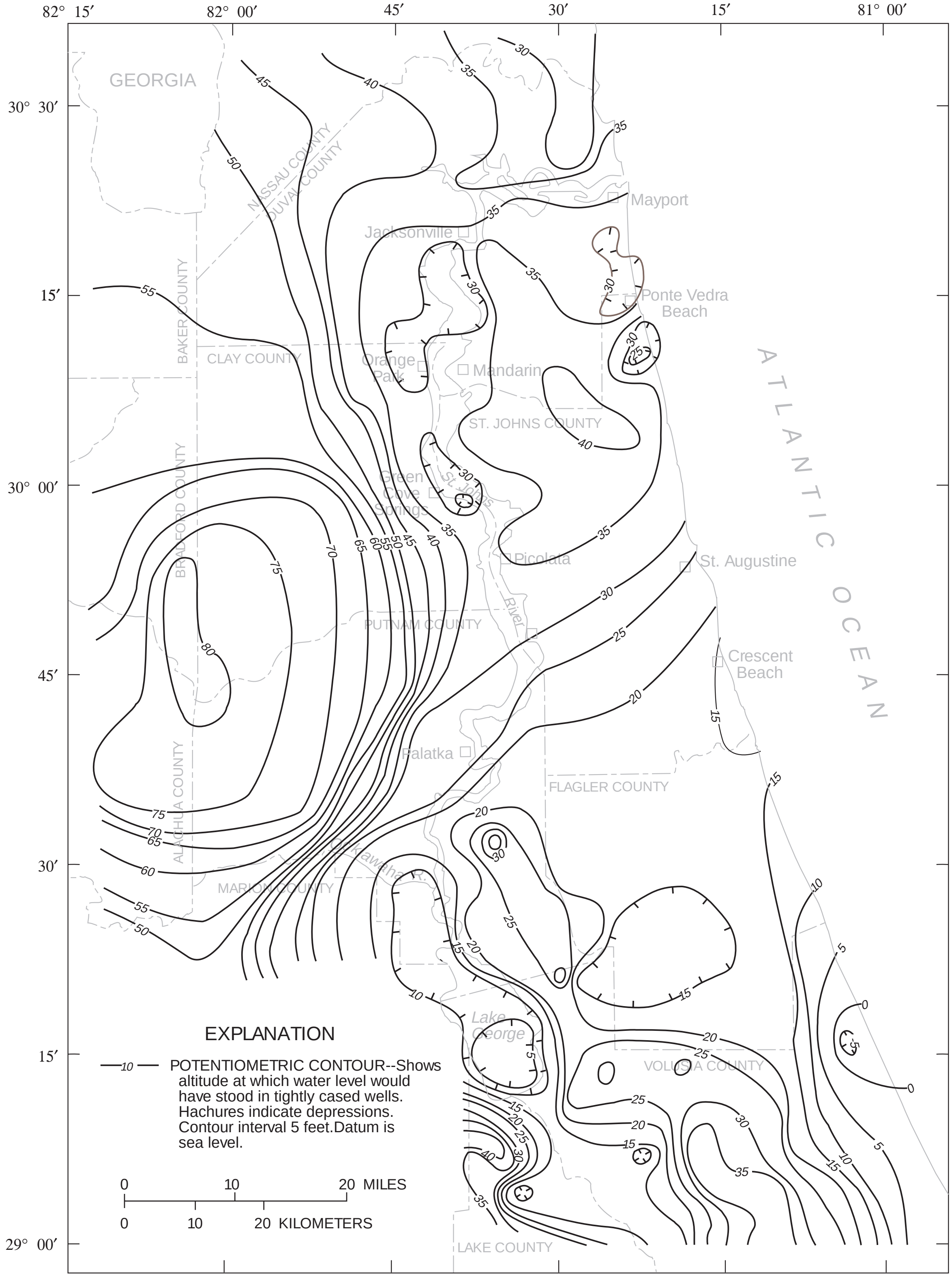


**Figure 7.** Potentiometric surface of the Upper Floridan aquifer, September 1991 (modified from Sumner and others, 1992).

and from about 80 to less than 15 ft above sea level in these respective areas in September 1991 (fig. 7). The large depression in the potentiometric surface south of Jacksonville is probably caused, in part, by withdrawals from industrial and public-supply wells, and possibly by diffuse upward leakage or undetected spring discharge into the St. Johns River. The depression in the potentiometric surface of the Upper Floridan aquifer in the Green Cove Springs area is probably caused by a combination of factors including diffuse upward leakage, spring flow, and withdrawals for public, agricultural, and domestic use. Spring discharge and diffuse upward leakage are the probable cause of the depression in the potentiometric surface near the confluence of the St. Johns and the Ocklawaha Rivers, near Welaka. The intermediate confining bed in this area is thin, making conditions favorable for spring formation. Additionally, it is possible that channel dredging or excavation in the St. Johns River has, in places, breached or partially breached the semiconfining unit overlying the Upper Floridan aquifer and has allowed water from the Upper Floridan aquifer to discharge into the river (Tibbals, 1990, E28).

## WATER QUALITY

The quality of surface water, ground water, and springs in the study area are briefly discussed in the following sections. Most of the water-quality data used in this investigation are from previous reports. These data were obtained primarily during the 1970's and 80's as part of areal hydrologic studies by the USGS and St. Johns River Water Management District.

### Lower St. Johns River

The quality of water in the lower St. Johns River has been documented in many publications. Although data collection and descriptive reports for the St. Johns River from the Ocklawaha River to Orange Park are limited, considerable data have been collected for tributaries and for the St. Johns River near Jacksonville. Generally, water quality in the river is characterized as good in the sparsely populated area of the lower St. Johns River or poor in the urban area of Jacksonville (Campbell and others, 1989). Water-quality problems include low dissolved oxygen concentrations, and elevated nutrient concentrations and bacterial populations which result from point and nonpoint sources such as industrial discharges, agricultural runoff, municipal water treatment plants, septic tanks, and dairy farms. A detailed description of the nutrient and bacterial concentrations and the concentrations of other pollutants discharged into the water in the lower St. Johns River is beyond the scope of this report. However, certain chemical constituents (dissolved solids, chloride, and sulfate) in discharging ground water that could affect the quality of water in the lower St. Johns River will be discussed in a later section of this report.

Water quality in the Iower St. Johns River varies significantly with changing flow conditions. The flow, hence the water quality of the river is affected by ocean tides, rainfall, surface-water runoff, evapotranspiration, and wind. The extent to which these factors can affect the flow is primarily controlled by channel geometry and the available storage capacity of the river. Of these factors, ocean tides probably have the greatest effect on the quality of water in the river. Saltwater from the ocean advances up the St. Johns River during each incoming tide and recedes during each outgoing tide. A transition zone forms where the ocean water mixes with freshwater in the river. The length of the transition zone varies with each tidal cycle and with the amount of freshwater entering the river upstream. During periods of large freshwater inflow to the river, downstream flow can increase, reducing the length of the transition zone and shifting the zone toward the ocean. Reduced freshwater inflow can cause the transition zone to move a considerable distance upstream during periods of drought or reduced rainfall.

The chemical quality of water in the river also can change significantly over a short period of time as a result of the constant movement of the transition zone. At the Main Street Bridge in Jacksonville, for example, chloride concentrations increased more than fourfold in a few hours and more than tenfold in several days (Anderson and Goolsby, 1973, p. 54). Anderson and Goolsby (1973, p. 37) also documented changes in specific conductance of as much as 12,000 μS/cm during a single tide cycle.

Between the headwaters of the St. Johns River and the point at which it discharges into the Atlantic Ocean, an undetermined amount of mineralized ground water from the Upper Floridan aquifer discharges through springs and by upward leakage through the intermediate confining unit. Ground-water discharge of mineralized water is a potential source of highly concentrated solute species such as chloride and sulfate. In some areas along the lower St. Johns River, water from the Upper Floridan aquifer could be more mineralized than the riverwater. Under certain conditions, such as during a drought when low-flow conditions exist, ground water could cause increased mineralization of the riverwater. A small amount of water flows into the St. Johns River from surface-water sources during these periods and the mineralized ground water discharging into the river can significantly affect water quality. However, in the areas where saltwater from the ocean affects the quality of water in the lower St. Johns River, water that enters the river from the Upper Floridan aquifer probably is of better quality than the riverwater.

## Upper Floridan Aquifer

Available data for ground-water quality in the study area were used to evaluate the potential effect of natural ground-water discharge from the Upper Floridan aquifer into the lower St. Johns River basin. Maps indicating the distribution of selected constituents in the study area are included in this section. These data were obtained from the files of the U.S. Geological Survey and the St. Johns River Water Management District, and from published reports (Bermes and others, 1963; Fairchild, 1977; Munch and others, 1979; Ross and Munch, 1980; Rutledge, 1982; Spechler and Hampson, 1984; Navoy and Bradner, 1987; and Spechler, 1994).

### Dissolved Solids

The concentration of dissolved solids in water is a common indicator of mineralization. The areal distribution of dissolved solids in water collected from the Upper Floridan aquifer in parts of Duval, Clay, St. Johns, Putnam, Flagler, and Volusia Counties is shown in figure 8. Dissolved-solids concentrations range from about 100 to 5,000 mg/L (unpublished data in files of the U.S. Geological Survey) and generally increase toward the east and the south. Lowest dissolved-solids concentrations are in much of Clay and western Putnam Counties, where concentrations of less than 150 mg/L are common. Highest dissolved-solid concentrations are in the area near Hastings in southwestern St. Johns County. Relatively high dissolved-solids concentrations also are present in west-central Flagler County, and in several areas adjacent to the St. Johns River near Welaka, east of Palatka, and north of Riverdale.

Specific conductance data were used to estimate dissolved-solids concentrations in some areas where dissolved-solids concentrations were not available. Although specific conductance values cannot be used to precisely determine dissolved-solids concentrations in natural waters, they can be used to estimate dissolved-solids concentrations. Based on the specific conductance in the study area, multiplication of the specific conductance values by 0.66 gives a reasonable approximation of the dissolved-solids concentration.

### Chloride

Chloride is a major constituent of dissolved solids in parts of St. Johns, Putnam, and Flagler Counties. The primary mechanisms by which chloride increases in ground water include the dissolution of minerals in rocks of the aquifer, relict or connate water mixing with freshwater, and the intrusion of seawater. The distribution of chloride in water from the Upper Floridan aquifer in the study area is shown in figure 9. Concentrations range from 4 to 3,700 mg/L and generally increase toward the south (Navoy and Bradner, 1987; unpublished data in files of the U.S. Geological Survey). The lowest chloride concentrations are present in Clay, southwestern Duval, and western Putnam Counties where concentrations of less than 10 mg/L are common. Highest chloride concentrations were measured in southwestern Flagler County. Relatively high chloride concentrations (concentrations exceeding 500 mg/L) also are present in southern St. Johns and northern Flagler Counties and in areas adjacent to the St. Johns River near Palatka and Welaka (fig. 9). The area north of Riverdale also could be an area where chloride concentrations in ground water exceed 500 mg/L.

### Sulfate

Sulfate concentrations in water from the Upper Floridan aquifer range from about 1 to 1,300 mg/L (Spechler, 1994; unpublished data in files of the U.S. Geological Survey) and generally increase toward the east and south (fig. 10). Lowest concentrations typically are in Clay and Putnam Counties, where concentrations of sulfate are less than 10 mg/L. Highest sulfate concentrations are present north of Riverdale. Sulfate concentrations greater than 500 mg/L also are present in southern St. Johns County and in two small areas east of Green Cove Springs.

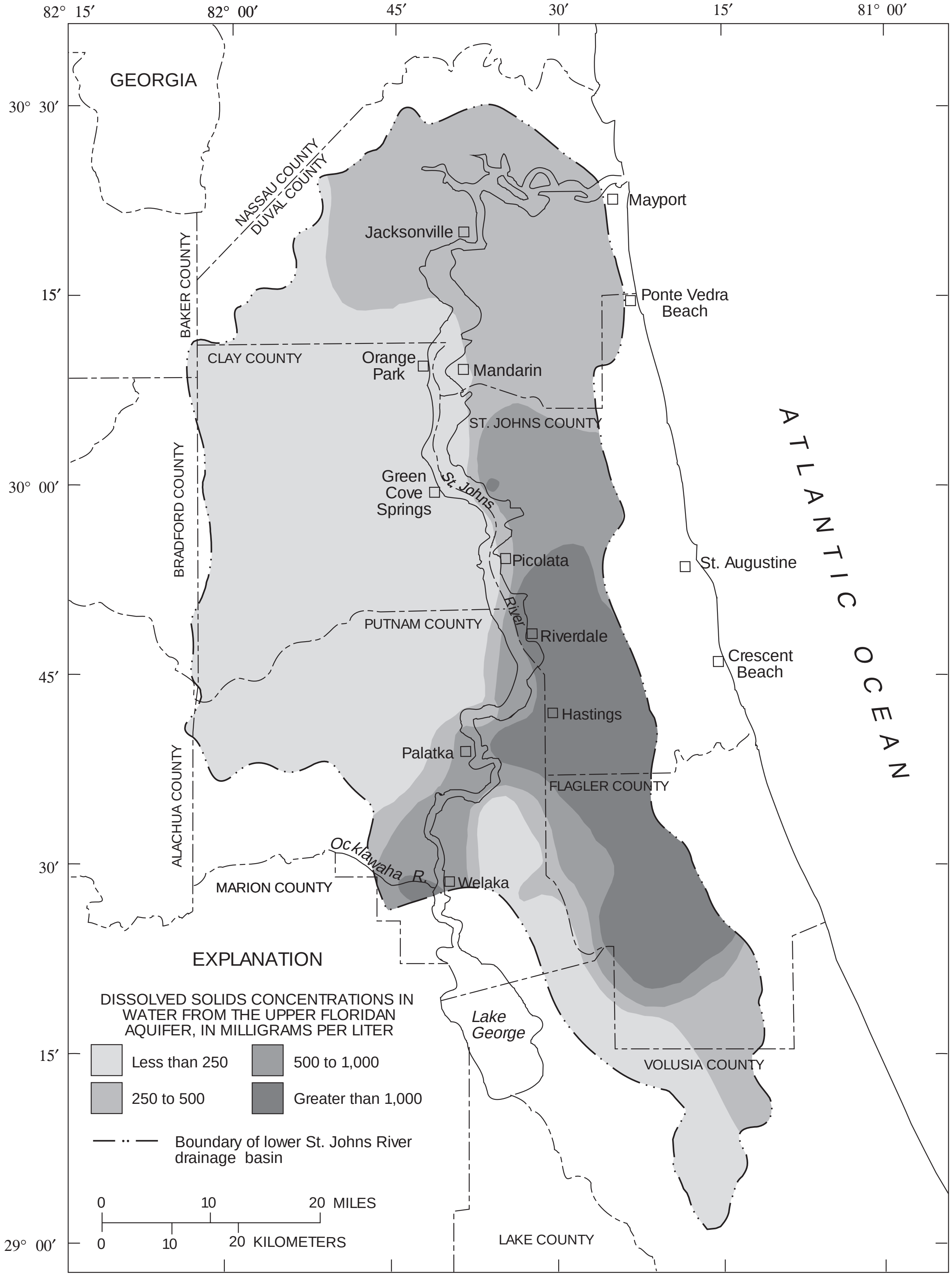


**Figure 8.** Generalized distribution of dissolved-solids concentrations in water from the Upper Floridan aquifer (data from Munch and others, 1979; Ross and Munch, 1980; Rutledge, 1982; Spechler and Hampson, 1984; Navoy and Bradner, 1987; Spechler, 1994; and the files of the U.S. Geological Survey and St. Johns River Water Management District).

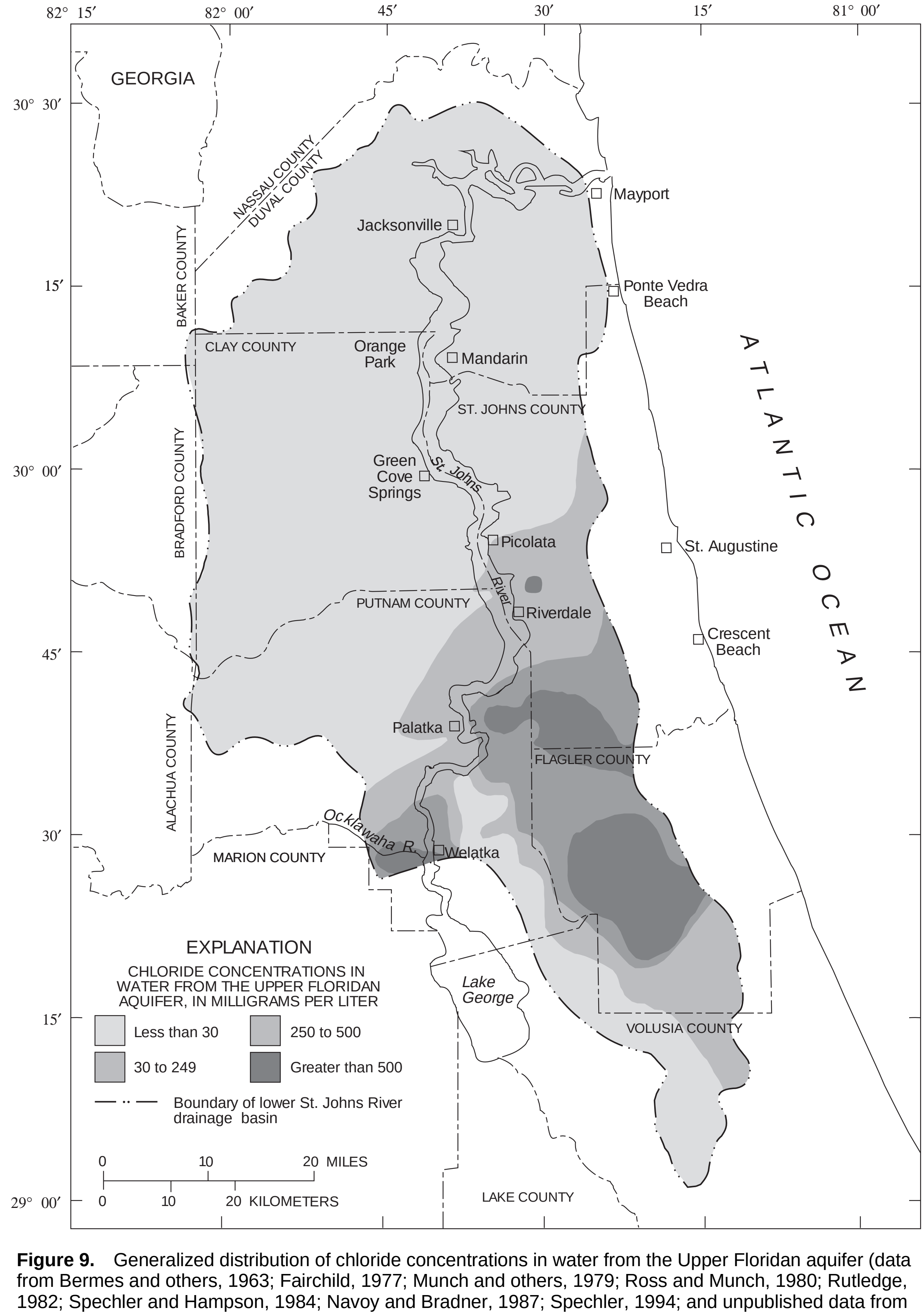


**Figure 9.** Generalized distribution of chloride concentrations in water from the Upper Floridan aquifer (data from Bermes and others, 1963; Fairchild, 1977; Munch and others, 1979; Ross and Munch, 1980; Rutledge, 1982; Spechler and Hampson, 1984; Navoy and Bradner, 1987; Spechler, 1994; and unpublished data from the files of the U.S. Geological Survey and St. Johns River Water Management District).

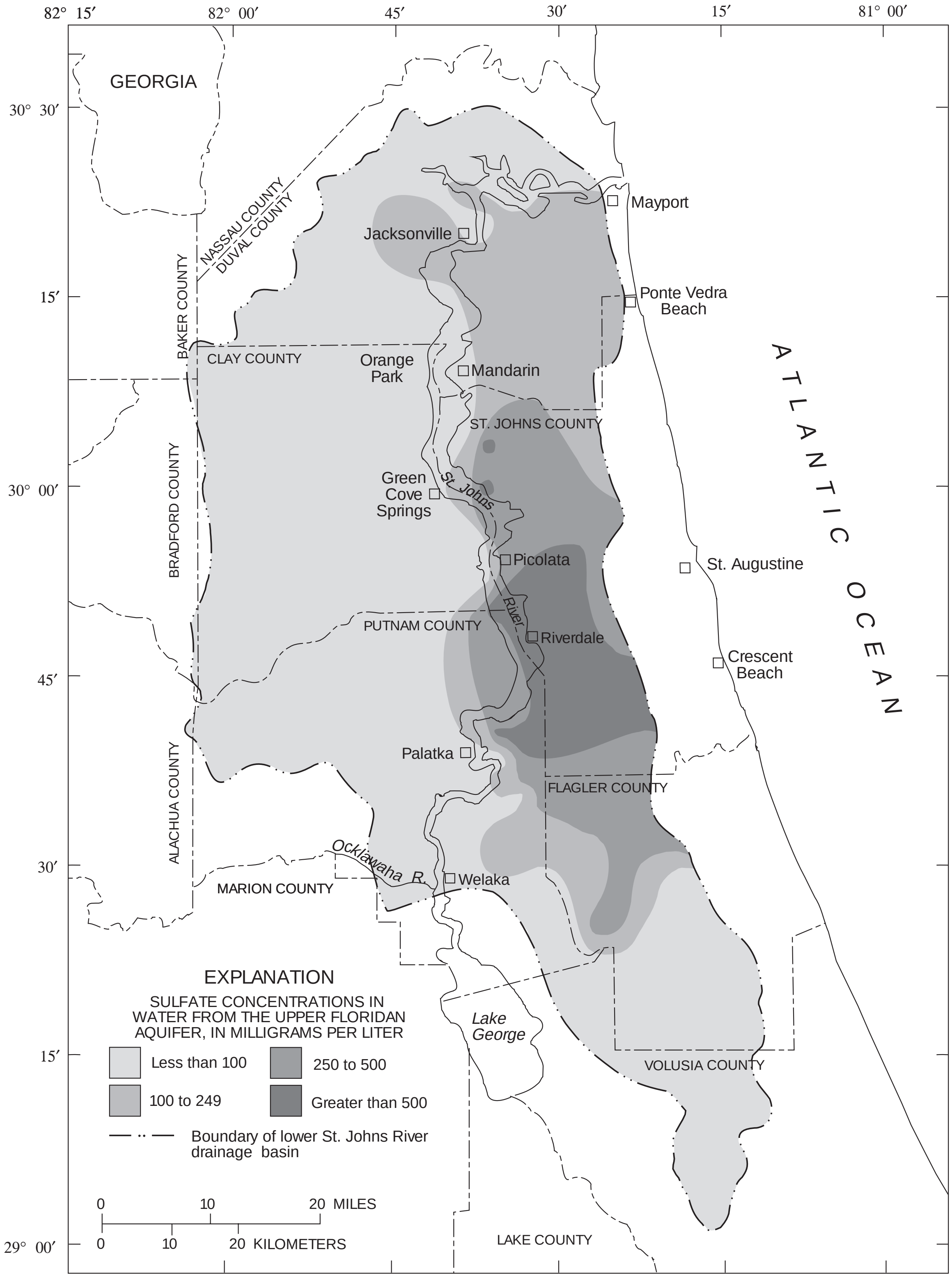


**Figure 10.** Generalized distribution of sulfate concentrations in water from the Upper Floridan aquifer (data from Bermes and others, 1963; Ross and Munch, 1980; Spechler and Hampson, 1984; Spechler, 1994; and the files of the U.S. Geological Survey and St. Johns River Water Management District).

High sulfate concentrations in southern St. Johns and parts of northeastern Putnam and northern Flagler Counties are often associated with high chloride concentrations. This could indicate that the high concentrations of sulfate are, in part, related to the presence of ancient seawater that has not been flushed from the aquifer by freshwater. However, in some areas of northwestern and west-central St. Johns County, the high concentrations of sulfate are not associated with high concentrations of chloride. High sulfate concentrations are probably the result of the dissolution of sulfate-bearing minerals.

### Springs

Nine gaged springs that discharge water into the St. Johns River are located in or near the study area (fig. l). Only five springs are known to discharge water into the St. Johns River between the Ocklawaha River and Mayport. The remaining four springs, Beecher, Croaker Hole, Mud, and Forest Springs, are located a few miles to the south of the study area.

The quality of water discharging from these springs is variable. Limited water-quality data indicate that average dissolved-solids concentrations range from about 133 to 3,564 mg/L and sulfate concentrations from 10 to 260 mg/L (table l). However, sulfate concentrations in most of the springs generally are less than 100 mg/L.

Average chloride concentrations range from 5.8 to 1,600 mg/L. Chloride concentrations in water from Green Cove and Wadesboro Springs in the northern part of the study area are less than 10 mg/L. Chloride concentrations in water from springs near the confluence of the Ocklawaha and St. Johns Rivers are higher and more variable. The average chloride concentration in water discharging from Satsuma Spring is 1,600 mg/L but at Beecher Springs, several miles to the south, chloride concentrations average only 78 mg/L. A water sample collected at the mouth of Croaker Hole Spring, located in Little Lake George (St. Johns River), had a chloride concentration of 720 mg/L; however, inside the spring, several vents observed discharging water had chloride concentrations ranging from 740 to 880 mg/L. Chloride concentrations as high as 1,600 mg/L also have been determined in water discharging from Salt Springs, about 8 mi south of the study area (Tibbals, 1990, p. E94).

## ESTIMATED GROUND-WATER DISCHARGE FROM THE UPPER FLORIDAN AQUIFER

One purpose of this study was to estimate total ground-water discharge from the Upper Floridan aquifer to the St. Johns River within the lower St. Johns River drainage basin. To expedite the process, hydrogeologic data from two subregional RASA models that overlapped the study area were used. The subregional model by Krause and Randolph (1989) extends south to central St. Johns County in northern Florida.

**Table 1.** Average discharge, loads, and concentrations of selected chemical constituents of springs from the Upper Floridan aquifer in and near the study area (from Rosenau and Faulkner, 1975; Rosenau and others, 1977; and the files of the USGS)

[$ft^3/s$, cubic feet per second; mg/L, milligrams per liter; ton/yr, tons per year; --, no data]

| Spring (see figure 1 for location) | Average discharge ($ft^3/s$) | Dissolved solids (mg/L) | Dissolved solids loads (ton/yr) | Chloride (mg/L) | Chloride load (ton/yr) | Sulfate (mg/L) | Sulfate load (ton/yr) |
|---|---|---|---|---|---|---|---|
| Beecher[a] | 10 | 252 | 2,483 | 78 | 769 | 13 | 128 |
| Croaker Hole[a] | 84 | 1,834[b,d] | 151,822 | 720[d] | 59,603 | 160[d] | 13,245 |
| Green Cove | 3.5 | 181 | 624 | 5.8 | 20 | 54 | 186 |
| Forest[a] | .30 | 1,518[b] | 449 | 600[d] | 177 | 87[d] | 26 |
| Mud[a] | 2.3 | 688[d] | 1,559 | 290[d] | 657 | 43[d] | 98 |
| Nashua | .27 | -- | -- | -- | -- | -- | -- |
| Satsuma | 1.8 | 3,564[b] | 6,322 | 1,600 | 2,838 | 260 | 460 |
| Wadesboro[c] | 1.2 | 133 | 157 | 8.5 | 10 | 10 | 12 |
| Welaka | 2.2 | 849 | 1,841 | 370 | 802 | 57 | 124 |

[a]Spring located outside of study area.
[b]Dissolved-solids concentrations estimated from specific conductance.
[c]Possibly not an Upper Floridan aquifer spring.
[d]Single sample value.

The subregional model by Tibbals (1990) includes the remainder of the study area (fig. 11).

Features of and assumptions for the RASA models are described in Krause and Randolph (1989) and Tibbals (1981, 1990). The reader is referred to these reports for discussions of the steady-state model calibration, boundary conditions, methods used to simulate spring flow, and derivation of confining-unit leakage coefficients.

Data input within the study area involved assigning hydrogeologic data to nodes within a grid. The grid consists of 14 rows and 27 columns. Each of the 378 nodes measures 4 mi on each side and 16 $mi^2$ in area. Because of the configuration of the study area boundaries, only 174 of the nodes were considered "active." The position of the grid on the study area is shown in figure 11. Orientation of the grid coincides with the position of the grid used in the two subregional RASA models.

Ground-water discharge from the Upper Floridan aquifer to the lower St. Johns River drainage basin occurs as diffuse upward leakage or spring flow. Water from the Upper Floridan aquifer moves upward through the intermediate confining unit to the surficial aquifer system in the discharge areas of the lower St. Johns River drainage basin. The water then moves laterally through the surficial aquifer system or into streams and creeks where it eventually discharges into the St. Johns River.

The rate of leakage through the intermediate confining unit is controlled by the leakance coefficient of the intermediate confining unit and the head difference between the Upper Floridan aquifer and the surficial aquifer system. The equation representing this relationship can be expressed by Darcy's Law as

$$Q = K'/b'(hr-hf)A\,C, \qquad (1)$$

where

$Q$ is ground-water discharge or leakage, in cubic feet per second;

$K'$ is vertical hydraulic conductivity of the intermediate confining unit, in feet per day;

$b'$ is thickness of the intermediate confining unit, in feet;

$K'/b'$ is leakance coefficient, in feet per day per foot;

$hr$ is altitude of water level of the surficial aquifer system, in feet above sea level;

$hf$ is altitude of water level of the Upper Floridan aquifer system, in feet above sea level;

$A$ is surface area, in square feet; and

$C$ is conversion factor from days to seconds.

Leakance coefficients of the intermediate confining unit are highly variable. Leakance coefficients for the intermediate confining unit required to deliver RASA-simulated rates of vertical flow between the Upper Floridan aquifer and the surficial aquifer system reported for the study area range from less than $1\times10^{-8}$ (ft/d)/ft to $1\times10^{-4}$ (ft/d)/ft (fig. 12), (C.H. Tibbals and R.E. Krause, U.S. Geological Survey, written commun., 1993). The lowest leakance coefficients generally are in areas where diffuse recharge and discharge rates are low—areas where the confining units are relatively thick or have low permeability. The highest leakance coefficients generally are in areas where diffuse recharge and discharge rates are highest-areas where the confining units are relatively thin or permeable.

Total diffuse ground-water discharge to the lower St. Johns River basin was calculated by determining leakance coefficients and average heads for the surficial aquifer system and Upper Floridan aquifer at each node within the lower St. Johns River drainage basin. Leakance coefficients, as previously mentioned, were obtained from the subregional RASA studies. Average heads in the Upper Floridan aquifer at each node were determined by interpolating directly from the September 1990 potentiometric-surface map (fig. 6), which represented a time when water levels in much of northeastern Florida were at or near record lows. Water-level altitudes in the surficial aquifer system were estimated from USGS 1:100,000 scale topographic maps.

Discharge rates for springs in and near the study area were determined by standard streamflow measurements (table l). In Krause and Randolph (1989), spring discharge was not explicitly simulated by a separate water-budget program. The effects of known springs on the potentiometric surface of the Upper Floridan aquifer are implicitly accounted for by the diffuse upward leakage rates determined during model calibration. Tibbals (1990), however, did a separate water-budget program for springs. Therefore groundwater discharge from Satsuma and Welaka Springs was added to the diffuse upward leakage rate to get total ground-water discharge from the Upper Floridan aquifer to the surficial aquifer system.

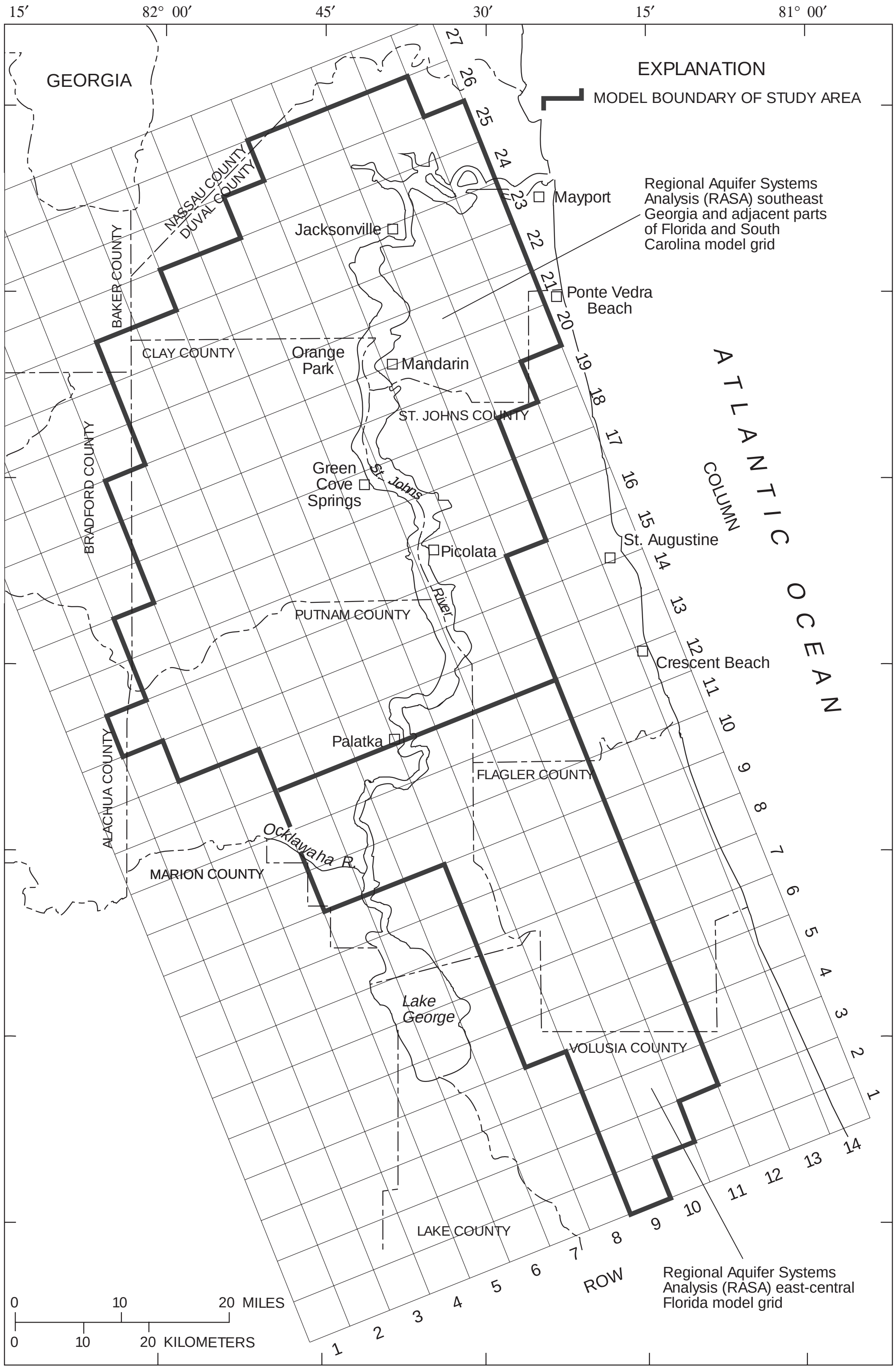


**Figure 11.** Study area model boundary and grid.

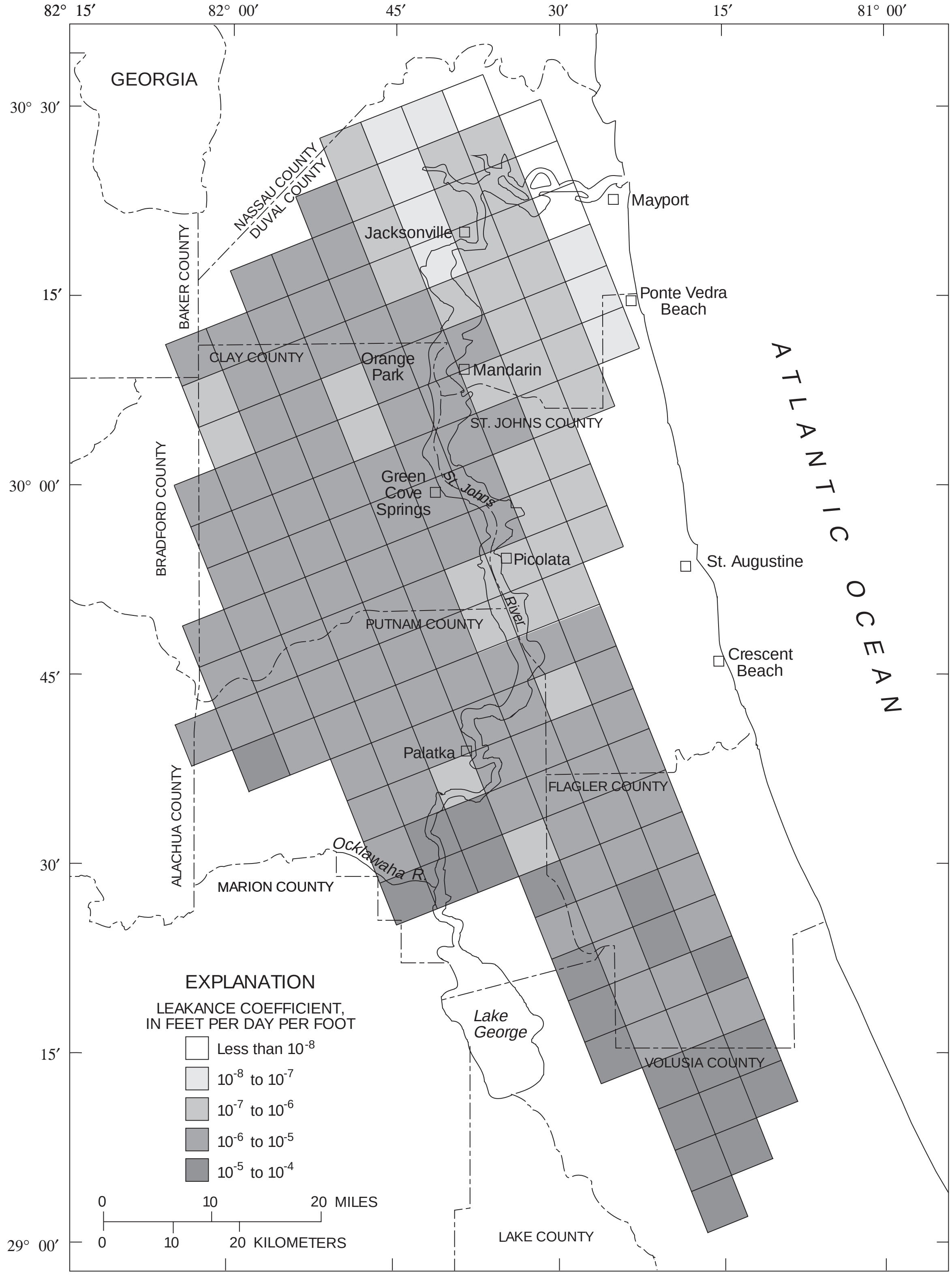


**Figure 12.** Estimated leakage coefficients of the intermediate confining unit (from Krause and Randolph, 1989; Tibbals, 1990; and C.H. Tibbals and R.E. Krause, U.S. Geological Survey, written commun., 1993).

Total ground-water discharge to the lower St. Johns River basin, determined by adding the calculated flow from all nodes with an upward hydraulic gradient in the study area and spring flow at Welaka and Satsuma Springs, was estimated at 86 $ft^3/s$ based on September 1990 Upper Floridan heads. Estimated leakage rates for each node within the lower St. Johns River drainage basin ranged from about 0 to 9 in/yr (fig. 13).

Total ground-water discharge to the lower St. Johns River also was computed for September 1991. Variables used to compute ground-water discharge for September 1990 were again used for the September 1991 estimate, except for potentiometric-surface altitudes, which increased in the drainage basin by an average of about 4 ft from the September 1990 levels. Potentiometric-surface altitudes rose between 2 and 6 ft as a result of near-record rainfall in much of the study area. The calculated discharge rate from the Upper Floridan aquifer to the river was about 133 $ft^3/s$, an increase of about 55 percent from the September 1990 calculated discharge. The increase in ground-water discharge was due to a greater upward hydraulic gradient in discharge areas, as well as to a reversal in the hydraulic gradient from recharge to discharge in areas where the two heads were nearly equal.

Potentiometric-surface altitudes in the Upper Floridan aquifer in most of the study area were near or at historical lows during September l990. Accordingly, ground-water discharge to the lower St. Johns River (assuming that the surficial aquifer system heads have remained relatively constant since predevelopment times) also could have been at a historical low. The average potentiometric surface of the Upper Floridan aquifer was higher during predevelopment times than at present (Johnston and others, 1980; Krause and Randolph, 1989; Tibbals, 1990). Estimated declines from predevelopment heads to heads measured in September 1990 range from less than 10 to more than 30 ft in the areas of higher pumpage (near Jacksonville).

Although changes in the potentiometric surface do not occur equally over the entire area, ground-water discharge to the river during predevelopment times was considerably higher than during September 199O. The potential effects of a higher potentiometric surface on total groundwater discharge to the river are shown in figure 14. For example, if in the past, the potentiometric surface of the Upper Floridan aquifer averaged 12 ft higher than the September 1990 levels, total ground-water discharge to the lower St. Johns River would have been about 300 $ft^3/s$, an increase of approximately 249 percent from the September 1990 calculated discharge. Conversely, a continued average decline of another 4 ft from the September 1990 levels could decrease the amount of ground-water discharge to the river to about 50 $ft^3/s$, a decline of about 42 percent.

## ESTIMATED CHEMICAL-CONSTITUENT LOADS IN GROUND-WATER DISCHARGE

The contribution of constituent loads into the lower St. Johns River from the Upper Floridan aquifer were estimated for this report. Total loads were determined by adding the calculated loads at each node with an upward hydraulic gradient within the lower St. Johns River drainage basin. It is assumed that all the water from the Upper Floridan aquifer that moves upward through the intermediate confining unit to the surficial aquifer system within the drainage basin eventually drains into the lower St. Johns River. Constituent loads from the Upper Floridan aquifer for each node were calculated using the following equation:

$$L = Q \times C \times 0.9855, \qquad (2)$$

where

$L$ is load, in tons per year;

$Q$ is ground-water discharge, in cubic feet per second;

$C$ is concentration of chemical constituents in water from the Upper Floridan aquifer, in milligrams per liter; and

0.9855 is a conversion factor.

Because load is a function of ground-water discharge and constituent concentration, changes in either variable can affect the calculation of load. An average constituent concentration in water from the Upper Floridan aquifer for each node was determined by interpolating concentrations in water from selected wells. However, some uncertainty concerning the accuracy of constituent concentrations exists because of long-term and seasonal changes in the chemical quality of water within the aquifer. In much of the area, water analyzed from the Upper Floridan aquifer was collected during the 1980’s however, in some areas, the most recent water samples were collected

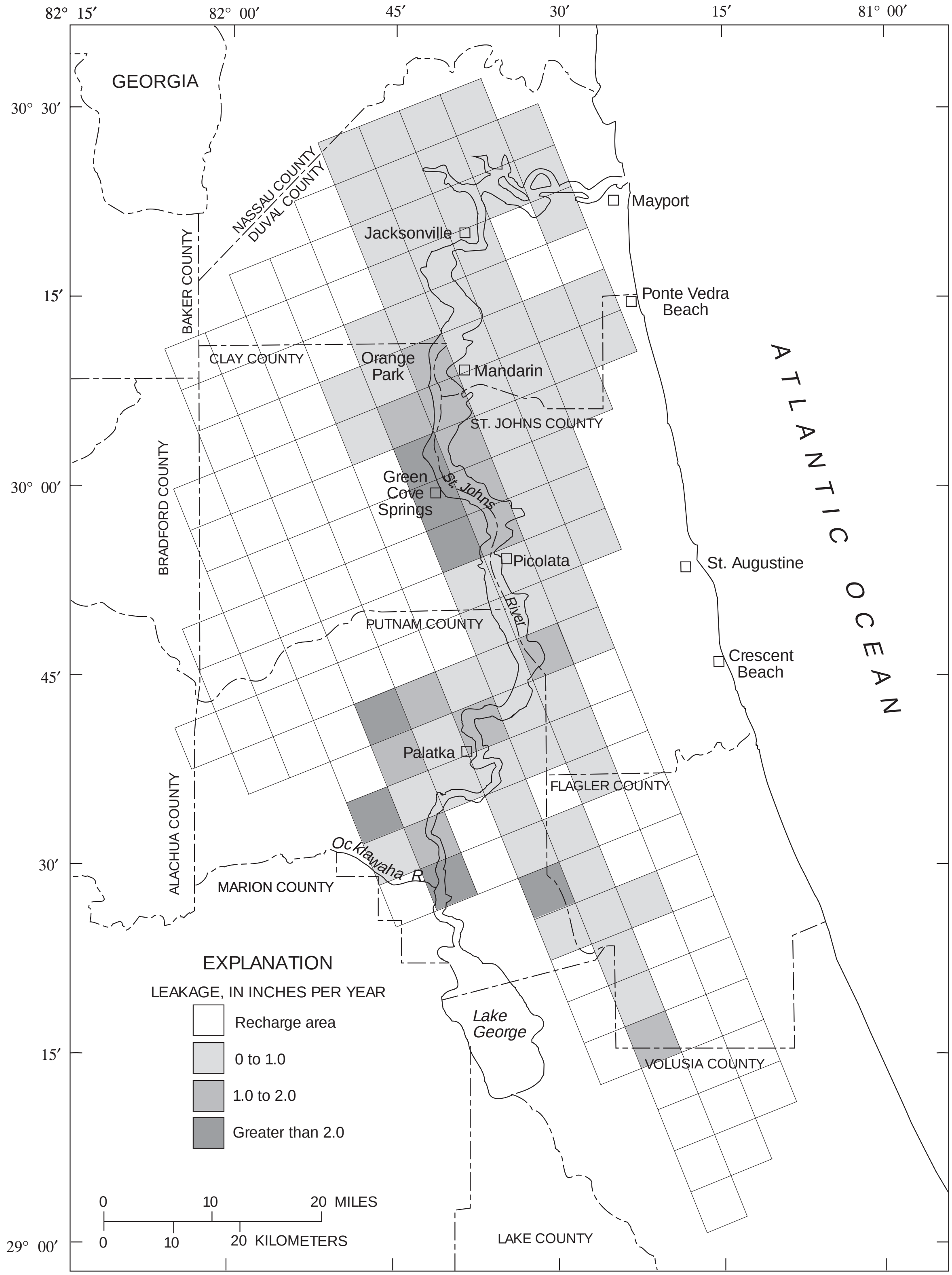


**Figure 12.** Estimated discharge from the Upper Floridan aquifer through the intermediate confining unit, September 1990.

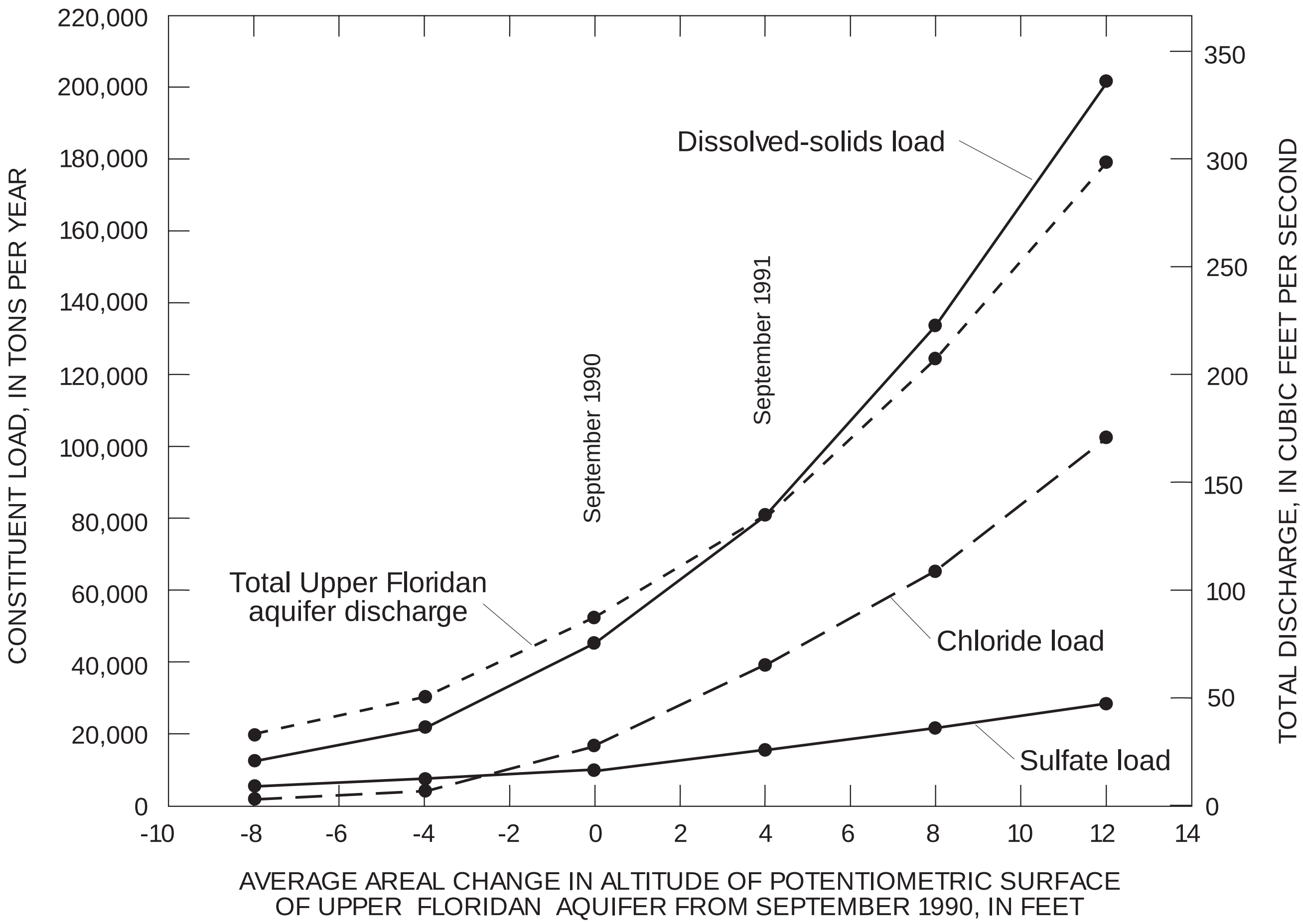


**Figure 13.** Relation of total discharge and chemical-constituent load to change in Upper Floridan aquifer potentiometric surface.

during the 1970's. Increases in constituent concentration might have occurred with time in selected wells. Seasonal changes in water levels due to pumpage also can affect the constituent concentration in water from the Upper Floridan aquifer. Munch and others (1979) documented the relation between chloride concentrations and the potentiometric surface in southwestern St. Johns County and near Palatka. Chloride concentrations in many wells increased during the spring, generally a period of greater irrigation-water use and lower potentiometric surface.

Total estimated constituent loads also can vary depending on the chemical and physical changes in the Upper Floridan aquifer water as it moves through the intermediate confining unit and surficial aquifer system. The degree of mineralization and the chemical-constituent loading of water are largely determined by the initial chemical composition of water entering the overlying hydrogeologic units, the composition and solubility of rocks with which it comes in contact, and the length of time the water remains in contact with these rocks. Therefore, estimated constituent loads could vary depending on the geochemical reactions that occur. For the purpose of this report, the assumption was made that little chemical change occurs as the water moves through the intermediate confining unit and the surficial aquifer.

Dissolved-solids loads discharging into the lower St. Johns River were estimated at 47,000 ton/yr based on September 1990 heads. Estimates of chloride and sulfate loads based on September 1990 heads were 18,000 and 9,500 ton/yr, respectively. The average 4-ft increase in the altitude of the potentiometric surface of the Upper Floridan aquifer throughout the entire lower

St. Johns River drainage basin during September 1991 increased dissolved-solids loads discharging into the lower St. Johns River to about 81,000 ton/yr, a 76 percent increase from September 1990. Chloride loads increased to 39,000 ton/yr, a 117 percent increase; and sulfate loads increased to about 15,000 ton/yr, a 58 percent increase. Constituent fluxes for dissolved solids, chloride, and sulfate, in (ton/yr)/mi$^2$ based on September 1990 heads, also were calculated to compare loading rates for the various nodes within the study area and are shown in figures 15-17.

Estimated ground-water discharge and loads in four zones of the lower St. Johns River (fig. 18) were calculated based on September 1990 heads. The drainage basin was subdivided based on ground-water flow lines within the surficial aquifer system. The contribution of ground-water discharge from the Upper Floridan aquifer to four zones in the lower St. Johns River drainage basin is shown in figure 19. The largest contribution of ground water to the river is from zone A. In this zone, approximately 35 ft$^3$/s of ground water discharges to the St. Johns River. Conversely, only 2 ft$^3$/s were discharged in zone D. Nearly all of zone D is underlain by the thickest part of the intermediate confining unit that has very low leakance coefficients.

Approximately 16,000 of the 18,000 ton/yr of the chloride load potentially could enter the St. Johns River through the surficial aquifer system in zone A (fig. 19). Little chloride load is contributed through zones B, C, and D. The largest contribution of sulfate load is through zone B, of which approximately 6,000 ton/yr could be discharged into the river. The total dissolved-solids constituent load that could enter the St. Johns River is estimated at 47,000 ton/yr. Approximately 41,000 ton/yr of dissolved solids are discharged into the river from zones A and B.

## SUMMARY

The lower St. Johns River, a 101-mile long segment of the St. Johns River, begins at the confluence with the Ocklawaha River and ends where the river discharges into the Atlantic Ocean at Mayport. The river ranges in width from about 600 feet to 3 miles. The St. Johns River is affected by tides as far upstream as Lake George, 106 miles from the mouth and, under certain conditions, as far as Lake Monroe, approximately 161 miles upstream. Because of the tidal nature of the river, the chemical quality of the riverwater is highly variable. Saltwater from the ocean advances inland during incoming tides and recedes during outgoing tides. The advancing ocean water mixes with the existing fresh riverwater, thereby increasing the salinity of the river.

Three hydrogeologic units are present in the study area: the surficial aquifer system, the intermediate confining unit, and the Floridan aquifer system. The surficial aquifer system overlies the intermediate confining unit and contains deposits of sand, clay, shell, limestone, and dolomite. The intermediate confining unit, which consists primarily of the Hawthorn Formation, underlies the entire area. The clay and silts of the intermediate confining unit retard the vertical movement of water between the surficial aquifer system and the Floridan aquifer system. The intermediate confining unit sediments, generally of low permeability, vary in thickness and areal extent. The intermediate confining unit also could be locally breached by sinkholes, fractures, and other openings, providing connections between the Floridan aquifer system and the surficial aquifer system. Leakage coefficients are estimated to range from $1 \times 10^{-8}$ to more than $1 \times 10^{-4}$ foot per day per foot. The highest values generally are where aquifer recharge or discharge rates are greatest, coinciding with areas where the confining units are relatively thin or permeable.

The Floridan aquifer system, the major source of ground water in northeastern Florida, consists of limestone and dolomite. The potentiometric surface of the Upper Floridan aquifer ranged from about 75 to less than 10 feet above sea level in September 1990. The Upper Floridan aquifer discharges ground water along the entire length of the lower St. Johns River. Large depressions in the potentiometric surface are believed to be caused by one or more of the following: (1) water withdrawals for industry, public-supply, and agriculture use; (2) diffuse upward leakage; and (3) spring discharge.

The quality of water in the Upper Floridan aquifer varies throughout the study area. Dissolved solids in water from the Upper Floridan aquifer range from about 100 to 5,000 milligrams per liter. Chloride and sulfate concentrations are estimated to range from 4 to 3,700 milligrams per liter and l to 1,300 milligrams per liter, respectively. Saltwater from the ocean affects much of the lower St. Johns River; therefore, water discharging from the Upper Floridan aquifer in most areas probably is less mineralized than riverwater. However, in some areas of the lower St. Johns River, water discharging from the Upper Floridan aquifer could be more mineralized than the riverwater.

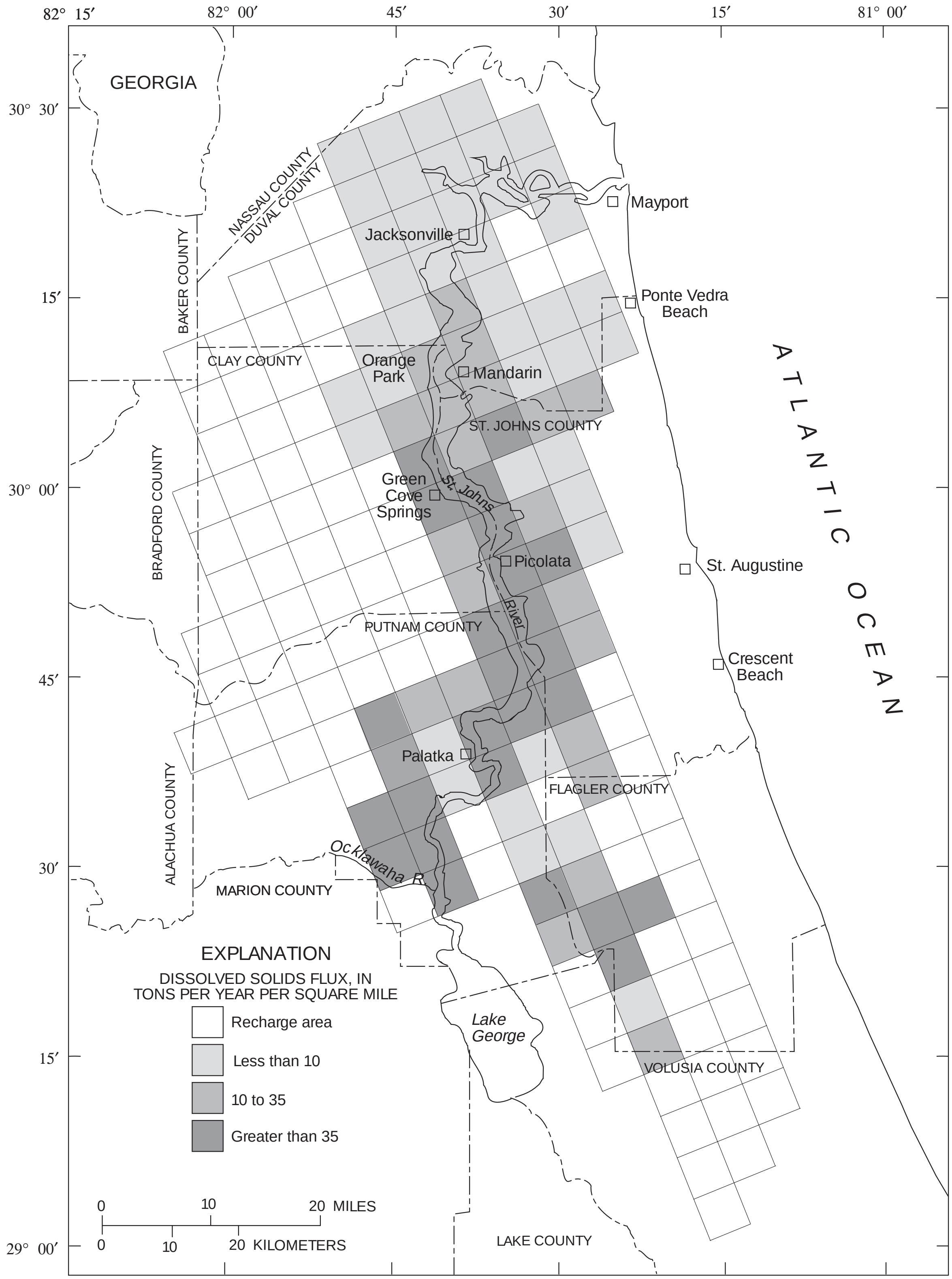


**Figure 14.** Estimated dissolved-solids flux, September 1990.

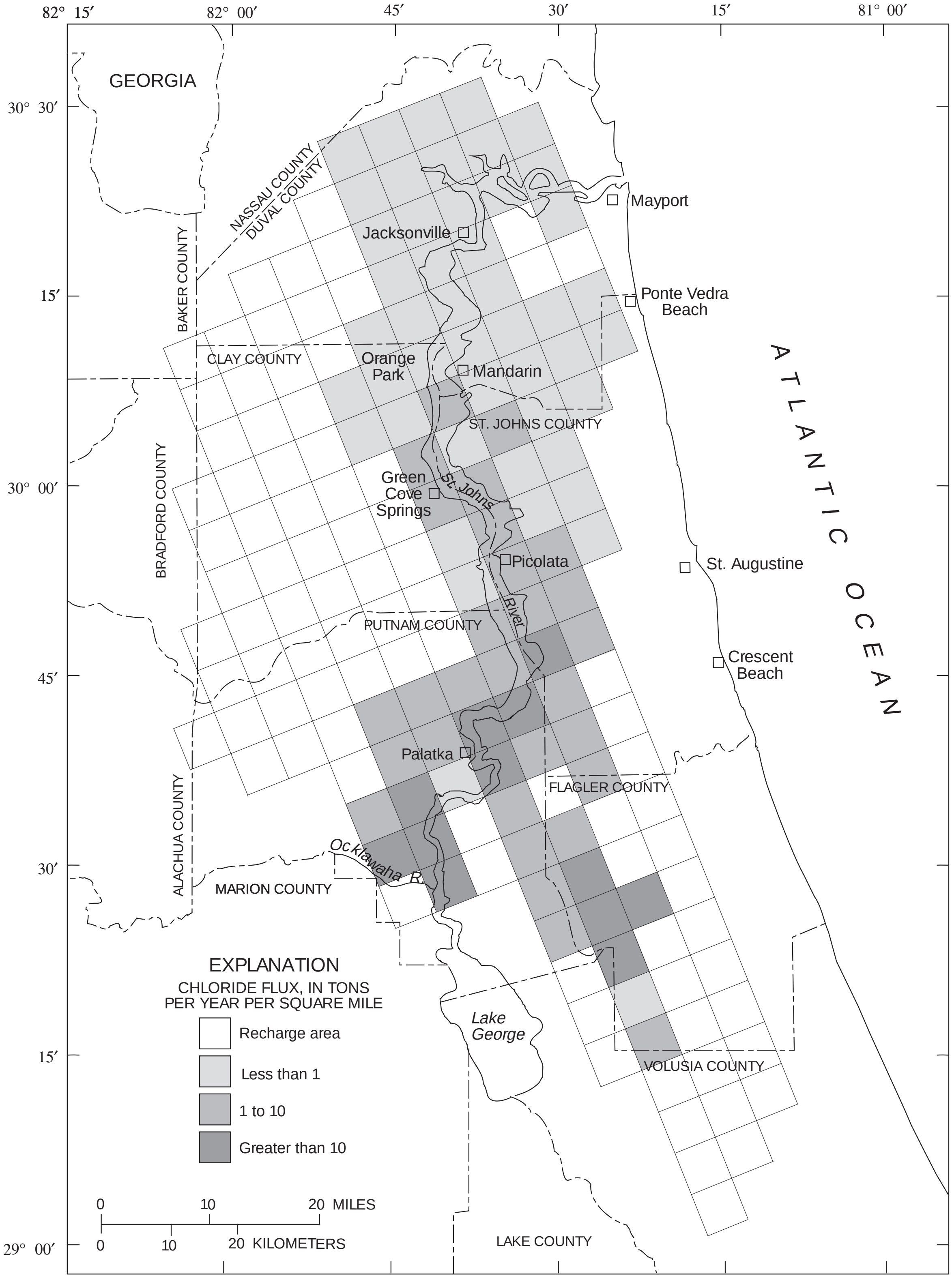


**Figure 15.** Estimated chloride flux, September 1990.

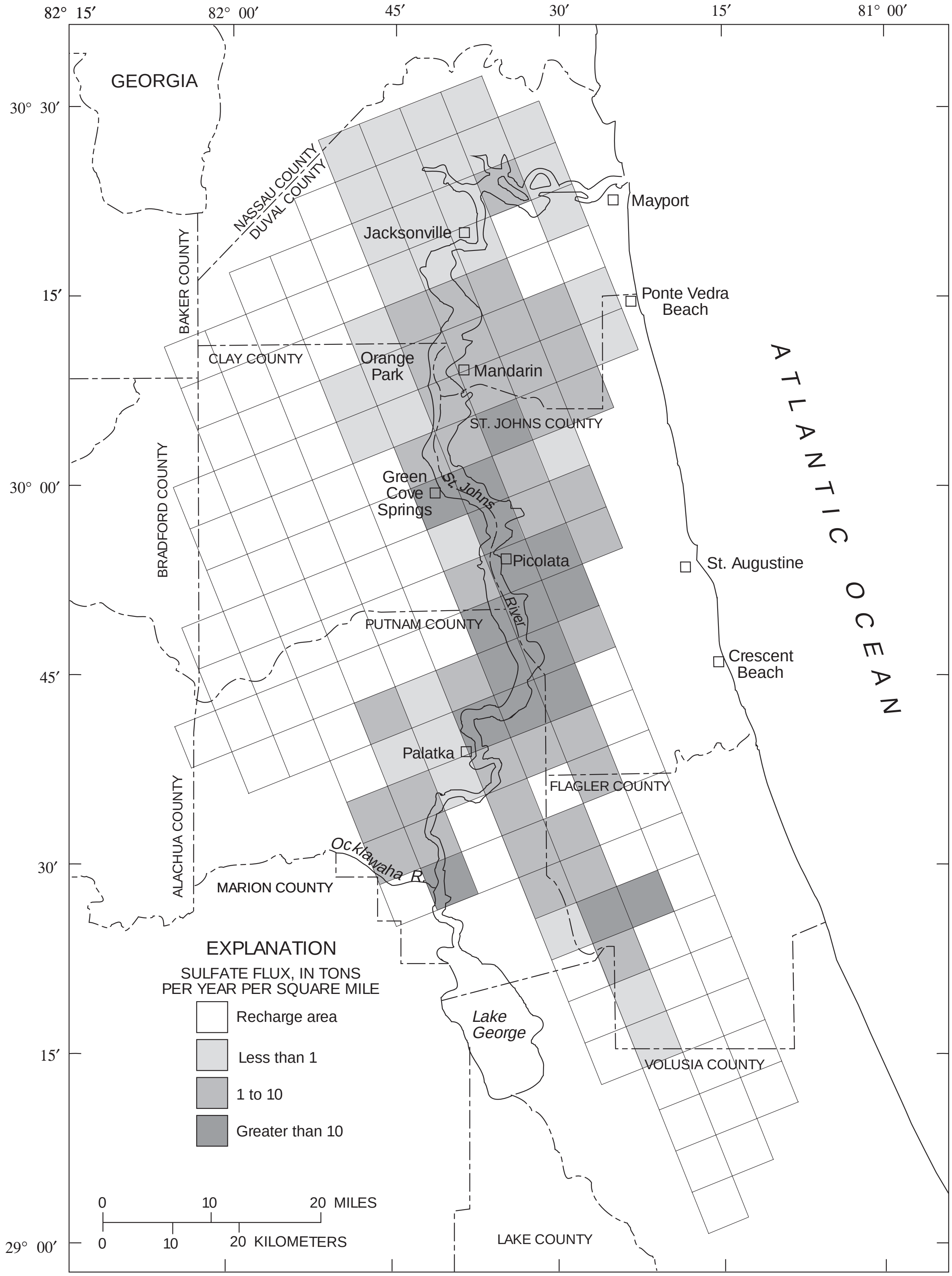


**Figure 16.** Estimated sulfate flux, September 1990.

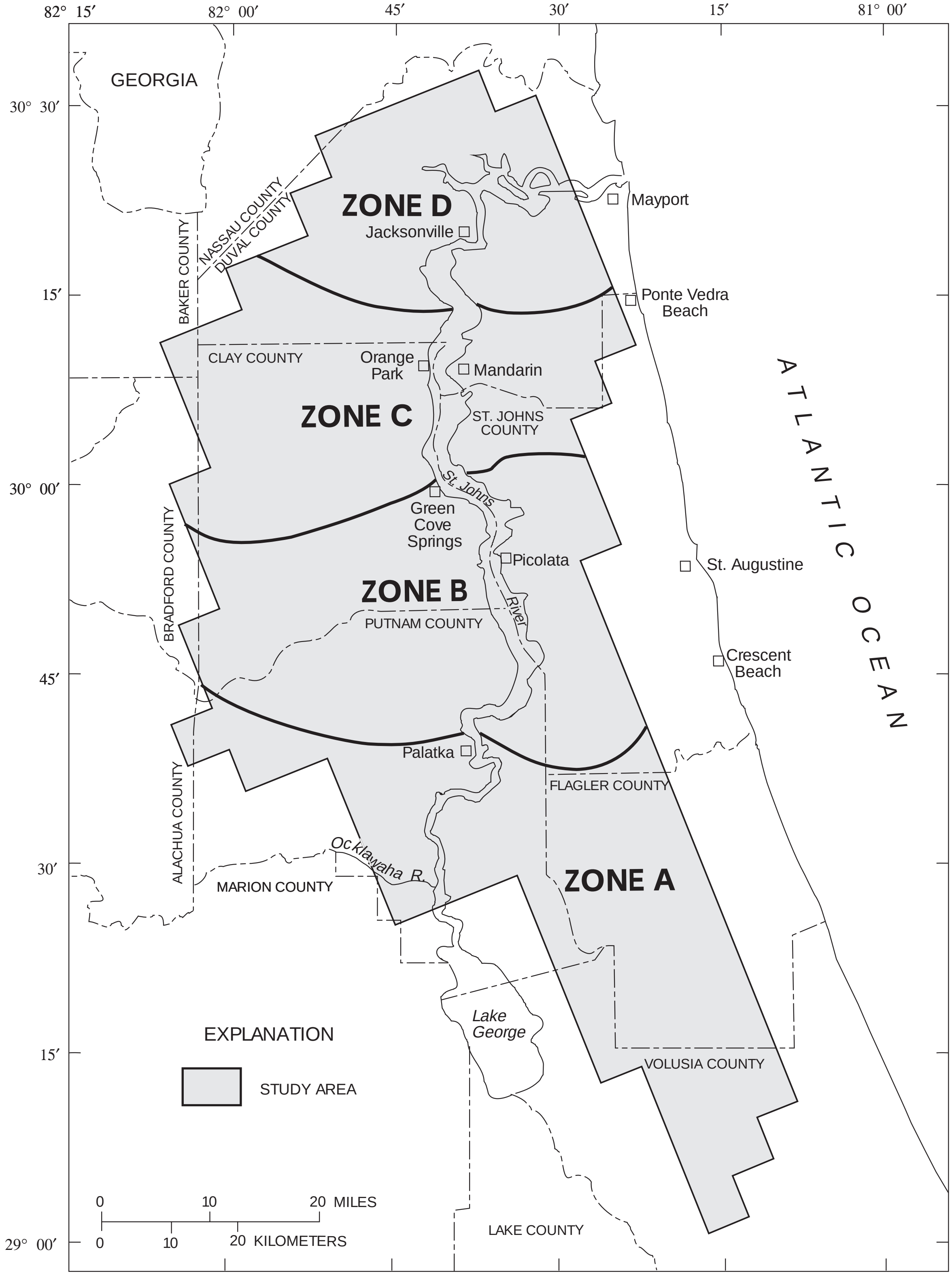


**Figure 17.** Location of zones used to compute cumulative constituent load and flow of Upper Floridan aquifer water discharging into the surficial aquifer system.

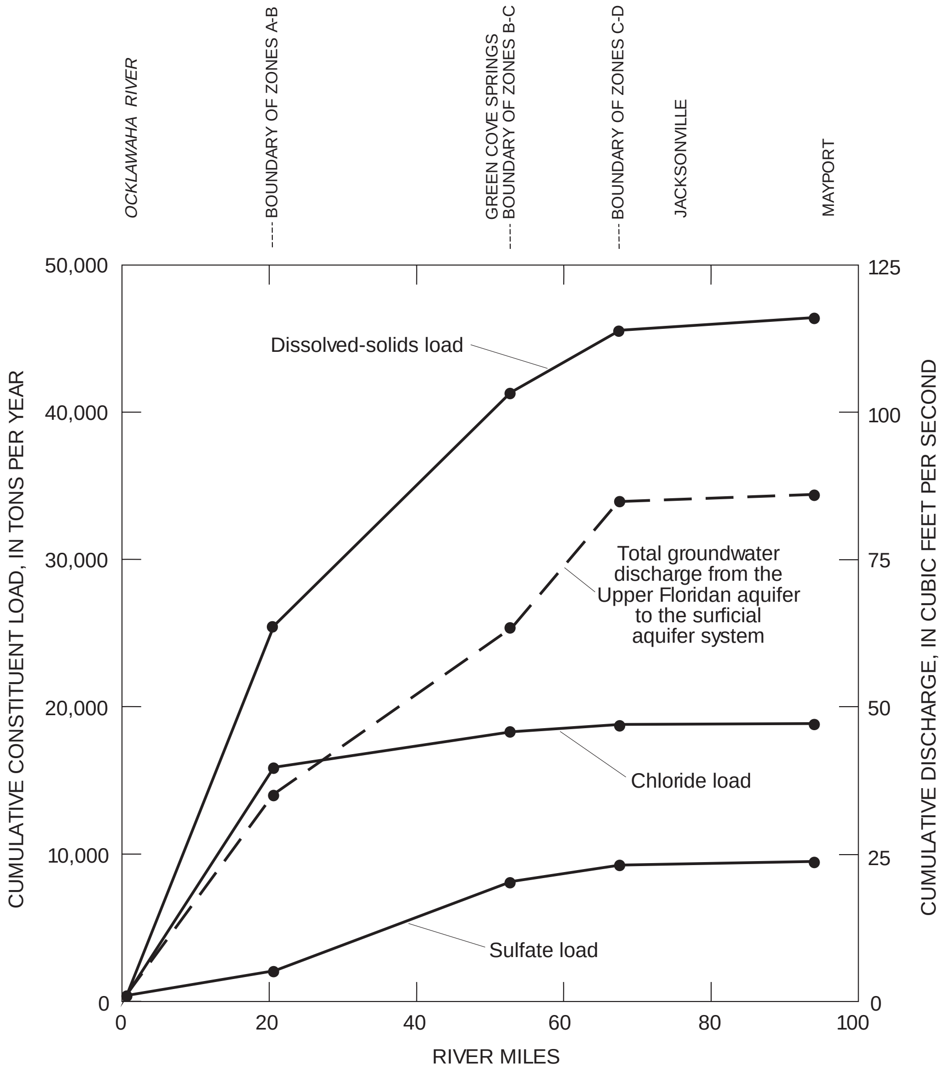


**Figure 18.** Cumulative constituent load and flow of Upper Floridan aquifer water discharging into the surficial aquifer system, September 1990.

Water from the Upper Floridan aquifer moves upward through the intermediate confining unit to the surficial aquifer system in the discharge areas of the lower St. Johns River drainage basin. The water then moves laterally through the surficial aquifer system or into streams and creeks where it eventually discharges into the St. Johns River. Ground-water discharge to the river is controlled by the leakance coefficient of the intermediate confining unit and the head difference between the Upper Floridan aquifer and the surficial aquifer system.

Ground-water discharge and constituent loads from the Upper Floridan aquifer to the lower St. Johns River were estimated based on the potentiometric surfaces within the drainage basin for September 1990 and 1991. Estimated total discharge by diffuse upward leakage and spring flow to the lower St. Johns River was 86 cubic feet per second, based on September 1990 heads. Total estimated dissolved-solids load to the river from the Upper Floridan aquifer was 47,000 tons per year. Total estimated chloride and sulfate loads were 18,000 and 9,500 tons per year, respectively. Water levels in the Upper Floridan aquifer in September 1991 averaged about 4 feet higher than in September 1990 as a result of near record rainfall throughout most of the study area. Total estimated Floridan aquifer system discharge to the lower St. Johns River was about 133 cubic feet per second. Estimated dissolved-solids, chloride, and sulfate loads discharging into the river also increased to 81,000, 39,000, and 15,000 tons per year, respectively.

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