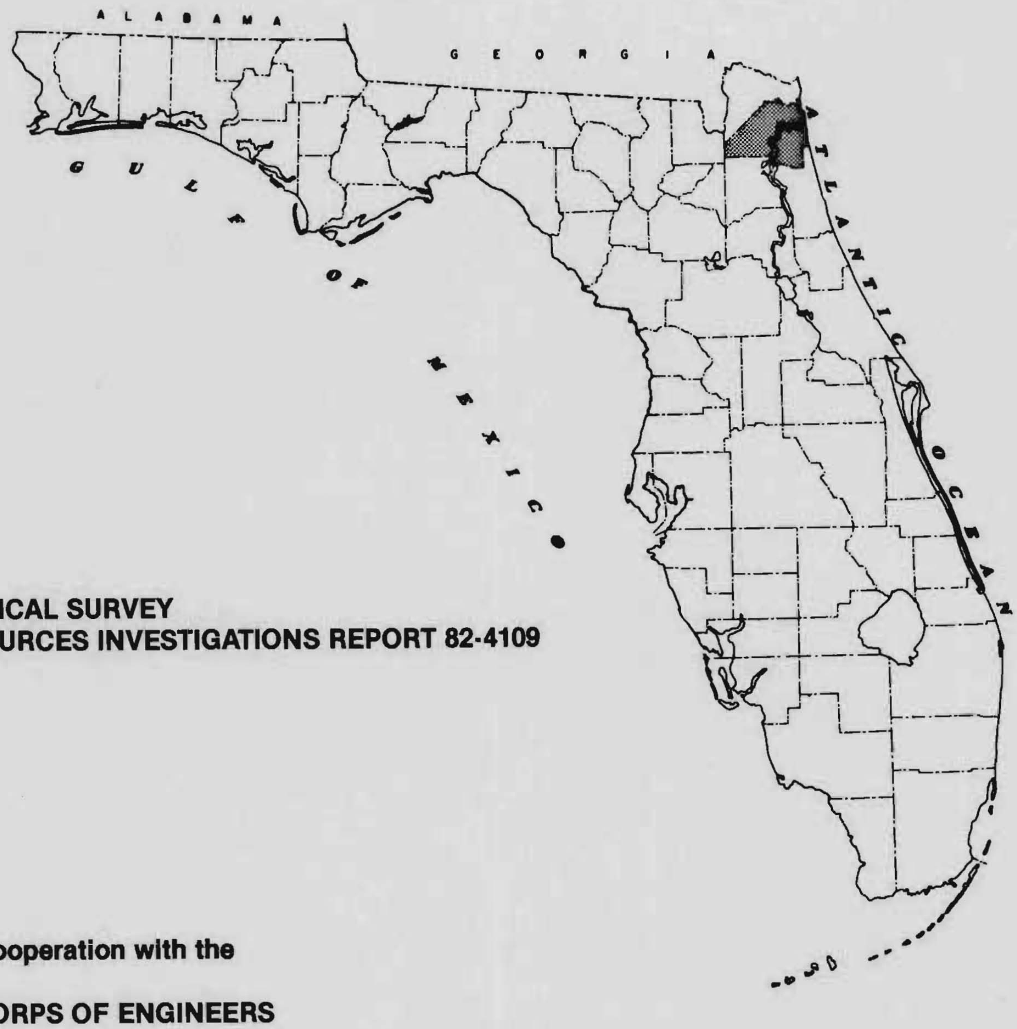
APPRAISAL OF THE INTERCONNECTION BETWEEN THE ST. JOHNS RIVER AND THE SURFICIAL AQUIFER, EAST-CENTRAL DUVAL COUNTY, FLORIDA



U.S. GEOLOGICAL SURVEY
WATER-RESOURCES INVESTIGATIONS REPORT 82-4109

Prepared in cooperation with the

U.S. ARMY CORPS OF ENGINEERS

82-4109 APPRAISAL OF THE INTERCONNECTION BETWEEN THE ST. JOHNS RIVER AND THE SURFICIAL AQUIFER, EAST-CENTRAL DUVAL COUNTY, FLORIDA 82-4109

CONVERSION FACTORS

For those readers who may prefer to use International System of Units (SI) rather than inch-pound units, the conversion factors for terms used in this report are listed below:

Multiply	By	To obtain SI unit
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
gallons per minute (gal/min)	0.06309	liters per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meters per second (m^3/s)
foot per second (ft/s)	0.3048	meters per second (m/s)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)
pound per cubic inch (lb/in^3)	0.03613	gram per cubic centimeter (g/cm^3)
degrees Fahrenheit (°F)	5/9 (°F-32)	degrees Celsius (°C)
micromho per centimeter at 25° Celsius (umhos/cm at 25°C)	1.000	microsiemen per centimeter at 25° Celsius (uS/cm at 25°C)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

APPRAISAL OF THE INTERCONNECTION BETWEEN THE ST. JOHNS RIVER AND THE SURFICIAL AQUIFER, EAST-CENTRAL DUVAL COUNTY, FLORIDA

By Rick M. Spechler and Roy B. Stone, Jr.

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Tallahassee, Florida

1983

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

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By Rick M. Spechler and Roy B. Stone, Jr.

ABSTRACT

The proposed deepening of the navigation channel in the St. Johns River to about 46-48 feet below sea level (45 feet below mean low water) may breach up to 11 feet of the limestone unit of the lower part of the surficial aquifer along a 25-mile channel. The limestone supplies water to numerous domestic wells along the river in the Jacksonville area.

The limestone ranges in depth from about 10 to 75 feet below sea level in the study area. In the navigation channel, depth to the top of the limestone ranges from about 39 to 47 feet. Recent channel improvements to a depth of about 39-41 feet below sea level (38 feet below mean low water) have breached the limestone at many locations. Where breaching has not yet occurred, less than 1 to about 6 feet of undifferentiated sediments overlie the limestone. These sediments, consisting predominantly of sand with some clay and silt, are generally too permeable to form an effective confining layer.

Hydrologic data indicate that an interconnection between the river and the limestone already exists at several locations. Where water in the limestone adjacent to the river is unconfined, saline water may move from the river through the sediments and into the limestone until a hydraulic equilibrium is reached. If water in the limestone adjacent to the river is semiconfined but is unconfined beneath the channel, saline water may move inland through the breached limestone. The distance that the saline water would move depends upon the height of the river stage, the difference in density between fresh ground water and saline river water, and the potentiometric surface and permeability of the limestone unit.

Chloride concentrations determined from 40 wells tapping the limestone unit range from 8 to 6,600 milligrams per liter. However, in most of the wells sampled, chloride concentrations ranged from 8 to 30 milligrams per liter. Water from one test well, 250 feet from the river, had a chloride concentration of 6,600 milligrams per liter.

The proposed dredging operation in the Jacksonville Harbor is not expected to alter significantly the present hydrologic system. Some encroachment of saline water could occur where the limestone is breached; however, the current position of the interface most likely represents conditions that will be present after future channel improvements.

INTRODUCTION

The city of Jacksonville is a major seaport utilized by commercial ships and by the U.S. Navy. The city's harbor facilities are located along the St. Johns River as far as 25 miles inland. Access to the ocean is through a dredged navigation channel.

The history of the navigation channel, known as the Jacksonville Harbor, dates back to 1852 when Congress appropriated funds for a survey and experimental dredging at the mouth of the St. Johns River. Actual dredging of a 10-foot-deep by 80-foot-wide channel began in 1870. By 1910 the navigation channel was dredged to a depth of about 24 feet below mean low water. The channel was deepened to 30 feet below mean low water in 1918 and to 34 feet in 1952. Dredging of the present 38-foot channel began in 1970 and was completed in 1977.

Channel depths reported by the U.S. Army Corps of Engineers are based on mean low water. For convenience, mean low water throughout this report was converted to sea level. Sea level ranges from about 1 foot below mean low water near Jacksonville University to about 3 feet below mean low water at Mayport, and is directly related to tidal fluctuations in the St. Johns River.

The U.S. Army Corps of Engineers proposes to deepen the dredged part of the navigation channel from its present depth of about 39-41 feet to 46-48 feet below sea level (about 45 feet below mean low water). The proposed dredging requires that an additional 2 feet be removed when rock is encountered and 2 feet more "allowable" for overrun. Therefore, the proposed dredging could penetrate as much as 11 feet of a limestone unit which is part of the surficial aquifer in the Jacksonville area and which supplies water to numerous domestic wells along the river.

The U.S. Geological Survey, in cooperation with the U.S. Army Corps of Engineers, conducted a 1-year study to determine the effects of proposed deepening of the navigation channel on the surficial aquifer. A specific objective was to determine the degree of interconnection that exists currently between the limestone adjacent to the river and the limestone in the riverbed that is to be dredged.

The report describes the hydrology and chemical quality of water in the surficial aquifer and the physical and chemical characteristics of the St. Johns River. The report also discusses the interconnection between the river and surficial aquifer and appraises the effects of the proposed dredging. Evaluations are based upon data obtained from Federal reconnaissance reports, published and unpublished geologist's logs, well driller's logs, water-quality analyses, and information supplied by the Corps of Engineers.

Previous Investigations

Leve (1961; 1966) and Leve and Goolsby (1969) briefly describe the surficial aquifer in northeast Florida. Cooke (1945), Vernon (1951), Puri and Vernon (1964), and Leve (1966) describe the geology of the area. Fairchild (1972) and Causey and Phelps (1978) describe the hydrogeology of the surficial aquifer in Duval County, but refer to it as the shallow aquifer. As the term "shallow" is vague, the use of the term is being discontinued in recent reports prepared by the U.S. Geological Survey in Florida and is being replaced by the term "surficial" wherever the aquifer is contiguous with the land surface.

Anderson and Goolsby (1973) and investigations by the U.S. Army Corps of Engineers (1970; 1972a; 1972b; 1979) describe the physical and chemical characteristics of the St. Johns River. In addition, numerous studies have been conducted by the U.S. Army Corps of Engineers on navigational improvements for the Jacksonville Harbor.

Acknowledgments

The authors wish to express their appreciation to the following governmental agencies, firms, and individuals: the U.S. Army Corps of Engineers, who drilled the test wells; Offshore Power Supply for granting permission to construct a tidal gage on their property; the U.S. Park Service at Fort Caroline National Memorial; Alexander Brest and Lester Sanders for permission to drill observation wells on their property; the City of Jacksonville for granting permission to drill on city road right-of-ways and supplying bench-mark data; the Florida Department of Transportation for supplying bench-mark data; J. Don Kane, Director of the physical plant at Jacksonville University, for allowing the monitoring of wells on their property; the St. Johns River Water Management District, consultants, and well drillers who made geologic logs available; and to the numerous well owners who permitted the collection of water samples and water-level measurements from their wells.

DESCRIPTION OF STUDY AREA

Location and Setting

The study area is about 320 mi^2 in eastern Duval County, Fla., and includes the St. Johns River and adjacent areas, from its mouth to approximately 25 miles upstream (fig. 1).

The relatively flat topography consists of marine terraces formed during those periods in the Pleistocene when sea levels were higher than at present. The terraces lie approximately parallel to the coastline. South of the river, these terraces are generally 30 to 50 feet above sea level; the highest altitude is about 85 feet in the vicinity of Fort Caroline National Memorial. North of the St. Johns River, altitudes rarely exceed 30 feet, and much of the area is covered by saltwater marshes.

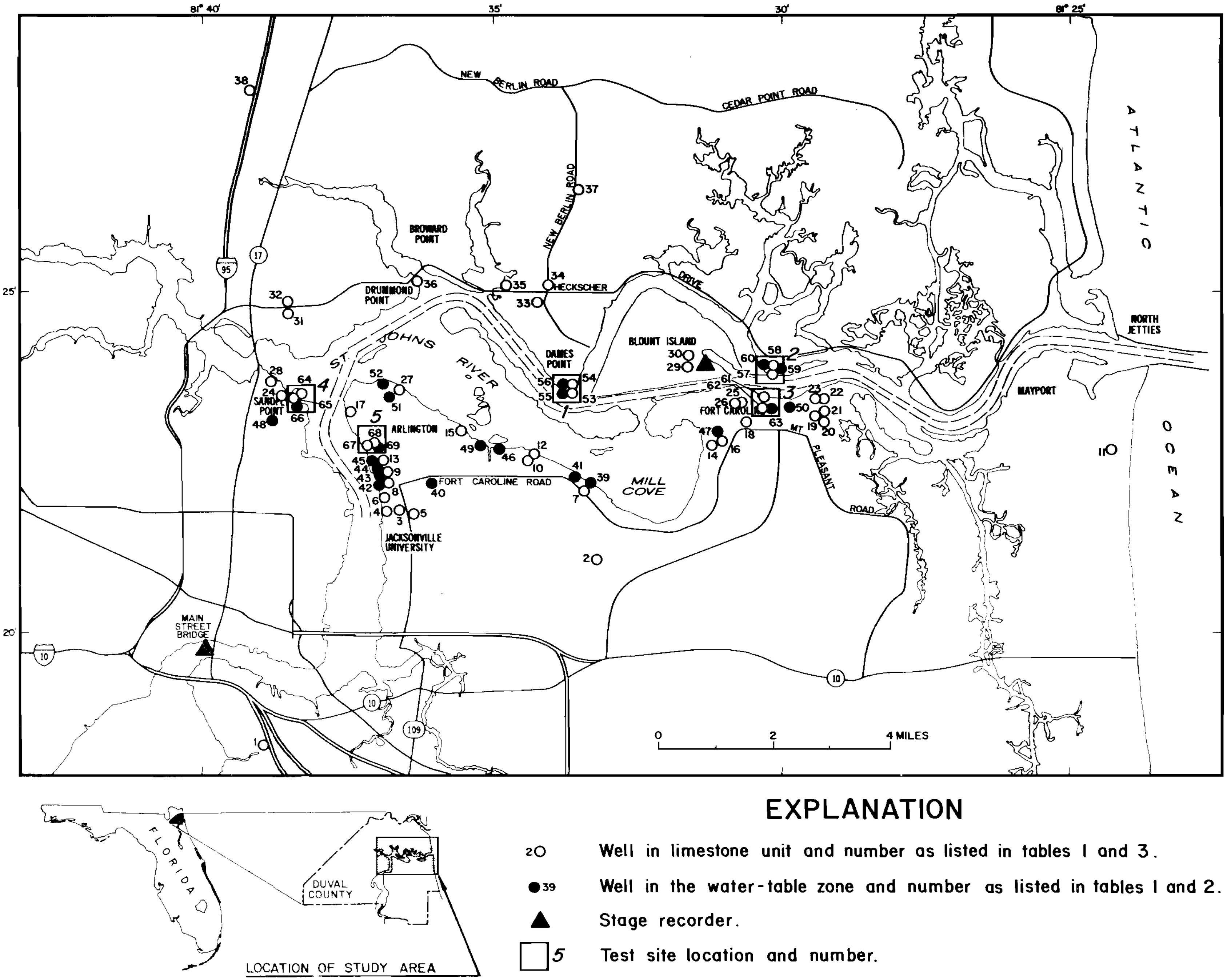


Figure 1.--Location of study area, inventoried wells, test well sites, and stage recorders.

The climate of the area is subtropical. The average annual temperature is 69.5°F, with July and August the warmest months and January the coldest. Average annual rainfall is approximately 52 inches, two-thirds of which falls between June and October.

Surface drainage is primarily through the St. Johns River and its tributaries. Both the St. Johns River and its tributaries are tidal throughout the study area.

St. Johns River

The headwaters of the St. Johns River is a marsh near Fort Pierce, Fla., about 312 miles from its mouth near Mayport. The river, which flows on a northward course to Jacksonville and then eastward to the ocean, ranges in width in the study area from about 1,250 feet at the Main Street Bridge to more than 2 miles at Mill Cove. The navigation channel between the ocean and Jacksonville is about 40 feet deep and 400 to 900 feet wide.

The St. Johns River has a drainage area of about 9,430 mi^2 and is a tidal estuary in its lower reaches. At the mouth of the river, the tidal range averages 4.9 feet. The ocean tide generates a progressive tidal wave that moves up the river with gradually diminishing amplitude; at the Main Street Bridge, the range averages 1.5 feet. Rising ocean tides force large amounts of water up the river. Most of this water subsequently flows back toward the ocean as the tide falls. These tidal flows average 87,000 ft^3/s at the Main Street Bridge in Jacksonville, and peak flows exceeding 150,000 ft^3/s are common (Anderson and Goolsby, 1973, p. 1). Velocities range from zero at slack tide to 3 ft/s near peak high and low tides. The average tidal flow is more than seven times as large as the average freshwater flow.

Seawater moving upstream from the mouth of the St. Johns River mixes with the river water to form a zone of transition. The chemical character of the water in this zone varies from seawater near the coast to freshwater farther inland. Between the City of Jacksonville and the ocean, the river shows some vertical stratification between seawater and overlying river water. Daily maximum chloride concentrations in the river range from 2,000 mg/L at the Main Street Bridge to 19,000 mg/L at Mayport 50 percent of the days. At Drummond Point, about halfway between these two sites, daily maximum chloride concentrations exceeded 10,000 mg/L about 50 percent of the days and 15,000 mg/L less than 7 percent of the days (fig. 2).

Hydrogeology

The study area is underlain by unconsolidated and consolidated deposits of Holocene to late Miocene age that collectively comprise the surficial aquifer (fig. 3). The deposits of Holocene and Pleistocene age are primarily sand and clayey sand that locally contain shell beds. These deposits are underlain by sand, shell, clay, and limestone of Pliocene or late Miocene age. The limestone, where present, occurs at the base of these deposits and is the major water-yielding zone in the surficial aquifer. Where the limestone is missing, ground water is obtained from sand and shell beds. The surficial aquifer is about 50 to 100 feet thick in the study area.

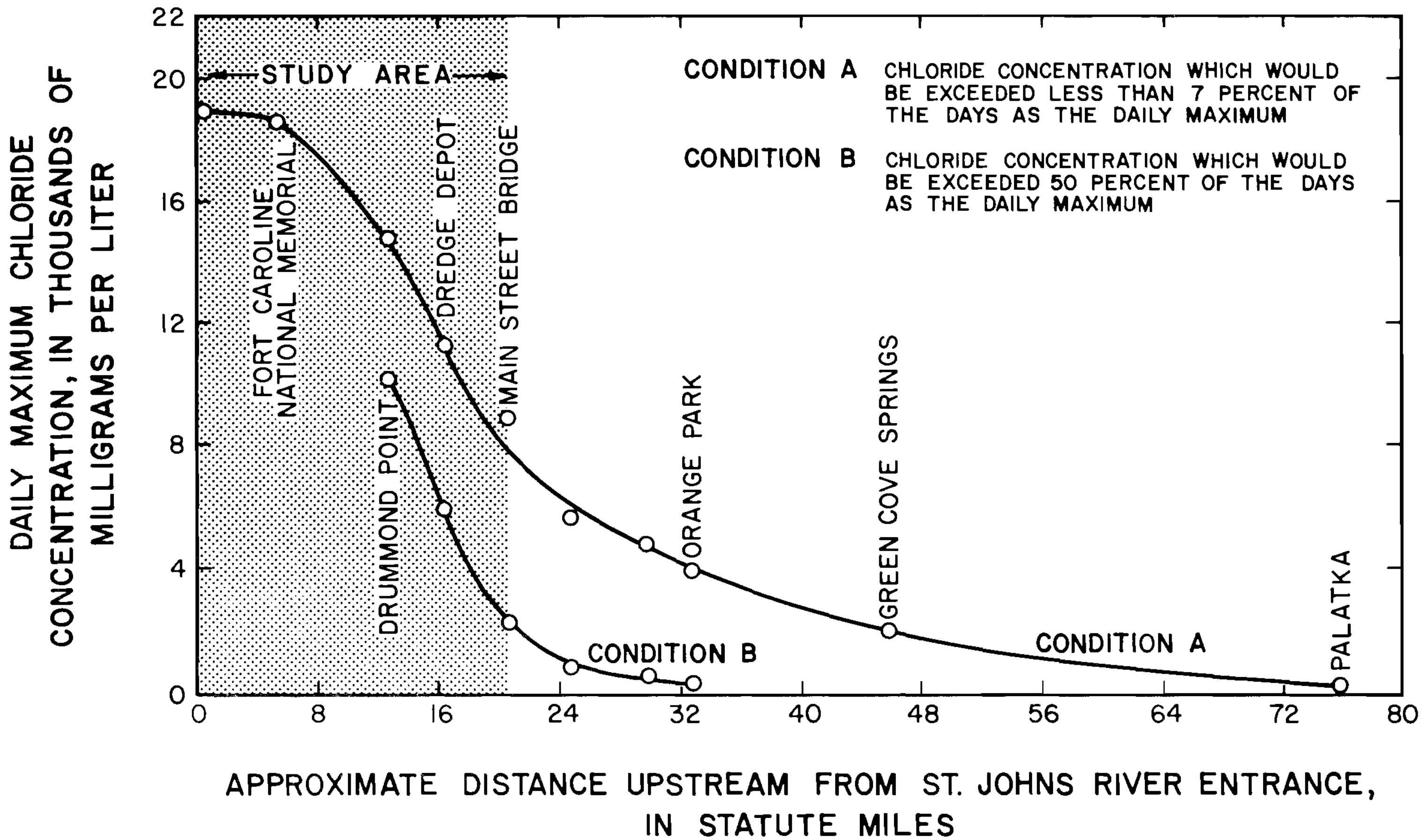


Figure 2.--Approximate longitudinal variation in the daily maximum chloride concentration under two conditions in the lower St. Johns River.

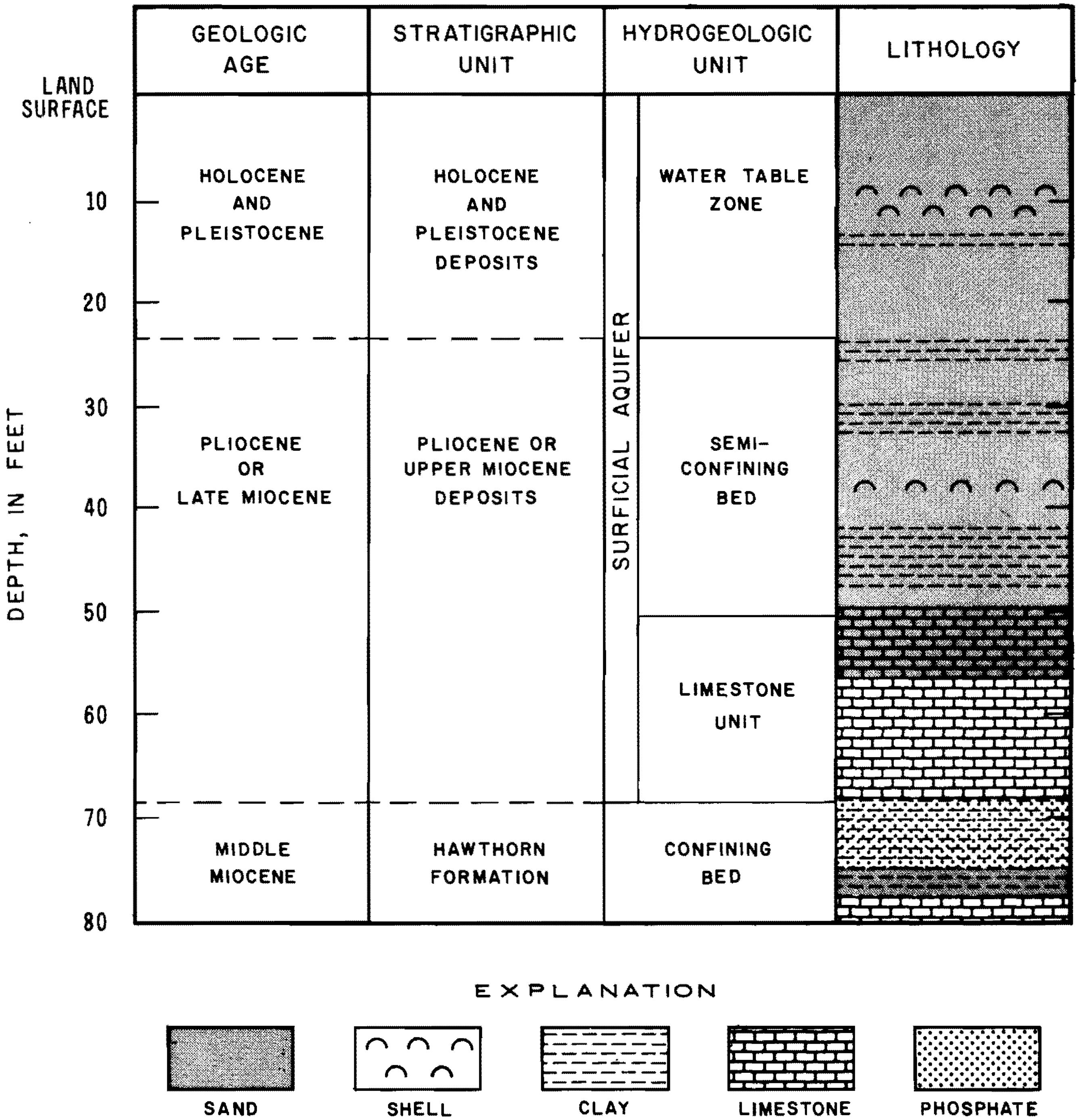


Figure 3.--Generalized hydrogeologic column of the surficial aquifer.

The Hawthorn Formation of middle Miocene age underlies the surficial aquifer throughout the study area. The Hawthorn consists mainly of gray to olive-green clay, sandy clay, and sandy limestone containing abundant amounts of phosphatic sand, granules, and pebbles. Its thickness ranges from 300 to 450 feet. In most places the upper part of the Hawthorn is marked by the presence of phosphate-rich sediments which distinguish the Hawthorn from overlying deposits (Fairchild, 1972, p. 21). The Hawthorn Formation overall has low permeability and it functions as a confining bed, severely retarding movement of water between the surficial aquifer and the underlying Floridan aquifer.

The Floridan aquifer is the principal source of water in northeastern Florida and in much of the remainder of the State. However, because of the hydraulic separation provided by the Hawthorn Formation, the proposed deepening of the St. Johns River will not affect the Floridan aquifer. Hence, further discussion of the Floridan aquifer is beyond the scope of this study.

SURFICIAL AQUIFER

The surficial aquifer can be subdivided into three parts (fig. 3). In the upper part of the aquifer, water occurs under unconfined or water-table conditions and this part of the aquifer is referred to as the water-table zone. Underlying the water-table zone are discontinuous beds of sediments with lower permeability. The low permeability zone is referred to as the semiconfining bed as it partially confines water in the underlying beds. Beneath the semiconfining bed is the limestone part of the surficial aquifer, referred to in this report as the limestone unit. It is the principal water-yielding zone of the surficial aquifer and is the focus of this study.

Water-Table Zone

Undifferentiated sediments of Pleistocene and Holocene age underlie the study area. These sediments, which constitute the water-table zone, are as much as 50 feet thick. They consist primarily of medium-to-fine unconsolidated quartz sand, and may contain thin beds of green to gray sandy clay, which in places contain shells, particularly near the coast.

Recharge to the water-table zone is chiefly by the infiltration of rainwater, or water from lakes, streams, or marshes. Water is discharged from the zone by evapotranspiration, by infiltration into the underlying units in areas where the water table is higher than the potentiometric surface of the limestone unit, by seepage into surface water bodies, and by pumpage.

Water levels in the water-table zone vary seasonally and respond to rainfall or lack of rainfall. However, fluctuations in water levels from wells near the St. Johns River are primarily in response to ocean tides. Water levels in several wells at the test sites fluctuated only a few tenths of a foot or less. These small fluctuations are attributed to the low permeability of the sediments.

Average water levels in the water table zone at the test site were about equal to or slightly greater than water levels in the underlying limestone unit. In the wells where a downward potential existed, the difference was small, generally not exceeding a few tenths of a foot. An exception was at test site 2, where differences in water levels between test wells 58 and 60 were about 1 foot.

In areas not affected by the St. Johns River or its tributaries, water from this zone is characterized by low dissolved solids concentration of less than 100 mg/L and by a hardness of generally less than 60 mg/L as $CaCO_3$ (Leve and Goolsby, 1969, p. 9). In some areas, the water contains more than 0.3 mg/L of iron (Causey and Phelps, 1978, p. 28), but except for iron, the water generally meets the drinking water standards of the U.S. Environmental Protection Agency (1975, 1977).

Chloride concentrations of water sampled from 20 wells in the water-table zone generally ranged from about 8 to 30 mg/L (tables 1 and 2). However, water from some wells near the St. Johns River had higher chloride concentrations. For example, wells 46 and 55, both within 100 feet of the St. Johns River, had water with chloride concentrations of 72 and 3,400 mg/L, respectively. Franks (1980, p. 7), in a study at the U.S. Naval Station near Mayport, reported chloride concentrations ranging from 46 to 5,200 mg/L.

The water-table zone provides water for lawn irrigation, heat pumps, and domestic purposes (table 2). Yields generally range from 10 to 15 gallons per minute (gal/min), although some wells in relatively thick and permeable beach sands along the coast yield as much as 25 gal/min (Leve, 1966, p. 23). Transmissivities determined by Ebasco Services, Incorporated (written commun., 1980), about 1.5 miles north of Blount Island, averaged about 800 ft^2/d.

Semiconfining Beds

Below the water-table zone, beds of lower permeability occur in most of the study area. These beds consist of fine-to-medium, well sorted sand interbedded with layers of gray-green silty clay, clayey sand, and shell. Thickness of these beds vary within the study area and generally range from 5 to 40 feet. These beds, where present, partially confine water in the limestone unit below.

Geologic data from 10 test wells drilled at 5 test sites show that the semiconfining beds occur at test sites 1, 2, 4, and 5 (fig. 1). Thicknesses ranged from about 20 feet at test site 5 to about 35 feet at test sites 1 and 4. At test site 3 little confining material is present and the limestone unit is probably hydraulically connected directly to the water-table zone.

Table 1.--Well records and chemical analyses of water from the wells at the test sites

Test site number	Well number[a]	USGS identi-fication number	Aquifer zone[b]	Land surface altitude[c] (ft)	Depth (ft)	Casing depth (ft)	Date of water sample	Chloride (mg/L)	Specific conductance (umho/cm at 25°C)	Distance from River (ft)	Distance from Edge of navigation channel (ft)
	53	302314081333201	LU	3.6	64.7	56.0	04/15/80	980	3,870	10	300
							04/30/80	900	3,700		
							07/10/80	940	3,800		
1							08/01/80	840	3,510		
							09/16/80	860	3,480		
	54	302317081332901	LU	5.6	51.1	46.6	04/07/80	510	2,920	260	560
							08/08/80	480	2,480		
							09/16/80	580	2,530		
	55	302314081333202	WT	3.8	9.0	7.0	07/21/80	3,400	10,000	10	300
	56	302317081332902	WT	5.9	8.0	7.0	07/21/80	85	380	265	565
							09/16/80	24	260		
	57	302333081295901	LU	6.3	54.0	49.6	04/29/80	2,800	9,200	15	700
							07/11/80	2,750	9,000		
							09/18/80	2,000	6,600		
2	58	302337081295901	LU	8.5	55.5	51.0	04/09/80	4,400	13,400	325	1,025
							08/08/80	3,100	10,000		
							09/18/80	3,200	10,400		
	59	302335081295901	WT	7.0	7.2	5.5	07/21/80	18	360	150	850
	60	302337081295902	WT	8.6	8.0	6.0	07/21/80	16	380	330	1,030
							09/18/80	10	260		
	61	302311081300001	LU	3.2	50.0	43.6	04/03/80	6,600	19,700	250	550
							08/08/80	5,900	17,100		
							09/16/80	5,600	16,800		
3	62	302301081300101	LU	9.2	51.0	47.0	04/03/80	16	200	1,000	1,300
							09/16/80	12	130		
	63	302301081300102	WT	9.8	11.0	9.0	09/16/80	18	120	1,000	1,300
	64	302307081380501	LU	6.9	46.0	40.5	04/10/80	73	850	50	1,950
4	65	302303081381501	LU	6.9	43.0	35.7	04/02/80	68	890	700	2,700
							09/16/80	90			
	66	302303081381502	WT	6.9	6.0	4.0				700	2,700
	67	302225081370201	LU	4.9	40.3	37.8	09/16/80	100		25	2,525
5	68	302226081365601	LU	6.8	42.0	38.0	09/16/80	70		475	3,000
	69	302226081365602	WT	6.9	9.0	7.0	09/16/80	26	490	475	3,000

[a] Location of wells shown in figure 1.
[b] LU, limestone unit; WT, water table.
[c] Altitudes shown are feet above sea level determined with level instrument.

Table 2.--Well records and chemical analyses of water from the water-table zone

Well number[a]	USGS identification number	Depth[b] (ft)	Land surface altitude[c] (ft)	Date of water sample	Chloride (mg/L)	Specific conductance (umho/cm at 25°C)	Distance from River (ft)	Distance from Edge of navigation channel (ft)	Water used[d]
39	302148081330701	39	10	12/10/79	9	270	350	7,450	D,I
40	302148081354801	25	42	12/10/79	18	220	5,000	6,200	I
41	302157081332501	25	20	01/11/80	13	200	700	6,300	HP
42	302159081364801	34	25	06/28/79	19		200	1,100	I
43	302201081364801	22	25	06/28/79	25	190	200	1,300	I
44	302208081364401	32	30	06/28/79	71	240	900	2,300	I
				02/06/80	40	180			
45	302222081365401	10	8	06/28/79	18	210	500	2,800	I
46	302225081344501	22	10	02/10/79	72	330	100	6,100	HP,I
47	302243081305301	30	10	07/11/79	19	170	2,100	4,000	I
48	302253081381701	25	15	11/21/79	21	290	2,600	3,600	I
49	302227081350501	22	20	07/10/79	23	130	400	7,400	I
50	302300081295401	25	10	01/16/80	12	220	1,000	2,300	I
51	302308081363701	23	12	07/10/79	19	160	1,300	4,800	I
52	302321081363901	32	5	06/25/79	14	110	200	4,400	HP

[a] Location of wells shown in figure 1.
[b] Depths shown are reported.
[c] Altitude shown is feet above sea level estimated from topographic maps.
[d] D, domestic; I, irrigation; HP, heat pump.

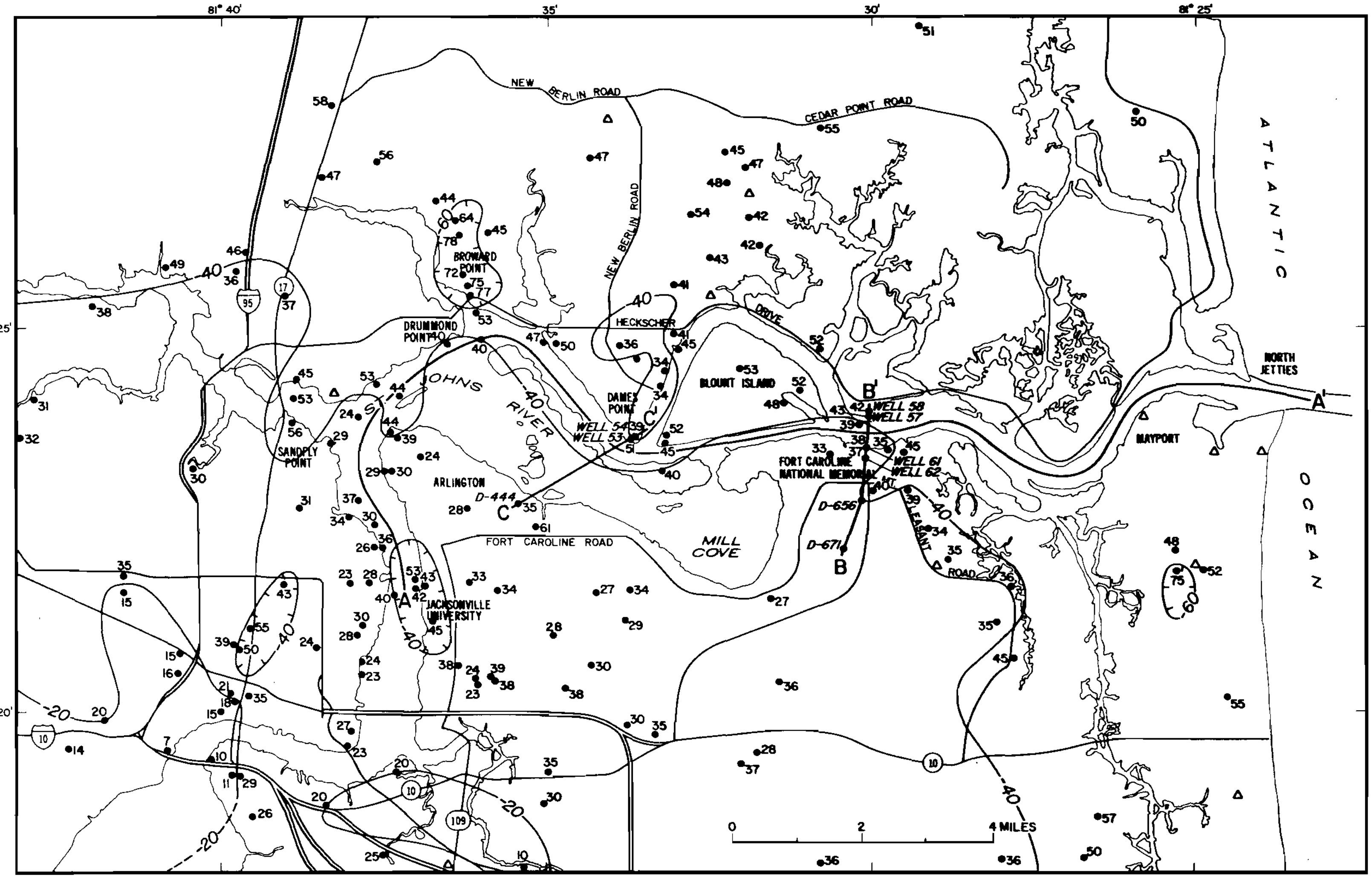
Limestone Unit

A permeable limestone unit 5 to 40 feet thick is the principal water-yielding zone of the surficial aquifer. Geologist's and well driller's logs show that the top of the limestone ranges from about 10 to 75 feet below sea level and is underlain by the Hawthorn Formation. The limestone is deepest in the northwest and southeast parts of the study area (fig. 4). At the test sites, the depth to the limestone ranges from about 28 feet at test site 5 to 51 feet at test site 1. Along the coast and locally in the Arlington area, the limestone is discontinuous and grades into a medium-to-coarse sand and shell deposit.

Figure 5 shows a generalized lithologic section along the present navigation channel in the St. Johns River from Jacksonville University to the ocean. The approximate depth to the top of the limestone is based upon core borings and jet probings completed prior to 1973 before dredging to the present depth of about 39-41 feet. This information, supplied by the U.S. Army Corps of Engineers, indicates that the top of the limestone in the navigation channel generally ranges from about 39 to 47 feet below sea level. However, particular data points used in the lithologic cross section indicate a minimum depth of 40 feet in most of the channel because of overrun and other factors. The top of the limestone, which is more variable than can be shown in the illustration, can vary in depth as much as 6 or 7 feet within relatively short distances. Channel improvements on the Jacksonville Harbor, completed in 1977, have breached the limestone at many locations, exposing about 0.4 mi^2 (18 percent of the 2.2 mi^2 navigation channel) of the limestone unit directly to saline river water. Two areas where the breaching has been most extensive are from near Jacksonville University northward for about 4 miles and from Fort Caroline National Memorial eastward for about 3 miles. Where the limestone has not been breached, undifferentiated sediments consisting mainly of sand with some clay and silt overlie the limestone. Thicknesses of these sediments range from less than 1 foot to more than 6 feet. The proposed dredging will remove these sediments thereby exposing the limestone over a 0.7 mi^2 area (about 32 percent) along the entire length of the navigation channel.

The limestone unit in the study area is recharged by downward leakage of water from the water-table zone where the water table is above the potentiometric surface of the limestone unit and by ground-water inflow from adjacent areas. Water from the limestone unit is discharged primarily by ground-water outflow, either through the water-table zone or directly into the St. Johns River and its tributaries, and by pumpage.

Water levels vary seasonally and generally are highest from June to October when rainfall is greatest, and lowest from November to May when rainfall is less. However, abnormal conditions occurred just preceding and during the study period. Rainfall during September 1979 was 17.75 inches, about 45 percent above normal. During this period, water levels in the area generally rose sharply, as indicated by the hydrographs of wells 37 and 2 in figure 6. From June to September 1980, rainfall for the area was about 40 percent below normal, causing water levels to decline rapidly. Figure 7 shows the generalized potentiometric surface of the limestone unit for May 1980. The potentiometric surface is an imaginary surface to which water will rise in tightly cased wells that penetrate the aquifer zone.



EXPLANATION

35• *D-444*	WELL -- Non-italic number indicates depth to limestone unit, in feet below sea level. Italic number is well number.
△	WELL -- Indicates where limestone unit was not encountered.
—*-20*--	CONTOUR -- Shows altitude of top of limestone unit where present. Dashed where approximate. Contour interval 20 feet. Datum is sea level.
A——A'	Line of geologic section, as shown in figures 5, 11 and 12.

Figure 4.--Configuration of the top of the limestone unit of the lower part of the surficial aquifer.

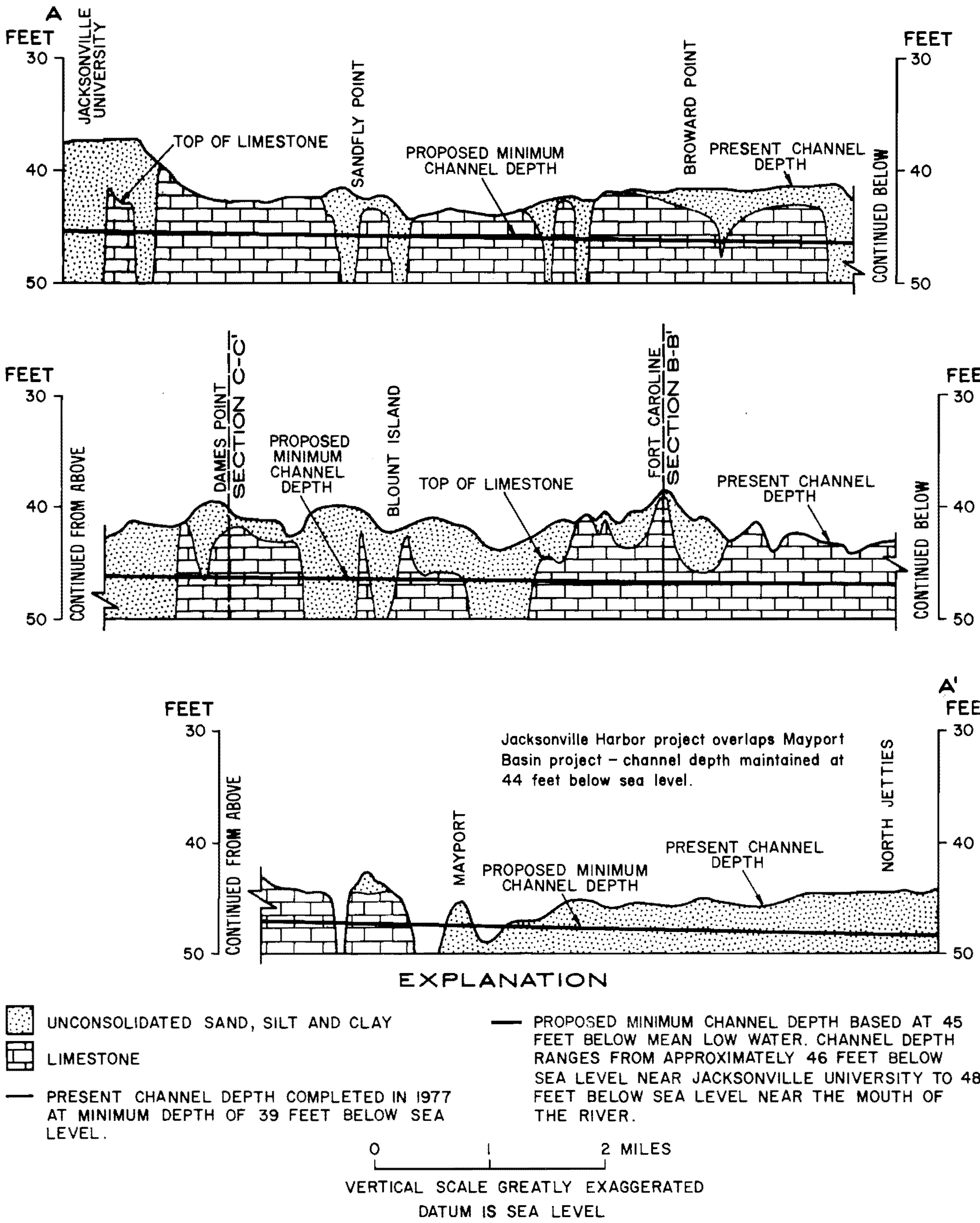


Figure 5.--Lithologic section A-A' along the St. Johns River.

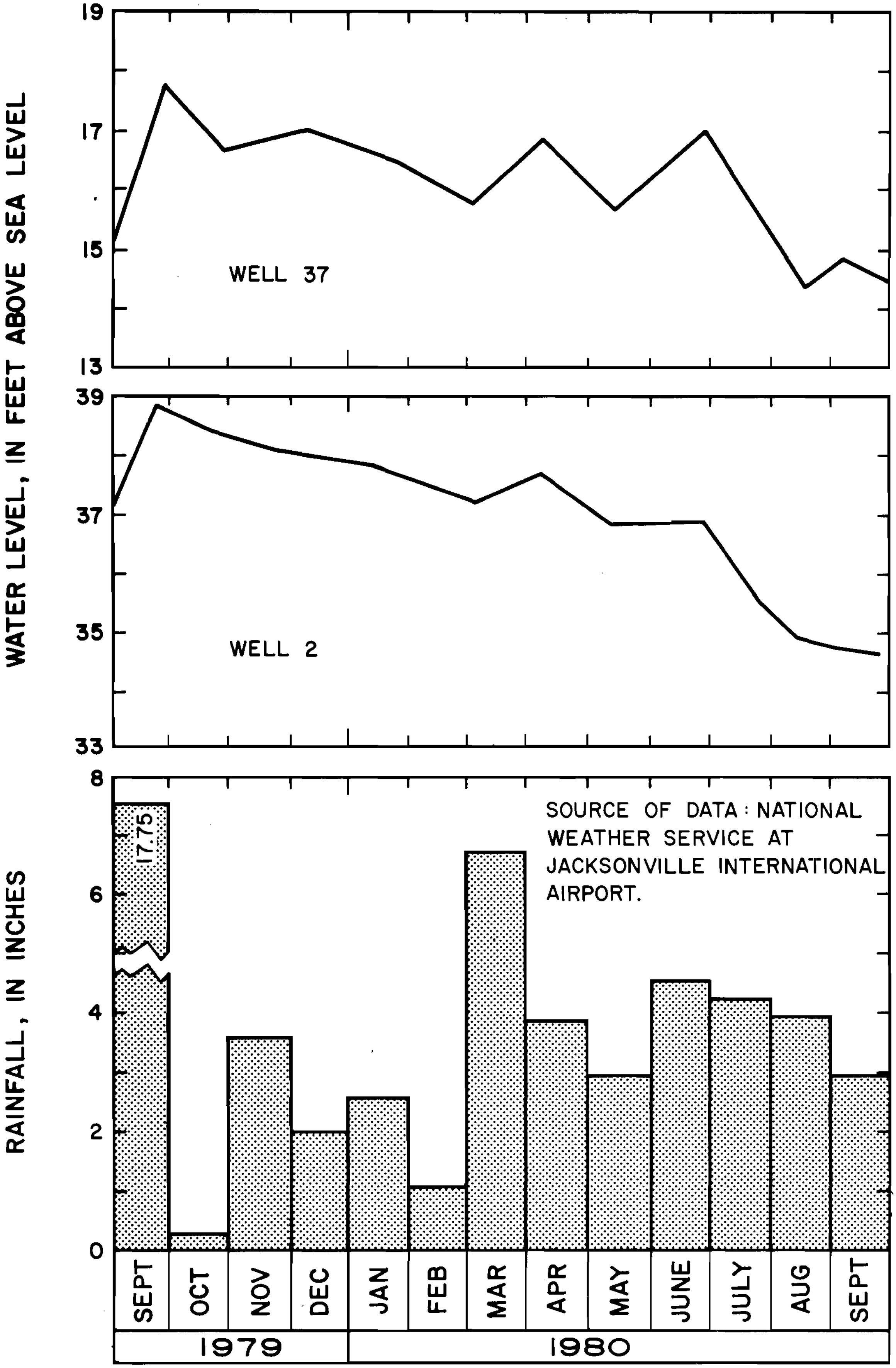
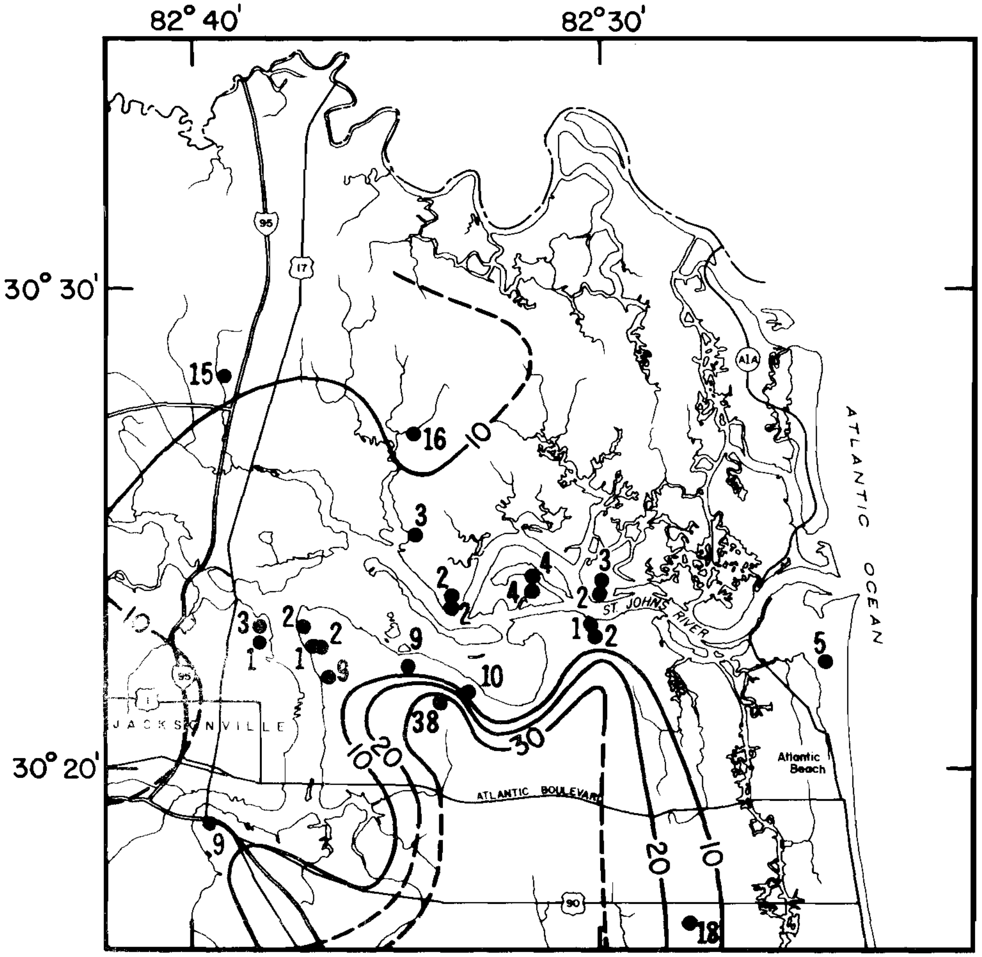


Figure 6.--Rainfall at Jacksonville and fluctuations of water levels in wells 37 and 2, 1979-80.



EXPLANATION

——30—— POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in a tightly cased well. Dashed where approximately located. Contour interval 10 feet. Datum is sea level.

5● WELL--Number indicates water level in feet above sea level.

0 1 2 3 4 MILES

Figure 7.--Generalized configuration of the potentiometric surface of the limestone unit, May 1980.

In general, ground water moves from areas where the potentiometric surface is relatively high toward areas where the potentiometric surface is relatively low, normal to the contour lines. Figure 7 shows that ground water generally flows toward and discharges into the St. Johns River and its tributaries.

Water from the limestone unit is primarily used for lawn irrigation, domestic purposes, and in heat-exchange units in air conditioning and heating systems (table 3). Well yields for most parts of Duval County are generally between 30 and 100 gal/min with yields as great as 200 gal/min occurring in some wells (Causey and Phelps, 1978, p. 23). Estimated transmissivities for this unit, determined from specific capacity tests, range from 250 ft^2/d to 1,300 ft^2/d (Causey and Phelps, 1978, p. 20).

Water from the limestone unit is generally of good quality except near the coast, in brackish-water marshes, and along parts of the St. Johns River. Although the water is usually hard, Fairchild (1972) and Causey and Phelps (1978) reported that concentrations of most chemical constituents generally do not exceed the standards for drinking water established by the U.S. Environmental Protection Agency (1975, 1977). Iron concentrations are highly variable and in some areas exceed the 0.3 mg/L recommended limit (Causey and Phelps, 1978, p. 28).

Chloride concentrations determined for water samples collected from 40 wells tapping the limestone unit ranged from 8 to 6,600 mg/L (tables 1 and 3). However, in most of the wells sampled, chloride concentrations ranged from 8 to 30 mg/L, which is considered to be "background" range for fresh ground water unmixed with saline river water. Exceptions are in areas where the potentiometric head is near sea level and in low-lying areas adjacent to the St. Johns River, where concentrations are generally much higher. Several test sites along the river yielded water with chloride concentrations that ranged from 480 to 6,600 mg/L.

APPRAISAL OF THE INTERCONNECTION BETWEEN THE ST. JOHNS RIVER AND THE LIMESTONE UNIT

Hydraulic Relations

To determine the potentiometric surface and to evaluate the effects of tidal fluctuations on water levels of the limestone unit, test wells were drilled at 5 test sites adjacent to the St. Johns River (fig. 1). At each test site, two wells were drilled into the limestone unit, one well near the edge of the river and the other at least 250 feet from the river. Continuous water-level recorders were installed on each test well and on well 4, about 1 mile north of Jacksonville University. Water-level records ranging from 1 to 25 days were collected during May and June 1980.

Figures 8 and 9 show hydrographs of wells at each test site. Water levels fluctuate in response to ocean tides. The fluctuations are caused by the pressure loading response to incoming and outgoing tides, by the movement of water from the river into the limestone, and by water discharging from the limestone.

Table 3.--Well records and chemical analyses of water from the limestone unit

Well number[a]	USGS identification number	Depth[b] (ft)	Land surface altitude[c] (ft)	Date of water sample and water level measurement	Chloride (mg/L)	Specific conductance (umho/cm at 25°C)	Water level (in ft) Below land surface	Water level (in ft) Above sea level	Distance from River (ft)	Distance from Edge of navigation channel (ft)	Water used[d]
1	301806081385005	67.5	15	05/13/80			5.92	9.08			U
2	302113081333702	75.1	45.6	05/02/80			7.78	37.82			U
3	302126081362701	125	44	12/07/79	10				1,400	3,200	I
4	302126081363801	56.2	16.2	12/10/79	8	380	7.12	9.08	250	1,900	U
5	302127081361501		45	01/09/80	16	460			2,400	4,250	D,I
6	302136081363801	90	35	12/07/79	20	450			500	1,950	U
7	302145081330501	57.5	15.3	12/10/79	8	290	4.84	10.46	400	7,500	U
8	302157081364201	63	30	06/16/80	16	190			500	1,500	I
9	302159081364501	37	30	06/28/79	56				400	1,300	I
				01/10/80	20	110					
10	302212081341501	140	48	07/11/79	11	160			1,100	5,600	I
				06/13/80	11	170					
11	302215081243101	61.0	9	05/14/80			4.07	4.93			U
12	302218081340801	80	20	06/27/79	14	210	11.36	8.64	400	4,900	D,I
13	302223081364801	38	13	06/28/79	16	260			1,000	3,000	I
14	302228081305701		20	07/11/79	13	300			1,100	5,250	HP
				06/13/80	13	270					
15	302236081351801	96	10	07/10/79	33	300			300	8,000	I,HP
				06/13/80	48	360					
16	302237081304801	80	15	07/11/79	16	330			2,000	4,800	HP
				06/13/80	16	290					
17	302242081371201	55.5	7	12/10/79	24	230	5.32	1.68	450	2,300	U
18	302253081302401	75	30	07/11/79	12	250			2,300	2,600	I
				06/13/80	11	200					
19	302257081290901	86	50	07/11/79	16	380			2,400	2,750	I
				01/15/80	14	340					

Table 3.--Well records and chemical analyses of water from the limestone unit--Continued

Well number[a]	USGS identification number	Depth[b] (ft)	Land surface altitude[c] (ft)	Date of water sample and water level measurement	Chloride (mg/L)	Specific conductance (umho/cm at 25°C)	Water level (in ft)		Distance from		Water used[d]
							Below land surface	Above sea level	River (ft)	Edge of navigation channel (ft)	
20	302258081291201	65	40	07/11/79	25	390			2,750	3,000	I
21	302259081290901	65	40	07/11/79	27	400			2,450	2,700	I
				01/15/80	13	340					
22	302302081291201	120	80	02/20/80	9	250			2,000	2,500	D,I
23	302302081291202	100	70	02/20/80	9	260			2,050	2,550	D,I
24	302307081381701	100	5	07/18/79	21	550			100	3,100	D
				02/10/80	17	510					
25	302310081303501	96	25	01/15/80	14	170			1,350	1,400	D,I
26	302310081303502	100	25	06/27/79	17	150			1,350	1,400	U
27	302314081362401		8	07/10/79	17	170			300	5,300	I,HP
				06/13/80	18	210					
28	302318081382801	75	6	11/21/79	18	290			125	4,400	D,I
29	302335081312701	59.5	12.1	05/20/80			8.30	3.80	1,500	1,700	U
30	302342081312501	59.5	13.9	05/20/80			9.62	4.28	2,400	2,600	U
31	302424081381701	64	10	07/17/79	10	400			3,000	5,600	I
32	302426081381801	65	10	07/17/79	8	300			3,500	6,000	I
33	302435081340301		15	02/07/79	500	2,000			3,400	3,950	D,I
34	302445081335701	70	8	07/19/79	15	330			3,700	5,000	D
35	302445081344801	88.4	5	02/08/80			3.17	1.83	100	2,000	U
36	302447081362001		15	12/03/79	10	210			700	2,100	D
				06/13/80	9	220					
37	302633081333001	88.0	25	05/15/80			9.32	15.68			U
38	302835081390301	105.5	22	05/22/80			7.35	14.65			U

[a] Location of wells shown in figure 1.
[b] Depths shown to nearest tenth of foot are measured; other depths are reported.
[c] Altitude shown to nearest tenth of foot above sea level determined with level instrument; other altitudes estimated from topographic maps.
[d] U, unused; I, irrigation; D, domestic; HP, heat pump.

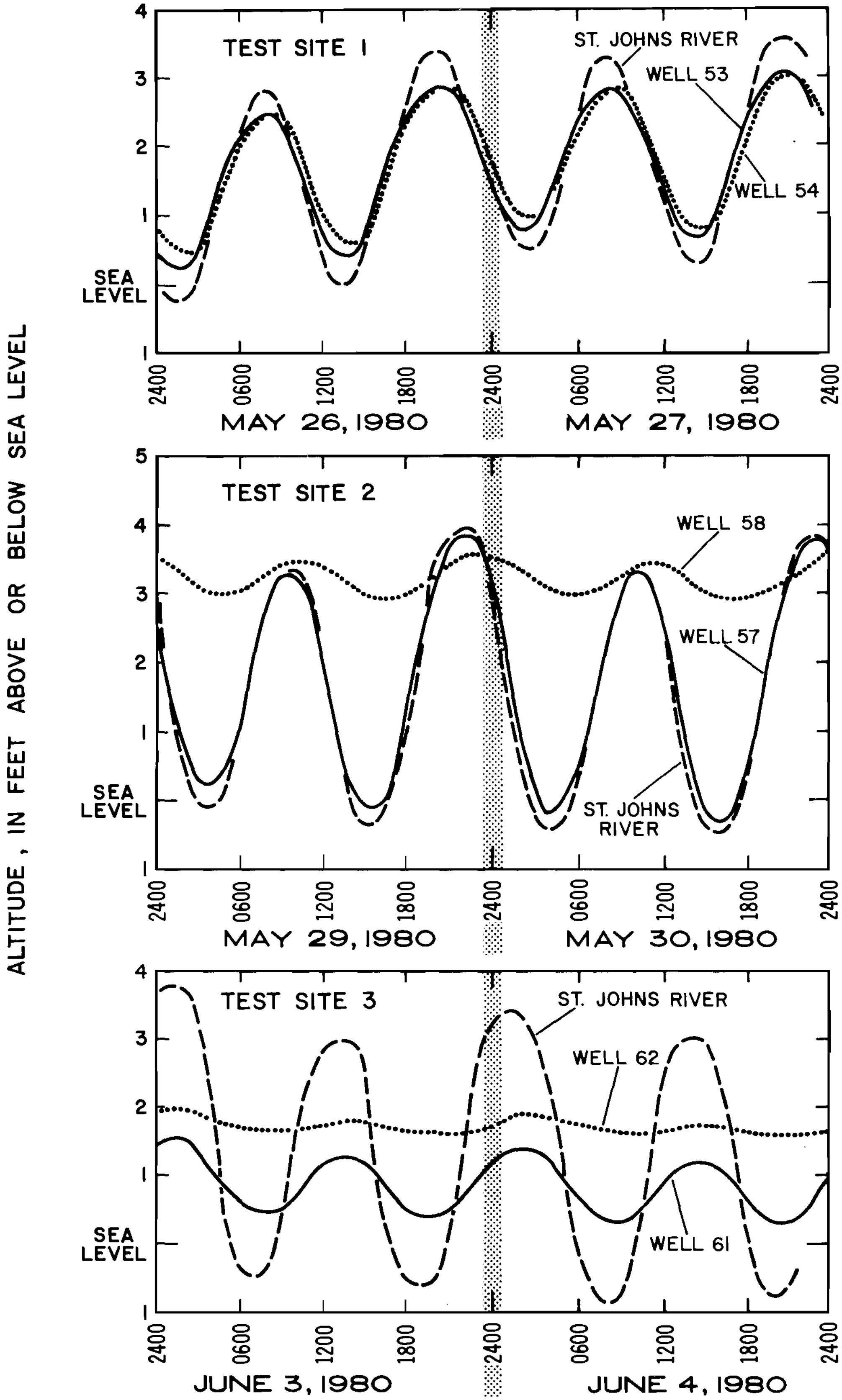


Figure 8.--Hydrographs of the St. Johns River and wells at test sites 1, 2, and 3.

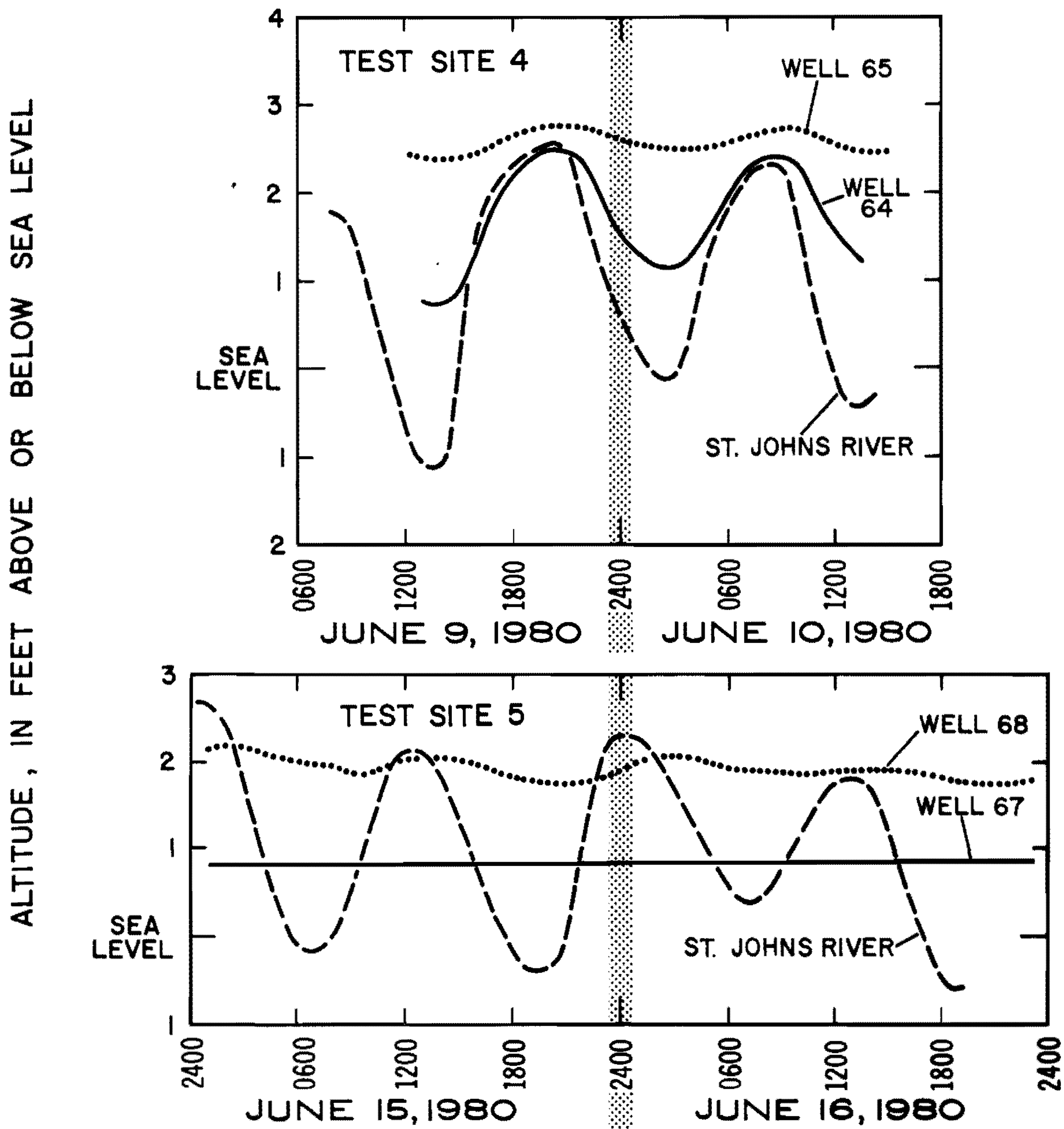


Figure 9.--Hydrographs of the St. Johns River and wells at test sites 4 and 5.

The degree to which ground-water levels in the study area respond to tides depends primarily on the distance from the river, the degree of interconnection between the limestone and the river, and the hydraulic properties of the limestone. For example, water levels in test well 57, only 15 feet from the edge of the river, fluctuated about 90 percent of the range of the river stage, while water levels in test well 58, about 325 feet from the river, fluctuated less than 20 percent of the river stage range (fig. 8). The small tidal fluctuation in well 58 can possibly be explained by a decrease in permeability and change in lithology of the limestone and by its increased distance from the river. In wells 53 and 54, which are 10 and 260 feet away from the river, respectively, the water level in both wells fluctuated about 75 percent of the river stage range. In the vicinity of these wells, the limestone in the river either has been breached or the overlying sediments are thin. The relatively large fluctuations in these wells are a result of a high degree of interconnection between the limestone and the river. At well 67 (fig. 9), located 25 feet from the river, the water level fluctuated only a few hundredths of a foot. At this location, the limestone contains a high percentage of clay and is not very permeable; therefore, the water level in well 67 does not respond much to tidal fluctuations in the river.

Altitudes of water levels in wells penetrating the limestone unit decrease toward the river, and at the test sites average approximately 1 to 2 feet above sea level. These water levels are high enough to prevent a significant landward invasion of saline water from the river. However, in the surficial aquifer beneath the river, the saline water from the river, which is denser than freshwater, displaces the freshwater and forms a saline water wedge whose base rests on the confining bed of the Hawthorn Formation.

Figure 10 is a conceptual view of the saline water-freshwater relations along the river in the underlying surficial aquifer, as developed from Hubbert's theory (1940). The interface, which is in a state of dynamic equilibrium, is considered to be stable, with freshwater flowing over it toward the river. Because the equipotential lines are curved, so as to accommodate flowing freshwater, the head at the interface differs from that vertically above it. However, assuming that the interface has a slight slope and the equipotential lines are nearly vertical, then the freshwater heads at the interface would be about the same as those measured anywhere in the freshwater section, and the approximate depth to the saline water can be expressed by the following equation:

$$h_s = \frac{\rho_f}{\rho_s - \rho_f} h_f$$

where h_s is the depth to the saline water-freshwater interface below sea level, h_f is the elevation of the freshwater head above sea level, ρ_f is the freshwater density, and ρ_s is the saline water density.

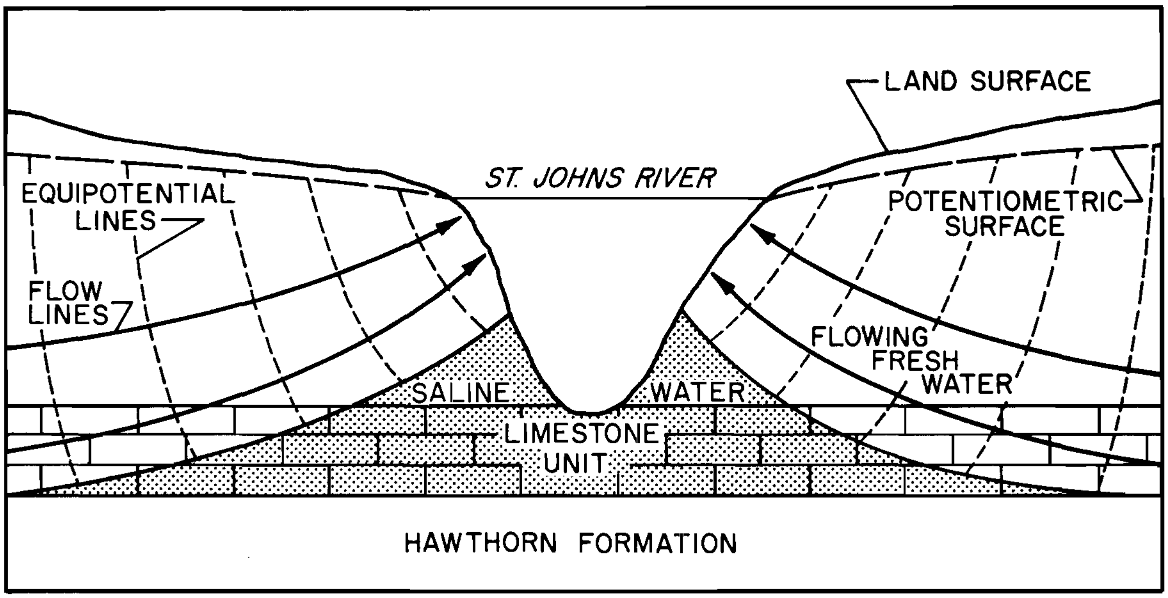


Figure 10.--Conceptual view of saline water-freshwater relations.

The density of fresh ground water is, for practical purposes, 1.000 g/cm^3 and the density of the river water in the study area ranges from about 1.005 to 1.025 g/cm^3 based on chemical data from this report and from Anderson and Goolsby (1973). If the average density of the river water is 1.015 g/cm^3, for example, then the above equation shows that $h_s = 67\ h_f$. Thus, for every foot of freshwater above sea level, there are 67 feet of freshwater below sea level. If ρ_s is 1.005 g/cm^3, then the equation would show that $h_s = 200\ h_f$, indicating that there are 200 feet of freshwater below sea level for every foot above. Near the mouth of the river where the river water densities may be as great as 1.025 g/cm^3, the equation would show that $h_s = 40\ h_f$.

A generalized hydrogeologic section through test sites 2 and 3 is shown in figure 11. At test site 3, the limestone unit is overlain predominantly by sand, and the water in it is probably unconfined. The base of the limestone is estimated to be about 66 feet below sea level, based on driller's logs of the area. Away from the river, where the freshwater head is 1 foot or more above sea level, the limestone probably contains freshwater throughout its thickness, assuming that the average density of river water at this location is 1.015 g/cm^3. Where the freshwater head is less than 1 foot above sea level, the aquifer is probably invaded by the saline river water.

A generalized hydrologic section through test site 1 is shown in figure 12. There, the limestone is overlain by beds of clay and clayey sand and its base is estimated to be about 70 feet below sea level. The density of the river water at this location is estimated to be somewhat less than at test site 3. Therefore, where the freshwater head is about 1 foot or more, the limestone probably contains freshwater throughout its thickness, as was the case at test site 3.

Water-Quality Relations

Sixty wells were sampled to determine water quality and the approximate position of the saline water-freshwater interface in the surficial aquifer. Most wells sampled contained chloride concentrations of less than 30 mg/L (tables 1, 2, and 3). However, in 16 wells near the river, chloride concentrations were higher. Figure 13 is a generalized map showing the areas where chloride concentrations in the surficial aquifer exceeded 30 mg/L. Accurate delineation of the area where chloride concentrations exceed 30 mg/L is difficult because very few wells are in the saline-water zones.

Water from four wells that tap the water-table zone had chloride concentrations greater than 30 mg/L (tables 1 and 2). Chloride concentration of water from well 46, about 100 feet from the river, was 72 mg/L and from test well 56, about 265 feet from the river, was 85 mg/L. A chloride concentration of 3,400 mg/L was determined in water from test well 55, located 10 feet from the river. Water from well 44 about 900 feet from the river had a chloride concentration of 71 mg/L. However, the relatively high chloride concentration in this well may be from contamination from a water softener discharge.

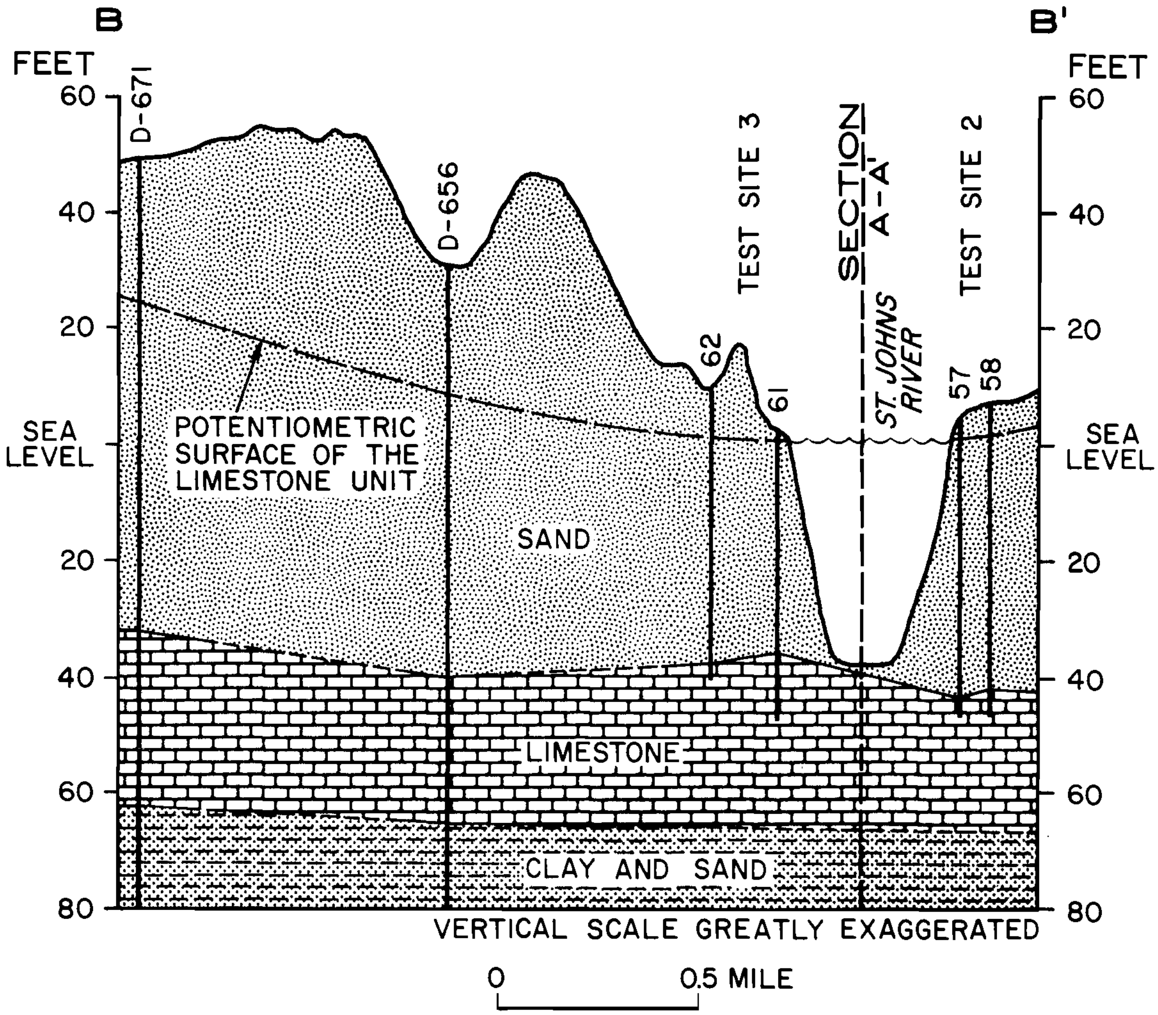


Figure 11.--Hydrogeologic section along line B-B'.

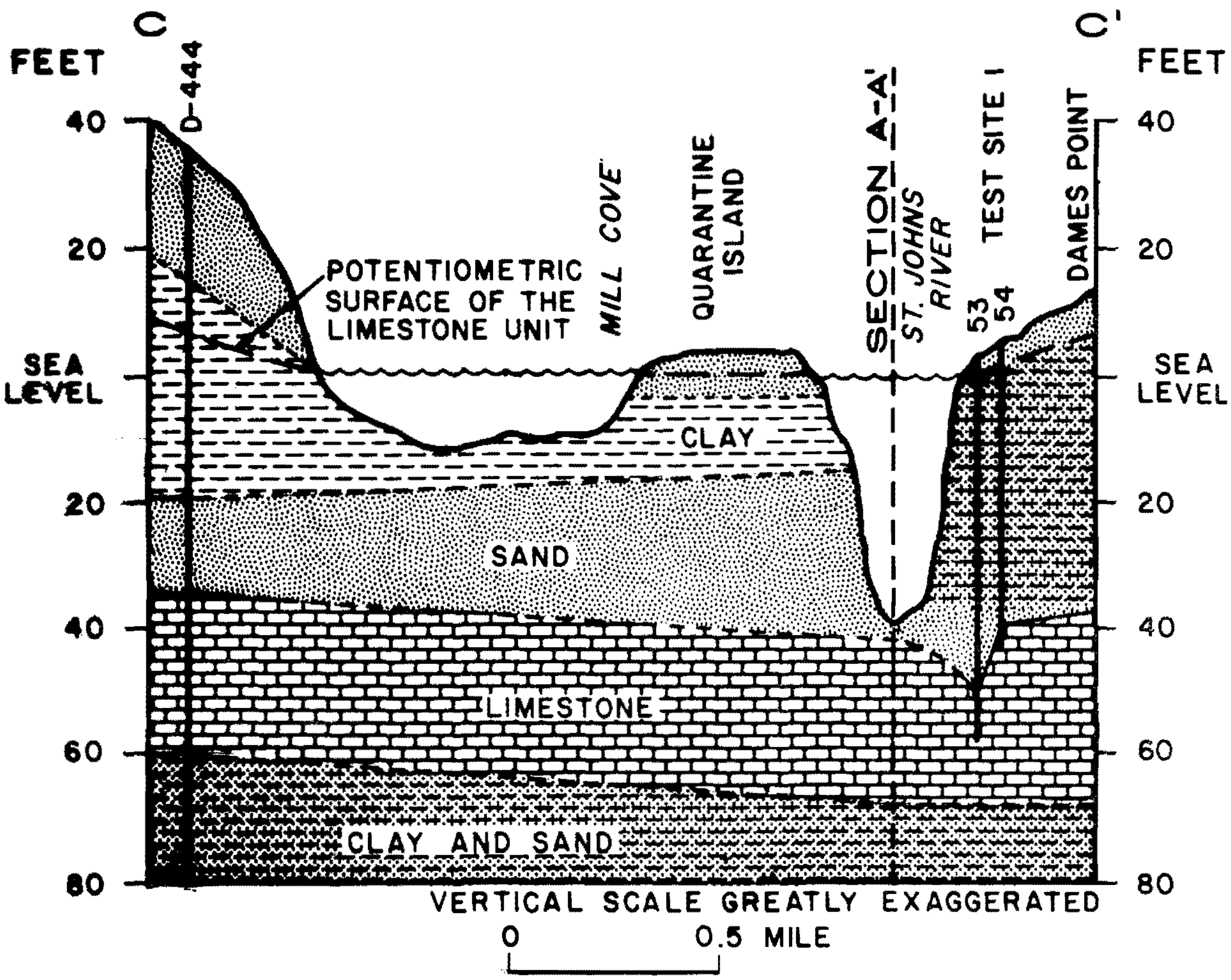
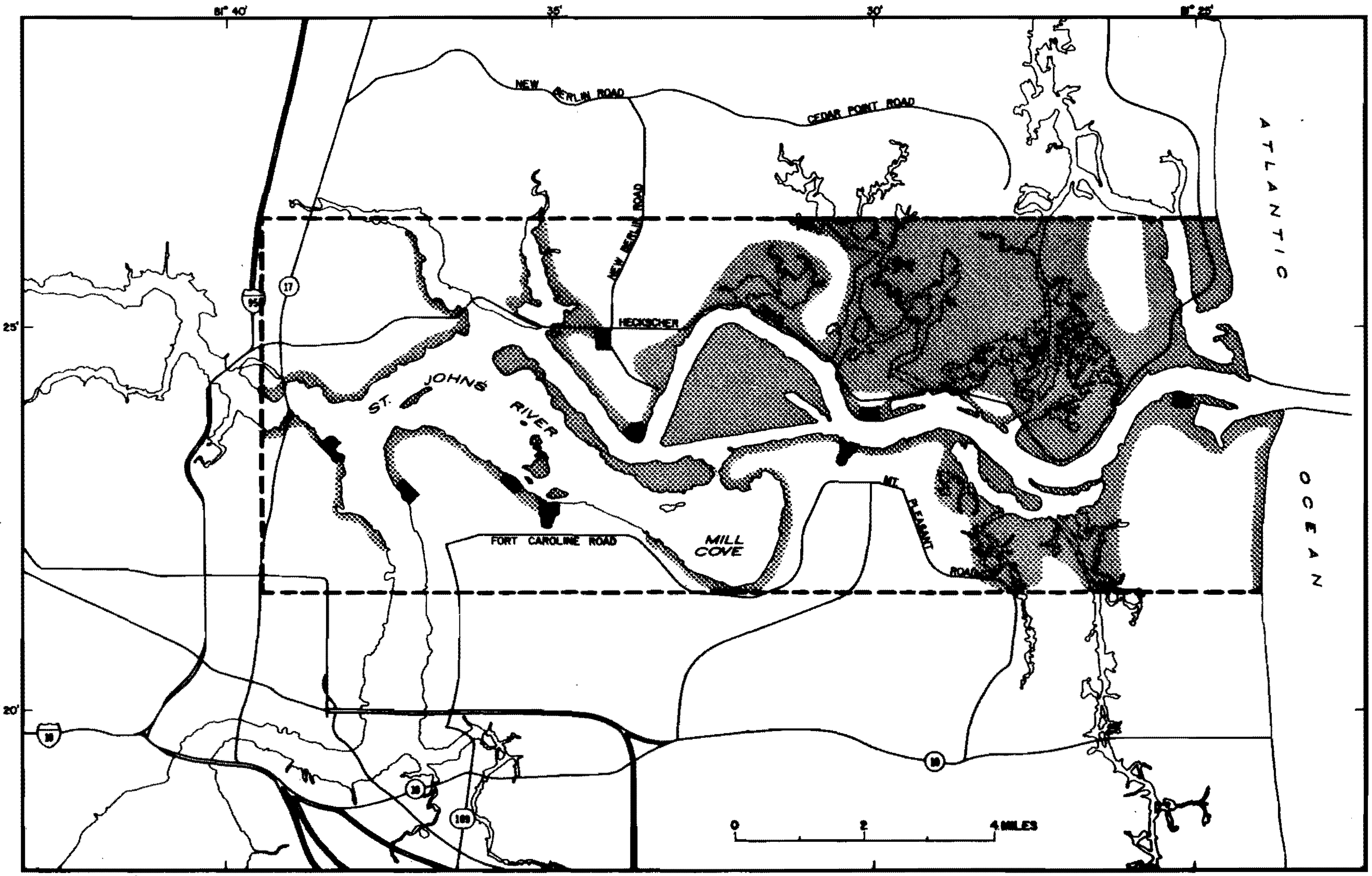


Figure 12.--Hydrogeologic section along line C-C'.



EXPLANATION

CHLORIDE CONCENTRATION IN THE SURFICIAL AQUIFER

- [white box] Probable areas not exceeding 30 milligrams per liter.
- [black box] More than 30 milligrams per liter, based on water quality data.
- [stippled box] Probable areas exceeding 30 milligrams per liter, based on topography and potentiometric surface.
- --- Intensive study area boundary.

Figure 13.--Generalized distribution of chloride in water from the surficial aquifer adjacent to the St. Johns River.

Chloride concentrations in wells tapping the limestone unit ranged from 8 to 6,600 mg/L (tables 1 and 3). Water from the limestone unit had chloride concentrations greater than 30 mg/L in 12 wells. These wells, with the exception of well 33 and test well 65, are less than 500 feet from the edge of the river. In water samples from wells 9 and 15 and test wells 64, 67, and 68, between 50 feet and 500 feet from the river, chloride concentrations were relatively low and did not exceed 100 mg/L. In test wells 53, 54, 57, 58, and 61, all less than 325 feet from the river, chloride concentrations were considerably higher and ranged from 480 to 6,600 mg/L. Water from test well 61, 250 feet from the river, contained the highest chloride concentration (6,600 mg/L) of the wells sampled.

From April to September 1980, test wells 53, 54, 61, and 62 were sampled periodically to detect changes in chloride concentrations. Test wells 53 and 61 showed substantial decreases. Chloride concentrations in well 53, located 10 feet from the river, ranged from 980 to 840 mg/L. In well 61, located 250 feet from the river, chloride concentrations decreased from 6,600 to 5,600 mg/L. This decrease in chloride concentration, though it does not generally correspond with areal rainfall data, could be explained by the occurrence of local rainfall from thunderstorms and by the gradual flushing of saline water which had infiltrated into the limestone unit during periods of extreme high tides.

High chloride concentrations in ground water may not necessarily indicate good hydraulic connection between the river and the limestone unit. Other ways in which high chloride water can enter the limestone unit, besides the lateral movement from the river, include the downward infiltration of saline water from areas inundated by tidal floods, from fill material, and from tidal marshes, which cover much of the northeastern part of the study area. High tides generated by winds during hurricanes and major storms have resulted in widespread flooding into low-lying areas. Flood profiles of the St. Johns River show that the 25-year frequency flood produces stages of about 4 feet above sea level at the Main Street Bridge to about 5.5 feet at Mayport. Stages of 6 feet at the Main Street Bridge and 8.5 feet at Mayport could occur during the 100-year frequency flood (U.S. Department of Housing and Urban Development, Federal Insurance Administration, 1977). Figure 14 shows the 100-year frequency flood map for the study area. As indicated on the map, the extent of flooding is greater on the northern side of the river than on the southern side, because of lower land elevations.

Sediments dredged from the river have been deposited on spoil islands, on eroded areas along the shoreline, and on once low-lying marshy areas such as Blount Island. The water in these sediments, often containing significant chloride concentrations, is flushed and diluted by infiltrating rainwater, and eventually infiltrates downward. The high chloride concentrations of water from wells 57 and 58 may partially be the result of downward percolation of saline water from fill material into the underlying limestone unit. Water from well 57, which is about 54 feet deep and 15 feet from the river, had chloride concentrations ranging from 2,000 to 2,800 mg/L. Well 58, drilled to approximately the same depth, is 325 feet from the river and had chloride concentrations ranging from 3,100 to 4,400 mg/L.

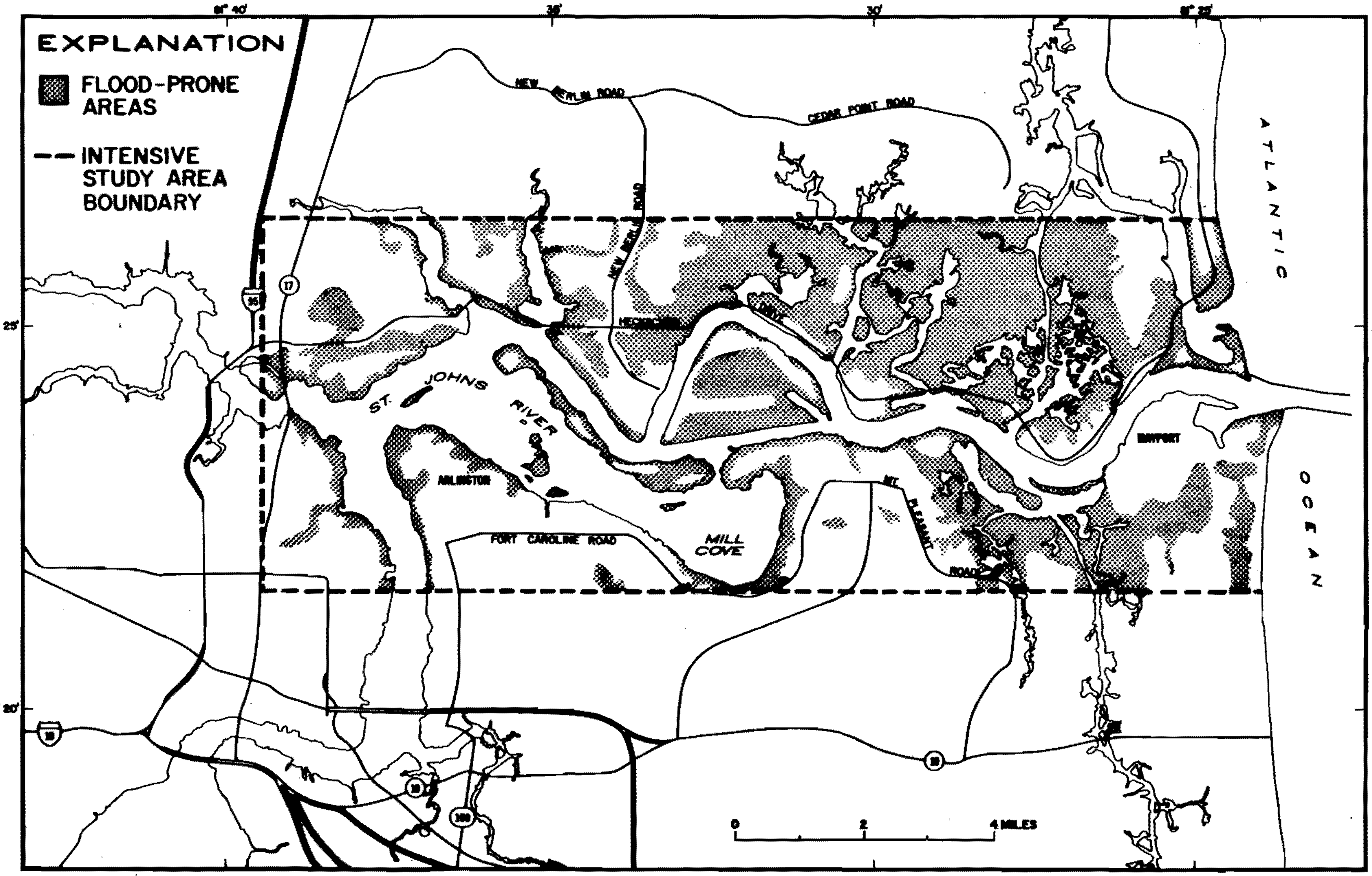


Figure 14.--Location of flood-prone areas adjacent to the St. Johns River inundated by 100-year flood.

PROBABLE EFFECTS OF HARBOR IMPROVEMENT

The proposed dredging operation in the navigation channel to 46-48 feet below sea level will breach the limestone unit at many locations, exposing about 0.7 mi^2, or about 32 percent of the limestone unit in the navigation channel to saline river water. Much of the overlying semiconfining material and limestone will be removed, thus increasing the hydraulic connection between the limestone and the river. However, hydrologic and geologic data indicate that at the test sites, and at many other locations along the river, an interconnection between the river and the limestone already exists.

At several locations along the St. Johns River, water with high chloride concentrations occurs in the limestone unit several hundred feet from the river. In unconfined conditions, saline water from the river can move naturally through the permeable sediments and into the limestone until a hydraulic equilibrium is reached. Where water in the limestone adjacent to the navigation channel is semiconfined, the overlying poorly permeable sediments restrict saline water infiltration into the limestone. The distance that the saline water would move depends upon the height of the river stage, the difference in density between fresh ground water and saline river water, and the potentiometric surface and permeability of the limestone unit.

Dredging to the proposed depth of 46-48 feet below sea level will have no effect on the Floridan aquifer. The Floridan aquifer is separated from the surficial aquifer by 300 to 450 feet of the Hawthorn Formation. The Hawthorn Formation generally contains beds of low permeability that confine the water in the Floridan aquifer and hydraulically separate it from the surficial aquifer.

The proposed dredging of the Jacksonville Harbor is not expected to alter significantly the present surface water-ground water relations. The current position of the saline water-freshwater interface probably represents the conditions that will be present along much of the river following future improvements. In areas where the potentiometric surface is low, such as many areas north of the St. Johns River, the position of the interface is estimated to be less than 1,000 feet from the river. On the south shore, where land altitude is generally much higher, the higher potentiometric surface probably limits the movement of saline water to less than 200 feet from the river.

SUMMARY AND CONCLUSIONS

The proposed deepening of the Jacksonville Harbor to about 46-48 feet below sea level (45 feet below mean low water) may breach up to 11 feet of limestone along a 25-mile channel. The limestone, the lowermost part of the surficial aquifer, supplies water to numerous domestic wells along the river in the Jacksonville area.

The limestone is 5 to 40 feet thick and the top of the unit generally ranges from 10 to 75 feet below sea level. At five test sites, the depth to the top of the limestone ranges from about 28 to 51 feet below sea level. Along the coast and locally in the Arlington area, the limestone is discontinuous and grades into a medium-to-coarse sand and shell. The water is generally of good quality except in low-lying areas along the St. Johns River, along the coast, and near brackish-water marshes. Water from the limestone is primarily used for lawn irrigation, domestic purposes, and heat exchange units in air conditioning and heating systems.

The top of the limestone in the navigation channel ranges from about 39 to 47 feet below sea level. At many locations, recent channel improvements have cut into the limestone exposing about 0.4 mi^2 of the limestone's surface to saline river water. Two areas where the breaching has been the most extensive are near Jacksonville University northward for about 4 miles and from Fort Caroline National Memorial eastward for about 3 miles. Where the limestone has not been penetrated by channelization, undifferentiated sediments consisting predominantly of sand, with some clay and silt, overlie the limestone. Thickness of these sediments range from less than 1 foot to 6 feet and generally are too permeable to form an effective confining bed.

Water-level data indicate that 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.

Hydrologic data indicate that an interconnection between the St. Johns River and the limestone already exists at many locations. Where water in the limestone is unconfined, saline water can move naturally through the 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 channel has been breached, saline water can move inland through the breached section of the limestone.

Chloride concentrations from wells tapping the limestone unit range from 8 to 6,600 mg/L. In five test wells less than 325 feet from the river, chloride concentrations ranged from 480 mg/L to 6,600 mg/L. In five other wells less than 500 feet from the river, chloride concentrations ranged from 33 to 100 mg/L.

The proposed dredging operations in the Jacksonville Harbor are not expected to alter significantly the present hydrologic system. The current position of the interface probably represents the position that will exist after future improvements. Along parts of the river where the potentiometric surface of the limestone unit is relatively low, the saline water-freshwater interface is estimated to be less than 1,000 feet from the river. Where the potentiometric surface is higher, the interface is estimated to be less than 200 feet from the river.

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