Geology, Hydrology, and Water Quality of the Surficial Aquifer System in Volusia County, Florida

By G.G. Phelps

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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND ABBREVIATIONS

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

Multiply inch-pound unit	By	To obtain metric unit
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Transmissivity	
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)

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

$$°C = 5/9\,(°F - 32)$$
$$°F = (9/5\,°C) + 32$$

Chemical concentrations are given in micrograms per liter (µg/L) and in milligrams per liter (mg/L).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C); formerly termed micromhos per centimeter at 25 degrees Celsius (µmho/cm at 25 °C) in U.S. Geological Survey reports.

Sea level: In this report "sea level" refers to the 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 "Sea Level Datum of 1929."

Altitude, as used in this report, refers to distance above or below sea level.

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ABSTRACT

The surficial aquifer system in Volusia County comprises Miocene to Holocene age sediments that overlie the Floridan aquifer system. The sediments consist of sand, sandy clay, shell, and calcareous silty clay, that together range in thickness from about 40 to more than 100 feet. Locally, the surficial aquifer system can be subdivided into upper and lower permeable zones separated by 5 to 10 feet of areally discontinuous clay or silty sand.

Of the recorded 4,500 wells that tap the surficial aquifer system, more than 3,200 are used for irrigation and about 800 are used for domestic supply. Water use from the surficial aquifer system in 1987 totaled about 4.2 million gallons per day. The water level can be 30 feet or more below land surface in ridge areas, but is less than 10 feet below land surface on terraces and in the interridge area near the St. Johns River. In 1986, water levels in the upper permeable zone generally ranged 3 to 6 feet higher at the end of the wet season (fall) than in the dry season (spring). Water levels in wells tapping the lower permeable zone generally fluctuated less than 2 feet, except when influenced by pumping from the underlying Upper Floridan aquifer.

Recharge to and discharge from the surficial aquifer system is strongly influenced by heads in the underlying Upper Floridan aquifer. Important recharge areas are along the De Land Ridge and the western part of the Talbot Terrace; some recharge occurs along the Atlantic Coastal Ridge. The recharge rate in the ridge areas probably ranges from 9 to 18 inches per year, whereas in nonridge areas the rate is about 0 to 8 inches per year.

Reported laboratory hydraulic conductivities for surficial aquifer system core samples ranged from 7.6×10^{-5} to 3.4×10^{-1} feet per day with a median of 1.0×10^{-2} feet per day, and reported field hydraulic conductivities ranged from 3.0×10^{-2} to 12.8 feet per day with a median of 2.9×10^{-1} feet per day. The transmissivity of the lower permeable zone in Oak Hill (southeastern Volusia County), calculated from an aquifer test, is 1,200 feet squared per day, and the corresponding hydraulic conductivity is about 30 feet per day. In the Oak Hill area, pumpage from the lower permeable zone is constrained by the potential for upconing of saltwater, rather than by the hydraulic properties of the aquifer.

Chloride concentrations of water from wells tapping the upper permeable zone ranged from 1.2 to 15,000 milligrams per liter; for the lower permeable zone, the range was from 5.7 to 340 milligrams per liter. In both zones, nutrient concentrations at some sites were higher than would be expected for natural ground water, indicating some effect from infiltrating surface water or human activity.

INTRODUCTION

Volusia County covers an area of about 1,200 mi^2 (square miles) in east-central Florida (fig. 1). Rapid population growth in the county has been spurred by increased tourism along the Atlantic Coast, by the growth of Orlando to the south (making some areas of south Volusia County a bedroom community of Orlando) and by a strong agricultural industry in the western and northwestern part of the county. The increase in population has also increased the demand for water for public and industrial supply, increased the need for development of areas that were once unpopulated, and increased the need for additional areas for disposal of municipal waste. These activities and demands either directly, or indirectly, affect the water resources of the county.

Previous hydrologic studies in the area focused almost entirely on the Floridan aquifer system, which is the main source of potable water in the county. The surficial aquifer system, which consists of the sediments overlying the Floridan, has not been studied in detail. The surficial aquifer system is not a major source of drinking water except in the southeastern part of the county. Its most important hydrologic function is to store and transmit water to and from the underlying Floridan aquifer system.

Information about the surficial aquifer system is needed to help county planners and environmental managers make informed decisions when evaluating plans for future development. To that end, the U.S. Geological Survey, in cooperation with Volusia County, conducted this study during 1985 through 1988 to provide geologic and hydrologic information on the surficial aquifer system.

Purpose and Scope

This report presents and interprets all the data collected during the hydrologic study of the surficial aquifer system of Volusia County in 1985-88. Because the study was of a reconnaissance nature and covered the entire county, the resulting interpretations are somewhat generalized. More detailed site-specific investigations may

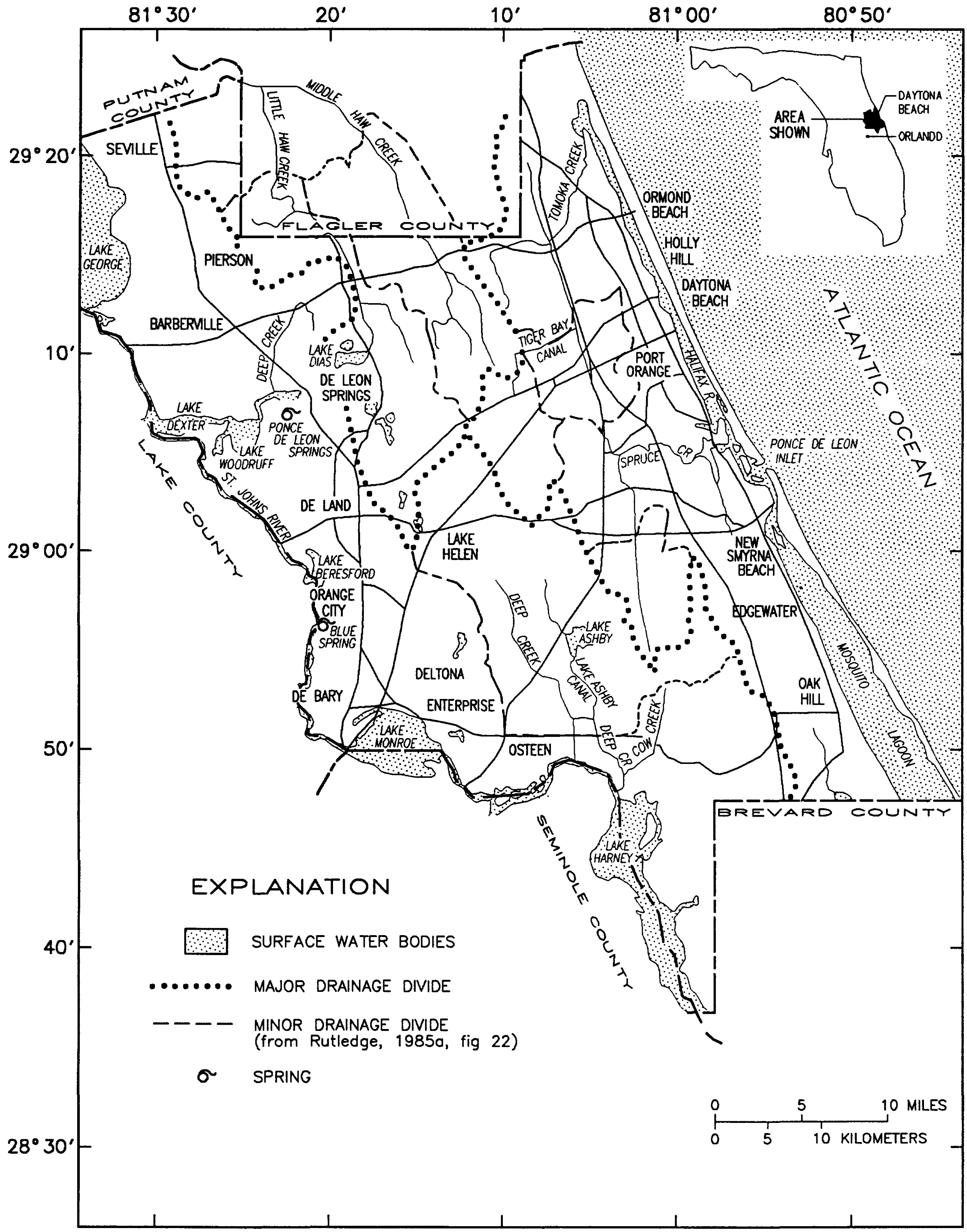


Figure 1. Location of major political and drainage features of Volusia County.

be needed to evaluate local geohydrologic conditions and effects of development. This report is the first to define "background" conditions in the surficial aquifer system, and thus, may be useful for determining the types of data to be collected in future investigations.

This report includes the following types and formats of data and information:

1. Describes the lithology and thickness of the surficial aquifer system in Volusia County by using geologic sections, geophysical logs, and test drilling results;
2. Shows water levels in the surficial aquifer system using maps, hydrographs, and tabular data;
3. Describes the hydraulic characteristics of the surficial aquifer system at selected locations in the county as determined by field testing and laboratory analysis of cores;
4. Updates and refines the delineation of important recharge areas in the county based on the water-level information; and
5. Describes the water-quality characteristics of the surficial aquifer system through chemical analyses of water from 52 wells.

Previous Investigations

Early reconnaissances of the ground-water resources of Volusia County were done by Wyrick and Leutze (1956), and Wyrick (1960, 1961). These studies included well inventories, results of test drilling, aquifer testing of the Upper Floridan aquifer, and ground-water sampling for chloride concentration. Knochenmus (1968), and Knochenmus and Beard (1971) studied both the ground-water and surface-water features of Volusia County, and their reports include major-ion analyses of water from two wells that tap the surficial aquifer system. Bush (1978) made computer simulations of ground-water flow in the Upper Floridan aquifer in part of central Volusia County, and Simonds and others (1980) used areal photographs, together with field observations, to correlate fluctuations of the water table in the area with vegetation type. Rutledge (1985b) analyzed a long-term aquifer test done in central Volusia County. Other work by Rutledge (1982, 1985a) includes a detailed study of the hydrology of the northwestern part of the county and a countywide study emphasizing the occurrence of brackish water. Because the Floridan aquifer system is the major source of potable water in the county, it received the most emphasis in both of the investigations by Rutledge.

Well Records and Well-Numbering System

Records of wells in Volusia County are maintained by several government agencies. The U.S. Geological Survey and the St. Johns River Water Management District have computerized data bases and paper files on well records that contain geologic, hydrologic, water-level, geophysical-log, water-quality, and water-use data. The U.S. Geological Survey assigns a unique 15-digit site identification number to each well inventoried. The first 13 digits of the number denote the latitude and longitude of the well, and the last two digits denote a sequential number for wells located in the same 1-second latitude by 1-second longitude block. For example, well 291007081101613 is the 13 well inventoried at latitude 29°10'07" N. and longitude 81°10'16" W. In some instances, the site identification number may not be identical to the actual latitude and longitude location of the well.

The Florida Geological Survey keeps records of geologic data for wells throughout the State including more than 400 wells in Volusia County. Some well records are for the surficial aquifer system, but most are for the Floridan aquifer system.

The Volusia County Building Inspection Department maintains a data file called VOLDATA that includes all wells permitted by that department since 1976. That file contains useful information about the rate wells are being drilled, the uses of new wells, and when added to historic data, the total number of wells in the county. In June 1988, the VOLDATA file contained information on 12,314 wells, of which about 4,500 tap the surficial aquifer system. More than 3,200 wells (primarily in the eastern part of the county) are used for irrigation, mostly for lawns and gardens. About 800 wells are used for domestic supply. Most domestic wells that tap the surficial aquifer system are in the southeastern part of the county (Rutledge, 1985a, figs. 7 and 8).

Table 1 contains information from the files of the U.S. Geological Survey on selected wells tapping the surficial aquifer system. Included in this table are the types of data collected during this study and a well number for ease of reference to wells without using the complete U.S. Geological Survey site identification number.

Water Use

Total water use from the surficial aquifer system in 1980 was estimated by Rutledge (1985a, p. 16) to be about 3 Mgal/d (million gallons per day). Updated water-use estimates for 1987 were calculated using data collected by the St. Johns River Water Management District in 1985 (Marella, 1986). Because 16 percent of the domestic wells in the VOLDATA file tap the surficial aquifer system, the total domestic self-supplied water use from Marella (1986, table 2), 5.32 Mgal/d, was multiplied by 0.16 to obtain an estimate of 0.85 Mgal/d for domestic water use from the surficial system. Information in VOLDATA is inconclusive on the percentage of surficial aquifer wells used for air conditioning cooling water, so it was assumed that about 16 percent of the wells (the same percentage as for domestic self-supplied wells) were used for air conditioning. Marella (1986, p. 16) reports a total of 6.23 Mgal/d used for air conditioning in Volusia County, so 16 percent of that number is about 1 Mgal/d.

Table 1. Inventory of selected wells completed in the surficial aquifer system

[Data collected: G, geophysical log; S, water sample analyzed; W, water level measured; and --, no data]

Well No.	Site identification	Local identifier		Depth of well (feet)	Altitude of land surface (feet)	Date well constructed	Data collected
1	284353081015801	84310101		40	13	--	--
2	284359081021201	84410101	Morgan Alderman	50	10	--	--
3	284822080573502	84805702	Maytown Shal	30	28	05-01-86	S,W
4	284822080573503	84805703	Maytown Int.	58	28	05-01-86	W
5	284823081075601	84810703	W F Field Lemon	19	10	01-01-52	--
6	284825081000901	84805901	Game Refuge Shal	21	20	--	W
7	284846081114001	84811102	#1 Shal well, SR	30	7	07-26-82	--
8	284846081114002	84811103	#2 Shal well, SR	12	5	07-27-82	S
9	285002080503001	85005002	US 1 Shal	30	10	05-06-86	W
10	285002080503002	85005003	US 1 Int.	58	10	05-06-86	G,W
11	285037080504801	85005001	Putnam Shal	32	15	01-01-81	--
12	285038081013901	85010101	G A Snyder Nr C	85	--	01-01-36	--
13	285114081032801	85110301	Springhill Ct.	46	20	--	S
14	285129080510501	Oak Hill	Town Hall Int.	60	10	02-23-87	G,S,W
15	285129080510502	Oak Hill	Town Hall Shal	30	10	02-23-87	S,W
16	285131081135101	85111306	Well, Garfield	--	22	--	--
17	285138080505001	85105003	Simmons Shal	30	--	--	W
18	285138080505002	85105004	Simmons Int.	57	20	04-30-86	G,W
19	285143080521001	85105203	Loomis Shal	34	5	--	W
20	285143081191001	85111903	US 17-92 Shal	8	25	07-13-82	--
21	285152080520901	85105204	Cummins Shal	27	10	05-05-86	W
22	285152080520902	85105205	Cummins Int.	59	10	05-05-86	G,W
23	285221081095003	85210903	USGS auger hole	63	43	02-16-67	--
24	285221081095004	85210904	USGS auger hole	44	45	02-16-67	W
25	285330080513701	85305103	US1 Shal	24	12	--	--
26	285343081140401	85311404	D Boster Pk Shal	27	73	04-29-86	S,W
27	285343081140402	85311405	D Boster Pk Int.	63	73	--	G,
28	285403080490001	85404901	S of Eldora Shal	--	3	--	S
29	285413080552001	85405506	Volco + Cow Creek	25	17	--	--
30	285437081181402	85411802	SJRWMD Shal	13	82.5	--	S,W
31	285437081181403	85411803	USGS Int. Or. Cty	71	82.5	--	S,W
32	285447080520201	85405201	11 Pine St. Shal	36	12	03-01-81	--
33	285512081202802	85512002	USGS Shal	7	10	--	--
34	285545080493201	85504901	Turtlemound Shal	--	9	--	S
35	285549080493101	85504902	NR Beach Shal	17.3	15	--	W
36	285625080525201	85605206	Tommy Jo Shal	32	22	05-07-86	S,W
37	285625080525202	85605207	Tommy Jo Int.	69	22	05-07-86	G,S,W
38	285630081174701	85611706	Coleman Sch Shal	38	38	04-28-86	S,W
39	285630081174702	85611707	Coleman Sch Int.	73	38	04-28-86	G,W
40	285634081191301	85611905	USGS auger hole	65	47.5	02-13-67	--

Table 1. Inventory of selected wells completed in the surficial aquifer system—Continued

[Data collected: G, geophysical log; S, water sample analyzed; W, water level measured; and --, no data]

Well No.	Site identification	Local identifier		Depth of well (feet)	Altitude of land surface (feet)	Date well constructed	Data collected
41	285634081191302	85611903	USGS auger hole	56	47.1	02-14-67	--
42	285634081191303	85611904	USGS auger hole	35	48.4	02-14-67	--
43	285643081122602	85611202	USGS Test well	37	36.4	01-01-65	S,W
44	285655081165602	85611602	USGS Test well	32	19.8	01-01-65	W
45	285704080502801	85705004	Cedar Cr. Resort	29	5	12-01-80	--
46	285715080504001	85705005	River + Grunion	14	2	05-01-81	--
47	285742080533201	85705301	Denson Dr. Shal	25	20	10-01-80	--
48	285757081174301	85711701	N Thorpe Shal	38	68	04-28-86	W
49	285825080535601	85805301	Hill St. Shal W	29	22	09-01-80	--
50	285834081044301	85810401	Rasley + SR 415	15	47	--	S
51	285843081125102	85811202	USGS auger hole	37	50.4	02-24-67	--
52	285857081135701	85811304	Norris Shal	40	69	04-23-86	S,W
53	285901081193801	85911901	USGS auger hole	63	30	02-15-67	--
54	285901081193802	85911902	USGS auger hole	38	30	02-16-67	--
55	285902080551101	85905505	Wildwood Dr. Shal	18	10	02-01-81	--
56	285904081152602	85911502	USGS Test well	22	78.4	01-01-65	--
57	285904081152604	85911505	USGS auger hole	56	78.6	02-10-67	--
58	285904081152605	85911506	USGS auger hole	78	78.7	02-20-67	--
59	285904081164701	85911601	USGS auger hole	99	60.5	02-20-67	--
60	285904081171101	85911704	USGS auger hole	64	33.5	02-14-67	--
61	285904081171102	85911706	USGS auger hole	32	33	02-14-67	--
62	285904081171103	85911705	USGS auger hole	96	33.5	02-23-67	--
63	285916080520301	85905201	4619 Katy Dr. S	20	15	06-01-81	--
64	285940080575601	85905713	1460 Glencoe Shal	25	30	03-01-81	S
65	290006080544101	90005403	116 Shal	39	7	--	--
66	290025081185001	90011801	SW7 GR Shal	36	68	04-23-86	S,W
67	290025081185002	90011802	SW7 GR Int.	64	68	04-23-86	G,S,W
68	290026080580201	90005801	71 P Shal	26	20	02-01-81	--
69	290029081223601	90012205	Old S Shal	7	5	07-09-82	--
70	290056081210801	90012109	RR Track Shal	16	25	07-13-82	S,W
71	290106081132103	90111303	USGS Test well	47	39.3	01-01-65	W
72	290107081062002	90110603	USGS Test well	21	40.3	01-01-65	W
73	290114081121602	90111202	17S31E16 USGS	14	38.6	08-22-67	--
74	290117081183501	90111803	Euclid Ave Sch	37	43	04-24-86	W
75	290132081085401	90110801	USGS Core well	82	40	--	--
76	290132081112601	90111101	17S31E15 131	4.1	37	03-01-77	--
77	290134080554201	90105516	318 N Shal	18	7	07-01-81	--
78	290147080534701	90105302	806 S Shal	26	10	11-01-80	--
79	290155080560301	90105612	Edward St. Shal	16	7	07-01-81	S
80	290159081130002	90111305	USGS Test well	36	37.6	08-15-67	--

Table 1. Inventory of selected wells completed in the surficial aquifer system—Continued

[Data collected: G, geophysical log; S, water sample analyzed; W, water level measured; and --, no data]

Well No.	Site identification	Local identifier		Depth of well (feet)	Altitude of land surface (feet)	Date well constructed	Data collected
81	290159081130003	90111306	USGS Test well	5	39.5	08-15-67	--
82	290215081153601	90211501	Tropical Terr	24	70	01-01-79	--
83	290243081175301	90211703	Marks Sch Shal	41	80	04-24-86	W
84	290243081175302	90211704	Marks Sch Int.	66	80	04-24-86	G,W
85	290253081121302	90211202	USGS Test well	21	39.9	08-16-67	--
86	290310080542101	90305401	1500 Beacon Shal	15	10	06-01-81	S
87	290326081192701	90311901	Teds Sheds	45	90	04-21-86	W
88	290410081105702	90411002	USGS Test well	10	40.7	08-21-67	--
89	290414081105601	90411003	16S31E34 412	--	41.2	03-01-77	--
90	290421081210601	90412102	Grand Av Shal	38	73	04-22-86	W
91	290421081210602	90412103	Grand Av Int.	71	73	04-22-86	G,W
92	290431081162401	90411601	USGS auger hole	26	51.4	02-28-67	--
93	290432081144903	90411404	USGS Test well	47	42.8	01-01-65	--
94	290432081144904	90411405	USGS Test well	7	43	06-13-66	--
95	290447081102305	90411005	USGS I-4 Shal W	20	40	03-24-78	S,W
96	290500081100501	90511001	USGS Test well	17	45.4	08-17-67	--
97	290508081200601	90512006	Tall Oaks Shal	35	100	04-17-86	S,W
98	290508081200602	90512007	Tall Oaks Int.	69	100	04-17-86	G,S,W
99	290510080555001	90505502	Jennifer Circle	21	15	05-01-81	--
100	290512081213602	GLENWOOD	2-inch well	--	71.1	--	--
101	290520080561501	90505604	Ponce De Leon Cir	20	5	07-01-81	--
102	290534081175003	90511703	USGS Test well	11	63	01-01-65	W
103	290548081190301	90511903	Wolf well SR 11	48	93	04-16-86	W
104	290550081022201	90510205	Hickory Lane Shal	30	25	05-01-81	S
105	290554081160801	90511603	Marsh Rd Shal	34	65	--	S,W
106	290554081160802	90511604	Marsh Rd Int.	75	65	04-15-86	G,S,W
107	290621080564301	90605602	102 M Shal	21	10	02-01-81	--
108	290622081221501	90612201	Spring Shal	5.5	5	07-09-82	W
109	290625081000301	90610001	Touchstone Cir	16	12	03-01-81	S
110	290653081200301	90612002	16S30E18 Trailer Ct	48	30	02-27-67	--
111	290655081111203	90611105	USGS Test well	24	40	01-01-65	W
112	290656080583701	90605816	Burgoyne Rd Shal	26	12	10-01-80	--
113	290658081162701	90611601	L Daugharty Shal	18	47	--	W
114	290712081231101	90712302	S De Leon Spr Shal	7	5	07-20-82	--
115	290713081053602	90710502	USGS Test well	20	25	01-01-67	--
116	290713081053603	90710503	USGS Test well	54	25	01-01-67	--
117	290718080595401	90705907	Tarrytown Tr Shal	21	10	04-01-81	--
118	290731080572001	90705705	Oriole Ave Shal	23	20	04-01-81	S
119	290734081014801	90710106	Tracy Dr Shal	27	27	05-01-81	--
120	290752081050401	90710504	USGS Test well	14	25	01-01-67	--

Table 1. Inventory of selected wells completed in the surficial aquifer system—Continued

[Data collected: G, geophysical log; S, water sample analyzed; W, water level measured; and --, no data]

Well No.	Site identification	Local identifier		Depth of well (feet)	Altitude of land surface (feet)	Date well constructed	Data collected
121	290752081050403	90710506	USGS Test well	45	25	01-01-67	--
122	290756081211101	90712107	De Leon Tower Shal	43	53	04-14-86	S,W
123	290756081211102	90712107	De Leon Tower Int.	71	53	04-14-86	G,S,W
124	290758081001701	90710004	Hugh St Shal	21	7	05-01-81	--
125	290830081013301	90810117	Caspter Av Shal	20	30	04-01-81	--
126	290840081084502	90810804	USGS Core hole	24	43	01-01-67	--
127	290840081084503	90810805	USGS auger hole	48	43	01-01-67	--
128	290843081103301	90811002	16S30E02 Tiger	--	37.7	03-01-77	--
129	290924081000201	90910607	US 92 USGS 1.25"	18	27	--	S,W
130	290924081000201	90910008	Brook cir Shal	22	10	05-01-81	--
131	290947081232901	90912306	US 17 Shal	35	9	--	S,W
132	290947081232902	90912307	US 17 Int.	84	9	--	G,S,W
133	291001081094201	91010902	15S31E26 Indian	10.6	44.8	03-01-77	--
134	291002081113501	91011104	15S31E27 413	--	38.6	03-01-77	--
135	291004081101406	91011006	Tiger Bay test	57	40.8	04-01-75	--
136	291004081101407	91011007	Tiger Bay test	40	41.2	04-01-75	W
137	291004081111303	91011103	Mile W. Shal	20	38	02-01-78	W
138	291005081101308	91011008	Tiger Bay test	60	40.7	04-01-75	--
139	291005081101309	91011009	Tiger Bay test	40	40.5	04-01-75	W
140	291006081101010	91011010	Tiger Bay test	59	40.4	04-01-75	W
141	291006081101011	91011011	Tiger Bay test	37	40.4	04-01-75	--
142	291007081002301	91010007	Elizabeth Pl Shal	21	10	06-01-81	--
143	291007081101613	91011013	Tiger Bay test 20	41.2	02-03-78	W	
144	291009081305402	91013003	Volusia Town Shal	--	20	01-01-79	S,W
145	291010081102212	91011012	Tiger Bay test 59	41.3	04-01-75	--	
146	291010081102214	91011014	Tiger Bay test	20	41.3	02-01-78	--
147	291022081004901	91010008	Katherine St Shal	18	7	06-01-81	--
148	291023080590201	91005905	Gladys Terr Shal	21	15	05-01-81	--
149	291032081181301	91011804	Lk Dias Shal	37	50	04-15-86	S,W
150	291032081181302	91011805	Lk Dias Int.	74	50	04-15-86	G,S,W
151	291050081144601	91011401	15S30E24 424	8.4	42.6	03-01-77	--
152	291142081122801	91111201	15S31E16 Gopher	--	40.57	03-01-77	--
153	291157081025401	91110236	Lucas Shal	19	28	01-01-51	S
154	291158081025301	91210234	Volusia Ave Shal	18	27	--	--
155	291226081000801	91210002	Old Trail 411 Shal	21	20	03-01-81	--
156	291226081000901	91210004	Old Trail 409 Shal	--	26	--	S
157	291257081001301	91210003	Lenox Shal	20	10	05-01-81	S
158	291258081313702	91213104	Emporia 2" Shal	8	7	01-01-79	W
159	291302081033301	91310304	Berkshire Av Shal	25	40	06-01-81	--
160	291325081003701	91310006	Harvey St Shal	20	20	05-01-81	--

Table 1. Inventory of selected wells completed in the surficial aquifer system—Continued

[Data collected: G, geophysical log; S, water sample analyzed; W, water level measured; and --, no data]

Well No.	Site identification	Local identifier		Depth of well (feet)	Altitude of land surface (feet)	Date well constructed	Data collected
161	291328081025001	91310204	Michael Av Shal	14	10	06-01-81	--
162	291330081150901	91311502	Tomoka Land Co.	93	35	01-01-73	--
163	291343081254602	91312508	R Jones Shal	8	52	01-01-79	W
164	291353081160401	91311601	Union Camp Shal	20	34.1	01-30-78	W
165	291357081274301	91312707	Crosby Shal	30	68	04-03-86	S,W
166	291357081274302	91312708	Crosby Int.	74	68	04-03-86	G,S,W
167	291405081012901	91410111		19	12	06-01-81	--
168	291405081015901	91410111	Daytona Ave + 5th	19	12	06-01-81	--
169	291427081273401	91412730	Ziebarth N Obs	9	77	12-18-79	--
170	291427081273402	91412731	Ziebarth S Shal	24	77	01-10-80	--
171	291427081273403	91412732	Ziebarth Shal Irr	--	77	--	W
172	291433081284103	91412819	J LTaylor Shal W	8.5	51.6	12-01-78	--
173	291433081284104	91412820	SJRWMD 55 Ft Int	--	51.96	04-01-80	--
174	291437081274902	91412729	Pierson Elem Sch	8	75	09-01-78	--
175	291441081254801	91412511	Kalota Shal	37	65	04-10-86	W
176	291441081254802	91412512	Kalota Int.	59	65	04-10-86	G,W
177	291444081031301	91410306	Unabelle St Shal	18	10	05-01-81	--
178	291453081265401	91412616	Johnson W Shal	11	60	12-18-79	W
179	291453081265402	91412617	Johnson E Shal	22	60	01-10-80	--
180	291453081265403	91412618	Johnson Shal Irr	--	60	--	--
181	291457081270902	91412727	14S28E27 USGS	10	65	06-01-78	W
182	291507081031501	91510302	Decator St Shal	31	7	05-01-81	--
183	291508081043501	91510402	Par Av Shal	24	37	05-01-81	--
184	291511081125101	91511201	SR40 Shal	15	32	07-08-82	--
185	291520081290001	91512905	Swifty Shal	42	58	04-07-86	W
186	291520081290002	91512906	Swifty Int.	73	58	04-07-86	G,W
187	291526081014101	91510103	Morningside Shal	21	12	03-01-81	S
188	291530081023201	91510201	Riverside Dr Shal	24	7	05-01-81	--
189	291537081124701	91511202	Cone Rd Shal	--	42	--	S
190	291605081035701	91610308	Pine Trail Shal	14	7	05-01-81	--
191	291626081283602	91612803	Connersville Shal	9	40	02-01-79	--
192	291641081021801	91610202	Hollywood St Shal	20	15	05-01-81	--
193	291718081023201	91710203	Wye St Shal	25	15	05-01-81	--
194	291751081024901	91710204	Oak Dr Shal	18	20	04-01-81	--
195	291806081284301	91812807	Nolan Rd Shal	30	50	04-01-86	G,S,W
196	291806081284302	91812808	Nolan Rd Int.	61	50	04-01-86	S,W
197	291813081053701	91810502	Feed Store	40	20	07-01-53	--
198	291819081025701	91810203	Country Club Dr	26	12	03-01-81	--
199	291820081075901	91810701	Tymber Cr Rd Shal	57	25	--	--
200	291823081035401	91810305	825 Beach St	23	7	06-01-50	--

Table 1. Inventory of selected wells completed in the surficial aquifer system—Continued

[Data collected: G, geophysical log; S, water sample analyzed; W, water level measured; and --, no data]

Well No.	Site identification	Local identifier		Depth of well (feet)	Altitude of land surface (feet)	Date well constructed	Data collected
201	291842081060901	91810604	Nursery Shal	41	25	03-01-81	--
202	291846081031301	91810308	Ormwood Dr Shal	21	25	03-01-81	--
203	291906081033201	91910314	60 River Dr	17	12	12-01-54	--
204	291907081031801	91910315	13 River Dr	19	10	01-01-54	--
205	291910081033001	91910310	47 Brooks Dr	--	12	01-01-52	--
206	291933081294501	91912905	Seville Fire Tower	31	50	03-31-86	W
207	291936081035401	91910305	Palm + J Anderson	16	5	03-01-53	--
208	291951081072601	91910703	NG 11	75	33	--	W
209	291959081074301	92010701	Old Post Office	14	32	01-01-30	--
210	292020081073501	92010703	National Garden	75	30	--	--
211	292020081073502	92010704	National Garden	15	30	--	--
212	292028081080202	92010805	NG 25	49	30	--	W
213	292041081075501	92010701	NG 6	66	28	--	W
214	292056081080201	92010806	NG 5A	65	30	--	S,W
215	292056081080202	92010807	NG 5B	15	30	--	S,W
216	292059081041401	92010403	Morningstar Av	14	10	05-01-81	--
217	292059081055002	92010515	NG 12S	20	3	--	W
218	292105081073101	92110706	National Garden	30	32	--	--
219	292121081041901	92110404	San Jose Dr Shal	18	5	06-01-81	S
220	292129081073701	92110705	National Garden	65	32	--	--
221	292147081044401	92110401	Dug Well on J A	14	10	01-01-23	W
222	292151081073301	92110701	NG 4A	60	33	--	W
223	292151081073302	92110702	NG 4B	23	33	--	--
224	292154081075701	92110703	National Garden	65	28	--	--
225	292216081075401	92210702	Halifax Plantation	58	30	--	--
226	292252081083602	92210802	Halifax Plantation	70	32	--	--
227	292258081065001	92210601	HP 11	18	3	--	W
228	292304081071901	92310707	HP 14	18	5	--	S,W
229	292309081082701	92310802	Halifax Plantation	65	32	--	--
230	292311081075801	92310705	HP 13	51	25	--	W
231	292318081075701	92310706	HP 36	49	20	--	S,W
232	292323081083201	92310803	Halifax Plantation	23	30	--	--
233	292325081080301	92310808	Halifax Plantation	15	24	--	--
234	292346081084001	92310805	Halifax Plantation	23	32	--	--
235	292347081080901	92310807	Halifax Plantation	23	22	--	--
236	292359081084501	92310806	Halifax Plantation	23	32	--	--
237	292409081085001	92410803	Halifax Plantation	23	30	--	--
238	292410081081701	92410806	Halifax Plantation	45	22	--	--
239	292412081083801	92410804	Halifax Plantation	23	32	--	--
240	292421081072302	92410702	Halifax Plantation	13	6	--	--
241	292428081085201	92410805	Halifax Plantation	45	30	--	--

The major use of water from the surficial aquifer system is for lawn irrigation, which was 2 Mgal/d in 1980 (Rutledge, 1985a, p. 16). The rate of use for 1987 was estimated by multiplying the 1980 rate by the percentage increase in other categories of water use in Volusia County between 1980 and 1985. Public supply use increased by 17 percent and domestic self supply increased by 15 percent (Rutledge, 1985a, table 2; Marella, 1986, tables 1 and 2), so a 15 percent increase in lawn irrigation was assumed.

Total use of water, in million gallons per day, from the surficial aquifer system in 1987 was thus estimated to be:

	Mgal/d
Domestic self supplied	0.9
Air conditioning	1.0
Lawn irrigation	2.3
Total	4.2

ENVIRONMENTAL SETTING

Climate

The climate of Volusia County is humid subtropical. The average annual temperature is 70.4 °F at De Land and 70.3 °F at Daytona Beach. Average annual rainfall is 54.57 inches at De Land and 48.46 inches at Daytona Beach. The rainy season occurs from June through September when about half of the total annual precipitation falls. During the summer, convection thunderstorms can produce heavy but localized rainfall, resulting in several inches of precipitation falling in one location but perhaps little or none falling a few miles away.

Climate exerts a significant influence on the patterns of water use in Volusia County. For example, large amounts of water may be pumped from the Floridan aquifer system during the coldest months of winter to protect plants from freezing in the fern growing areas of northwestern Volusia County. The heavy pumping results in a sudden decline of water levels and concern about a potential increase in chloride concentration of the ground water. In the late winter and early spring, a large influx of tourists at the beaches causes a noticeable increase in ground-water use for municipal supply in eastern Volusia County.

Physiography

Two distinct physiographic features predominate in Volusia County--ridges and terraces (fig. 2)--which are relict shoreline features formed when sea level alternately fell and rose in response to the advances and retreats of Pleistocene glaciation within the last 2 million years (MacNeil, 1950). The fluctuating sea level formed a series of shoreline features of ridges (beach dunes), scarps (shorelines), and terraces (the seafloor near shore).

The highest and oldest feature found in Volusia County is the De Land Ridge (figs. 2 and 3). White (1970) believes the ridge was part of the Wicomico Shoreline formed during the Sangamon Interglaciation (which ended about 100,000 years ago) when the sea level was about 100 feet higher than it is at present. The next younger feature is the Talbot Terrace which occurs between altitudes of 25 and 50 feet above sea level. Rima Ridge, which separates the Talbot from the next younger terrace, the Pamlico, is 5 to 10 feet higher than the Talbot Terrace. The Pamlico Terrace ranges in altitude from 8 to 25 feet. In some places, the Atlantic Coastal Ridge, which separates the Pamlico and the youngest terrace, the Silver Bluff, is as much as 30 feet higher than the Pamlico (Knochenmus, 1968). The Atlantic Beach Ridge barrier island is an active feature of the present-day sea level. Because the ridges are relatively high in altitude and are very permeable, they are frequently devoid of surface drainage.

The absence of surface drainage is particularly significant on the De Land Ridge because it has reinforced the development of karst on the ridge. Karst results when limestone is dissolved by water, resulting in an irregular land surface. Features of karst include lack of surface drainage, the presence of sinkholes, springs, round lakes, and, according to White (1970, p. 123-124), a wide variation in the altitude of contemporaneous relict shoreline features such as the Wicomico Shoreline. Surficial karst features are best developed on the De Land Ridge because it is the highest feature in the county and thus has not been repeatedly modified by sea inundations.

GEOLOGIC AND HYDROLOGIC FRAMEWORK

Geologic Units

The geologic units in Volusia County most relevant to this study were originally described by Wyrick (1960). The Oldsmar Formation, of early Eocene age, consists mostly of white limestone with thin beds of dolomite, and, in the lower part, beds of gypsum and anhydrite. In Volusia County, the top of the Oldsmar is about 1,300 feet below sea level and thickness is about 500 feet (Miller, 1986, p. B22 and pls. 4 and 5). Above the Oldsmar lies the Avon Park Formation of middle Eocene age, which ranges in thickness in Volusia County from about 100 to 250 feet (Wyrick, 1960, fig. 12) and is known for its characteristic alternating layers of white, light gray, or light brown limestone and dark brown dolomite. Overlying the Avon Park is the Ocala Limestone of late Eocene age, which is composed of cream-to-white fossiliferous limestone. The surfaces of both the Ocala and the Avon Park are erosional, and because of extensive erosion, the Ocala Limestone is thin (less than 100 feet) in most of Volusia County, and absent on much of the De Land Ridge. These Eocene carbonates dip and thicken to the east.

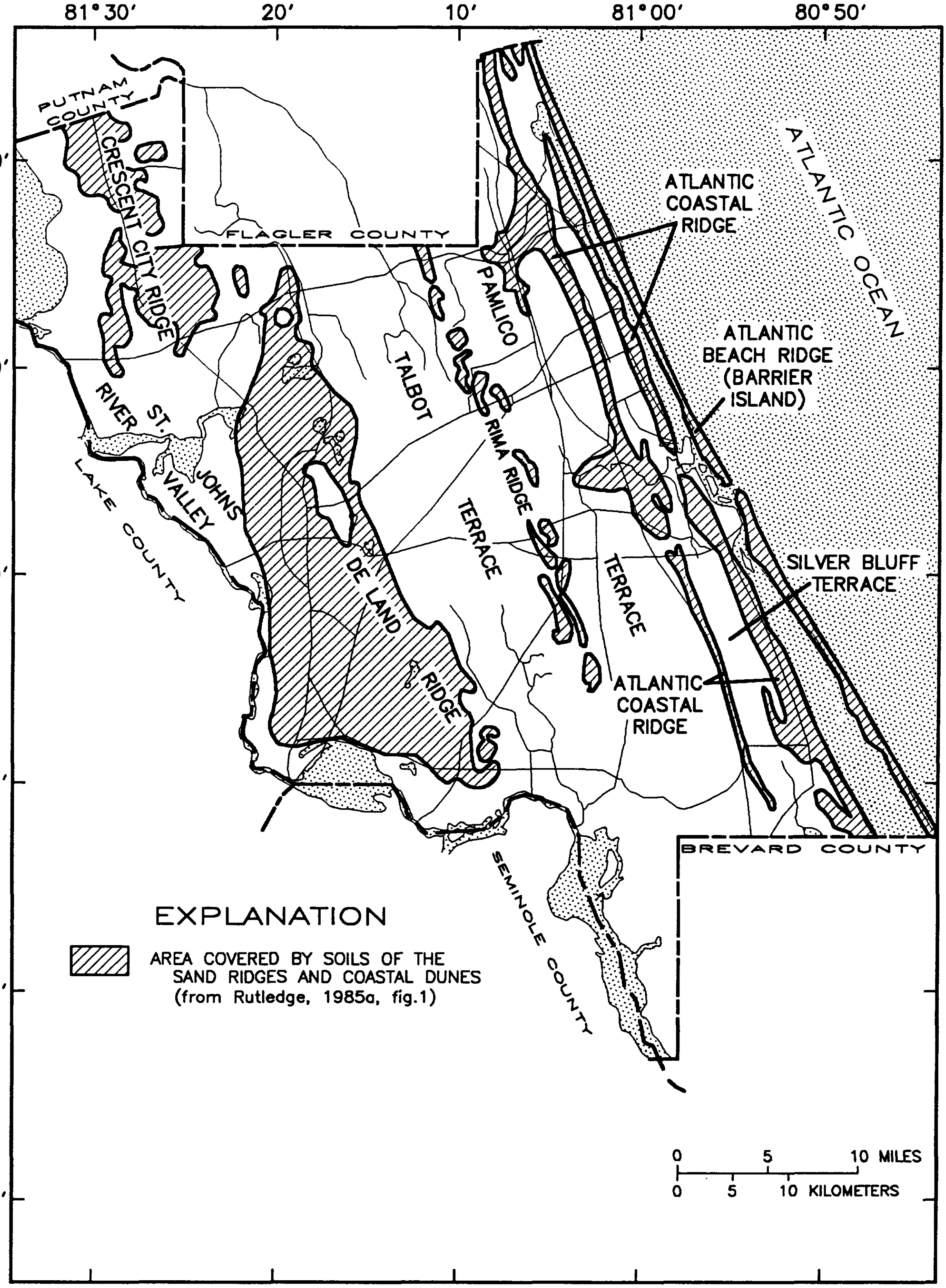


Figure 2. Major physiographic features of Volusia County.

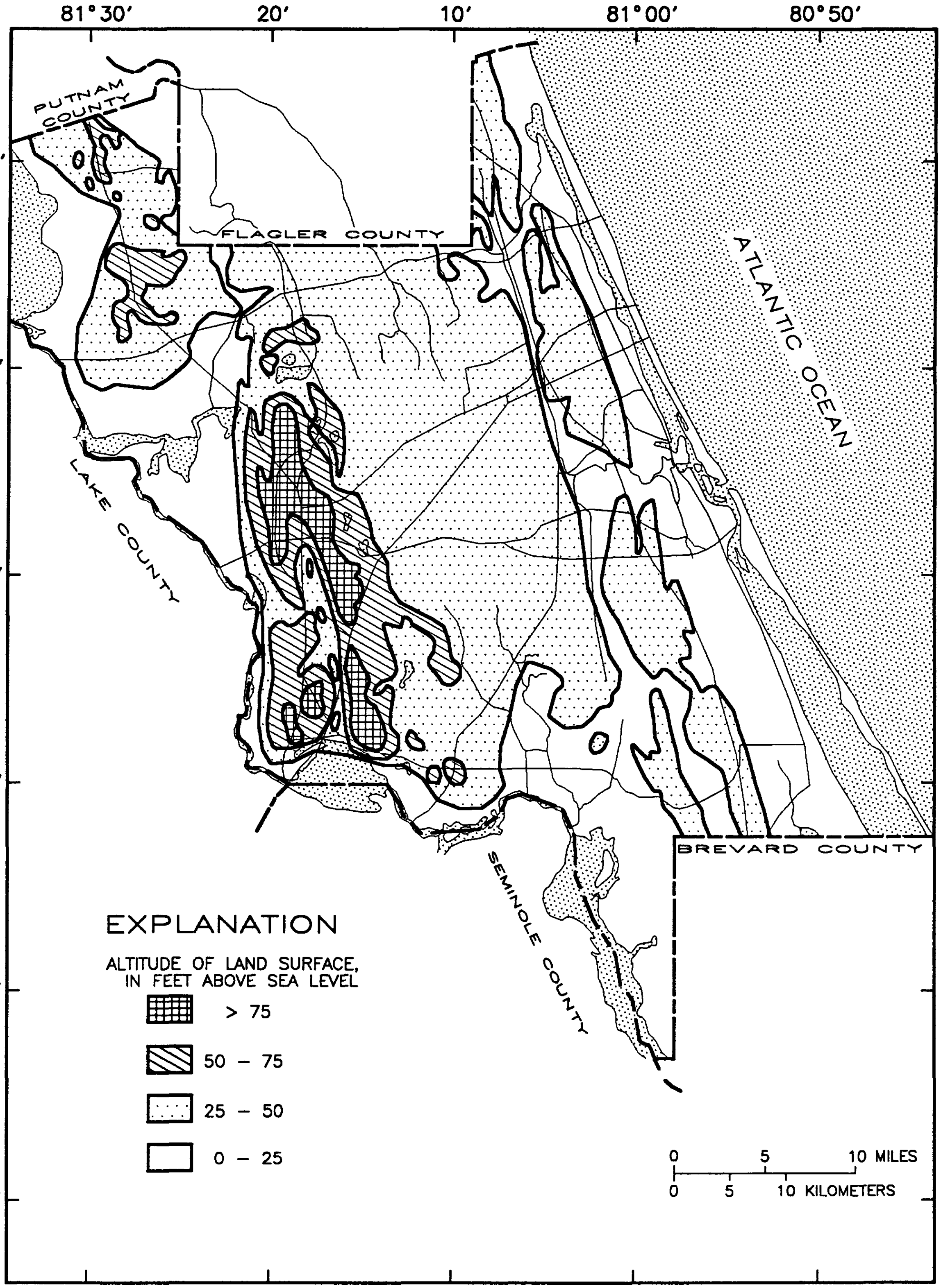


Figure 3. Topography of Volusia County (from Rutledge, 1985a, fig. 3).

Overlying the marine carbonates are the Miocene and Pliocene deposits, consisting of unconsolidated beds of fine- to medium-grained sand, shells, and silty calcareous clay. The Caloosahatchee Formation, thought by Cooke (1945, p. 214) to be Pliocene but more recently assigned to the Pleistocene by Brooks (1981), consists of beds of fine sand, shells, and calcareous silty clay. The middle Miocene-age Hawthorn Formation is absent in much of Volusia County but has been tentatively identified in some wells in the western part of the county, based primarily on the presence of phosphate in well cuttings. However, it is possible that the phosphate results from later reworking of the Hawthorn Formation. The overall thickness of the Miocene or Pliocene deposits in Volusia County is about 20 to 50 feet.

The surficial sediments of Pleistocene to Holocene age consist of fine- to medium-grained quartz sand, sandy clay, and locally, beds of shell. In some areas, the sand has been cemented into "hardpan" by deposition of iron oxide at the water table. The Anastasia Formation, found in the eastern part of the county, consists primarily of coquina, which can vary from cemented and moderately hard to uncemented. This formation also contains varying amounts of quartz sand, silt and organic material (Toth, 1988, p. 46). The Pleistocene-to-Holocene deposits are generally 20 to 50 feet thick but locally can be as much as 100 feet thick.

Hydrologic Units

Three hydrologic units are present in Volusia County. They are (in the order in which they would be penetrated by a well): the surficial aquifer system, the intermediate confining unit, and the Floridan aquifer system. The surficial aquifer system in Volusia County is defined as comprising all of the water-yielding sediments overlying the Floridan aquifer system. These sediments occur at land surface and range in thickness from about 50 to 100 feet. In many areas of the county, the surficial aquifer system can be subdivided into an upper and a lower permeable zone which are separated by 5 to 10 feet of clay, or silty clay and sand. Although this poorly permeable layer was found at many sites, it is not believed to be areally continuous.

Underlying the surficial aquifer system in most of the county is an intermediate confining unit of clay or silty sand of Miocene age. The confining unit is leaky, but serves to confine water in the underlying Floridan aquifer system under artesian pressure (the water level in wells tapping the aquifer is above the top of the aquifer). The confining unit is thicker and more areally continuous in the eastern part of the county than in the west, where in some localities it is absent. In the central and western parts of the county, where the intermediate confining unit is apparently not continuous and mappable, the overlying sediments contain sufficient clay or silt to confine the Upper Floridan in all but a few areas on the De Land Ridge.

The Floridan aquifer system in Volusia County is composed of permeable beds of limestone and dolomite of the Oldsmar Formation and Avon Park Formation and, where present, the Ocala Limestone. The Floridan underlies all of Volusia County (and all of the Florida Peninsula) and is the main source of potable water in the county. In much of central Florida, the Floridan aquifer system can be divided into the Upper Floridan aquifer and the Lower Floridan aquifer, separated by a zone of lower permeability (Miller, 1986, p. B45). The transmissivity of the Upper Floridan aquifer in Volusia County (derived from computer modeling, flow net analyses, and a few aquifer tests) ranges from about 10,000 to 100,000 ft^2/d (feet squared per day) (Tibbals, 1981, fig. 6.). Along the Atlantic coast and along the valley of the St. Johns River, both the Upper Floridan and Lower Floridan aquifers contain salty water and are not used for water supply. In other parts of the county, the Upper Floridan aquifer contains freshwater, but the chloride concentration increases with depth. Most of the freshwater in the Upper Floridan in Volusia County is derived from recharge within the county. The altitude of the top of the Upper Floridan aquifer ranges from about 3 feet above sea level to more than 180 feet below sea level (both in west-central Volusia), and averages about 50 feet below sea level throughout most of the county (fig. 4) (Rutledge, 1985a, fig. 6).

DESCRIPTION OF THE SURFICIAL SEDIMENTS

During this study, 43 wells were drilled into the surficial sediments to provide lithologic, water-level, and water-quality data. At some sites, two wells were drilled, one about 30 feet deep and the other between 60 and 80 feet deep. Each well was given a number in table 1, but for simplicity in figure 5 only one well number of each pair is shown--usually it is the shallow well, but in one case it is the deep well. The locations of these wells, 14 core holes described by Kimrey (1990), and test wells studied by the St. Johns River Water Management District are shown in figure 5.

The thickness of the surficial sediments ranges from about 50 to 100 feet in most of Volusia County (fig. 6). In the extreme eastern part of the county, the thickness of sediments exceeds 100 feet in a few areas, and in the western part of the county, along the De Land Ridge and in the area of Deep Creek (fig. 1), the sediments may be as much as 175 feet thick. The surficial sediments near Orange City (fig. 1) exceed 200 feet in thickness.

Based on the data available, a general description of the surficial aquifer system is as follows: From land surface to about 30 feet in depth, the sediments are primarily sand with some shell and small amounts of silt. These sediments constitute the upper permeable zone of the surficial aquifer system. At most places, 5 to 10 feet of clay or clayey silt underlie the uppermost sand. The clay or silt layer within the surficial aquifer system is probably not continuous over the entire county in the same sense that the Floridan aquifer system is continuous, so no attempt was made to correlate it from one site to another. Below this clay or silt layer is

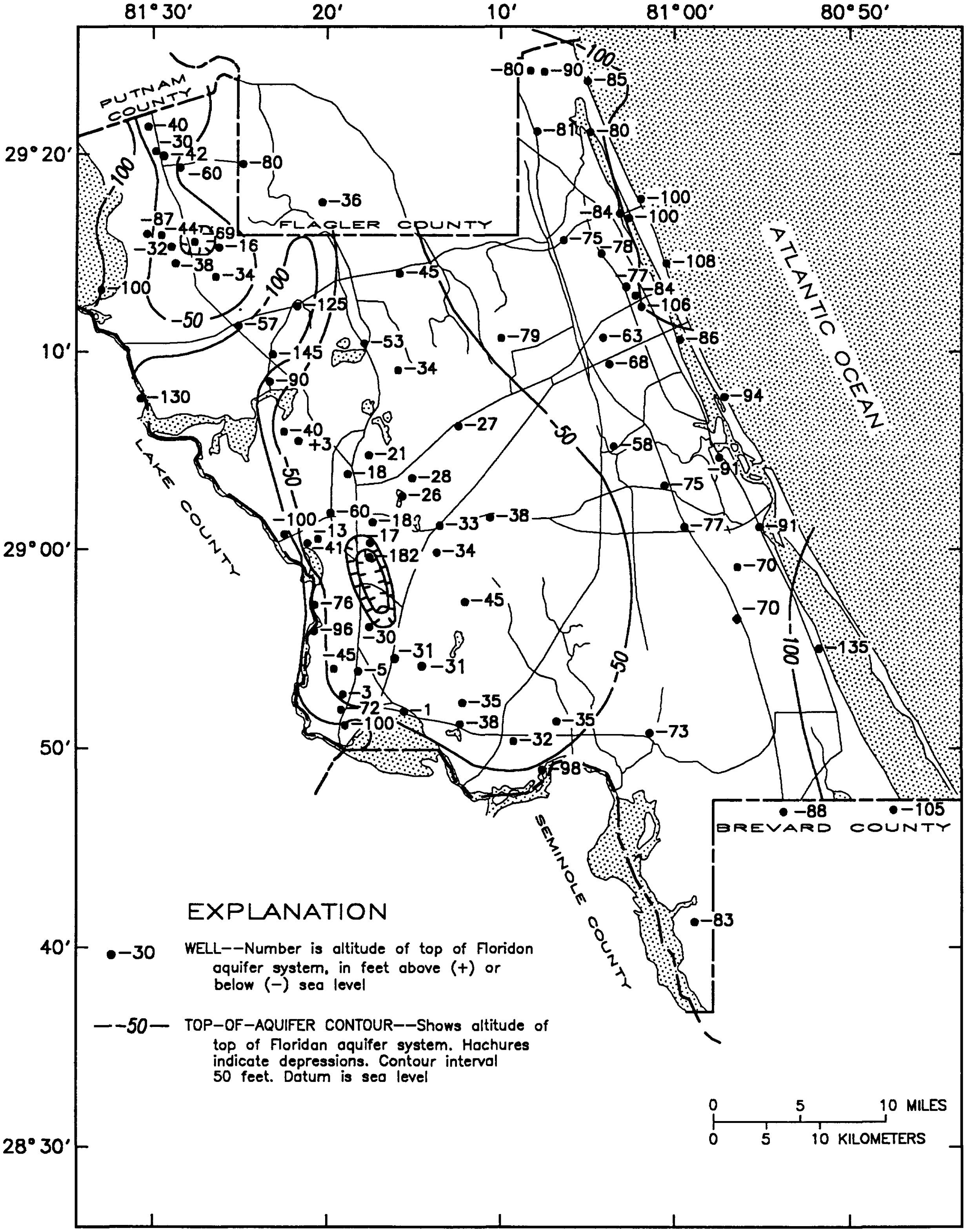


Figure 4. Altitude of top of Floridan aquifer system (from Rutledge, 1985a, fig. 6).

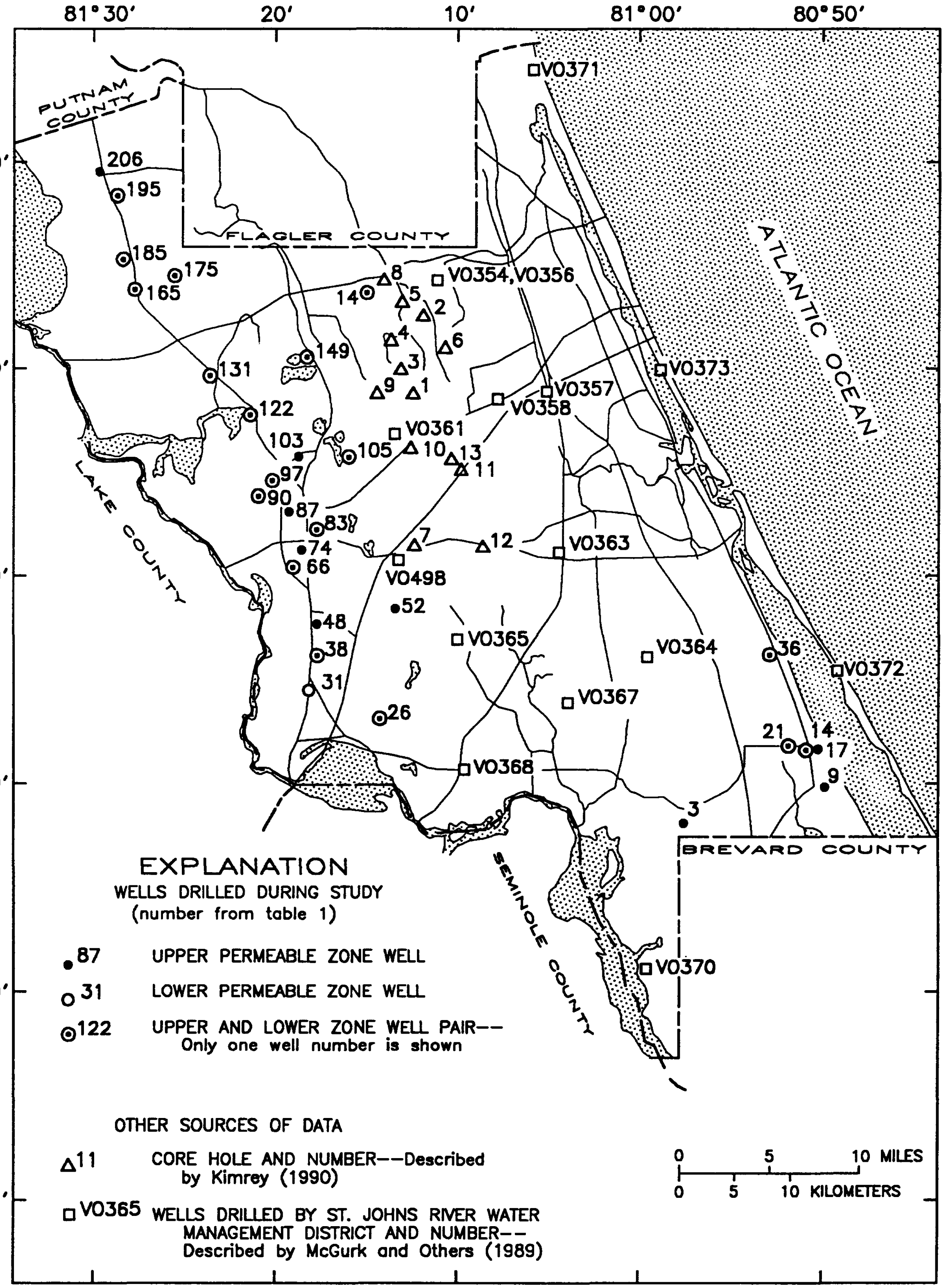


Figure 5. Locations of test wells drilled, core holes, and St. Johns River Water Management District wells.

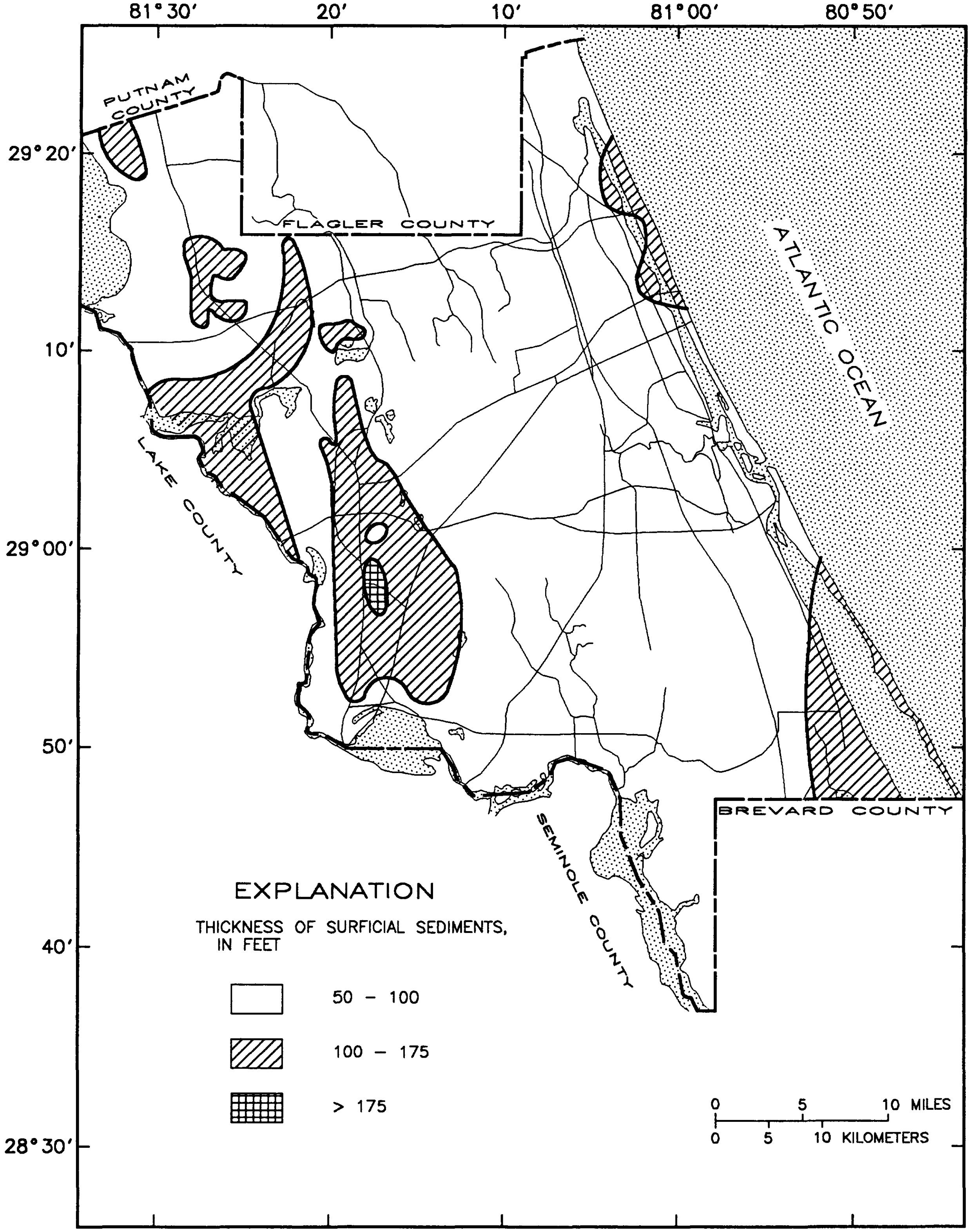


Figure 6. Thickness of sediments overlying the Floridan aquifer system.

another layer of sand and shell about 20 feet thick, which is designated as the lower permeable zone of the surficial aquifer system. In the eastern part of the county, the lower permeable zone is composed mostly of indurated shell (coquina). This lower zone in turn is underlain by more clay and silt; this last sequence forms the confining layer between the surficial aquifer system and the underlying Floridan aquifer system. Knochenmus and Beard (1971, p. 9) concluded that, because the clastic deposits are lenticular and discontinuous, variations in permeability are great.

Geologic sections (locations shown in fig. 7) based on well data from the files of the U.S. Geological Survey, the Florida Geological Survey, and the St Johns River Water Management District are shown in figures 8a-c. Well information is given in table 2. Some wells used in construction of the sections are not in the U.S. Geological Survey data base, so other identification numbers, if applicable, are shown in table 2. Also, many of the wells used to compile the geologic section tap the Floridan aquifer system and, therefore, are not included in the well inventory in table 1.

Many of the logs did not contain sufficient detail to differentiate geologic units of the surficial aquifer system, so although the Hawthorn Formation appears to be absent on some of the sections, its absence or presence cannot be confirmed with the data available. It is a common belief that the absence of the Hawthorn Formation implies that the Floridan aquifer system is unconfined, but generally, in Volusia County, this is true only in isolated places along the De Land Ridge in the vicinity of sinkholes. In many areas, late Miocene or Pliocene-age sediments contain sufficient clay, fine sand, or silt to poorly confine the Floridan aquifer system. Differentiation among geologic formations in the Floridan aquifer system is not within the scope of this investigation.

Section A-A′ in figure 8a shows the range in altitude of land surface (10 feet to more than 100 feet above sea level) and top of the Eocene-age carbonates corresponding to the Upper Floridan aquifer (about 40 feet above to about 125 feet below sea level) along the karst ridges in the western part of the county. In contrast, section C-C′ (fig. 8b), which includes wells along the Silver Bluff Terrace and the Atlantic Coastal Ridge in the eastern part of the county, shows much less variation. Land surface ranges from 5 to about 30 feet above sea level, and the top of the Upper Floridan aquifer ranges from about 75 feet to about 125 feet below sea level.

Natural gamma logs were run on the test wells drilled during the study to help differentiate between the upper and lower permeable zones. Logs, completion depths, and screened sections from selected wells are shown in figures 9a-f. At sites where a pair of wells were drilled, the deeper of the two wells was logged. Although some types of clay do not exhibit high gamma activity, high gamma counts generally indicate a clay layer, whereas low activity usually indicates a clean sand or shell. The approximate boundaries of the upper and lower permeable zones of the surficial aquifer system are shown in figures 9a-f. Because the zones are not continuous over the county, no attempt was made to construct sections between the test well sites. In the following discussion the well numbers refer to table 1.

At most sites, the gamma-activity peak at a depth of about 20 to 40 feet below land surface delineates the bottom of the upper permeable zone of the surficial aquifer system. The bottom of the lower zone probably is indicated by the peaks at depths of 55 to 60 feet in well 22 (fig. 9b), and at 65 to 70 feet in well 37 (fig. 9c), respectively. At some sites in the western part of the county, such as wells 196 (fig. 9f) and 166 (not shown), gamma activity at the bottom of the lower zone does not appear to increase, and water-level data indicate a good hydraulic connection between the lower zone and the Upper Floridan aquifer. At other sites, such as well 39 (fig. 9c) and wells 176 and 186 (not shown), the deeper well of each pair inadvertently penetrated into the Upper Floridan aquifer, as shown by the much lower gamma activity characteristic of limestone at a depth of 55 feet in well 39.

The log of well 98 (fig. 9e) does not show peaks that would indicate good separation of the zones within the surficial aquifer system, but water levels and water-quality data (discussed in later sections) indicate that the two zones are distinct at this site. Apparently, silt or clay layers not showing a high gamma activity are found at the site.

The log of well 84 (fig. 9d), which is located in De Land, shows a gamma activity peak at a depth of about 50 to 60 feet that may indicate good separation between zones of the surficial aquifer system; however, neither well would yield water when pumped and shortly after the wells were drilled, both wells became dry. Because of the lack of water-level data, no attempt was made to delineate zones of the surficial aquifer system at well 84. At well 132 (fig. 9f), in an area of low land surface altitude near Deep Creek, the log indicates some clay from about 5 to 40 feet below land surface. Although there does not appear to be a significant clay layer separating the upper and lower zones, based on a 1-foot water-level difference, the tentative delineation of the two zones is obvious in figure 9f.

Wells at two sites near the western edge of the Talbot Terrace were also logged. Well 106 (fig. 9e) shows gamma activity peaks which indicate good separation between the upper and lower permeable zones. The deeper well does not appear to penetrate the Upper Floridan aquifer, although the decline in water level during freeze-protection pumping from the Upper Floridan indicates a good hydraulic connection between the lower permeable zone and the Upper Floridan aquifer at that site. Water levels shown in figure 9e were not measured during freeze-protection pumping. The gamma log of well 27 (fig. 9b) does not indicate a high gamma-activity clay layer at the completion depth of the well, and the water level in the well was at times similar to that in the Upper Floridan, but during most of the study, the well was dry and would not yield a water sample.

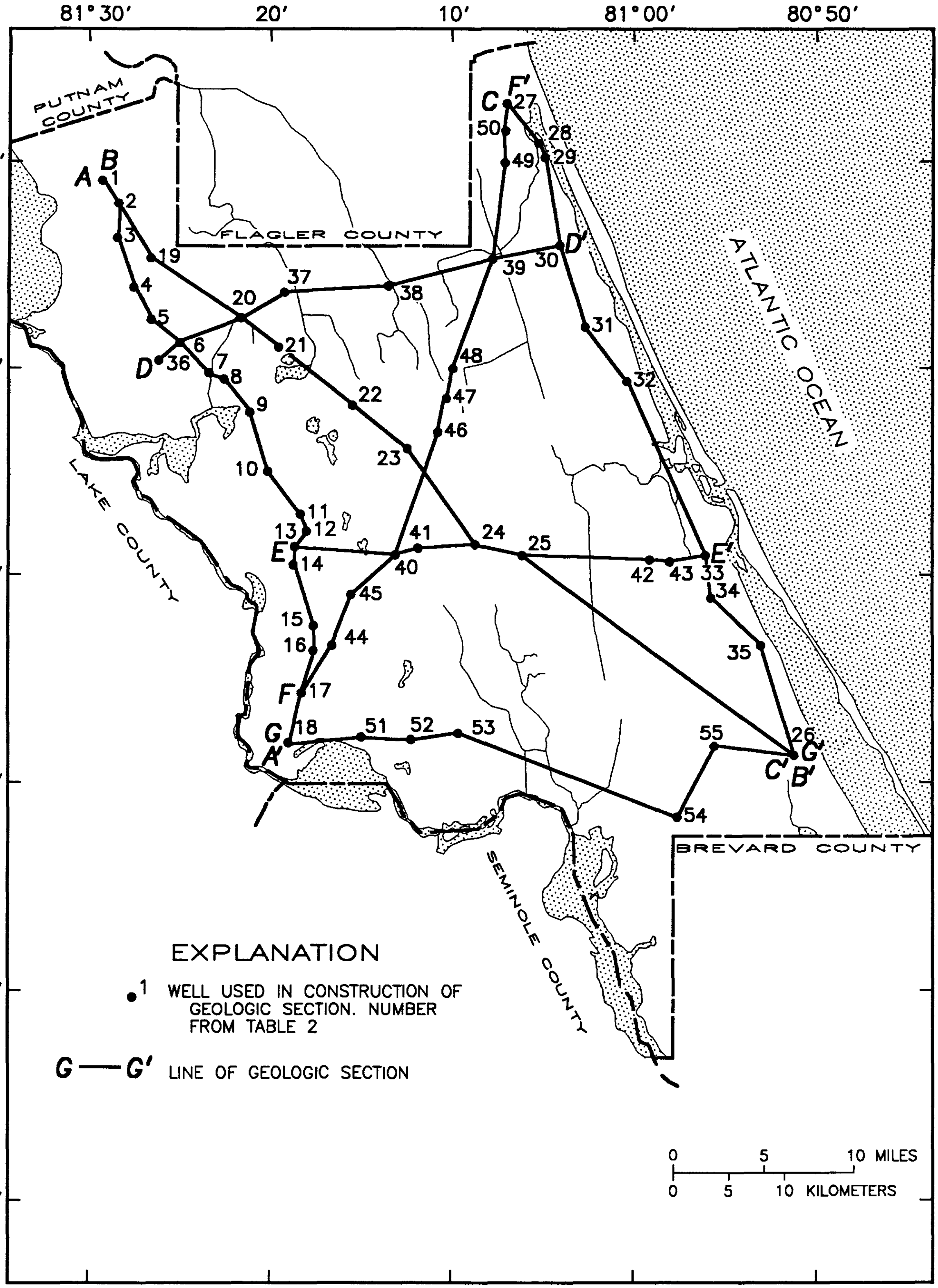
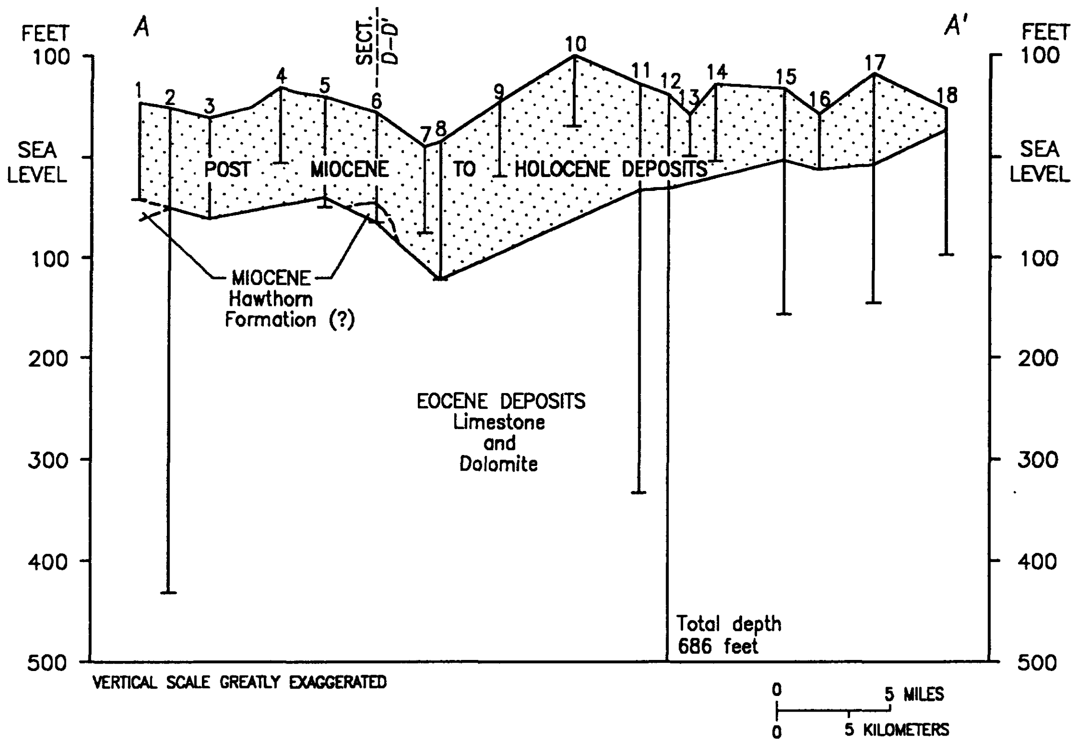


Figure 7. Location of geologic sections.

Table 2. Wells used for geologic sections

[Agency maintaining well record: SJRWMD, St. Johns River Water Management District; USGS, U.S. Geological Survey; and FGS, Florida Geological Survey; --, indicates no data]

Well No. in fig. 7	Latitude	Longitude	Agency	Other identification No.	Well No. from table 1
1	291907	0812916	FGS	W-167	--
2	291806	0812843	USGS		196
3	291626	0812836	USGS		191
4	291357	0812743	USGS		166
5	291226	0812650	FGS	W-451	--
6	291117	0812513	SJRWD		--
7	290947	0812329	USGS		132
8	290930	0812302	USGS		--
9	290756	0812111	USGS		123
10	290508	0812006	USGS		98
11	290307	0811823	FGS	W-8503	--
12	290205	0811810	FGS	W-6353	--
13	290117	0811835	USGS		--
14	290025	0811850	USGS		67
15	285757	0811743	USGS		48
16	285630	0811747	USGS		39
17	285437	0811814	USGS		--
18	285156	0811903	FGS	W-10638	--
19	291520	0812654	SJRWD		--
20	291216	0812155	SJRWD		--
21	291101	0812002	SJRWD		--
22	290818	0811551	FGS	W-456	--
23	290610	0811251	USGS		--
24	290132	0810854	USGS		75
25	290105	0810615	USGS		--
26	285129	0805105	USGS		14
27	292304	0810719	USGS		228
28	292106	0810524	FGS	W-3472	--
29	292027	0810510	FGS	W-3473	--
30	291610	0810415	FGS	W-11099	--
31	291202	0810240	FGS	W-3569	--
32	290931	0810026	FGS	W-3525	--
33	290105	0805610	FGS	W-924	--
34	285900	0805548	FGS	W-4579	--
35	285649	0805304	USGS		--
36	291024	0812640	USGS		--
37	291330	0811916	USGS		--
38	291407	0811401	FGS	W-12034	--
39	291511	0810726	USGS		--
40	290103	0811323	USGS		--
41	290114	0811216	USGS		--
42	290047	0805910	USGS		--
43	290045	0805810	FGS	W-11668	--
44	285650	0811656	USGS		--
45	285904	0811529	USGS		--
46	290655	0811112	USGS		--
47	290843	0811035	USGS		128
48	291004	0811014	USGS		--
49	291951	0810726	USGS		208
50	292151	0810733	USGS		222
51	285204	0811512	FGS	W-8575	--
52	285200	0811230	FGS	W-11589	--
53	285221	0810950	USGS		--
54	284822	0805735	USGS		4
55	285148	0805452	USGS		--



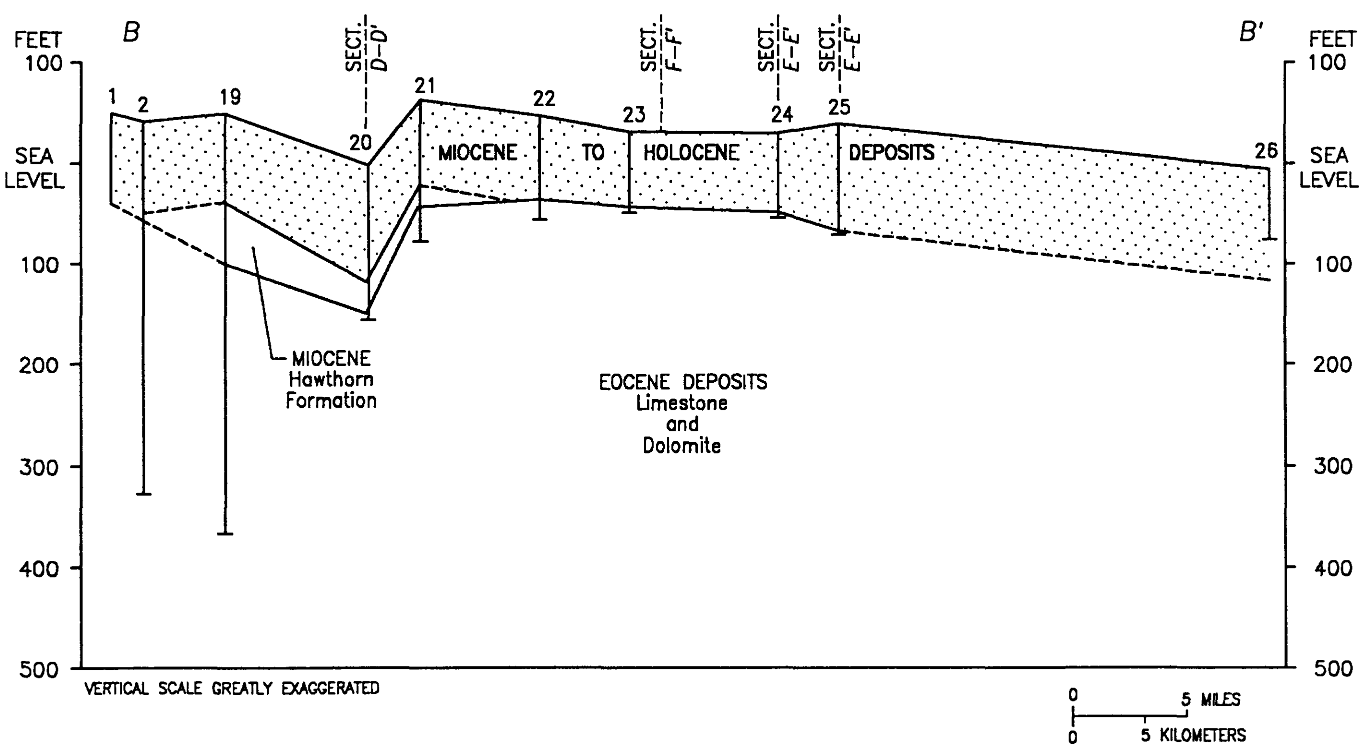


Figure 8a. Geologic sections A-A' and B-B' (lines of section shown in fig. 7 and plot numbers in table 2).

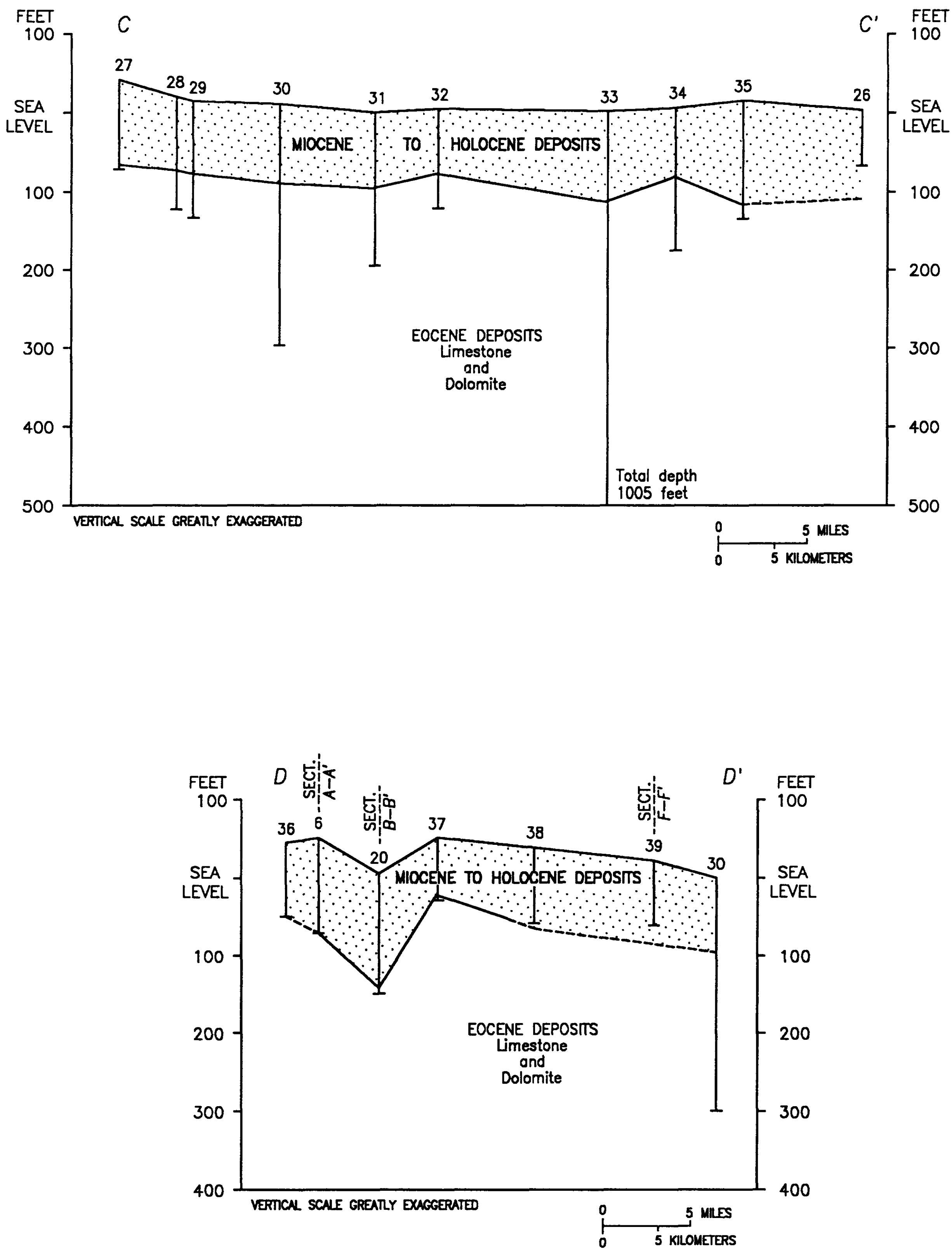


Figure 8b. Geologic sections C-C' and D-D' (lines of section shown in fig. 7 and plot numbers in table 2).

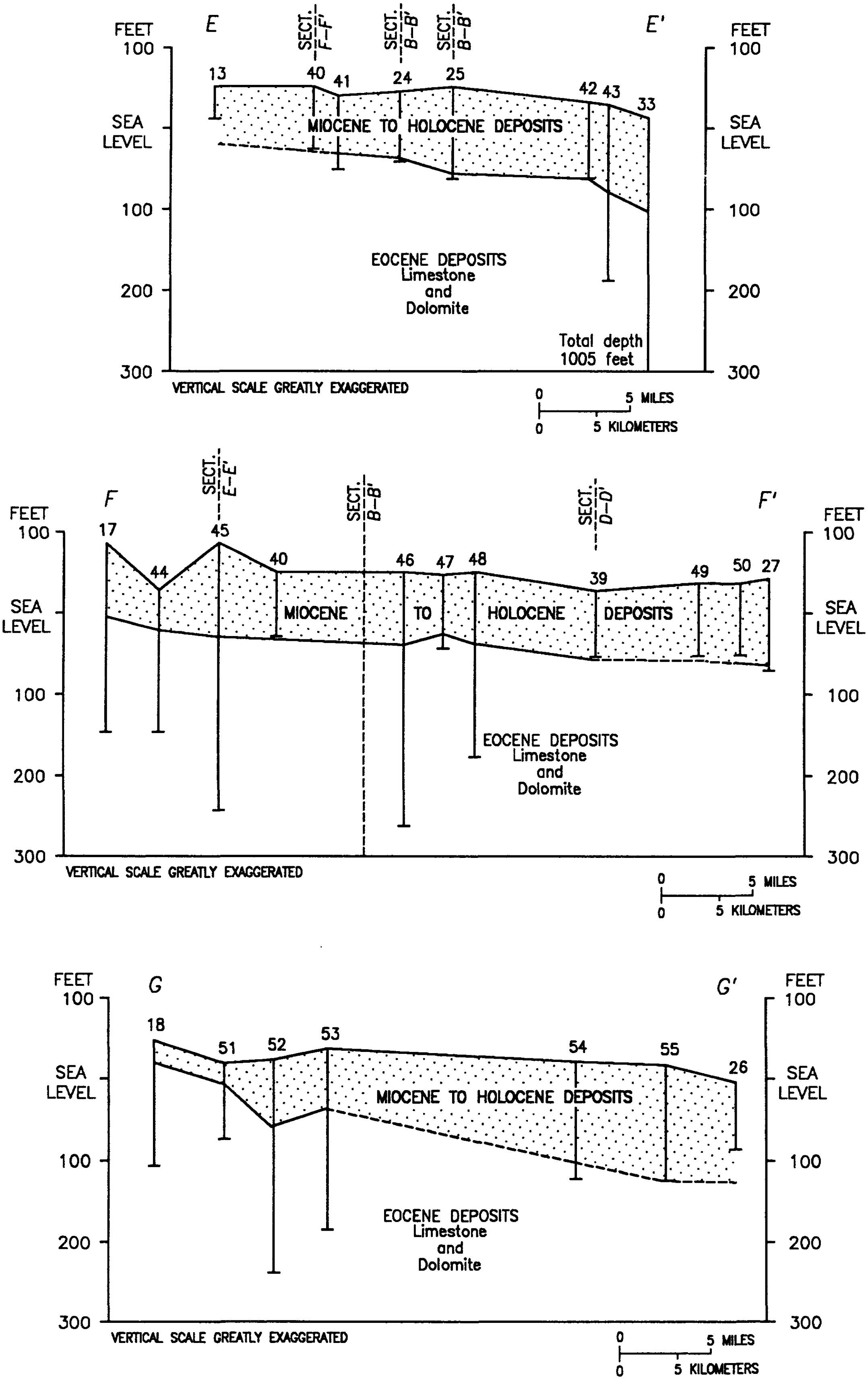


Figure 8c. Geologic sections E-E', F-F', and G-G' (lines of section shown in fig. 7 and plot numbers in table 2).

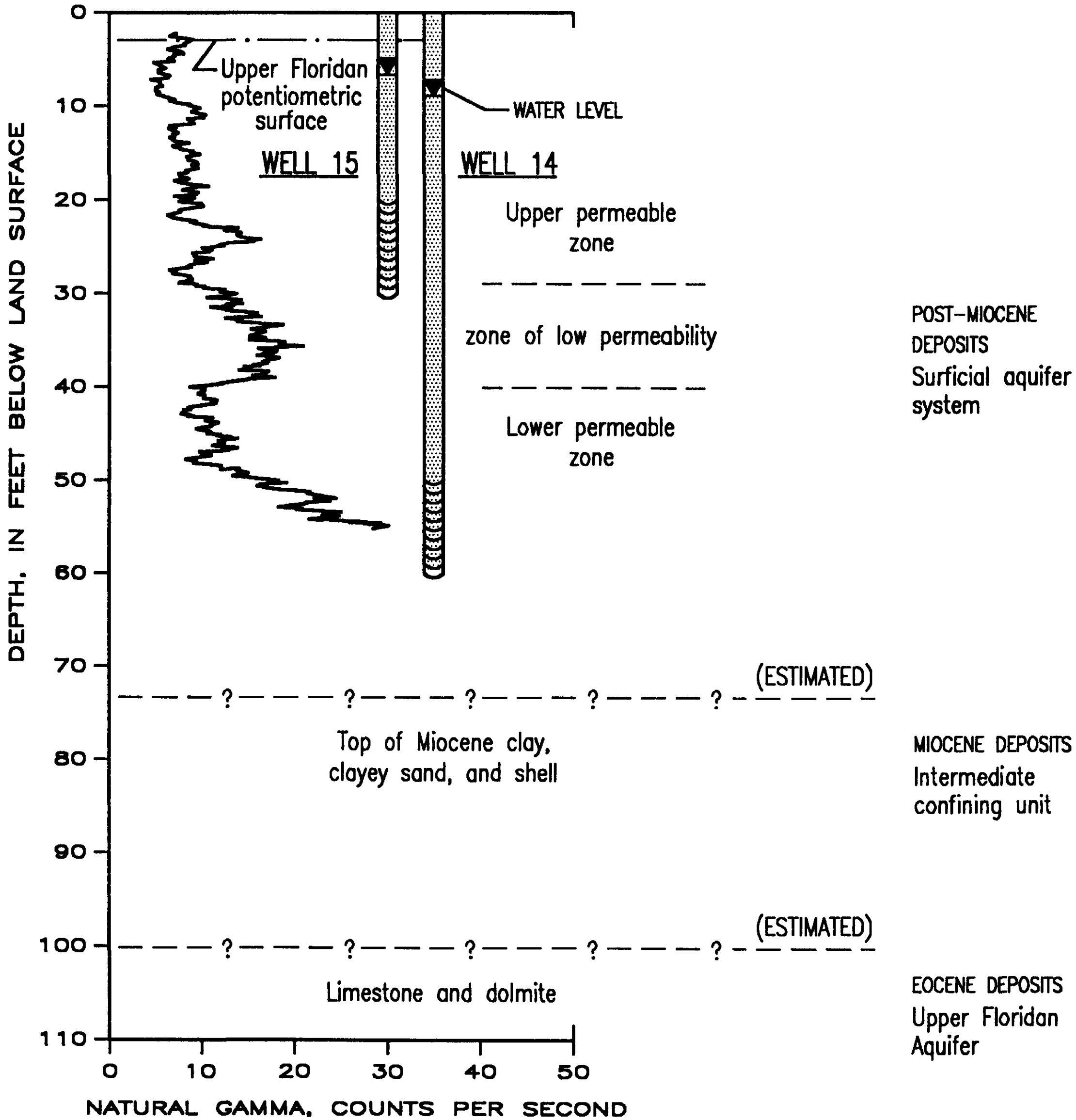


Figure 9a. Natural gamma logs of test well pair 14,15 (locations shown in fig. 5).

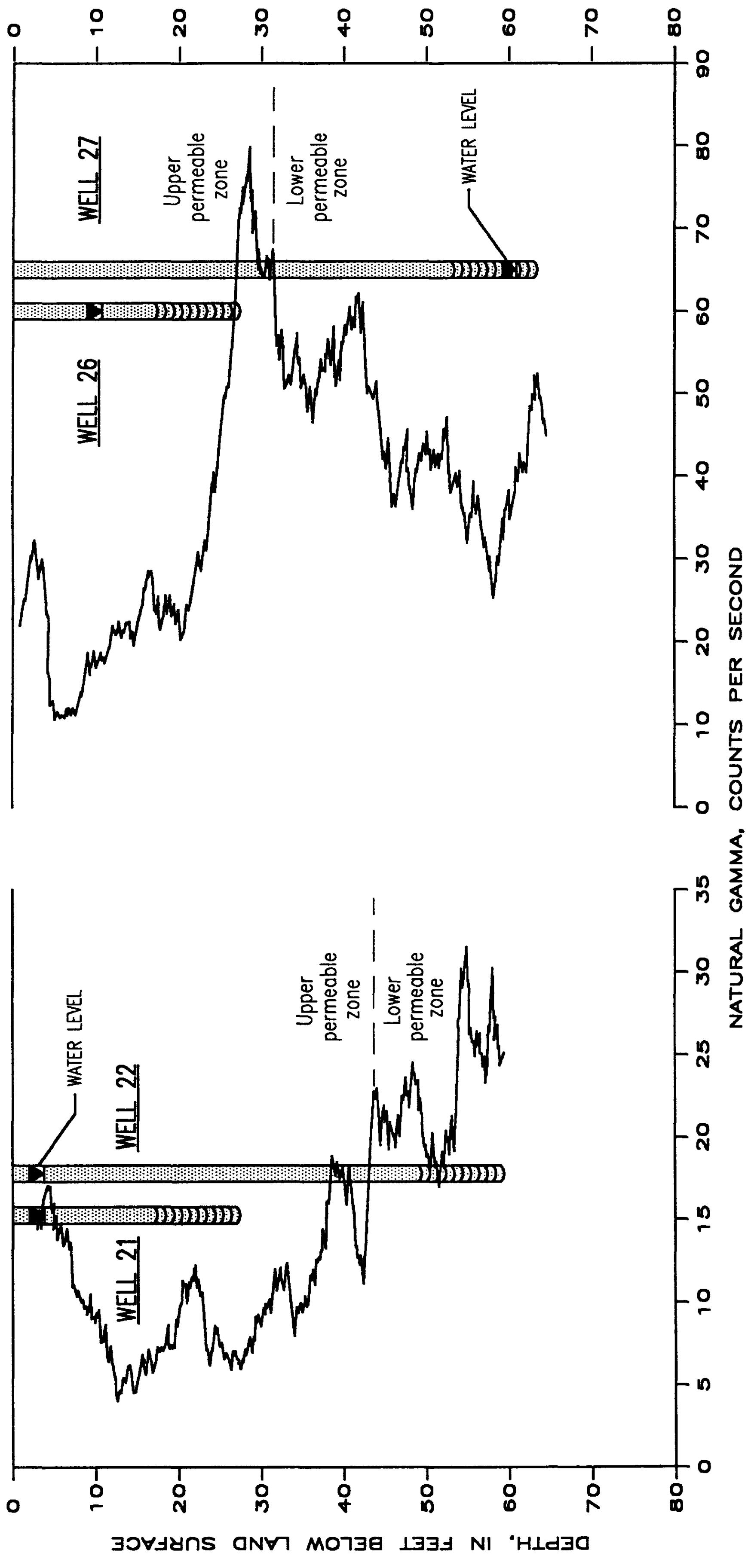


Figure 9b. Natural gamma logs of test well pairs 21,22 and 26,27 (locations shown in fig. 5).

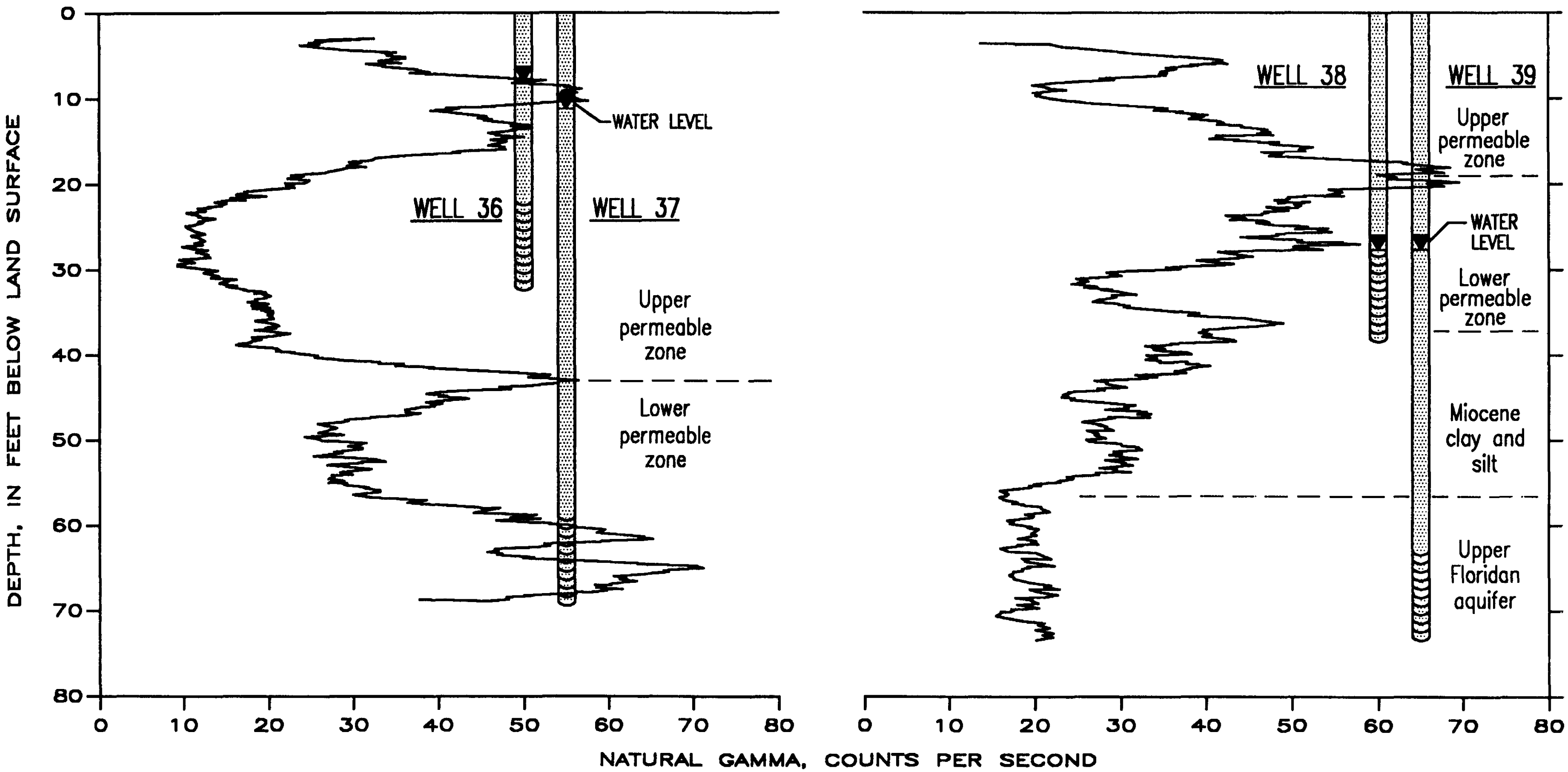


Figure 9c. Natural gamma logs of test well pairs 36,37 and 38,39 (locations shown in fig. 5).

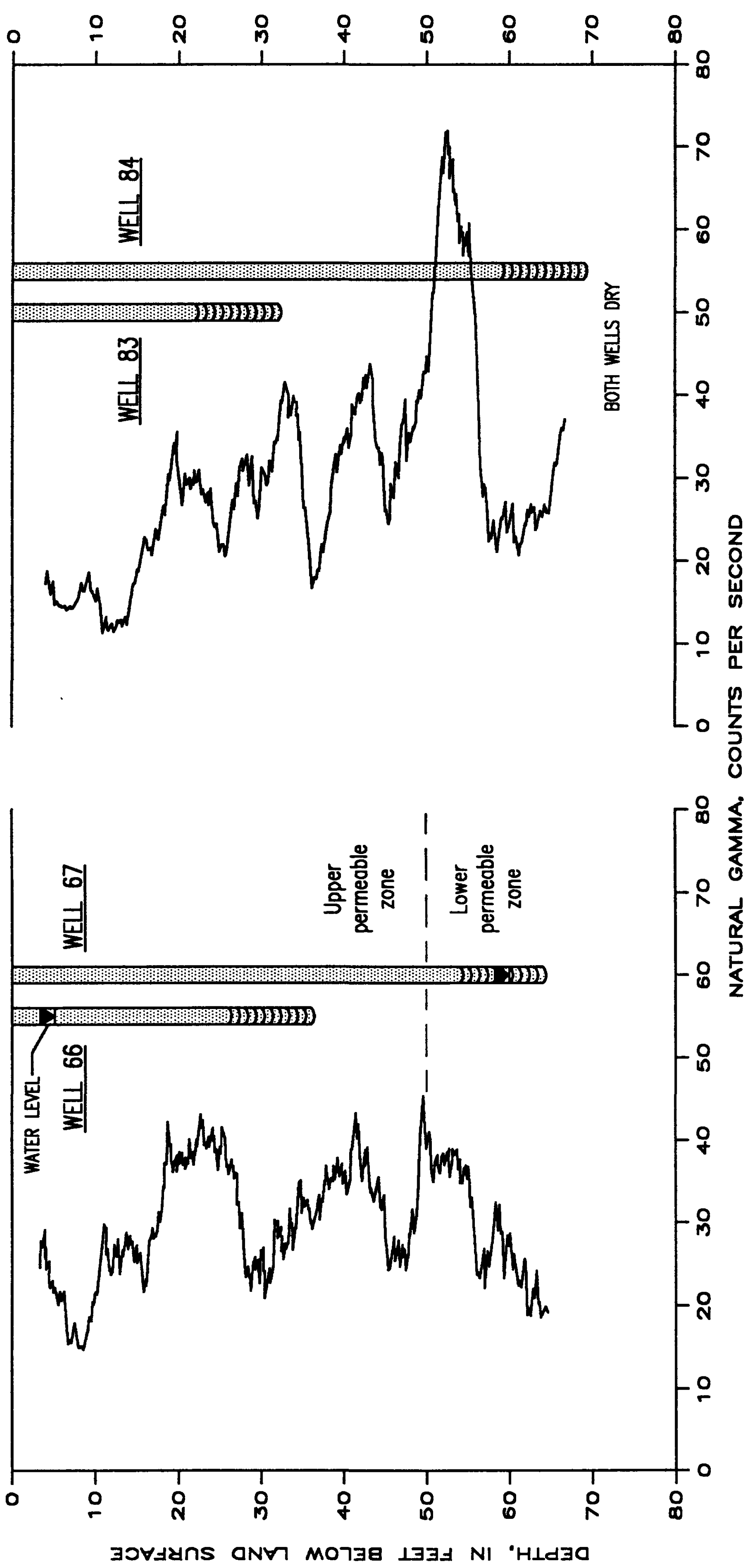


Figure 9d. Natural gamma logs of test well pairs 66,67 and 83,84 (locations shown in fig. 5).

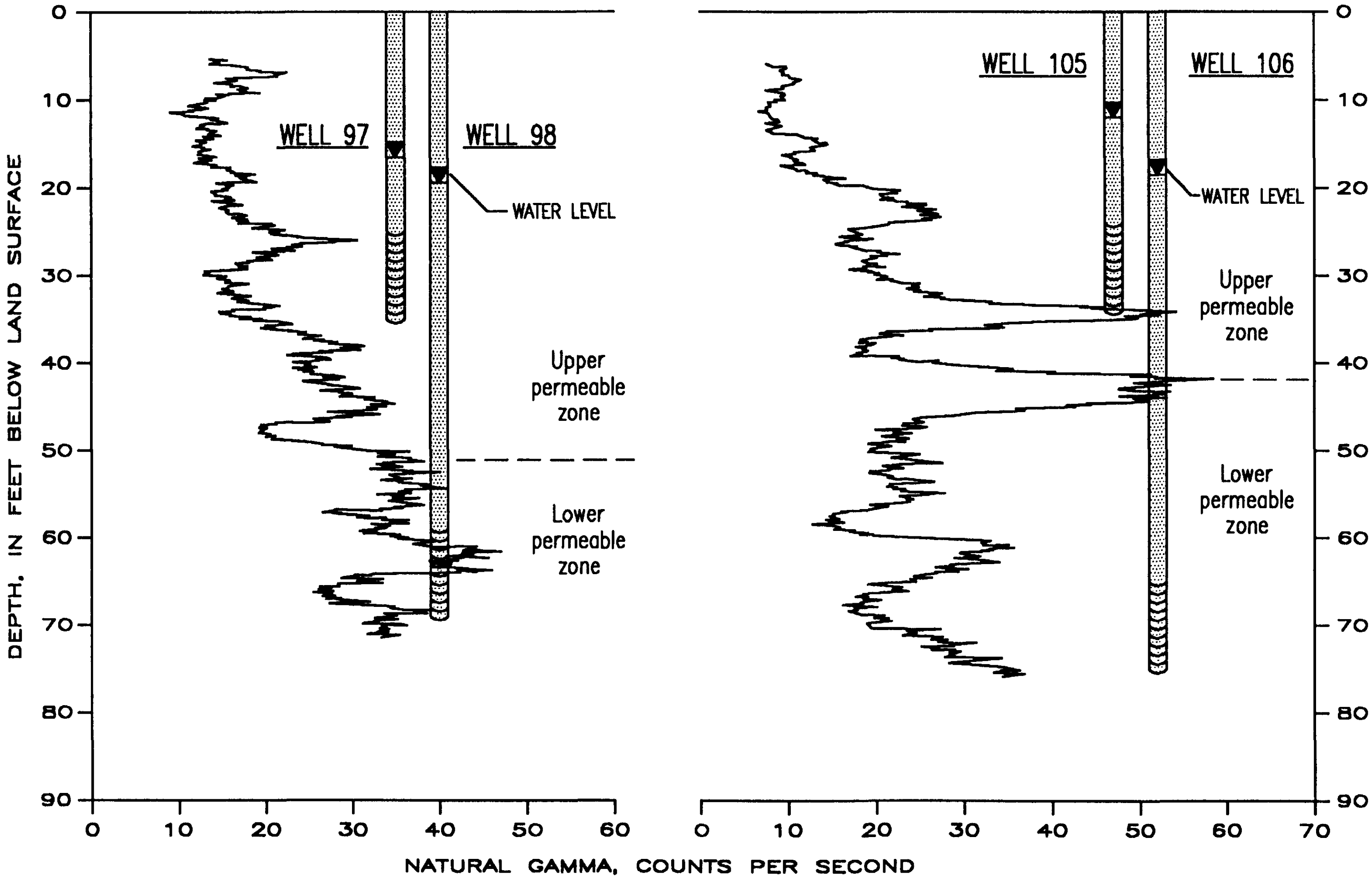


Figure 9e. Natural gamma logs of test well pairs 97,98 and 105,106 (locations shown in fig. 5).

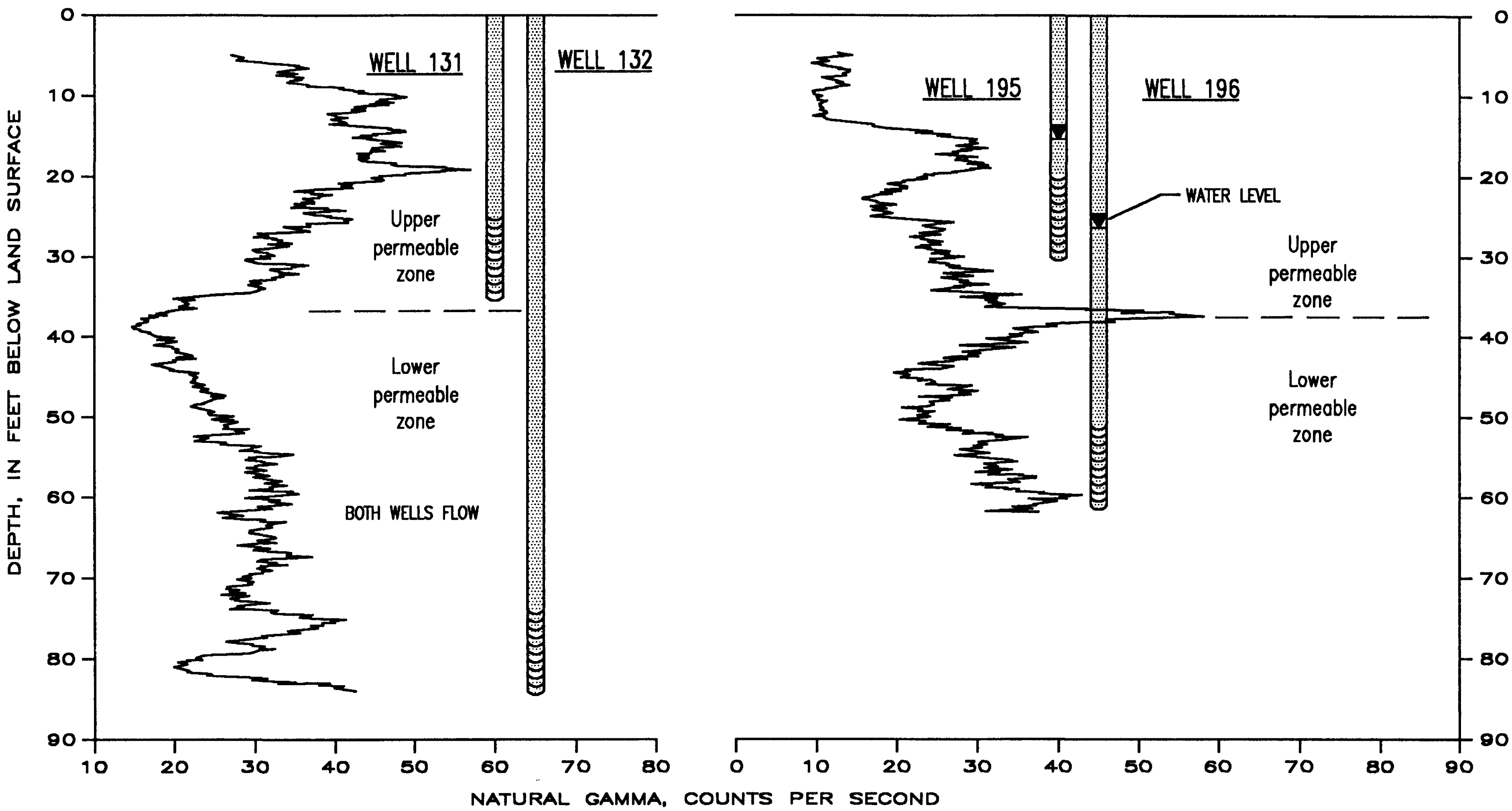


Figure 9f. Natural gamma logs of test well pairs 131,132 and 195,196 (locations shown in fig. 5).

At well 14 (fig. 9a) in the eastern part of the county, the gamma log does not show a peak between the upper and lower permeable zones which could indicate hydraulic connection between the two zones, but when the lower permeable zone was pumped for 19 hours, no response was seen in the upper permeable zone.

From the preceding discussion, it can be seen that, although natural gamma logs can be a useful tool, the results must be interpreted in conjunction with other hydrologic data, such as water levels and water-quality information. Though a peak of high gamma counts usually indicates the presence of a clay layer which can act as a confining layer, the absence of a peak does not necessarily indicate the absence of confinement.

GROUND WATER

Water Levels

During the study, water levels were measured periodically in a network of about 90 wells tapping both permeable zones of the surficial aquifer system. Also, water levels are recorded continuously at two U.S. Geological Survey observation wells in the surficial aquifer system in Volusia County. Records of historic water levels collected by Laughlin and Collins (1969), Knochenmus and Beard (1971), and by Gomberg (1985a) were also studied.

Seasonal Fluctuations

Water levels were measured in wells tapping the upper permeable zone in February through May 1986 (fig. 10) and in September 1986 (fig. 11). Spring water levels usually are lower than fall water levels because only about 30 percent of total yearly rainfall occurs from November through April. In 1986, water levels in wells tapping the upper permeable zone generally were 3 to 6 feet higher in the fall than in the spring, although higher than average rainfall in January and February probably caused spring water levels to be higher than average. Well 195 showed the largest fluctuation in water level during the study, about 5 feet between July 1986 and April 1987 (table 3). Several wells, including wells 105, 131, and 217, showed less than 1 foot of water-level fluctuation.

Water levels in wells tapping the lower permeable zone generally fluctuated less than 2 feet, except in wells in the northwestern part on the county affected by pumping from the Upper Floridan aquifer for freeze protection during February 1987. At wells 176 and 196, for example, the fluctuation for the year was about 7 to 11 feet because of the drawdown from freeze-protection pumping. The water levels in the upper permeable zone appeared to be unaffected by the pumping.

The depth below land surface to the water table in the surficial aquifer system varies from one physiographic area to another. On ridge areas, where land-surface altitude is greater than 50 feet above sea level, the water table can be 30 feet or more below land surface, whereas on terraces and in the interridge area near the St. Johns River it is less than 10 feet below land surface. At some sites, either a perched condition exists or the surficial materials are unsaturated. For example, wells 83 and 84 both were dry throughout the study. Well 26 (in the upper permeable zone) showed fluctuations similar to other upper permeable zone wells, but well 27, the lower permeable zone well of the pair, was dry except in September 1986 at the end of the rainy season.

Long-Term Fluctuations

At present (1989) the U.S. Geological Survey maintains continuous water-level recorders on two wells tapping the upper permeable zone of the surficial aquifer system in Volusia County (wells 143 and 164). Continuous records were collected at three other wells (wells 43, 71, and 111) from 1966 through 1968. One lower permeable zone well (well 222) has long-term periodic record available. There are no continuous water-level records for wells tapping the lower permeable zone. The locations of long-term observation wells are shown in figure 12.

From May 1985 through May 1987, water-levels fluctuated 3.9 feet in well 143 and 9.8 feet in well 164, both tapping the upper permeable zone. Hydrographs for the two wells and rainfall at De Land for May 1985 through May 1987 are shown in figure 13a. Hydrographs for the period of record (1978 through 1988) for both wells are shown in figure 13b. At well 143, the minimum water level was 32.99 feet above sea level in July 1981 and the maximum was 38.41 feet in September 1984, a difference of 5.42 feet. During the study, water levels in the well fluctuated 3.9 feet. At well 164, the minimum water level was 23.08 feet above sea level in July 1981 and the maximum was 34.16 feet in September 1979, a difference of 11.08 feet. In the summer of 1981, rainfall in central Florida was much less than average.

Water-level measurements at wells 43, 71, and 111 during 1966-68 as reported by Laughlin and Collins (1969) and Knochenmus and Beard (1971) indicated that the water level fluctuated about 18, 5, and 6 feet, respectively.

Data collected by Gomberg (1985a) from well 223 and other nearby wells in northeastern Volusia County during 1981 to 1985 were also examined. At well 223, the water level fluctuated about 8 feet, with the minimum water level in August 1981. At that well, the water level was usually about 10 feet below land surface, but during the summer of 1981 it dropped to about 18 feet below. At a nearby well (not included in table 1) where the water level was usually within 3 feet of land surface, the level dropped to about 12 feet below land surface in 1981, a fluctuation of at least 9 feet for the period of record.

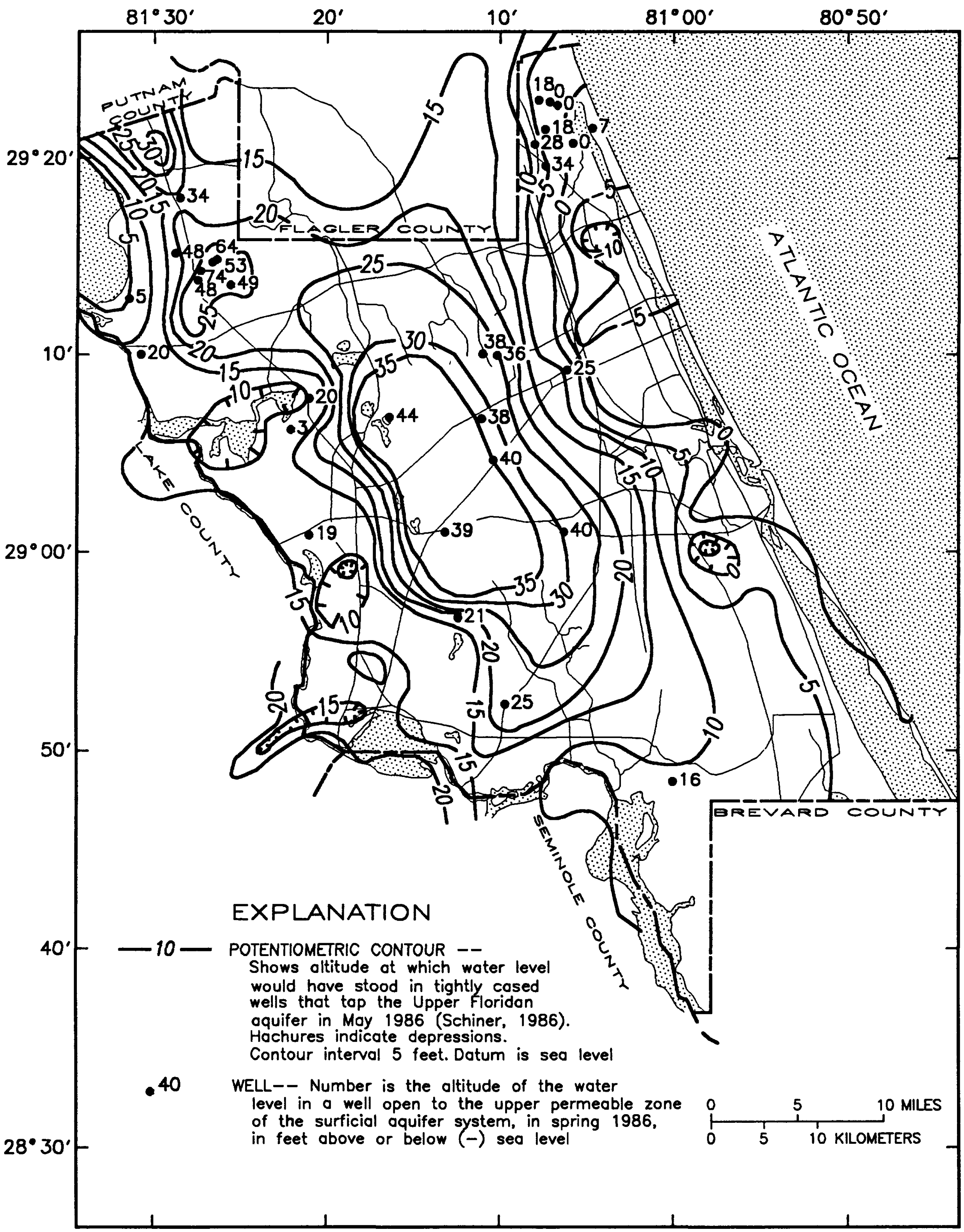


Figure 10. Water levels in wells completed in the upper permeable zone of the surficial aquifer system, February through May 1986, and potentiometric surface of the Upper Floridan aquifer, May 1986.

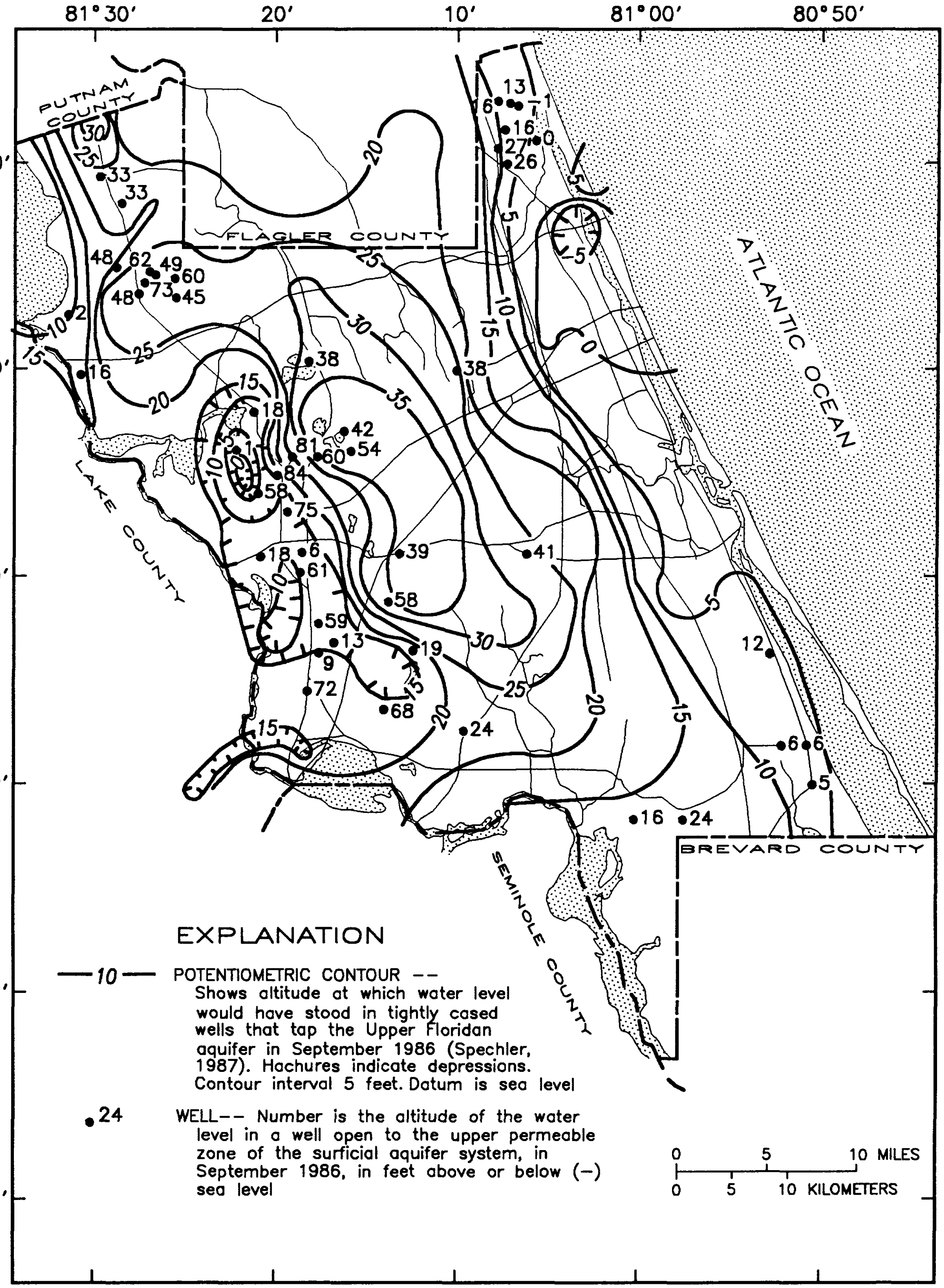


Figure 11. Water levels in wells completed in the upper permeable zone of the srficial aquifer system and potentiometric surface of the Upper Floridan aquifer, September 1986.

Table 3. Water levels in well pairs drilled during the study

[Well numbers are from table 1. Water level: --, indicates not measured. Aquifer zone: U, upper permeable zone; L, lower permeable zone. Datum is sea level]

Well No.	Site identification No.	Aquifer zone	Date	Water level (feet)	Difference in water level (feet)
3	284822080573502	U	09-16-86	23.7	
4	284822080573503	L	09-16-86	19.8	
					3.9
		U	02- 09-87	24.1	
		L	02-09-87	19.8	
					4.3
		U	04-22-87	24.5	
		L	04-22-87	20.5	
					4.5
9	285002080503001	U	09-22-86	5.0	
10	285002080503002	L	09-22- 86	2.9	
					2.1
		U	02-09-87	--	
		L	02-09-87	4.8	
					--
17	285138080505001	U	09-16-86	5.2	
18	285138080505002	L	09-16-86	5.3	
					0.1
		U	02-09-87	4.6	
		L	02-09-87	--	
					--
21	285152080520901	U	09-16-86	6.4	
22	285152080520902	L	09-16-86	6.4	
					0
		U	02-09-87	7.1	
		L	02-09-87	6.8	
					0.3
26	285343081140401	U	09-17-86	68.2	
27	285343081140402	L	09-17-86	11.2 (Lower zone well dry except on this date)	
					57.0
30	285437081181402	U	07-30-86	71.1	
31	285437081181403	L	07-30-86	33.2	
					37.9
		U	09-16-87	72.3	
		L	09-16-87	32.5	
					39.8
		U	03-16-87	70.5	
		L	03- 16-87	31.8	
			03-16-87		38.7
		U	05-14-86	70.9	
		L	05-14-86	33.8	
					37.1

Table 3. Water levels in well pairs drilled during the study—Continued

[Well numbers are from table 1. Water level: --, indicates not measured. Aquifer zone: U, upper permeable zone; L, lower permeable zone. Datum is sea level]

Well No.	Site identification No.	Aquifer zone	Date	Water level (feet)	Difference in water level (feet)
36	285625080525201	U	09-15-86	11.9	
37	285625080525202	L	09-15-86	10.2	
					1.7
		U	02-09-87	10.9	
		L	02-09-87	11.4	
					-0.5
		U	04-22-87	12.3	
		L	04-22-87	10.6	
					1.7
38	285630081174701	U	07-29-86	7.6	
39	285630081174702	L	07-29-86	7.7	
					-0.1
		U	09-18-86	8.5	
		L	09-18-86	8.9	
					-.4
		U	02-10-87	7.5	
		L	02-10-87	7.4	
					.1
66	290025081185001	U	07-30-86	58.8	
67	290025081185002	L	07-30-86	7.9	
					50.9
		U	09-24-86	60.6	
		L	09-24-86	7.5	
					53.1
		U	02- 10-87	59.2	
		L	02-10-87	6.4	
					52.8
		U	03-19-87	59.9	
		L	03-19-87	7.4	
					52.5
90	290421081210601	U	09-24-86	57.5	
91	290421081210602	L	09- 24-86	19.1	
					38.4
		U	02-10-87	57.9	
		L	02-10-87	16.5	
					41.4
97	290508081200601	U	09-23-86	83.8	
98	290508081200602	L	09-23-86	81.2	
					2.6
		U	02-10-87	82.6	
		L	02-10-87	79.5	
					3.1
		U	03-18-87	84.1	
		L	03-18-87	81.4	
					2.7

Table 3. Water levels in well pairs drilled during the study—Continued

[Well numbers are from table 1. Water level: --, indicates not measured. Aquifer zone: U, upper permeable zone; L, lower permeable zone. Datum is sea level]

Well No.	Site identification No.	Aquifer zone	Date	Water level (feet)	Difference in water level (feet)
105	290554081160801	U	07-28-86	54.4	
106	290554081160802	L	07-28-86	47.0	
					7.4
		U	09-23-86	53.8	
		L	09-23-86	46.3	
					7.5
		U	02-10-87	54.6	
		L	02-10-87	[1]44.6	
					10.0
		U	03-24-87	54.4	
		L	03-24-87	46.9	
					7.5
122	290756081211101	U	04-14-86	20.4	
123	290756081211102	L	04-14-86	--	
					--
		U	07-17-86	18.9	
		L	07-17-86	10.0	
					8.9
		U	09-23-86	18.2	
		L	09-23-86	9.8	
					8.4
		U	03-23-87	19.7	
		L	03-23-87	10.2	
					9.5
149	291032081181301	U	07-28-86	38.8	
150	291032081181302	L	07-28-86	31.1	
					7.7
		U	09-23-86	38.1	
		L	09-23-86	31.2	
					6.9
		U	02-10-87	39.1	
		L	02-10-87	30.6	
					8.5
		U	04-07-87	41.6	
		L	04-07-87	32.5	
					9.1
165	291357081274301	U	04-08-86	48.2	
166	291357081274302	L	04-08-86	27.4	
					20.8
		U	07-22-86	47.2	
		L	07-22-86	24.9	
					22.3

Table 3. Water levels in well pairs drilled during the study—Continued

[Well numbers are from table 1. Water level: --, indicates not measured. Aquifer zone: U, upper permeable zone; L, lower permeable zone. Datum is sea level]

Well No.	Site identification No.	Aquifer zone	Date	Water level (feet)	Difference in water level (feet)
165	291357081274301	U	09-11-86	47.8	
166	291357081274302	L	09-11-86	28.6	
					19.2
		U	02-11-87	[1]45.3	
		L	02-11-87	[1]15.5	
					29.8
		U	04-06-87	49.3	
		L	04-06-87	27.4	
					21.9
175	291441081254801	U	07-23-86	59.5	
176	291441081254802	L	07-23-86	32.3	
					27.2
		U	09-11-86	59.6	
		L	09-11-86	33.3	
					26.3
		U	02-11-87	59.8	
		L	02-11-87	[1]22.5	
					37.3
185	291520081290001	U	04-08- 86	48.4	
186	291520081290002	L	04-08-86	22.6	
					25.8
			07-23-86	46.2	
		U	07-23-86	21.5	
		L			24.7
		U	09-11-86	47.6	
		L	09-11-86	22.2	
					25.4
		U	02- 11-87	46.3	
		L	02-11-87	20.3	
					26.0
195	291806081284301	U	04-08-86	33.6	
196	291806081284302	L	04-08-86	20.5	
					13.1
		U	07-21-86	31.1	
		L	07-21-86	19.8	
					11.3
		U	09-11-86	33.1	
		L	09-11-86	20.9	
					12.2
		U	02-11-86	32.0	
		L	02-11-86	[1]13.6	
					18.4
		U	04-06-87	36.0	
		L	04-06-87	21.0	
					15

Footnote at end of table.

Table 3. Water levels in well pairs drilled during the study—Continued

[Well numbers are from table 1. Water level: --, indicates not measured. Aquifer zone: U, upper permeable zone; L, lower permeable zone. Datum is sea level]

Well No.	Site identification No.	Aquifer zone	Date	Water level (feet)	Difference in water level (feet)
214	292056081080201	U	03-13-86	28.3	
215	292056081080202	L	03-13-86	28.2	
					.1
		U	09-08-86	27.3	
		L	09- 08-86	27.1	
					.2
		U	04-09-87	28.8	
		L	04-09-87	28.8	
					0

[1]Affected by pumping for freeze protection from the previous night.

Gomberg (1985a) also measured water levels in a well tapping the lower permeable zone. These data show a fluctuation of about 10 feet from 1981 through 1985. The minimum water level, about 9 feet below land surface, occurred in June 1981.

Comparison of Water Levels

Comparison of water levels in wells tapping the upper and lower permeable zones of the surficial aquifer system and Upper Floridan aquifer can be useful in indicating the degree of hydraulic connection between aquifers and the direction of the vertical hydraulic gradient. Table 4 shows a comparison of water levels at the test well pairs drilled during this study. In some pairs, for example, such as wells 195 and 196, and wells 185 and 186, the lower permeable zone and Upper Floridan aquifer wells have water levels that are about the same, indicating a good hydraulic connection between the two. At other sites such as wells 30 and 31, and 97 and 98, the water levels are different, and the connection between zones apparently is poor.

Both the magnitude and direction of the vertical hydraulic gradient between the surficial aquifer system and the Upper Floridan aquifer fluctuate seasonally (table 3). At some locations where the gradient is small (such as wells 36 and 37, and wells 38 and 39), the gradient is sometimes upward, sometimes downward. Under natural conditions (excluding wells affected by freeze-protection pumping) the magnitude of the vertical head difference during the wet season ranged from about 53 feet at wells 66 and 67 to -0.4 foot at wells 38 and 39. During the dry season, the head difference at wells 66 and 67 was also about 53 feet, whereas at wells 38 and 39 it was 0.5 foot. The magnitude of the difference did not change at any well by more than 3 feet during the study except at some wells in the northwestern part of the county where water levels in the lower permeable zone of the surficial aquifer system were affected by freeze-protection pumping from the Upper Floridan aquifer.

Comparison of water levels also indicates whether a particular area is an area of recharge to, or discharge from, the Upper Floridan aquifer. For example, in wells 105 and 106 the water level in the upper zone well is higher than in the lower zone well, and both are higher than the hydraulic head in the Upper Floridan aquifer; thus the area is a recharge area for the Upper Floridan. In contrast, at wells 9 and 10 and wells 17 and 18, the hydraulic head in the Upper Floridan is higher than in the surficial aquifer system, and thus the area is a discharge area for the Upper Floridan. At those two sites, the hydraulic gradient within the surficial aquifer system is downward, and the lower zone is thus receiving recharge from the upper zone of the surficial aquifer system and from the Upper Floridan aquifer. It is thus probable that ground-water discharges from the lower zone of the surficial aquifer system to Mosquito Lagoon.

Recharge and Discharge

In Volusia County, recharge to and discharge from the surficial aquifer system are closely related to hydrogeologic conditions in the Upper Floridan aquifer. In many areas of the county, the surficial aquifer system temporarily stores water that later percolates downward slowly to the Upper Floridan. Recharge to the Upper Floridan is important because most of the water withdrawn from wells and discharging naturally from the Upper Floridan in Volusia County comes from recharge occurring within the county. Blue Spring (the ninth largest in Florida with an average

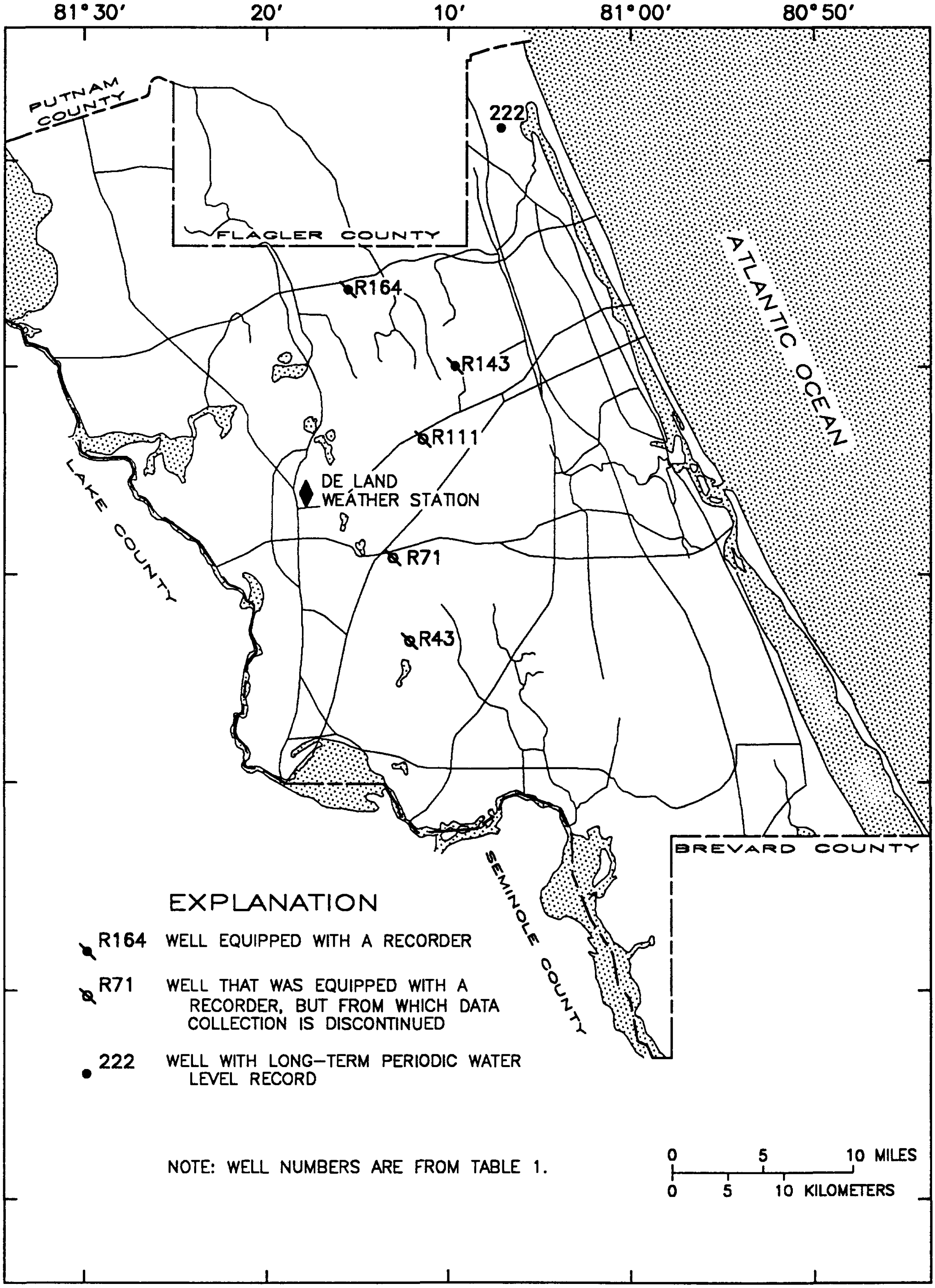


Figure 12. Locations of wells with hydrograph records longer than 2 years.

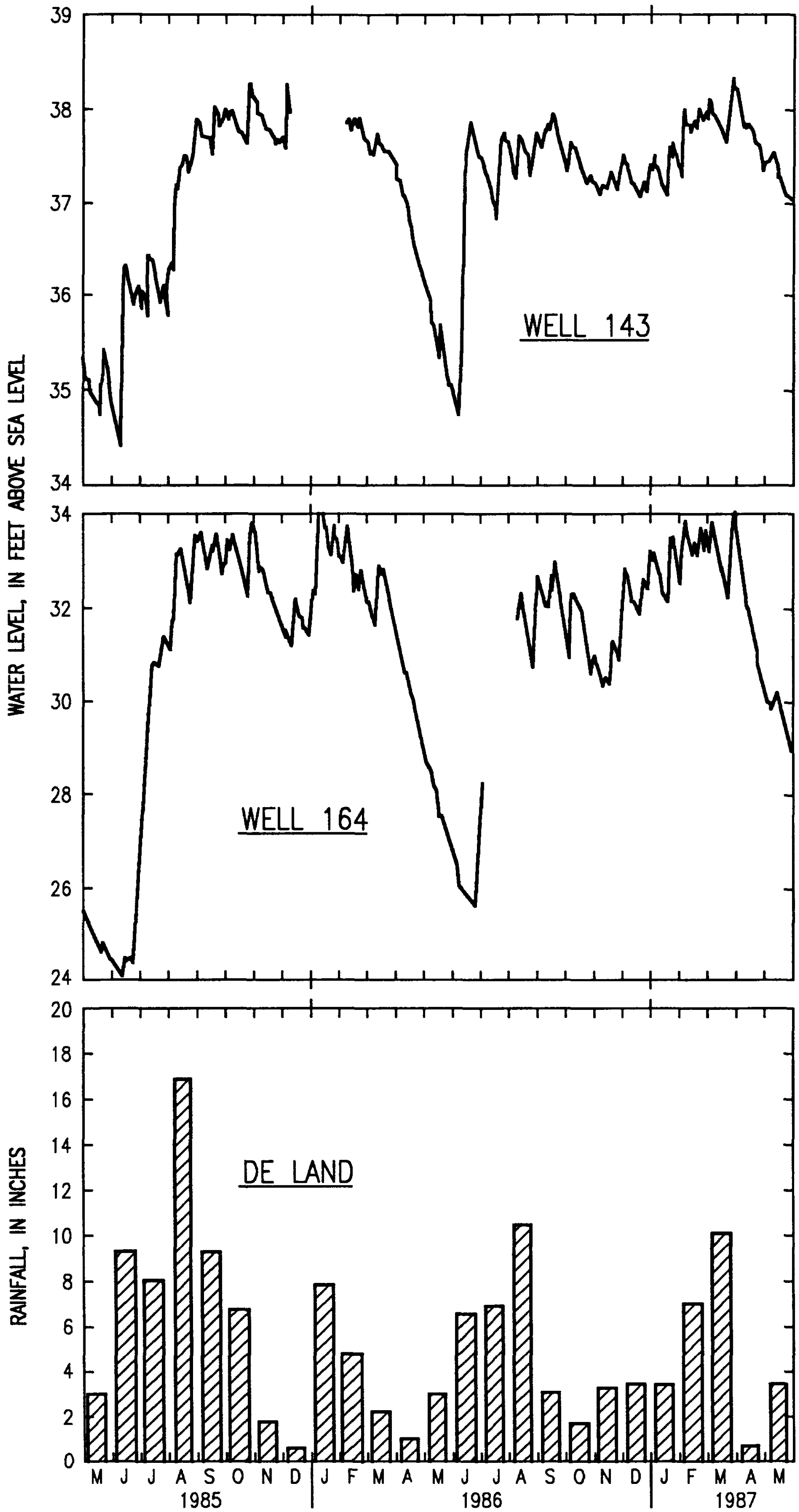


Figure 13a. Hydrographs for wells 143 and 164 completed in the upper permeable zone and rainfall at De Land, May 1985 through May 1987.

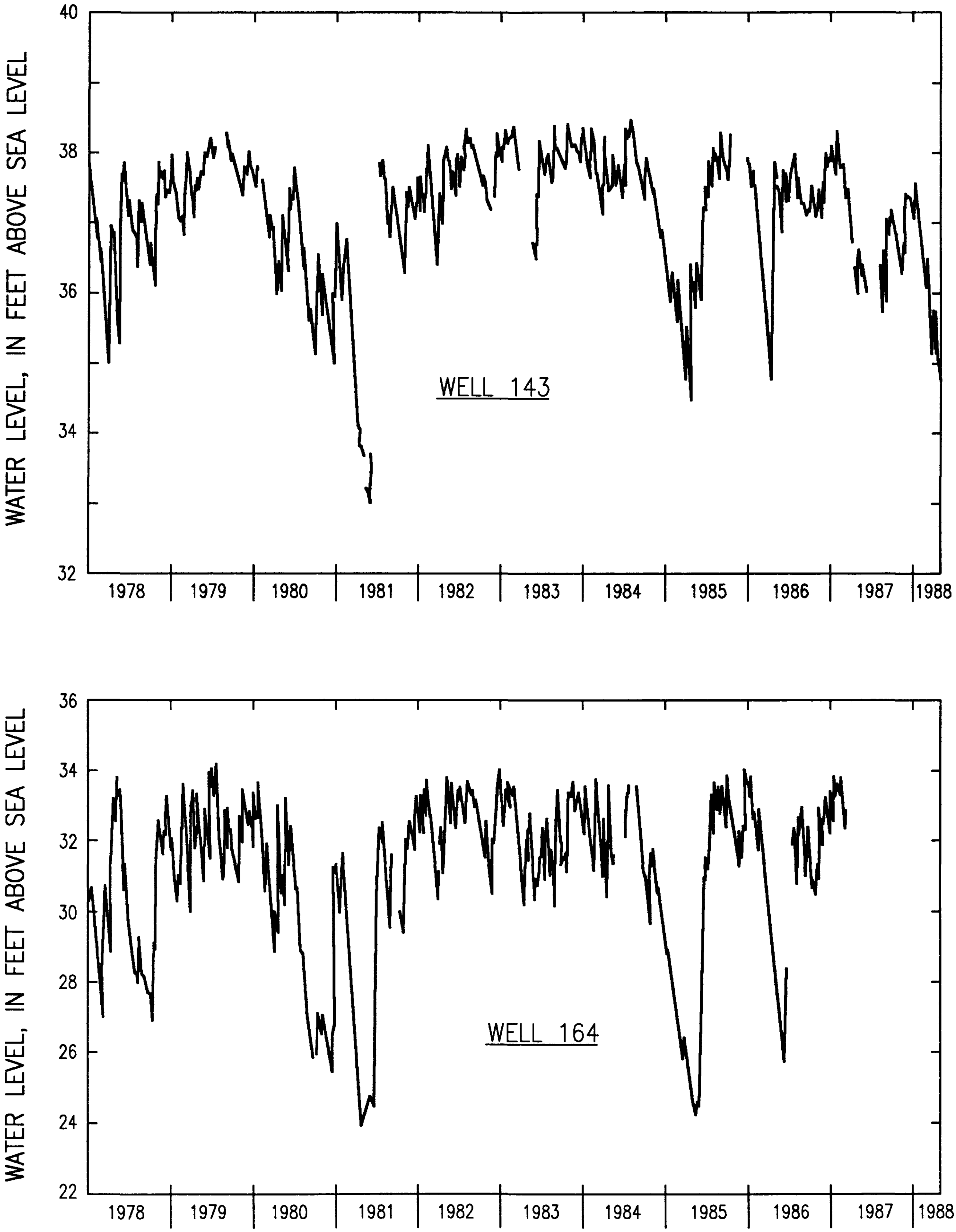


Figure 13b. Hydrographs for wells 143 and 164 completed in the upper permeable zone for the period of record.

Table 4. Comparison of water levels in wells completed in the surficial aquifer system and the Upper Floridan aquifer, September 1986

[Well numbers are from table 1. U, upper permeable zone; L, lower permeable zone; A, approximate; --, indicates no data]

Well No. and zone	Site identification No.	Water level above sea level: Upper zone (feet)	Lower zone (feet)	Upper Floridan (feet)
3 (U), 4 (L)	284822080573502/03	24	20	18 A
9 (U), 10 (L)	285002080503001/02	5	3	10 A
17 (U), 18 (L)	285138080505001/02	6	5	10 A
21 (U), 22 (L)	285152080520901/02	6	6	10 A
26 (U), 27 (L)	285343081140401/02	68	11	15 A
30 (U), 31 (L)	285437081181402/03	72	32	22
37 (U), 37 (L)	285625080525201/02	12	10	9
38 (U), 39 (L)	285630081174701/02	9	9	16 A
66 (U), 67 (L)	290025081185001/02	61	8	8 A
83 (U), 84 (L)	290243081175301/02	Dry	Dry	--
90 (U), 91 (L)	290421081210601/02	58	19	15 A
97 (U), 98 (L)	290508081200601/02	84	81	15 A
105 (U), 106 (L)	290554081160801/02	54	46	35 A
122 (U), 123 (L)	290756081211101/02	18	10	12
149 (U), 150 (L)	291032081181301/02	38	31	34
165 (U), 166 (L)	291357081274301/02	48	29	26 A
175 (U), 176 (L)	291441081254801/02	60	33	30 A
185 (U), 186 (L)	291520081290001/02	48	22	22 A
195 (U), 196 (L)	291806081284301/02	33	21	21 A

flow of 105 Mgal/d) and Ponce de Leon Springs (average flow 20 Mgal/d) are both located in Volusia County. A detailed discussion of water budgets for both the surficial and Upper Floridan aquifer systems in Volusia County is found in Rutledge (1985a, p. 34-38 and p. 45-46).

The main condition that must be met for rainfall to recharge the surficial aquifer system is that the uppermost sediments must be unsaturated and of sufficient permeability to allow downward percolation. This condition occurs in many areas of the county, particularly where the water table in the surficial aquifer system is higher than the potentiometric surface of the underlying Upper Floridan aquifer (a downward vertical hydraulic gradient exists). Such areas are recharge areas for both the surficial aquifer system and the Upper Floridan, and most of the water that recharges the surficial aquifer system in those areas eventually recharges the Upper Floridan. In other areas, where the potentiometric surface of the Upper Floridan is above the water table of the surficial aquifer system (an upward vertical hydraulic gradient exists), the surficial system receives recharge from the Upper Floridan (although the actual rate of recharge may be very low because of the low permeability of intervening sediments). In such areas, rainfall can still recharge the surficial aquifer system as long as the surficial sediments are unsaturated. The surficial aquifer system, thus, can receive recharge from both above and below. Such areas are recharge areas for the surficial aquifer system, but discharge areas for the Upper Floridan aquifer.

Recharge and Discharge Areas

Recharge and discharge areas generally can be delineated using the physiography and topography of the county (figs. 2 and 3) and the relation between the potentiometric surface of the Upper Floridan aquifer and land surface. The relation was mapped by Knochenmus (1968, fig. 3), and is shown in figure 14. It is still (1989) considered valid because no significant change in the potentiometric surface has occurred since the figure was compiled.

Another indicator that can be used to help delineate recharge areas is runoff. Rainfall not used by plants or evaporated must either contribute to surface runoff or recharge the ground-water reservoir. Knochenmus (1968, fig. 2) prepared a map showing annual rainfall and annual runoff for Volusia County which is probably still applicable. Runoff data from that map are shown in figure 15. Streamflow in Volusia County is mostly outflow from the surficial aquifer system because all significant surface-drainage systems in Volusia County have their headwaters

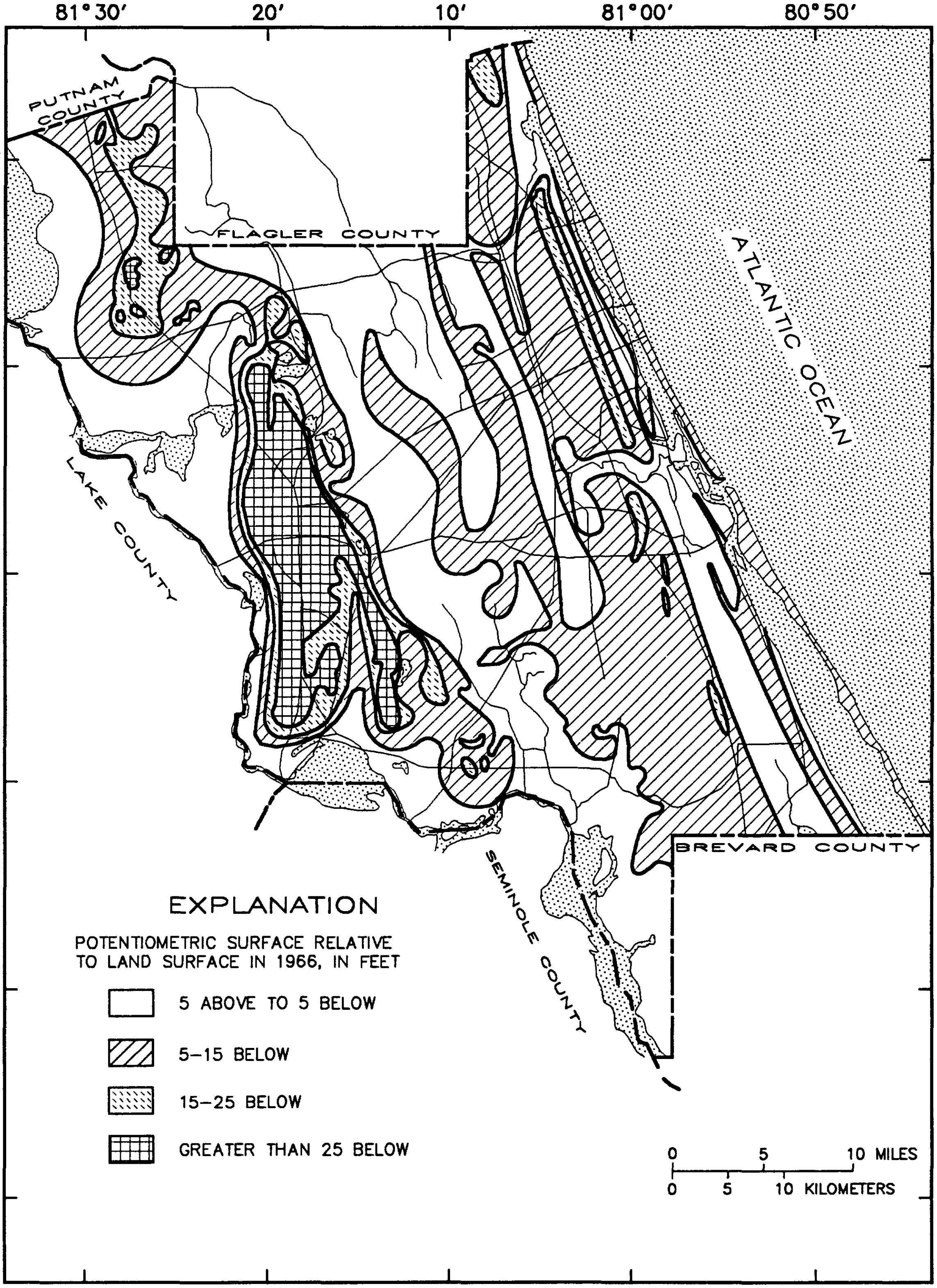


Figure 14. Relation of the potentiometric surface of the Upper Floridan aquifer to land surface (from Knochenmus, 1968, fig. 3).

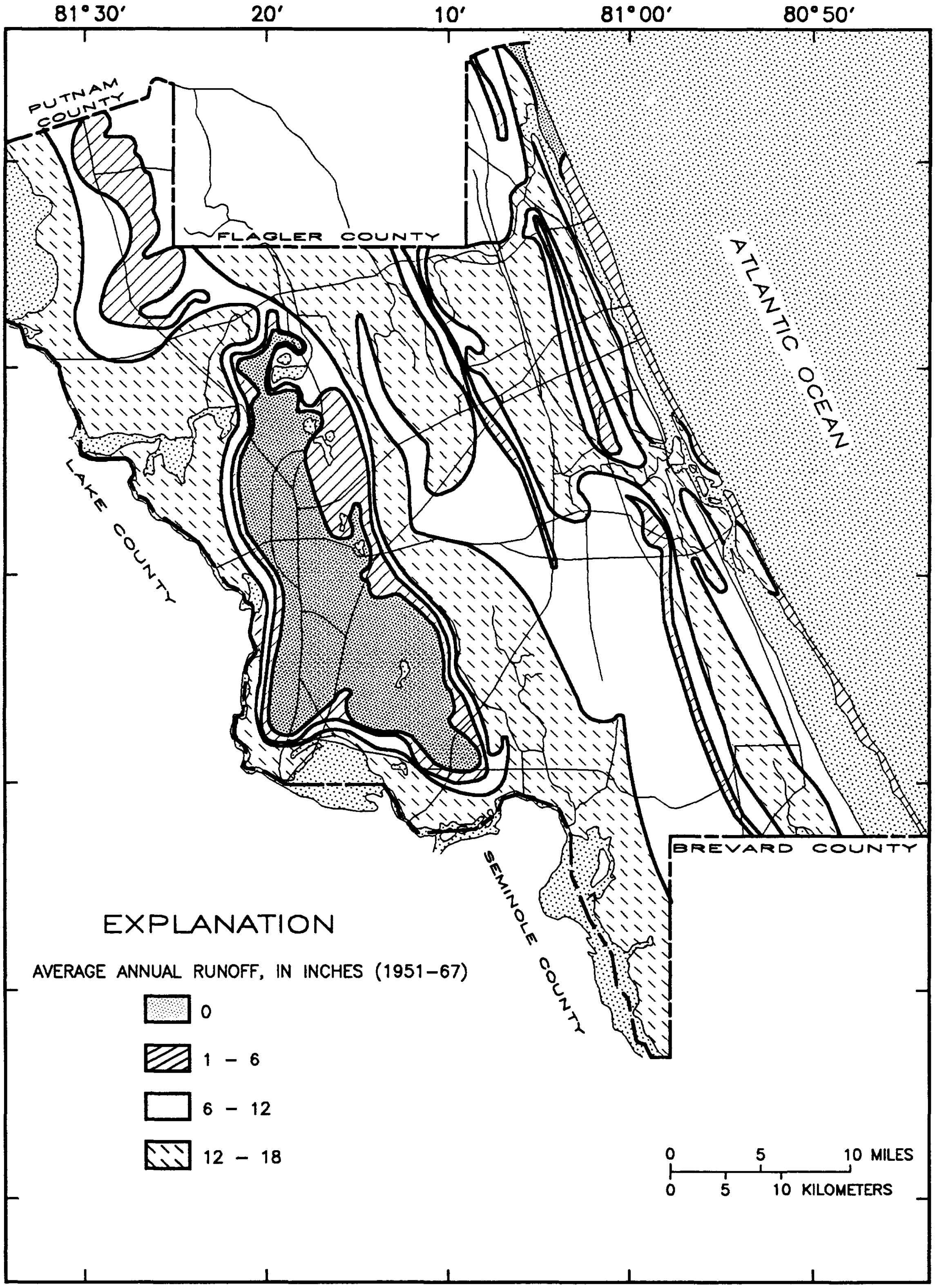


Figure 15. Average runoff (from Knochenmus, 1968, fig. 2).

within the county (Rutledge, 1985a, p. 36). The following discussion shows how figures 14 and 15 are used to delineate recharge areas in different parts of the county.

In the western part of the county, the De Land and Crescent City Ridges (fig. 2) are recharge areas for both the surficial aquifer system and the Upper Floridan aquifer. Throughout the area, the land surface altitude is mostly greater than 50 feet (fig. 3). The potentiometric surface of the Upper Floridan aquifer is at least 15 feet below land surface throughout most of the area and more than 25 feet below land surface in some of the area (fig. 14). The ridges, which are karst areas, have no surface drainage and thus no runoff (fig. 15). Recharge rates to the surficial system are high, and most of the water that enters the surficial aquifer system moves relatively quickly downward, recharging the Upper Floridan aquifer. By contrast, in the areas of relatively low land surface altitude between the two ridges and along the valley of the St. Johns River, rejected recharge to the surficial aquifer system occurs because the unsaturated surficial sediments are thin and there is a persistent upward vertical hydraulic gradient.

On the relatively flat Talbot and Pamlico Terraces (fig. 2) in the central part of the county, the altitude of land surface is generally about 25 to 50 feet (fig. 3) and the potentiometric surface of the Upper Floridan aquifer ranges from slightly above to about 15 feet below land surface. The area produces about 6 to 18 inches of runoff per year (fig. 15). In most of the area there is a downward vertical hydraulic gradient but it is very small and, because of the flat land surface and low transmissivity in the Upper Floridan aquifer, the surficial sediments remain saturated, or nearly so, much of the time. Kimrey (1990) concluded that recharge is being rejected from the surficial aquifer system along the western edge of the Talbot Terrace. Computer simulations of a test area in central Volusia County, by Bush (1978), indicate that significant amounts of the rejected recharge could be captured by lowering heads in the Upper Floridan. Thus, in the central part of the county, the surficial aquifer receives recharge at a slow rate, acts as a storage bank for water that can slowly percolate downward to the Upper Floridan aquifer, and also discharges excess water. In the relatively flat area of the terrace, land surface relief of only 5 feet can be the difference between a swampy "bay" where recharge is rejected, or a dry "island," where water can infiltrate and percolate downward at a slow rate.

Rima Ridge (fig. 2), which separates the Talbot and Pamlico Terraces, is higher in altitude than the surrounding terraces. It is an important area of local recharge to the surficial aquifer system and to the Upper Floridan as well, but because of its small area, cannot be considered a major recharge area.

In the eastern part of the county, sandy beach ridges with altitudes of about 25 feet alternate with low interridge areas with altitudes of about 5 to 10 feet (figs. 2 and 3). The potentiometric surface of the Upper Floridan aquifer (fig. 14) in some places is above land surface, and generally no more than 15 feet below land surface (except along the northern part of the Atlantic Coastal Ridge (fig. 2) where the potentiometric surface may be as much as 25 feet below land surface). Runoff ranges mostly from 6 to 18 inches per year, although on the Atlantic Beach Ridge (the barrier island), runoff is only 1 to 6 inches, probably reflecting a higher infiltration rate for the surficial sediments. Along the beach ridge in this area, the surficial aquifer system receives local recharge from rainfall, and is also recharged by upward leakage from the underlying Upper Floridan aquifer. The rate of upward leakage is thought to be very low because the sediments between the surficial aquifer system and the Upper Floridan aquifer have low permeability.

Knochenmus and Beard (1971, p. 12) concluded that for the Upper Floridan aquifer "no area in Volusia County can be considered the principal recharge area." This statement was meant to counter the widely accepted misconception that Upper Floridan recharge occurs primarily in areas where the potentiometric surface of the Upper Floridan aquifer is relatively high. In Volusia County, the potentiometric-surface high of the Upper Floridan is at the western edge of the Talbot Terrace, not along the De Land Ridge, where the highest rates of recharge to the Upper Floridan occur. Knochenmus and Beard (1971) cited work by Visher and Wetterhall (1967) concluding that in the Floridan aquifer system, most potentiometric-surface highs are indicative of areas of low transmissivity and low, or rejected, recharge.

To summarize, recharge to the surficial aquifer system can occur wherever the surficial sediments have an unsaturated zone and are permeable. Thus, the recharge to the surficial aquifer takes place, at least locally, throughout much of the county. However, for recharge to enter the Upper Floridan aquifer, there must be a downward vertical hydraulic gradient between both zones of the surficial aquifer system and the Upper Floridan, and the sediments between the surficial aquifer system and the Upper Floridan must be permeable.

Rates of Recharge

Rates of recharge to a ground-water reservoir can be estimated using water budgets or by summing the rises portrayed in hydrographs. Computer-modeling studies by Bush (1978) and Tibbals (1981) provided the basis for a water budget of the surficial aquifer system described by Rutledge (1985a, table 4). He estimated that the rate of recharge in ridge areas of the county (western part) ranged from 10 to 18 in/yr (inches per year), whereas in terrace (nonridge) areas not in areas of artesian-flow in the Upper Floridan (central part of the county), the rate was about 4 in/yr. In areas of artesian flow, he calculated that the surficial aquifer received about 4 in/yr of upward leakage from the Upper Floridan aquifer. Rutledge assumed that the residual water of the ground-water budget for the surficial aquifer system eventually reached the Upper Floridan aquifer; that is, net recharge to the surficial aquifer system equals discharge (flowthrough) to the Upper Floridan.

During this study, rates of recharge to the surficial aquifer system were estimated using hydrograph data from three wells tapping the upper permeable zone (locations are shown in fig. 12) of the surficial aquifer system. The analysis utilized a method described by Rasmussen and Andreasen (1959, p. 94-95) in which recharge is estimated by summing the rises in ground-water stage and multiplying the result by the gravity yield (specific yield). As mentioned by Rasmussen and Andreasen (1959, p. 94), this estimate falls short of the true recharge by the amount of ground-water drainage occurring during the rise. A specific yield (S_y) of 0.25 was estimated by Knochenmus and Beard (1971, p. 31) and probably represents an upper limit. A minimum value of S_y is estimated to be 0.10. Because of the detailed data available, hydrographs for wells 43, 71, and 111 for 1966-69 were analyzed. An example of the use of this method is shown for well 43 in figure 16. The calculated recharge is as follows:

	Recharge, inches					
	Well 43		Well 71		Well 111	
Time interval	S_y = 0.25	S_y = 0.10	S_y = 0.25	S_y = 0.10	S_y = 0.25	S_y = 0.10
5-66 to 4-67	16.05	6.42	20.10	8.04	18.60	7.44
5-67 to 4-68	7.05	2.82	15.60	6.24	21.60	8.64
5-68 to 4-69	28.80	11.52	22.50	9.00	27.60	11.04

Rainfall at De Land was 50.07 inches for May 1966 to April 1967, 40.22 inches for May 1967 to April 1968, and 68.83 inches for May 1968 to April 1969. The recharge calculated for S_y = 0.25 thus ranged from about 17 to 54 percent of rainfall and, for S_y = 0.10, from 7 to 21 percent of rainfall. At well 43, located in a basin with no surface runoff, evapotranspiration can be estimated by subtracting the recharge rate from the rainfall (assuming that there is no horizontal ground-water outflow). For May 1966 to April 1967, estimated evapotranspiration was about 34 inches for S_y = 0.25 and 44 inches for S_y = 0.10; for May 1967 to April 1968 about 33 inches for S_y = 0.25 and 37 inches for S_y = 0.10; and for May 1968 to April 1969 was about 40 inches for S_y = 0.25 and 57 inches for S_y = 0.10. At well 43, the evapotranspiration rate estimated by this method and assuming a value of S_y of 0.25 is similar to the 38 to 39 inches estimated by Rutledge (1985a, table 4). For S_y = 0.25, the arithmetic mean of the three annual recharge rates calculated is 17 in/yr at well 43.

At wells 71 and 111, runoff must also be considered because the wells are in basins that produce runoff. Rutledge (1985a, p. 36) reports that streamflow in Volusia County is mostly outflow from the surficial aquifer system. Recharge rates calculated using S_y = 0.25 are high, so the estimate of S_y = 0.10 may be more accurate at those sites. Mean recharge rates based on that figure are about 8 in/yr and 9 in/yr for wells 71 and 111, respectively. Other factors influencing the relatively high recharge rates calculated include differences in vegetation type, nonrepresentative rainfall data because precipitation can vary widely from one area to another due to extremely localized convection thunderstorms during the summer, or because the assumption of no horizontal ground-water outflow is not correct.

Recharge enters the surficial aquifer system throughout much of Volusia County. The highest rates of recharge occur in the ridge areas having no surface drainage, in the western part of the county. Locally, recharge rates in that area can range from 6 to 18 in/yr (Tibbals, 1981, fig. 8; Rutledge, 1985a, table 4), which compare favorably to the 17 in/yr calculated at well 43. The ridge areas without surface drainage occupy about 16 percent of the county. In the ridge areas, most of the recharge to the surficial aquifer system moves quickly downward to the Upper Floridan aquifer.

Substantial recharge also occurs on the Talbot and Pamlico Terraces. Although the terraces are not as conducive to recharge as the ridges (the downward vertical ground-water gradient is very slight, the unsaturated zone is thin, and the permeability of the underlying sediments ranges considerably), the terraces cover about 50 percent of the county. A recharge rate of 8 or 9 in/yr is estimated for the terrace areas. Recharge also occurs in ridge areas with surface drainage, but because such areas account for only about 6 percent of the county, the amount of recharge occurring there is much less significant than in other areas.

Recharge to the surficial aquifer system also occurs along the coastal ridges in the eastern part of the county at rates that can be as high as 10 in/yr, but because the areas of this recharge are small and localized, recharge amounts are not significant. In the coastal ridges, the surficial aquifer system also receives recharge by upward leakage from the Upper Floridan aquifer. Recharge rates for the surficial aquifer system can be summarized as follows:

Area type	Approximate area (mi^2)	Estimated recharge rate (in/yr)	(Mgal/d)
Artesian flow from Upper Floridan	336	0-4	0-64
Terraces	600	8-9	228-257
Ridges without surface drainage	192	6-18	55-165
Ridges with surface drainage	72	9-10	31-34

Hydraulic Characteristics of the Surficial Aquifer System

The hydraulic characteristics of the surficial aquifer system in Volusia County vary with the lithology. The lithology, in turn, is very heterogeneous because the materials were deposited during cyclic transgressions and regressions of the sea. Knochenmus and Beard (1971, p. 9) concluded that "it appears that the variation in vertical permeability is as great from site to site within the same physiographic division as between sites within different physiographic divisions." Hydraulic characteristics of an aquifer can be determined by both laboratory and field techniques. Each method has certain advantages and disadvantages.

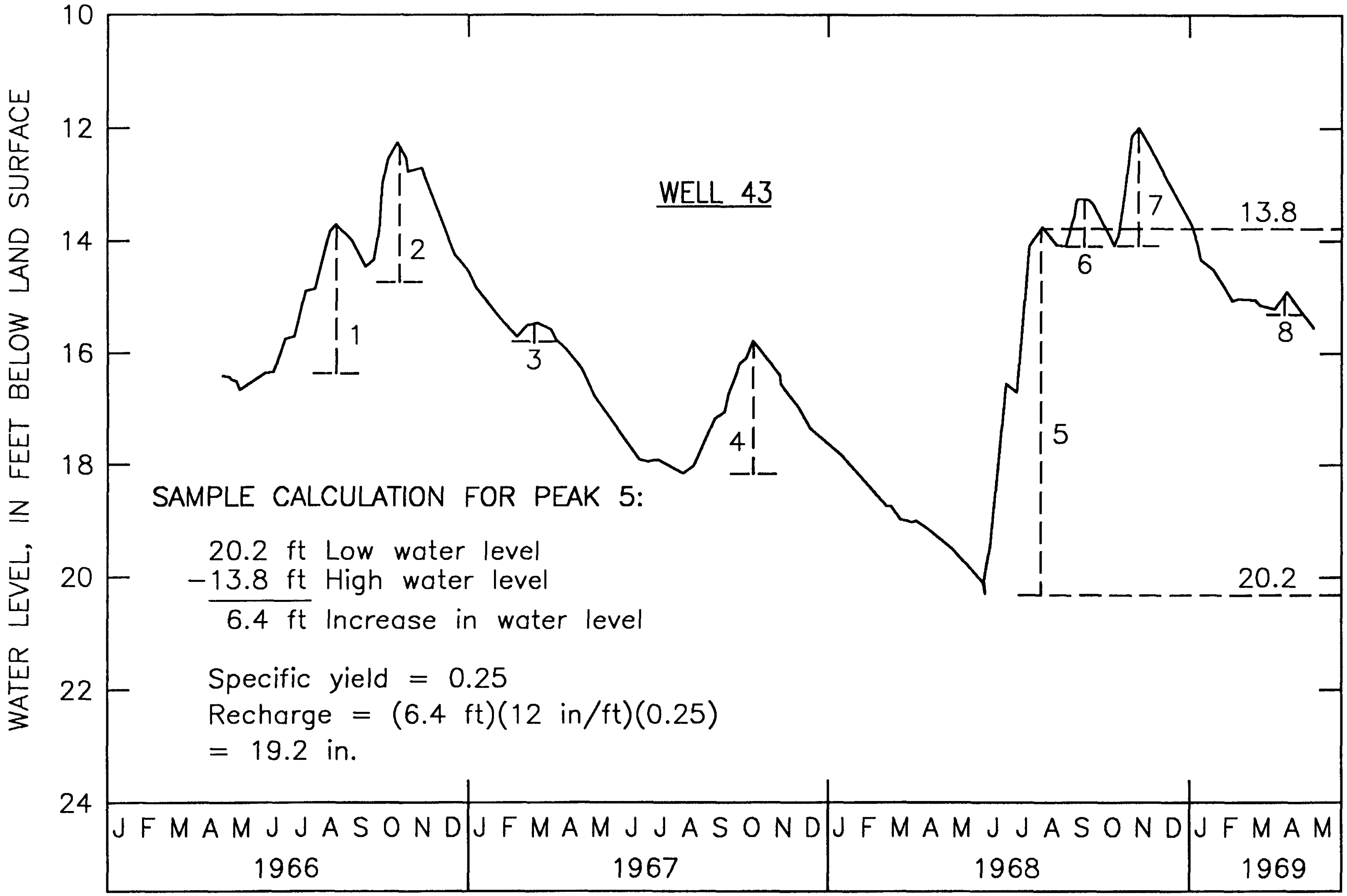


Figure 16. Calculation of recharge using the hydrograph of well 43.

Laboratory Determinations of Hydraulic Conductivity

Core samples collected in the field can be analyzed in a laboratory to determine their hydraulic conductivity. Laboratory conductivities tend to be lower than field determinations for several reasons. Sediments containing more permeable materials tend to be distorted during coring and probably are further disturbed during transit to the laboratory. The coring process itself can cause compaction of the materials, thereby reducing the permeability of the core sample. Finally, samples of more permeable material often cannot be recovered during the coring process, so those cores that are analyzed tend to be biased toward lower permeability.

Kimrey (1990) described hydraulic characteristics of samples from 14 core holes in central Volusia County. The locations of these core holes are shown in figure 5; the laboratory-determined hydraulic characteristics for 11 clay samples from the core holes are given in table 5. Hydraulic conductivities range from 7.6×10^{-5} to 3.4×10^{-1} ft/d with a median of 1.0×10^{-2} ft/d. The least permeable sample came from a clay layer less than 1 foot thick. In core hole 7, a zone of clay with a laboratory hydraulic conductivity of 1.1×10^{-4} ft/d was about 9 feet thick. Kimrey (1990), reported that, in general, the clay layers could not be correlated from hole to hole, and thus, concluded that confining units within, and at the base of the surficial aquifer system, are not continuous.

If several laboratory hydraulic conductivities are available for various samples in a single borehole, the true hydraulic conductivity of the formation can be estimated by techniques described by Bouwer (1978, p. 131-133). In heterogeneous material, such as is found in the surficial aquifer system, the permeability distribution appears to be random and the average hydraulic conductivity of the formation should be determined using the geometric mean, rather than using one value for the entire sequence or using the arithmetic mean of several values.

Table 5. Laboratory hydraulic conductivities for selected core samples in Volusia County

[Core hole numbers refer to figure 5; ft/d, feet per day; modified from Kimrey, 1990]

Core hole No.	Depth (feet)	Description of core sample	Average hydraulic conductivity, K(ft/d)
3	44-49	Bluish-gray plastic clay, with traces of brown-gray fine sand inclusions.	2.4×10^{-1}
7	32-33	Bluish-gray sandy clay with traces of shell fragments	3.4×10^{-1}
7	20-29	Gray plastic clay with traces of shell fragments	1.1×10^{-4}
8	62-63	Bluish-gray plastic clay	2.6×10^{-3}
8	69-70	Light gray slightly clayey fine sand with fine shell fragments	3.6×10^{-2}
9	64-65	Light gray slightly clayey fine sand with traces of shell fragments	2.2×10^{-2}
10	31-33	Bluish-gray plastic clay with large limestone inclusions	8.1×10^{-3}
11	52-53	Bluish-gray clay with small horizontal sand lenses, (brittle as received)	1.0×10^{-2}
12	46-47	Bluish-gray sandy clay with traces of shell fragments	7.6×10^{-5}
13	36-37	Greenish-gray clay (slightly brittle as received)	7.8×10^{-4}
14	80-81	Greenish-gray clay (brittle as received)	1.0×10^{-2}

Field Determinations of Hydraulic Conductivity

Field hydraulic conductivity values are generally determined by some type of aquifer testing technique which can range from a simple slug test of a single well to a more complex aquifer test using a pumped well and several observation wells.

Slug injection tests were made by the St. Johns River Water Management District on some test wells drilled during this study and on some test wells drilled by the Water Management District. The slug test involves the instantaneous injection (or withdrawal) of a slug of water into (or from) a well. The resulting drop (or recovery) in water level is measured and a field value of hydraulic conductivity calculated. The well should be fully developed and open to the full thickness of the aquifer being tested. It is important to note that the test generally applies only to the material close to the well and indiscriminate use of the results can lead to erroneous conclusions (Ferris and Knowles, 1963, p. 299).

Field hydraulic conductivities determined by McGurk and others (1989) are shown in table 6. The values range from 3×10^{-2} to 12.8 ft/d with a median of 2.9×10^{-1} ft/d, much higher than the laboratory values in table 5 (7.6×10^{-5} to 3.4×10^{-1} ft/d), primarily because the slug tests measured the hydraulic conductivities of the more permeable strata of the surficial aquifer system, whereas the laboratory tests (as discussed previously) measured the hydraulic conductivity of the least permeable strata.

In a repeat test on each of two wells, the calculated hydraulic conductivity values differed by an order of magnitude. Although it is not known whether such variability would be observed in the other wells, on the basis of these tests, it appears that the range of error in the slug tests may be one order of magnitude.

Table 6. Field hydraulic conductivities for wells in Volusia County

[Data from McGurk and others, 1989. Well or site numbers refer to table 1 and figure 6. Aquifer zone: U, upper permeable zone; L, lower permeable zone; ft/d, feet per day]

Well or site No.	Interval tested (feet)	Aquifer zone	Hydraulic conductivity (ft/d)
206, V0185	20-30	U	1.0×10^{-1} 4.5×10^{-2}
V0354	55-75	L	1.0 2.1×10^{-1}
123, V0372	62-72	L	3.0×10^{-2}
122, V0360	32-42	U	1.5×10^{-1}
V0356	45-65	L	7.7
V0357	48-58	L	3.1
V0193	16-40	U	1.9×10^{-1}
V0361	53-73	L	1.0
V0363	50-69	L	1.7×10^{-1}
V0364	53-73	L	2.9×10^{-1}
30, V0197	20-30	U	2.2×10^{-1}
V0368	40-60	L	4.0×10^{-1}
4, V0369	57-70	L	1.7
V0370	50-60	L	4.8
V0371	0-20	U	12.8
V0373	20-40	U	5.2×10^{-1}

Aquifer Tests

Results from earlier studies

Perhaps the most representative method, but also the most complicated and labor intensive one, of determining field values of hydraulic parameters is by an aquifer test, in which a well is pumped and the drawdown and recovery of water levels in one or more observation wells, are recorded and analyzed.

Gomberg (1980, 1981) performed numerous aquifer tests in both the upper and lower permeable zones of the surficial aquifer system in northeastern Volusia County. He calculated transmissivity values for the upper zone ranging from less than 100 to more than 1,300 ft^2/d, and concluded that the variations were caused mostly by variations in the thickness of the permeable zone. Hydraulic conductivities estimated from Gomberg's data for the upper permeable zone ranged from about 4 to 110 ft/d. Transmissivities for the lower zone ranged from less than 300 to more than 9,300 ft^2/d. Hydraulic conductivities calculated from these aquifer tests ranged from 28 to 49 ft/d. The large range in transmissivity values for the lower zone is caused by variations in thickness of the aquifer and in permeability, which results from lithologic variations (Gomberg, 1980, p. v). Sediments containing more silt and clay have lower transmissivities than those composed mostly of sand and shell. No other aquifer tests for the surficial aquifer system were found in the existing literature because most past studies of the water resources of Volusia County have concentrated on the Floridan aquifer system.

Oak Hill aquifer test

In the Oak Hill area of southeastern Volusia County (fig. 1), the water in the Upper Floridan aquifer is not potable because of high chloride concentration. Therefore, most of the water supply for the area is withdrawn from domestic wells that tap the lower zone of the surficial aquifer system.

An exploratory auger boring was drilled in the area and the lithology of the sediments encountered was as follows:

Land surface to 15 feet	fine, light buff-colored sand
15-35 feet	fine, light brown sand
35-45 feet	fine, light gray sand
45-50 feet	fine, light gray sand, with some shell
50-60 feet	fine, light gray sand and shell hash
60-70 feet	gray silty sand and shell hash

Because of the desire not to penetrate the confining layer between the surficial sediments and the Upper Floridan aquifer, drilling was stopped at 70 feet below land surface. Based on information about the casing depths of wells in the area which penetrate the Upper Floridan, it is estimated that the bottom of the lower permeable zone is no more than 75 to 80 feet below land surface. Thus, based on test drilling and the natural gamma log of well 14 in figure 9a, the thickness of the lower zone at the site is about 35 to 40 feet.

Four pairs of wells were drilled near the Oak Hill Town Hall (fig. 17). A 6-inch production well (well 285129080510501) was completed into the lower permeable zone. The well was drilled using the mud-rotary method and completed with a wire-wound plastic screen from 50 to 60 feet below land surface. The screen was gravel packed and the well was developed by surging and with compressed air. Twenty feet to the east of the production well, a 6-inch well was drilled (well 285129080510502), also by mud rotary, and a plastic casing with a wire-wound plastic screen emplaced at a 20- to 30-foot depth was installed and gravel packed. Development was similar to that for the production well. Three pairs of 2-inch diameter observation wells were augered at distances of 126, 154, and 250 feet (fig. 17). Each pair was composed of a 60-foot deep well screened from 50 to 60 feet, and a 30-foot deep well screened at the 20- to 30-foot depth. The observation wells were developed with compressed air.

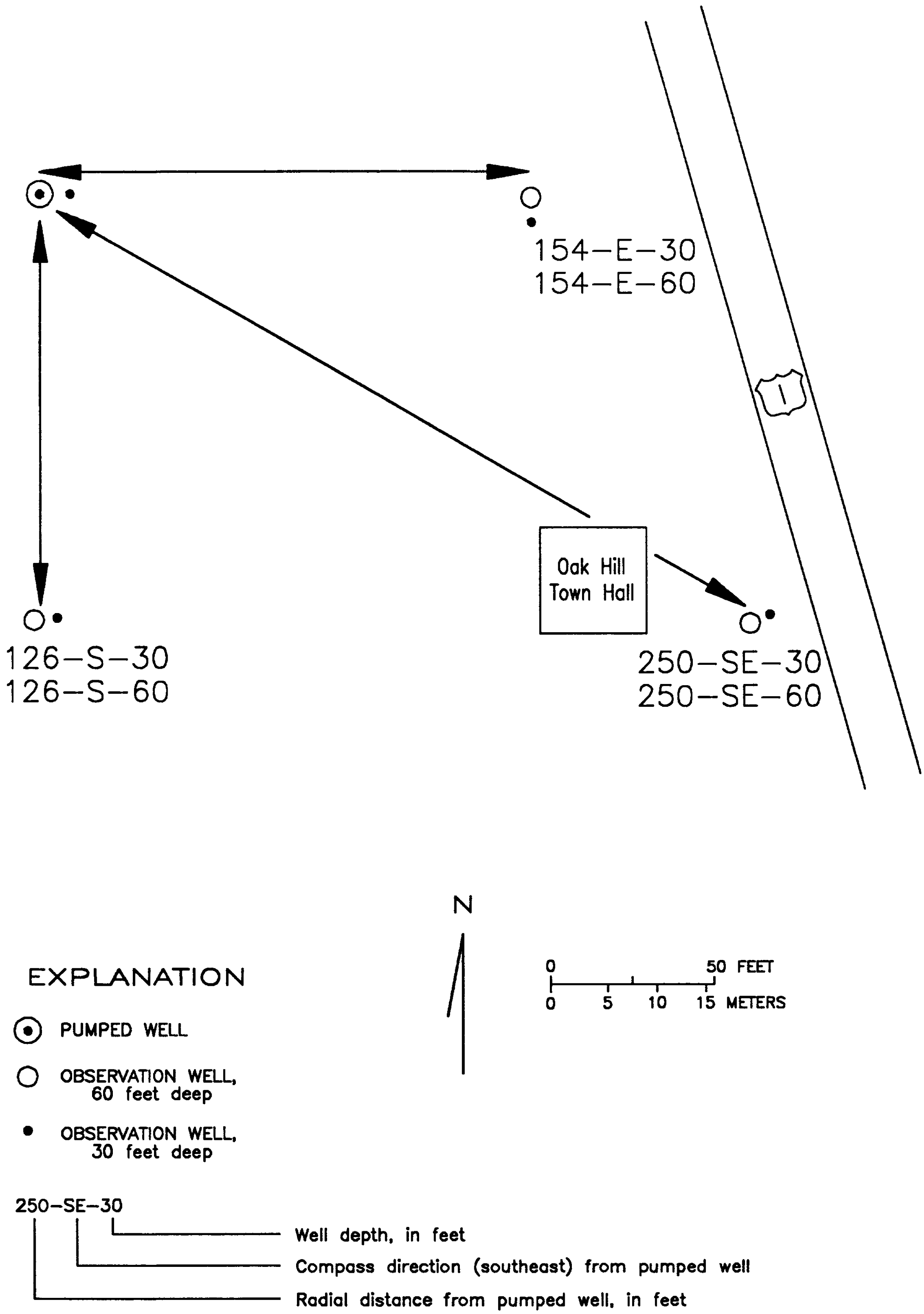


Figure 17. Sketch of Oak Hill aquifer test site.

Water levels in the well pairs during nonpumping periods are given in table 7. The mean difference in depth to water between the upper and lower zones is about 1 foot. Although the natural gamma log in figure 9a does not show the presence of a high gamma-activity clay layer between the upper and lower zones, the fine sand and silt found at the site apparently provide sufficient confinement to separate the two zones, based on the data collected while pumping the lower zone.

Table 7. Depth to water in well pairs at Oak Hill test site

[Datum is land surface; depth is in feet; -- indicates no data]

Well	Date 02-26-87	03-03-87	03-04-87	09-14-87	09-17-87
285129080510501	8.46	8.45	8.63	--	9.79
285129080510502	6.60	7.39	7.35	8.74	8.27
Difference	1.86	1.06	1.28	--	1.52
154-E-60	6.80	8.22	8.45	9.69	8.43
154-E-30	6.32	7.43	7.50	8.34	7.00
Difference	.48	.79	.95	1.35	1.43
250-SE-60	7.65	6.51	6.68	8.06	8.93
250-SE-30	7.06	5.92	5.90	6.84	7.76
Difference	.59	.59	.78	1.22	1.17
125-S-60	10.12	10.09	10.26	11.54	11.40
125-S-30	9.37	9.36	9.36	10.80	10.39
Difference	.75	.73	.90	.74	1.01

An aquifer test was conducted on March 4-5, 1987. The production well was pumped at 50 gal/min (gallons per minute) for about 19 hours. The response of the upper permeable zone to pumping the lower permeable zone was slight. In well 285129080510502, 20 feet east of the production well and 30 feet deep, the water level dropped about 0.05 foot after 5 minutes of pumping, remained steady for about 8 hours of pumping, and slowly returned to static level. In well 154-E-30, the water level slowly rose about 0.03 foot during the entire test. In well 250-SE-30, the level fell 0.05 foot and was slowly rising when the test ended after 19 hours of pumping. In well 126-S-30, the water level rose, then fell, then rose, with a fluctuation of about 0.04 foot (see fig. 17).

The maximum drawdowns in the lower permeable zone observation wells were: well 154-E-60, 0.79 foot; well 250-SE-60, 0.68 foot; and well 126-S-60, 1.33 feet. Variations in the drawdowns appear to be caused not only by differences in distance from the pumped well but perhaps also by anisotropy in the aquifer, probably caused by the heterogeneity of the sediments due to the depositional environment, and by the fact that all the wells did not fully penetrate the lower zone.

The aquifer test data were analyzed using Jacob's (1946) method, a curve-matching technique using the modified Bessel function. The method is applicable to leaky aquifers which have reached steady state. Figure 18a shows plots of drawdown against time for the three observation wells which indicate that steady state had been reached late in the test. To calculate transmissivity using Jacob's method, drawdown at each observation well was plotted against its respective distance from the production well at some time after steady state had been reached, in this case, 615 minutes into the test. A best fit to the Bessel function curve was made and, using the value of the Bessel function at the match point, a transmissivity of 1,200 ft^2/d was calculated. Assuming a thickness of the lower zone of 35 to 40 feet, this corresponds to a hydraulic conductivity of about 30 ft/d. Figure 18b shows the calculation of transmissivity.

The lower zone of the surficial aquifer receives leakage from above and below, so a leakance value was not calculated because the effects of the two sources of leakage cannot be separated with the data from this test.

Because the underlying Upper Floridan aquifer contains salty water, the specific conductance of water from the production well was monitored during the test. Before the test began, the specific conductance of the water was 575 μS/cm (microsiemens per centimeter) at 25° Celsius. After 15 hours of pumping, the specific conductance had risen to 720 μS/cm and after 19 hours to 800 μS/cm. If large-scale production of water from wells completed into the lower zone of the surficial aquifer in the Oak Hill area is contemplated, a long-term test to monitor changes in water quality would be useful.

QUALITY OF WATER

Previous studies of the ground water resources of Volusia County (Knochenmus and Beard, 1971) and Rutledge (1985a) did not address the chemical quality of water in the surficial aquifer system in detail and most discussions of water quality emphasized the chloride concentration in the water. During this study, 52 wells were sampled for major constituents, trace elements, and nutrients using techniques documented by Wood (1976) and Skougstad and others (1979). At 12 locations, both the upper and lower permeable zones were sampled. The locations of wells sampled are shown in figure 19.

Upper Permeable Zone

Water from 39 wells tapping the upper permeable zone of the surficial aquifer system were sampled in 1987. Physical characteristics, major constituents, and trace elements of the water samples are given in table 8, and nutrient concentrations in table 9. Also given in table 8 are chloride analyses of water collected by Rutledge (1985a) in 1982.

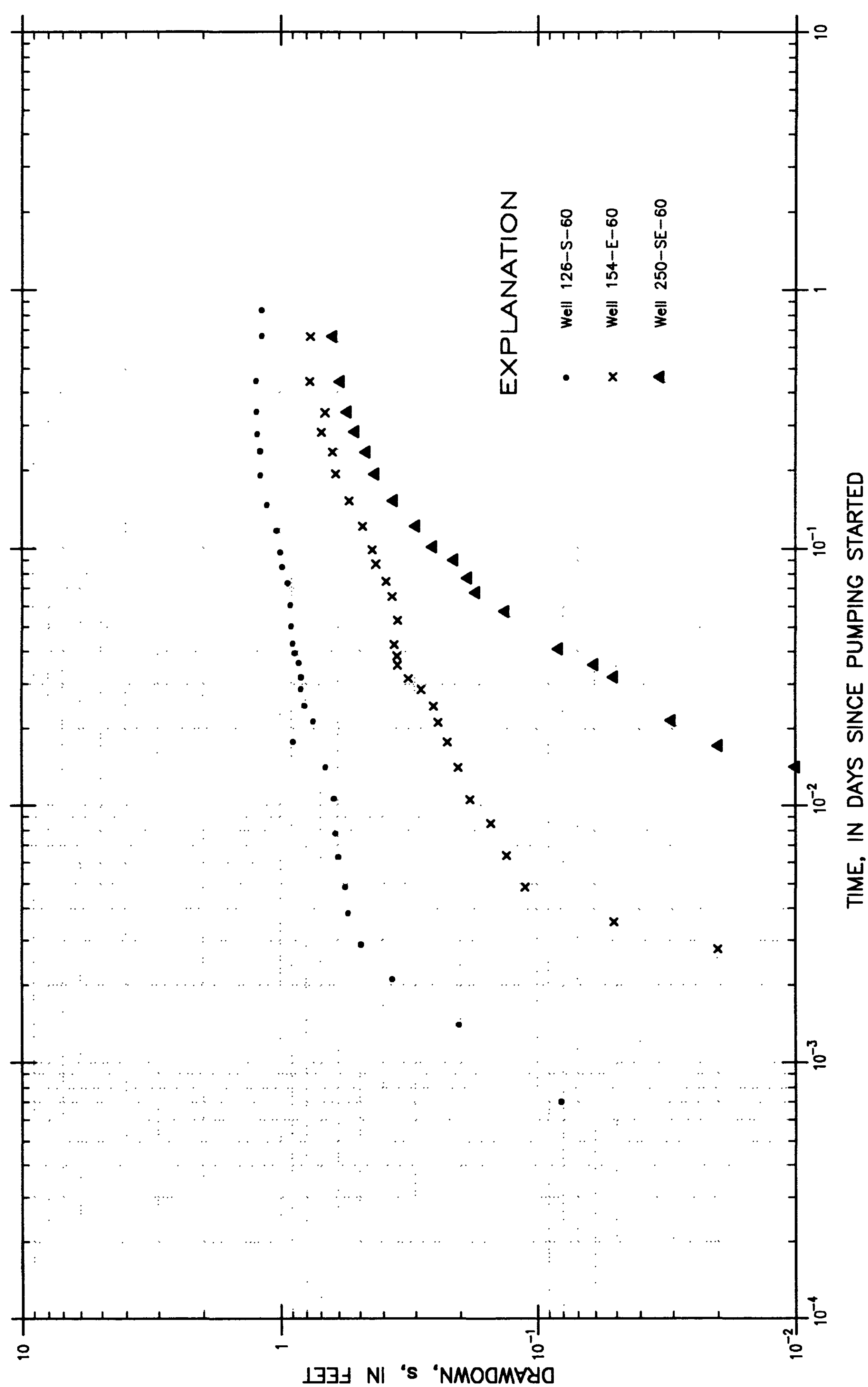


Figure 18a. Time-drawdown plot for Oak Hill observation wells.

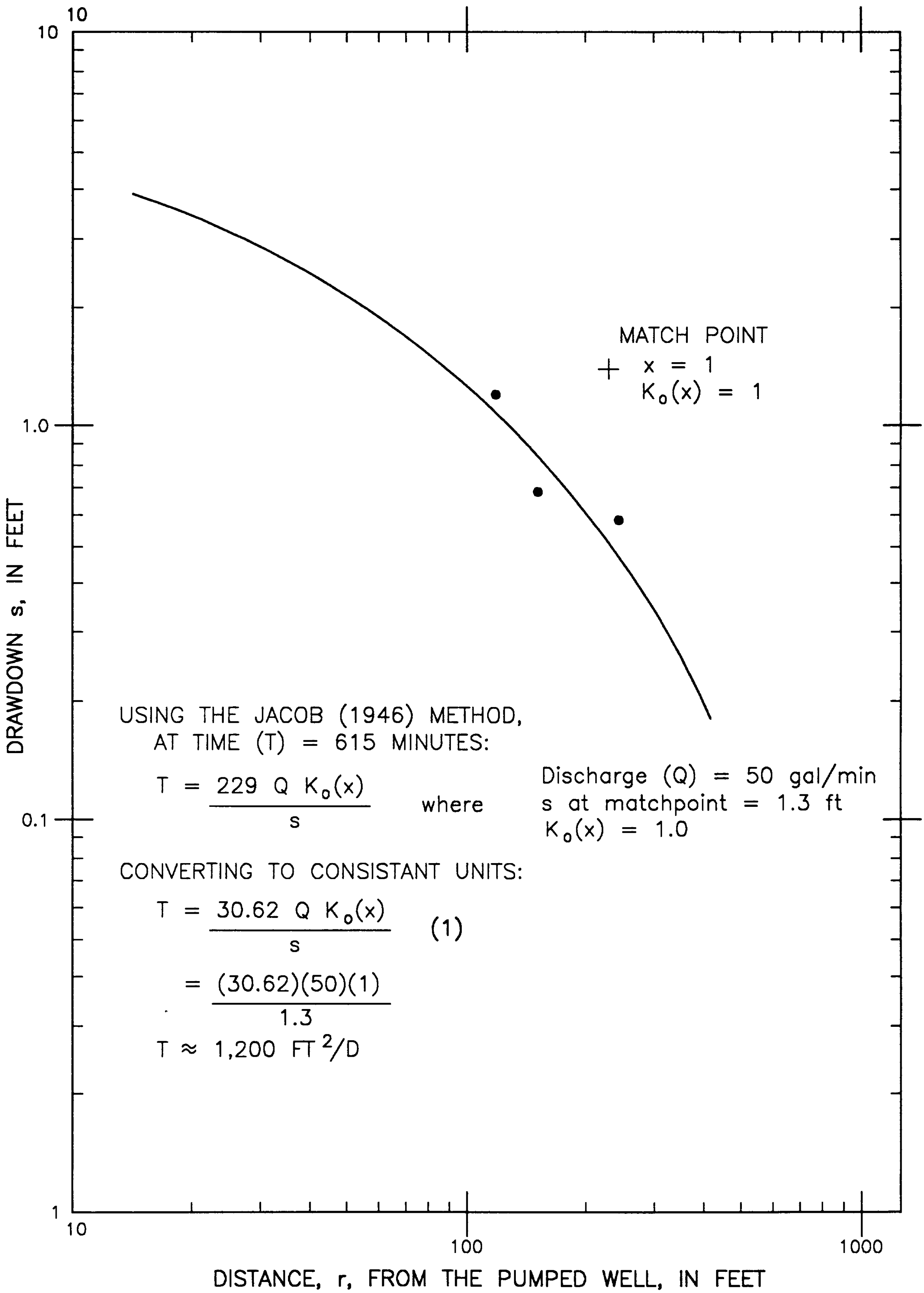


Figure 18b. Calculation of transmissivity of the lower permeable zone at Oak Hill.

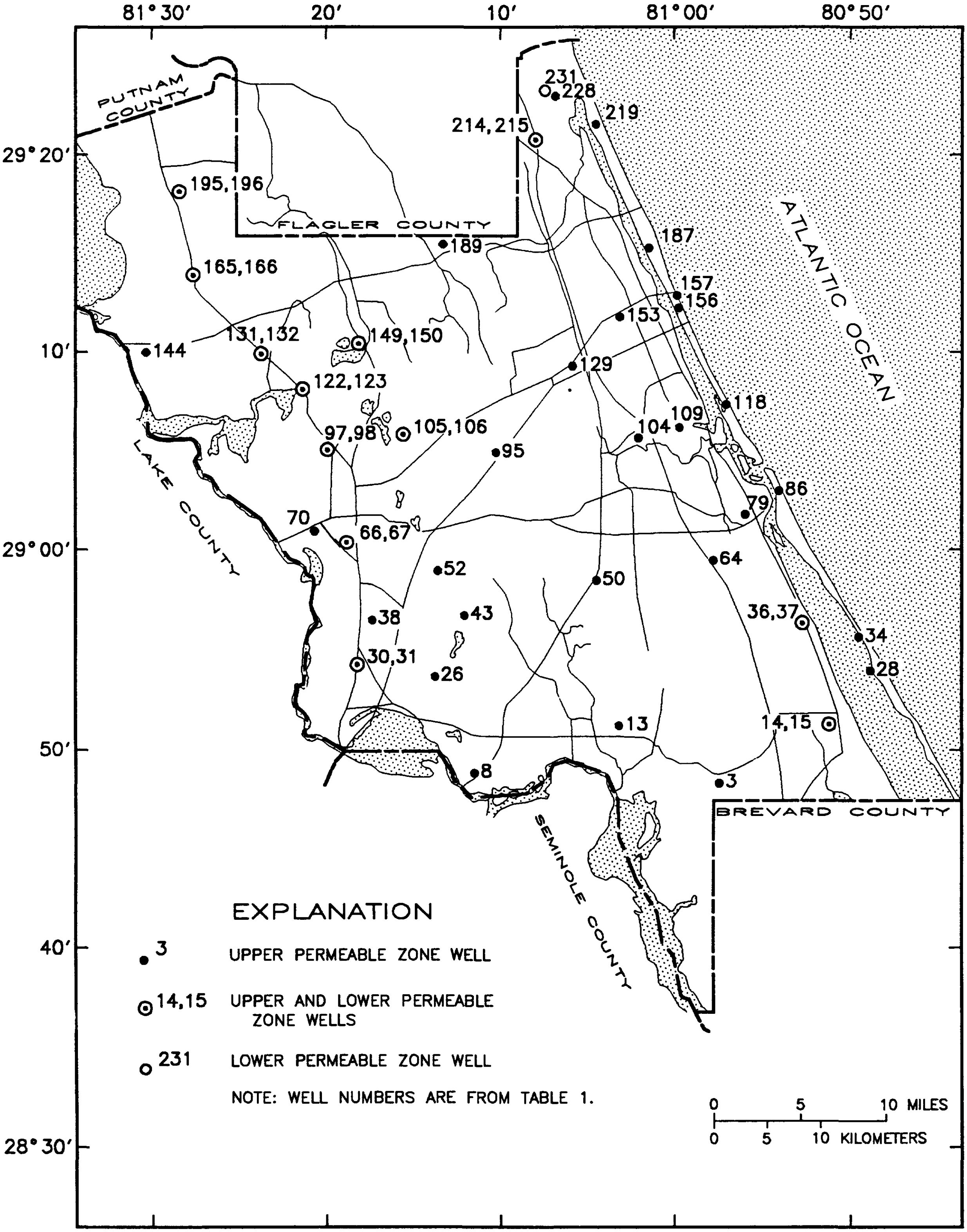


Figure 19. Locations of wells sampled during this study.

Table 8. Physical and chemical characteristics of water from the upper permeable zone

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, microgram per liter; -- indicates no data; <, less than; >, greater than]

Well No.	Station No	Date	Specific conductance (µS/cm)	Field pH (standard units)	Alkalinity (Lab) (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L) as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolvd (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Iron total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Strontium, dissolved (mg/L) as Sr)
3	284822080573502	04-22-87	175	5.85	46	50	17	1.8	15	0.90	27	<0.1	0.3	16	2,400	1,500	90
8	284846081114002	07-29-82	1,750	--	--	--	--	--	--		500	--	--	--	--	--	--
		03-12-87	2,050	7.20	132	350	100	23	250	3.4	510	74	.20	14	15,000	450	1,900
13	285114081032801	02-09-82	--	--	--	--	--	--	--	--	15	--	--	--	3,800	--	--
		05-06-87	410	7.05	234	230	89	2.5	11	.70	18	<.1	.10	16	--	3,200	610
15	285129080510502	03-10-87	350	--	110	130	47	1.8	17	1.3	23	13	.10	6.4	1,600	190	230
26	285343081140401	03-12-87	150	5.35	14	28	10	.80	7.8	.90	16	1.6	.20	9.8	1,800	790	80
28	285403080490001	05-21-87	1,730	6.85	341	420	130	23	140	5.2	240	30	.50	8.8	540	400	1,100
30	285437081181402	03-16-87	60	5.15	3.3	15	1.6	2.7	2.2	1.9	5.0	5.7	<.10	6.2	6,000	20	50
34	285545080493201	05-21-87	>41,100	7.30	157	5,000	350	1,000	8,800	310	15,000	2,100	1.2	4.7	430	350	6,000
36	285625080525201	04-22-87	375	7.35	131	140	54	1.3	20	.20	36	2.2	.40	4.5	620	230	260
38	285630081174701	03-16-87	500	7.15	213	250	94	2.3	12	1.3	34	4.6	.80	12	24,000	620	680
43	285643081122602	08-16-66	230	7.40	--	100	40	.70	5.1	.40	8.0	0	.10	6.1	--	1	--
		03-12-87	230	7.85	105	110	43	1.0	5.2	.40	7.2	2.5	<.10	7.1	--	--	310
50	285834081044301	02-26-82	--	--	--	--	--	--	--	--	10	--	--	--	--	--	--
		04-23-87	500	6.70	227	210	83	1.7	8.5	1.1	10	<.1	.40	25	9,200	8,300	420
52	285857081135701	03-19-87	530	4.75	6.6	140	36	12	34	16	61	77	.20	3.6	100	160	210
64	285940080575601	02-03-82	--	--	--	--	--	--	--	--	49	--	--	--	--	--	--
		04-23-87	375	6.35	135	140	52	1.4	16	3.4	18	14	.40	3.4	7,500	6,800	280
66	290025081185001	03-19-87	200	7.75	97	94	36	.90	3.8	.90	1.2	4.2	.10	9.0	40	<10	370
70	290056081210801	07-16-82	38	--	--	--	--	--	--	--	2.0	--	--	--	--	--	--
		03-24-87	35	5.00	4.9	5	1.5	.40	3.9	1.8	2.2	3.8	.20	6.0	220	110	30

Table 8. Physical and chemical characteristics of water from the upper permeable zone—Continued

[μS/cm, microsiemens per centimeter; mg/L, milligrams per liter; μg/L, microgram per liter; -- indicates no data; <, less than; >, greater than]

Well No.	Station No	Date	Specific conductance (μS/cm)	Field pH (standard units)	Alkalinity (Lab) (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L) as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolvd (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Iron total recoverable (μ/L as Fe)	Iron, dissolved (μg/L as Fe)	Strontium, dissolved (mg/L) as Sr)
79	290155080560301	02-03-82	--	--	--	--	--	--	--	--	45	--	--	--	--	--	--
		04-23-87	625	7.10	216	220	81	5.1	32	2.2	53	23	.30	6.6	400	170	470
86	290310080542101	02-04-82	--	--	--	--	--	--	--	--	90	--	--	--	--	--	--
		04-23-87	1,050	7.00	254	330	110	13	79	12	160	58	1.2	9.8	2,500	2,100	700
95	290447081102305	03-03-82	--	--	--	--	--	--	--	--	41	--	--	--	--	--	--
		05-12-87	300	6.00	69	110	39	3.1	19	1.0	42	<.1	.20	22	6,400	4,500	280
97	290508081200601	03-18-87	80	5.40	--	20	7.0	.60	2.4	1.8	5.8	5.8	0.10	4.3	90	30	70
104	290550081022201	02-03-82	--	--	--	--	--	--	--	--	10	--	--	--	--	--	--
		04-27-87	200	7.05	79	88	33	1.2	8.3	.50	12	3.6	.10	9.2	30	30	190
105	290554081160801	03-25-87	240	4.85	1.8	72	18	6.6	6.7	16	9.9	24	.10	3.6	260	40	150
109	290625081000301	02-02-82	--	--	--	--	--	--	--	--	150	--	--	--	--	--	--
		04-27-87	750	7.15	249	290	110	3.7	46	2.8	86	20	.20	5.1	1,600	1,400	550
118	290731080572001	02-01-82	--	--	--	--	--	--	--	--	150	--	--	--	--	--	--
		04-27-87	1,050	7.05	248	360	130	8.4	68	6.9	150	49	.50	6.0	30	<.10	800
122	290756081211101	03-24-87	200	7.10	49	55	20	1.3	8.1	3.0	6.7	15	.20	6.0	23,000	20	100
129	290922081060901	03-09-82	--	--	--	--	--	--	--	--	18	--	--	--	--	--	--
		04-28-87	700	6.45	226	250	87	8.2	36	1.1	84	<.1	.10	12	22,000	16,000	170
131	290947081232901	03-24-87	1,050	6.90	154	300	95	15	85	3.6	230	10	.20	19	800	30	720
144	291009081305402	03-03-82	500	--	--	--	--	--	--	--	70	--	--	--	--	--	--
		04-07-87	575	6.70	201	240	96	1.1	32	.50	55	26	.40	7.3	360	280	410
149	291032081181301	04-07-87	54	5.60	7.0	9	2.8	.50	4.5	.40	7.1	4.0	.30	5.1	620	320	30

Table 8. Physical and chemical characteristics of water from the upper permeable zone—Continued

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, microgram per liter; -- indicates no data; <, less than; >, greater than]

Well No.	Station No	Date	Specific conductance (µS/cm)	Field pH (standard units)	Alkalinity (Lab) (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L) as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolvd (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Iron total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Strontium, dissolved (mg/L) as Sr)
153	291157081025401	04-13-87	900	7.20	266	350	130	4.8	30	2.4	69	57	.40	7.7	--	1,800	670
156	291226081000901	04-14-87	710	7.05	290	300	100	12	37	1.8	66	3.2	.60	22	60	50	760
157	291257081001301	12-22-81	--	--	--	--	--	--	--	--	55	--	--	--	--	--	--
		04-14-87	440	7.45	142	160	59	2.5	17	1.1	25	14	.60	5.8	1,000	1,000	310
165	291357081274301	04-06-87	185	5.35	8.0	54	12	5.9	7.8	8.2	11	50	.40	6.2	750	40	100
187	291526081014101	12-22-81	--	--	--	--	--	--	--	--	61	--	--	--	--	--	--
		04-13-87	400	6.85	99	150	51	5.6	11	5.2	25	31	.70	7.9	150	100	210
189	291537081124701	05-11-87	600	7.00	289	280	93	11	25	1.9	36	<.1	.30	24	--	--	430
195	291806081284301	04-06-87	120	6.00	15	40	13	1.8	3.0	6.2	11	17	<.10	1.5	640	30	100
215	292056081080202	04-09-87	110	5.55	27	32	10	1.6	8.1	.30	13	4.0	.40	8.1	18,000	530	70
219	292121081041901	12-17-81	--	--	--	--	--	--	--	--	2,000	--	--	--	--	--	--
		04-28-87	4,800	7.35	192	490	140	34	670	24	1,300	160	.40	13	60	10	1,400
228	292304081071901	04-09-87	14,500	6.35	83	2,200	400	280	2,500	70	4,900	220	.40	9.6	68,000	65,000	3,000

Table 9. Nutrient concentrations in water from the upper permeable zone

Well No.	Station No.	Date	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, ammonia plus organic total (mg/L as N)	Nitrogen, NO_2 plus NO_3 total (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus ortho, total (mg/L as P)
3	284822080573502	04-22-87	0.100	0.010	<0.02	<0.020	0.710	0.330
8	284846081114002	03-12-87	.470	<.010	3.0	<.020	1.10	.050
13	285114081032801	05-06-87	.170	<.010	.40	.020	.170	.090
15	285129080510502	03-10-87	.080	.010	.33	.050	.600	.250
26	285343081140401	03-12-87	.180	<.010	.27	<.020	1.60	.500
28	285403080490001	05-21-87	.940	.010	1.6	.870	.560	.500
30	285437081181402	03-16-87	.030	<.010	.40	1.10	.880	.010
34	285545080493201	05-21-87	.060	<.010	<.20	.020	.160	.090
36	285625080525201	04-22-87	.040	<.010	<.20	<.020	.450	.230
38	285630081174701	03-16-87	.050	<.010	.50	.060	4.20	.040
43	285643081122602	03-12-87	.050	<.010	<.20	.020	.740	.030
50	285834081044301	04-23-87	.270	<.010	.42	<.020	1.20	.180
52	285857081135701	03-19-87	.060	<.010	<.20	14.0	.100	<.010
64	285940080575601	04-23-87	.930	<.010	1.3	<.020	.320	.260
66	290025081185001	03-19-87	.040	<.010	<.20	.410	.060	.020
70	290056081210801	03-24-87	.160	.010	.32	.020	.050	.020
79	290155080560301	04-23-87	.050	.010	<.20	.370	.100	.060
86	290310080542101	04-23-87	.170	.030	.65	.800	1.80	1.30
95	290447081102305	05-12-87	.180	.030	.57	.050	.420	.250
97	290508081200601	04-20-87	.030	<.010	.38	3.40	.280	.010
104	290550081022201	04-27-87	.030	<.010	<.20	.180	.120	.080
105	290554081160801	03-25-87	.030	.010	.32	18.0	.200	.020
109	290625081000301	04-27-87	.190	<.010	.48	<.020	.150	.140
118	290731080572001	04-27-87	.020	.140	.33	5.40	.400	.390
122	290756081211101	03-24-87	.020	<.010	.44	.380	7.00	.290
129	290922081060901	04-28-87	.100	<.010	.65	.020	.040	.010
131	290947081232901	03-24-87	.370	<.010	.65	<.020	.140	.080
144	291009081305402	04-07-87	.070	<.010	1.1	<.020	.100	.040
149	291032081181301	04-07-87	.100	.020	.37	.020	.370	.080
153	291157081025401	04-13-87	.430	<.010	.52	.110	.320	.060
156	291226081000901	04-14-87	.470	<.010	.70	<.020	.070	.020
157	291257081001301	04-14-87	.060	<.010	<.20	.110	.790	.390
165	291357081274301	04-06-87	.030	<.010	<.20	.930	.280	.080
187	291526081014101	04-13-87	.030	.110	.38	4.20	.460	.400
189	291537081124701	05-11-87	.180	<.010	.37	<.020	.220	.090
195	291806081284301	04-06-87	.040	.020	<.20	.850	.300	.100
215	292056081080202	04-09-87	.220	.010	.63	.030	.270	.110
219	292121081041901	04-28-87	.060	.160	.35	8.60	.470	.460
228	292304081071901	04-09-87	1.20	.020	1.5	.110	.430	.020

The specific conductance of water from the upper zone varied widely, from a minimum of 35 µS/cm at well 70, west of De Land, to more than 41,000 µS/cm at well 34 near the Atlantic Ocean. The highest chloride concentration in water from an upper zone well (15,000 mg/L) (milligrams per liter) was found at well 34, and the lowest (1.2 mg/L) at well 66 in De Land. The highest hardness of water from the upper zone was 5,000 mg/L as $CaCO_3$ at well 34. The hardness at well 228 was 2,200 mg/L as $CaCO_3$. Excluding those two sites, the mean hardness of water from upper zone wells was 140 mg/L. Although wells along the St. Johns River and along the Atlantic coast tend to yield waters with high chloride concentrations and high specific conductances, insufficient data were available to draw any statistical correlations between well locations and chloride concentration or specific conductance. The general distribution of chloride in the upper permeable zone of the surficial aquifer system, updated from Rutledge (1985a) with data collected in 1987, are shown in figure 20.

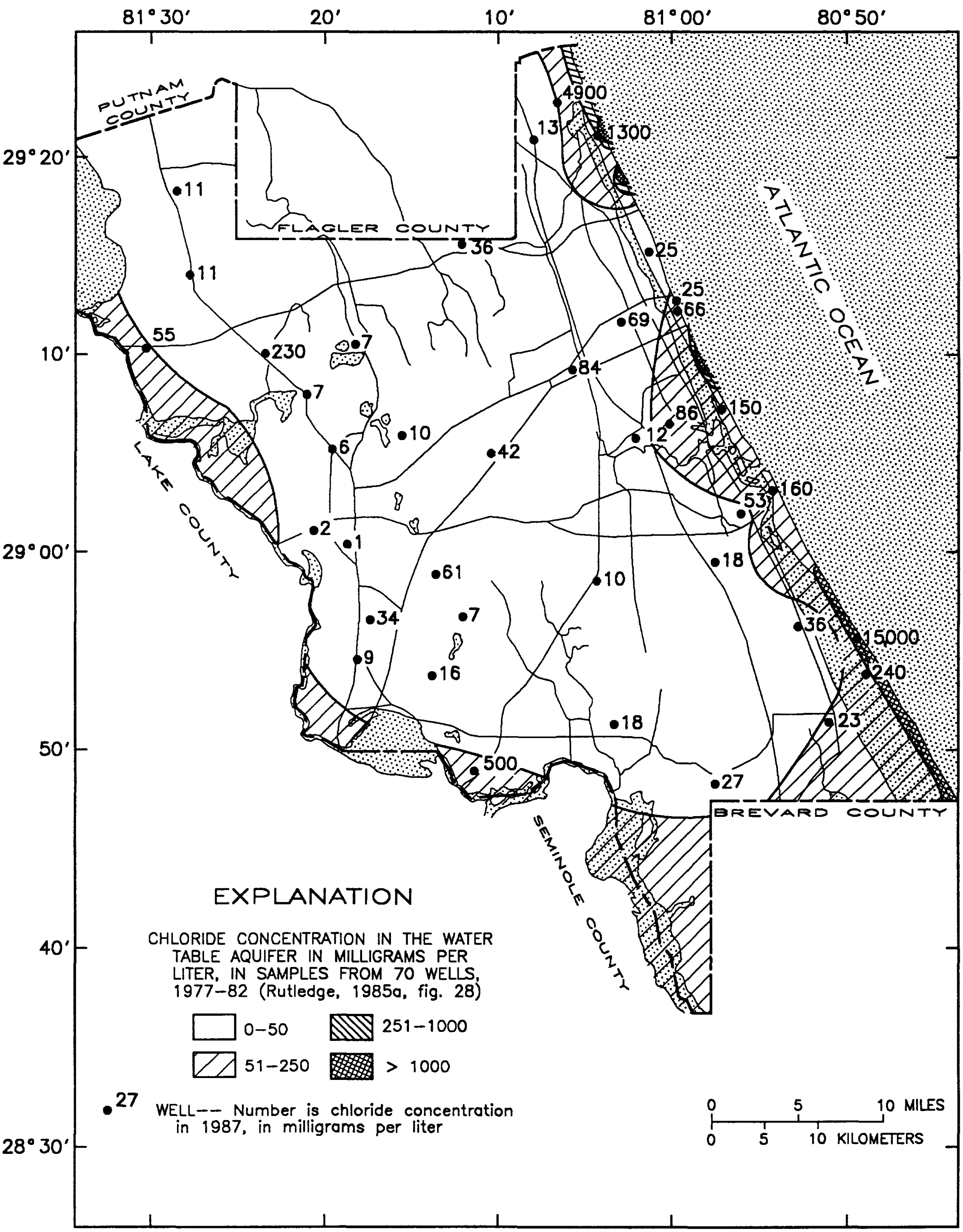


Figure 20. Distribution of chloride concentration in water from the upper permeable zone and concentrations from individual wells in 1987.

The chloride concentrations at wells 52, 95, and 129 (61, 42, and 84 mg/L, respectively) are somewhat higher than might be expected. This might be because the wells are located in terrace areas with poorly developed surface drainage and because water leaves the upper zone mostly by evapotranspiration, eventually resulting in an increased concentration of dissolved constituents in the ground water. Local fertilizer application or highway runoff may also cause the high chloride concentrations. The chloride concentration of 230 mg/L at well 131 occurs because the site is topographically low, the surficial water-bearing sediments are thin, the vertical hydraulic gradient is upward, and the underlying Upper Floridan aquifer contains water with a chloride concentration greater than 250 mg/L (Rutledge, 1985a, fig. 30).

Chloride concentrations of water from some wells (for example, wells 64, 86, 109, 157, 187, and 219) sampled during this study were significantly lower than in water samples collected in 1981-82 (table 8). This is probably due to the fact that recharge to the surficial aquifer system was reduced during the drought conditions which occurred in 1981 and early 1982. All of those wells are located on the Atlantic Coastal and Atlantic Beach Ridges. Some other wells (such as wells 8, 13, 43, 50, 70, 79, 95, and 118) show little change in chloride concentration between 1981-82 and 1987. Most of those wells are located on inland ridges or terraces, except well 118 (fig. 19). The sample from well 129 had a higher chloride concentration in 1987 than in 1982, perhaps because the well was pumped longer before the sample was collected.

A trilinear diagram showing chemical composition can be useful in indicating similarities or differences in chemical water type (Hem, 1970, p. 268-269), although it does not show the differences in total ion concentrations. The presence of two geochemical facies is indicated by two distinct trends in the trilinear diagram for water samples from the upper zone (fig. 21). Samples from wells located on the De Land and Crescent City Ridges, shown by open circles in figure 21, form one geochemical facies. Chloride concentrations from the samples ranged from 1.2 to 34 mg/L. All wells in that group were located at sites with land surface altitude greater than 35 feet above sea level, and the median land surface altitude for wells in the group was 65 feet. The remaining wells, located on the terraces, beach ridges, and in the St. Johns River Valley, yield water forming a second geochemical facies. The chloride concentration of water from this group of wells showed a wider variation than did the previous group. The median land surface altitude for the sites in the group was 29 feet above sea level. The two geochemical facies, thus, seem to be related to the physiographic location of the site. The sites on the De Land and Crescent City Ridges have been emergent for a longer period of time and have thus had a longer period of freshwater recharge from precipitation flushing out old seawater. The other group of sites, which generally are located at lower altitudes, have been inundated by the sea more frequently and more recently and, thus, the shallow ground water may show the effects of repeated cycles of mixing relict seawater with fresh rainwater.

Another constituent of interest is iron; high concentrations of iron give water an unpleasant taste and can stain plumbing fixtures, sidewalks, and buildings. Total iron in water from upper zone wells ranged from 30 μg/L (micrograms per liter) at well 104 to 68,000 μg/L at well 228 (table 8). The median concentration for all wells, except wells 34 and 228, was 800 μg/L. Data on the dissolved iron concentration may be more useful than total iron because older wells with iron casings may yield water containing iron particles corroded from the casing and also because sand or clay suspended in turbid samples may contain significant amounts of iron. Dissolved iron ranged from 1.0 μg/L to 65,000 μg/L with a median (excluding wells 34 and 228) of 210 μg/L. The low iron concentrations at wells 43 and 104 may be because of recent recharge to the aquifer.

Other constituents of interest in the study area are the nutrients nitrogen and phosphorus. Some small amounts of phosphorus are found in ground water because of the dissolution of phosphate minerals, but nitrogen is nearly always found in water as the result of biological activity (Hem, 1970, p. 180-187). Nitrogen and phosphorus compounds in ground water generally are the result of human activities, such as the application of fertilizers or because of the presence of human or animal waste. In surface water, high nutrient concentrations are detrimental because they encourage the rapid growth of algae which deplete the water of the oxygen necessary for fish to survive. In ground water used for potable water supply, nitrate concentrations greater than 10 mg/L can cause methemoglobinemia, a disease that can be fatal to infants under the age of 1 year (U.S. Environmental Protection Agency, 1989). Because the presence of nutrients in ground water generally indicates influence of human activity, their presence can also indicate other potential problems, such as contamination by bacteria and viruses.

In general, nutrient concentrations in the upper zone are higher in the western part of the county (the agricultural area) than in the eastern part. Nutrient concentrations in water from wells tapping the upper permeable zone are given in table 9. The highest concentration of total ammonia (1.20 mg/L as N) was at well 228, in eastern Volusia County; the lowest concentrations (0.02 mg/L) were at wells 118 and 122. Well 118, a backyard irrigation well, had a relatively high concentration of nitrate-plus-nitrite of 5.4 mg/L (as N). High nitrate-plus-nitrite concentrations also were detected in samples from well 105 (18 mg/L), in an agricultural area, and well 52 (14 mg/L), which is a backyard irrigation well. Ten wells had nitrate-plus-nitrite concentrations of less than 0.02 mg/L as N, the detection limit for the laboratory method used. Well 122, a test well near De Leon Springs, had the highest total phosphorous concentration (7 mg/L as P) of all the upper zone wells. The minimum total phosphorous concentration (0.04 mg/L) was at well 129, a test well along a highway right-of-way near Daytona Beach. The maximum orthophosphate concentration (1.3 mg/L as P) was in a backyard irrigation well (well 86) and the minimum concentration (less than 0.01 mg/L), was at well 52.

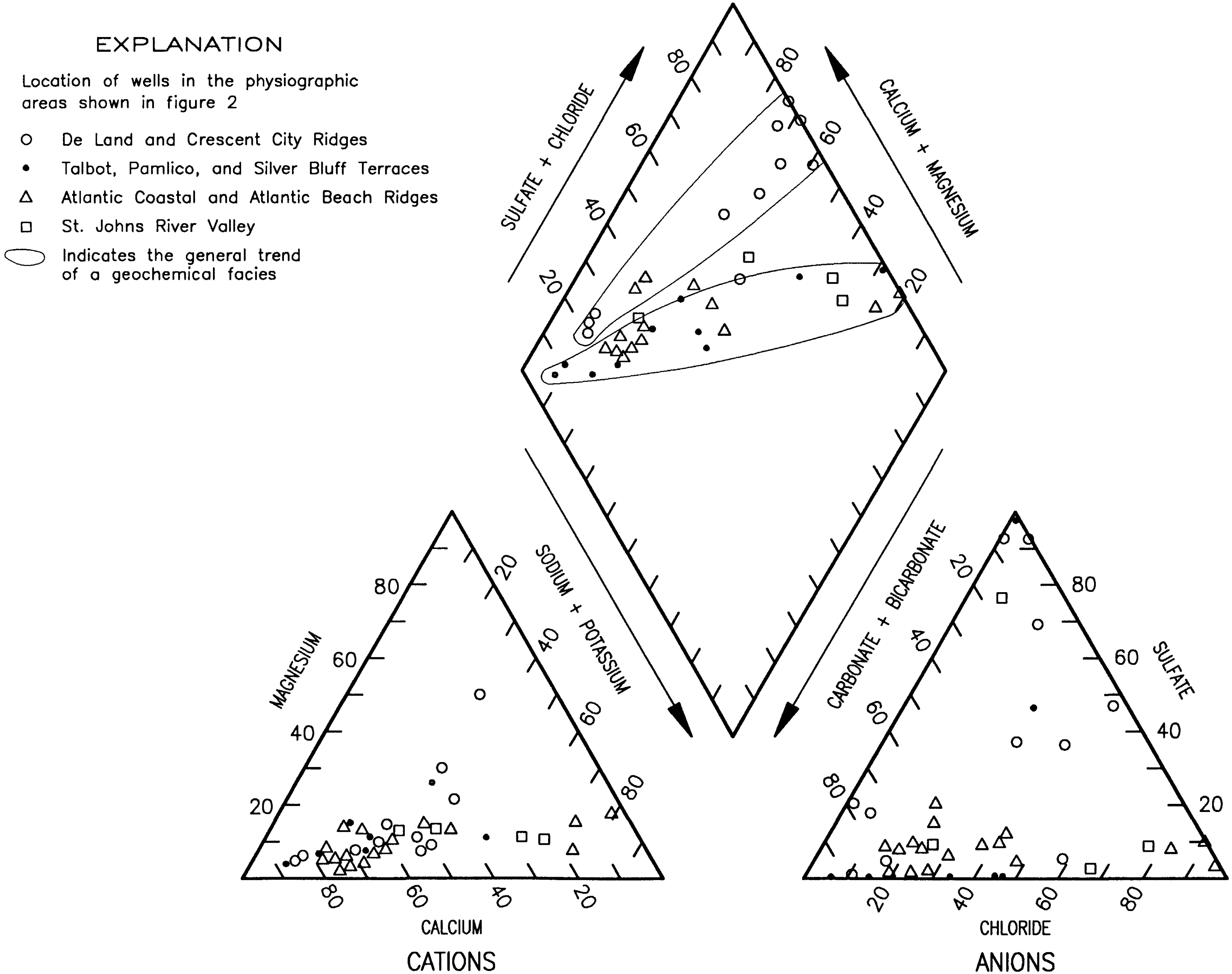


Figure 21. Chemical composition of water in the upper permeable zone.

Lower Permeable Zone

Thirteen wells tapping the lower permeable zone of the surficial aquifer system were also sampled and analyzed in 1987. Results of these analyses are given in tables 10 and 11. The chloride concentration ranged from a minimum of 5.7 mg/L at well 98 to a maximum of 340 mg/L at well 132, in an area of artesian flow from the underlying Upper Floridan aquifer. The median chloride concentration for all samples was 10 mg/L. The median specific conductance for all samples was 300 μS/cm. The maximum was 1,400 μS/cm at well 132 and the minimum was 200 μS/cm at well 98. Hardness ranged from 85 mg/L (as $CaCO_3$) at well 98, to 360 at well 132, with a median value of 130 mg/L.

A trilinear diagram showing ionic compositions for water samples from wells in the lower permeable zone is shown in figure 22. Most of the wells yield calcium bicarbonate type water. Data are insufficient to determine if both calcium magnesium sulfate type and sodium chloride type waters exist in the zone.

The median total iron concentrations for water from the lower zone was 1,300 μg/L and the median dissolved iron concentration was 130 μg/L. Total iron concentrations in water from the lower zone ranged from a maximum of 82,000 μg/L at well 166 to a minimum of 130 μg/L at well 231. Dissolved iron concentrations ranged from 640 μg/L at well 67 to 20 μg/L at well 132. As mentioned previously, some of the total iron may be contributed by particles spalled from the well casing or from suspended sediments.

Nutrient concentrations for wells tapping the lower zone are given in table 11. Ammonia-plus-total-organic nitrogen ranged from less than 0.2 mg/L as N at well 98 to 2.7 mg/L at well 67, located in De Land. Other wells that yielded water with ammonia-plus-organic nitrogen concentrations greater than 2.0 mg/L were wells 106 and 166, both in agricultural areas. At well 106 the ammonia-plus-organic-nitrogen concentration was 2.2 mg/L, whereas the nitrate-plus-nitrite nitrogen concentration was less than 0.02 mg/L; at well 105, a water-table well at the same location, ammonia-plus-organic nitrogen concentration was 0.3 mg/L whereas the nitrate-plus-nitrite nitrogen concentration was 18 mg/L. The highest nitrate-plus-nitrite concentration in water from an intermediate aquifer well was 0.430 mg/L as N at well 231, located in Bulow Creek State Park in the eastern part of the county.

The highest total phosphorus concentration was 11 mg/L at well 67 (which also had the highest concentration of ammonia-plus-organic nitrogen). Total phosphorus at well 66, an upper zone well at the same location, was only 0.06 mg/L. Total phosphorus concentrations greater than 5 mg/L were also found at well 166 (in an agricultural area), well 196 (in a pasture), and well 123 (in a woodland area). Well 122, an upper zone well at the same location as well 123, also had the highest total phosphorus concentration of the upper zone wells. These concentrations were probably affected by septic tank effluent. Although in some cases nutrient concentrations appear to be related to use of fertilizers or other agricultural activities, other nutrient data are more difficult to explain, such as the nutrient concentrations at wells 67, 166, and 231. The reconnaissance nature of the water-quality sampling during this study did not yield sufficient data to show correlations between land use and water quality. Also, in some areas, phosphate concentrations in water in the lower zone may be related to phosphate minerals in the aquifer.

Summary of Water Quality from Both Zones

A summary of the range of properties and constituents in waters from the two zones is given in table 12. The median concentrations for some constituents are lower in the lower permeable zone than for wells tapping the upper permeable zone; however, statistical comparisons between the water quality of the upper and lower zones cannot be made with the data available because water quality depends not only on aquifer zone, but also on physiographic location of the well. Without data from both zones at numerous sites in each physiographic area, meaningful comparisons cannot be made.

Figure 23 shows major-ion concentrations of water from selected wells and the mean concentrations for all wells sampled in each zone. The wells were selected to show the range in concentration of constituents in water from each zone. Wells 34 and 228 were deleted from the calculations of the means for upper zone wells because of their very high dissolved solids concentrations. In both zones, the water generally has a high chloride concentration in areas where the underlying Floridan aquifer system contains salty water (Rutledge, 1985a, fig. 30). The median concentration of dissolved iron was 230 μg/L for the upper zone and 130 μg/L for the lower zone.

SUMMARY AND CONCLUSIONS

In Volusia County, the Miocene-to-Holocene age sediments that overlie the Floridan aquifer system constitute the surficial aquifer system. The sediments consist of sand, silt, clay, and shell that collectively range in thickness from about 40 to more than 100 feet in some areas of the western part of the county. In many areas of the county, the surficial aquifer system can be subdivided into an upper and a lower permeable zone which are separated by 5 to 10 feet of clay and silty material. Although the clay or silt layers were found at numerous sites, they are not believed to be areally continuous.

About 4,500 wells are completed into the surficial aquifer system in Volusia County, of which more than 3,200 are used for irrigation. About 800 wells that tap the surficial aquifer system are used for domestic supply. Estimated total water use from the surficial aquifer system in 1987 is 4.2 Mgal/d.

Table 10. Physical and chemical characteristics of water from the lower permeable zone

[μS/cm, microsiemens per centimeter; mg/L, milligrams per liter; -- indicates no data]

Well No.	Station No.	Date	Specific conductance (μS/cm)	Field pH (standard units)	Alkalinity (Lab) (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Iron total recoverable (μg/L as Fe)	Iron, dissolved (μg/L as Fe)	Strontium, dissolved (mg/L as Sr)
14	285129080510501	03-10-87	750	--	235	270	100	5.0	43	1.6	100	<0.1	0.30	38	250	200	20
31	285437081181403	03-16-87	250	7.60	117	120	44	1.4	5.3	1.1	9.0	.6	.10	13	10,000	150	260
37	285625080525202	04-22-87	810	7.00	309	330	120	6.9	40	1.5	85	<.1	.30	59	870	540	810
67	290025081185002	03-19-87	230	7.75	104	120	43	1.9	7.9	1.2	7.1	15	.10	6.6	22,000	640	340
98	290508081200602	03-18-87	200	7.10	56	85	31	1.9	6.9	2.1	5.7	33	.10	12	1,300	480	200
106	290554081160802	03-25-87	270	7.30	104	120	46	1.0	5.7	0.70	9.4	12	.10	6.8	280	100	280
123	290756081211102	03-24-87	290	7.65	109	120	45	2.4	6.9	.90	10	13	.10	8.6	31,000	30	300
132	290947081232902	03-24-87	1,400	7.35	156	360	120	15	120	2.9	340	17	.20	20	600	20	860
150	291032081181302	04-07-87	280	7.40	128	130	50	1.0	7.1	.70	10	3.2	.40	8.3	5,800	40	280
166	291357081274302	04-06-87	350	7.55	164	160	60	3.4	6.4	1.1	9.6	8.8	.40	19	82,000	30	310
196	291806081284302	04-06-87	300	7.45	130	130	51	1.3	9.1	.80	5.8	9.8	.30	43	16,000	160	230
214	292056081080201	04-09-87	550	7.15	264	260	99	2.6	16	.60	24	<.1	.40	13	170	110	540
231	292318081075701	04-09-87	400	7.10	165	170	65	1.8	15	.40	25	7.2	.40	6.2	130	130	340

Table 11. Nutrient concentrations in water from the lower permeable zone

Well No.	Station No.	Date	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, ammonia plus organic total (mg/L as N)	Nitrogen, NO_2 plus NO_3 total (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, ortho, total (mg/L as P)
14	285129080510501	03-10-87	0.560	<0.010	0.68	<0.020	0.280	0.270
31	285437081181403	03-16-87	.040	<.010	.93	.030	4.60	.070
37	285625080525202	04-22-87	.820	<.010	1.0	<.020	.200	.070
67	290025081185002	03-19-87	.040	<.010	2.7	.080	11.0	.090
98	290508081200602	03-18-87	.060	<.010	<.20	<.020	.500	.160
106	290554081160802	03-25-87	.050	<.010	2.2	<.020	.210	.150
123	290756081211102	03-24-87	.090	<.010	1.2	<.020	6.20	.040
132	290947081232902	03-24-87	.420	<.010	.50	<.020	.140	.070
150	291032081181302	04-07-87	.080	.020	.50	.030	2.30	.450
166	291357081274302	04-06-87	.060	<.010	2.0	<.020	7.80	.100
196	291806081284302	04-06-87	.200	.030	1.3	.070	5.60	.820
214	292056081080201	04-09-87	.130	.010	.22	.020	.310	.280
231	292318081075701	04-09-87	.080	<.010	.32	.430	.150	.120

During the study, water levels were measured periodically in about 90 wells and continuously in two wells tapping the surficial aquifer system. The depth to water below land surface varies with the topography and ranges from less than 10 feet below to 30 feet or more below land surface. In 1986, water levels in wells tapping the upper zone generally were 3 to 6 feet higher in the fall, at the end of the wet season, than in the spring. The maximum water-level fluctuation measured between wet and dry seasons was 5 feet. Water levels in several wells fluctuated less than 1 foot. Water levels in wells tapping the lower zone generally fluctuated less than 2 feet, except those that were affected by pumping from the Upper Floridan aquifer for freeze protection during February 1987.

The highest recharge rates to the surficial aquifer system (and thus, to the Upper Floridan aquifer) are found along the De Land Ridge and the western part of the Talbot Terrace. The recharge rate on the ridge areas probably ranges from about 9 to 18 in/yr, whereas in nonridge areas the rate ranges from about 0 to 8 in/yr. Recharge rates calculated by summing the rises in the hydrographs of three wells are higher than rates estimated from water budgets, partly because some of the recharge measured in the hydrograph method comprises ground-water outflow which was assumed to be negligible in water-budget calculations.

Laboratory hydraulic conductivity values for core samples of clay collected in Volusia County ranged from 7.6×10^{-5} to 3.4×10^{-1} ft/d with a median of 1.0×10^{-2} ft/d. Field hydraulic conductivities determined by slug tests ranged from 3.0×10^{-2} to 12.8 ft/d with a median of 2.9×10^{-1} ft/d.

The transmissivity of the lower permeable zone of the surficial aquifer system in Oak Hill (southeastern Volusia County) determined from an aquifer test, was 1,200 ft^2/d. In the Oak Hill area, the rate at which water can be produced from the lower zone is limited by the possibility of upconing saltwater from the underlying Upper Floridan aquifer rather than by the hydraulic properties of the aquifer.

Water samples from 39 wells tapping the upper zone and 13 wells tapping the lower zone were analyzed for major constituents, trace elements, and nutrients. Chloride concentrations for the upper permeable zone ranged from 1.2 mg/L to 15,000 mg/L; for the lower permeable zone the range was 5.7 mg/L to 340 mg/L. In both zones nutrient concentrations at some sites were higher than would be expected for natural ground water, indicating some effect from surface water or human activity.

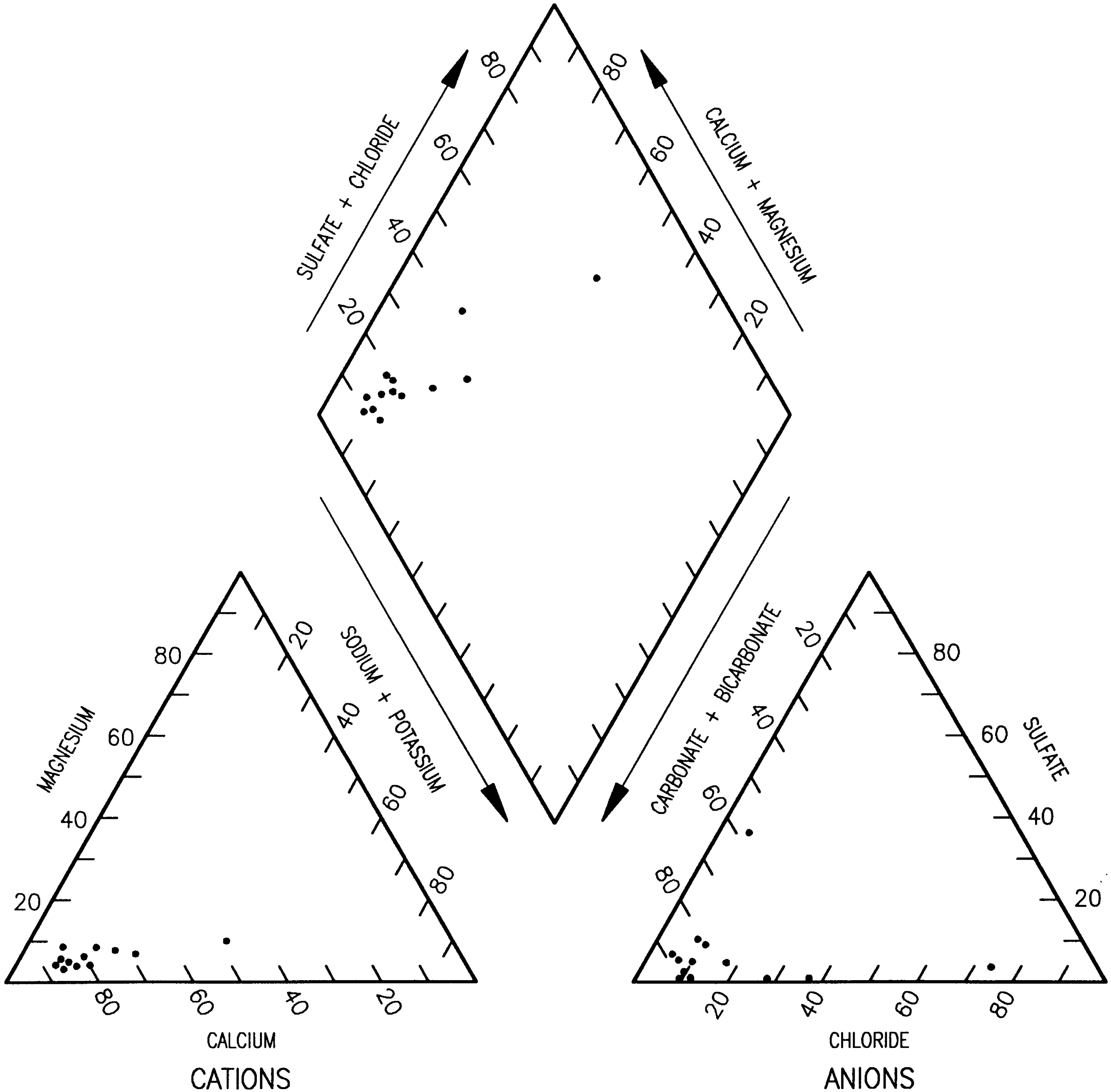


Figure 22. Chemical composition of water in the lower permeable zone.

Table 12. Statistical summary for physical and chemical characteristics of water from the upper and lower permeable zones of the surficial aquifer system, Volusia County

[Aquifer zone: U, upper zone; L, lower zone]

Characteristic or constituent	Aquifer zone	Number of samples	Minimum	Median	Maximum
Specific conductance (µS/cm)	U	46	35	405	41,800
	L	13	200	300	1,400
Hardness (mg/L as $CaCO_3$)	U	40	5	140	5,000
	L	13	85	130	360
Noncarbonate hardness	U	40	0	15	2,100
(mg/L as $CaCO_3$)	L	13	0	12	210
Alkalinity (mg/L as $CaCO_3$)	U	39	1.8	132	341
	L	13	56	130	309
Calcium (mg/L as Ca)	U	41	1.5	52	400
	L	13	31	51	120
Magnesium (mg/L as Mg)	U	41	.4	2.5	1,000
	L	13	1.0	1.9	15
Sodium (mg/L as Na)	U	41	2.2	16	8,800
	L	13	5.3	7.9	120
Potassium (mg/L as K)	U	41	.2	1.8	310
	L	13	.4	1.1	2.9
Chloride (mg/L as Cl)	U	57	1.2	36	15,000
	L	13	5.7	10	340
Sulfate (mg/L as SO)	U	41	0	10	2,100
	L	13	.1	8.8	33
Fluoride (mg/L as F)	U	41	.10	.30	1.20
	L	13	.10	.30	.40
Silica (mg/L as SiO)	U	41	1.5	7.5	25
	L	13	6.2	13	59
Strontium (µg/L as Sr)	U	40	30	295	6,000
	L	13	20	300	860
Iron, total (µg/L as Fe)	U	38	30	900	68,000
	L	13	130	1,300	82,000
Iron, dissolved (µg/L as Fe)	U	39	1.0	230	65,000
	L	13	20	130	640
Ammonia (mg/L as N)	U	40	.02	.07	1.2
	L	13	.04	.09	.82
Nitrite (mg/L as N)	U	40	.01	.01	.16
	L	13	.01	.01	.03
Ammonia plus organic nitrogen	U	40	.20	.38	3.0
(mg/L as N)	L	13	.20	.93	2.7
Nitrate plus nitrite	U	40	.02	.05	18
(mg/L as N)	L	13	.02	.02	.43
Phosphorus (mg/L as P)	U	40	.04	.32	7
	L	13	.14	.50	11
Orthophosphate, total	U	40	.01	.09	1.3
(mg/L as P)	L	13	.04	.12	.82

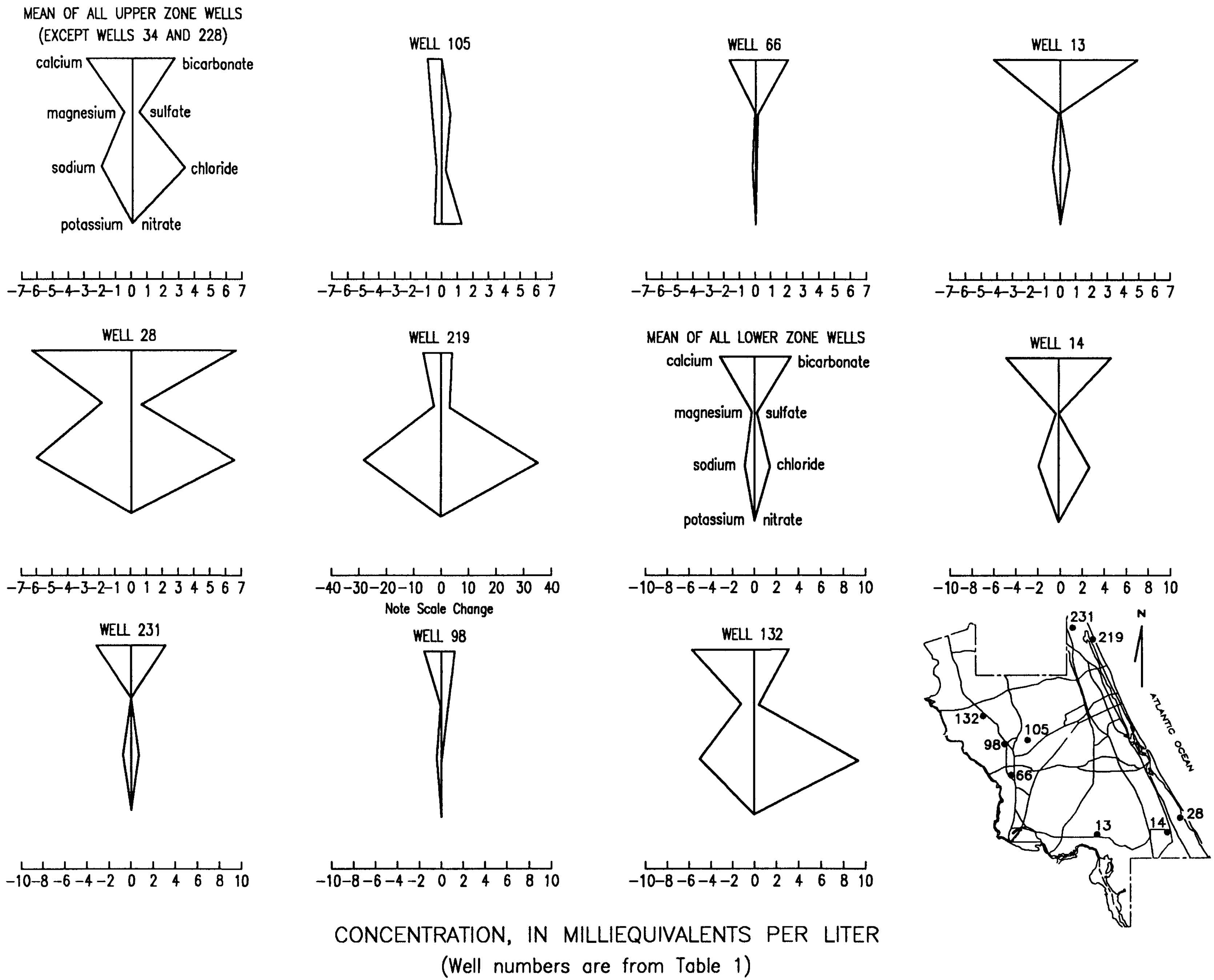


Figure 23. Major ion concentrations of water from selected wells.

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