

GROUND-WATER RESOURCES OF FLAGLER COUNTY, FLORIDA

By A.S. Navoy and L.A. Bradner

U.S. GEOLOGICAL SURVEY

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ST. JOHNS RIVER WATER MANAGEMENT DISTRICT



Tallahassee, Florida

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CONVERSION FACTORS

The inch-pound units used in this report may be converted to metric (International System) units by the following factors.

<u>Multiply inch-pound unit</u>	<u>By</u>	<u>To obtain metric unit</u>
<u>Length</u>		
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
<u>Area</u>		
square mile (mi ²)	2.590	square kilometer (km ²)
<u>Flow</u>		
gallon (gal)	8.785	liter (L)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]
million gallons per day (Mgal/d)	0.0438	cubic meter per second (m ³ /s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
<u>Transmissivity</u>		
foot squared per day (ft ² /d)	0.0929	meter squared per day (m ² /d)

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$^{\circ}\text{F} = 1.8^{\circ}\text{C} + 32$$

Additional Abbreviations

NOAA - National Oceanic Atmospheric Administration
 mg/L - milligrams per liter
 µg/L - micrograms per liter

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."

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ABSTRACT

Ground water is the only significant source of potable water in Flagler County. Usable water occurs in the Upper Floridan aquifer, the intermediate aquifer system, and the surficial aquifer system. The predicted influx of population is expected to place stresses on the water resources of the county.

Although rainfall averages almost 50 inches per year, most of the water leaves as evapotranspiration and streamflow. Less than 1 inch per year recharge may be occurring to the Upper Floridan aquifer, the highest yielding aquifer.

The Upper Floridan aquifer consists of the Avon Park Formation, the Ocala Limestone, and the basal dolomitic limestone of the Hawthorn. Use of the Upper Floridan aquifer for public water supply is limited in most of the county because it contains marginally potable or brackish water. It is used extensively for agricultural irrigation.

The intermediate aquifer system consists of thin, discontinuous lenses of sand, shell, and limestone between clays overlying the Floridan aquifer system. The intermediate aquifer system is an important part of the public water supply for the county because of the good quality of the water. The intermediate aquifer system has variable yields because of the discontinuous lenses.

The surficial aquifer system is composed of sand and shell with varying fractions of finer materials. Well yields are small in the west and central parts of Flagler County, but the surficial aquifer system is an adequate source for domestic supply on the barrier island. A zone of freshwater in the surficial aquifer system is very important in the Hammock area, being the local source of most domestic supply in the area.

Changes in hydrologic conditions from the 1950's include a long-term decline in water levels in the Upper Floridan aquifer coincident with lower-than-average rainfall and a greater seasonal fluctuation of water levels. Chloride concentrations of water in the Upper Floridan aquifer do not appear to have changed significantly, presently ranging from 7 to 3,700 milligrams per liter.

Development will place stress on the aquifers and may result in upconing of brackish water in pumping centers and in lateral saltwater intrusion in coastal areas.

INTRODUCTION

Flagler County, located in northeast Florida (fig. 1), is expected to have a significant population growth over the next several decades. The County's rural character has remained, apparently because of a scarcity of large supplies of potable water. The population size was rather stable for at least 30 years. However, between 1970 and 1980, large community developments doubled the population of the county. The growth rate from 1940 and projected growth is shown below:

<u>Year</u>	<u>Census population</u>	
1940	3,000	
1950	3,368	
1960	4,566	
1970	4,454	
1980	10,913	
1990	25,700	} (Projected by Smith and Sincich, 1983.)
2020	54,700	

In spite of its scarcity, ground water is the only significant source of potable water in Flagler County. The rapidly growing population has placed an increased demand on ground-water resources. Coastal areas in Flagler County will be the areas of greatest development, and present capacities of water treatment systems will be inadequate if development continues as projected.

Purpose and Scope

In October 1979, the U.S. Geological Survey began an investigation of the County's ground-water resources in cooperation with the Flagler County Board of Commissioners and the St. Johns River Water Management District. The purpose of the investigation was to: (1) describe the occurrence and quality of ground water in Flagler County, (2) define the current and potential problem areas of water quality, and (3) provide the hydrologic data needed for management of the water resources. The investigation, including data collection, compilation, and interpretation, was conducted for 3 years. Most attention was given to the Upper Floridan aquifer. The remaining effort concerned the other aquifers and the surface-water resources. Special emphasis was given to the eastern part of the county where most ground-water development has occurred, or is projected to occur. This report summarizes results of the investigation.

Previous Investigations

A ground-water reconnaissance of a three-county area, including Flagler County, was made by Bermes and others (1963a; 1963b). Most of the quantitative work was done on the Upper Floridan aquifer. Potentiometric-surface maps were prepared for April 1956, September 1956, and September 1958. Detailed chemical analyses were made on samples from 8 wells in the Upper Floridan aquifer in the county; chloride analyses were performed on water from 10 wells; and 5 aquifer tests were performed on wells in the Upper Floridan aquifer.

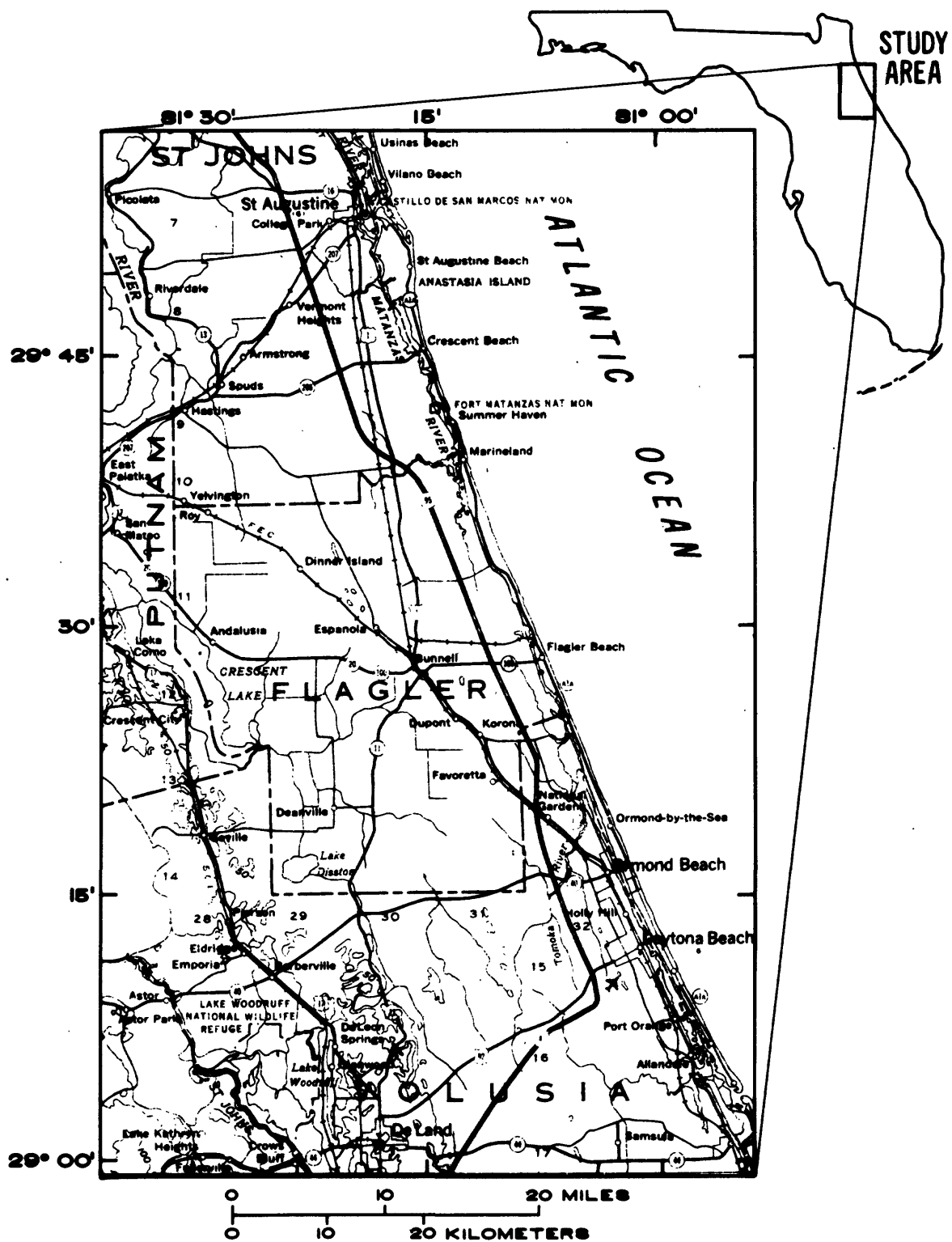


Figure 1.--Location of study area.

Kenner and Crooks (1963) summarized the surface-water resources of the same three-county area, concurrent with that of Bermes and others. One long-term streamflow station was located within the county and intermittent streamflow measurements were made at 10 additional sites.

Black, Crow, and Eidsness/CH₂M-Hill Inc., in 1977 evaluated the water-resources and water-supply potential on the Palm Coast development property. Their interpretations were based on data from 39 test wells.

Munch and others (1979a; 1979b) examined the occurrence of saline water in the Upper Floridan aquifer in a three-county study. Within Flagler County, they focused on the agricultural area west of Bunnell.

Frazee and McClaugherty (1979) reported on the characteristics of aquifers along the coast from Flagler County north to Fernandina Beach. Areas of saline-water intrusion were delineated and sources of potable water were indicated.

Acknowledgments

Appreciation is expressed to the many Flagler County residents who provided access to their wells. Special thanks are due to Garry A. Balogh, of the Palm Coast development property; Don Chinnery, the Flagler County engineer; and William Lenssen, whose information and advice greatly enhanced this report. Appreciation is also expressed to the staff of the Water Resources Evaluation Department of the St. Johns River Water Management District.

ENVIRONMENTAL SETTING

Flagler County is an area of 504 mi² (square miles) along the east coast of north central Florida (fig. 1). It is bounded on the east by the Atlantic Ocean and on the north, west, and south respectively by St. Johns, Putnam, and Volusia Counties. About one-half of its common boundary with Putnam County lies in Crescent Lake.

Most of the population is concentrated in Bunnell (the county seat) and coastal communities. Major industries are agriculture, tourism, and forestry.

Physiography and Drainage

Land-surface altitude within Flagler County varies from sea level to 50 feet. Most of the county is less than 30 feet in altitude. Altitudes above 30 feet occur in a small area in the southwestern corner of the county. Altitudes are below 5 feet in large parts of the county. The topography has been largely influenced by terrace formation during the Pleistocene Epoch. These terraces are flat, horizontal expanses of sand and shell deposits that were the sea floor when sea level stood higher than at present. The three terraces in Flagler County are from highest to lowest: (1) the Talbot Terrace, (2) the Pamlico Terrace, and (3) the Silver Bluff Terrace (fig. 2).

The Talbot Terrace is the highest landmass in Flagler County and was formed when the sea stood about 45 feet above the present level. The base of the Talbot is outlined by the 25-foot altitude contour in most of the

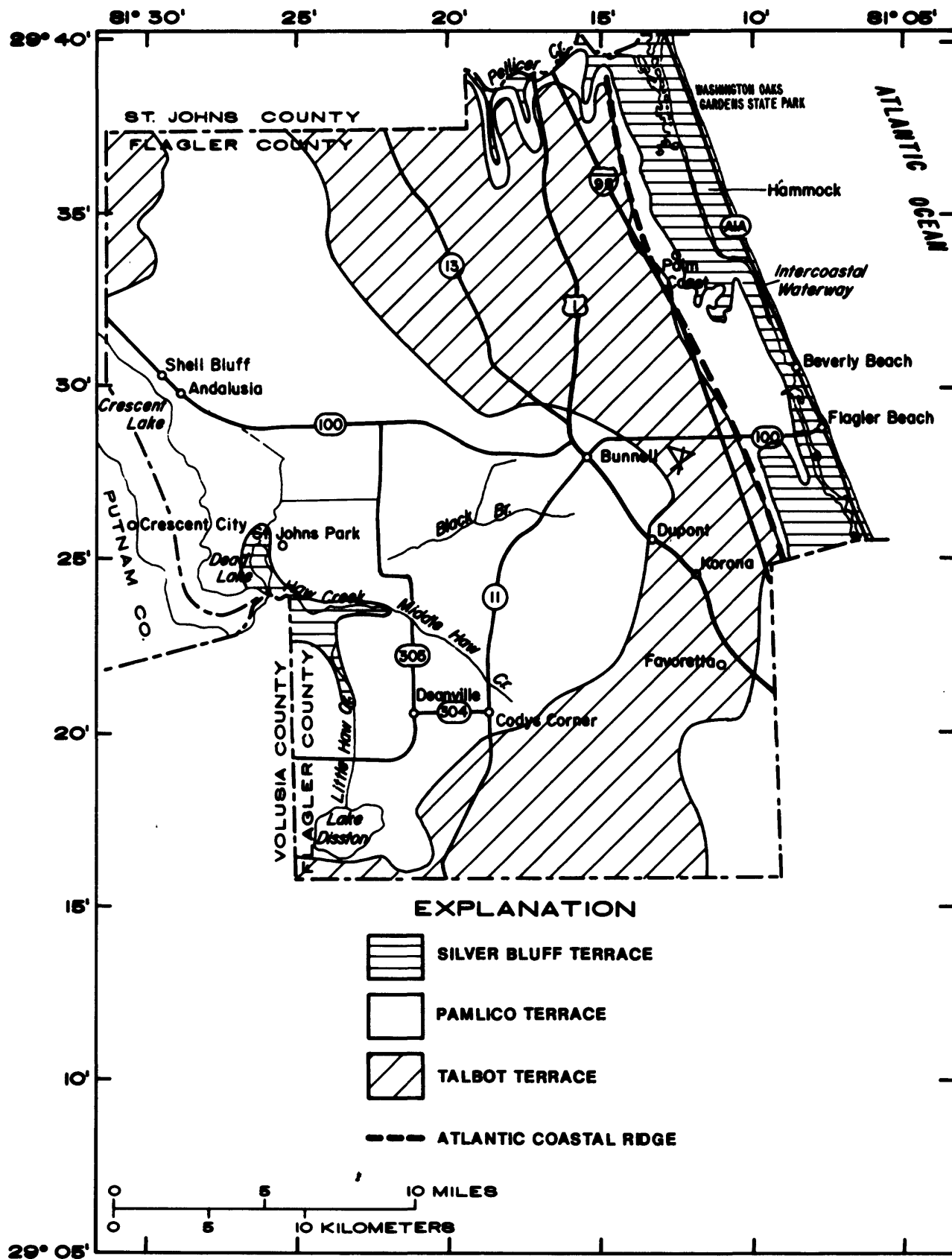


Figure 2.--Pleistocene marine terraces (from Bermes and others, 1963, fig. 3).

county. Its east edge is particularly well defined in northeast Flagler County where it is seen as a linear feature parallel to the coastline. The eastern edge of the Talbot is commonly referred to as the Atlantic Coastal Ridge.

The next lower terrace is the Pamlico, which was formed when sea level was 25 to 30 feet above the present level. It occurs in a narrow band east of the Talbot Terrace, and covers about two-thirds of the county area west of the Talbot.

The Silver Bluff Terrace is the lowest landmass in Flagler County, and was formed when the sea stood 5 to 10 feet above the present level. In east Flagler it occurs as an elongate band, adjacent to the coast and up to several miles in width. A small area occurs in west Flagler along Haw Creek and Crescent Lake.

Drainage in Flagler County is controlled by the Atlantic Coastal Ridge, which is the topographic high in the study area. Drainage east of the ridge is either to the Intracoastal Waterway or into the Atlantic Ocean by relatively short streams that flow eastward. The remainder of the county tends to be poorly drained; streams are so poorly developed that much of the area is marshland. Drainage is through sluggish tributaries to Haw Creek and Crescent Lake and thence to the St. Johns River.

Rainfall and Evapotranspiration

Flagler County has a humid, subtropical climate with high annual rainfall and moderate temperatures. The mean annual temperature is about 70 °F.

Figure 3 shows yearly rainfall for 1942-82 derived from National Oceanic and Atmospheric Administration stations located at Marineland, Crescent City, Daytona Beach and St. Augustine (fig. 1). The Marineland station was used for data through 1978 and the St. Augustine station was used from 1979 through 1982. Mean annual rainfall for Flagler County for the 41-year period was approximately 49.67 in/yr (inches per year).

In most years, wet and dry seasons are pronounced. About 65 percent of the average rainfall tends to occur during the 5 months of June through October. Local thunderstorms account for most of the summer rainfall. Winter rains tend to be areal or regional in distribution and associated with movement of large frontal-type weather systems.

The major loss of water through the hydrologic cycle in the county is by evapotranspiration (the combination of plant transpiration and physical evaporation). The evapotranspiration rate for Flagler County is estimated to be greater than 35 in/yr (Lichtler and others, 1968).

Geology

The oldest geologic unit penetrated by water wells in Flagler County is the Avon Park Formation of late middle Eocene age. This formation is composed of beds of white to brown limestone and dolomite; dense, indurated zones tend to alternate with highly porous zones. The top of the Avon Park generally dips north in Flagler County; ranging from about 100 feet below

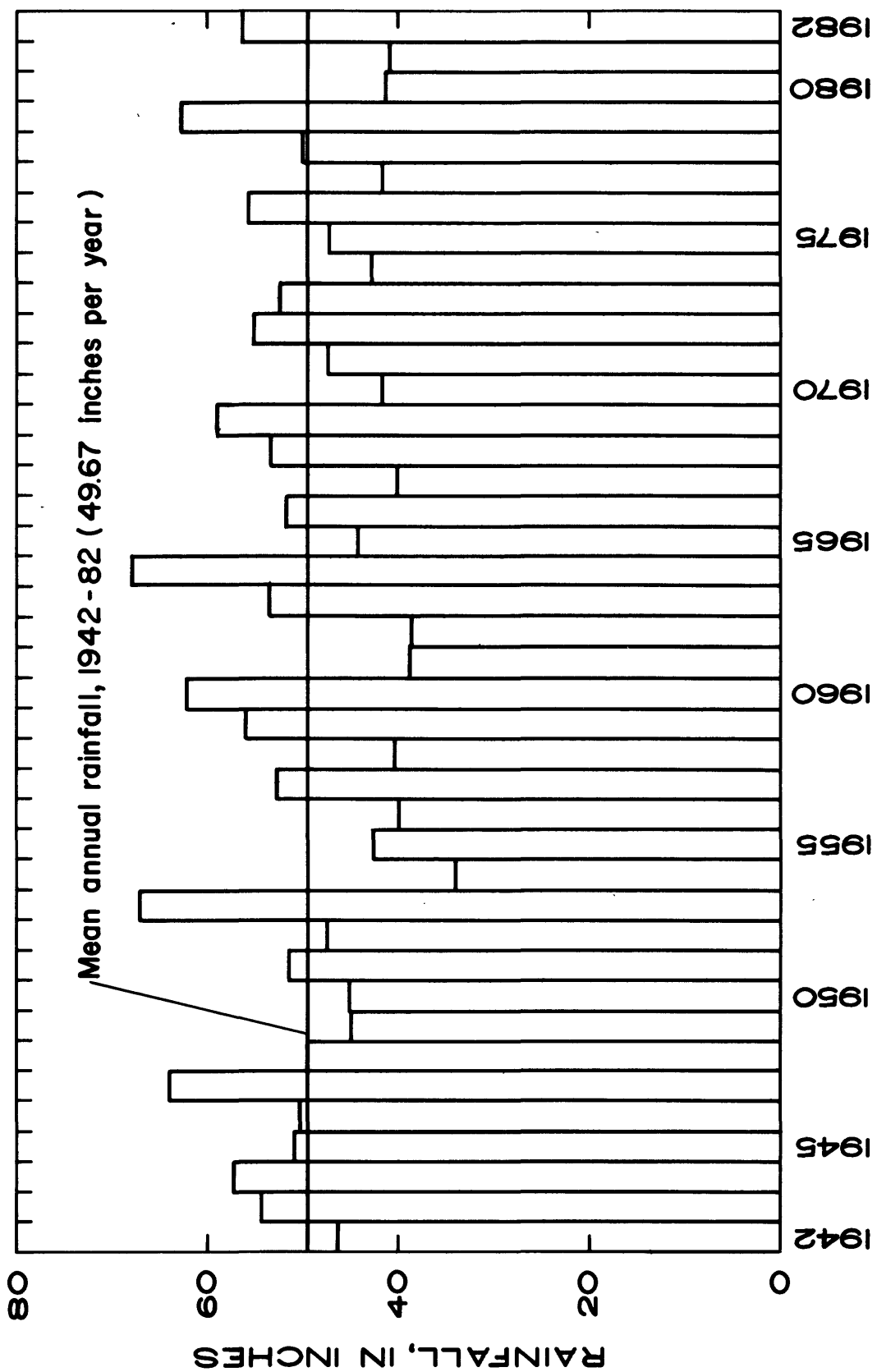


Figure 3.--Annual rainfall for Flagler County (calculated from Crescent City, Daytona Beach, Marineland, and St. Augustine NOAA stations).

sea level in southern Flagler to about 300 feet below sea level in the north (Bermes and others, 1963a, p. 25-27, fig. 6). The thickness of the Avon Park ranges from about 170 to 235 feet.

The Ocala Limestone overlies the Avon Park Formation throughout Flagler County. The Ocala, of late Eocene age, is a white-to-tan, highly fossiliferous limestone that ranges in thickness from 150 feet in the north to less than 50 feet in the south (Bermes and others, 1963a, p. 29, fig. 6). The Ocala Limestone is tapped extensively by wells.

The middle Miocene Hawthorn Formation overlies the Ocala Limestone except where absent in most of south Flagler County. The base of the formation is dolomitic limestone, but the remainder of the formation is sandy clay and marl, interbedded with lenses of phosphorite pebbles, phosphatic sand, and phosphatic sandy limestone.

Upper Miocene or Pliocene deposits occur in a band that parallels the coastline. The deposits consist of interstratified lenses of marine sand, shell, and clay that overlie the Hawthorn Formation where present. Where the Hawthorn is absent, these deposits overlie the Ocala Limestone.

Sand, clay, and shell deposits of Pleistocene and Holocene age comprise the surficial aquifer system in Flagler County. These deposits are described by Bermes and others (1963a, p. 32-33) as fine- to medium-grained sand with thin clay and shell lenses. The shell lenses are loosely to well-cemented coquina beds that occur near and parallel to the coast. The coquina beds, named the Anastasia Formation (Parker and others, 1955, p. 100), crop out on the beach at Washington Oaks Gardens State Park.

HYDROGEOLOGY

Aquifers

The ground-water reservoir tapped in Flagler County consists of three units: the Upper Floridan aquifer, the intermediate aquifer system, and the surficial aquifer system (fig. 4).

Upper Floridan aquifer.--The Upper Floridan aquifer consists of the upper part of the Avon Park Formation and the Ocala Limestone of Eocene age; and, where present, the basal dolomitic limestone of the Hawthorn Formation. Altitude of the top of the Floridan aquifer system is shown in figure 5. The Upper Floridan aquifer contains water under artesian conditions throughout Flagler County. The confining unit consists of the marls, clays, and dolomites of the upper part of the Hawthorn Formation, the clays in the upper Miocene or Pliocene deposits, and the sand, clay and shell deposits of the Pleistocene and Holocene. The aquifer is highly productive, yielding from 50 gal/min (gallons per minute) to greater than 1,000 gal/min depending on well and pump size. The more permeable zones are capable of storing and transmitting large quantities of ground water. However, use of the aquifer is limited by the generally brackish water it contains in much of Flagler County. Most wells that tap the Upper Floridan in Flagler County are open to the Ocala Limestone and, where present, the dolomitic limestone of the Hawthorn Formation. Fewer wells penetrate the underlying Avon Park Formation because of the additional expense of deeper drilling and the likelihood of encountering saline water in deeper wells.

Intermediate aquifer system.--The intermediate aquifer system consists of upper Miocene or Pliocene deposits. It is an artesian, inhomogeneous ground-water system. The primary water-bearing zones are relatively thin and discontinuous lenses of permeable sand, shell, and limestone. These lenses vary in thickness from less than 1 to more than 10 feet, and were formerly known as secondary artesian aquifers but now constitute the intermediate aquifer system. These lenses are generally composed of relatively clean shell material that occur principally in the east one-half of the county, at depths of about 40 to 90 feet below land surface. The clays within the intermediate aquifer system act as confining beds for these units. The sand, clay, and shell units of the Pleistocene and Holocene also act as confining beds. Yields of wells that tap the intermediate aquifer system range from less than 5 to more than 50 gal/min. Though low yielding compared to well yields in the Upper Floridan aquifer, this system is an important source of potable water in east and northeast Flagler where the Upper Floridan contains potable water of marginal quality or nonpotable water.

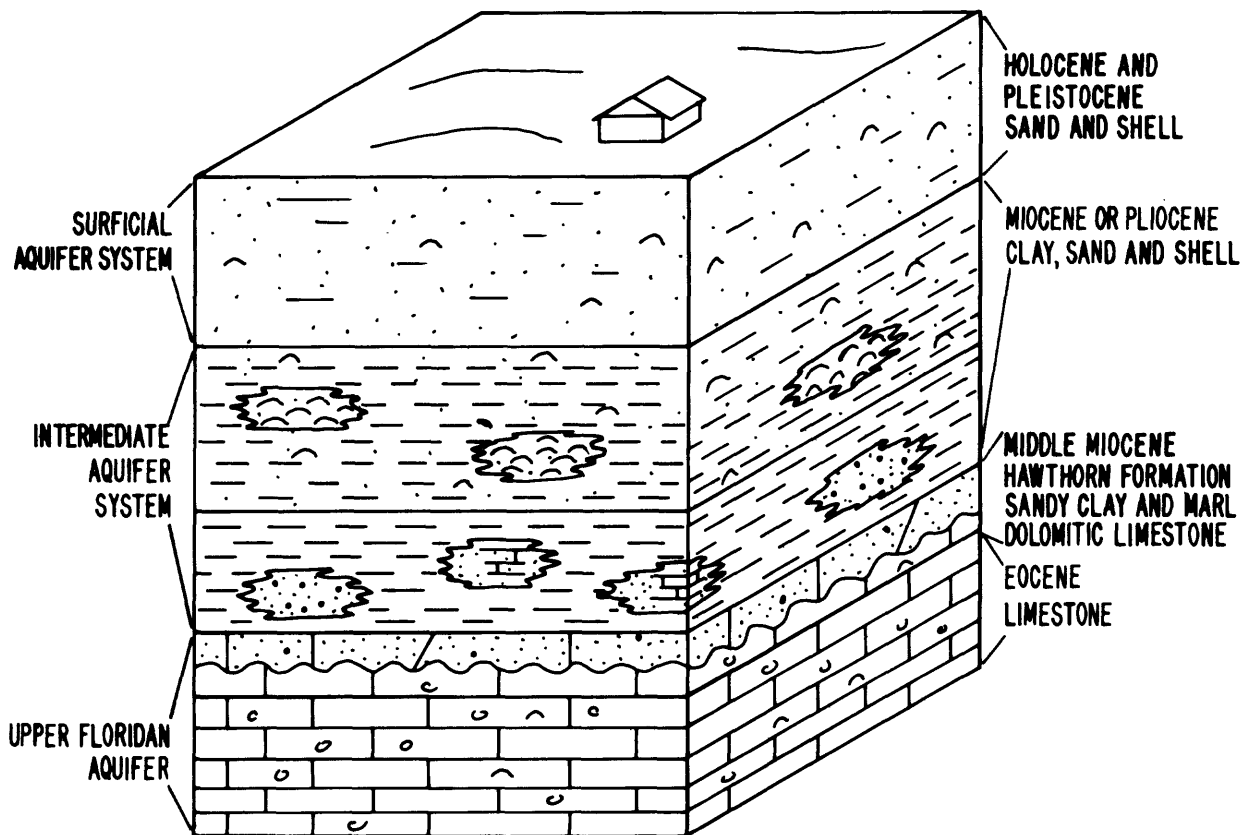


Figure 4.--Stratigraphic and hydrogeologic column in Flagler County.

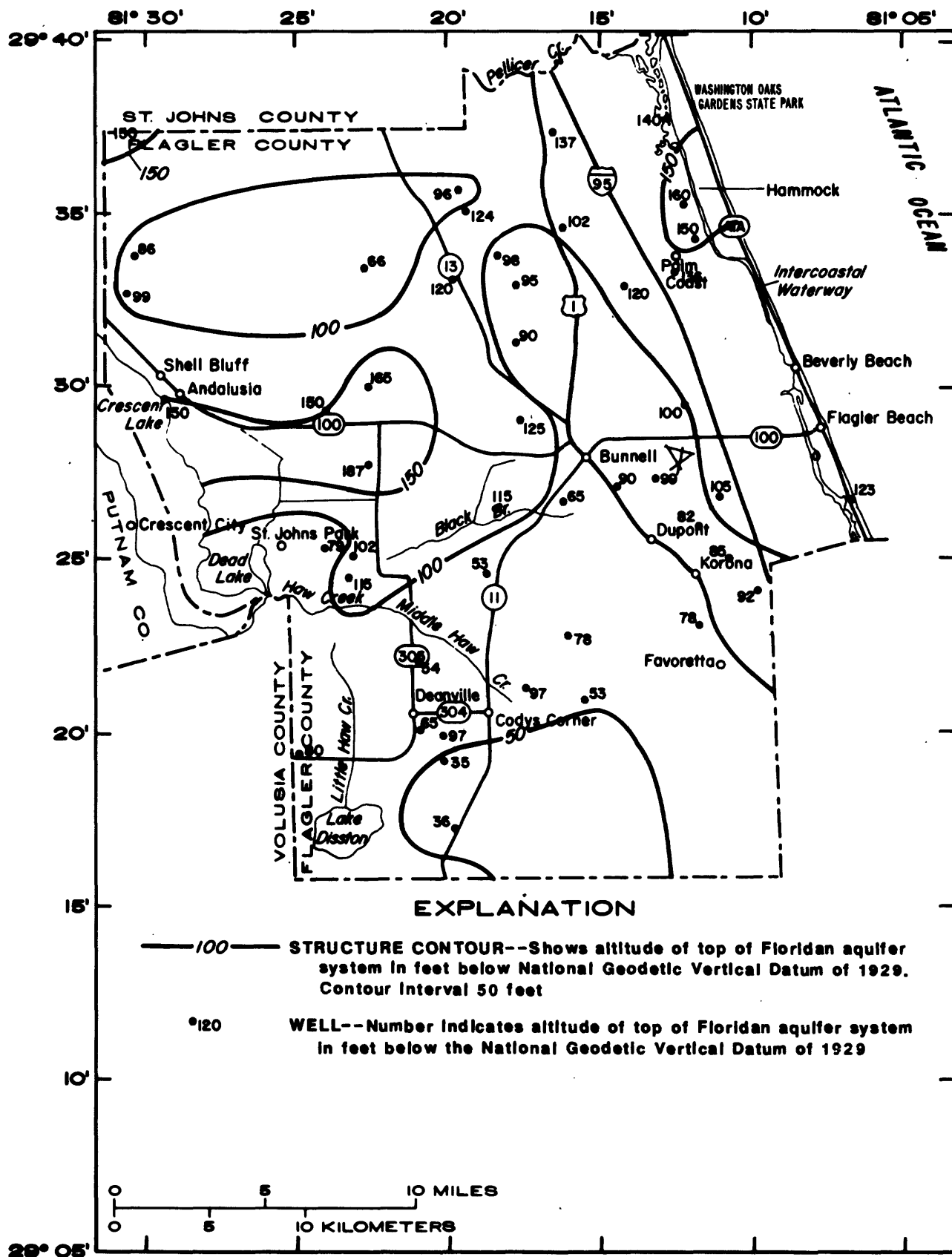


Figure 5.--Altitude of the top of the Floridan aquifer system in Flagler County.

Surficial aquifer system.--Deposits of Pleistocene and Holocene age comprise the unconfined surficial aquifer system in Flagler County. These deposits are composed of sand and shell with varying fractions of finer material. They range in thickness from less than 20 feet in south and central Flagler to more than 50 feet in north Flagler. In central and west Flagler fine materials predominate making it difficult to develop adequate well yields; most wells there yield less than 2 gal/min. Sands tend to dominate in east-central Flagler and shell material (coquina) is dominant along part of the coastal bar. In these areas, the surficial aquifer system yields small to moderate amounts of water (10-50 gal/min). However, the surficial aquifer system is a locally important source of domestic water supply, particularly in coastal areas where the deeper aquifers contain non-potable water.

Ground-Water Movement

In a ground-water flow system, water enters an aquifer in recharge areas and flows downgradient to areas of lower head in discharge areas. In general, the least mineralized ground water occurs in recharge areas, and the most mineralized occurs in discharge areas. Optimum development and use of an aquifer may be highly dependent upon understanding the flow system.

Upper Floridan aquifer.--The most significant recharge area to the Upper Floridan aquifer in the Flagler County flow system is the De Land Ridge, which is outside the county boundary. In general, recharge areas are well-drained uplands characterized by poorly developed stream systems and karst topography (depressions in limestone bedrock areas that may contain lakes). A significant source of recharge within the county comes from the surficial aquifer system where the water table is higher than the artesian head in the Upper Floridan aquifer and where materials existing between the Floridan aquifer system and surficial aquifer system have high vertical hydraulic conductivities.

Recharge from the De Land Ridge is estimated to range from 0.9 in/yr to 2.6 in/yr (Rutledge, 1982, p. 58) in the area of northwest Volusia County that is immediately adjacent to Flagler County. The area directly to the south of Flagler County is estimated to have a recharge rate of approximately 1 in/yr (Tibbals, 1981, fig. 8). Rutledge (1982, p. 57) calculated that approximately 2.9 Mgal/d (million gallons per day) enters Flagler County from northwest Volusia County. The contours of the potentiometric surface in figure 6 indicate that the recharge from the west part of the county moves toward the discharge areas downstream of Lake Disston and the recharge to the central area of the county moves toward Favoretta and Bunnell.

Within Flagler County, recharge to the Upper Floridan aquifer is very low. Recharge rates in the Pamlico and Talbot Terrace areas may range from 0 to 1 in/yr (Tibbals, 1981, fig. 8). This is because of little or no difference in water levels in the different aquifer systems, and high levels of evapotranspiration in the swamps.

Water in the Upper Floridan aquifer is discharged within the county in topographically low areas along the Atlantic Coast, adjacent to Crescent Lake, and in the Haw Creek basin (fig. 6). Discharge in these areas occurs

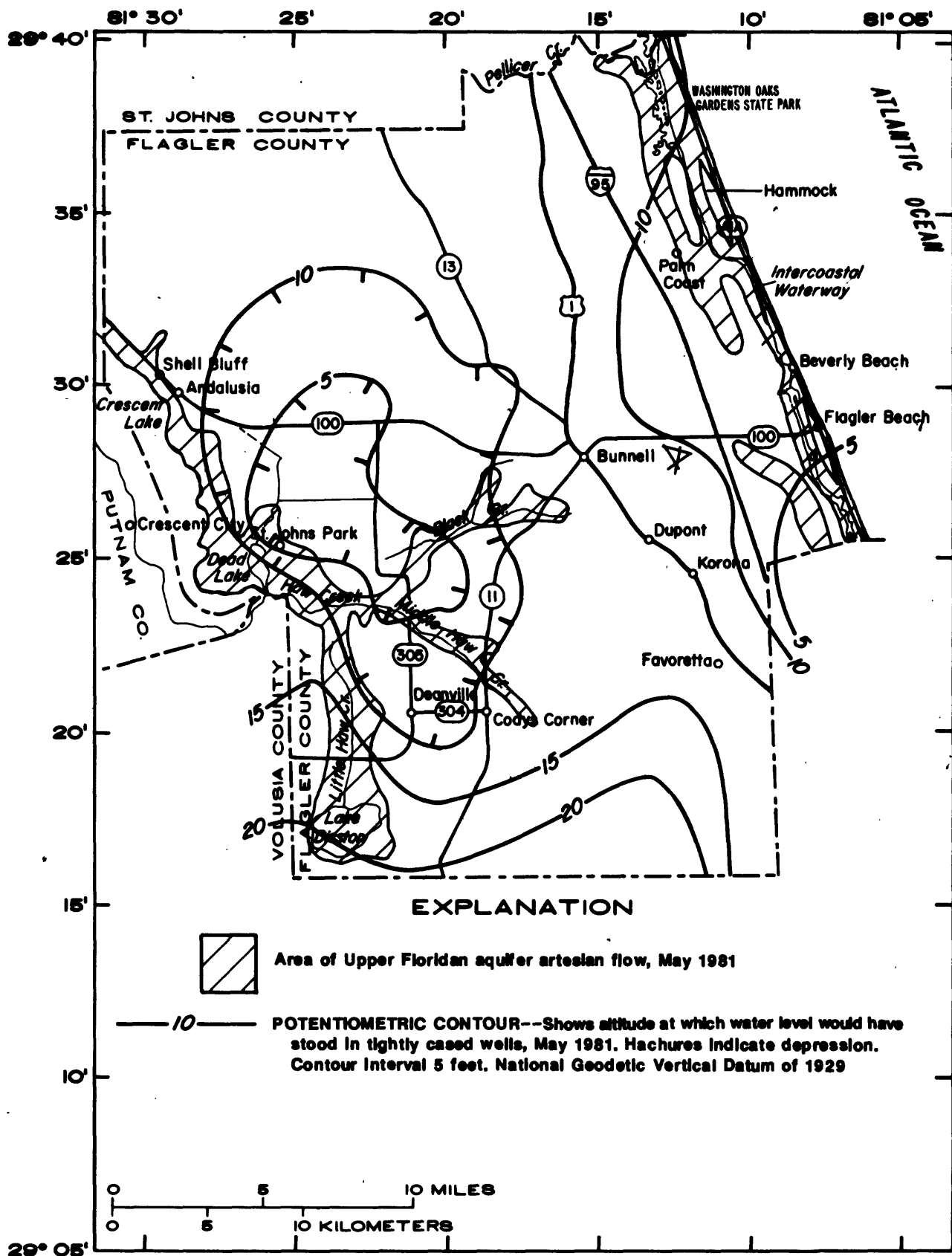


Figure 6.--Potentiometric surface of the Upper Floridan aquifer and areas of artesian flow in May 1981 (from Schiner and Hayes, 1981).

by upward seepage and free-flowing wells that tap the the Upper Floridan aquifer. Discharge in the rest of the county also occurs by pumpage of wells in the Upper Floridan aquifer for agricultural irrigation or public supply.

Intermediate aquifer system.--The intermediate aquifer system receives recharge from either the underlying Upper Floridan or the overlying surficial aquifer system, depending on respective head relations. In areas of discharge from the Upper Floridan aquifer (fig. 6) a potential exists for recharge to the intermediate aquifer system. Conversely, a potential exists for recharge from the surficial aquifer system to the intermediate aquifer system in Upper Floridan aquifer recharge areas. The amount of recharge to the intermediate aquifer system is dependent on its degree of confinement and the head differentials.

Surficial aquifer system.--The sand and shell beds of the surficial aquifer system receive recharge from rainfall, and, in Upper Floridan aquifer discharge areas, by upward movement of water from the Upper Floridan. Except where the unsaturated zone is relatively thick, most recharge occurs on the low-relief areas of the Pamlico and Talbot Terraces. These areas are generally poorly drained. Swamplike conditions often form when the aquifer is fully saturated and excess water ponds. Water is discharged from the surficial aquifer system through evapotranspiration, pumpage, lateral seepage to streams, canals, and the ocean, and downward seepage to the lower aquifer systems.

Hydraulic Properties

Upper Floridan aquifer.--The transmissivities from aquifer tests made on wells in the Upper Floridan aquifer are compiled in table 1. Locations of the wells are shown in figure 7. Results of the aquifer tests were given in previous hydrologic investigations. The transmissivities range from 9,270 to 61,000 ft²/d (foot squared per day). Storage coefficients ranged from 0.00036 to 0.0009 and leakance ranged from 0.00014 d⁻¹ to 0.0023 d⁻¹.

Table 1.--Transmissivities from aquifer tests in wells of the Upper Floridan aquifer

Site No.	Station identification No.	Well depth (feet)	Thickness of aquifer penetrated (feet)	Transmissivity (ft ² /d)	Storage coefficient	Leakance (d ⁻¹)
1	¹ 291902081185601	350	290	37,000	---	---
2	¹ 291955081200901	175	75	25,000	0.0002	0.0023
3	¹ 292817081115701	345	215	36,000	.0005	.0007
4	¹ 292846081223301	495	335	37,000	.0009	---
5	² 292616081131401	223	121	23,000	---	---
6	² 293036081171401	172	49	9,400	.0001	.00089
7	² 293234081293601	405	250	26,000	---	---
8	² 293325081124801	330	153	50,000	.0001	.0011
				61,000	.0007	.00042
9	³ Palm Coast LW-51	180	62	9,270	.00042	.00014
10	³ Palm Coast LW-49	225	122	12,000	.00036	.00026

¹Bermes and others, 1963a, p. 67.

²Bentley, 1977, p. 37-40.

³Black, Crow, and Eidsness/CH₂M-Hill, 1977, p. 6-3.

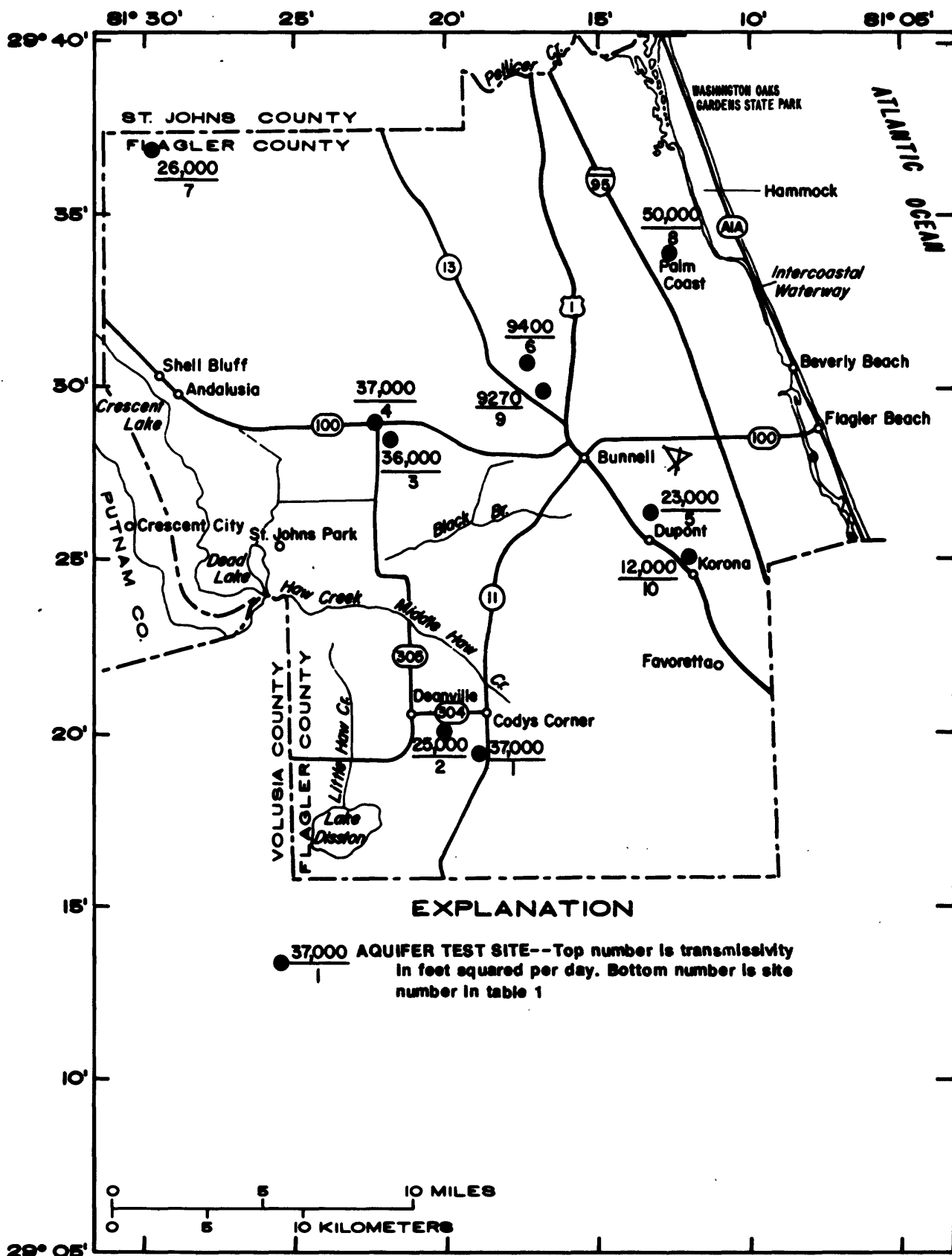


Figure 7.--Transmissivities in the Upper Floridan aquifer.

Intermediate aquifer system.--Current available data indicate that the most productive zones of the intermediate aquifer system are located near the center of the Talbot Terrace in east Flagler (Bermes and others, 1963a, fig. 3). By use of well cuttings, geophysical logs, and aquifer test data, it was determined that the most transmissive zones are shell zones that vary in depth and thickness. The most productive zones occur at depths of 60 to 95 feet below land surface (Black, Crow, and Eidsness/CH₂M-Hill, Inc., 1977, p. 4-3 to 4-16). Specific capacities for 4-inch diameter screened test wells tapping clean shell zones ranged from 1 to 22 (gal/min)/ft (gallons per minute per foot) of drawdown.

Age Dating of Ground Water

Flow rates, circulation patterns, and residence time of water in a ground-water system can be investigated by the determination of the relative age of water in various parts of the system. Water samples from eight wells in the Upper Floridan aquifer were analyzed for apparent age by use of carbon-14 isotope decay rates. The results of analysis are given in table 2 and in figure 8.

Table 2.--Carbon-14 analyses of ground water in Flagler County and vicinity

Site No.	Station identification No.	Station name	Date of sample	Carbon-14 percent modern	Carbon-14, dissolved, apparent age ¹
<u>Wells in the Upper Floridan aquifer</u>					
1F	291036081175801	Hendrix Well on SR 11, east of Barberville	82-02-17	34.4	8,600
2F	291818081190501	Firetower Well near Codys Corner	82-02-17	35.8	8,300
3F	292342081183701	Sorenson Well near Codys Corner	82-02-18	3.2	27,800
4F	292521081222301	Harper Well near St. Johns Park	82-02-18	<3.6	>26,800
5F	292528081255301	Stock well at St. Johns Park	82-02-22	<6.8	>22,300
6F	292559081111101	Seminole Pkwy Well at Sesame Blvd.	82-02-22	19.1	13,300
7F	292741081305801	Newbold Irrigation Well at Crescent City	82-02-16	26.8	10,600
8F	293504081183601	Palm Coast Well LW-3 near Bunnell	82-02-26	<2.2	>30,700
<u>Wells in the intermediate aquifer system</u>					
9F	293406081174601	Palm Coast Well SW-91 near Bunnell	82-03-01	18.8	13,400
10F	293636081180901	Palm Coast Well SW-92 near Bunnell	82-03-01	24.9	11,200

¹Apparent age is in years before present.

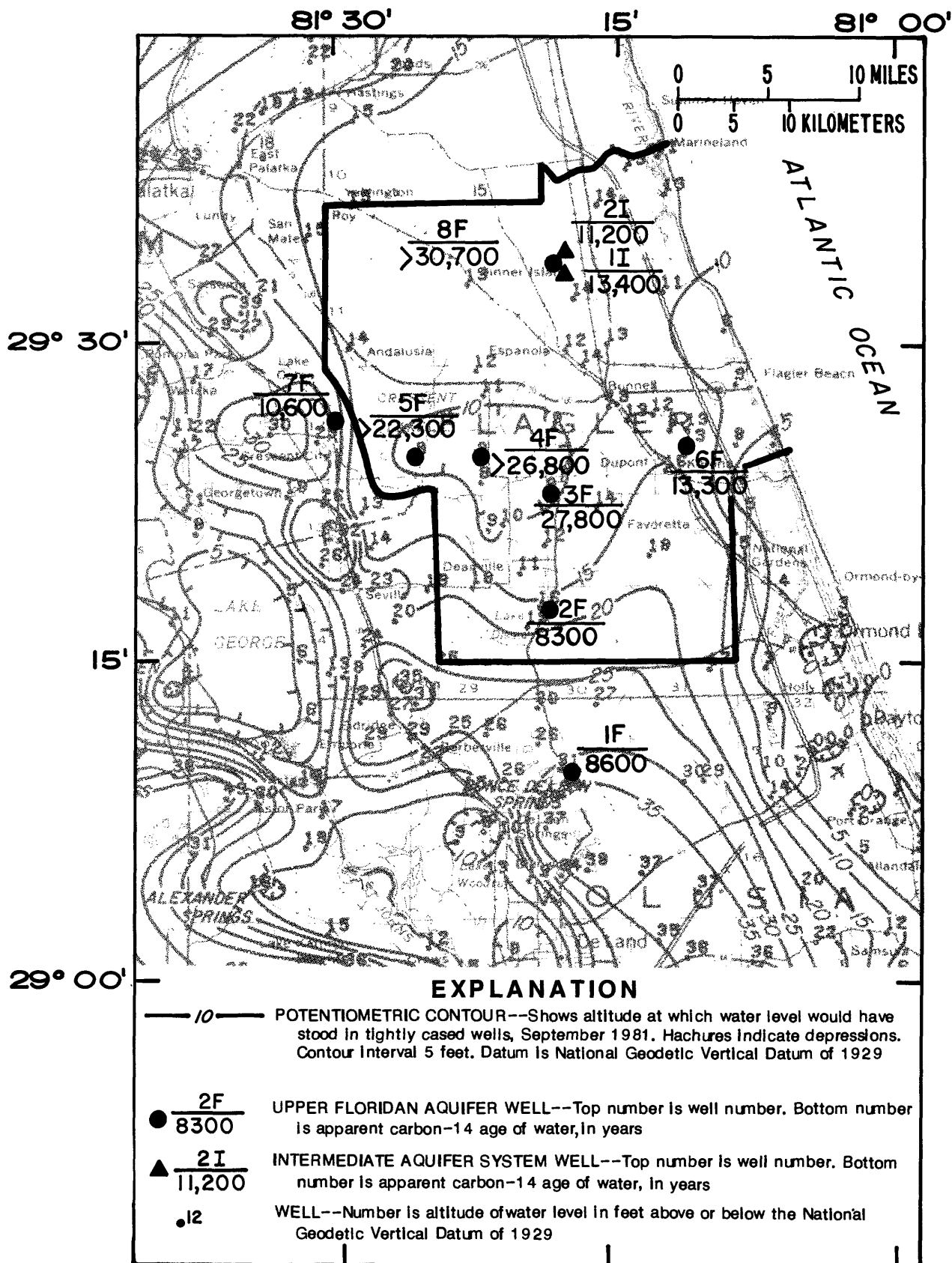


Figure 8.--Age of water in Flagler County and vicinity.

The youngest age water in the study area is near the De Land Ridge where most recharge that directly affects Upper Floridan aquifer water quality in Flagler County probably occurs. Well 1F is in the high recharge area in Volusia County; wells 2F and 6F are immediately downgradient in Flagler County.

Well 7F is in the high recharge area on the Crescent City Ridge in Putnam County, and well 5F is generally downgradient in Flagler County. The disparity in ages of the two sets of values probably indicates that most recharge from the Crescent City Ridge does not reach the interior of Flagler County but, rather, is discharged in the Crescent Lake discharge area, whereas recharge from the De Land Ridge does reach into Flagler County.

The remaining three wells in the Upper Floridan aquifer that were sampled and analyzed for carbon-14 (wells 3F, 4F, and 8F) are in low recharge areas in the interior part of Flagler County. These wells yielded older age water which may indicate that little recharge to the Upper Floridan occurs in Flagler County.

Two water samples from wells in the intermediate aquifer system in the northern part of the county were also dated. A comparison with Upper Floridan aquifer water from a nearby well showed that the intermediate aquifer system water is much younger (fig. 8). Apparently, the confining beds that overlie the intermediate aquifer system are permeable enough to allow recharge from the sand beds of the surficial aquifer system, but the recharge to the Upper Floridan aquifer in the north-central part of the county is negligible.

Water samples from the surficial aquifer system were not dated, but the age of most of the water in the sand and shell beds is probably very young. Possible exceptions would be where older Upper Floridan aquifer water discharges into the surficial aquifer system.

WATER USE

Ground water in Flagler County is used for public supply and for agriculture. The county has no significant industrial or commercial water use. The municipalities and large developments in the county pump from both the intermediate aquifer system and Upper Floridan aquifer.

Pumpage for public supply water use is shown in table 3. At the current usage of about 132 gal (gallons) per capita per day, approximately 7.2 Mgal/d would be required to support a population of 54,700 projected by the University of Florida for the year 2020 (Smith and Sincich, 1983).

The amount of ground water used for agriculture from 1979 to 1983 is more than three times that used for public and domestic supply (table 3). Of the water used for agriculture, 97.5 percent is withdrawn from the Upper Floridan aquifer. Surface water used mostly for livestock and irrigating turf grass accounts for the remainder of agricultural use.

Table 3.--Public, domestic self-supplied, and agricultural use of water, Flagler County, 1979-83
(From Marella, 1981-84)

<u>Public and domestic self-supplied</u> ¹										
	<u>1979</u>		<u>1980</u>		<u>1981</u>		<u>1982</u>		<u>1983</u>	
	Popu- lation served (Mgal/d)	Water used (Mgal/d)	Popu- lation served (Mgal/d)	Water used (Mgal/d)	Popu- lation served (Mgal/d)	Water used (Mgal/d)	Popu- lation served (Mgal/d)	Water used (Mgal/d)	Popu- lation served (Mgal/d)	Water used (Mgal/d)
Bunnell	1,784	0.28	1,900	0.28	1,900	0.26	1,900	0.23	1,900	0.22
Flagler Beach	2,000	.34	2,039	.36	2,331	.32	2,350	.30	2,581	.36
Palm Coast	3,500	.74	4,500	1.06	5,000	1.10	5,500	.92	7,278	.97
Domestic self-supplied	<u>1,762</u>	<u>.33</u>	<u>2,474</u>	<u>.50</u>	<u>2,910</u>	<u>.54</u>	<u>3,209</u>	<u>.48</u>	<u>2,027</u>	<u>.27</u>
Total	9,046	1.69	10,913	2.20	12,141	2.22	12,959	1.93	13,786	1.82

<u>Agricultural</u>					
	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>
Ground water in Mgal/d	8.37	12.66	6.96	5.85	6.45
Surface water in Mgal/d	.18	.12	.17	.17	.17
Acres irrigated, in thousands	7.23	7.68	6.23	6.23	5.93

¹Ground water only

HYDROLOGIC CONDITIONS 1979-82 Upper Floridan Aquifer

Water levels.--Daily records of water levels were collected for five wells in the Upper Floridan aquifer during this investigation (fig. 9). Hydrographs for these wells reflect water-level conditions throughout the county, and illustrate seasonal and annual fluctuations (fig. 10). Wet to dry seasonal fluctuations are usually about 2 to 3 feet in Flagler County. In most years the seasonal low occurs in April or May at the end of the dry season, and the seasonal high occurs in September or October at the end of the rainy season. The calendar year 1980 was a notable exception to these seasonal extremes in Flagler County as well as in most of east-central Florida. Drought conditions prevailed during the summer months of 1980 so that September water levels were lower than the May 1980 levels over a wide area of east-central Florida (G.R. Schiner, U.S. Geological Survey, written commun., 1981). Drought conditions prevailed through the winter of 1980-81 and resulted in many record low water levels in the Upper Floridan aquifer in May 1981.

Potentiometric surface maps were constructed twice yearly (May and September) during the investigation, focusing on a map for each wet and dry season. The maps for September 1978 and May 1981 are shown as figures 11 and 6, respectively. The general configuration of the contours remain similar through time, with altitude changes due to climatic conditions. Notable features of the potentiometric surface are the depression in the west-central part of the county, the high in the southeast, and the generally low gradient.

The pronounced depression in west-central Flagler originates because of natural discharge in the Haw Creek basin and agricultural pumpage. The highest water levels are in south and southeast Flagler, where a potentiometric surface mound results from recharge on the nearby De Land Ridge in Volusia County. Other than in the areas of the depression and the mound, the potentiometric surface of the Upper Floridan aquifer tends to be rather flat and featureless in the remainder of Flagler County.

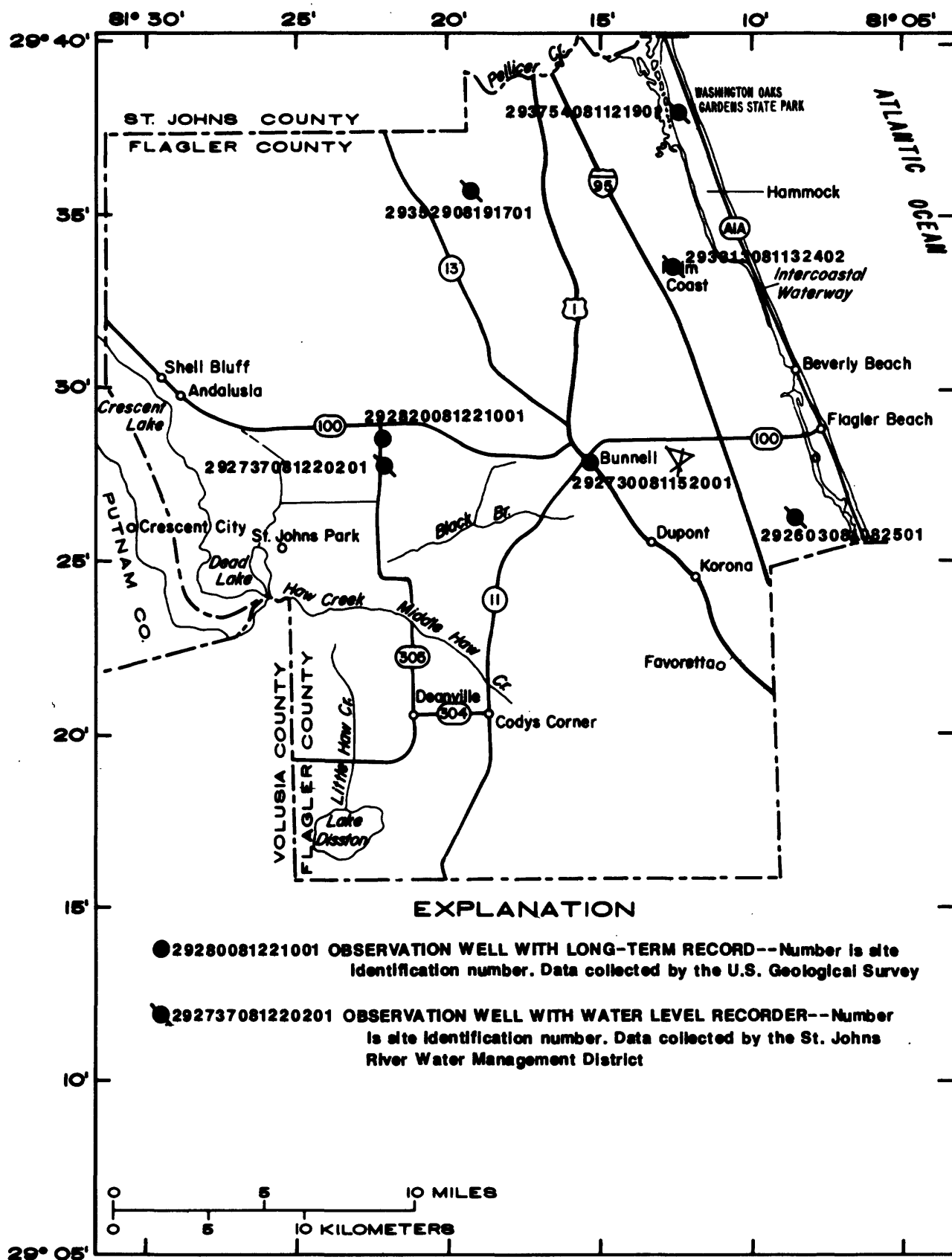


Figure 9.--Location of observation wells with long-term records in the Upper Floridan aquifer.

In figure 6, the area where water levels in the Upper Floridan aquifer would be above land surface is delineated by comparing the May 1981 potentiometric surface with topographic altitudes. These areas are confined to low-lying areas in the Haw Creek-Crescent Lake basin and to a narrow strip along the Atlantic Coast.

Water quality.--The concentration of dissolved solids in water is a common measure of mineralization. The Florida Department of Environmental Regulation (Florida Department of State, 1982) states that dissolved solids in drinking water used for community water systems should not exceed 500 mg/L (milligrams per liter); however, higher concentrations are permitted if no other maximum contaminant levels are exceeded. Dissolved solids in water samples from wells in the Upper Floridan aquifer ranged from 190 to 6,300 mg/L (fig. 12). The concentrations exceeded 500 mg/L over about three-

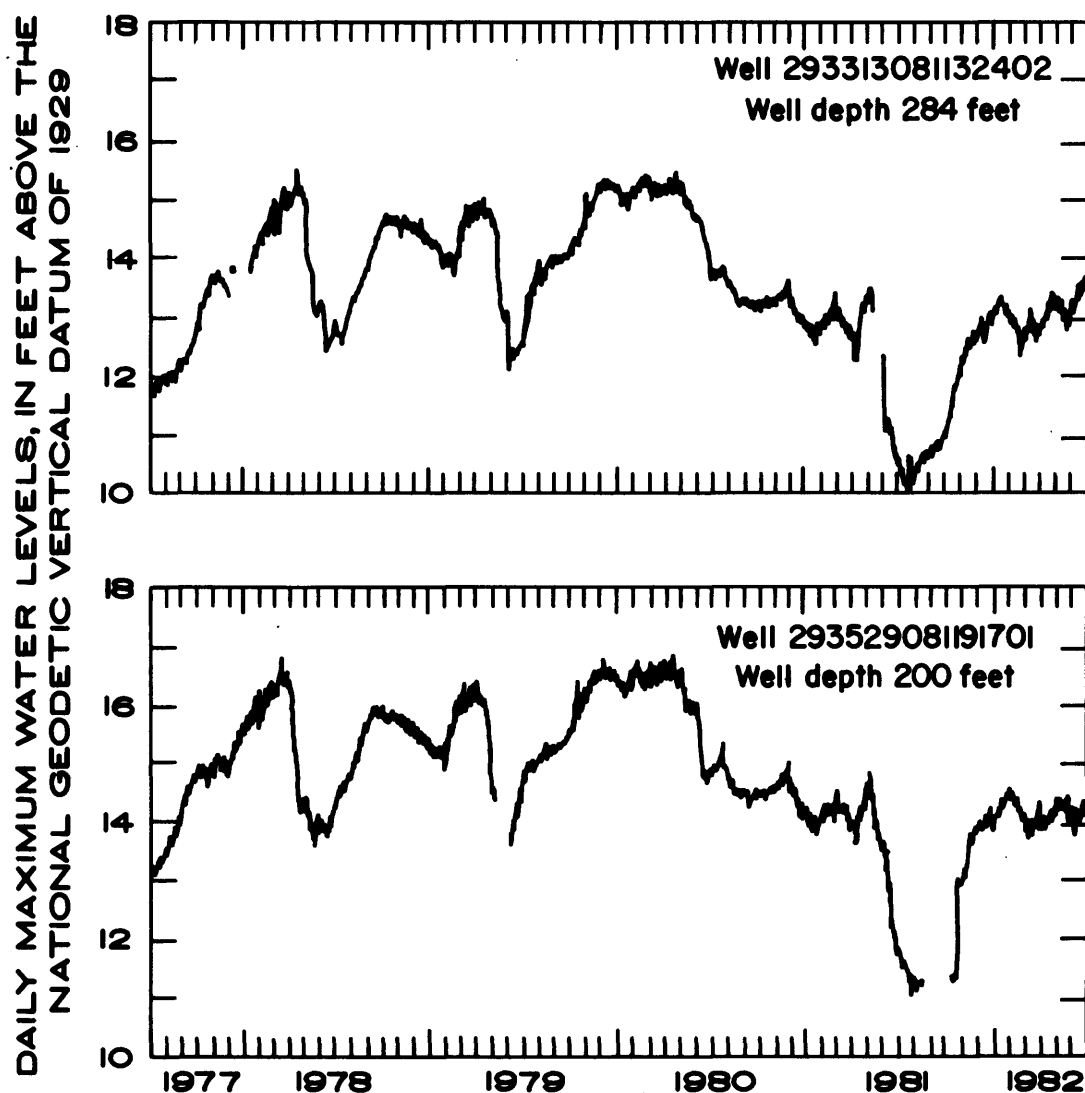


Figure 10.--Water levels in wells in the Upper Floridan aquifer, 1978-82. (data from the St. Johns River Water Management District).

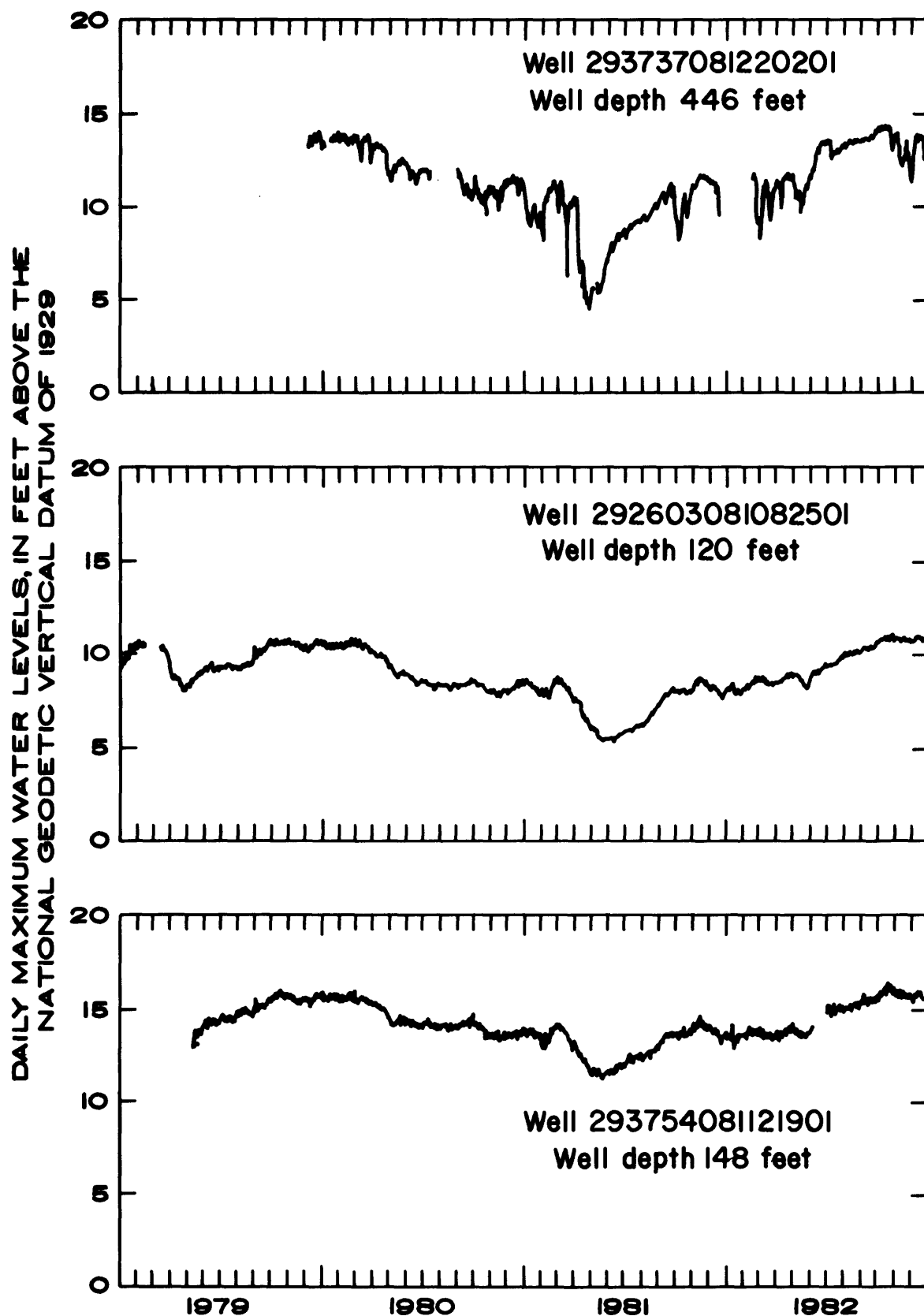


Figure 10.--Water levels in wells in the Upper Floridan aquifer, 1978-82
(data from the St. Johns River Water Management District)--Continued.

quarters of the county. Lowest concentrations are in southeast Flagler generally coincident with the potentiometric surface high related to recharge that enters the county from the De Land Ridge. The highest concentrations are in or near discharge areas along the coast and in west-central Flagler.

Chloride is a major constituent of dissolved solids in coastal Florida. Its concentration is used as an indicator of the extent of saltwater intrusion or amount of remnant seawater in an aquifer. The recommended maximum chloride concentration for public water supplies is 250 mg/L (Florida Department of State, 1982). Chloride concentrations ranged from less than 7 mg/L in southwest Flagler to 3,700 mg/L in west-central Flagler (fig. 13).

Hardness of water is due principally to the cations calcium and magnesium. Hard water may have detrimental effects such as causing excessive soap consumption and the formation of encrustations or boiler scale (U.S. Environmental Protection Agency, 1977a). Water from the Upper Floridan aquifer in Flagler County (fig. 14) is very hard (greater than 300 mg/L as calcium carbonate) except in the southern part where the water is moderately hard to hard (75-300 mg/L as calcium carbonate).

Sulfate in water is generally associated with remnant seawater in an aquifer or from dissolution of minerals, such as gypsum or anhydrite, that are commonly found in carbonate rocks. Higher sulfate concentrations are generally coincident with the highest dissolved solids in the county; that is, in discharge areas in west-central Flagler and along the coast. However, the proportionality between sulfate and dissolved solids is different between the water in west-central Flagler and the coastal area. Water in the coastal area has a greater proportion of sulfate and is more likely to be from remnant sea water than dissolved minerals.

High iron concentration in water is generally considered undesirable to taste and causes rust-colored stains on clothing, plumbing fixtures, and other materials. The occurrence of iron in the Upper Floridan aquifer in Flagler County is quite variable.

Intermediate Aquifer System

Water levels.--Figure 15 shows the water levels measured in wells of the intermediate aquifer system during May 1979. A contour map of the potentiometric surface was not drawn because of the lenticular nature of individual beds. Water levels in wells tapping the intermediate aquifer system are near land surface but wells usually do not flow except when levels are very high. Figure 16 is a continuous hydrograph of a well in the intermediate aquifer system from 1978 to 1982. The generally large and frequent fluctuations throughout the period of record is noticeable. The range in fluctuation from 1979 to 1982 was approximately 0 to 6 feet.

Water quality.--The dissolved solids concentration of water from wells in the intermediate aquifer system ranged from 290 to an estimated 2,000 mg/L (fig. 17). In noncoastal areas, the highest dissolved solids concentration was 620 mg/L. The chloride concentration of water samples from wells in the intermediate aquifer system ranged from 21 to 1,230 mg/L (fig. 18). In inland areas the highest chloride concentration was 119 mg/L.

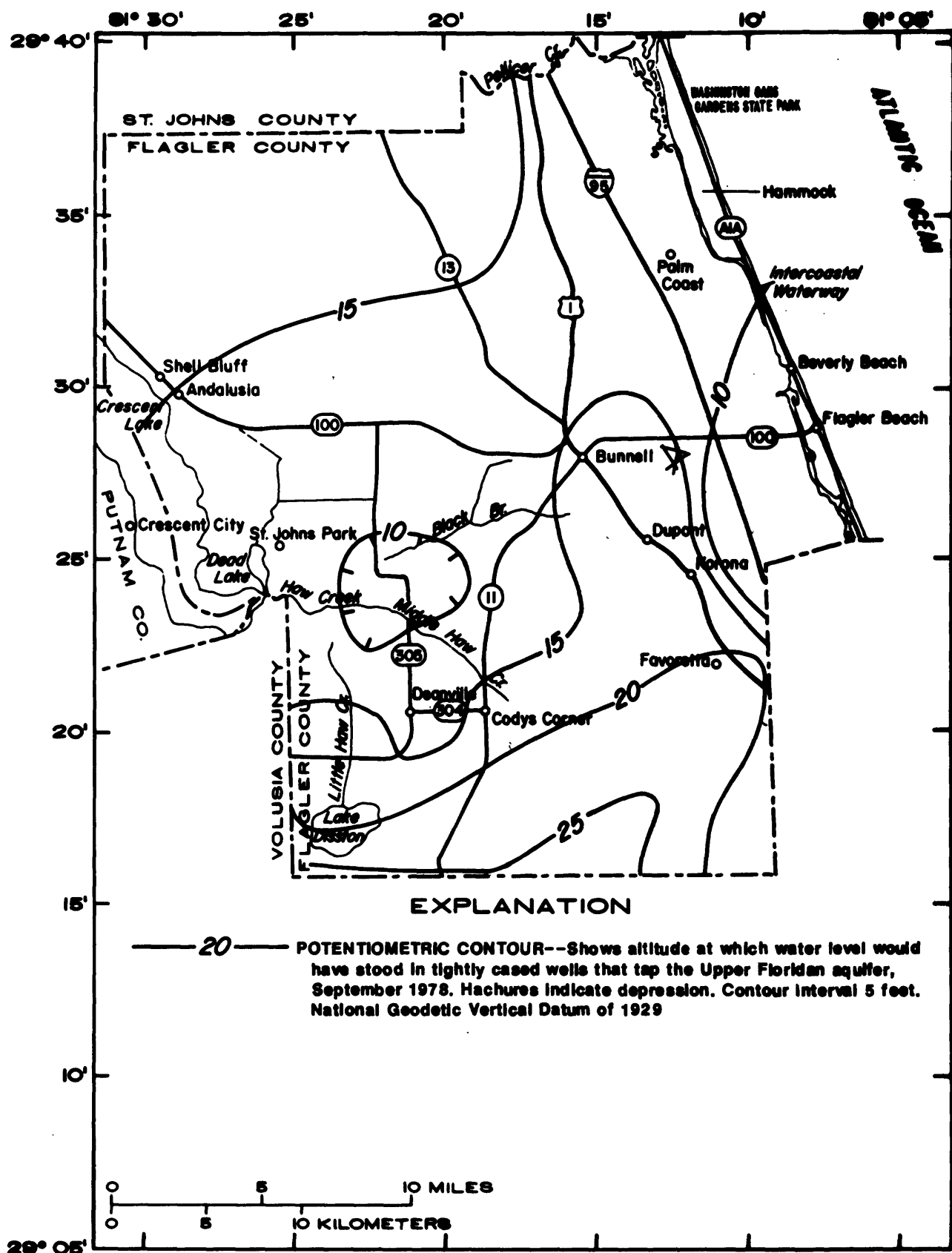


Figure 11.--Potentiometric surface of the Upper Floridan aquifer, September 1978 (from Watkins and others, 1979).

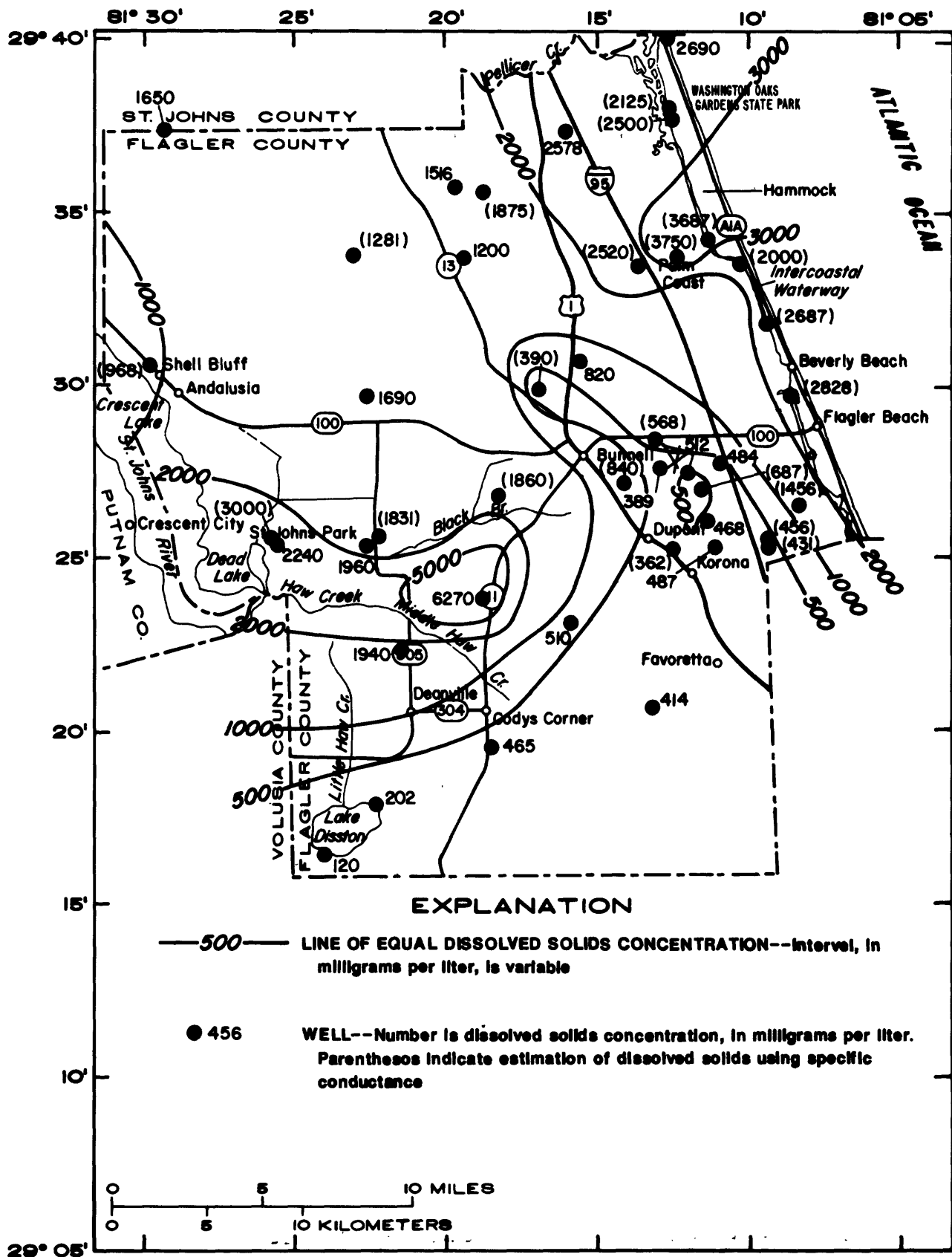


Figure 12.--Dissolved solids concentration of water from wells in the Upper Floridan aquifer.

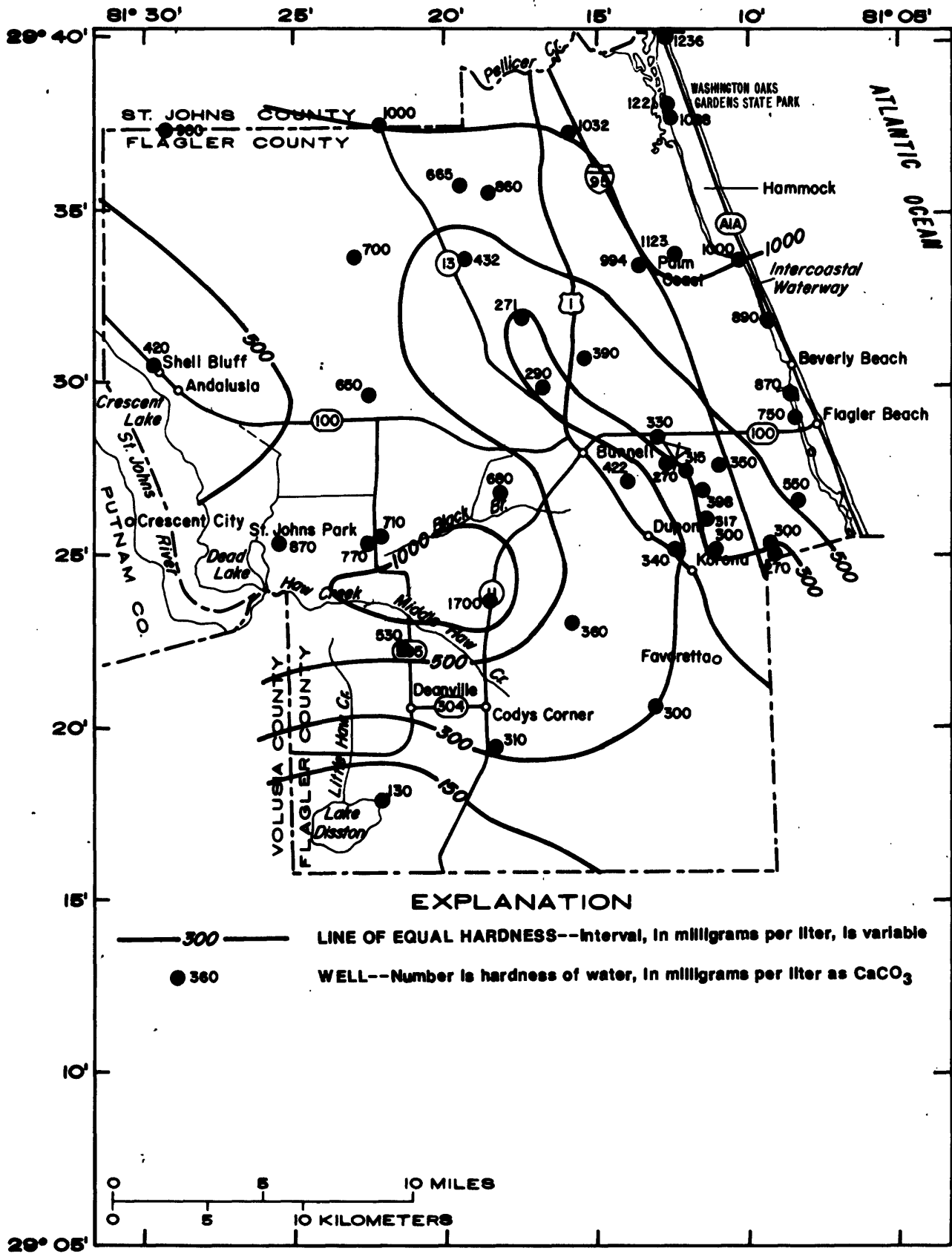


Figure 14.--Hardness of water from wells in the Upper Floridan aquifer.

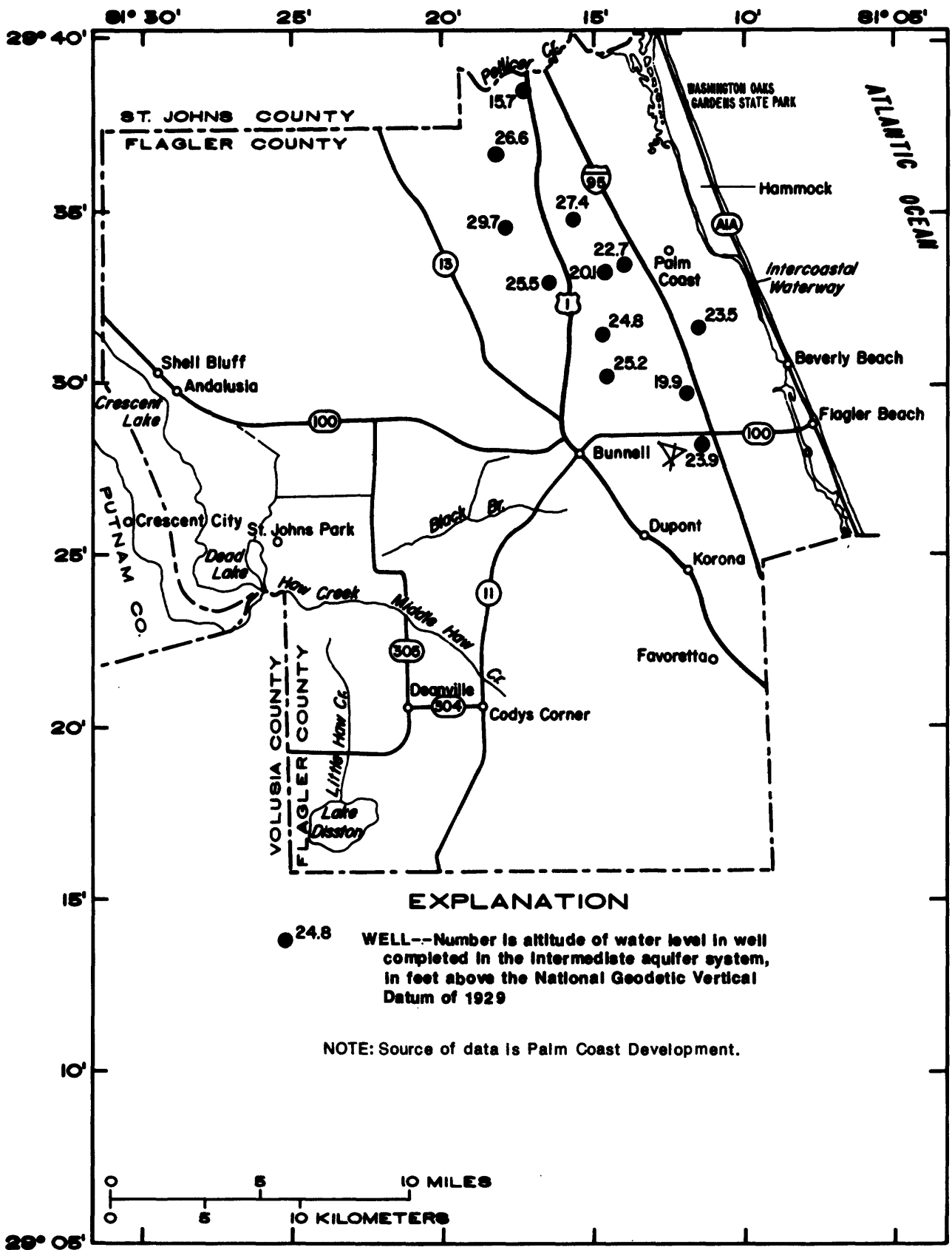


Figure 15.--Water levels in wells of the intermediate aquifer system, May 1979.

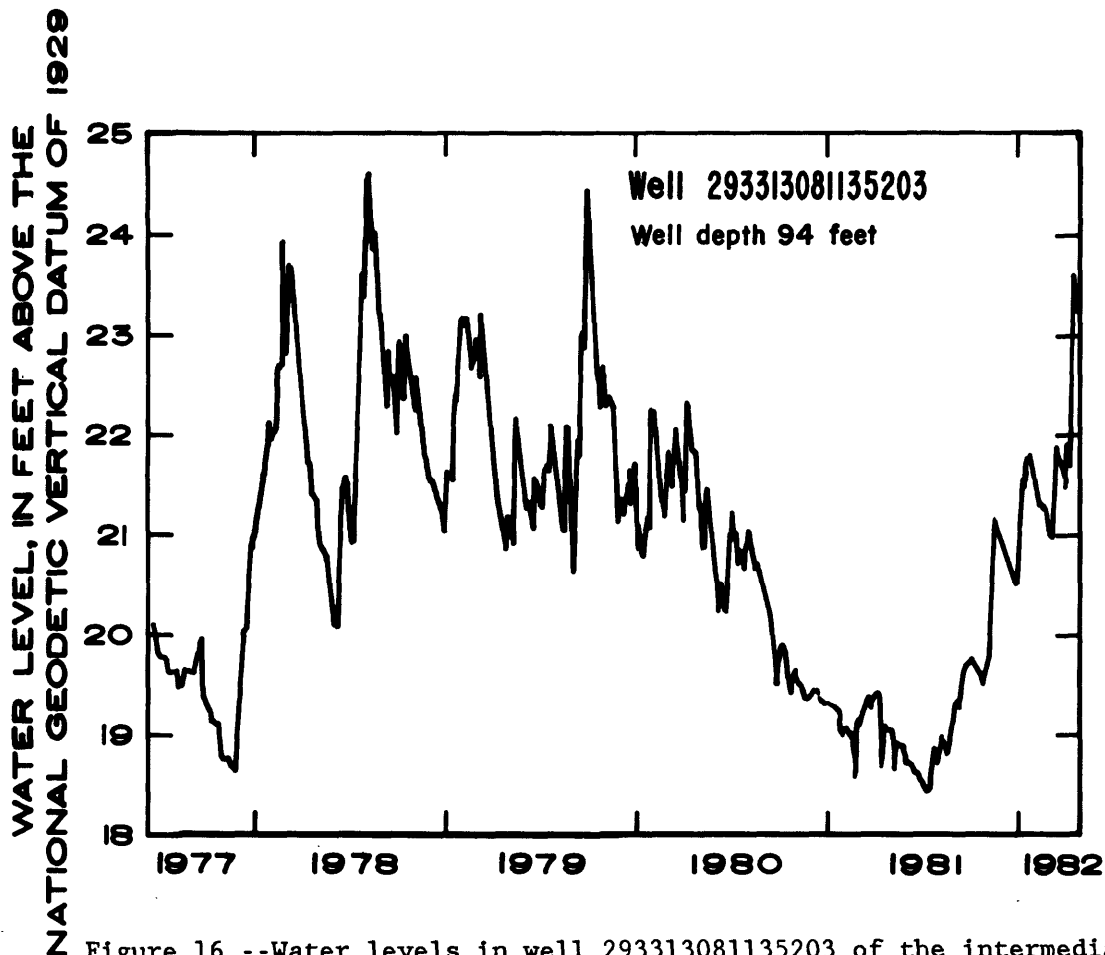


Figure 16.--Water levels in well 293313081135203 of the intermediate aquifer system.

Hardness as CaCO_3 of water from wells in the intermediate aquifer system ranged from 275 to 730 mg/L (fig. 18). In inland areas, the highest hardness was 398 mg/L. The sulfate concentration ranged from 0 to 170 mg/L. In inland areas, the highest sulfate was 5 mg/L. The iron concentration ranged from 0 to 4,000 $\mu\text{g/L}$ (micrograms per liter). The chemical constituent data in figures 17 and 18 are not contoured because the aquifer system is laterally discontinuous. The quality of the water in the intermediate aquifer system is mostly uniform, except for the coastal areas. It is not as areally variable as the water quality of the Upper Floridan aquifer.

Surficial Aquifer System

Water levels.--The water table in the surficial aquifer system is generally directly related to the altitude and configuration of the land surface. Water levels beneath the high sandy ridges on the mainland may range from 6 to 10 feet below land surface. Levels are at or near land surface in many of the extensive, flat terraces of mainland Flagler County.

Water quality.--Dissolved solids concentrations of water from wells in the surficial aquifer system ranged from 109 to 4,380 mg/L (fig. 19). Water with high dissolved solids also occurs in and near the area of low yield in the west-central part of the county. Chloride concentrations ranged from 17 to 2,400 mg/L and hardness as CaCO_3 ranged from 41 to 1,300 mg/L (soft to very hard water) (fig. 20). Sulfate concentrations ranged from 0.6 to 280 mg/L. High chloride and sulfate concentrations and high hardness are generally coincident with the areas of high dissolved solids. Iron concentrations of samples from inland areas were higher except for one well that is approximately 500 feet from a drainage canal, which may affect the iron concentration.

Ground Water in the Hammock Area

An increase in residential development on the barrier island in north-east Flagler County locally known as Hammock led to a closer investigation of the surficial aquifer system of that area. The island is separated from the mainland by the estuarine Matanzas River and Intracoastal Waterway. This strip of land can supply potable water only from the upper part of the surficial aquifer system. Both the Upper Floridan and intermediate aquifer system contain brackish water.

The low altitude of the area, the proximity of brackish surface waters, and the potential for upward leakage of brackish ground water, prevents large lenses of freshwater from accumulating in the surficial aquifer system. Also, the coquina in the surficial aquifer system is highly permeable, so lateral movement of ground water is relatively rapid precluding a high mounding of the water table in the divide area between ocean and estuary. The high permeability of the coquina allows free interchange of water between the aquifer and surface-water bodies.

Data on water levels and water quality were collected for wells ranging in depth from 15 to 35 feet, all open to the coquina beds that are part of the surficial aquifer system in the Hammock area. Water levels are highest in the interior part of the area, and did not exceed an altitude of about 4 feet above sea level.

The dissolved solids concentrations (fig. 21) of water from wells in the surficial aquifer system range from 194 to 4,060 mg/L. Lowest concentrations generally occur in the central part of the area, and are coincident with the area of highest water levels in the surficial aquifer system. The highest dissolved solids concentrations occur in the west-central part of the Hammock area, where more mineralized water has intruded eastward from the low-lying area adjacent to the Intracoastal Waterway and from the Upper Floridan aquifer. Analyses of water from wells in the Upper Floridan aquifer in the Hammock area indicate similar quality to water in the surficial aquifer system around free-flowing wells in the Upper Floridan aquifer.

The areal distribution of chloride concentrations, total hardness as CaCO_3 (figs. 22 and 23), and sulfate concentrations is similar to that of the dissolved solids concentrations. Lowest concentrations are near the center of the area and farthest from the ocean and Intracoastal Waterway.

Iron concentrations for water samples from the aquifer range from 6 $\mu\text{g/L}$ to 9,100 $\mu\text{g/L}$. There is no apparent pattern to the distribution.

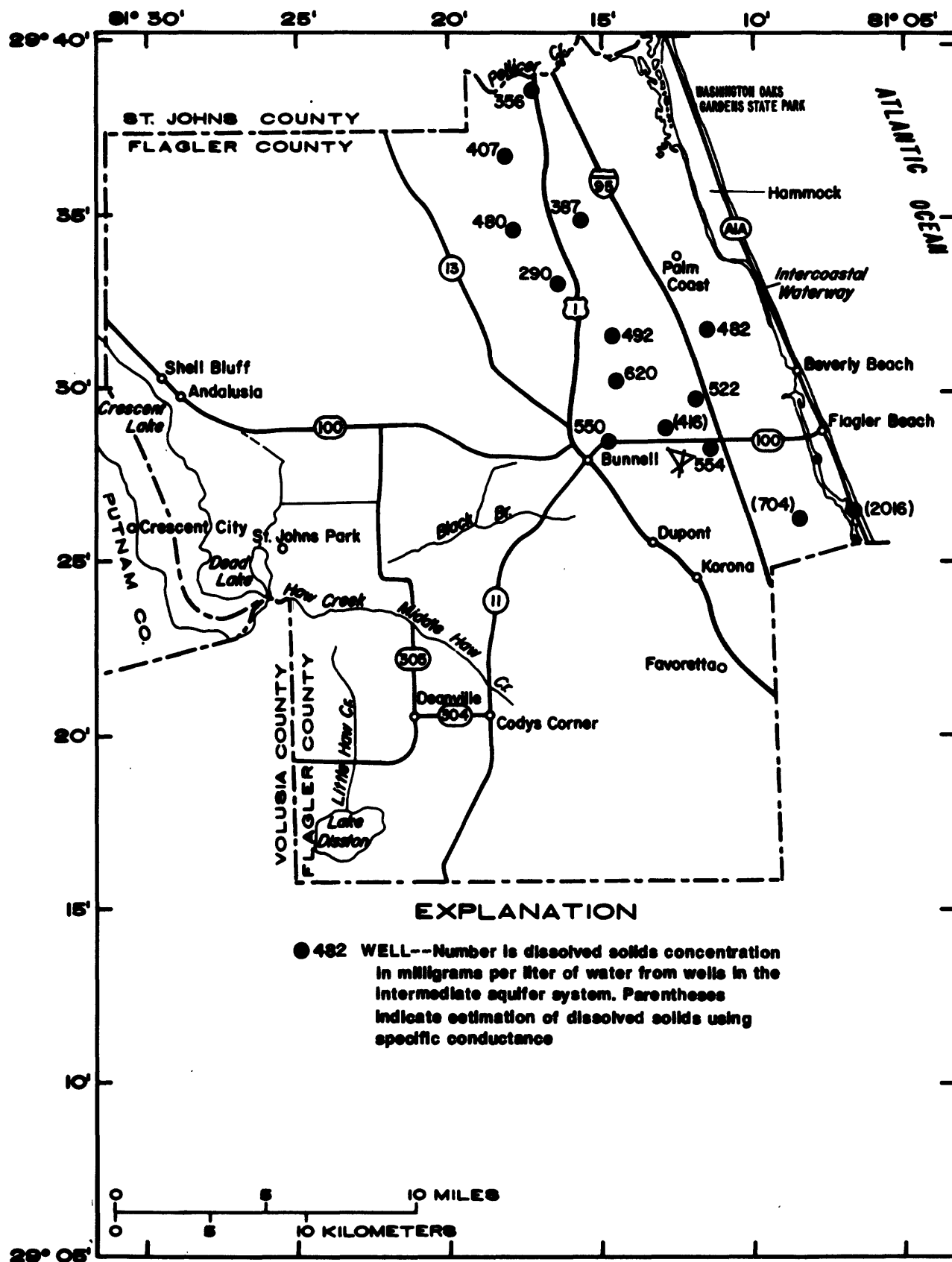


Figure 17.--Dissolved solids concentration of water from wells in the intermediate aquifer system.

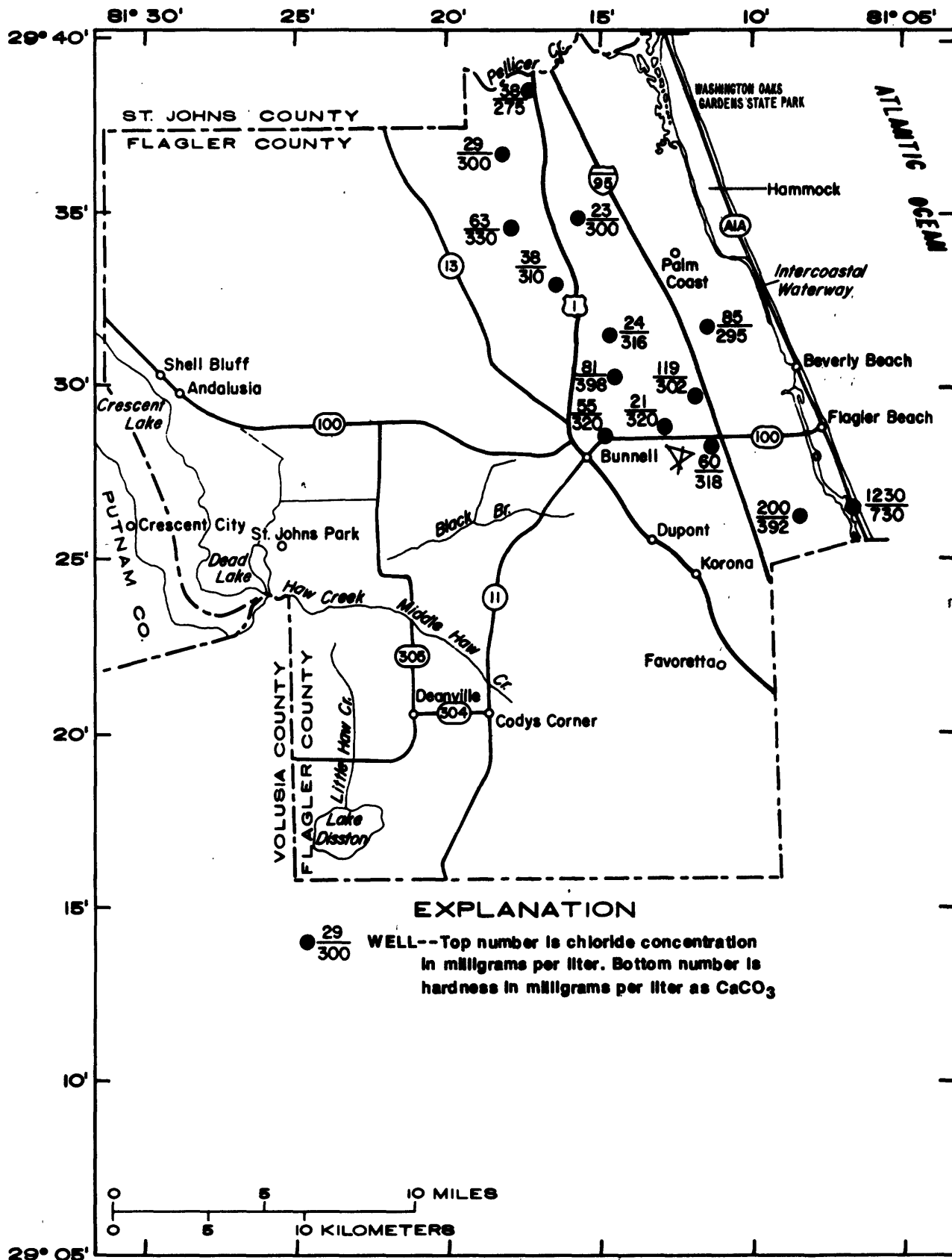


Figure 18.--Chloride concentration and hardness of water from wells in the intermediate aquifer system.

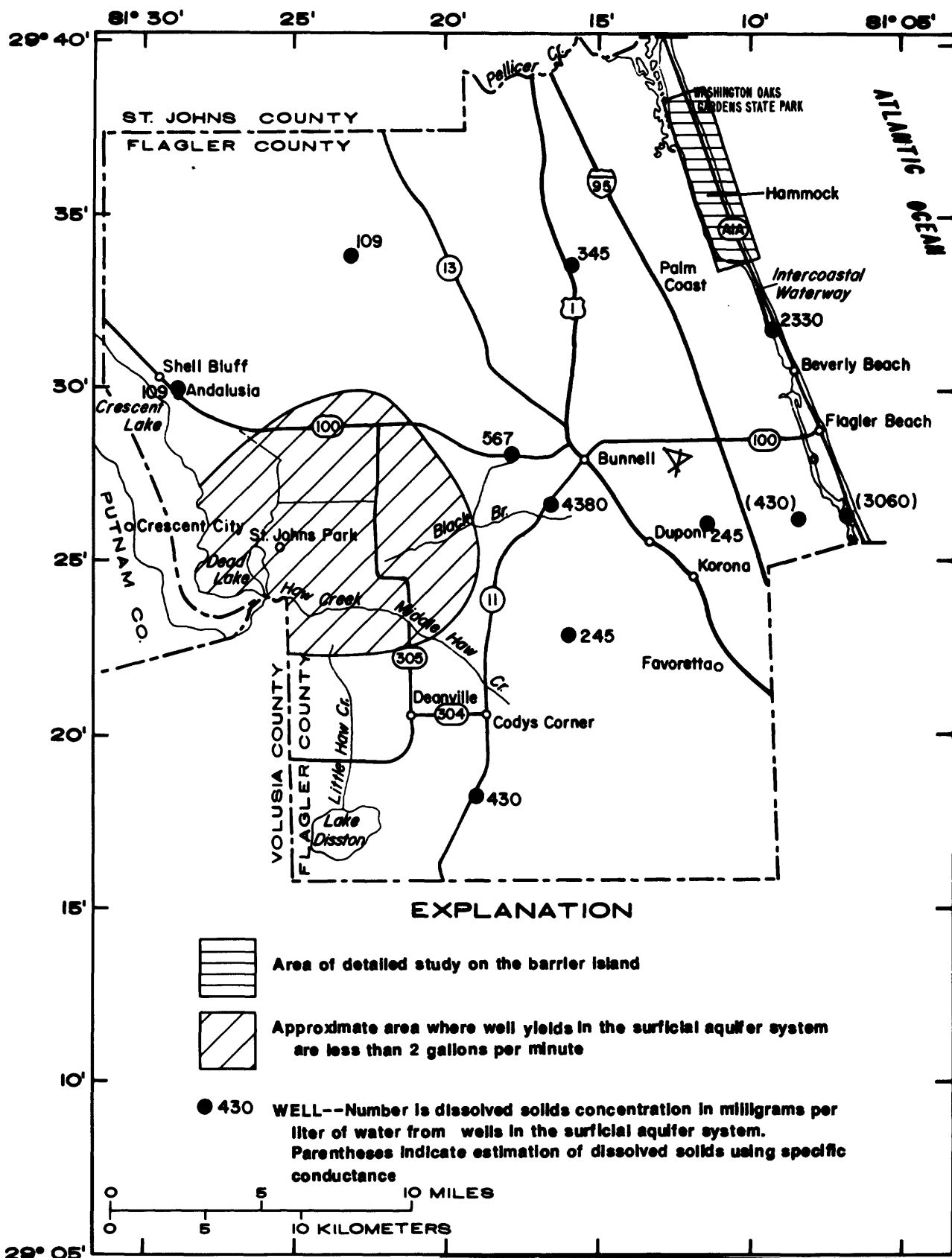


Figure 19.--Dissolved solids concentration of water from wells in the surficial aquifer system.

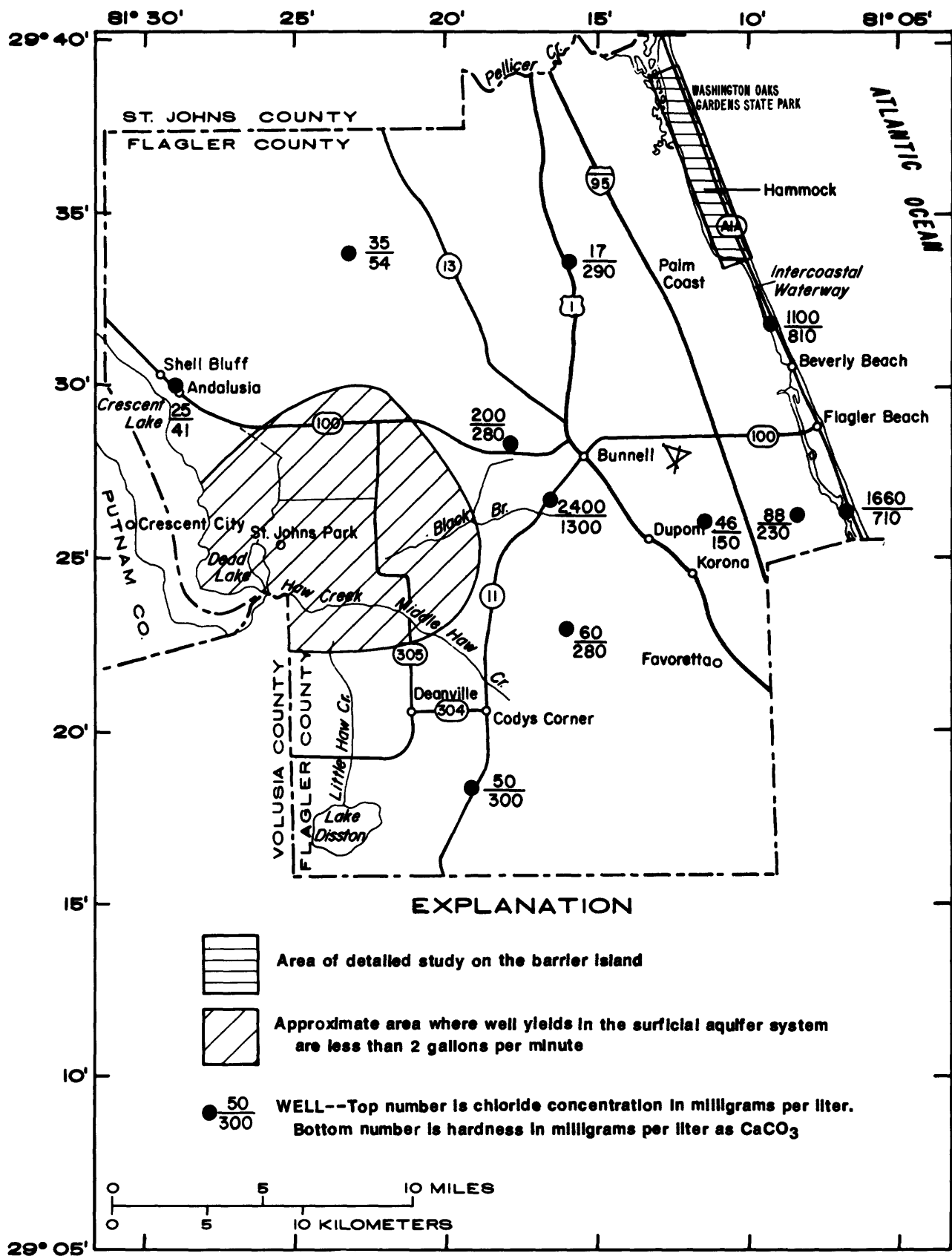


Figure 20.--Chloride concentration and hardness of water from wells in the surficial aquifer system.

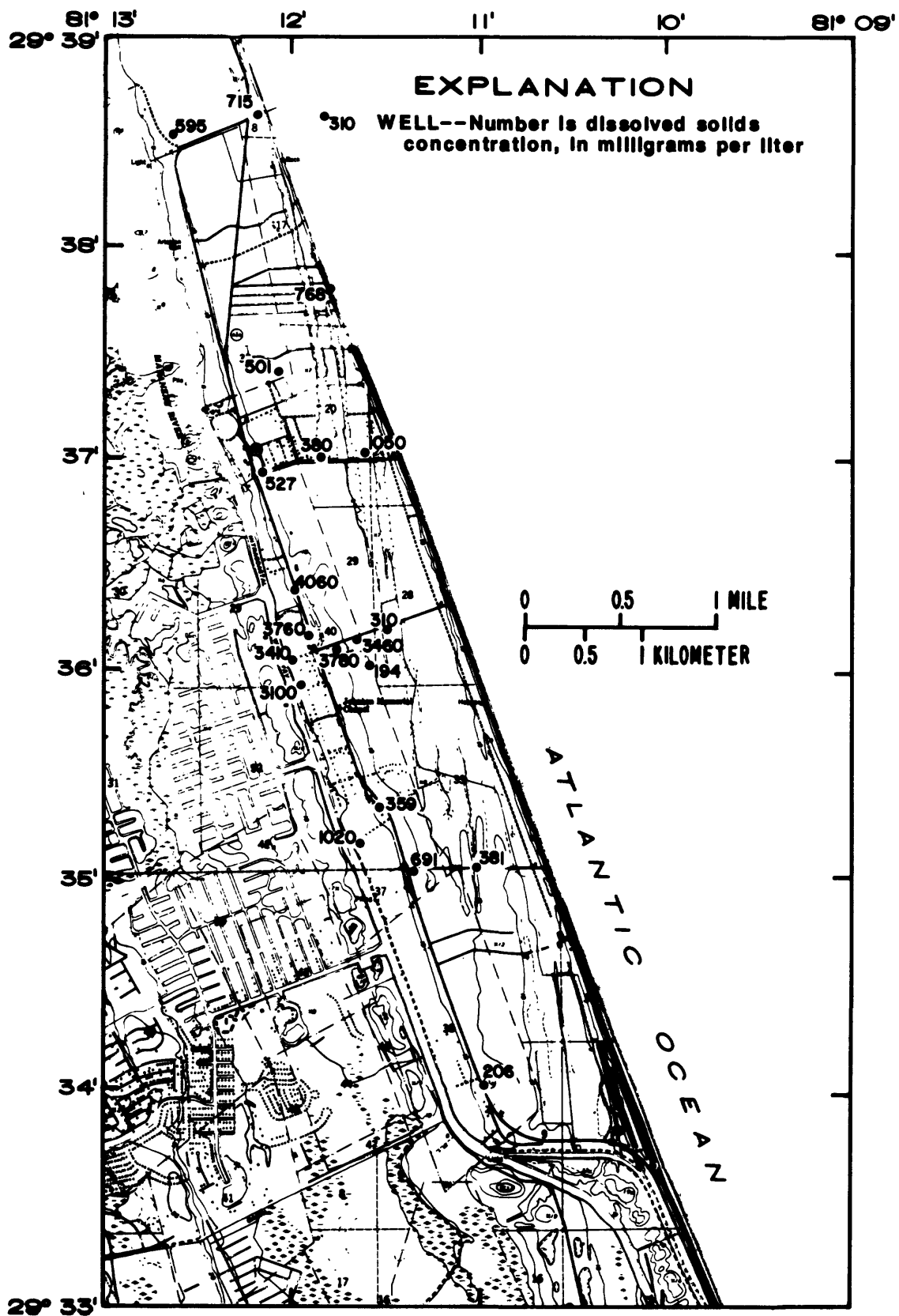


Figure 21.--Dissolved solids concentration of water from wells in the surficial aquifer system in the Hammock area.

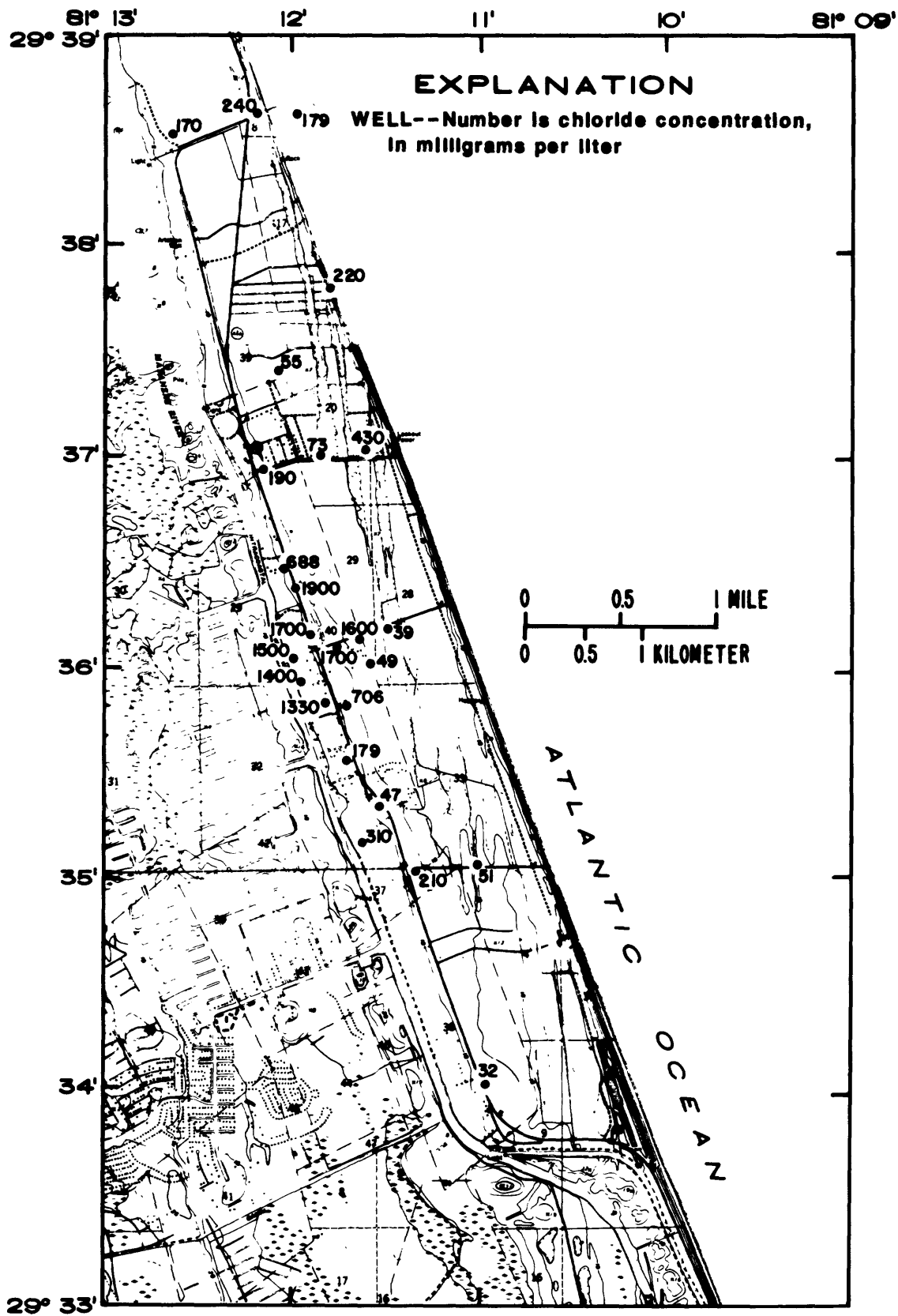


Figure 22.--Chloride concentration of water from wells in the surficial aquifer system in the Hammock area.

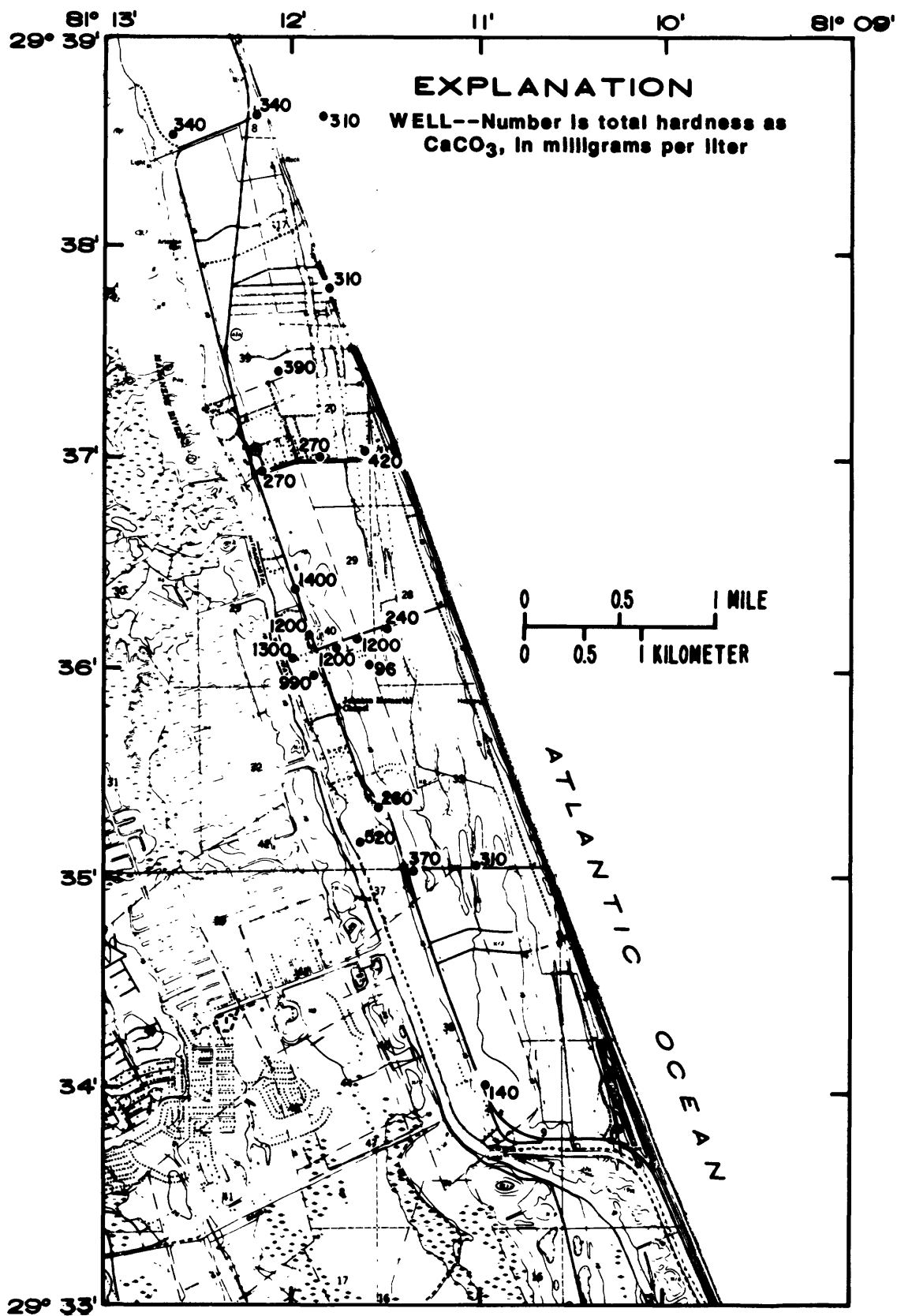


Figure 23.--Hardness of water from wells in the surficial aquifer system in the Hammock area.

The data indicate that quality of water in the surficial aquifer system is variable and depends on proximity to the ocean, estuary, or the free-flowing wells in the Upper Floridan aquifer. The freshest ground water occurs in a north-south trending zone in the center of the area, and farthest from the ocean, estuary, or the free-flowing wells. The use of the upper part of the surficial aquifer system may be limited by its vulnerability to pollution by sources of poor quality water that may be introduced to the canals, abandoned coquina pits, or to the land surface.

EFFECTS OF MAN'S USE ON HYDROLOGY Hydrologic Changes Since the 1950's

The Upper Floridan aquifer water-level and water-quality data collected by Bermes and others (1963a) provide an opportunity to compare and contrast early 1980's hydrogeologic conditions to those of the late 1950's. Long-term records from two observation wells in Flagler County (fig. 9) are available from March 1936 to the present for well 292750081152001 (F-14) located at Bunnell, and January 1956 to the present for well 292820081221001 (F-44) located approximately 7 miles west of Bunnell.

Long-term trends of water-level decline are apparent in each hydrograph in figure 24. The longest record (well F-14) shows that water levels declined from a 1936-50 mean annual water level of approximately 17 feet above sea level to a 1951-82 mean level of slightly less than 14 feet above sea level. The hydrograph of well F-44 shows a decline of approximately 2 feet in mean annual water level from 1956-82.

Another trend shown by the hydrographs is an increase in annual water level fluctuations. For well F-14, the annual fluctuation is approximately 2 feet for the period 1936 to 1960. After 1960, the annual fluctuation increased to 3 to 4 feet. Well F-44 shows marked annual variations of as much as 10 feet during dry years. The change in annual water level fluctuation is probably due to climatic trends or to increased dry-season irrigation. The fluctuations in well F-44, in an agricultural area, are more pronounced than that of well F-14, with extreme low-water levels coincident with the dry season and with crop irrigation. Well F-14 is not in an agricultural area.

Figure 25 shows the changes in potentiometric surface of the county between September 1958 and September 1978. The potentiometric surface of September 1958 was the highest measured by Bermes and others (1963a). The potentiometric surface of September 1978 (Watkins and others, 1979) is among the highest of the past 5 years. Figure 25 indicates the potentiometric surface declined slightly over most of the county except in localized areas along the coast and at Crescent Lake.

Bermes and others (1963a; 1963b) also collected water-quality data for the Upper Floridan aquifer in the late 1950's. No continuous chloride concentration data are available for wells in the county, therefore, a long-term trend could not be projected. Of the data that were available for comparison, changes in chloride concentration were less than 15 percent, except in an area north of Espanola and in an area east of Codys Corners.

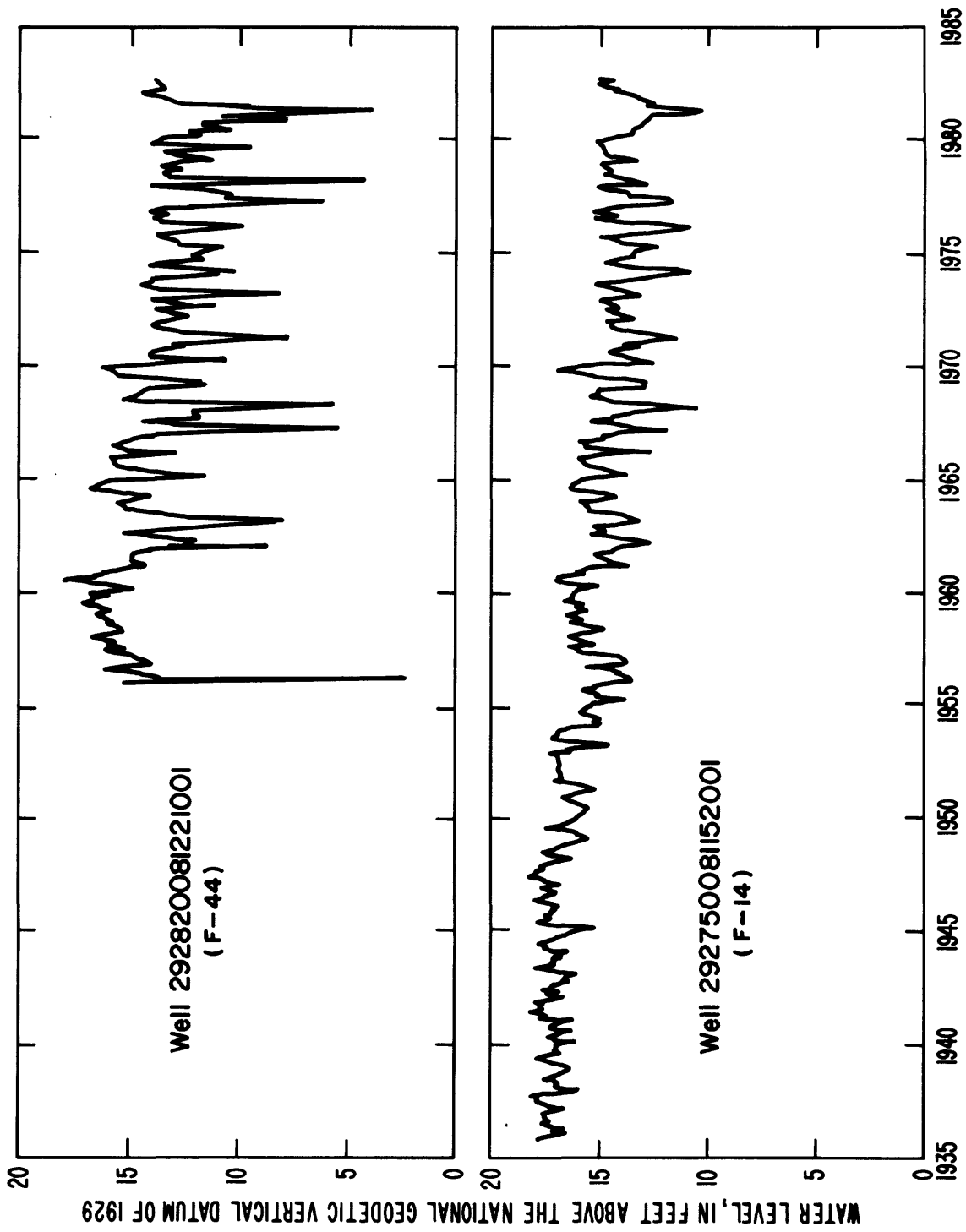


Figure 24.--Hydrographs of well 292750081152001 and 292820081221001.

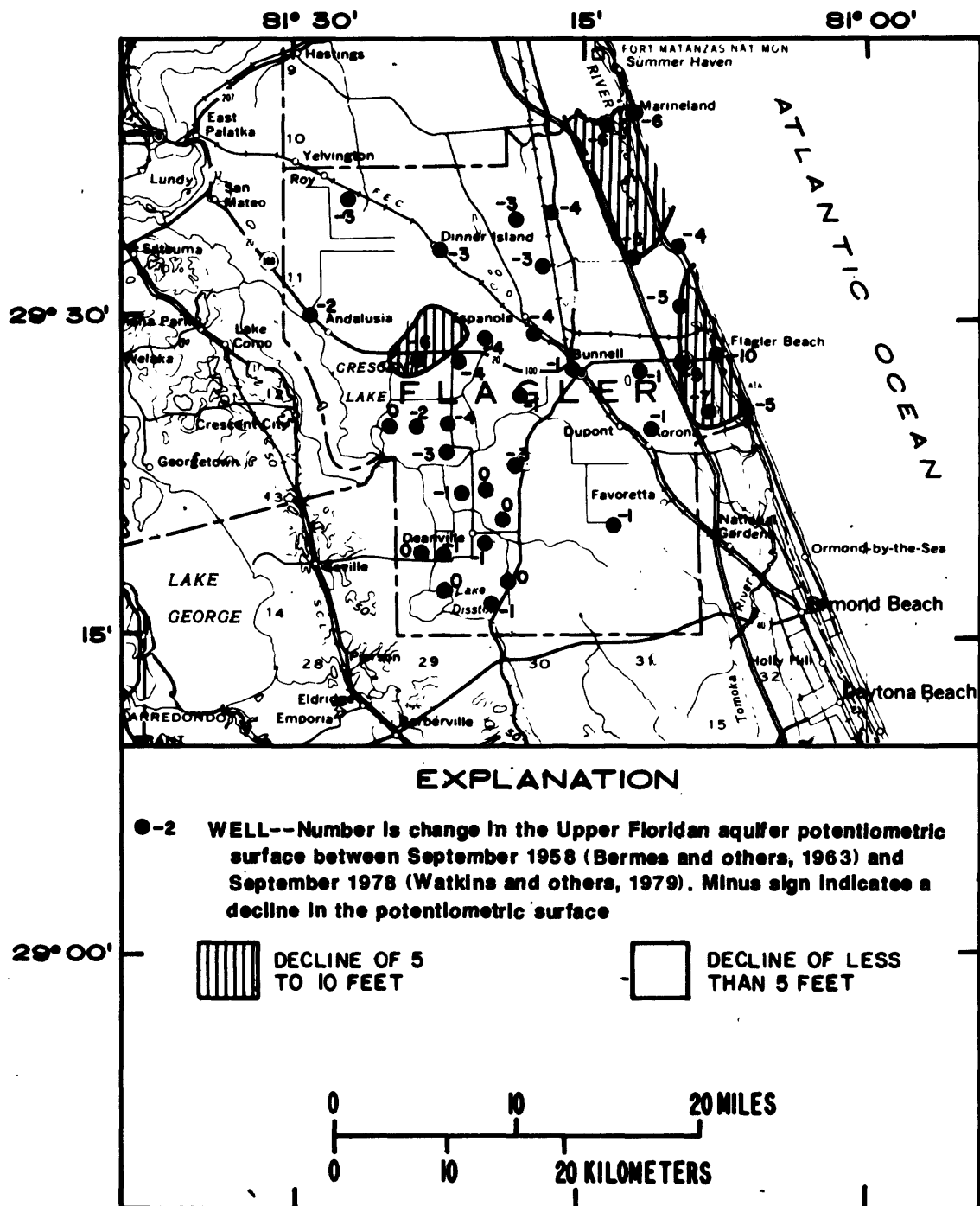


Figure 25.--Change in the potentiometric surface of the Upper Floridan aquifer between September 1958 and September 1978.

The two areas of anomalous change are probably due to differences in interpretation. Examination of Bermes and others (1963b) well records shows that the wells used for control in these areas were very shallow (for Upper Floridan aquifer penetration) and may not have reached the Upper Floridan or could have been open to the intermediate aquifer system also. In the area north of Espanola, considerably higher chloride concentrations and other minerals were detected in water from wells in the Upper Floridan aquifer during the study period. In this area, intermediate aquifer system water quality is approximately the same as Upper Floridan aquifer data reported by Bermes. It was not possible to sample the same wells that were used for the earlier study. It seems likely then that the quality change may be a matter of depth or condition of the wells or well casings. Also, the questioned area has not had enough pumping stress over the past 2 decades to precipitate a water-quality change.

In the area east of Codys Corners, surficial or intermediate aquifer system water quality cannot account for the higher chloride value of Bermes. Because only one value was reported, substantiation is lacking. Although the well is unused at present, pumping stress may have been a factor in the 1950's.

Evidence indicates that a water-quality change in the Upper Floridan aquifer was coincidental with the decline in potentiometric surface since the late 1950s. However, detailed data are scarce and the areas that indicate a larger rise in chloride concentration are also the areas that already contain nonpotable water in the Upper Floridan aquifer.

Effects of Development

Withdrawals.--One effect of pumping of wells in the Upper Floridan aquifer in well fields in the county is a rise in chloride concentrations from water in individual wells. With an increase in rainfall, however, the chloride concentrations tend to decrease. The decrease is probably due to reduced pumpage and increased recharge. These conditions indicate that saline water is locally upconing with pumping, and continuous lateral salt-water intrusion probably is not occurring.

Agricultural withdrawals in the central part of the county are seasonal and depend mainly on the rainfall pattern. Highly mineralized water occurs at all depths of the Upper Floridan aquifer in this area, therefore, the change in water quality due to heavy pumpage will not influence the potability of the water.

Dry-season withdrawals in the agricultural areas have increased seasonal fluctuations in the potentiometric surface of the Upper Floridan aquifer. Long-term rainfall deficiencies during the 1970's has increased the demand for irrigation water and placed more stress on the Upper Floridan aquifer.

Available data do not indicate that transitory increases in mineralization are a problem to any major users of the intermediate or the surficial aquifer systems. Continuous, concentrated pumping of the intermediate aquifer system could possibly raise the chloride concentrations, particularly in coastal areas.

There are not enough data to determine long-term effects on the surficial aquifer system; however, long-term withdrawals in the coastal area and barrier island may cause lateral intrusion of saline water into the surficial aquifer system.

Probable future effects. --Agricultural development will probably not increase significantly in Flagler County, but residential development is projected to continue and accelerate. Water-treatment systems in the county use water from the Upper Floridan aquifer and the intermediate aquifer system. With increased coastal residential development and tourism, the demand for treated water will probably exceed the designed production rates for the public-supply systems in the county. Well-field practices such as wide spacing of wells and alternation of withdrawals are in concert with best management of the resource.

The surficial aquifer system yields low to moderate amounts of water to domestic wells. The aquifer is likely to be stressed because of effects of development in the coastal areas, particularly in the Hammock area. Basic hydrologic principles indicate that development in these areas could seriously affect the quality of the water by: (1) reducing recharge due to increased surface runoff from impervious surfaces, (2) lowering water levels so that lateral saltwater intrusion could occur, and (3) recharging the surficial aquifer system with highly mineralized irrigation water.

MONITORING CONSIDERATIONS

Continued monitoring of ground-water levels and quality should be considered for each of the three aquifer systems in Flagler County. Type and intensity of data collection needed is related to the future distribution and intensity of stress placed on the aquifers, but some general guidelines are listed below.

Data from long-term, high-discharge aquifer tests on the Upper Floridan aquifer would be useful in better quantifying the response of the vertical saltwater interface with upconing in well-field areas, particularly in areas where the confining zone is thin between the discontinuous aquifers of the intermediate aquifer system and the underlying Floridan aquifer system. Continuing data collection on water-level fluctuations and water quality in both stressed and unstressed areas throughout the county would be desirable. In areas of withdrawal from the intermediate aquifer system and Upper Floridan aquifer, maintenance of high water levels and acceptable quality water in the surficial aquifer system would also be desirable.

In the Hammock area the upper part of the surficial aquifer system is the sole local source of potable water for domestic supply. Contamination by brackish water from free-flowing wells in the Upper Floridan aquifer is gradually being reduced by the St. Johns River Water Management District's program of plugging free-flowing wells. Continued monitoring of water levels and quality are desirable for areas of potential development and zones of highly mineralized water.

SUMMARY AND CONCLUSIONS

The population of Flagler County has been stable for at least three decades, but recent developments and future expansions of communities are projected to increase the population by 1990 to more than five times the population in 1970. This population influx is expected to place stresses on the water resources of the County.

Most of Flagler County tends to be poorly drained due to flat topography and a poorly developed stream system. Most of the county is less than 30 feet altitude with altitudes below 5 feet occurring in large areas near the coast.

Rainfall has averaged about 49.67 in/yr over a 41-year period in Flagler County. Most of this water leaves the County as evapotranspiration; the remainder recharges the surficial aquifer system and eventually leaves as streamflow or downward recharge to the lower intermediate and Floridan aquifer systems.

The oldest geologic unit penetrated by water wells in Flagler County is the Avon Park Formation, composed of limestone and dolomite. The Ocala Limestone, which overlies the Avon Park Formation, is a white to tan limestone. The Ocala Limestone is tapped extensively by wells. The Hawthorn Formation is absent in south Flagler County, but overlies the Ocala Limestone where present. The Hawthorn Formation is dolomitic limestone at the base and sandy clay and marl above. Recent surficial deposits overlying the Hawthorn Formation consist of sand, clay, and shell.

Ground water is the only significant source of potable water in Flagler County. The water occurs in the Upper Floridan aquifer, the intermediate aquifer system, and the surficial aquifer system.

The Upper Floridan aquifer in Flagler County consists of the upper part of the Avon Park Limestone and the overlying Ocala Limestone; and where present, the basal dolomitic limestone of the Hawthorn Formation. Its use is limited because it contains marginally potable or brackish quality water in much of Flagler County. Most wells that tap the Upper Floridan in Flagler County are open to the Ocala Limestone and, where present, the Hawthorn dolomitic limestone. Wells in the Upper Floridan aquifer are used for public water supply by several water-treatment systems.

The Upper Floridan aquifer is confined by marls, clays, and dolomites of the Hawthorn Formation, where present, and by the clays of the overlying aquifers that occur throughout the county. Relatively thin and discontinuous lenses of sand, shell, and limestone occur within the confining beds and are collectively referred to as the intermediate aquifer system. The intermediate aquifer system is an important source of potable water in east and northeast Flagler where the Upper Floridan aquifer contains marginally potable or nonpotable water. This aquifer system is used for part of the public water supply for several water-treatment systems in the county.

The surficial aquifer system is composed of sand and shell with varying fractions of finer materials. In central and west Flagler, the silts and clays predominate and it is difficult to obtain adequate well yields greater than 5 gal/min. Sand tends to dominate in east-central Flagler, and coquina becomes dominant along part of the coast. The coastal surficial aquifer

system yields small to moderate amounts of water, and is locally an important source of domestic water supply. The most important function of the surficial aquifer system, however, is to store and transmit recharge water to the underlying intermediate and Floridan aquifer systems in areas where recharge is possible.

Aquifer tests made on wells in the aquifer systems indicate that the Upper Floridan aquifer is the most productive aquifer in the county. The intermediate aquifer system varies in productivity, with the most productive shell zones occurring at depths of 60 to 95 feet below land surface. The surficial aquifer system has very low productivity.

The Upper Floridan aquifer receives little recharge within Flagler County. High-rate recharge areas that contribute most of the recharge to the Flagler County flow system are to the south and southwest on the De Land Ridge. Age dating of ground water by carbon-14 indicates that these areas are receiving more recharge mixing with the older water and reducing the apparent age of the water as well as influencing the water quality. The combination of little recharge to the Floridan within Flagler County (0-1 in/yr) and limited outside recharge are reflected in the generally poor quality water (greater than 1,000 mg/L dissolved solids concentration) from the Upper Floridan aquifer in most of the county. The best quality water (less than 500 mg/L dissolved solids concentration) from the Upper Floridan aquifer occurs in south Flagler County where the recharge enters from the De Land Ridge.

The intermediate aquifer system is recharged from either the underlying Upper Floridan aquifer or the overlying surficial aquifer system, depending on respective head relations. The most permeable zones of the intermediate aquifer system are in the east one-half of the county, and most recharge in this area is by downward movement of freshwater from the surficial aquifer system. Age dating of water in the intermediate aquifer system indicates much younger water than the Upper Floridan aquifer, a result of more recharge from the overlying surficial deposits. In general, quality of water from the intermediate aquifer system tends to be fresh and quite uniform throughout Flagler County. Less than 700 mg/L dissolved solids concentration occur in water from most wells in the intermediate aquifer system except for near-coastal areas where brackish water has migrated upward from the Upper Floridan aquifer or westward from the ocean.

The surficial aquifer system is recharged primarily by infiltration of rainfall and surface water and also by upward movement of water in Upper Floridan aquifer discharge areas. In general, the surficial aquifer system contains freshwater throughout the county except in near-coastal areas. It is the only local source of potable water for domestic supply in the narrow strip of coastal land known as the Hammock area. Here a zone of freshwater (less than 500 mg/L dissolved solids) is maintained in the upper part of the surficial aquifer system by recharge from local rainfall. This source of potable water is further limited by the potential for migration of brackish surface water from abandoned coquina pits and canals, free-flowing wells in the Upper Floridan aquifer, and the adjacent ocean and estuarine waters.

Changes in hydrologic conditions from the 1950's include a long-term decline in water levels in the Upper Floridan aquifer coincident with lower-than-average rainfall and a greater seasonal fluctuation of water levels.

Chloride concentrations of water in the Upper Floridan aquifer do not appear to have changed significantly over this same period, ranging at present from 7 to 3,700 mg/L.

Development, particularly in coastal areas, will place stress on the aquifers. Increased pumping in the well fields may cause upconing of brackish water. Extensive development in the coastal areas will probably lower the surficial aquifer system water levels and could cause lateral saltwater intrusion.

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