HYDROGEOLOGY IN THE AREA OF A FRESHWATER LENS IN THE FLORIDAN AQUIFER SYSTEM, NORTHEAST SEMINOLE COUNTY, FLORIDA

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By G. G. Phelps and K. P. Rohrer

ABSTRACT

Northeast Seminole County, Florida, contains an isolated recharge area of the Floridan aquifer system that forms a freshwater lens completely surrounded by saline water. The freshwater lens covers an area of about 22 square miles surrounding the town of Geneva, and generally is enclosed by the 25-foot land-surface altitude contour. Thickness of the lens is about 350 feet in the center of the recharge area. The hydrogeologic units in descending order consist of the post-Miocene sand and shell of the surficial aquifer; Miocene clay, sandy clay, and shell that form a leaky confining bed; and permeable Eocene limestones of the Floridan aquifer system. The freshwater lens is the result of local rainfall flushing ancient seawater from the Floridan aquifer system.

Sufficient quantities of water for domestic and small public-supply systems are available from the Floridan aquifer system in the Geneva area. The limiting factor for water supply in the area is the chemical quality of the water. Chloride concentrations range from less than 20 milligrams per liter in the center of the recharge area to about 5,100 milligrams per liter near the St. Johns River southeast of Geneva. Constituents analyzed included sulfate (range 1 to 800 milligrams per liter), hardness (range 89 to 2,076 milligrams per liter), and iron (range 34 to 6,600 micrograms per liter).

Because the freshwater lens results entirely from local recharge, the long-term sustained freshwater yield of the aquifer in the Geneva area depends on the local recharge rate. To estimate recharge, water budgets were calculated for 1981 and 1982, and for a long-term average using data from 1941 to 1970. It is estimated that recharge was about 5 inches (5.4 million gallons per day) in 1981, a year with much less than normal rainfall. In 1982, recharge was about 13 inches (13.8 million gallons per day). Average recharge for 1941 through 1970 was estimated to be about 11 inches (11.3 million gallons per day). Freshwater that recharges the aquifer in the Geneva area is either pumped out or flows north and northeast to discharge near or in the St. Johns River. Average annual outflow from the lens is about 10 inches per year. No measurable change in the size or location of the freshwater lens has occurred since studies in the early 1950's, probably because throughout most of that time, rates of pumpage from the aquifer have been very low and the disruption of the equilibrium between freshwater and saltwater has not resulted in detectable deterioration of water quality in the lens. If the freshwater outflow from the lens is reduced to less than 10 inches per year over the long term, deterioration of water quality will eventually occur.

INTRODUCTION

The Floridan aquifer system in northeast Seminole County, Fla., contains an isolated recharge area that forms a freshwater lens surrounded by brackish water (chloride concentration greater than 250 mg/L). Freshwater in the aquifer is derived from local precipitation falling on an area of comparatively high altitude centered around the town of Geneva, about 20 miles northeast of Orlando. As the population of Florida has grown, so has the need for freshwater. Some of the most esthetically desirable locations for development along the coast and the St. Johns River have no freshwater available. For that reason, the demand for freshwater in areas such as the Geneva lens has increased, both for local development and for exportation to areas where the water is not potable.

Because all of the freshwater in the Geneva area comes from local recharge, estimates of the recharge rate are important to local government officials in planning water use in the area. Previous to this study, hydrologic data available for the Geneva area were not sufficient to determine accurately the rate of recharge and to locate precisely the transition between the freshwater and brackish water.

The U.S. Geological Survey, in cooperation with the St. Johns River Water Management District (which has the responsibility of permitting water use in east-central Florida) performed this study for the following purposes:

1. To describe the geohydrology and ground-water quality in the Geneva area;
2. To delineate the lateral and vertical extent of the freshwater lens; and
3. To estimate the recharge rate to the freshwater lens by evaluating the hydraulic characteristics of the Floridan aquifer system and overlying confining beds, and evaluating climatological data.

Purpose and Scope

This report describes the hydrogeology of the area containing the freshwater lens, estimates the recharge rate and provides data needed for water management decisions by the Water Management District and local government agencies. Information on ground-water recharge in this report may also be useful to hydrogeologic investigations of other areas of Florida.

This report does not attempt to provide a "safe yield" withdrawal rate for the Geneva area. Since the term "safe yield" was discussed by Todd (1959), there has been no agreement among hydrogeologists about how to quantify the concept. Clearly, the entire amount of water recharged to an aquifer is not available for use without creating adverse effects, but no simple means of calculating the "safe yield" exists. Mathematical modeling of chemical solutes such as the chloride ion shows promise in providing the answers, but first an understanding of the geohydrology of the area, the flow system, and the water chemistry are needed. The information from this study could provide background data for such future modeling studies.

Description of Study Area

The study area comprises about 60 mi^2 surrounding the town of Geneva (fig. 1) in northeast Seminole County, Fla. The area is bounded on the north by the St. Johns River, on the south by the Econlockhatchee River and on the west and east by Lakes Jessup and Harney, respectively. The active recharge area is about 15 mi^2 in area, but because of regional ground-water flow patterns, the freshwater lens extend over an area of about 22 mi^2.

Acknowledgments

The authors wish to thank the property owners of Geneva for their cooperation in allowing access to their property for data collection and for test drilling. Thanks also, to the Seminole County Engineering Division for assistance in locating test drilling sites. Valuable assistance in preparation of lithologic and geologic logs from test well drill cuttings was given by J. A. Miller, hydrologist, U.S. Geological Survey, Atlanta, Ga. Geophysical logging was done by R. A. Johnson, St. Johns River Water Management District.

Previous Investigations

A general description of the ground-water resources of Seminole County was made by Stringfield (1934). In a later publication (Stringfield, 1936), information about Seminole County was included in a study of the water resources of the Florida Peninsula. Stubbs (1937) also reported on the ground-water hydrology of Seminole County, with emphasis on the water supply for the city of Sanford. Data reports by Heath and Barraclough (1954), Barraclough (1962a), and an interpretive report by Barraclough (1962b) provided a reconnaissance of the ground-water resources of Seminole County. Tibbals (1977) studied the availability and quality of ground water in the county and delineated recharge and discharge areas. He also described the geohydrology of the Floridan aquifer system in east-central Florida (Tibbals, 1981). The scope of each of those reports was countywide or larger, restricting the amount of time and detail that could be devoted to study of the freshwater lens near Geneva.

Well-Numbering System

The U.S. Geological Survey assigns a unique 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 284233081045202 is the second well inventoried at latitude 28°42'33" N. and longitude 81°04'52" W. Due to later revisions the site identification number may not be identical to the actual latitude-longitude location of the well.

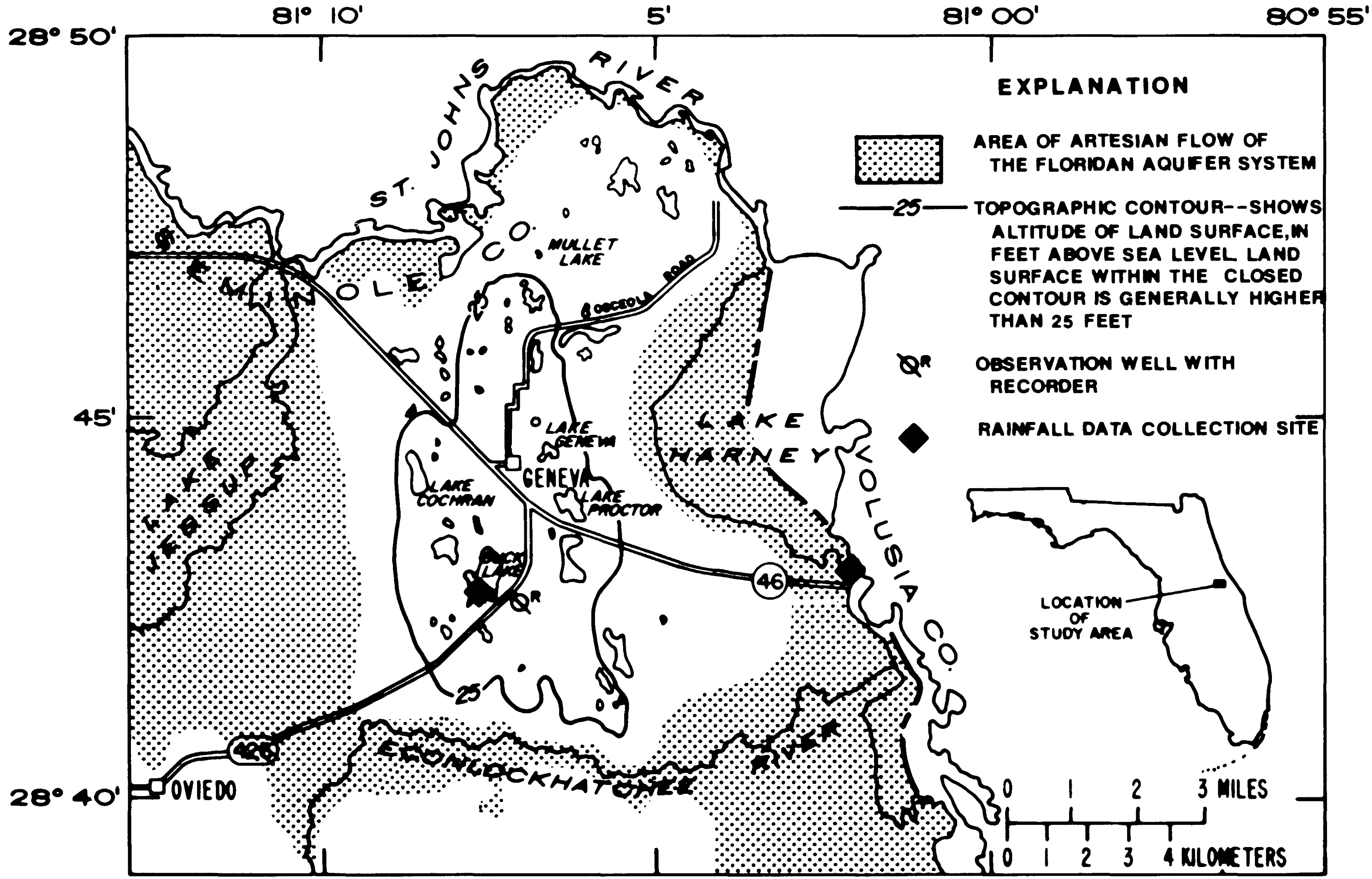


Figure 1.--Location of study area, areas of artesian flow of the Floridan aquifer system, and approximate location of the 25-foot topographic contour.

Methods of Investigation

Field work for the study done by the U.S. Geological Survey and the St. Johns River Water Management District included a well inventory, quality of water sampling, and test drilling. Existing geologic and hydrologic data were compiled and evaluated. Well data collected by Tibbals (1977) in 1973 and 1974 were updated to provide a well inventory for the Geneva area. A water level recorder was installed on a well tapping the Floridan aquifer system, and a rain gage was also installed (fig. 1). Water samples from more than 40 wells were collected and analyzed for major constituents. Test wells were drilled at 9 sites to determine hydraulic properties of the intermediate confining unit and the Floridan aquifer system, and to determine water-quality changes with depth. Specific capacity tests and geophysical logs were run in the test wells. Hydrologic properties of the soil types in the area were studied and used to estimate runoff from the recharge area. Rainfall, water level, and runoff data were used to compute water budgets to estimate the amount of recharge available to the Floridan aquifer system under existing conditions.

GEOLOGIC FRAMEWORK

Geologic History

The Florida Peninsula is composed of a thick sequence of marine limestone and dolomite deposited over a period of about 100 million years (m.y.) during the Cretaceous and Tertiary geologic time periods. Regional submergence of most of the southeastern United States and deposition of marine sediments occurred throughout the Cretaceous Period (about 138 to 63 m.y. ago). A regression of sea level, evidenced in the geologic record by a break in deposition of sediments (an unconformity) occurred at the end of the Cretaceous Period. Then throughout most of the Paleocene and Eocene Epochs of the Tertiary Period (from about 63 to 38 m.y. ago), the Florida Peninsula was a relatively shallow (water depth about 150 ft) carbonate reef (Chen, 1965, p. 5). Then in the Oligocene and Miocene Epochs (about 38 to 5 m.y. ago), the deposition across much of the Florida Peninsula of land-derived clastic sediments, as opposed to marine carbonate sediments, indicates gradual marine regression.

Many of the topographic features of Florida are believed to be relict shoreline features formed when the sea fell, then rose in response to the advances and retreats of Pleistocene glaciation within the last 2 m.y. (MacNeil, 1950). Some recent workers (Opdyke and others, 1984) suggest that isostatic uplift of the Florida Peninsula because of the dissolution of limestone, rather than changes in sea level, is the mechanism of relict shoreline formation. White (1970, p. 114) traced a series of beach ridges which includes Geneva Hill (fig. 2) in northeast Seminole County from the Orange-Seminole County line northward to Palatka Hill. He believes this ridge was part of the Wicomico shoreline formed during the Sangamon interglaciation (about 100,000 years ago) when the sea level was about 100 feet higher than present. The Pamlico shoreline, about 25 feet above present sea level, formed during the mid-Wisconsin glacial recession (about 40,000 years ago). During late Wisconsin glaciation (which ended about 10,000 years ago) sea level fell again. Areas inundated by the Wicomico and Pamlico seas were exposed again to erosion, and sediments which were saturated by seawater at the time of deposition and again by subsequent sea transgressions began to be flushed by freshwater from local rainfall. It is significant that land surfaces less than 25 feet in altitude were the most recently inundated by the sea; in northeast Seminole County, fresh ground water is found in both surficial and Floridan aquifer systems where the land surface altitude is greater than 25 feet, but where altitudes are lower than 25 feet, most ground water is brackish.

The other major influence on the landforms of the study area is the process of karst formation. Karst results when limestone is dissolved by water. The limestone usually dissolves more rapidly in some areas than in others, resulting in an irregular land surface. Features of karst include lack of surface drainage, the presence of sinks, springs, and round lakes (caused by the coalesing of sinkholes), and a wide variation in the altitude of contemporaneous relict shoreline features such as the Wicomico shoreline (White, 1970, p. 123-124).

As a result of the combined processes of karst development on a limestone terrain and the deposition of a series of beach ridges, the topography of the recharge area is characterized by rolling sand hills ranging in altitude from 25 to 80 feet surrounded by a marshy low-lying area with altitudes that range from 5 to 20 feet.

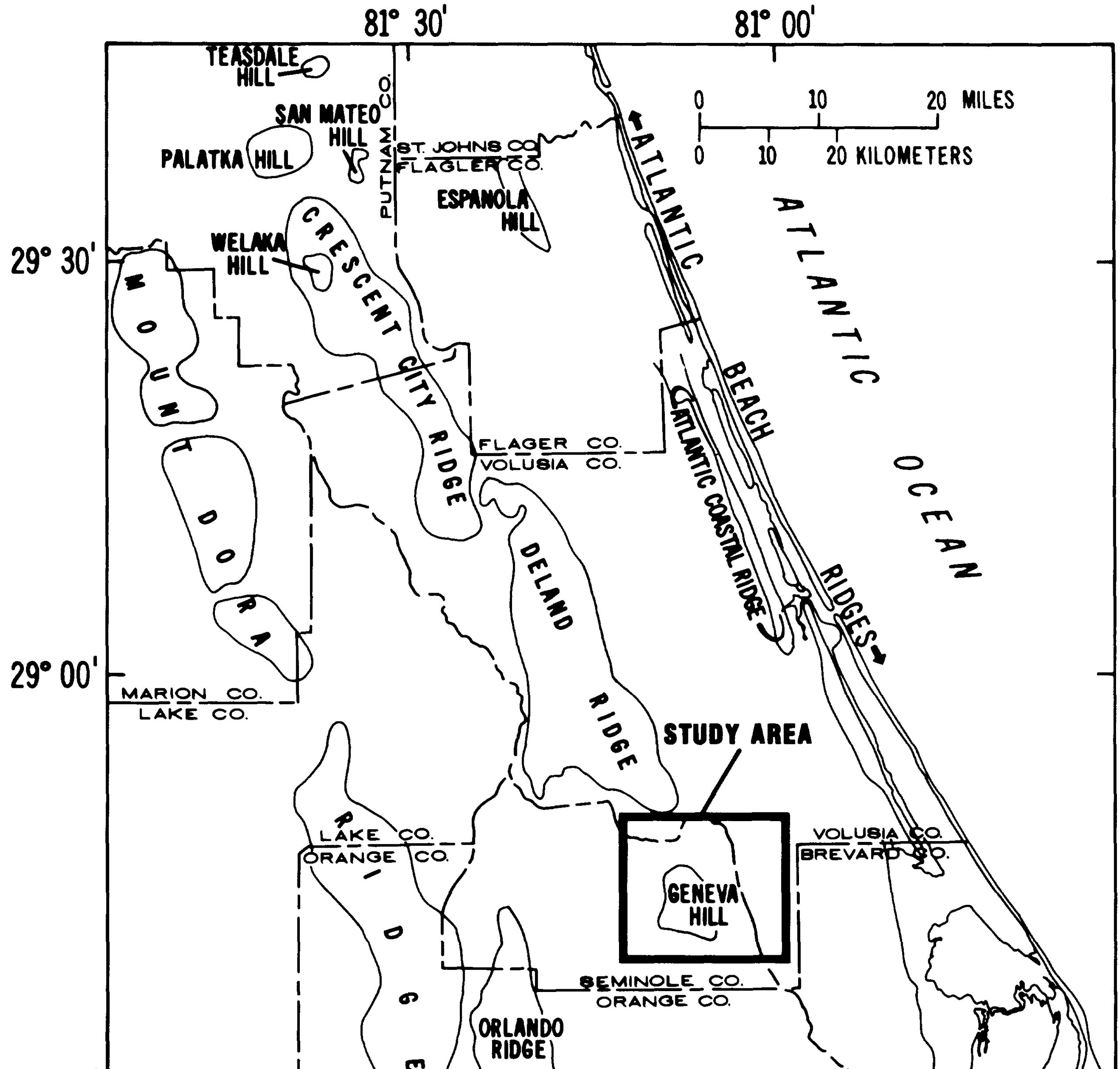


Figure 2.--Physiographic map of part of central Florida (modified from White, 1970, plate 1B).

Description of Geologic Units

The surficial deposits range in thickness from 10 to 70 feet. They consist of post-Miocene age (undifferentiated Pliocene to Holocene) deposits composed mostly of sand or sandy clay. In some low-lying areas surrounding Geneva, the surficial deposits are predominantly silt and clay.

Underlying the surficial deposits are about a 20 to 60 foot thickness of Miocene deposits--either the middle Miocene Hawthorn Formation or undifferentiated upper Miocene deposits. These deposits are predominantly shell and clayey sand with some sandy phosphatic limestone.

Limestones of Eocene to Oligocene age underlie the Miocene sediments and are found at depths ranging from 50 to about 120 feet below land surface. In descending order they consist of: occasional erosional remnants of the Suwannee Limestone of Oligocene age; the Ocala Limestone (10 to nearly 200 feet thick) and the Avon Park Formation, both of Eocene age. The base of the Avon Park has not been penetrated in the study area, but Chen (1965, fig. 10) estimated the formation to extend to a depth of about 1,500 feet below sea level in central Florida.

A more detailed discussion of the geology is given in the "Test Drilling" section of this report.

HYDROGEOLOGIC FRAMEWORK

Surficial Aquifer

The surficial aquifer, consisting of post-Miocene sediments, contains the water table. Water levels in the surficial aquifer are generally within 10 feet of land surface but can be as much as 20 feet below land surface on hilltops. Water levels usually increase in altitude rapidly in response to rainfall. In places, the surficial aquifer contains shell beds under confined conditions because of less permeable overlying sediments. In the Geneva area, limited use is made of the surficial aquifer for domestic supply and lawn or garden irrigation.

Intermediate Confining Unit

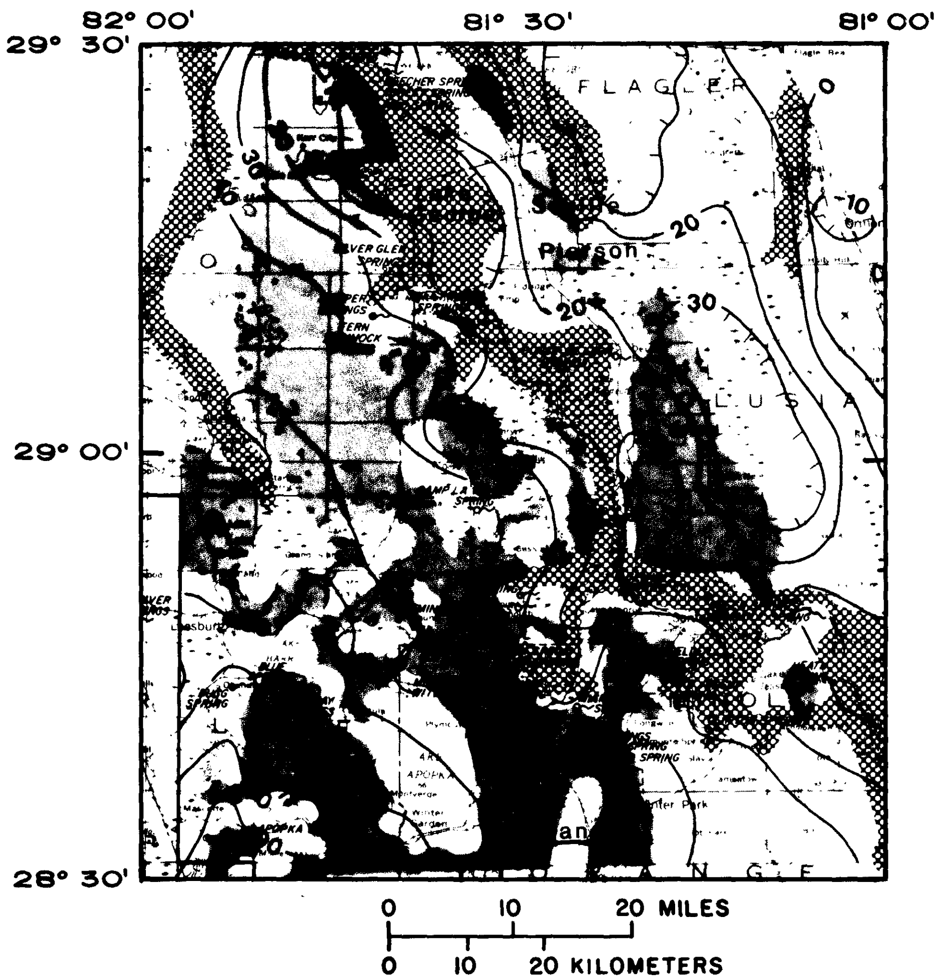
Miocene sediments form a confining layer between the surficial aquifer and the underlying Floridan aquifer system. Leakage through the confining layer is determined by the amount of clay present in the Miocene sediments and their thickness. On the topographic high area centered around Geneva the sediments are sandy and the confining beds are thus leaky. In the surrounding areas of low topography, clay layers as thick as 20 feet form a competent confining layer.

Floridan Aquifer System

The main source of water in the Geneva area is the Floridan aquifer system, which consists of permeable limestone and dolomite beds of Eocene to Oligocene age. Regional flow of water in the aquifer is generally northeastward from recharge areas in western Orange and Seminole Counties to discharge areas along the St. Johns River (fig. 3).

In the Geneva area, a local flow system that overlies the regional flow system has resulted in a freshwater lens surrounded by brackish water. A downward hydraulic gradient from the surficial aquifer to the Floridan aquifer system and the absence of thick clay layers have allowed local freshwater recharge to flush saltwater out of the sediments. The Geneva freshwater lens was first noted in the literature by Stringfield (1936, plate 16). The areal extent of the freshwater lens was first mapped by Barraclough in 1952-54 (1962b, fig. 36) and is shown in figure 4. In 1973-74, Tibbals (1977) refined the delineation of the lens and found little change from Barraclough's measurements (fig. 5).

Transmissivity estimates for the upper part of the Floridan aquifer system in the study area range from 1,700 to 17,000 ft^2/d (Tibbals, 1977, fig. 14) based on aquifer test analyses, and from 35,000 to 100,000 ft^2/d based on computer model simulation (Tibbals, 1981, fig. 6). The higher values derived from model simulation are thought to reflect the transmissivity of the full thickness of the upper part of the aquifer. The study area is located in a region of relatively low transmissivity that extends from the east coast of Florida to about the St. Johns River (Tibbals, 1981, fig. 6). Because of the relatively low transmissivity, flow through the Floridan in the region is generally slow-moving.



EXPLANATION

AREAS OF GENERALLY NO RECHARGE--Natural discharge areas based on areas of artesian flow May 1974 (Healy, 1975). Isolated depressions in potentiometric surface due to concentrated local pumpage may locally reverse gradient and induce limited recharge

AREAS OF HIGH RECHARGE (STEWART, 1980)--Extreme local relief may result in the occurrence of springs

AREAS OF LOW TO MODERATE RECHARGE--A downward gradient exists, but thickness and permeability of confining beds limit recharge

—10— POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells, May 1981 (Schiner and Hayes, 1981). Hachures indicate depressions. Contour interval 10 feet. Datum is sea level

SPRING

TWO OR MORE SPRINGS AT SAME LOCATION

Note: Data from Healy (1975) and Stewart (1980) were slightly modified by data from investigations in progress by the U.S Geological Survey, 1981.

Figure 3.--Recharge and discharge areas of central Florida and May 1981 potentiometric surface (from Phelps, 1984, figure 2).

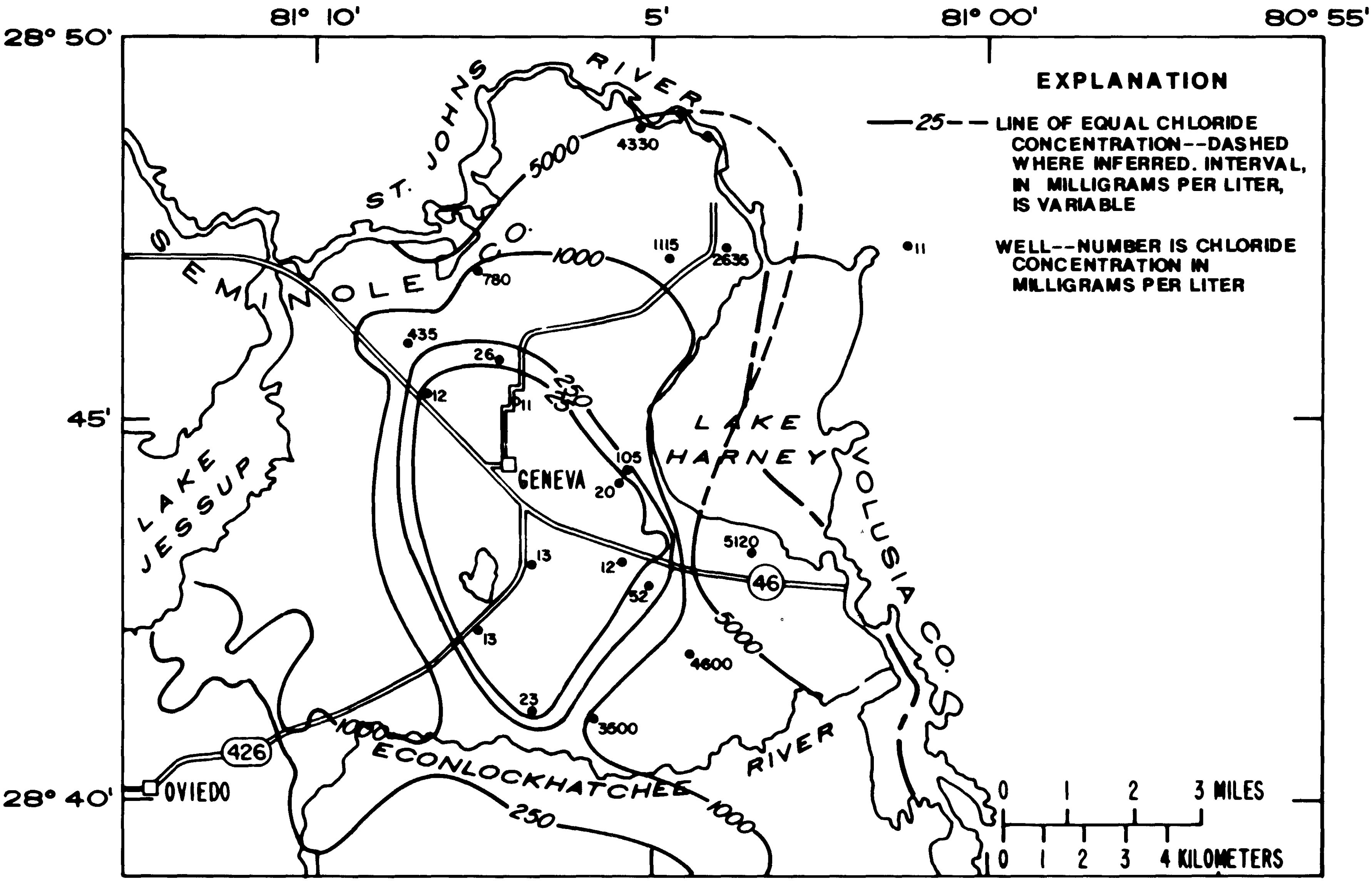


Figure 4.--Chloride concentration of water from the upper part of the Floridan aquifer system, 1951-54 (from Barraclough, 1962b).

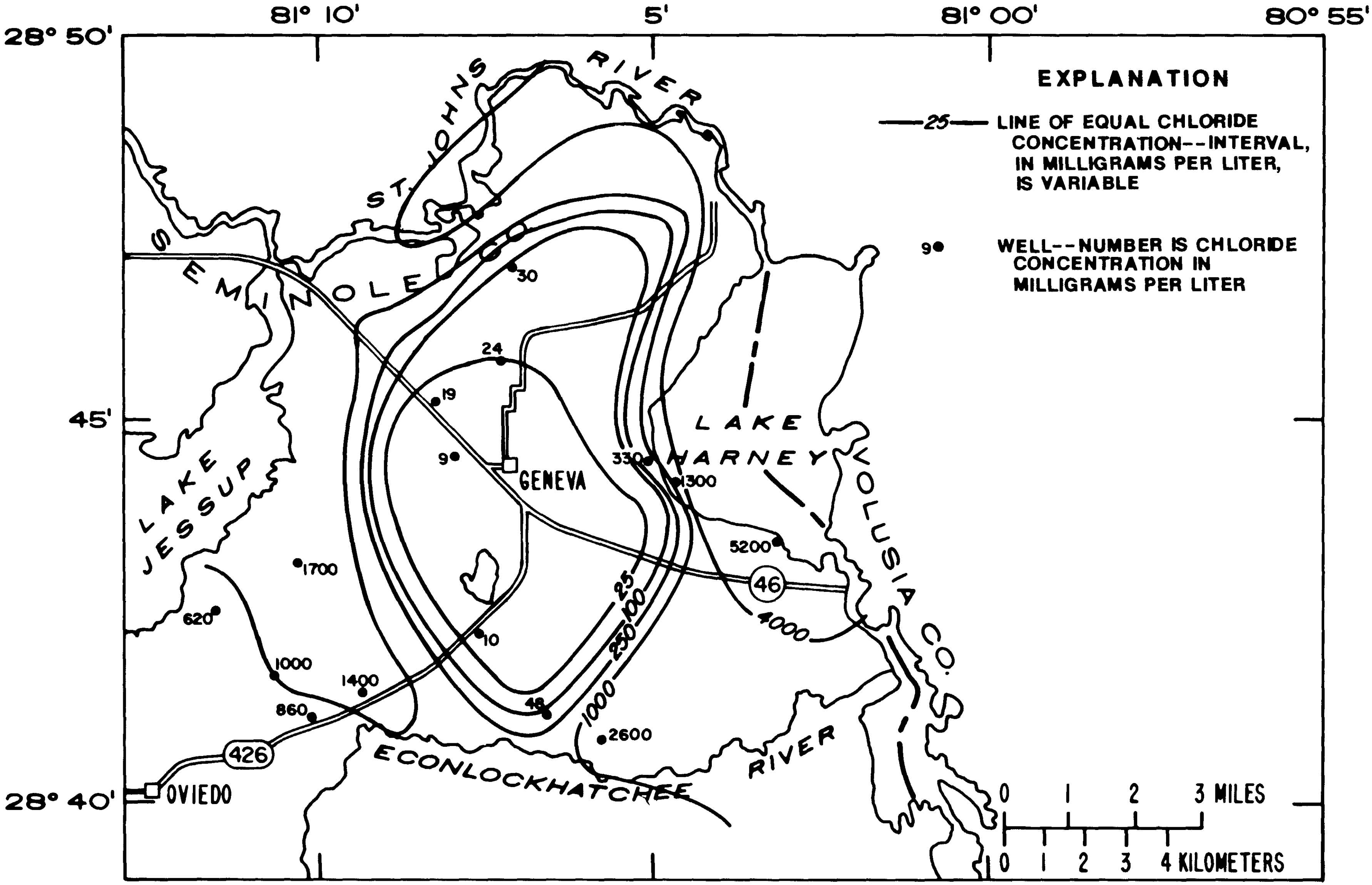


Figure 5.--Chloride concentration of water from the upper part of the Floridan aquifer system, 1973-74 (from Tibbals, 1977).

It is estimated that as many as 100 wells tap the Floridan aquifer system in the study area. The population of the area is growing and new wells are being drilled literally every day. Most of the wells are used for domestic supply for one or two families. Also, there are two municipal supply wells and six or seven irrigation wells. The well inventory prepared for this study concentrated mainly on wells in the transition zone between freshwater and brackish water. Wells inventoried for this study are shown in figure 6 and described in table 1.

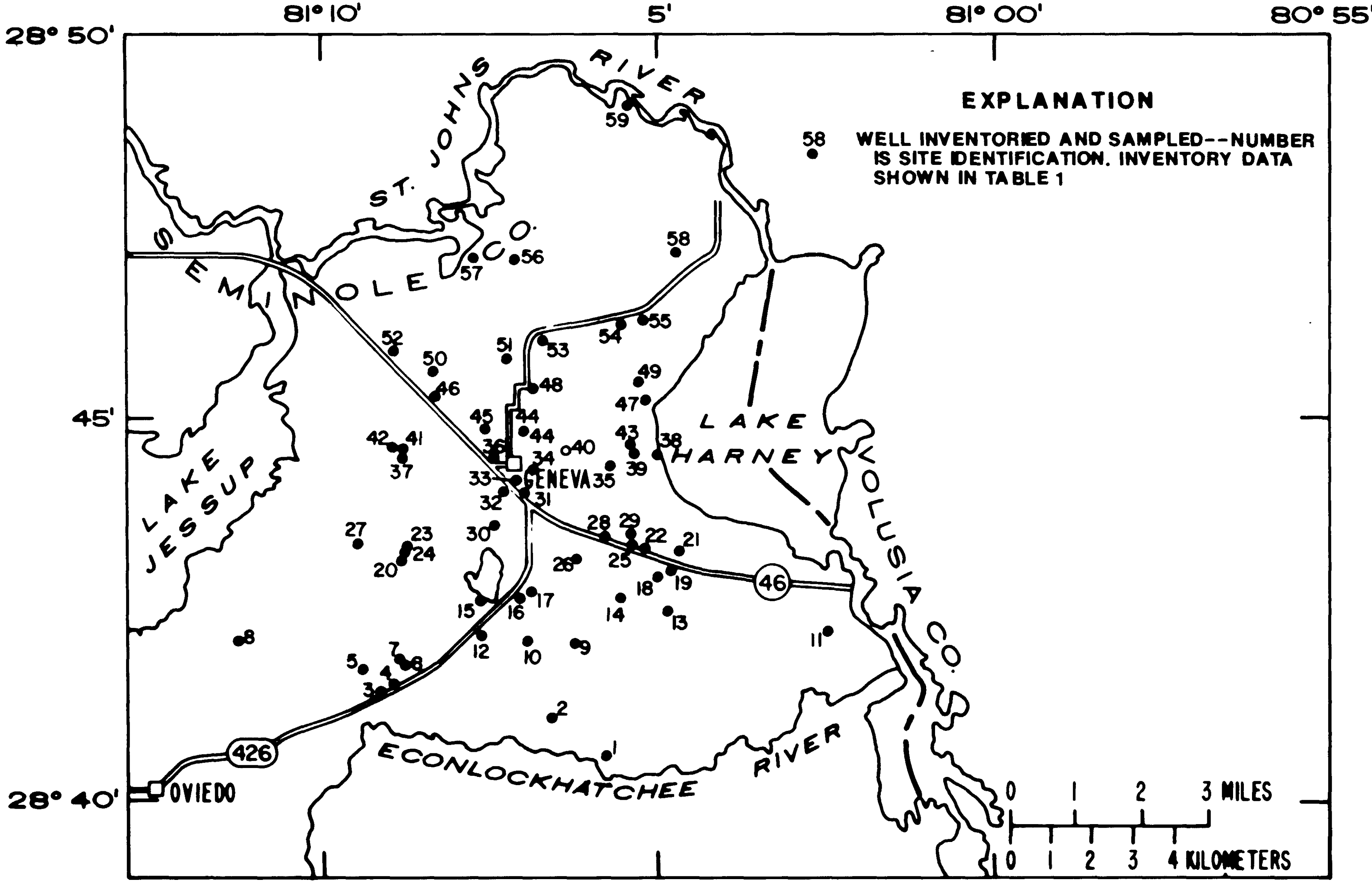


Figure 6.--Location of wells inventoried and sampled.

Table 1.--Well inventory

Site No.	Site identification No.	Name	Well depth (ft)	Casing Depth (ft)	Casing Diameter (in.)	Use of water	Land surface altitude (ft)	Aquifer or unit
1	284043081054401	Yarborough Hunt	78	--	2	Unused	26	Floridan
2	284111081063401	Yarborough Sect 3	90	--	2	Stock	25	Do.
3	284127081090501	Patterson	--	--	3	Domestic	28	Do.
4	284133081085501	McNair	230	--	4	do.	28	Do.
5	284146081092201	Norman	90	--	2	do.	25	Do.
6	284150081084601	Coleman Deep	160	124	4	Unused	29	Do.
7	284152081084801	Coleman Shallow	55	--	4	Domestic	30	Surficial
8	284207081111601	Soistman	205	76	4	Test	8.40	Floridan
9	284208081061301	Yarborough Sod	200	--	10	Irrigation	25	Do.
10	284210081065601	Snow Hill	--	--	2	Domestic	42	Do.
11	284217081023001	Killbee #3	154	58	4	Test	11.76	Do.
12	284219081074001	Ladd	101	--	2	Domestic	32	Floridan?
13	284233081045201	Killbee #1	100	77	4	Test	16.95	Floridan
13	284233081045202	Killbee #2	140	107	4	do.	16.95	Confining bed
14	284243081053301	Killbee Ranch	110	--	2	Stock	27	Surficial?
15	284244081073501	Farmer	200	--	4	Domestic	29.10	Floridan
16	284247081070601	Pellarin	188	--	4	do.	52	Do.
17	284247081070801	Pellarin Test	204	95	4	Test	49.07	Do.
17	284247081070802	do.	50	50	2	do.	49.07	Surficial
18	284300081045801	Conley	71	65	3	Domestic	16.27	Floridan?
19	284312081045101	Jepson Store	70	--	2	do.	19	Floridan
20	284312081084401	Fagan	126	--	4	do.	45	Do.
21	284319081044301	Cammack	94	58	3	Stock	17	Do.
22	284320081051201	Wilson	--	--	2	Domestic	22	Do.
23	284322081084301	Cockran For. East	203	90	4	Test	44.52	Do.
24	284322081084401	Davidson	--	--	4	Domestic	45	Surficial
25	284325081052401	Hillside #1	120	--	4	Irrigation	33	Floridan
26	284325081061201	Jepson Home	128	--	2	Domestic	30	Do.
27	284325081092701	Cockran For. West	165	56	4	Test	18.26	Do.
27	284233081045201	Cockran For. W. Shal.	37	37	2	do.	18.26	Surficial

Table 1.--Well inventory--Continued

Site No.	Site identification No.	Name	Well depth (ft)	Casing Depth (ft)	Casing Diameter (in.)	Use of water	Land surface altitude (ft)	Aquifer or unit
28	284329081054701	Lk Harney Water Asso	--	--	6	Public supply	38	Floridan
29	284331081052401	Hillside #2	250	59	6	Irrigation	30	Do.
30	284341081072601	Seminole Woods	210	145	8	Public supply	50	Do.
31	284411081065801	Yarborough Home	150	--	4	Domestic	68	Do.
32	284409081070901	Braddy	149	136	2	do.	72	Do.
33	284410081065201	Fire Station	--	--	4	Fire protection	68	Do.
34	284420081065201	Geneva School	250	105	8	Public supply	65	Do.
35	284423081052001	Jordan	136	--	4	Domestic	16	Do.
36	284428081072501	Ave C	60	60	2	Test	75.21	Surficial
36	284428081072603	Ave C Test well	393	117	6	do.	75.21	Floridan
37	284431081084501	Cochran	90	--	4	Domestic	35	Do.
38	284434081050101	Well nr Lk Harney	60	--	2	Unused	9.37	Do.
39	284435081052001	Fry	89	--	4	Domestic	12	Do.
40	284438081062201	Prevatt	110	80	2	do.	34	Do.
41	284438081084701	Johnson Deep	160	--	4	do.	43	Do.
42	284439081085501	Johnson Shallow	40	--	4	Irrigation	27	Surficial
43	284442081052401	Winona Dr	200	51	6	Test	13.33	Floridan
44	284447081070601	Ensor	255	--	4	Domestic	68	Do.
45	284456081073301	Hodges	--	--	4	do.	70	Do.
46	284519081081801	Rotundo	100	65	2	do.	27	Do.
47	284520081051001	Haddix	100	--	4	do.	7	Do.
48	284526081065401	Hisaw	170	--	4	do.	43	Do.
49	284531081051601	Vaughn	70	--	2	do.	9	Surficial?
50	284538081082001	Mockingbird Ln	--	--	2	do.	21	Do.
51	284550081071501	Cameron	126	77	4	Unused	23.38	Floridan
52	284553081085501	Blackard	80	--	2	Irrigation	19	Surficial
53	284604081063401	Moreau	79	--	2	Domestic	27	Surficial?
54	284619081053201	Steele	110	90	2	do.	18	Floridan
55	284626081051801	Kay Rd	200	83	4	Test	17.04	Do.
55	284626081052002	do.	50	50	2	do.	17.04	Surficial
56	284706081070801	Thrasher Pasture	178	99	6	Unused	15.61	Floridan
57	284706081073801	Thrasher Home	157	99	2	Domestic	24	Do.
58	284712081044301	County Landfill	141	70	4	Unused	21.20	Do.
58	284712081044303	do.	30	30	2	Test	21.20	Surficial
58	284712081044304	do.	47	47	2	do.	21.20	Do.
59	284909081052101	McCall	94	--	2	Unused	11.30	Floridan

HYDROLOGIC CONDITIONS

Rainfall

During the study, a drier than average year (1981) was followed by a wetter than average year (1982), which allowed data collection during both types of conditions and an evaluation of the response of the hydrologic system to a range of climatic conditions. The 30-year average rainfall computed by the National Oceanic and Atmospheric Administration for 1941 to 1970 at Sanford (12 miles northwest of Geneva) is 53.32 inches (fig. 7). The average rainfall at Sanford for the entire period of record (1913-82) is 51.33 inches. Rainfall in Sanford in 1981 was 41.67 inches and in 1982, 59.91 inches.

Rainfall at a gage on Lake Harney (about 3 miles east of Geneva) for 1981 and 1982 (fig. 8) was 41.84 and 73.06 inches, respectively. The difference between 1982 rainfall at Sanford and Lake Harney is due to the widely scattered nature of convection thunderstorms that commonly occur in Florida.

A recording tipping bucket rain gage was established at Buck Lake in July 1981 and data were collected until June 1982. Data from the Buck Lake rain gage are shown in figure 8.

Lakes and Surficial Aquifer

Several shallow lakes in the Geneva area store rainfall that then percolates downward through the surficial aquifer to the Floridan aquifer system. Some lakes, such as Lake Cochran (fig. 1), contain water only during the wettest months of wet years and at other times are swamps or are dry beds. The two halves of Lake Proctor (fig. 1) once formed a single lake, but the lake stage has been lowered through time and the lake is now bisected by State Road 46.

Lake Geneva had the largest stage fluctuation of the five lakes in Seminole County monitored by Barraclough during 1953-56 (1962b, p. 40). The lake's stage ranged about 7 feet (21.5 to 28.2 feet in altitude). During 1953-56, the lake level was 2 to 6 feet higher than water levels in nearby wells in the Floridan aquifer system. Periodic measurements of the stage levels in Lake Geneva were discontinued in 1979. In March 1981, a staff gage on the lake was out of the water (stage was less than 20.86 feet above sea level). The lake became two shallow ponds because the center of the lake was dry. By May 1981, the eastern part of the lake (where the staff gage is located) was completely dry. It remained dry until the end of the summer of 1982 when above average rainfall refilled the lake. On October 14, 1982, the lake stage was 23.05 feet above sea level.

A staff gage was installed on Buck Lake (fig. 1), a major lake in the Geneva area, in April 1981. Within a month, the lake level had dropped so that the gage was out of the water. Stage levels of Buck Lake are shown in table 2. Although the minimum stage reached during the drought of 1981 is not known, the fluctuation from 1981 to 1982 was at least 3 feet. From September 1981 to September 1982 the potentiometric surface of the Floridan aquifer system in the area fluctuated about 3 feet and was lower than the lake level. None of the lakes in the Geneva area appear to be directly connected to the Floridan.

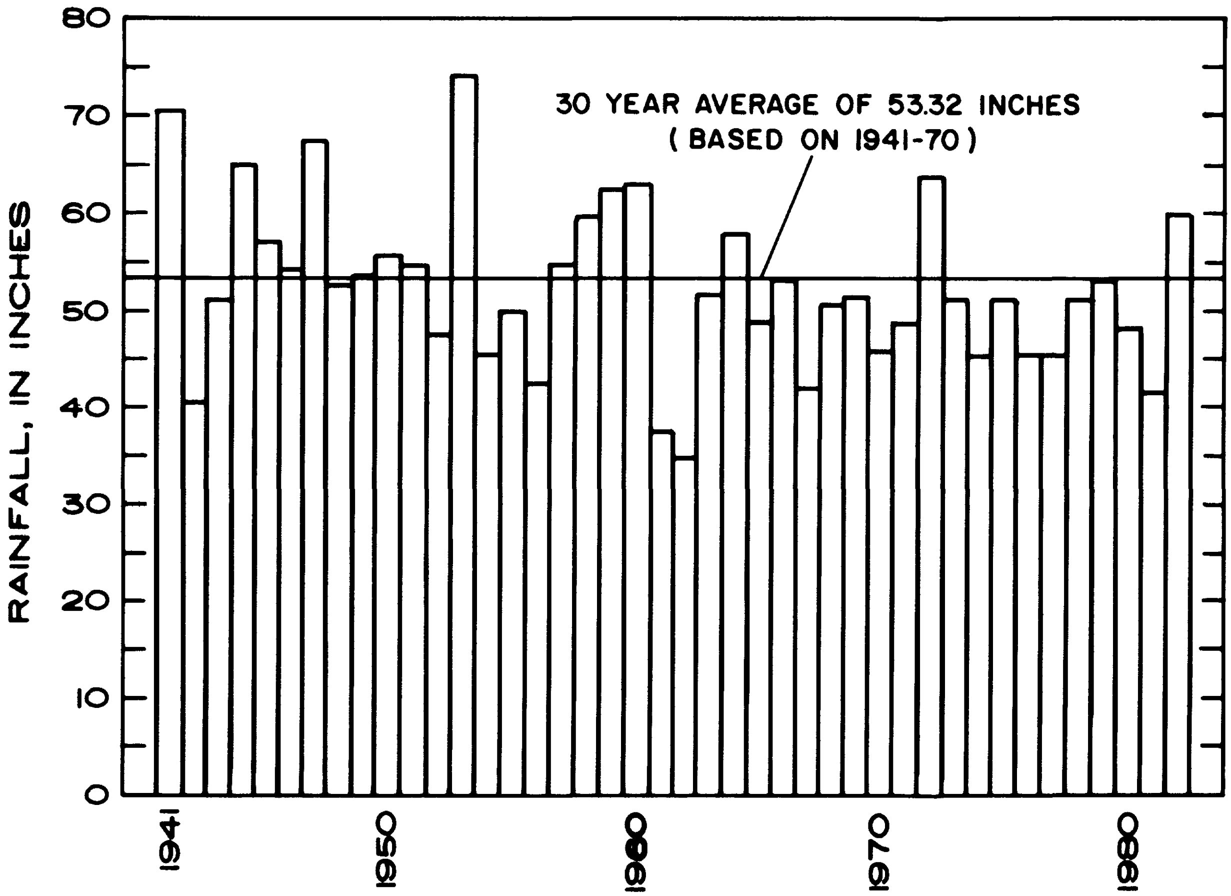
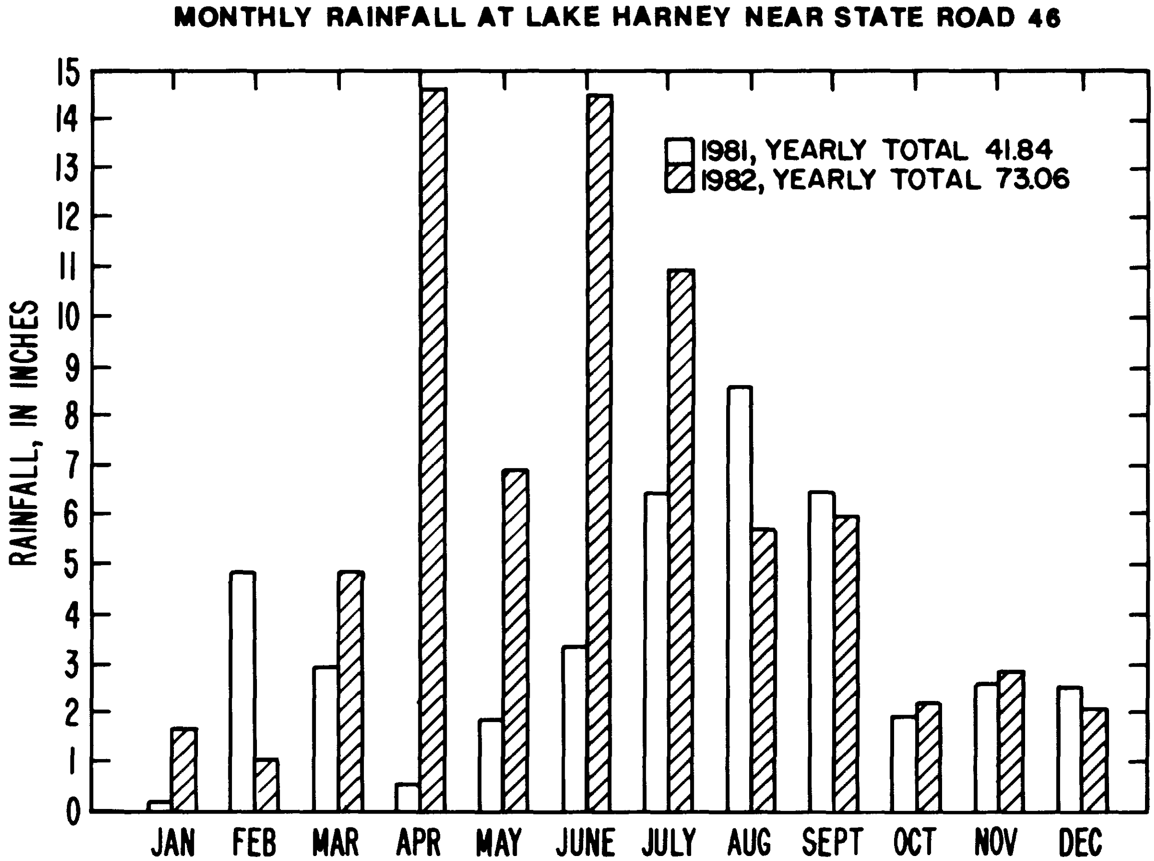


Figure 7.--Rainfall at Sanford, Florida, 1941-82 (data from National Oceanic and Atmospheric Administration climatological station at Sanford).

Water levels in several existing wells and five test wells in the surficial aquifer were measured during the study. Water-level data are shown in table 3. The maximum fluctuation was about 2-1/2 feet. Because most of the test wells were drilled after the drought period the minimum levels that occurred during the dry year (1981) were not documented. Depth to water in the surficial aquifer wells ranged from 1-1/2 feet at site 27 (land surface altitude 18.26 feet) to 20-1/2 to 24 feet at site 36 (land surface altitude 74.21 feet).

Floridan Aquifer System

Potentiometric surface maps of the Floridan aquifer system in Seminole County were compiled by Barraclough (1962b, figs. 7 and 8) for January 1954 (following a wet year in 1953) and January 1956 (following a dry year in 1955) and are shown in figure 9. Figure 10 shows potentiometric surface maps for September 1981 (dry year) and September 1982 (wet year) compiled by Schiner and Hayes (1981 and 1982). A comparison between these maps shows almost identical potentiometric surfaces, suggesting no long-term decline in the potentiometric surface in the Geneva area.



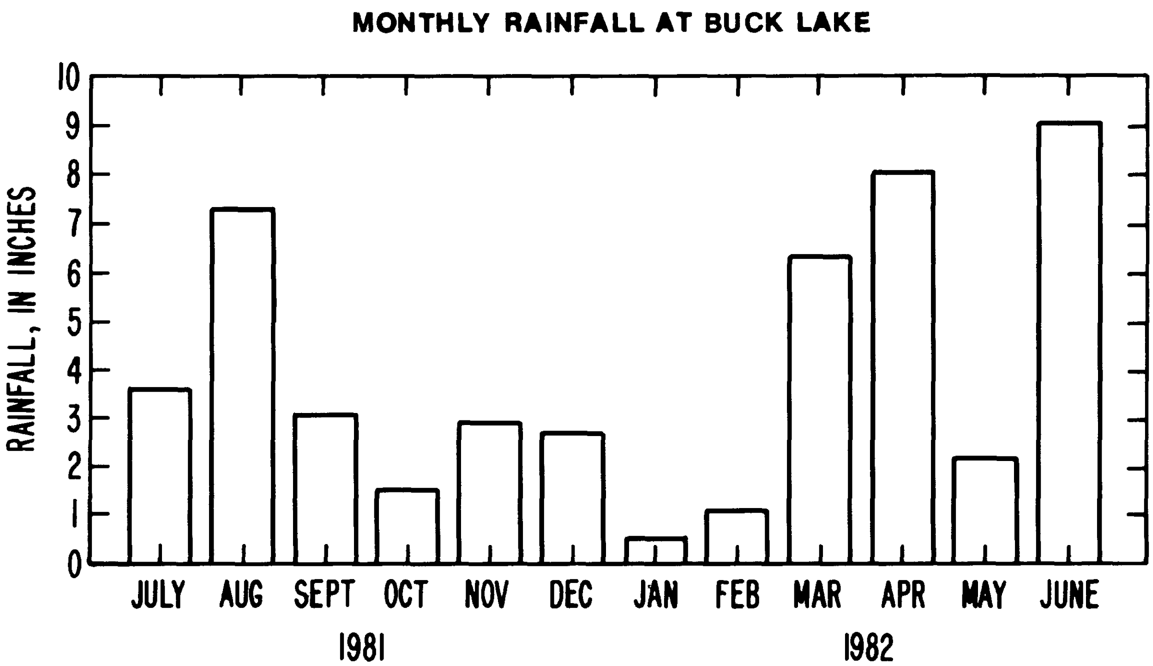


Figure 8.--Monthly rainfall at Lake Harney and Buck Lake, 1981-82.

Table 2.--Elevation of Buck Lake near Geneva, 1981-83

Date	Elevation (ft above sea level)
04-14-81	23.52
05-19-81	22.80
06-04-81	22.62
06-17-81	less than 22.60 (gage out of water)
09-14-81	do.
04-12-82	do.
05-12-82	do.
06-15-82	22.90
07-06-82	23.45
08-12-82	23.64
10-14-82	25.46
12-07-82	25.32
01-12-83	25.30
03-03-83	26.50

Table 3 shows water levels during 1982-83 for several wells tapping the Floridan aquifer system. A water-level recorder was installed on the test well at site 17. The minimum water level measured was 16.86 feet above sea level in January 1982, and the maximum was 20.17 feet above sea level in September 1982, a range of 3.31 feet.

The Geneva freshwater lens is a result of local recharge that percolates downward from the surficial aquifer to the Floridan. Recharge occurs when water levels in the surficial aquifer are higher than the water levels in the Floridan (a downward gradient exists). The area enclosed by the 25-foot altitude contour (fig. 1) is where most of the recharge occurs. For example, water levels of wells in the surficial aquifer and Floridan aquifer system (table 2) indicate a downward gradient at sites 17 and 36. The gradient is also downward at sites 20, 23, and 24, based on measured water levels and pump types at those sites. In some areas of lower topography the gradient is upward (discharge areas) whereas in other areas the gradient is downward, but the head difference between the surficial aquifer and Floridan aquifer system is slight and little recharge takes place. At site 55, the vertical hydraulic gradient changes direction seasonally--upward during the dry season and downward during the wet season.

The water level or head difference between the two aquifers is not the only factor controlling recharge. Other important factors are hydraulic conductivity and thickness of the intermediate confining unit. The confining unit must be thin and permeable enough to allow appreciable recharge to the upper part of the Floridan.

Table 3.--Water levels in selected wells, 1982-83

Site No.	Site identification No.	Aquifer	Well depth (ft)	Land surface altitude	Water levels in feet above sea level								
					1982				1983				
					05-13	07-20	09-10	12-06	01-20	02-16	03-15	04-28	05-19
11	284217081023001	Floridan	154	11.76	8.34	10.22	10.72	8.83	10.17	10.17	9.50	10.63	8.73
13	284233081045201	Confining bed	100	16.95	14.66	15.56	16.08	15.63	---	16.53	15.66	18.45	15.28
13	284233081045202	Floridan	140	16.95	---	15.72	16.23	15.62	---	16.57	16.74	15.67	14.10
17	284247081070801	do.	204	49.84	---	20.12	20.17	18.19	17.92	19.03	19.20	---	---
17	284247081070802	Surficial	50	49.84	---			41.61	40.76	42.52	41.12	43.25	42.47
23	284322081084301	Floridan	203	44.52	17.23	17.57	18.57	18.73	18.22	19.13	19.53	20.70	18.56
27	284325081092701	do.	165	18.26	16.72	18.03	18.72	18.54	18.00	18.31	19.21	19.41	16.90
27	284325081092702	Surficial	37	18.26	15.28	16.51	16.16	15.19	14.96	16.64	16.23	16.71	15.50
36	284428081072603	Floridan	393	75.21	13.25	14.23	14.93	15.43	14.75	---	14.69	16.14	15.11
36	284428081072501	Surficial	60	75.21	---	---	---	51.86	51.27	51.45	53.85	53.77	54.69
43	284442081052401	Floridan	200	13.33	12.36	14.40	14.63	14.35	14.63	13.74	15.15	15.28	13.07
55	284626081051801	do.	200	17.04	12.65	13.63	14.07	13.33	12.94	13.90	14.38	14.25	13.22
55	284626081052002	Surficial	50	17.04	---	---	---	13.35	12.65	14.26	14.04	14.13	13.01
58	284712081044301	Floridan	141	21.20	10.23	11.33	11.82	11.33	11.00	12.14	12.32	12.48	11.08
58	284712081044303	Upper surficial	30	21.20	---	---	---	16.11	15.93	18.32	18.65	18.00	16.65
58	284712081044304	Lower surficial	47	21.20	---	---	---	10.45	10.13	11.40	11.49	10.68	10.58

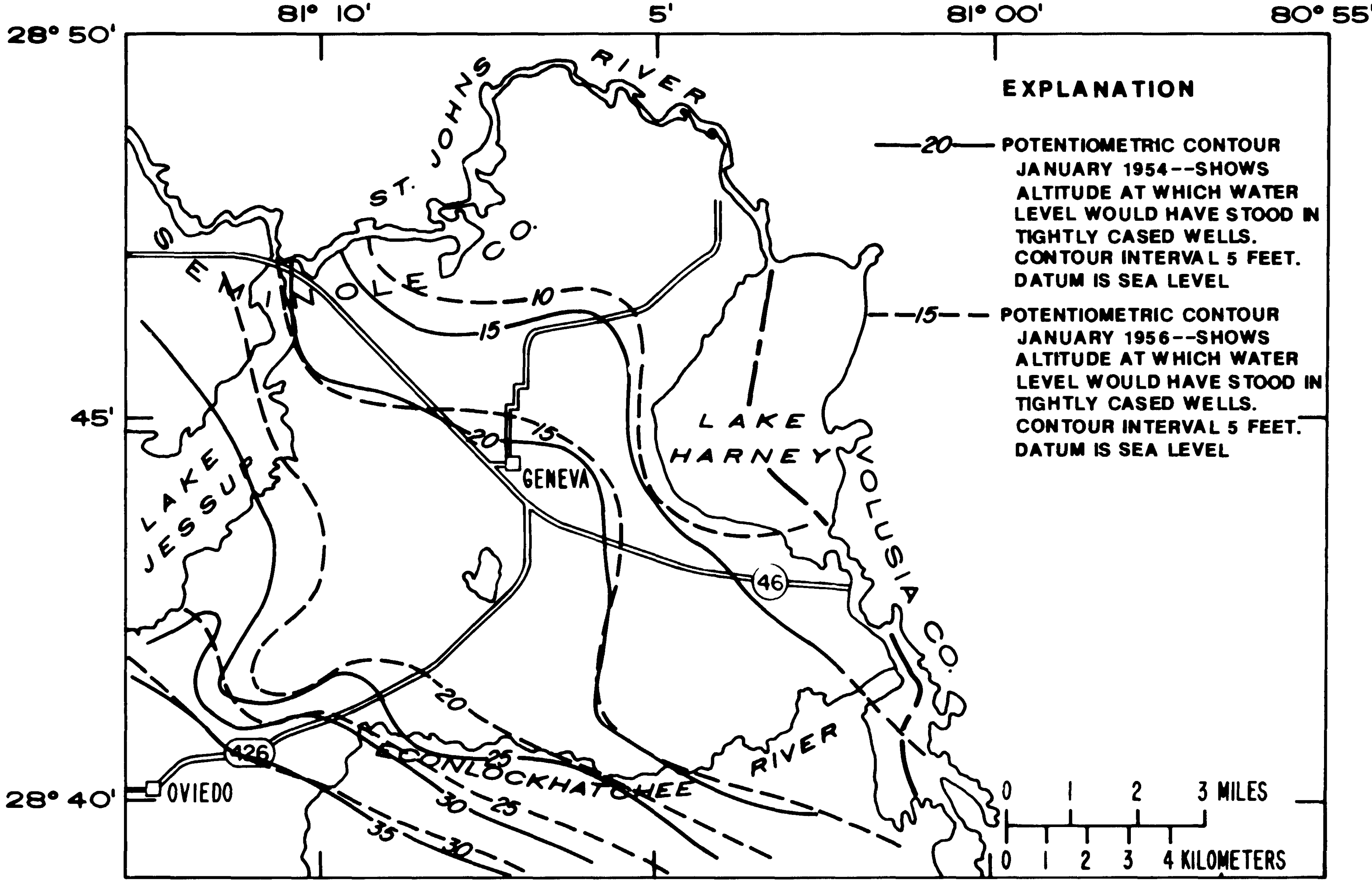


Figure 9.--Potentiometric surface of the upper part of the Floridan aquifer system, January 1954 and 1956 (from Barraclough, 1962b).

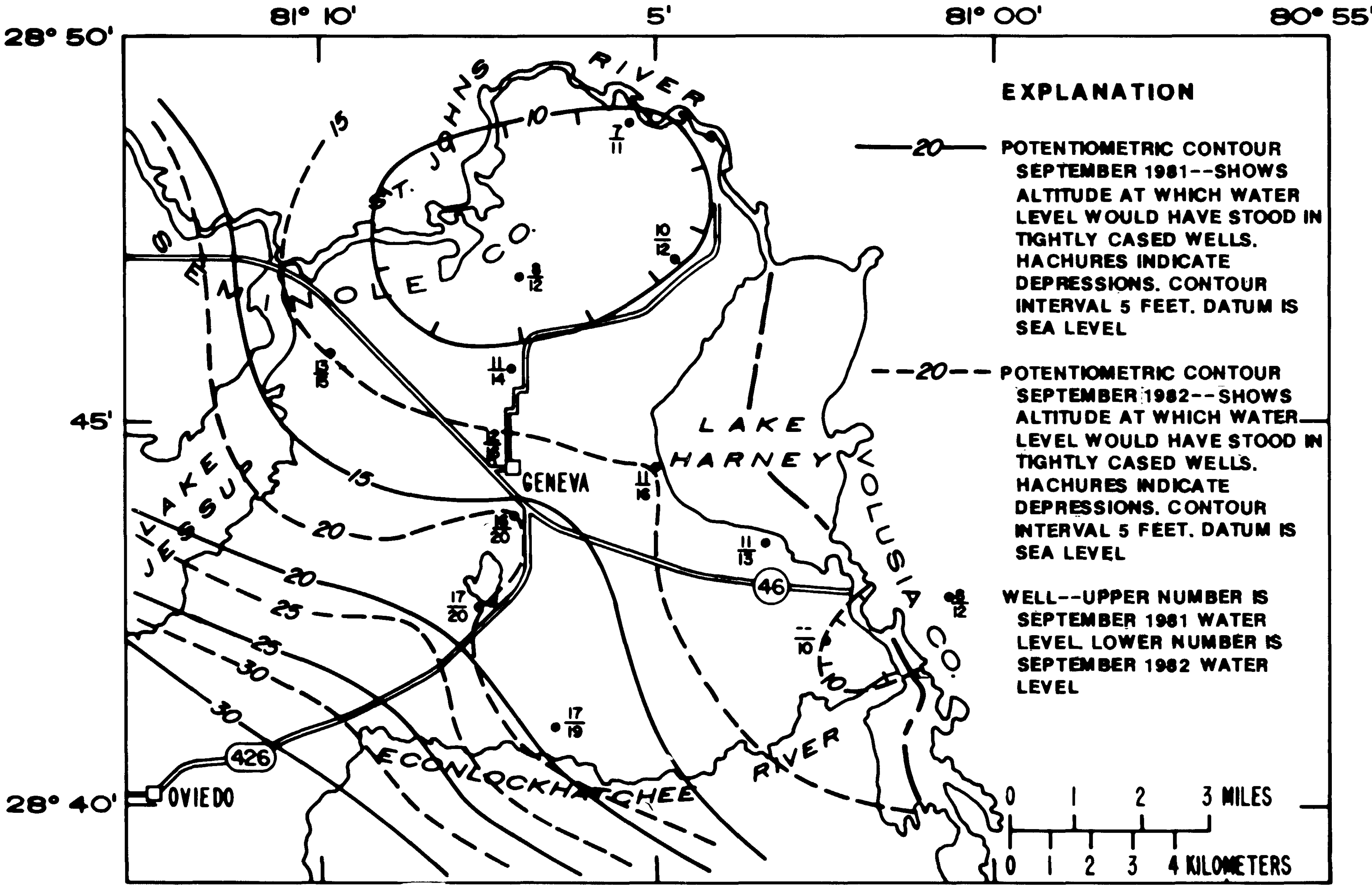


Figure 10.--Potentiometric surface of the upper part of the Floridan aquifer system, September 1981 and 1982 (from Schiner and Hayes, 1981; 1982).

TEST DRILLING

Purposes

Several test wells were drilled to obtain geologic and hydrologic data for this study. Specific data of interest included information on: (1) the thickness and lithology of material overlying the Floridan aquifer system, (2) the water-bearing properties of the Floridan aquifer system, and (3) the changes in water quality with location and depth.

Site Selection and Techniques

Eight 200-foot deep wells and one 400-foot deep well were drilled at locations shown in figure 11. Sites were selected to obtain the most information as stated above, with the additional considerations of accessibility of the site to the drill rig and permission from the property owners to drill. The 200-foot deep wells were drilled by air rotary and the 400-foot deep well by cable tool. The drilling techniques were selected to facilitate collection of water-quality samples and to obtain as much geologic information as possible while still allowing more rapid drilling than, for example, continuous split-spoon sampling or coring would provide. The 400-foot deep well at site 36 was drilled in conjunction with the Floridan Aquifer Regional Aquifer Systems Analysis study. Also, one auger hole and three shallow wells from which split-spoon samples were collected, were drilled to depths of less than 60 feet. A core of limestone from the Floridan aquifer system was obtained at site 23.

Geologic and geophysical logs for the test holes are shown in figure 12 and geologic sections are shown in figures 13, 14, and 15. In the following sections, the strata are discussed in the order penetrated.

Holocene to Miocene Deposits

Deposits of Holocene to Miocene age range in thickness from less than 50 feet at site 27 to as much as 137 feet at site 13 (fig. 12). The post-Miocene deposits were sampled by auger cuttings and split-spoon cores at sites 17, 27, 36, 55, and 58. These deposits are predominantly sand and clayey sand. The thickest clay was at site 8, a topographically low area where ground water has high chloride concentrations. The thick deposits of clay there have probably prevented saline water from being flushed out of the aquifer by recharge water.

The upper Miocene deposits are mostly shell, sand, and clayey sand. These deposits range in thickness from about 20 feet at sites 11 and 23 to 70 feet at site 55. Shell beds in the upper Miocene deposits yield as much as 50 gal/min to 2-inch diameter wells at some sites (for example at sites 7, 24, and 27).

Laboratory hydraulic conductivities of samples of clay from site 58 and sand from site 36 were 1.7×10^{-5} ft/d for the clay and 9.33 ft/d for the sand.

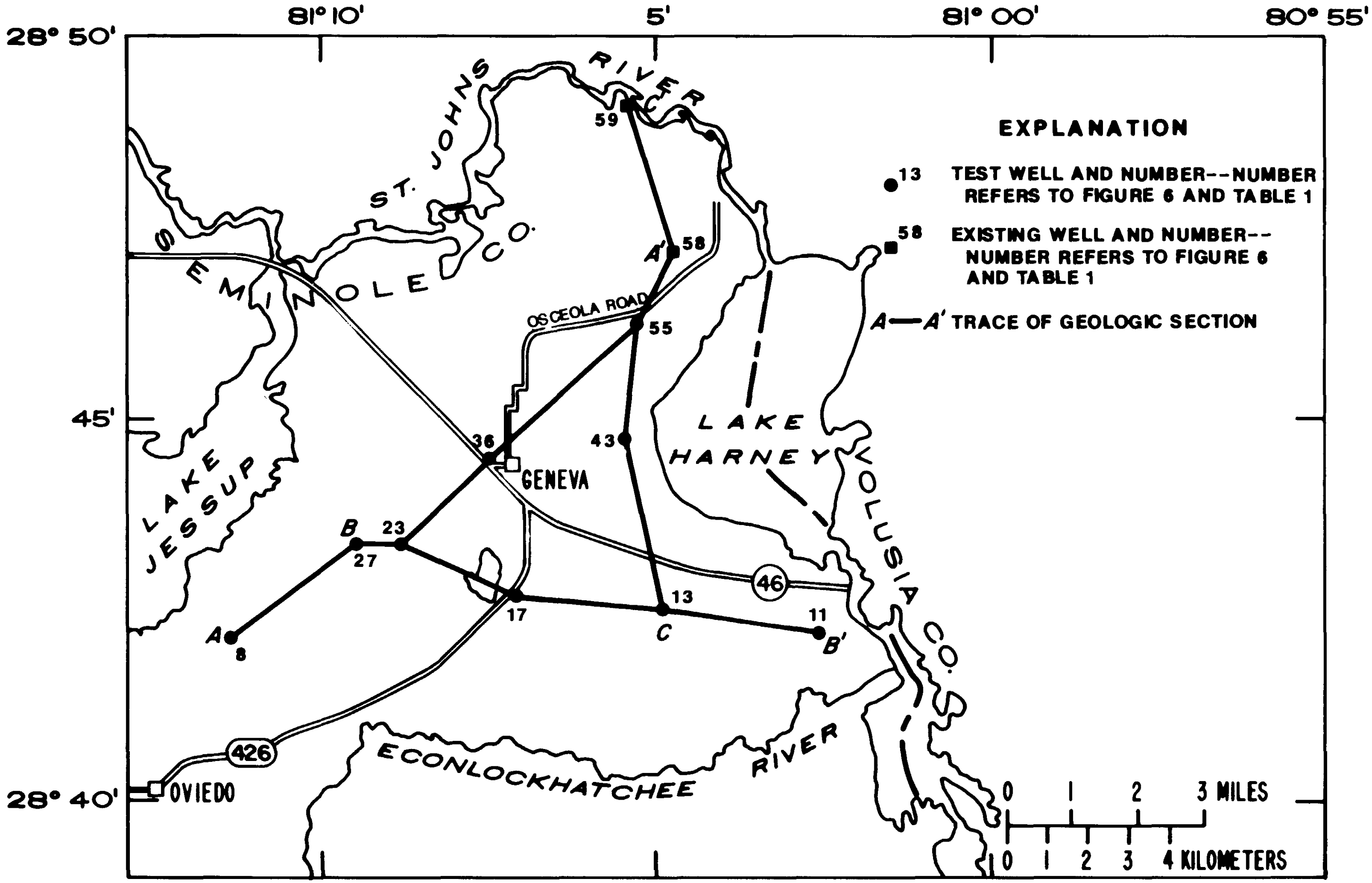


Figure 11.--Locations of test wells and geologic sections.

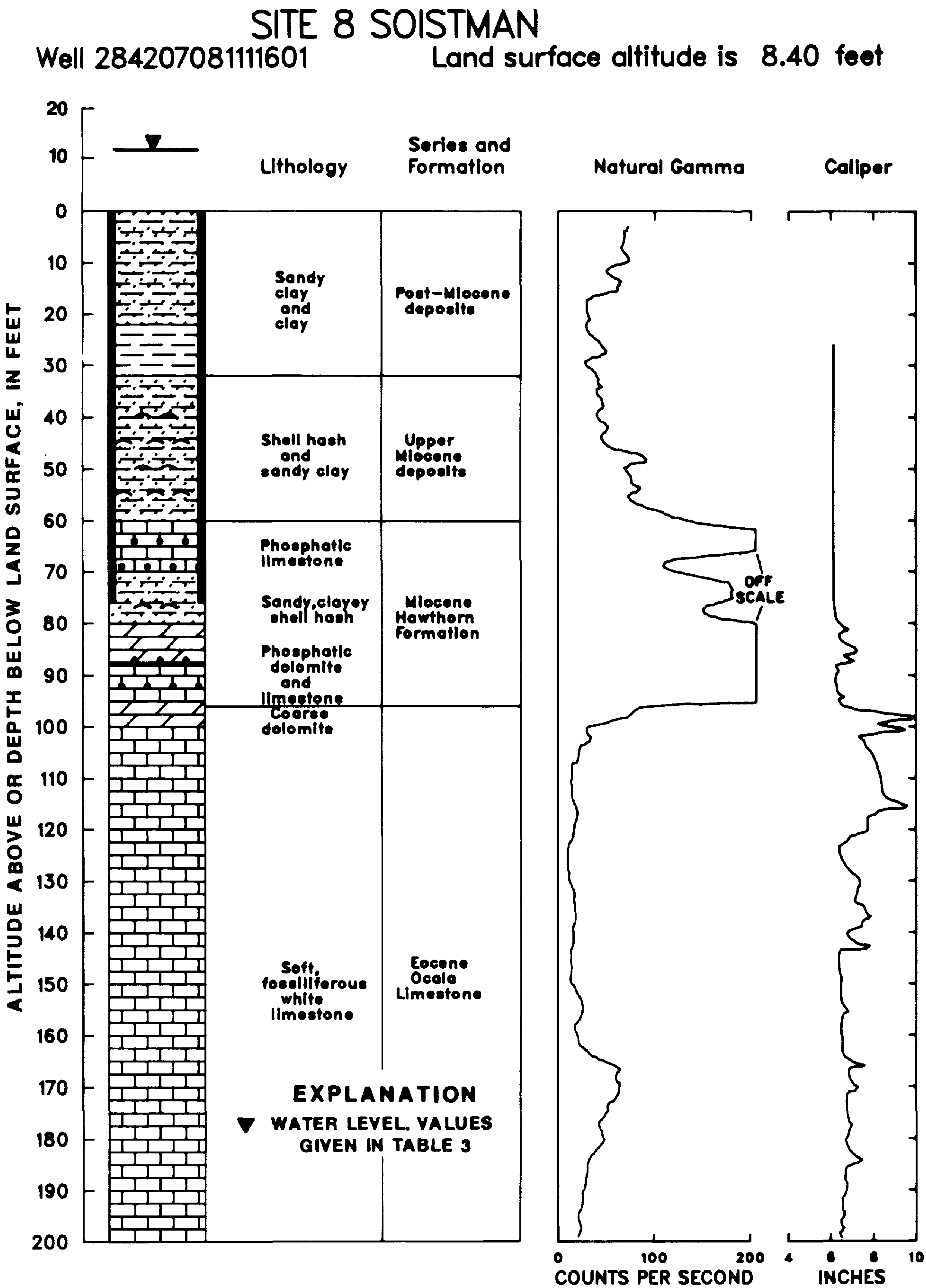


Figure 12.--Geologic and geophysical logs of test wells.

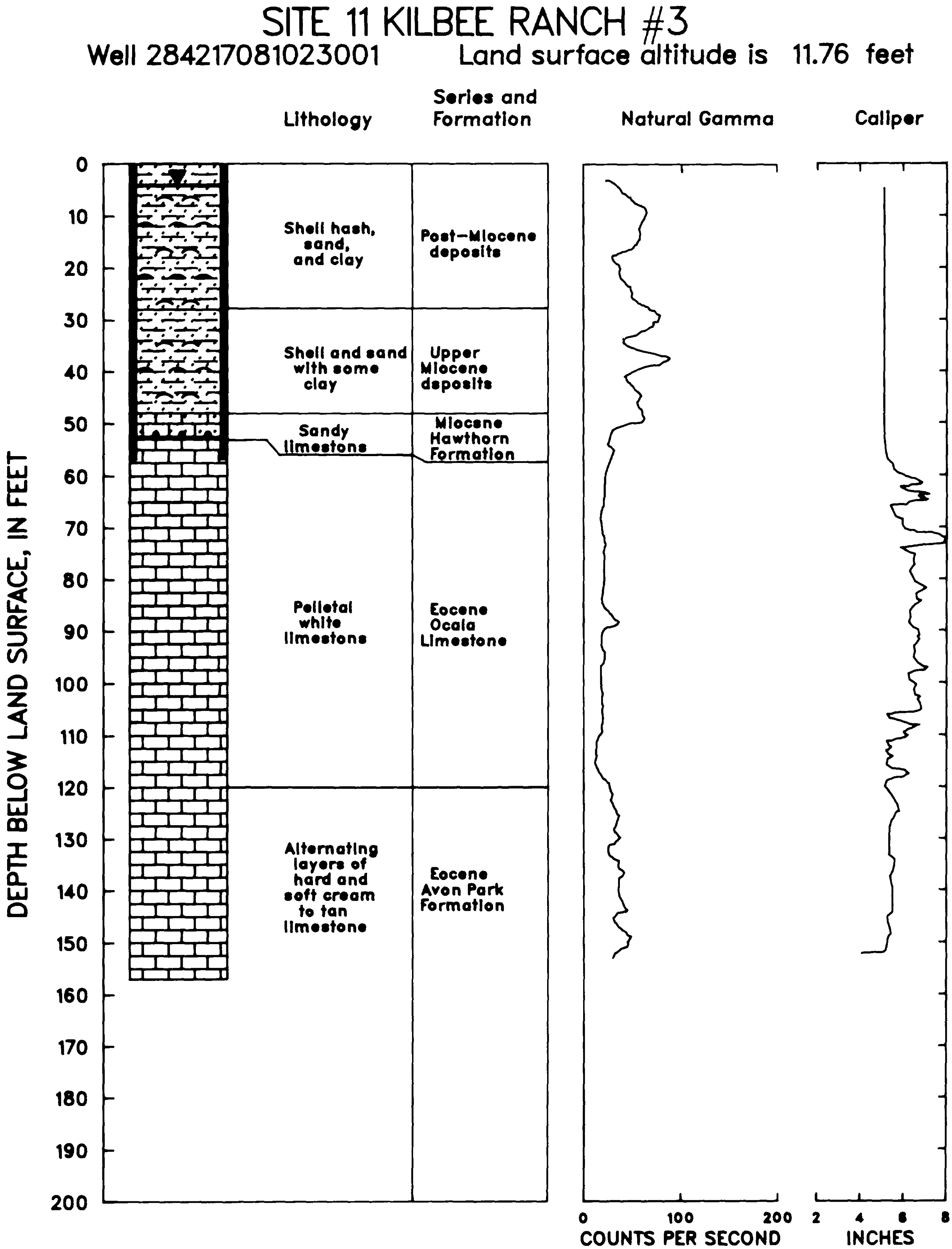


Figure 12.--Geologic and geophysical logs of test wells--Continued.

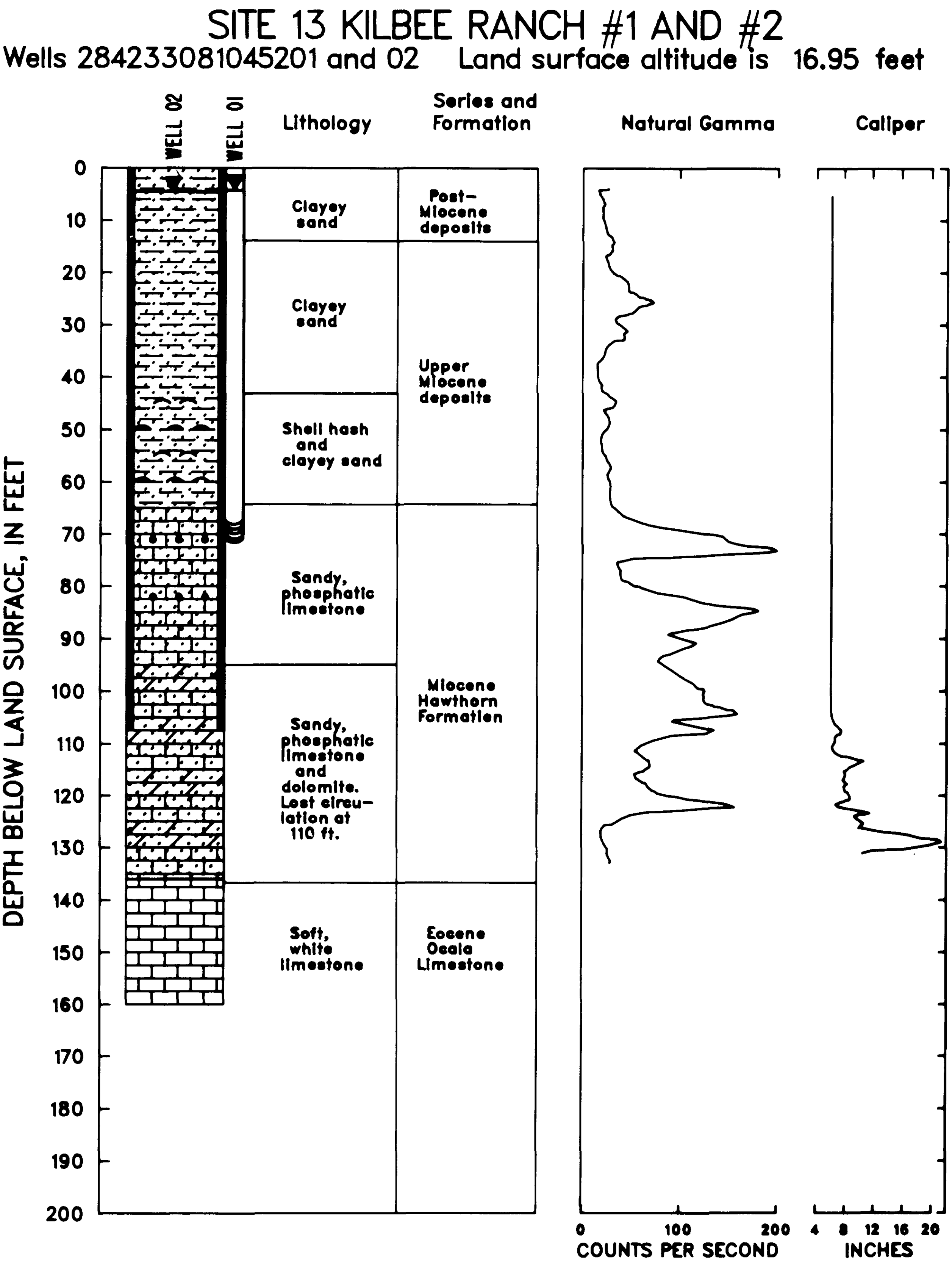


Figure 12.--Geologic and geophysical logs of test wells--Continued.

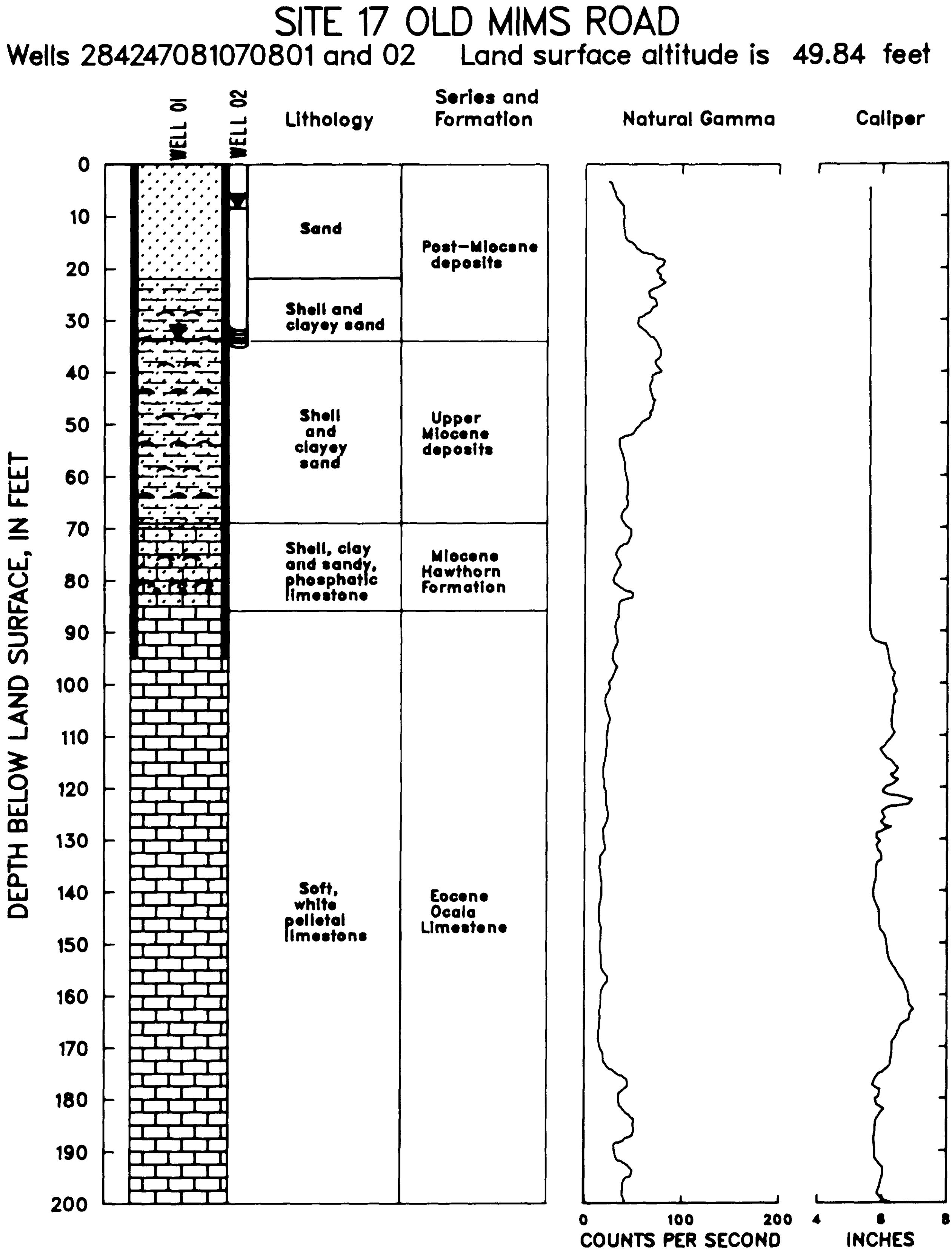


Figure 12.--Geologic and geophysical logs of test wells--Continued.

SITE 23 COCKRAN FOREST EAST

Well 284322081084301 Land surface altitude is 44.50 feet

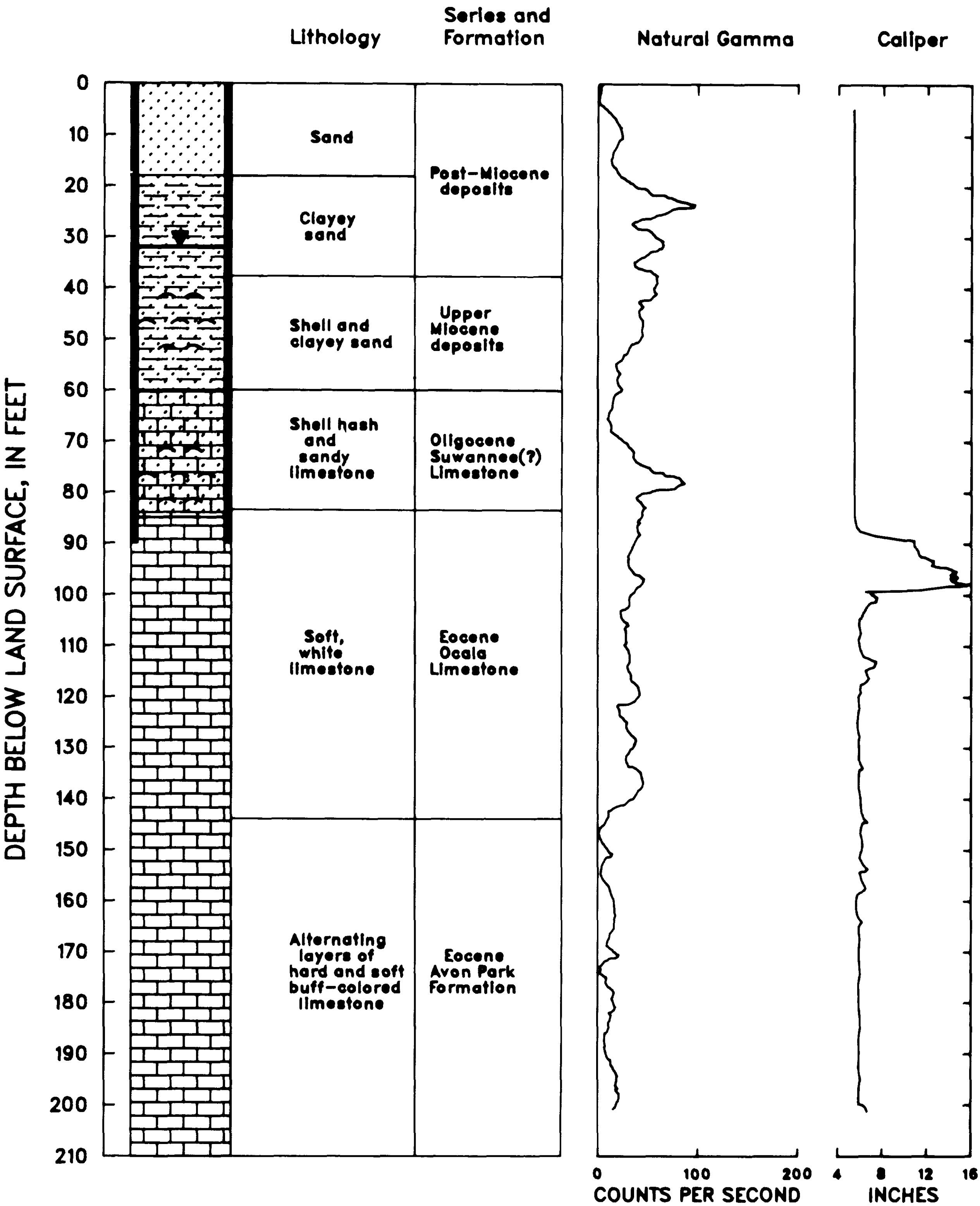


Figure 12.--Geologic and geophysical logs of test wells--Continued.

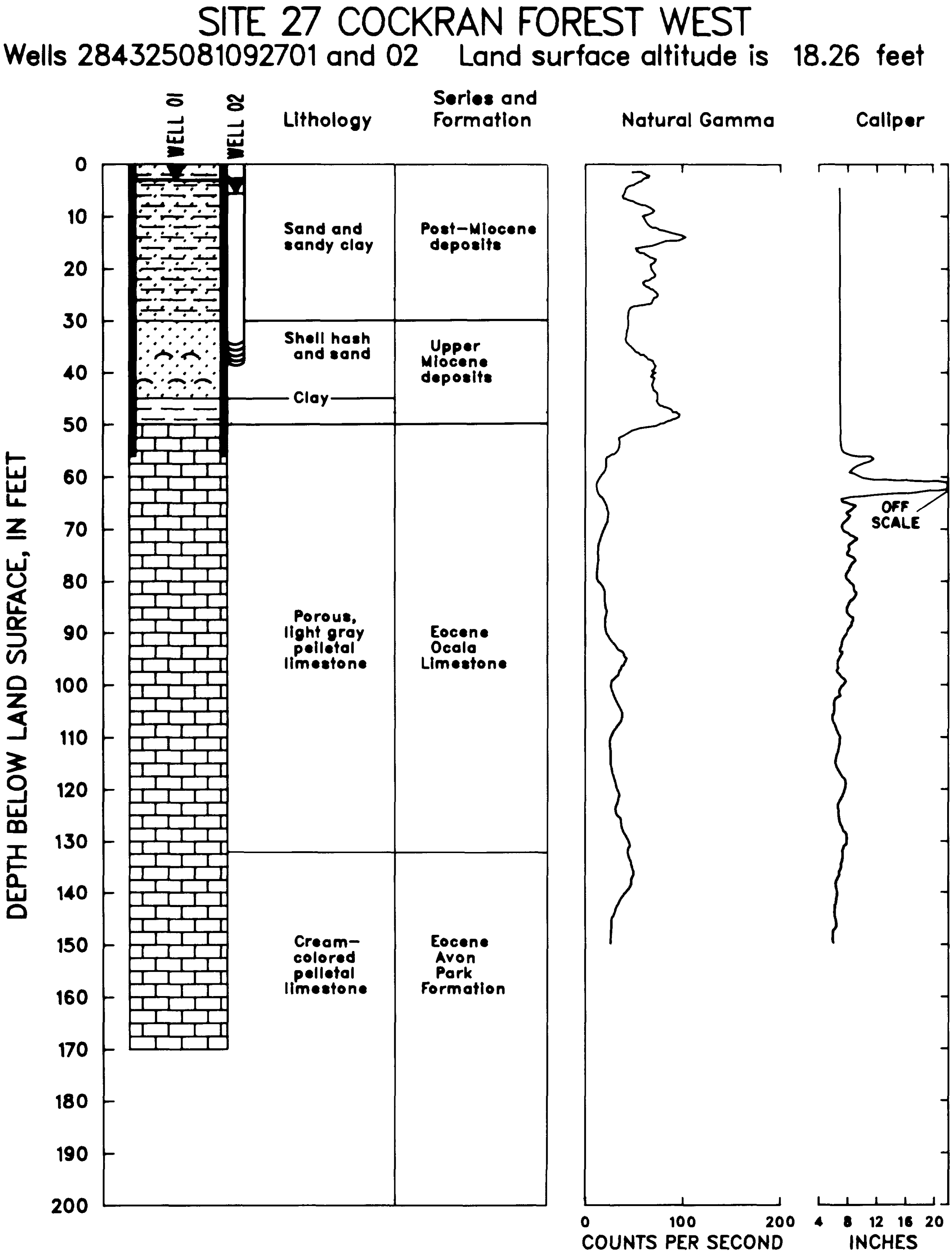


Figure 12.--Geologic and geophysical logs of test wells--Continued.

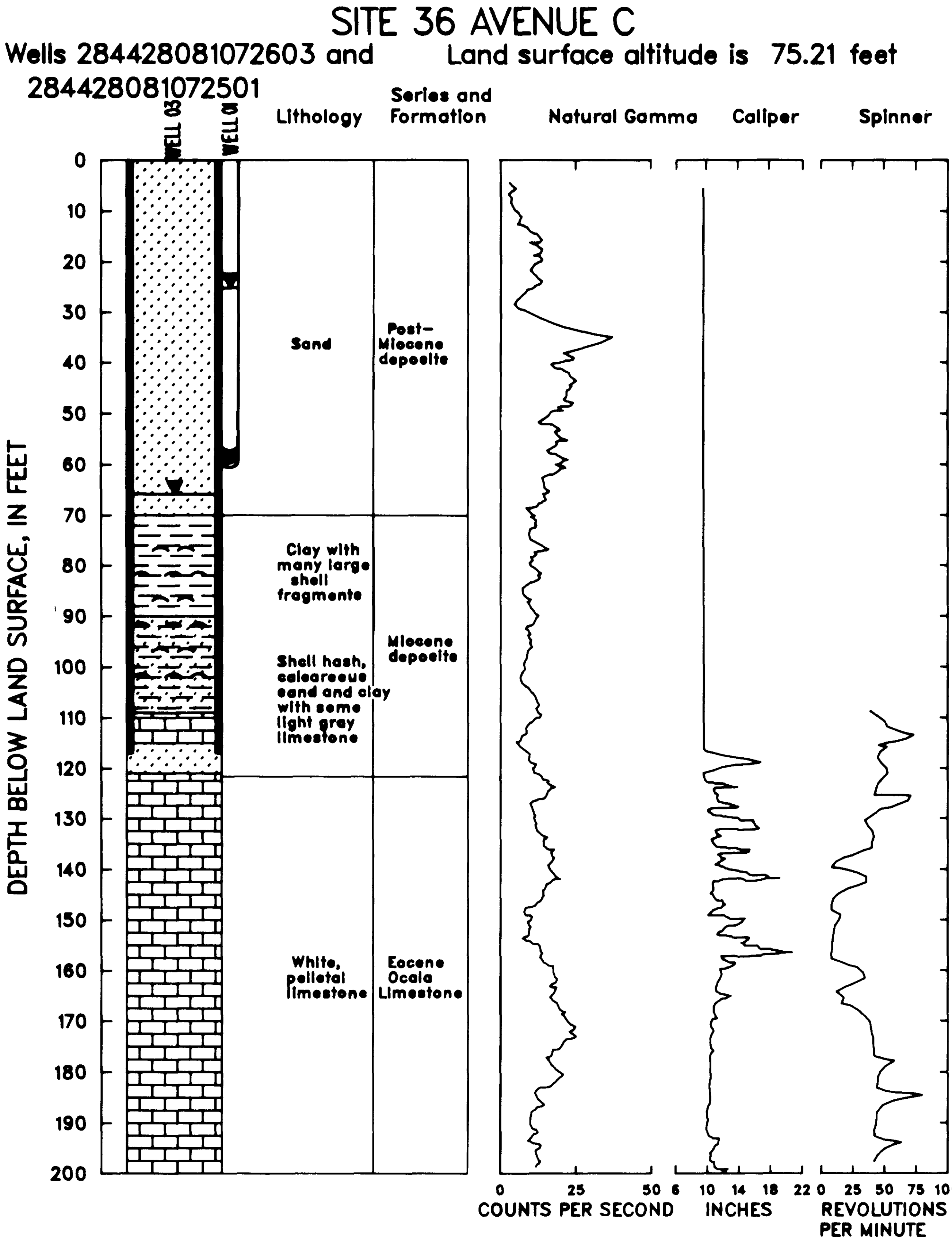


Figure 12.--Geologic and geophysical logs of test wells--Continued.

AVENUE C (continued)

Well 284428081072603 Land surface altitude is 75.21 feet

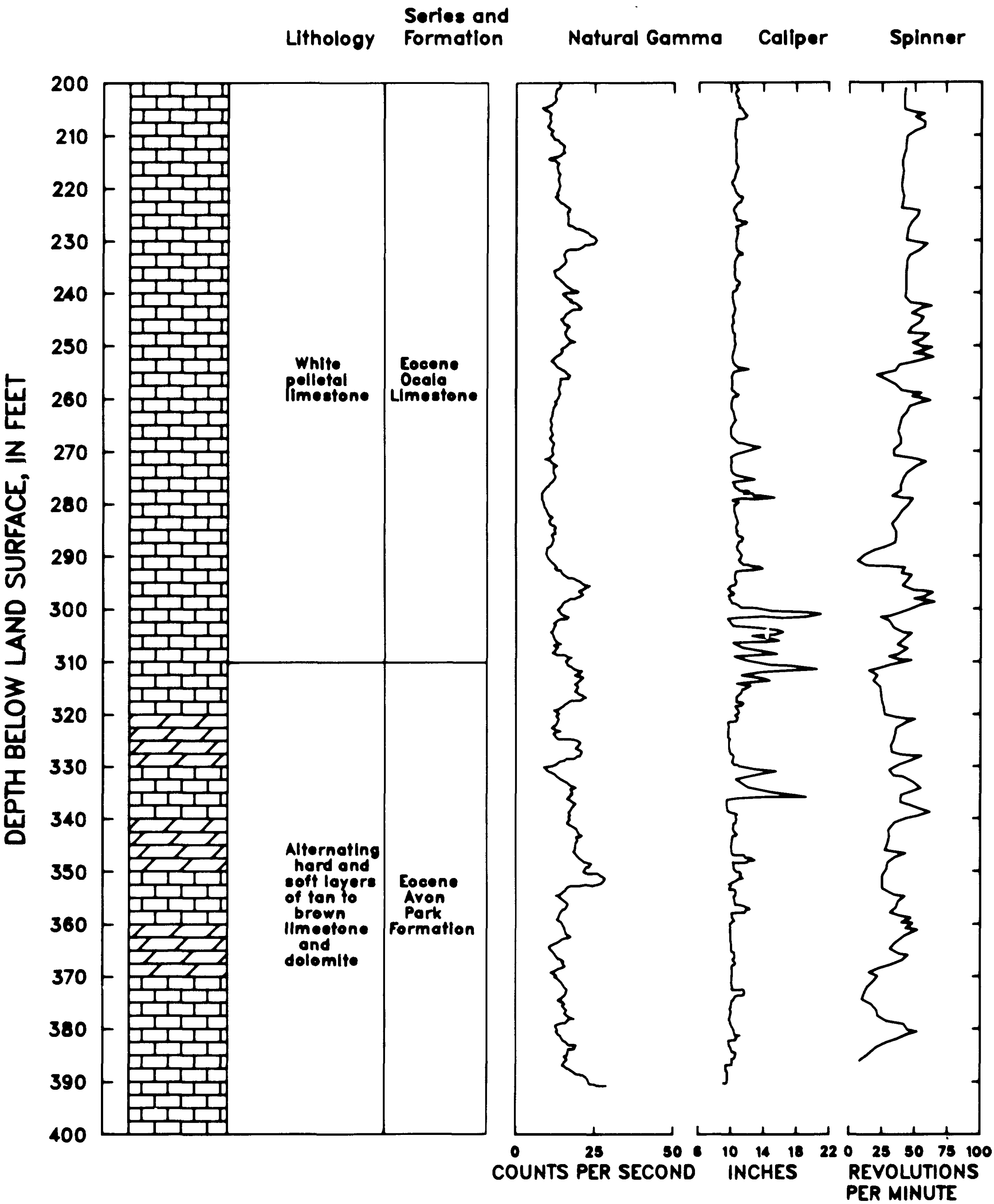


Figure 12.--Geologic and geophysical logs of test wells--Continued.

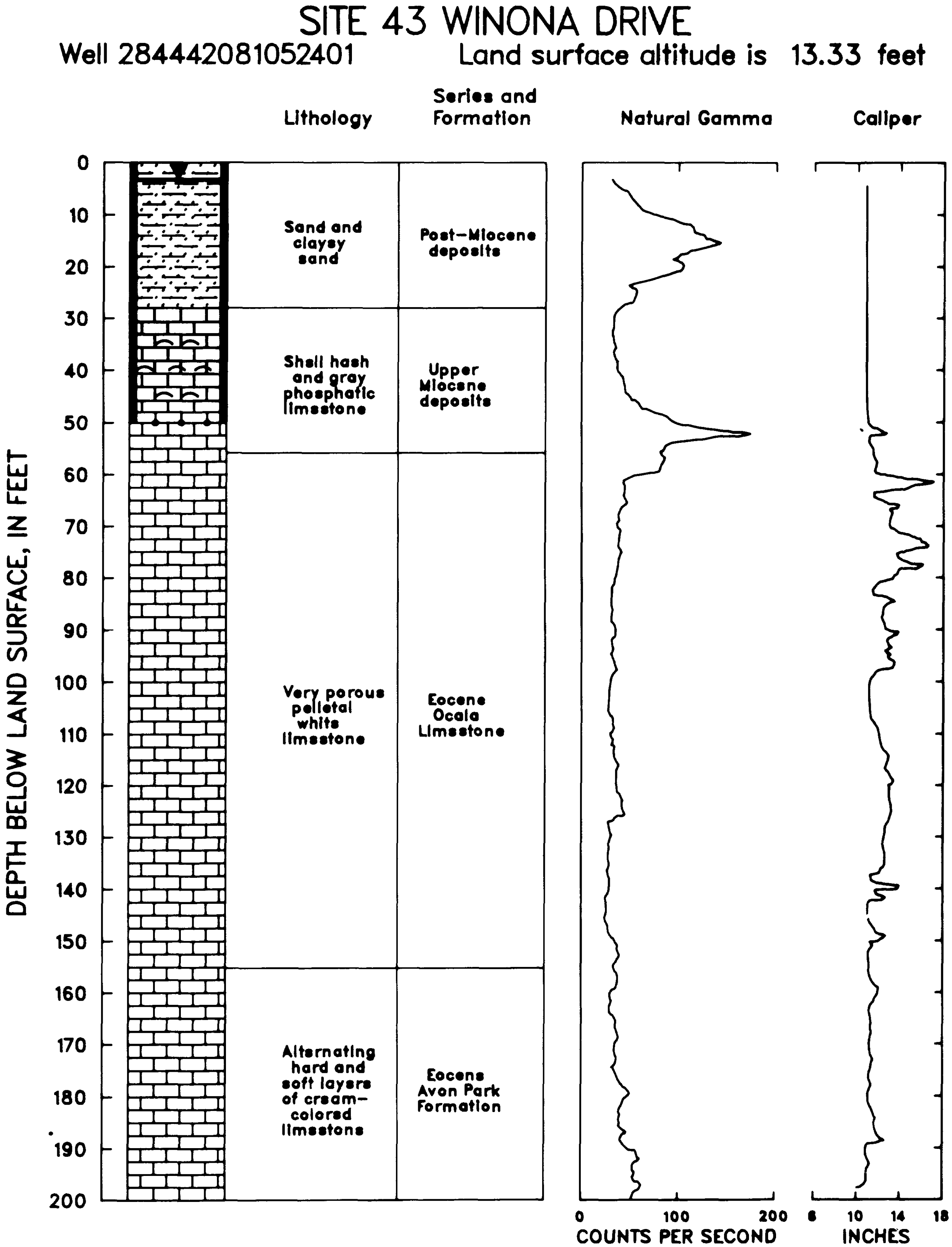


Figure 12.--Geologic and geophysical logs of test wells--Continued.

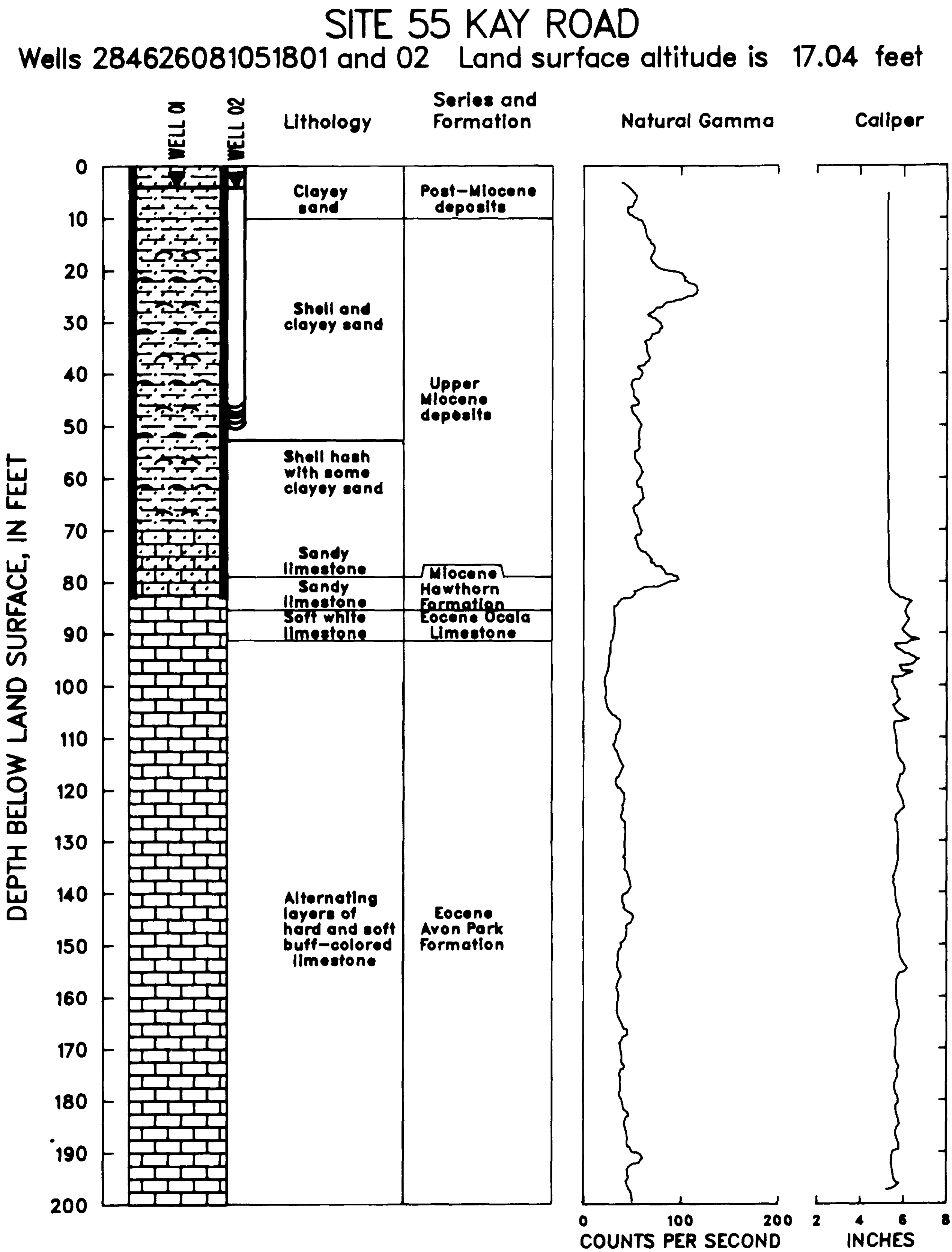


Figure 12.--Geologic and geophysical logs of test wells--Continued.

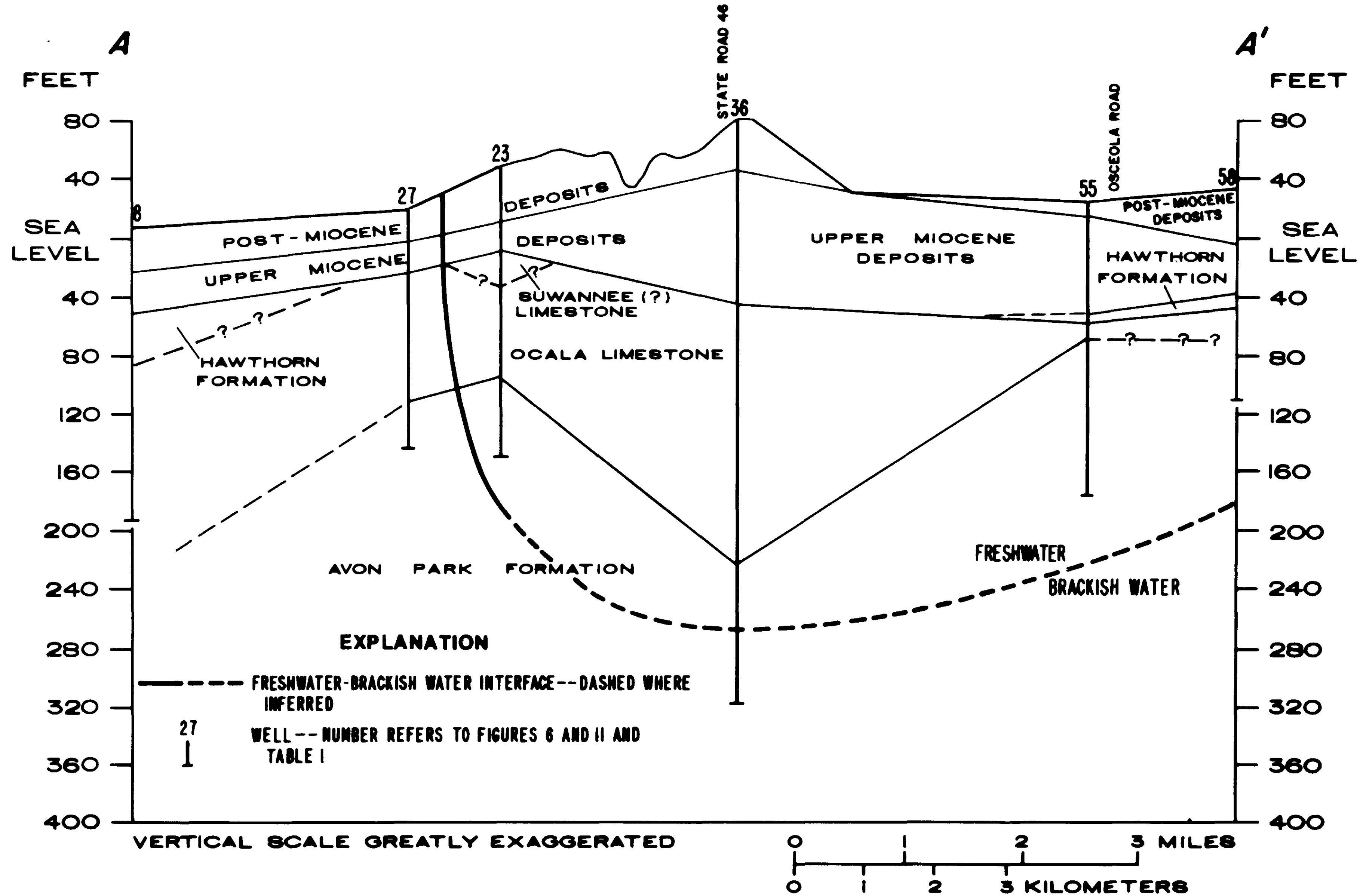


Figure 13.--Geologic section A-A' and approximate location of freshwater-brackish water interface.

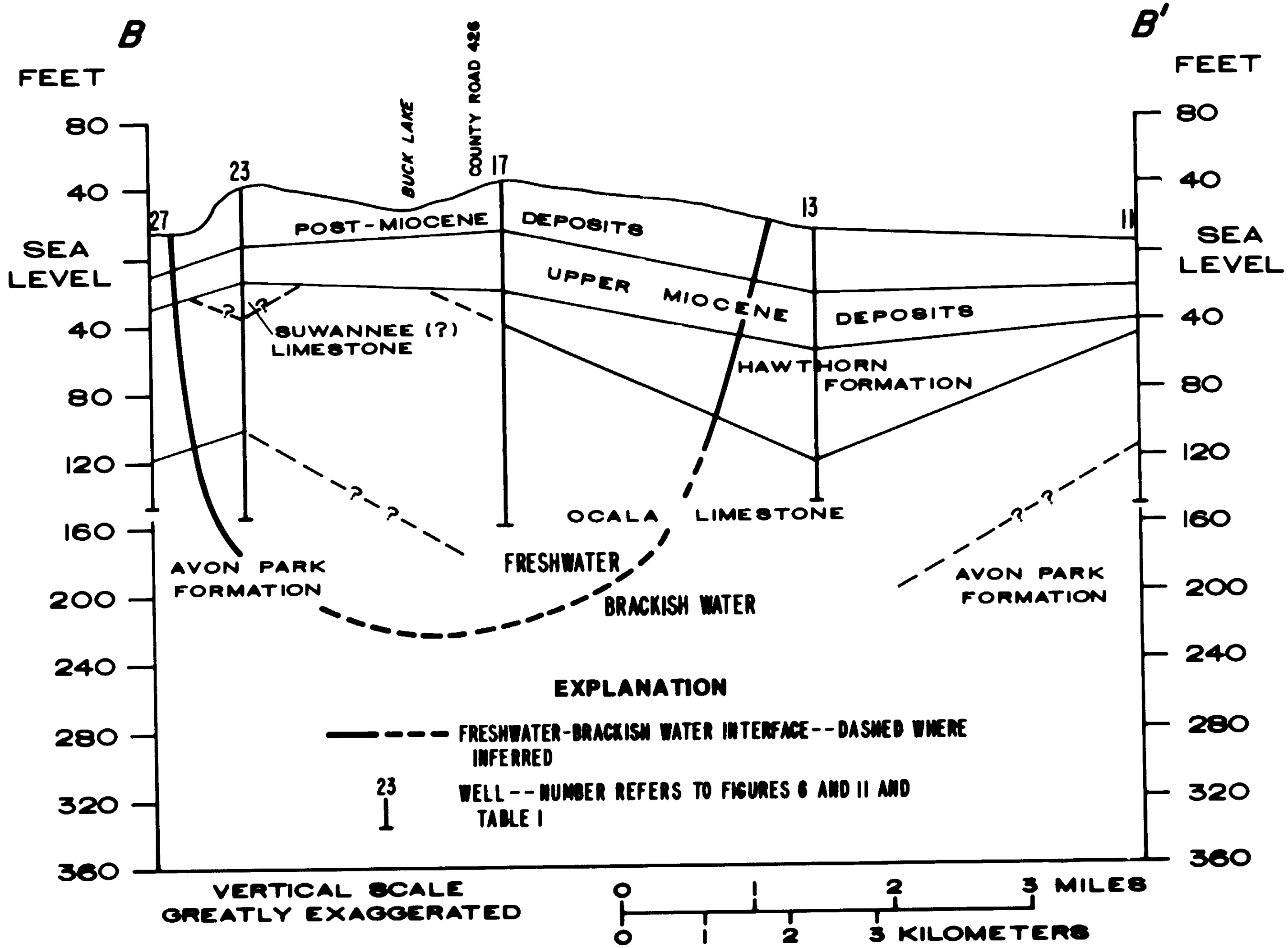


Figure 14.--Geologic section B-B' and approximate location of freshwater-brackish water interface.

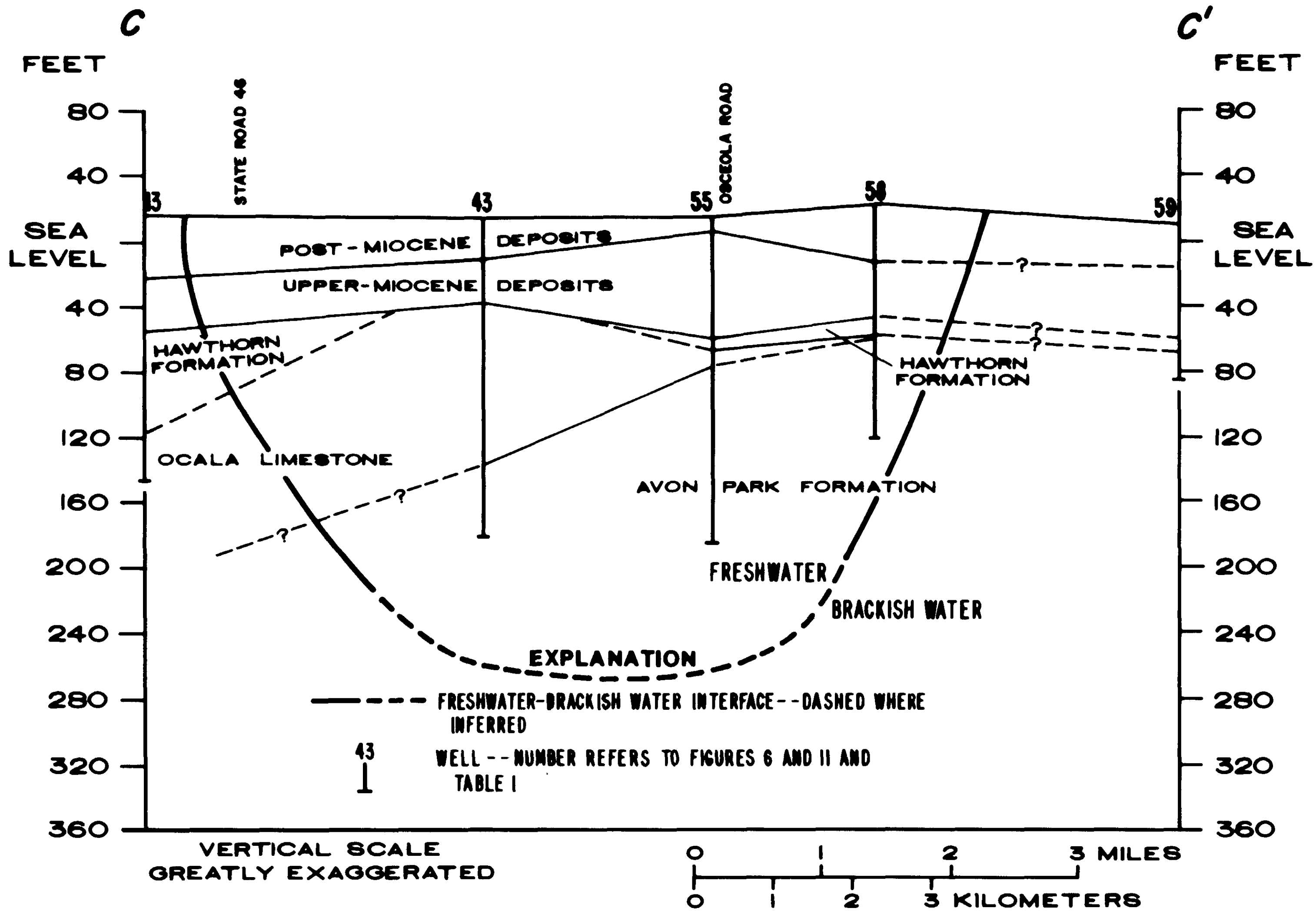


Figure 15.--Geologic section C-C' and approximate location of freshwater-brackish water interface.

The upper Miocene deposits in part of the study area are underlain by the middle Miocene Hawthorn Formation. The Hawthorn is thin to absent in part of the study area (sites 11, 23, 27, 43, 55) but is more than 70 feet thick at site 13 (figs. 12, 13, 14, 15). It contains no thick clay sequences but is mostly clayey sand and sandy phosphatic limestone and dolomite. The clayey sand of the Hawthorn, along with clay deposits of the upper Miocene, act as a confining layer for the underlying Floridan aquifer system. The Hawthorn limestone and dolomite are hydraulically connected with the Floridan.

Oligocene and Eocene Limestones

Description.--Underlying the Miocene deposits are soft, permeable limestones of Oligocene and Eocene age which comprise the Floridan aquifer system. Throughout most of the area, the Eocene Ocala Limestone is the uppermost limestone of the Floridan although at site 23 the Oligocene Suwannee Limestone is tentatively identified. The top of the aquifer ranges from about 20 feet below sea level (58 feet below land surface) at site 23 to 120 feet below sea level (137 feet below land surface) at site 13. The limestone surface is very weathered, eroded, and pockmarked with depressions as evidenced by the presence of cavities, the weathered limestone drill cuttings recovered, and the areal variation in altitude of the top of the Floridan. Cavity fill material recovered during drilling contained many well-rounded fragments of hard, gray, Hawthorn limestone. The Suwannee and Ocala Limestones are soft, white- to- light gray, fossiliferous, and very porous. The thickness of the Ocala Limestone ranges from about 200 feet at site 36 to about 5 feet at site 55 where the Ocala is almost entirely eroded (figs. 12, 13, 14, and 15).

Underlying the Ocala is the Avon Park Formation that consists of alternating layers of hard and soft light tan to brown limestone, dolomite, and dolomitic limestone. The bottom of the Avon Park was not penetrated during test drilling.

Water-bearing properties.--Well yield generally increases with depth of penetration into the limestones of the Floridan. The 400-foot deep test hole at site 36 was tested during drilling with a 2 horsepower submersible pump at several depths. The yield and specific capacity of the well were as follows:

Well depth (ft)	Formation	Yield (gal/min)	Specific capacity [(gal/min)/ft]
207	Upper part of Ocala	40	2.4
294	Lower part of Ocala	65	4.6
345	Upper part of Avon Park	75	12.7
400	Avon Park	116	12 (estimated)

The entire open section of the hole (116-400 feet) was also pumped with a 4 horsepower submersible pump for about 2 hours at 280 gal/min. Drawdown during pumping could not be measured, but the water level recovered to static level within 20 minutes.

Comparison of the caliper log and a flow meter traverse of the well at site 36 (fig. 12) indicates that much flow is from two cavernous zones. The most productive zone extends from 296 feet to 322 feet (lower part of Ocala Limestone-upper part of Avon Park Formation); significant flow also comes from a zone extending from 120 feet to 140 feet below land surface (upper part of Ocala Limestone).

At site 55 (where the Ocala Limestone is very thin) well yield was lower than from the other 200-foot deep test wells. During drilling with air, the discharge of the well surged, indicating that the yield was not sufficient to keep up with the rate at which water was forced out of the well by the air compressor. Site 55 was the only site at which this phenomenon occurred.

Transmissivity values at three sites in the Geneva area calculated by Tibbals (1977, fig. 14) using the recovery method are as follows:

Site 51	17,000 ft^2/d	(aquifer penetration about 50 feet)
Site 56	1,700 ft^2/d	(aquifer penetration about 80 feet)
Site 58	3,700 ft^2/d	(aquifer penetration about 70 feet)

Using a method described by Brown (1963, p. 336-338) transmissivity, based on the specific capacity, at site 36 is about 4,100 ft^2/d.

The values described above represent the lower limits for transmissivity of the upper part of the Floridan aquifer system in the Geneva area because none of the wells penetrate the full thickness of the upper part of the aquifer system. Transmissivity values based on individual aquifer tests are valuable as indicators of the potential yield at particular wells, but because of the heterogeneous and anisotropic nature of the cavernous limestone aquifer system, Tibbals (1981, p. 12-13) believes that transmissivity values derived from ground-water flow model calibrations have more regional significance than individual test values. Thus, the transmissivity values from Tibbals' model (1981, fig. 6), which range from 35,000 to 100,000 ft^2/d are used for hydrologic analyses in this report.

CHEMICAL QUALITY OF WATER

Water samples were analyzed to describe the general water quality of the area and to define more precisely the lateral and vertical extent of the freshwater lens. Geochemical analysis of the data can also help in understanding the hydrologic system in Geneva and, in particular, the recharge process. It can help, for example, to determine the source of the saline water, and if active intrusion or flushing is occurring.

Initially, 37 wells were sampled for chloride and hardness in May-June 1981. Subsequent sampling concentrated on wells in the transitional zone between freshwater and brackish water. Forty-nine wells were sampled for major constituents and iron in January-February 1982 and again in October 1982. Samples from test wells were taken during drilling at the top of the Floridan aquifer system and composite samples collected from the total open hole to determine if water quality changed with depth. At site 36 (the 400-foot deep well) composite water samples were collected at about 50-foot intervals and thief samples were collected from the bottom of the hole. Specific conductance was monitored continuously during the drilling of test wells.

Depending on the depth to water, either a centrifugal or submersible pump was used to sample existing wells. The 200-foot deep test wells were sampled using compressed air during drilling. Subsequent samples were collected with either a centrifugal or submersible pump. Table 4, which shows water-quality analyses, includes both historic data and data collected during this study. Wells tapping the surficial aquifer are denoted with an S and those tapping the Floridan aquifer system with an F.

Chloride is the constituent of most interest in the Geneva area. Samples collected in January-February 1982 show chloride concentrations for a drier-than-average dry season (fig. 16). Samples for October 1982 show chloride concentrations for the end of the wet season (fig. 17). Comparison of figures 16 and 17 to figures 4 (composite for 1951-54) and 5 (1973-74, a relatively dry period) indicates that apparently there are no significant changes in chloride concentrations from 1951 to 1982, though the freshwater lens is now better defined because of the existence of more wells to sample.

Some discrepancies were noted between the 1955 data reported by Barraclough (1962b, fig. 36), and the data collected by Tibbals (1977, fig. 11) and data from this study. At site 38, chloride concentration reported in 1955 was 695 mg/L. In 1973, the concentration was 330 mg/L, and in 1982, it was 290 mg/L. The difference between values for 1973 and 1982 is within the error of determination for the method used. At site 58 the 1955 chloride concentration was reported as 1,115 mg/L. In 1973, Tibbals (1977, fig. 11) reported a concentration of 150 mg/L after pumping for 6 hours at 90 gal/min. Samples collected for this study had chloride concentrations of 110 and 63 mg/L. The latter sample was collected after pumping about 20 minutes with a centrifugal pump, and the sample with a concentration of 110 mg/L was collected after clearing the well with compressed air for about one-half hour. Differences between the 1973 and the higher 1982 value are insignificant. The differences between the 1955 data and later analyses are probably due to better collection and analysis procedures used in the 1973 and 1982 studies, rather than from a flushing of saltwater from the aquifer, because water from wells along the southern bank of the St. Johns River has apparently not become fresher.

Table 4.--Chemical analyses of water from wells in the Geneva area

[Wells tapping the surficial aquifer are denoted with an S and those tapping the Floridan are noted with and F]

Station identification No.	Site No.	Aqui-fer	Date of sample (yr-mo-day)	Spe-cific con-duct-ance (umhos)	pH (units)	Alka-linity, field (mg/L as $CaCO_3$)	Hard-ness (mg/L as $CaCO_3$)	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as mg)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Chlo-ride, dis-solved (mg/L as Cl)	Sulfate, dis-solved (mg/L as SO_4)	Iron, dis-solved (ug/L as Fe)
284043081054401	1	F	74-06-07	8,980	7.4	188	676	140	78	1,700	50	2,600	450	330
			82-02-04	8,450	7.3	208	901	130	140	1,600	47	2,400	330	60
			82-10-12	8,250	6.8	183	917	120	150	1,400	45	2,500	380	40
284111081063401	2	F	74-06-07	593	7.3	214	242	75	13	23	3.0	48	15	30
			82-02-04	550	7.0	260	250	82	11	20	2.2	21	2.5	440
			82-10-12	558	6.4	264	267	87	12	28	2.0	20	3.0	350
284127081090501	3	F	82-02-01	6,800	7.2	138	794	120	120	1,300	36	2,000	320	1,300
284133081085501	4	F	82-02-01	6,800	7.3	136	753	120	110	1,100	35	2,000	320	170
			82-10-14	6,650	7.0	125	728	110	110	1,100	35	2,000	320	70
284146081092201	5	F	81-06-02	6,750	--	--	860	130	130	--	--	2,100	--	--
			82-02-01	7,500	7.4	139	835	120	130	1,300	39	2,200	350	30
			82-10-14	7,320	7.0	123	835	120	130	1,300	40	2,300	360	110
284150081084601	6	F	81-12-09	7,600	7.1	--	985	180	130	1,300	41	2,200	310	430
			82-10-12	7,020	6.6	127	769	110	120	1,200	35	2,100	32	270
284152081084801	7	S	81-07-15	750	--	--	200	--	--	--	--	100	--	--
			82-02-01	695	7.0	184	197	56	14	69	4.9	88	14	2,500
			82-10-12	698	6.4	174	180	54	11	68	4.4	100	20	1,500
284207081111601	8	F	81-11-09	5,000	6.8	140	637	120	82	730	20	1,500	190	70
			81-11-12	5,200	7.0	140	625	110	85	770	23	1,500	200	20
			81-11-23	4,750	6.3	--	--	--	--	--	--	1,340	--	--
284208081061301	9	F	82-01-28	425	7.0	201	196	74	2.6	9.2	1.1	12	.4	1,100
284210081065601	10	F	81-06-02	330	--	--	152	54	4.1	--	--	15	--	--
			82-01-26	340	7.0	123	144	51	4.1	8.3	3.1	11	19	82
			82-10-12	332	6.6	133	151	54	4.0	8.0	2.9	15	17	150
284217081023001	11	F	82-02-03	16,500	7.6	157	1,909	270	300	3,000	110	5,400	840	90
			82-02-08	16,200	7.4	144	1,934	280	300	2,900	93	5,100	870	320
			82-03-01	15,250	--	--	--	--	--	--	--	5,100	--	--
			82-10-11	15,400	6.8	139	2,076	320	310	2,700	380	4,800	800	110

Table 4.--Chemical analyses of water from wells in the Geneva area--Continued

[Wells tapping the surficial aquifer are denoted with an S and those tapping the Floridan are noted with and F]

Station identification No.	Site No.	Aquifer	Date of sample (yr-mo-day)	Specific conductance (umhos)	pH (units)	Alkalinity, field (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)	Iron, dissolved (ug/L as Fe)
284219081074001	12	F	54-03-01	403	7.3	--	200	78	1.2	--	--	11	1.0	--
			74-05-31	406	7.2	203	202	78	1.6	6.2	.7	10	.8	5,100
			81-06-02	400	--	--	216	84	1.5	--	--	11	--	--
			82-01-27	390	6.7	192	196	76	1.4	7.1	2.8	9.6	1.0	6,600
			82-10-14	411	7.0	205	193	75	1.4	6.3	.5	9.5	1.0	2,300
284233081045202	13	F	82-01-18	3,800	6.9	241	405	73	54	630	26	980	200	60
			82-01-19	3,750	7.4	--	422	75	57	650	27	990	200	20
			82-03-01	3,750	--	--	--	--	--	--	--	960	--	--
			82-10-11	3,370	6.8	233	371	63	52	550	24	810	160	10
284243081053301	14	S	74-06-07	433	7.1	204	204	74	4.5	7.6	1.4	8.2	7.1	270
			81-04-30	360	--	--	206	80	1.4	--	--	11	--	--
			82-02-01	425	6.8	217	199	77	1.6	7.4	1.1	8.7	.6	3,900
284243081053301	14	F	82-10-11	445	6.4	203	199	77	1.6	7.7	1.3	10	2.0	3,100
284244081073501	15	F	81-05-19	420	--	--	211	82	1.6	--	--	28	--	--
284247081070601	16	F	81-05-19	315	--	--	171	65	2.1	--	--	12	--	--
			82-10-14	352	7.2	164	160	61	1.9	6.5	.4	10	1.0	410
284247081070801	17	S	82-01-05	375	6.4	164	165	62	2.5	6.6	.6	13	2.5	--
284300081045801	18	F	54-03-02	561	7.7	--	206	71	7.0	--	--	60	1.0	--
			81-06-02	700	--	--	202	56	15	--	--	110	--	--
			82-01-27	740	6.9	199	194	53	15	83	3.6	110	2.3	2,400
			82-10-14	779	7.2	195	194	53	15	83	3.4	130	9.0	890
284312081045101	19	F	81-05-19	780	--	--	217	64	14	--	--	160	--	--
			82-01-27	840	7.2	165	199	55	15	90	3.7	140	16	600
			82-10-14	849	7.0	175	191	55	13	110	3.5	170	23	35
284312081084401	20	F	81-05-19	620	--	--	182	57	9.7	--	--	110	--	--
284319081044301	21	F	56-12-08	--	--	--	--	--	--	--	--	590	--	--
			56-12-08	--	--	--	--	--	--	--	--	600	--	--
			56-12-08	--	--	--	--	--	--	--	--	600	--	--
			56-12-08	--	--	--	--	--	--	--	--	600	--	--
			56-12-29	--	--	--	--	--	--	--	--	705	--	--

Table 4.--Chemical analyses of water from wells in the Geneva area--Continued

[Wells tapping the surficial aquifer are denoted with an S and those tapping the Floridan are noted with and F]

Station identification No.	Site No.	Aquifer	Date of sample (yr-mo-day)	Specific conductance (umhos)	pH (units)	Alkalinity, field (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)	Iron, dissolved (ug/L as Fe)
284319081044301	21	F	56-12-29	--	--	--	--	--	--	--	--	700	--	--
			56-12-29	--	--	--	--	--	--	--	--	710	--	--
			56-12-29	--	--	--	--	--	--	--	--	715	--	--
			57-12-29	--	--	--	--	--	--	--	--	705	--	--
			82-02-08	2,150	7.2	189	292	61	34	280	11	460	70	310
284320081051201	22	F	81-07-15	285	--	--	120	--	--	--	--	11	--	--
			82-01-27	275	6.9	126	121	46	1.5	7.6	1.1	9.0	1.2	640
			82-10-14	272	7.2	126	121	46	1.4	6.0	1.0	9.2	<1.0	490
284322081084301	23	F	81-12-09	510	7.5	156	143	48	5.6	31	2.6	84	13	34
			81-12-14	800	7.4	157	197	56	14	80	4.2	150	23	47
			81-12-17	670	7.3	--	198	61	11	63	3.1	160	29	43
284322081084401	24	S	81-12-17	525	7.3	154	162	53	7.2	44	2.0	70	10	1,200
			82-10-12	622	6.6	146	162	51	8.5	54	2.3	92	16	1,100
284325081052401	25	F	81-07-15	300	--	--	140	--	--	--	--	9.6	--	--
284325081061201	26	F	56-06-25	--	--	--	--	--	--	--	--	13	--	2,200
			81-06-02	315	--	--	156	60	1.4	--	--	12	--	--
284325081092701	27	S	81-11-30	4,500	6.6	143	559	92	80	810	22	1,400	180	80
			81-12-02	4,500	6.4	145	534	92	74	690	22	1,200	190	70
			82-10-12	4,380	6.8	119	495	81	71	690	21	1,300	190	<10
284329081054701	28	F	81-06-04	260	--	--	144	48	5.9	--	--	10	--	--
284331081052401	29	F	81-12-08	390	7.1	143	124	47	1.5	6.8	1.0	11	.5	330
			82-10-14	293	7.0	133	131	49	2.0	7.3	.4	9.6	1.0	470
284341081072601	30	F	81-06-02	300	--	--	132	49	2.4	--	--	9.8	--	--
			82-02-08	300	7.1	134	129	48	2.2	5.4	.7	9.1	1.2	200
284409081070901	32	F	81-05-19	240	--	--	110	40	2.4	--	--	11	--	--
			82-01-26	260	7.1	88	105	38	2.5	6.4	2.3	8.6	16	97
			82-10-14	267	7.0	95	110	40	2.5	6.1	2.5	10	18	28

Table 4.--Chemical analyses of water from wells in the Geneva area--Continued

[Wells tapping the surficial aquifer are denoted with an S and those tapping the Floridan are noted with and F]

Station identification No.	Site No.	Aquifer	Date of sample (yr-mo-day)	Specific conductance (umhos)	pH (units)	Alkalinity, field (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)	Iron, dissolved (ug/L as Fe)
284410081065201	33	F	81-06-02	310	--	--	130	46	3.6	--	--	13	--	--
284411081065801	31	F	81-04-30	260	--	--	135	48	3.7	--	--	13	--	--
			82-03-03	260	7.2	97	110	40	2.5	5.0	2.4	8.1	16	190
			82-10-14	256	7.0	98	111	40	2.6	5.4	2.2	9.5	14	<3
284423081052001	35	F	81-04-30	360	--	--	193	71	3.9	--	--	22	--	--
284431081084501	37	F	81-05-19	375	--	--	188	71	2.6	--	--	20	--	--
			81-09-14	407	--	--	131	47	3.4	--	--	25	--	--
			82-01-26	425	7.0	175	174	66	2.2	12	.8	16	4.1	250
			82-10-12	408	6.6	170	183	70	2.1	13	.6	26	7.0	450
284434081050101	38	F	55-02-02	2,540	7.7	--	405	88	45	--	--	695	108	--
			73-11-02	1,280	7.7	176	282	62	31	210	9.9	330	46	<10
			81-06-02	1,300	--	--	227	68	14	--	--	310	--	--
			82-01-27	1,390	7.3	185	249	60	24	170	6.2	300	37	49
			82-10-12	1,350	6.8	47	250	64	22	130	6.1	290	43	16
284435081052001	39	F	81-07-15	420	--	--	200	--	--	--	--	10	--	--
			82-01-27	460	6.8	197	182	70	1.7	8.4	.5	10	1.7	3,000
284438081062201	40	F	54-03-02	228	8.1	--	102	40	.5	--	--	8.5	4.0	--
			73-11-01	219	7.7	81	100	30	6.1	5.7	.9	12	3.2	<10
			81-06-02	265	--	--	94	37	.6	--	--	12	--	--
			82-10-14	213	7.0	83	90	35	.6	5.5	.8	12	3.0	53
284438081084701	41	F	81-09-14	685	--	--	193	73	2.7	--	--	62	--	--
			82-01-26	720	6.9	192	240	91	3.0	45	1.1	56	59	630
			82-10-12	676	6.6	206	252	96	3.0	40	1.0	53	65	710
284439081085501	42	S	81-09-14	334	--	--	159	61	1.6	--	--	9.0	--	--
			82-01-26	360	6.9	159	158	61	1.4	4.8	.8	7.6	4.9	4,700
			82-10-12	348	6.6	148	169	65	1.5	5.1	.4	7.8	6.0	3,500
284442081052401	43	F	82-02-16	380	6.9	197	195	73	3.2	18	1.0	8.7	.5	1,300
			82-03-01	450	7.1	203	223	82	4.4	12	.8	17	4.5	220
			82-10-11	390	6.5	--	189	73	1.6	6.7	.4	9.5	1.0	1,600

Table 4.--Chemical analyses of water from wells in the Geneva area--Continued

[Wells tapping the surficial aquifer are denoted with an S and those tapping the Floridan are noted with and F]

Station identification No.	Site No.	Aquifer	Date of sample (yr-mo-day)	Specific conductance (umhos)	pH (units)	Alkalinity, field (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)	Iron, dissolved (ug/L as Fe)
284447081070601	44	F	81-04-30	158	--	--	89	32	2.4	--	--	13	--	--
284456081073301	45	F	81-06-02	270	--	--	114	43	1.5	--	--	12	--	--
			82-01-26	260	7.0	104	109	41	1.5	9.5	1.0	8.7	3.0	160
			82-10-14	262	6.9	115	111	42	1.6	9.6	.8	10	3.0	180
284519081081801	46	F	55-02-07	416	8.0	--	228	82	5.6	--	--	12	2.5	--
			74-05-31	429	7.2	213	228	88	1.8	6.8	.9	19	5.5	4,000
			81-05-19	410	--	--	220	84	2.4	--	--	13	--	--
			82-01-26	440	6.9	198	202	77	2.4	6.9	.8	9.7	.2	4,000
			82-10-14	440	6.6	215	208	79	2.5	7.1	.8	9.9	2.0	4,000
284520081051001	47	F	81-07-15	400	--	--	150	--	--	--	--	38	--	--
			82-01-27	395	7.1	141	135	46	5.0	23	1.3	33	3.7	190
			82-10-12	407	6.8	146	150	51	5.6	24	1.4	38	4.0	300
284526081065401	48	F	81-06-02	230	--	--	96	36	1.5	--	--	16	--	--
			82-01-26	250	7.2	78	93	35	1.5	8.0	.5	13	12	91
			82-10-14	237	7.0	78	96	36	1.5	8.1	.1	15	14	58
284531081051601	49	S	81-07-15	370	--	--	160	--	--	--	--	12	--	--
			82-01-27	380	6.9	166	163	62	1.9	8.9	1.0	14	2.7	2,500
			82-10-12	360	6.8	171	167	64	1.8	7.5	.9	12	2.0	2,000
284538081082001	50	S	81-06-02	430	--	--	112	42	1.8	--	--	9.0	--	--
			82-01-26	450	6.9	228	217	84	1.8	6.0	.6	7.7	<.1	5,200
284550081071501	51	F	55-02-07	407	7.7	--	196	64	8.7	--	--	25	8.0	--
			73-08-22	470	7.6	194	197	70	5.4	16	1.3	24	.4	150
			81-04-30	410	--	--	208	74	5.7	--	--	26	--	--
			81-12-10	460	6.5	205	173	61	5.1	18	1.3	24	1.5	330
			82-10-11	440	6.6	--	200	71	5.4	17	1.2	24	3.0	180
284553081085501	52	S	81-06-02	820	--	--	291	100	10	--	--	120	--	--
			82-01-26	870	6.8	280	284	98	9.6	59	2.8	100	7.9	3,200
			82-10-14	745	6.5	276	265	94	7.4	41	1.9	69	6.0	7,800

Table 4.--Chemical analyses of water from wells in the Geneva area--Continued

[Wells tapping the surficial aquifer are denoted with an S and those tapping the Floridan are noted with and F]

Station identification No.	Site No.	Aquifer	Date of sample (yr-mo-day)	Specific conductance (umhos)	pH (units)	Alkalinity, field (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)	Iron, dissolved (ug/L as Fe)
284604081063401	53	S	81-06-02	530	--	--	283	110	2.1	--	--	14	--	--
			82-03-10	545	6.9	249	263	102	2.0	7.9	1.0	10	3.0	1,500
			82-10-14	556	6.5	278	258	100	2.0	9.7	.6	12	3.0	1,700
284619081053201	54	F	82-03-10	625	6.8	313	297	117	1.2	13	.8	21	3.6	1,600
284626081051801	55	S	82-03-09	610	7.6	289	258	97	3.9	17	2.3	22	4.5	60
			82-03-10	625	7.3	322	295	95	14	15	1.2	27	2.5	100
			82-10-11	630	6.7	308	310	110	8.5	15	.7	25	7.0	790
284706081070801	56	F	73-08-21	680	7.4	305	288	100	9.3	19	2.0	30	<1.0	280
			81-12-09	720	6.9	394	276	79	19	34	2.6	58	2.2	8
			81-12-09	640	6.6	318	271	98	6.4	15	1.6	19	<.1	330
			82-10-11	630	6.6	--	304	110	7.2	17	1.4	23	13	300
284706081073801	57	F	55-02-02	3,200	7.5	--	546	123	58	--	--	810	132	--
			56-06-25	3,040	7.3	--	664	162	63	--	--	755	112	--
			81-05-19	3,000	--	--	563	130	58	--	--	800	--	--
			82-10-11	3,250	6.8	--	468	110	47	410	15	740	94	170
284712081044301	58	F	73-03-26	740	--	--	232	--	--	--	--	82	7.6	20
			73-08-24	920	7.5	220	285	87	16	62	1.8	150	6.4	200
			82-03-10	770	7.6	217	263	84	13	46	1.6	110	7.5	44
			82-10-11	630	--	--	250	82	11	32	1.1	63	7.0	130
284909081052101	59	F	55-02-07	15,700	--	--	2,060	--	--	--	--	5,100	680	--

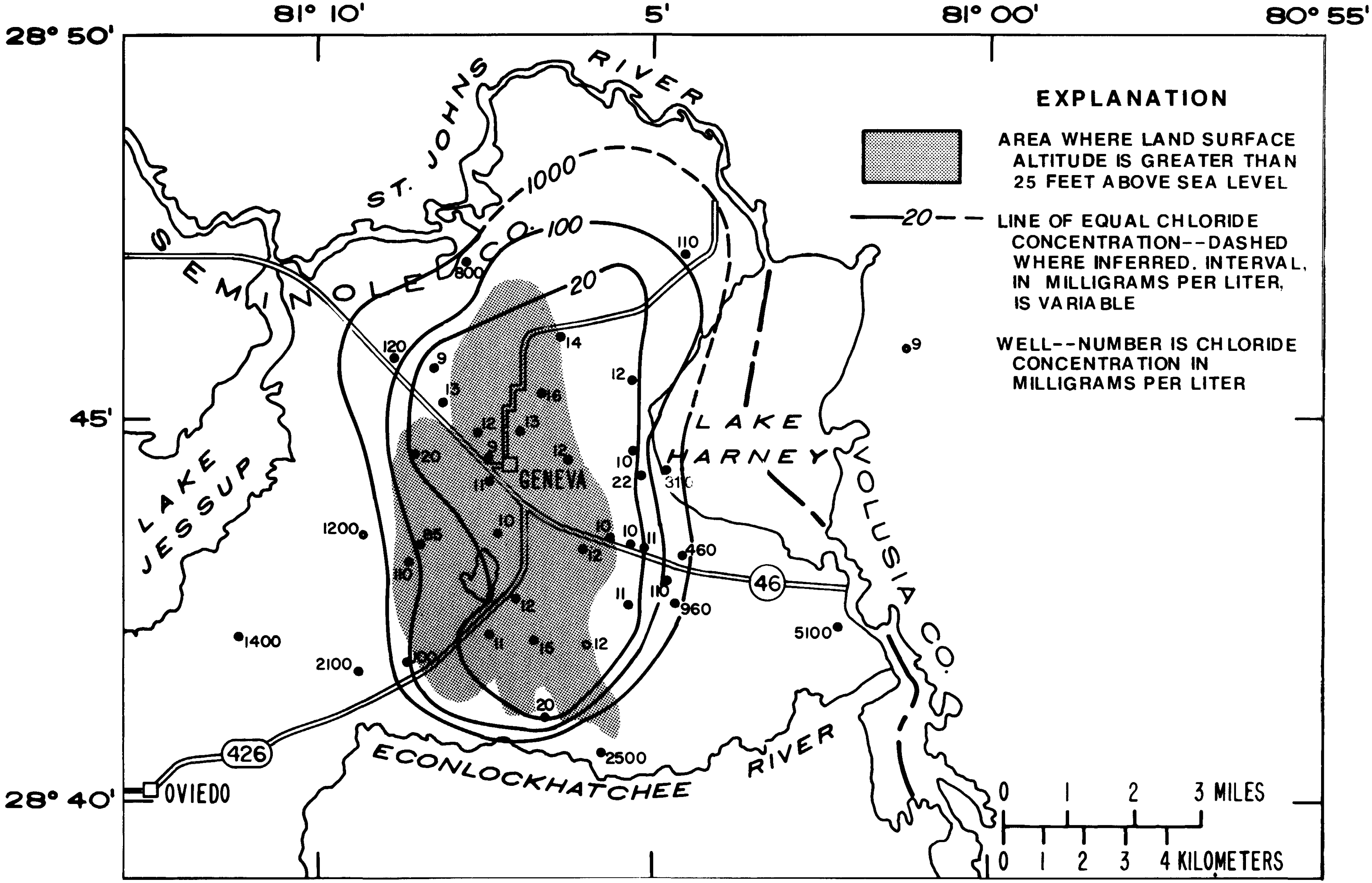


Figure 16.--Chloride concentration of water from the upper part of the Floridan aquifer system, November 1981-February 1982 (dry conditions).

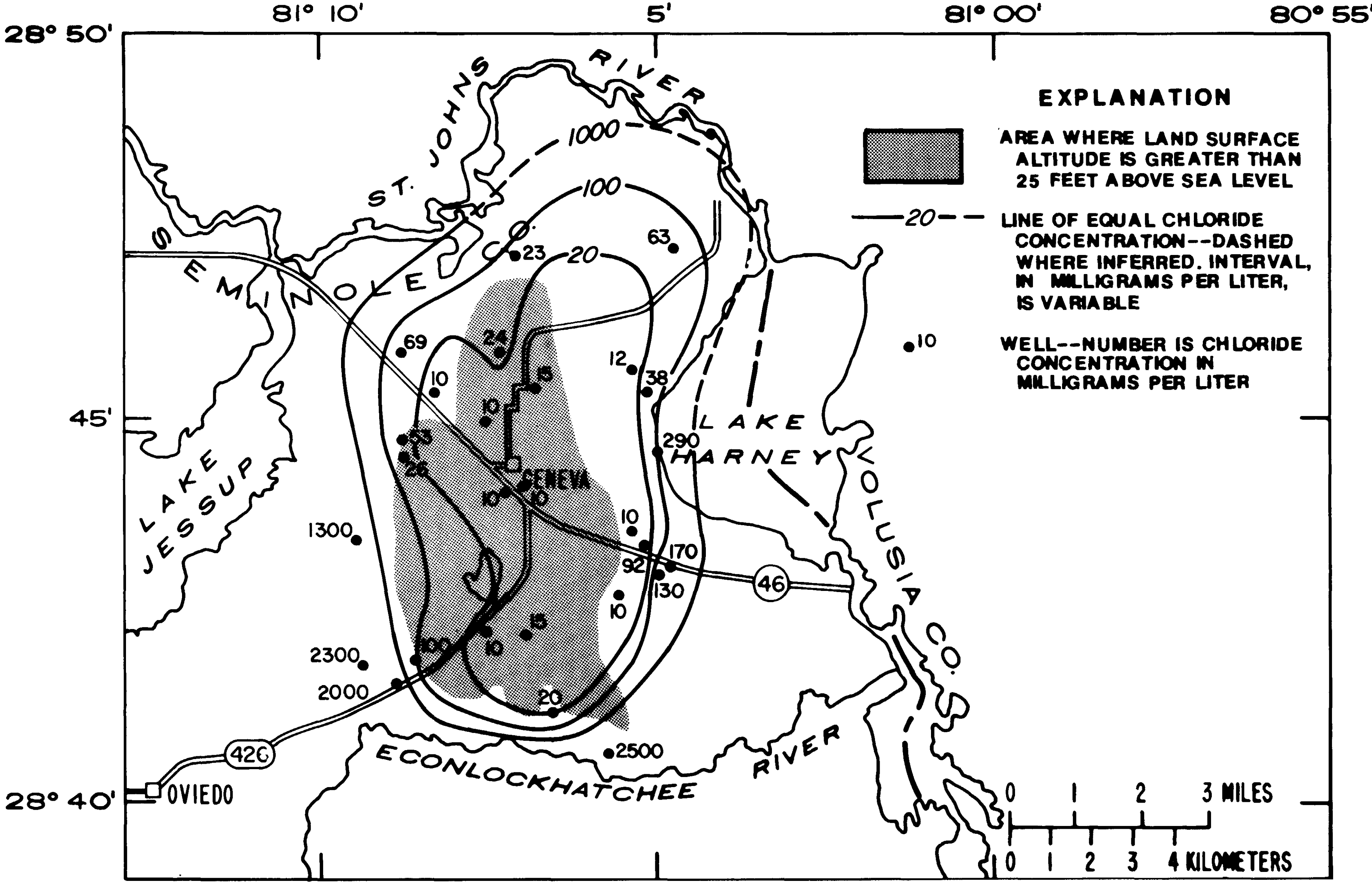


Figure 17.--Chloride concentration of water from the upper part of the Floridan aquifer system, October 1982 (wet conditions).

The increase in chloride concentration with depth was documented in several wells. For example, a sample obtained from pumping the entire open-hole section of the well at site 56 in December 1981 had a chloride concentration of 19 mg/L, but a thief sample from the bottom of the well immediately after pumping had a chloride concentration of 58 mg/L. The bottom sample was also silty and colored milky white because of suspended limestone particles. These facts imply that most of the water at well site 56 was coming from the upper part of the open hole and very little from the lower part where the chloride concentration was higher.

Increasing chloride concentrations with depth was also documented by comparing wells at sites 37 (90 feet deep) and 41 (160 feet deep) which had chloride concentrations of 26 mg/L and 65 mg/L, respectively, in October 1982. Considering differences in land-surface altitude, the well at site 41 penetrates about 60 feet deeper into the Floridan aquifer system than the well at site 37.

The 400-foot deep test well at site 36 showed a significant increase in chloride concentration with depth (table 5). Chloride concentration increased sharply from 63 mg/L at 345 feet to 930 mg/L at 393 feet. Site 36 is near the center of the recharge area and the thickness of freshwater at that site (about 350 feet) is probably the maximum for the freshwater lens. Figures 13, 14, and 15 show the approximate extent of the freshwater lens on the geohydrologic sections A-A', B-B', and C-C'. The interface between freshwater and brackish water is very sharp both horizontally and vertically.

Table 5.--Selected water-quality data for well 284428081072601 (site 36)

[Concentrations are in milligrams per liter and are dissolved, unless otherwise noted]

	Depth below land surface, in feet			
	207	290	345	393
Bromide (ug/L as Br)	--	0	0.4	5.6
Calcium (as Ca)	34	34	34	100
Chloride (as Cl)	8.7	9.0	63	930
Magnesium (as Mg)	1.5	3.8	7.3	61
Potassium (as K)	.8	.8	3.2	8.5
Sodium (as Na)	6.5	6.70	38	410
Specific conductance (umhos/cm)	210	214	406	3,200
Strontium (ug/L as Sr)	480	620	2,000	15,000
Sulfate (as SO_4)	2.7	2.3	9.8	62

Iron concentrations are also of interest because high concentrations can cause staining of plumbing fixtures and an unpleasant taste. The source of iron in the ground water is iron-rich minerals in the sand of the post-Miocene to Holocene deposits. As water seeps slowly downward through the sand, the iron-bearing minerals are dissolved. Iron concentrations are generally lower in water from the Floridan aquifer system than from the surficial aquifer, but paradoxically, some of the highest iron concentrations are found in wells that tap the top of the limestone. The top of the Ocala Limestone is an erosional surface, so a buried ancient soil at the top of the Ocala could result in a zone of sediments high in iron. Also, the corrosive effect of water on the iron casings for a long period of time may cause the iron concentrations of water from older wells to be higher than water from newer wells. Relatively deeper wells in the Floridan have lower iron concentrations than either surficial wells or shallow wells in the Floridan. Iron concentrations of wells that tap the Floridan aquifer system and the surficial aquifer are included in table 3.

Figure 18 shows sulfate (SO_4) concentrations of water from the upper part of the Floridan aquifer system. Concentrations range from less than 1 mg/L in the freshwater lens to 800 mg/L outside the lens. A source of sulfate in the ground water in the Geneva area is Pleistocene seawater which has been slowly flushed from the aquifer. The sulfate concentration of modern sea-water is about 2,700 mg/L (Parkhurst and others, 1980, table 2) and the ratio of chloride to sulfate in seawater is about 7.33. Thus, for seawater diluted to the point that its chloride concentration is less than 100 mg/L, the sulfate concentration due solely to the initial sulfate in seawater is about 14 mg/L or less. At sites where the ratio of chloride to sulfate is less than 7.33 another source of sulfate, such as dissolution of gypsum from the aquifer, is apparent. A marked increase in sulfate in the predominant direction of flow (northeast) is not observed, possibly due to the scarcity of gypsum in the aquifer in that direction.

Another sulfur compound in ground water is dissolved hydrogen sulfide gas, which causes the "rotten egg" smell noticed in some water from the Floridan aquifer system. The source is microbial reduction of dissolved sulfate in the aquifer. Hydrogen sulfide gas comes out of solution (degases) quickly when the water is aerated, so it is easily removed from home and public water systems. Rapid degassing makes accurate determination of the dissolved hydrogen sulfide concentration difficult.

The hardness of water depends on the concentration of dissolved bivalent cations such as calcium and magnesium, and is expressed in terms of equivalent milligrams per liter of calcium carbonate. The principal sources of hardness in water from the Floridan are dissolution of limestone, dolomite, and gypsum, and mixing of freshwater with seawater. The hardness of ground water in the Floridan generally increases with the amount of time the water is in contact with calcium- or magnesium-rich rocks such as limestone or dolomite; thus, in a general way, hardness is an indicator of residence time in the aquifer. Figure 19 shows the hardness of water from both the surficial and Floridan aquifer systems. The lowest hardness is found in the center of the recharge area and the highest in the discharge areas.

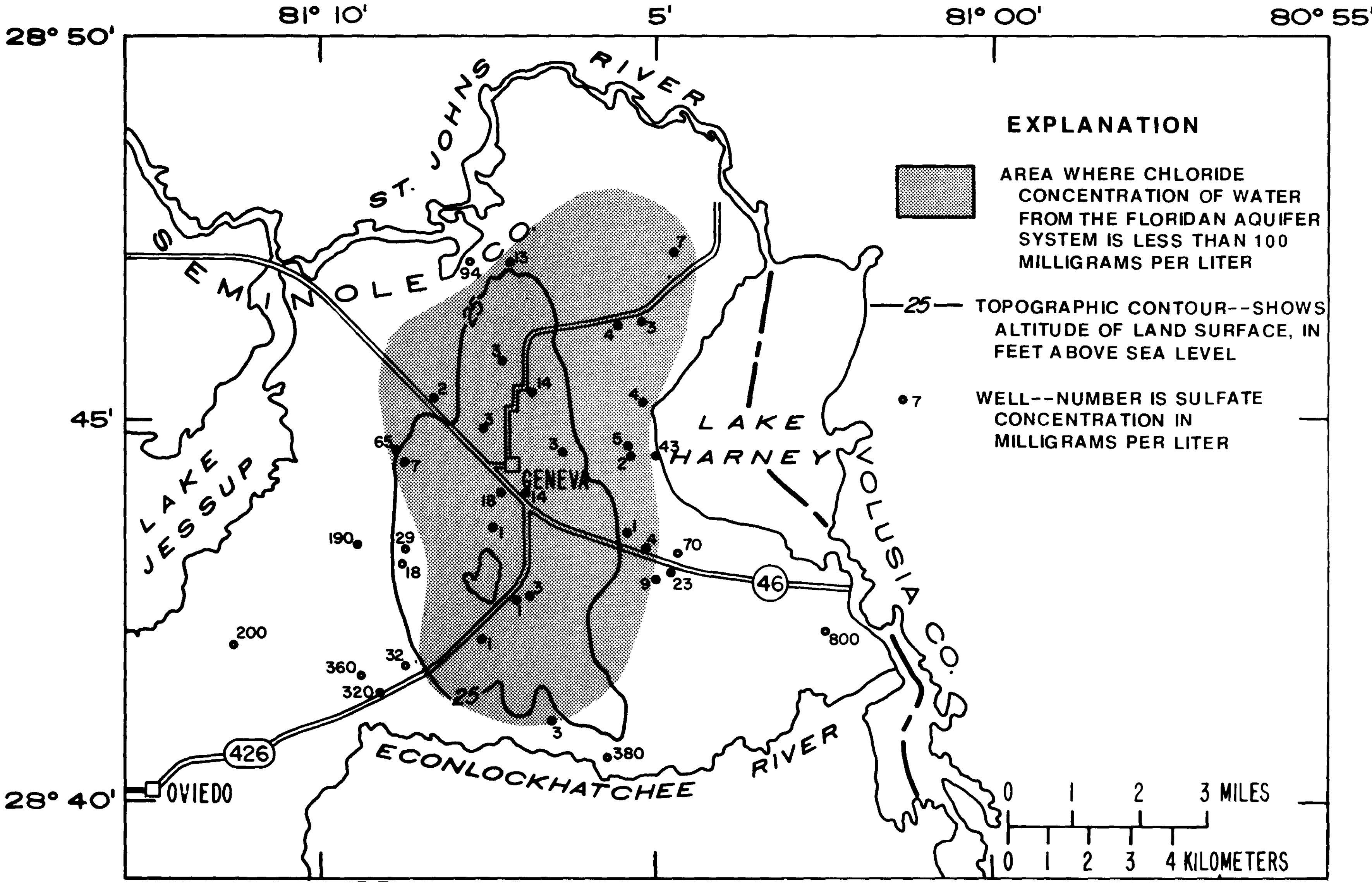


Figure 18.--Sulfate concentration of water from the upper part of the Floridan aquifer system, 1982.

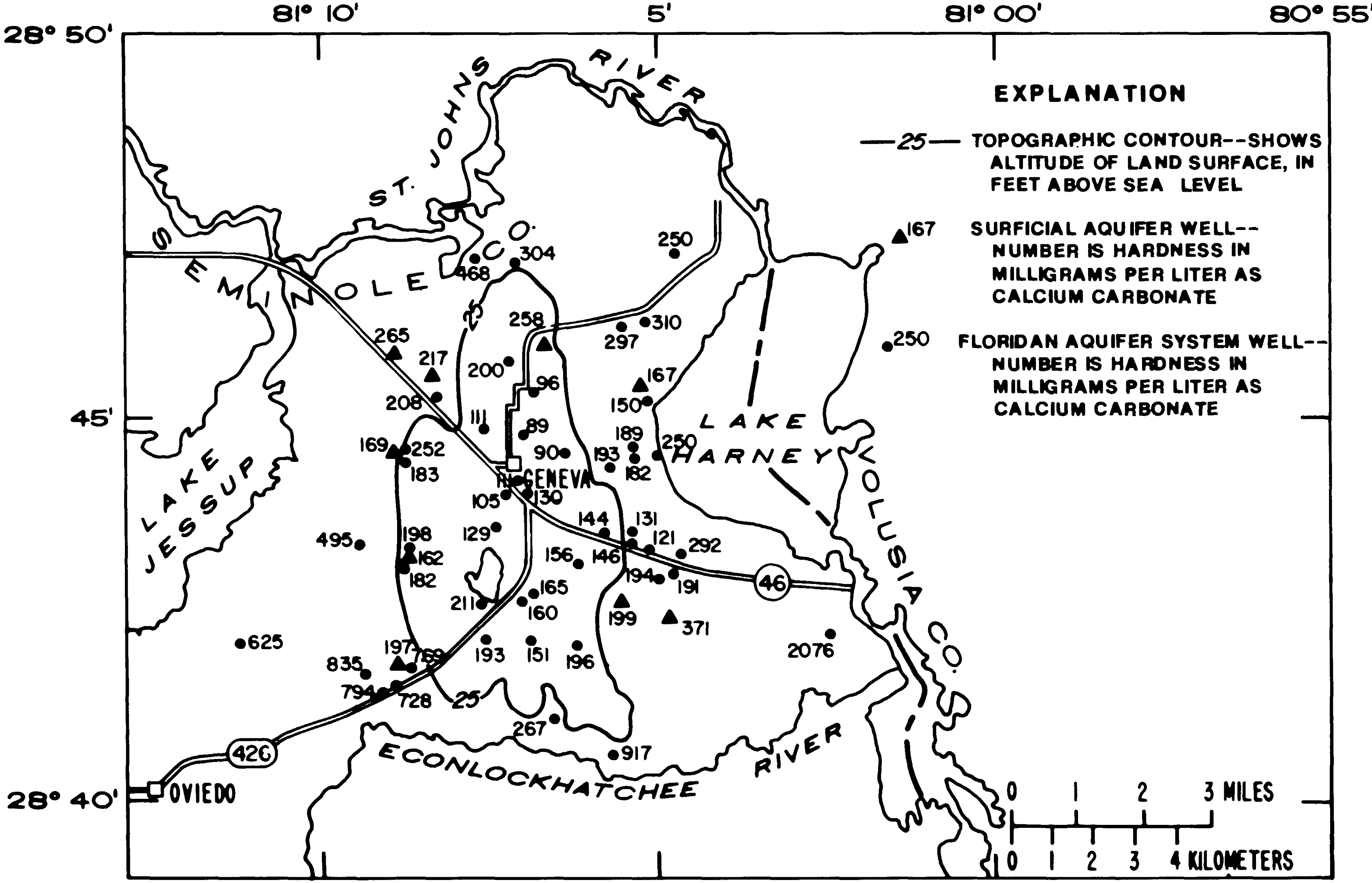


Figure 19.--Hardness of water from the surficial aquifer and the upper part of the Floridan aquifer system, 1981-82.

GEOCHEMICAL EVIDENCE OF FRESHWATER-SALTWATER MIXING

The major constituent concentrations of water from the Geneva area are plotted on a Piper diagram in figure 20. The position of each sample on the plot is in accordance with the relative proportions of the major chemical components of the sample. The mixing of a calcium-bicarbonate-type water (recharge water) with a sodium-chloride-type water (presumably seawater trapped in the formation) is indicated by the points in figure 20 that form a band from a calcium-bicarbonate-type water on the left side of the diagram to a sodium-chloride-type on the right side. Plotting the map locations of the various types of water in figure 21 shows that the calcium-bicarbonate-type water is found in the recharge area, mixing-zone-type water on the periphery of the recharge area, and sodium-chloride-type water in areas where no recharge occurs. Mixing-zone-type water also occurs at site 58, which is outside the active recharge area, but downgradient from the recharge area. This results from dispersion of the freshwater along the flow path.

Evidence of vertical as well as lateral mixing of freshwater and brackish water can be seen in figures 20 and 21. For example, the well at site 37 is 90 feet deep and yields calcium-bicarbonate-type water while the 160-foot deep well at at nearby site 41 produces mixing-zone-type water. Similarly, at sites 6 and 7, the shallower well produces mixing-zone-type water, while the deeper well produces sodium-chloride-type water.

The mixing of freshwater and seawater was also modeled and compared to water samples collected in the Geneva area. The computer program PHREEQE (Parkhurst and others, 1980) which simulates the mixing of two solutions as well as equilibration of the mixture with solid phases (minerals) was used to simulate the mixing of a seawater solution (assuming seawater during Pleistocene time was similar in chemical composition to that of today) with fresh ground water of the composition found at site 31. For simplicity, the mixing process was carried out in equilibrium with calcite at a constant temperature of 25°C and at atmospheric pressure, although these conditions may not be met during the natural mixing process.

The mixing of various percentages of seawater and freshwater was simulated, ranging from a mixture of 10 percent seawater and 90 percent freshwater to 0.1 percent seawater and 99.9 percent freshwater. Table 6 shows comparisons of major constituent concentrations calculated by the chemical model with samples collected in the Genenva area. Because the chloride ion (Cl^-) is conservative (that is, does not react with other ions under the conditions being simulated) chloride concentrations were used to compare the simulated and actual analyses. The table is arranged so that the analyses from wells in Geneva are in columns next to the simulated analysis with a similar chloride concentration. Thus the samples from sites 4, 5, and 6, which are far from the recharge area, resemble a mixture of 10 percent seawater and 90 percent freshwater, while the sample from site 31 resembles a mixture of 0.1 percent seawater and 99.9 percent freshwater. The wells at site 7 (which is shallower than the one at site 6) and site 58 (which is outside the recharge area but downgradient) are similar to a mixture of 0.5 percent seawater and 99.5 freshwater.

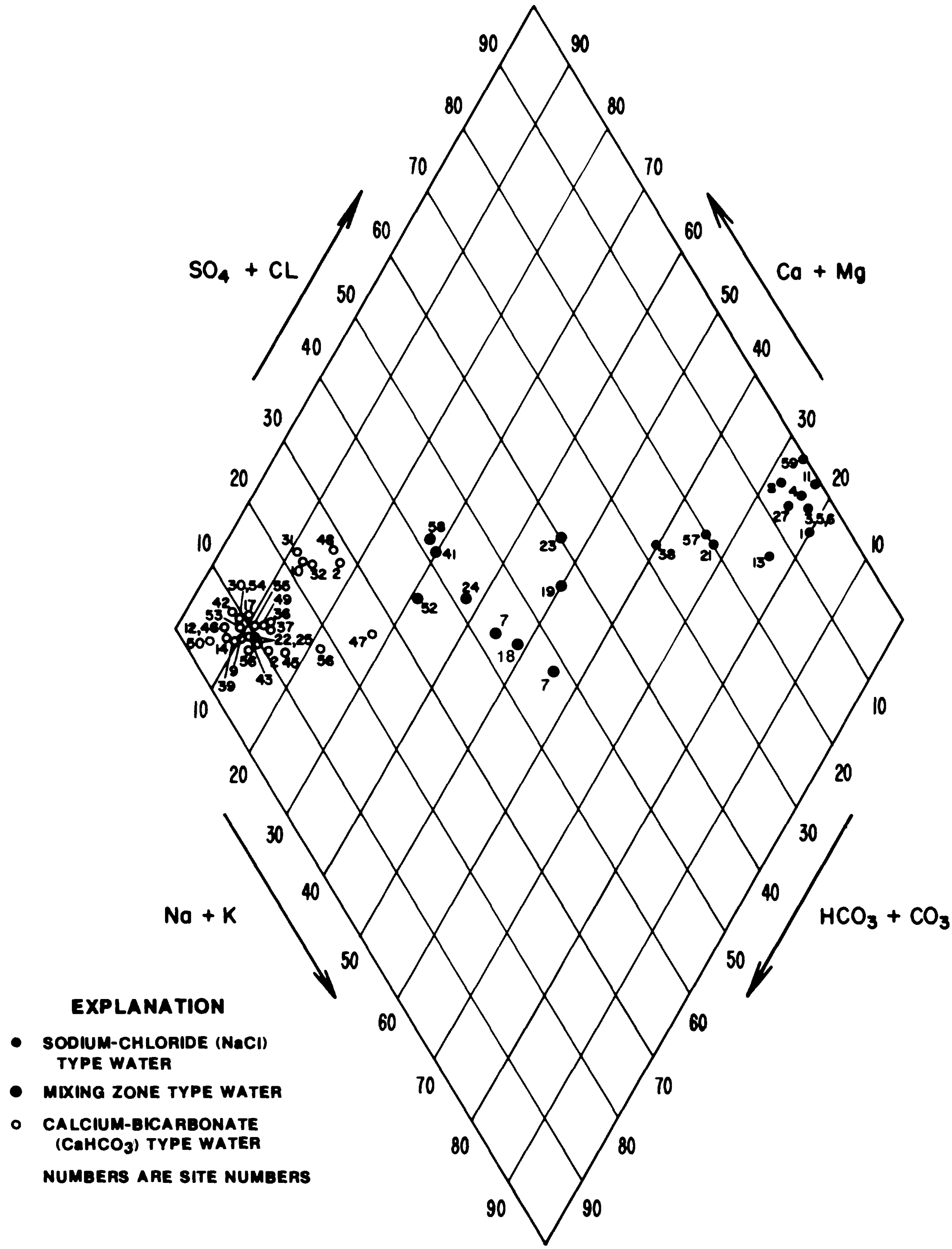


Figure 20.--Piper diagram for water samples from northeast Seminole County, 1981-82.

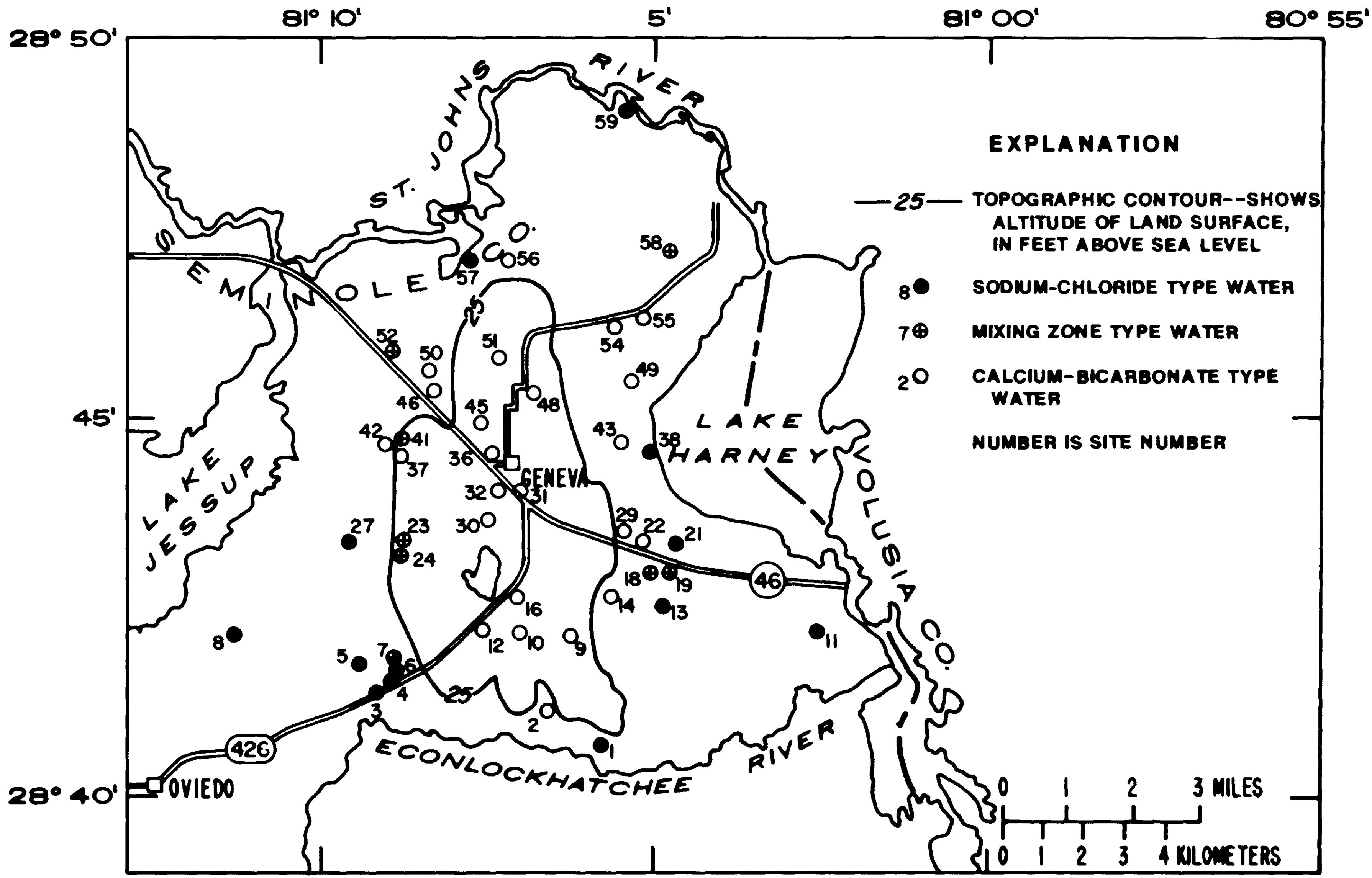


Figure 21.--Locations of wells shown in figure 20.

Table 6.--Examples of freshwater-saltwater mixing using the computer program PHREEQE and comparison to water samples from the Geneva area

[Concentrations are in milligrams per liter except iron which is in micrograms per liter]

Element	0.1 mix[1/]	Site 4	Site 5	Site 6	0.075 mix[1/]	Site 27	0.05 mix[1/]	0.005 mix[1/]	Site 7	Site 58	Site 19	Site 23	0.002 mix[1/]	0.001 mix[1]	Site 43	Site 55	Site 31
Ca	84	120	120	180	75	92	66	48	56	84	55	53	47	46	82	95	40
Mg	136	110	130	130	103	74	69	9.2	14	13	15	14	5.8	3.8	4.4	14	2.5
Na	1,120	1,100	1,300	1,300	842	690	563	60	69	46	90	71	33	16.2	12	15	4
K	44	35	39	41	33	22	23	44	4.9	1.6	3.7	4.2	3.4	2.8	.8	1.2	2.4
Fe	171	170	30	430	176	80	181	189	2,500	---	600	47	189	189	220	100	190
Cl	2,013	2,000	2,200	2,200	1,511	1,400	1,010	108	88	110	140	150	58	28	13	27	8.1
C	106	136	139	---	106	145	105	104	184	217	165	157	103	103	203	322	97
S	286	320	350	310	216	180	146	20	14	7.5	16	23	13	8.8	.1	2. 5	16

[1/] x mix: x = the fraction of seawater used in the mixing model. For example, 0.1 mix means 10 percent of the solution was seawater and 90 percent calcium carbonate water. All solutions were equlibrated with calcium carbonate at 25°C and atmospheric pressure.

The major difference between the analyses simulated by the model and those of samples collected in Geneva is in the concentrations of calcium and carbon. This is probably because calcite is dissolved as the ground water moves along the flow path. Site 31 at the center of the recharge area is most like the simulated analysis while site 55, far from the center of the recharge area, showed the most excess of calcium and carbon.

Figure 22 shows dilution diagrams for calcium, magnesium, sodium, potassium, and sulfate. In these diagrams, the concentration of the respective ion is plotted versus the chloride concentration of each sample. The curve plotted on each diagram represents the dilution curve for seawater with calcium bicarbonate water derived from the computer simulations using PHREEQE (table 6). The ratios will plot a straight line if no chemical reactions (such as dissolution or precipitation of minerals in an aquifer) are occurring. The plot for sodium versus chloride most clearly shows the dilution of seawater by freshwater with little other chemical activity. Many samples contain more calcium than predicted probably because of the dissolution of gypsum in the aquifer. Many of the potassium values plot below the dilution curve. This suggests that some potassium has been lost from the mixture of freshwater and seawater in the aquifer.

The high strontium concentration in the bottom zone of the deep test well at site 36 (table 5) is one piece of evidence that seems contrary to the flushing hypothesis. The concentration of 15 mg/L is almost twice the concentration in modern seawater. The source of the strontium is most likely not simple dilution of seawater (or even concentrated seawater) but dissolution of dolomite in the aquifer. High strontium concentrations of dolomite in rocks in Texas have been reported (Behrens and Land, 1972), and Sarver (1978) reported strontium concentrations up to 288 parts per million in Eocene dolomites of west-central Florida. A detailed analysis of the strontium problem is beyond the scope of this investigation.

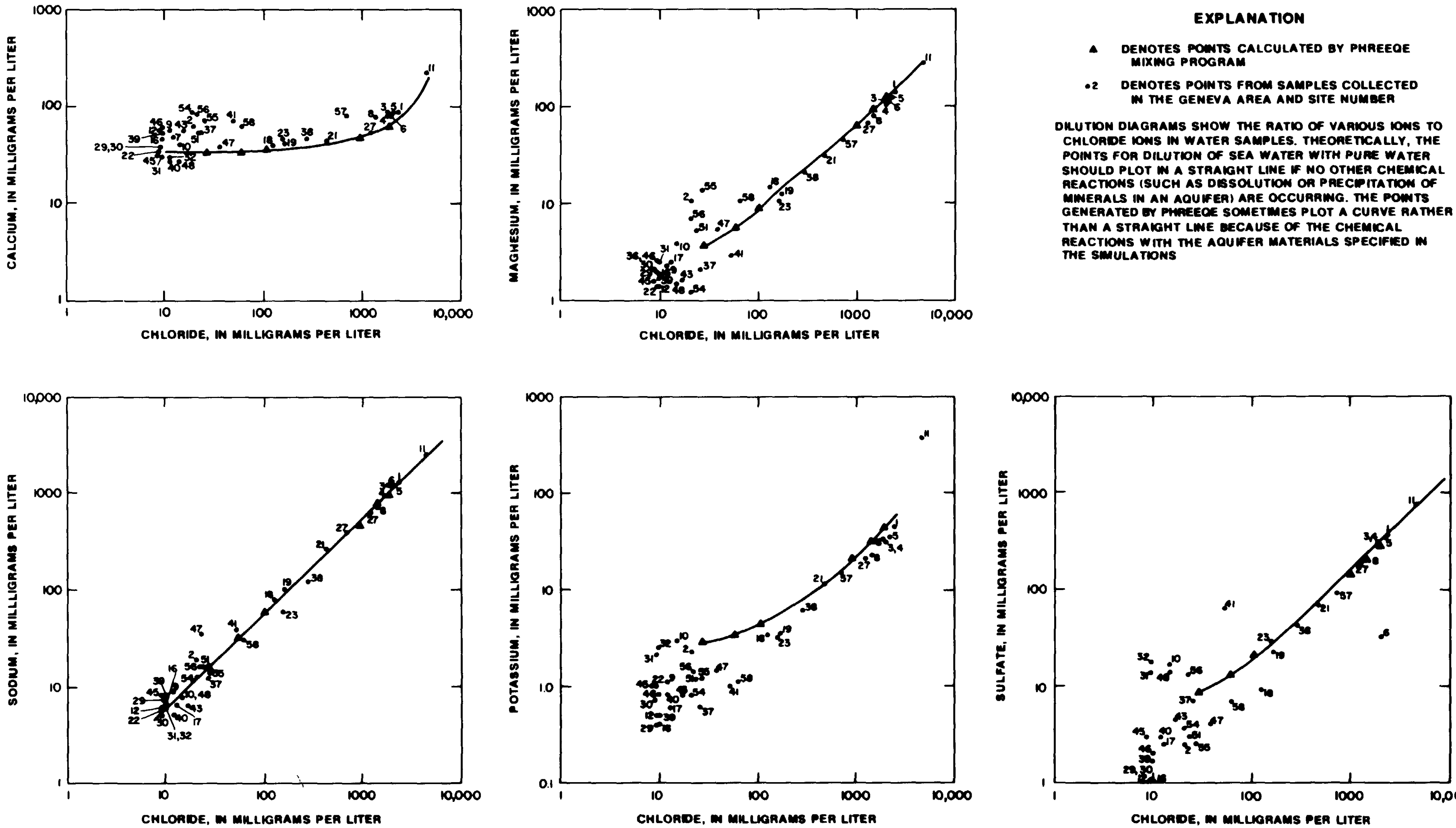


Figure 22.--Dilution diagrams for water samples from the Geneva area.

WATER BUDGET

The Water Budget Equation

Water budgets were calculated to estimate the amount of water recharging ground water in the Geneva area. The water budget equation is based on the principle of conservation of mass: the total input of water must equal total output. The surficial and Floridan aquifer systems must be considered separately.

The equation for the surficial aquifer can be stated as:

$$P + R = ET + Ru + Pu + GO_s + \Delta S_s + Re \quad (1)$$

where

P = precipitation
R = return from septic tank and irrigation infiltration
ET = evapotranspiration
Ru = runoff
Pu = pumpage (ground-water withdrawals)
GO_s = ground-water outflow from surficial (lateral)
ΔS_s = change in storage in the surficial aquifer
Re = downward leakage (recharge) to the Floridan (vertical)

Recharge available to the Floridan (Re) then can be estimated as the residual of the equation.

The equation for the upper part of the Floridan aquifer system within the area bounded by the 25-foot altitude contour is:

$$Re + GI = Pu + GO_F + \Delta S_F \quad (2)$$

where

Re = recharge from the surficial aquifer (vertical)
GI = ground-water inflow (lateral)
Pu = pumpage
GO_F = ground-water outflow from Floridan
ΔS_F = change in storage in the Floridan aquifer system

During the study (October 1980 through May 1983), the Geneva area experienced two significantly different hydrologic conditions (drought in 1981 and wetter-than-average conditions in 1982). Three water budgets were calculated to compare extremes with average conditions. During the 1981 drought, rainfall at Lake Harney was 41.84 inches, 11.48 inches less than the 30-year average annual rainfall of 53.32 inches at Sanford. Regression analysis indicated that this event was a 1 out of 10 year drought (that is, the probability of the event occurring would be 10 percent within any given year). In 1982, the rainfall at Lake Harney was 73.06 inches, 19.74 inches more than the 30-year average. A water budget for average conditions was estimated from hydrologic data for 30 years of record (1941 through 1970) at Sanford. Figure 8 is a hydrograph of monthly rainfall at Lake Harney for 1981 and 1982.

Recharge estimates calculated for the three water budgets were based on the area within the 25-foot altitude contour. In some areas of lower topography the hydraulic gradient is upward (discharge areas) while in other areas (particularly to the north and northeast of Geneva) the gradient is downward, but the head difference between the surficial and Floridan aquifers is so slight that little recharge can take place. In other areas, such as site 55, the vertical hydraulic gradient changes direction seasonally. Therefore, for the purpose of this analysis the "recharge area" is assumed to be the area inside the 25-foot altitude contour (fig. 1).

Estimating Evapotranspiration

Evapotranspiration is a term applied to the combined processes of evaporation of water from land and water surfaces and transpiration by plants. Evapotranspiration is the largest component of the water budget and also the most difficult to measure. It is important to differentiate between potential evapotranspiration (PET) and actual evapotranspiration (ET). PET is an estimate or calculation of the maximum amount of water that can be evapotranspired under specified conditions of land use, stage of plant growth and weather conditions. A limitation of most methods for estimating PET is the orientation towards the agricultural aspects of the problem; the amount of water that should be applied to various crops for optimum growth is calculated rather than the actual amount of water consumed by the plants under various conditions. Actual ET is always less than or equal to PET and is usually less than PET. Most methods for measuring actual ET are done under laboratory conditions so results extrapolated to field conditions may not be reliable. Measurements of actual ET in the field can be very time consuming and subject to error. Therefore, calculations of PET are often used to estimate actual ET in water budgets.

Some estimates of evaporation, PET and actual ET for central Florida are as follows:

Source and variable estimated	Value in inches per year
U.S. National Oceanic and Atmospheric Administration 1981 and 1982, Pan evaporation at Lisbon, Florida	59.64 (1981) 53.44 (1982)
Farnsworth and others, 1982, Average annual shallow lake free water surface evaporation	48.00
G. H. Hughes, U.S. Geological Survey, written commun., 1976, Areal average evapotranspiration for central Peninsular Florida	42.00
Florida Department of Natural Resources, 1970, p. 182, 30-year average consumptive use for citrus in central Florida	47.59
Smajstrla and Clark, 1982a, Potential evapotranspiration for Daytona Beach, Florida	50.56
Smajstrla and Clark, 1982b, Potential evapotranspiration for Orlando, Florida	53.72
Visher and Hughes, 1969, Average annual lake evaporation in east-central Florida	48.00

PET was estimated for the Geneva area using the modified Blaney-Criddle equation. This method of estimation presumes that the amount of water consumed by vegetation during the normal growing season is closely correlated with monthly temperatures, mean monthly percent of daytime hours, and monthly vegetative growth coefficients (which vary depending on the stage of growth of the crop). Stephens and Stewart (1963, p. 126) showed that the reliability of the Blaney-Criddle method is improved by including the cosine of the Sun's zenith angle to compensate for the lower power of the Sun's rays during late fall, winter, and early spring months. Critics of the method suggest that it overestimates PET because it does not take into account humidity, wind speed, water availability, and soil water holding capacity. Often such detailed climatological data are not available. In this analysis, it was assumed that soil moisture did not change (Walton, 1962, p. 23).

Consumptive use was weighted by land use. Land use for the Geneva area was determined from U.S. Geological Survey topographic quadrangle maps and areal photos flown in April 1980 by the Florida Department of Transportation. Verifications were made by ground reconnaissance. For the 1981 water budget, 75 percent of the study area was assumed to be covered by pasture and 25 percent by citrus or woodlands. In 1982, abundant rainfall resulted in the occurrence of areas of open water and swamp, so the land cover was: 58 percent pasture, 25 percent citrus and woodland, and 17 percent swamp. Land-cover percentages for the 30-year average budget were assumed to be the same as for 1982. No published data for consumptive use coefficients of swamp vegetation could be found so the pan evaporation coefficient was used.

Table 7 shows the monthly PET values calculated for the Geneva area for 1981, 1982 and 30-year average conditions using the modified Blaney-Criddle method. Total PET for 1981 was 47.71 inches, for 1982 57.68 inches, and for 30-year average conditions, 48.70 inches. The increase in PET from 1981 through 1982 can be explained partly by slightly higher than average temperatures in 1982 (table 7) and the increased evapotranspiration from swamp and lake areas that were dry in 1981.

Actual ET was estimated from PET as follows: The ratio of the estimated actual ET for average annual conditions to the 30-year average Blaney-Criddle PET was calculated, and it was assumed that in any given year, the ratio of actual ET to PET will be the same as the ratio of the long-term average values. Estimated actual ET for average annual conditions is 42 inches (G. H. Hughes, written commun., 1976), PET calculated using the Blaney-Criddle method for 30-year average conditions is 48.70 inches, and the ratio is 0.857. Thus, actual ET estimated for the water-budget calculation was 86 percent of the Blaney-Criddle PET or 41.03 inches for 1981 and 49.60 for 1982.

Runoff and Infiltration

The Geneva area does not have any perennial streams that enable gaging of discharge. However, runoff was calculated in Geneva for each individual storm in 1981 and 1982 using the soil cover complex method as outlined by the U.S. Soil Conservation Service (1975). The method allows calculation of direct surface runoff based on storm rainfall and the soil type and land use of the area. The soil in the Geneva recharge area is sandy and very well drained, whereas in the low-lying surrounding area, the soil is clayey and poorly drained (U.S. Soil Conservation Service, 1966).

Table 7.--Monthly potential evapotranspiration (PET) for the Geneva area for 1981, 1982, and thirty-year average climatic conditions using the modified Blaney Criddle method

Month	Thirty-year average monthly temperature (°F)	1981 Temperature (°F)	1982 Temperature (°F)	Potential evapotranspiration: Thirty-year average monthly PET	Potential evapotranspiration: 1981 Monthly PET	Potential evapotranspiration: 1982 Monthly PET
Jan	59.23	50.3	57.1	1.263	0.868	1.614
Feb	60.87	59.8	66.7	1.696	1.424	2.442
Mar	65.88	61.8	68.3	2.929	2.545	3.914
Apr	71.24	71.4	71.6	4.383	4.302	5.608
May	76.17	74.8	73.5	5.982	5.908	7.368
June	80.21	82.8	81.1	6.945	7.114	8.964
July	81.98	83.1	82.2	7.244	7.538	9.176
Aug	81.86	82.2	81.8	6.611	6.801	6.607
Sept	80.05	78.0	79.4	4.913	5.065	5.093
Oct	73.95	74.3	72.5	3.491	3.432	3.423
Nov	66.70	63.5	71.4	1.930	1.676	2.069
Dec	61.28	57.5	65.8	1.311	1.038	1.406
Total				48.70	47.71	57.68

Total runoff calculated for individual storms in 1981 was 0.3 inches. During 1982, April and June had individual storms producing large amounts of rain. A storm in April produced more than 12 inches of rain in 1 day, followed by 2 inches the next day. About 6 inches of runoff were calculated for that storm. In June, one storm produced about 7 inches of rain, followed by 2.4 inches the next day. About 4 inches of runoff was calculated for those storms. Most of the runoff was generated from the poorly drained soils along the periphery of the assumed boundary of the recharge area. Within the recharge area, runoff was minimal for the two large storms mentioned and the runoff that was generated drained into existing lakes or physiographic depressions and was, thus, available for recharge and evaporation. Thus, for these water budgets, runoff was assumed to be negligible.

Infiltration from septic tanks and irrigation water must be considered as recharge to the surficial aquifer. All the pumpage from the two public-supply systems in the area is exported from the Geneva area and, thus, is not returned to the system. Assuming that 70 percent of the pumpage from individual domestic wells is returned, and 30 percent of the pumpage from irrigation wells is returned, the total return infiltration is about 0.15 Mgal/d or 0.12 in/yr, a negligible amount.

Changes in Ground-Water Storage

Change in ground-water storage represents the volume of water either taken into or released from storage in the surficial aquifer and the Floridan. Change in storage is calculated by multiplying the head change over a given time period by the storage coefficient of the aquifer.

For unconfined aquifers, the storage coefficient is virtually the same as the specific yield (Lohman, 1972, p. 8). Based on dry sieve analysis, the specific yield of the surficial sand was estimated at 0.2. Surficial aquifer test wells drilled in early 1982 showed that fluctuations of surficial aquifer water levels were similar to those of surface-water bodies. Based on the staff gage located on Buck Lake, the average net water level decline in the surficial aquifer in 1982 was estimated to be 2.0 feet. In 1982, water levels rose about 4 feet. Thus, the change in storage for the surficial aquifer for 1981 was (-2 feet)(12 in/ft)(0.20) = -4.8 inches and for 1982 (4 feet)(12 in/ft)(0.20) = 9.6 inches. Change in storage in surface-water bodies was estimated to be 0.09 inch for 1981 and 0.18 inch for 1982. Thus, the change in storage totals are -4.89 inches for 1981 and 9.78 inches for 1982.

Change in storage in the Floridan is calculated by multiplying the head change over a given time period by the storage coefficient of the aquifer. The storage coefficient for the Floridan aquifer system was estimated to be 0.002 based on Lohman's (1972, p. 9) discussion of storage properties of confined aquifers. Average head change in the Floridan aquifer system in the Geneva area from September 1980 through September 1981 was 2.0 feet. The change in storage in the Floridan was about 0.05 inch and is, thus, negligible.

In 1982, the head change in the upper part of the Floridan was about 5 feet, resulting in a calculated 0.12 inch of water taken into storage in the Floridan, which is negligible.

For the 30-year average water budget, it was assumed that there were no changes in ground-water storage for the surficial aquifer and the Floridan (Walton, 1962, p. 23).

Ground-Water Outflow

Ground-water outflow from the surficial aquifer was assumed to be the same for all three water budgets and was calculated using Darcy's Law. The lateral hydraulic gradient between the surficial aquifer wells at sites 17 and 27 was 4.1 ft/mile. Transmissivity was estimated to be 1,000 ft^2/d based on several tests of the surficial aquifer in central Florida which showed transmissivity values ranging from 400 to 2,000 ft^2/d (Planert and Aucott, 1985, p. 20-23, and E. R. German, U.S. Geological Survey, oral commun., 1985). Calculated outflow for the surficial aquifer was thus, about 500,000 gal/d or 0.5 in/yr. There is no inflow to the surficial from outside the recharge area.

Ground-water outflow from the Floridan was calculated as the residual of the water budget equation for the Floridan aquifer system. Based on the potentiometric surface maps (fig. 10) and maps of chloride concentration (figs. 16 and 17) outflow from the recharge area is to the northeast. There is no inflow to the freshwater lens from outside the recharge area, based on the stability of the position of the fresh-brackish water interface. It is assumed that all of the outflow is thus derived from recharge in the Geneva area.

Ground-Water Withdrawals

Most of the ground-water withdrawals in the Geneva area are for domestic supply and agricultural uses. Two public supply well fields in the Geneva area supply water to users on the periphery of Geneva around Lake Harney and Mullet Lake, where fresh ground water is not available. There is no industrial use of ground water in Geneva.

Table 8 shows estimated water use for 1982 (Marella, 1983). Eighty-nine percent of total agricultural pumpage is for pasture, which includes water use for nurseries and livestock watering. Eleven percent is for citrus irrigation. In 1980, Lake Harney Water Association, Inc. had 121 service units and pumped about 32,000 gal/d. Mullet Lake Water Association, Inc., had 144 service units and pumped about 26,000 gal/d.

Table 8.--Estimated pumpage in the Geneva area in 1981

Domestic	Population	Pumpage (Mgal/d)
Lake Harney Water Association, Inc.	314	0.03
Mullett Lake Water Association, Inc.	400	.02
Individual wells	2,361	.18
Agriculture	(Acre-ft/d)	
Pasture	0.58	.19
Citrus	.06	.02
Total		0.44

Data from Marella, 1983.

For the purpose of water-budget calculations, all domestic wells were assumed to pump from the Floridan aquifer. A few wells that tap the surficial aquifer are used for lawn and garden irrigation but the withdrawals from such wells were negligible. Domestic use from individual wells was calculated by multiplying the estimated population by 75 gal/d per person. Total self-supplied domestic water use in 1982 was, therefore, about 180,000 gal/d.

Total pumpage from the Geneva area for 1982 is estimated at 0.44 Mgal/d which equals 0.37 inches distributed over the 22-square miles of the freshwater lens. The 1982 withdrawal rates were also used for the 1981 and 30-year average water budgets. This may overestimate withdrawals for long-term conditions somewhat, but withdrawals are still a small component of the budget.

Limitations of the Water Budgets

Although water budgets can be useful tools, they have limitations which must be considered when evaluating the results of the calculations. The main causes of the limitations are the assumptions that are made in conceptualizing the budget problem, and the inaccuracies that arise in estimating components of the budget.

Some of the assumptions which could have significant effects on the calculations are:

(1) that the recharge area is the area inside the 25-foot altitude contour,
(2) that there is no runoff from the recharge area,
(3) that all pumpage is from the Floridan,
(4) that there is no ground-water outflow from the Floridan toward the west.

Inaccuracies can also result because of the difficulty in measuring some of the parameters. For example, the estimates of the storage coefficients for the aquifers could be inaccurate and thus, the amount of water taken into or given up from storage incorrect. On the long term, some of the inaccuracies may average out, for example in estimates of ET and runoff; thus, calculations for any particular year are more sensitive to inaccurate estimates of the components, and therefore, should be used more cautiously than long-term budgets.

Conclusions Based on the Water Budgets

In the previous sections, the components of the water budget equations (equations 1 and 2) were discussed. Table 9 shows a compilation of the equations for both the surficial aquifer and the Floridan aquifer system. The budget for the surficial aquifer shows that in 1981 5.2 inches (5.4 Mgal/d) were available for recharge to the Floridan and outflow from the Floridan was about 4.8 inches (5 Mgal/d). In 1982, 13.2 inches (13.8 Mgal/d) were available for recharge to the Floridan and outflow from the Floridan was 12.8 inches (13.4 Mgal/d). Using the 30-year average climatological data, average recharge available to the Floridan is 10.8 inches (11.3 Mgal/d) and average outflow is 10.4 inches (10.9 Mgal/d). The difference, 0.4 inches, is the water consumed in the Geneva area.

A flow-net analysis was made to compare the outflow calculated in the water budgets to flows calculated using geohydrologic data and determine if the aquifer can carry the flows calculated in the budgets. Ground-water flow moving along flow lines perpendicular to equipotential contour lines can be calculated using Darcy's Law expressed by the following equation:

$$Q = TIL \qquad (3)$$

where

Q = discharge in cubic foot per day
T = transmissivity in square foot per day
I = average hydraulic gradient across potential in foot per mile
L = length of flow channel

In flow net analysis, it is assumed that flow in the aquifer is horizontal and the aquifer is homogenous and isotropic.

Table 9.--Components of the water budgets for 1981, 1982, and thirty-year average conditions, in inches per year

	1981	1982	Thirty-year average
Surficial aquifer			
Precipitation	41.84	73.06	53.32
Return infiltration	0	0	0
Evapotranspiration	41.03	49.60	42
Runoff	0	0	0
Withdrawals	0	0	0
Ground-water storage	.5	.5	.5
Change in ground-water storage	4.89	9.78	0
	5.2	13.2	10.8
Floridan aquifer system			
Recharge available	5.2	13.2	10.8
Ground-water inflow	0	0	0
Withdrawals	.37	.37	.37
Ground-water outflow	4.8	12.8	10.4
Change in ground-water storage	0	0	0

Potentiometric surface maps for September 1981 and September 1982 (fig. 10) were used for the flow net analysis and a range of transmissivity values from 17,000 ft^2/d to 91,000 ft^2/d were used for the calculations. Calculated flows are as follows:

Date	Transmissivity (ft^2/d)	Ground-water outflow (Mgal/d)	Ground-water outflow (in/yr)
1981	17,000	1.24	1.1
	65,000	4.7	4.5
	91,000	6.6	6.3
1982	17,000	2.0	1.9
	65,000	7.7	7.4
	91,000	10.8	10.3

For 1981 the ground-water outflow from the Floridan for a transmissivity of 65,000 ft^2/d compares well with the outflow calculated in the water budget, but for 1982 for the same assumed transmissivity, the water budget apparently over-estimates the amount of outflow. The discrepancy might be because of errors in estimating evapotranspiration or outflow from the surficial aquifer during the wetter-than-average year.

The average annual outflow from the Geneva freshwater lens is about 10 inches (or about 10 Mgal/d). Any reduction in the outflow to less than 10 inches per year will disturb the equilibrium between the freshwater and saltwater and cause a movement of the interface. Because of the large volume of water in the aquifer, a large amount of freshwater needs to be displaced before the movement of the interface is apparent. Thus, although ground-water outflow was reduced to about 5.5 inches in 1981, there was no apparent deterioration of water quality in the freshwater lens. In 1982, abundant rainfall again provided sufficient ground-water outflow to regain the balance between freshwater and saltwater. If ground-water outflow is reduced to less than 10 inches per year for a number of years, noticeable deterioration of water quality will eventually occur. At present, ground-water withdrawals are less than 5 percent of the average annual recharge rate so as yet, there is no discernible movement of the freshwater-saltwater interface. If ground-water development increases in the Geneva area, withdrawal rates should be evaluated continually, depending on precipitation. Monitoring of chloride concentrations of water in wells on the periphery of the lens is also desirable.

SUMMARY AND CONCLUSIONS

Northeast Seminole County, Fla., contains an isolated recharge area of the Floridan aquifer system that forms a freshwater lens completely surrounded by saline water. The freshwater lens covers an area of about 22 mi^2 surrounding the town of Geneva, and generally follows the 25 foot altitude contour. Thickness of the lens is about 350 feet in the center of the recharge area. The hydrologic units, in descending order, consist of the post-Miocene sand and shell of the surficial aquifer; Miocene clay, sandy clay, and shell that form a leaky confining bed; and permeable Eocene limestones of the Floridan aquifer system.

The purpose of the investigation was to delineate the vertical and lateral extent of the freshwater lens and to evaluate recharge potential. To accomplish these objectives, water samples from about 50 wells and geologic and geophysical data from test wells at nine sites were analyzed. Rainfall, runoff, lake level, and ground-water level data were used to estimate water budgets.

The potentiometric surface of the Floridan aquifer system varies about 5 feet seasonally and apparently has not declined significantly since 1964. Lake levels fluctuate with the amount of local rainfall. A long-term decline in lake levels may be occurring: the maximum stage recorded for Lake Geneva during the wetter-than-average year 1982 was 23.05 feet compared to a maximum of 28.2 feet observed by Barraclough (1962b, p. 40) from 1953-56.

Sufficient quantities of water for domestic and small public supply systems are available from the Floridan aquifer system in the Geneva area. Transmissivity values from specific capacity tests of the upper part of the Floridan range from about 1,700 to 17,000 ft^2/d (Tibbals, 1977, fig. 14). Transmissivity values derived from ground-water flow modeling ranged from 35,000 to 100,000 ft^2/d (Tibbals, 1981, fig. 6), and represent more accurately the transmissivity of the full thickness of the upper part of the aquifer system. The specific capacity of the test well at site 36 ranged from less than 3 [(gal/min)/ft] for the upper part of the Ocala Limestone to about 12 [(gal/min)/ft] for the upper part of the Avon Park Formation.

The limiting factor for water supply in the area is the chemical quality of the water. Chloride concentrations range from less than 20 mg/L in the center of the recharge area to about 5,100 mg/L near the St. Johns River southeast of Geneva. Other constituents analyzed included sulfate (range 1 to 800 mg/L), hardness (range 89 to 2,076 mg/L), and iron (range 34 to 6,600 ug/L).

Geochemical analyses support the conclusion that the freshwater lens is the result of local rainfall flushing ancient seawater from the Floridan aquifer system. In the higher elevation area near Geneva, the sediments overlying the Floridan aquifer system are very permeable, allowing water from higher stands of sea level to be flushed out by rainfall. In the surrounding low-lying areas the sediments contain thick clay layers which have slowed flushing of the trapped seawater.

Because the freshwater lens results entirely from local recharge, the recharge rate is important in estimating long-term sustained freshwater yield of the aquifer in the Geneva area. To estimate recharge, water budgets were calculated for 1981, 1982, and a long-term average using data from 1941 to 1970. It is estimated that recharge was about 5 inches (5.4 Mgal/d) in 1981, a year with much less than normal rainfall. In 1982, recharge was about 13 inches (13.8 Mgal/d). Average recharge for 1941-70 was estimated to be about 11 inches (11.3 Mgal/d).

Freshwater that recharges the Floridan aquifer system in the Geneva area is either pumped out or flows north and northeast to discharge in or near the St. Johns River. Average annual outflow is about 10 inches. The reduction of outflow to about 5 inches during the drought of 1981 did not cause detectable movement of the saltwater-freshwater interface because of the large volume of water that must be displaced before a change in water quality can be observed. If ground-water outflow is reduced to less than 10 inches per year over the long term, deterioration of water quality will eventually occur.

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