HYDROGEOLOGY OF THE SURFICIAL AND INTERMEDIATE AQUIFERS OF CENTRAL SARASOTA COUNTY, FLORIDA

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ABSTRACT

The hydrogeologic units underlying a 300-square-mile area in central Sarasota County, Florida, consist of the surficial aquifer, intermediate aquifers (Tamiami-upper Hawthorn and lower Hawthorn-upper Tampa aquifers) and confining units, the Floridan aquifer system, and the sub-Floridan confining unit. The saturated thickness of the surficial aquifer ranges from about 40 to 75 feet and the water table is generally within 5 feet of land surface. The Tamiami-upper Hawthorn is the uppermost intermediate aquifer. The top of the aquifer ranges from about 50 feet to about 75 below sea level and has an average thickness of about 100 feet. The lower Hawthorn-upper Tampa aquifer is the lowermost intermediate aquifer. The top of the aquifer ranges from about 190 to about 220 feet below sea level and its thickness ranges from about 200 to 250 feet.

The quality of water in the surficial and the two intermediate aquifers is acceptable for potable use except near the coast. Water from the Floridan aquifer system is used primarily for agricultural purposes because it is too mineralized for most other uses; therefore, the surficial and intermediate aquifers are developed for water supply. The artesian pressure of the various aquifers generally increases with depth.

A more detailed hydrogeologic description is presented for the Ringling-MacArthur Reserve, a 51-square-mile area in the central part of the county that may be used by Sarasota County as a future water supply. Average annual rainfall is 56 inches and evapotranspiration is about 42 inches at the Reserve. The area has a high water table, many sloughs and swamps, and undeveloped land, making it an attractive site as a potential source of water.

INTRODUCTION

The study are in central Sarasota County includes approximately 300 mi^2 in west-central Florida (fig. 1). This area is experiencing a rapid growth in population. Associated with this rapid growth is an increasing demand for potable water. Projections indicate that central Sarasota County may need an additional 30 Mgal/d by 2010. Water-supply systems are limited and some supplies from well fields near the coast require expensive treatment by reverse osmosis before use. Part of the current supply (up to 10 Mgal/d) is imported from Manatee County.

To meet the increasing demand for water, Sarasota County is planning to develop a water supply from a 51-mi^2 area known as the Ringling-MacArthur Reserve in the central part of the county (fig. 1). The area has a high water table, many sloughs and swamps, and undeveloped land, making it an attractive site as a potential source of water.

Purpose and Scope

Specific objectives of this study were to determine the hydrogeology, including the physical characteristics, hydraulic properties, water-level variations, and water quality in the surficial and intermediate aquifers within the study area and in more detail in the Ringling-MacArthur Reserve. Information presented in this report was obtained from data collected during this investigation, unpublished data on file with the U.S. Geological Survey, published U.S. Geological Survey reports, and consulting engineers' reports. Additional data were obtained from test drilling and water-quality sampling within the Ringling-MacArthur Reserve (fig. 1). Test wells that tap the surficial aquifer were installed. The wells were used for monitoring water levels, water-quality sampling, and determining depths to the first clay. Water samples were analyzed for a suite of chemical constituents. For convenience, the wells are numbered serially in figures and in tables.

Acknowledgments

The study was done in cooperation with Sarasota County. Valuable assistance in conducting this investigation was provided by many organizations and individuals. Personnel of the Florida Bureau of Geology, Florida Department of Transportation, Southwest Florida Water Management District, and Sarasota County provided support and access to well records and rock cuttings.

Special thanks are due to Loring Lovell and Jeffery Lincer, Sarasota County, for their cooperation and support during the study. Initial network design and data-collection efforts were directed by H. Sutcliffe, Jr., Sarasota field office, U.S. Geological Survey. Geronia Bowman, Sarasota field office, U.S. Geological Survey, provided technical support for hydrologic and geophysical data collection.

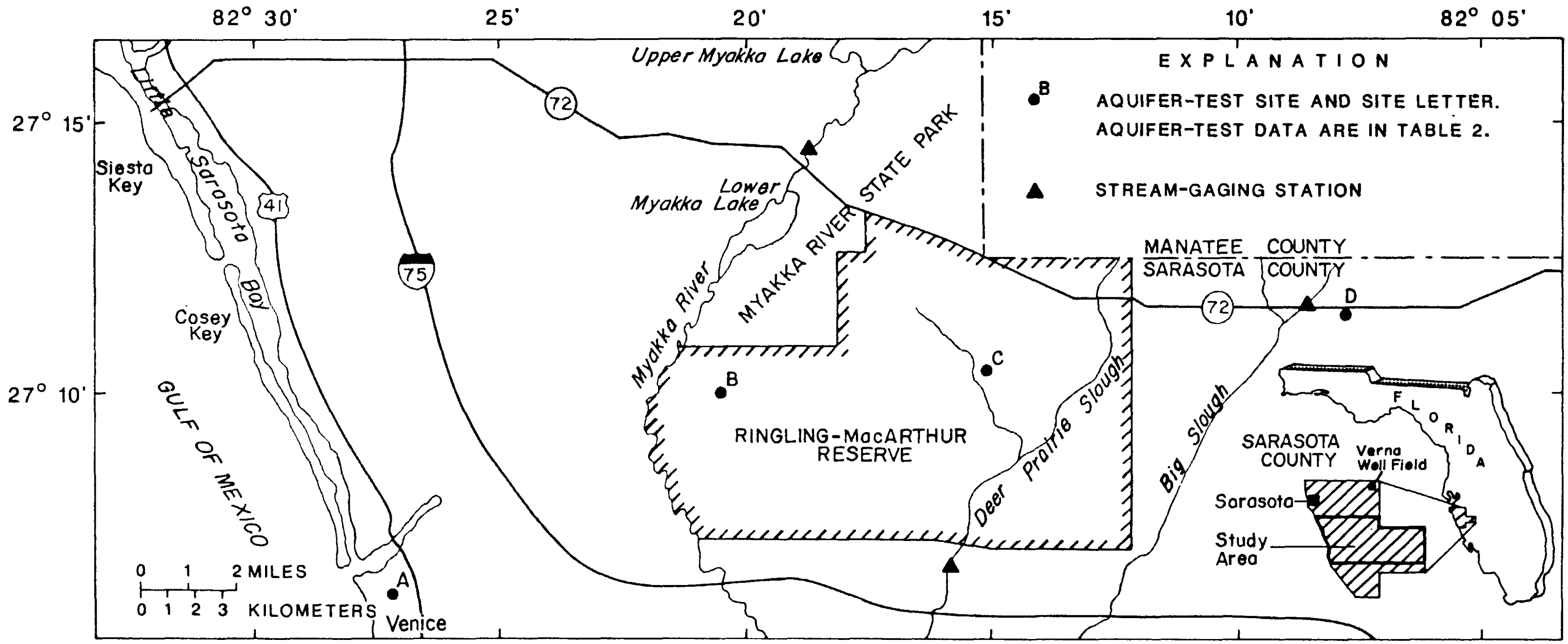


Figure 1.--Location of study area, Ringling-MacArthur Reserve, stream-gaging stations, and aquifer-test sites.

Previous Investigations

Central Sarasota County has been included in several local, county, and statewide ground-water resources investigations. However, evaluation of the hydrogeology of the surficial and intermediate aquifers had not been the principal subject of any previous investigation. Previous investigations described the occurrence and quality of water and identified water-bearing zones in the surficial and intermediate aquifers, but they did not include regional delineation or hydrologic evaluation of the aquifers.

Several previous investigations provide geologic and ground-water information. Stringfield (1933a; 1933b) described the geology, ground-water conditions, and yields of water-bearing strata in Sarasota County. Clark (1964) discussed local geology, water quality, and aquifer tests in the Venice area. Eppert (1966) reported on the stratigraphy of upper Miocene deposits in Sarasota County. Sutcliffe and Joyner (1968) gave results of packer tests in wells in the county. Joyner and Sutcliffe (1976) identified and described water resources in the Myakka River basin and included a description of water-bearing zones overlying the Floridan aquifer system. Wolansky (1983) defined the hydrogeologic framework for the Sarasota-Port Charlotte area. Miller and Sutcliffe (1984) reported the occurrence of radium-226 in ground water in Sarasota County.

Other reports that pertain mainly to water-supply development, but include information on the surficial and intermediate aquifers, include: Bishop (1960) who presented water-resource problems in Sarasota County and Smith and Gillespie, Inc. (1960), who reported on alternative ground-water supplies near Sarasota. Smalley, Wellford and Nalvin, Inc. (1963), addressed the water supplies of Sarasota County. Russel and Axon, Inc. (1965), presented an investigation of future sources of water supply in the Venice area. Joyner and Sutcliffe (1967) reported on saltwater contamination in wells on Siesta Key. Geraghty and Miller, Inc. (1974), reported on the engineering and financial feasibility of water-supply alternatives available to Venice Gardens. Geraghty and Miller, Inc. (1975), addressed the safe yield of wells at the Verna well field. Smith and Gillespie, Inc. (1975), reported on the safe yield and water quality of the surficial and intermediate aquifers in the Verna well-field area. Smalley, Wellford and Nalvin, Inc. (1977), presented a literature assessment of the Manasota Basin (Sarasota and Manatee Counties). Hutchinson (1984) discussed the hydrogeology of the Verna well-field area.

DESCRIPTION OF THE AREA

The Ringling-MacArthur Reserve, in the central part of the study area, occupies approximately 51 mi^2. The study area includes part of the Myakka River basin and coastal drainage areas. Heavy residential and commercial development characterizes the coastal areas, whereas inland areas are mostly rural, agricultural, or rangeland.

Physiography

Central Sarasota County is part of the Gulf Coastal Lowlands subdivision of the midpeninsular physiographic zone (White, 1970). As described by White, the Gulf Coastal Lowlands is a broad, gently sloping marine plain that is characterized by broad flatlands with many sloughs and swampy areas. Some of these areas have been drained by ditches and canals. Land-surface altitudes range from sea level near the coast to about 50 feet above sea level along the northeastern boundary.

The Myakka River is the major stream in central Sarasota County. Two smaller streams, Deer Prairie Slough and Big Slough (fig. 1), drain the central part of the study area. Numerous small streams drain coastal areas from the city of Venice to the city of Sarasota. These small streams are affected by tides throughout much of their length.

Climate

The average annual rainfall, based on records obtained at the Myakka River State Park from 1944 to 1981, is 56.0 inches. About 60 percent of the annual rainfall occurs from June through September. The dry season, October through May, is the peak irrigation season.

Mean monthly temperatures range from about 82°F in July and August to 61°F in January. The mean annual temperature is about 73°F. The moderately high temperatures result in large amounts of rainfall being lost to evapotranspiration. The losses vary depending on rainfall, temperature, distribution of vegetation communities, and land-use patterns.

Evaporation from areas that have standing water almost equals yearly potential evapotranspiration, or about 49 inches annually (Dohrenwend, 1977). The average annual evapotranspiration from vegetated land is about 38 inches (Dohrenwend, 1977). Based on an estimate of 35 percent of the study area being open water and 65 percent vegetated, the average annual evapotranspiration is about 41.8 inches at the Ringling-MacArthur Reserve.

HYDROGEOLOGIC FRAMEWORK

Aquifers in the study area consist of the surficial and intermediate aquifers (Tamiami-upper Hawthorn and lower Hawthorn-upper Tampa aquifers). The Floridan aquifer system, underlying the intermediate aquifers, is a thick, stratified sequence of limestone and dolomite that are hydraulically connected in varying degrees. The aquifer does not contain potable water in most of the study area and is not considered further in this report.

Geologic units that comprise the surficial aquifer are undifferentiated deposits of Holocene and Pleistocene age, the Caloosahatchee Marl of Pleistocene and Pliocene age, and the Bone Valley Formation of Pliocene age. Geologic units of the intermediate aquifers are the Pliocene Tamiami and Miocene Hawthorn Formations and parts of the Miocene Tampa Limestone that are not in hydraulic connection with the Floridan aquifer system.

SURFICIAL AQUIFER

The surficial aquifer consists primarily of permeable units in the undifferentiated deposits, the Caloosahatchee Marl, and the Bone Valley Formation (table 1). Permeable units near the top of the Tamiami Formation may be hydraulically connected to the surficial aquifer. The undifferentiated deposits are predominantly layers of fine- to medium-grained sand with some clay and shell. The Caloosahatchee Marl typically consists of marl and shell intermixed with stringers of limestone. Except for the limestone, the deposits are unconsolidated. The Bone Valley Formation consists of clayey sand and sandy clay with lens-like beds of quartz sand and considerable amounts of fossil fragments, phosphate nodules, and quartz pebbles. The surficial aquifer is generally unconfined; however, lenses of sand, marl, and limestone contain water under confined conditions in some areas. The saturated thickness in the surficial aquifer ranges from about 40 to 75 feet (fig. 2). The base of the surficial aquifer generally consists of clayey sand and sandy clay in the lower part of the Caloosahatchee Marl or upper part of the Tamiami Formation.

Depth to the water table of the surficial aquifer is generally less than 5 feet. In hilly areas where drainage channels are well defined, the water table may be more than 10 feet below land surface. In areas of low topographic relief and near the coast, the water table may be virtually at land surface. Fluctuations of the water table are generally seasonal and vary within about a 5-foot range. The lowest water table generally occurs during May or June at the end of the dry season. Water levels generally recover during the wet summer months to the annual high in September or October.

The general configuration of the water table is shown in figure 2. The altitude of the water table ranges from zero to about 10 feet above sea level near the coast to about 40 feet above sea level in the extreme northeast part of the study area. The direction of flow of the water is downgradient and normal to the contour lines. The water flows generally southwestward; however, this pattern is interrupted locally where the aquifer discharges to streams, lakes, or low swampy areas.

Major sources of recharge to the surficial aquifer are (1) rainfall, (2) upward leakage where the altitude of the potentiometric surface of the Tamiami-upper Hawthorn aquifer is higher than the water table, (3) infiltration of irrigation water, and (4) ground-water inflow from adjacent areas.

Table 1.--Hydrogeologic framework

[Modified from Wolansky, 1983]

Series	Stratigraphic unit	Hydrogeologic unit	Thickness (feet)	Lithology
Holocene Pleistocene	Undifferentiated deposits	Surficial aquifer	0-60	Nonmarine, light gray to yellow, fine- to medium-grained quartz sand; underlain by marine terrace deposits of sand and marl, including clay, shell, and peat deposits.
Pleistocene Pliocene	Caloosahatchee Marl		0-20	Shallow marine, gray, tan, or cream, unconsolidated, sandy marl, marl, and shell beds; hard, sandy limestone; some phosphate.
Pliocene	Bone Valley Formation		0-20	Mostly nonmarine, very light gray to gray, clayey sand and sandy clay with lens-like beds of light gray, fine- to medium-grained quartz sand with a considerable amount of land vertebrate fossil fragments, some marine fossil fragments, phosphate nodules, and quartz pebbles.
	Tamiami Formation	Confining bed Intermediate aquifers	0-50	Shallow marine, green to gray, sandy calcareous clay, gray marl, gray sandstone, and slightly consolidated tan to light gray limestone; all units contain some phosphate.
Middle Miocene	Hawthorn Formation	Confining bed and	200-400	Marine, interbedded layers of buff, sandy, clayey, phosphatic limestone and dolomite; gray, fine to medium sand; gray to greenish-blue sandy clay with abundant phosphate nodules.
Lower Miocene	Tampa Limestone	confining units Confining bed	150-300	Marine, white to light gray, sandy, often phosphatic, clayey limestone, silicified in part, with many molds of pelecypods and gastropods; often interbedded with light gray clay and sandy clay. A residual mantle of green to greenish-blue, calcareous clay is often developed.

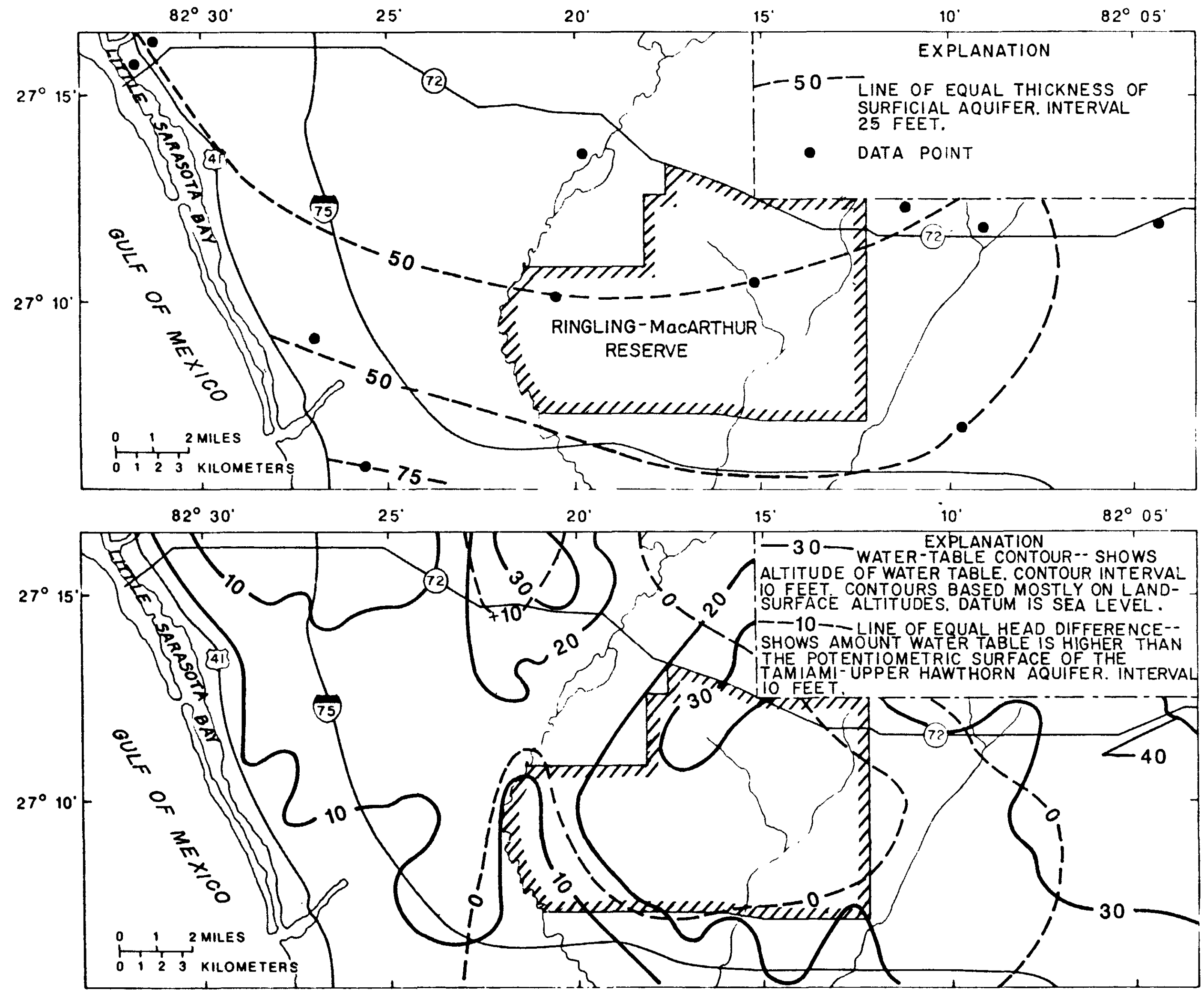


Figure 2.--Thickness of the surficial aquifer, altitude of the water table, and head difference between the water table and the potentiometric surface of the Tamiami-upper Hawthorn aquifer (modified from Wolansky, 1983).

Major types of discharge from the surficial aquifer are (1) evapotranspiration; (2) seepage into streams, lakes, swamps, and canals; (3) pumping from wells; and (4) downward leakage where the altitude of the water table is higher than the potentiometric surface of the Tamiami-upper Hawthorn aquifer.

The quantity of water that an aquifer will yield to wells depends upon the hydraulic characteristics of the aquifer. The hydraulic properties of the surficial aquifer vary from place to place primarily because of the large range in hydraulic conductivity of individual lithologic units and the heterogeneity in their distribution. Hydraulic properties have been computed from three aquifer tests of wells that penetrate sections of the surficial aquifer. Transmissivities determined from three tests ranged from 1,000 to 1,800 ft^2/d, and storage coefficients determined from two tests are 1.5×10^{-1} and 1.9×10^{-1} (table 2) (Clark, 1964; Geraghty and Miller, Inc., 1978). The surficial aquifer supplies water to wells at Venice (fig. 1). The yield of these wells is generally less than 50 gal/min.

The most common constituents in water that affect potability are dissolved solids, chloride, sulfate, and fluoride. Iron and color are commonly present in water from the surficial aquifer in objectionable amounts; however, they can be removed by treatment methods, including aeration and filtration. Recommended maximum concentrations for these constituents in public water supplies are as follows:

Constituent	Concentration,[1/] in milligrams per liter
Dissolved solids	500
Sulfate (SO_4)	250
Chloride (Cl)	250
Fluoride (F)	1.42[2/]
Iron (Fe)	0.3
Color (platinum-cobalt units)	75[3/]

[1/]Florida Department of Environmental Regulation (1982).

[2/]Based on the mean air temperature of study area, standard may vary based on local climatic conditions.

[3/]Standard for the source of supply.

The quality of water from the surficial aquifer generally is within the recommended limits for potable use, except near the coast. Concentrations of the above constituents generally increase from the northeast to the west and southwest. Concentrations of chloride, sulfate, and fluoride are generally within recommended limits, except near the coast. Concentrations of dissolved solids are less than 500 mg/L (milligrams per liter) in the northeast and increase to more than 1,000 mg/L near the coast. The U.S. Environmental

Table 2.--Aquifer properties derived from aquifer tests

[Location of test sites are shown in figure 1. Aquifer tests: Su, surficial; U, Tamiami-upper Hawthorn; L, lower Hawthorn-upper Tampa]

Test site	Aquifer tested	Transmissivity (ft^2/d)	Storage coefficient	Leakage coefficient [(ft/d)/ft]	Reference
A	Su	1,000	--	--	Clark, 1964
A	U	800	$1x10^{-4}$	$2x10^{-4}$	Clark, 1964
A	L	2,500	$1.2x10^{-4}$	$1x10^{-4}$	Clark, 1964
B	Su	1,070	$1.5x10^{-1}$	--	Geraghty and Miller, 1981
B	U, L	2,740	--	--	Geraghty and Miller, 1981
C	Su	1,800	$1.9x10^{-1}$	--	Geraghty and Miller, 1981
D	L	9,000	$1x10^{-4}$	$1.3x10^{-4}$	Geraghty and Miller, 1978

Protection Agency (1977) recommended limit for dissolved-solids concentration is 500 mg/L; however, water with dissolved-solids concentrations between 500 and 1,000 mg/L is commonly used for public supply in this area.

INTERMEDIATE AQUIFERS AND CONFINING UNITS

The intermediate aquifers and confining units consist of a series of intercalated permeable and poorly permeable material that function regionally as a water-yielding hydraulic unit that is separate from the surficial aquifer and the Floridan aquifer system. Within the study area, a discontinuous confining bed separates the two intermediate aquifers. The upper aquifer consists of the Tamiami Formation and the upper part of the Hawthorn Formation, herein called the Tamiami-upper Hawthorn aquifer, following the usage in Wolansky (1983). The lower aquifer consists of the lower part of the Hawthorn Formation and permeable parts of the upper Tampa Limestone that are not in hydraulic connection with the Floridan aquifer system and is called the lower Hawthorn-upper Tampa aquifer. The total thickness of these aquifers ranges from about 300 feet in the north to 375 feet in the south.

Tamiami-Upper Hawthorn Aquifer

The Tamiami-upper Hawthorn aquifer consists of partially consolidated deposits of phosphatic marl, shell, sand and clayey sand, and thin beds of phosphatic limestone. The altitude of the top of the aquifer ranges from about 50 feet below sea level in the northeast to about 75 feet below sea level in the southwest (fig. 3). Its thickness averages about 100 feet, increasing slightly in thickness to the southwest. Generally, clayey materials above and below the aquifer confine it; however, many lateral facies changes within the stratigraphic units result in local hydraulic connection between overlying or underlying aquifers. The Tamiami-upper Hawthorn aquifer, or parts of it, has also been referred to as "artesian zones 1 and 2" (Sutcliffe, 1975; Joyner and Sutcliffe, 1976) and "first artesian aquifer" (Clark, 1964).

The configuration of the potentiometric surface of the Tamiami-upper Hawthorn aquifer is shown in figure 3. The altitude of the potentiometric surface ranges from about 10 feet above sea level near the coast to 30 feet above sea level in the northeast. Water generally flows from the northeast to the west and southwest.

The Tamiami-upper Hawthorn aquifer is recharged by downward leakage from the overlying surficial aquifer, upward leakage from the underlying lower Hawthorn-upper Tampa aquifer, and ground-water inflow from adjacent areas to the northwest. Downward leakage from the surficial aquifer recharges the Tamiami-upper Hawthorn aquifer except in the southern and central parts of the study area where the Tamiami-upper Hawthorn aquifer discharges through upward leakage to the surficial aquifer because the potentiometric surface is higher than the water table. The water table of the surficial aquifer generally is zero to 10 feet higher than the Tamiami-upper Hawthorn aquifer (fig. 2). Recharge from the lower Hawthorn-upper Tampa aquifer to the Tamiami-upper Hawthorn aquifer is areawide. The potentiometric surface of the Tamiami-upper Hawthorn aquifer is generally 5 to 10 feet lower than the potentiometric surface of the lower Hawthorn-upper Tampa aquifer (fig. 3).

The hydraulic properties of the Tamiami-upper Hawthorn aquifer are more closely related to its lithology and to solution development within limestone and dolomite units than to variation in the aquifer's thickness. Data from an aquifer test are shown in table 2. Transmissivity was 800 ft^2/d, storage coefficient was $1x10^{-4}$, and leakage coefficient was $2x10^{-4}$ (ft/d)/ft.

The Tamiami-upper Hawthorn aquifer is the most highly developed aquifer in the coastal area. It supplies most of the water for domestic and irrigation use. Also, public-supply wells near Venice tap the aquifer.

Water in the Tamiami-upper Hawthorn aquifer is generally of acceptable quality for potable use, except near the coast. The chemical quality of water from wells that penetrate the aquifer may vary greatly depending in part upon the permeability of the aquifer. Water flows relatively fast through permeable zones such as fractures and solutional features. Water flows more slowly through less permeable parts of the aquifer and is in contact longer with soluble minerals; thus, water-quality characteristics differ.

The approximate regional distribution of selected chemical constituents in water from the Tamiami-upper Hawthorn aquifer is shown in figure 4. Dissolved-solids concentrations range from less than 500 mg/L in the northeast to more than 1,000 mg/L along the coast. Chloride concentrations range from

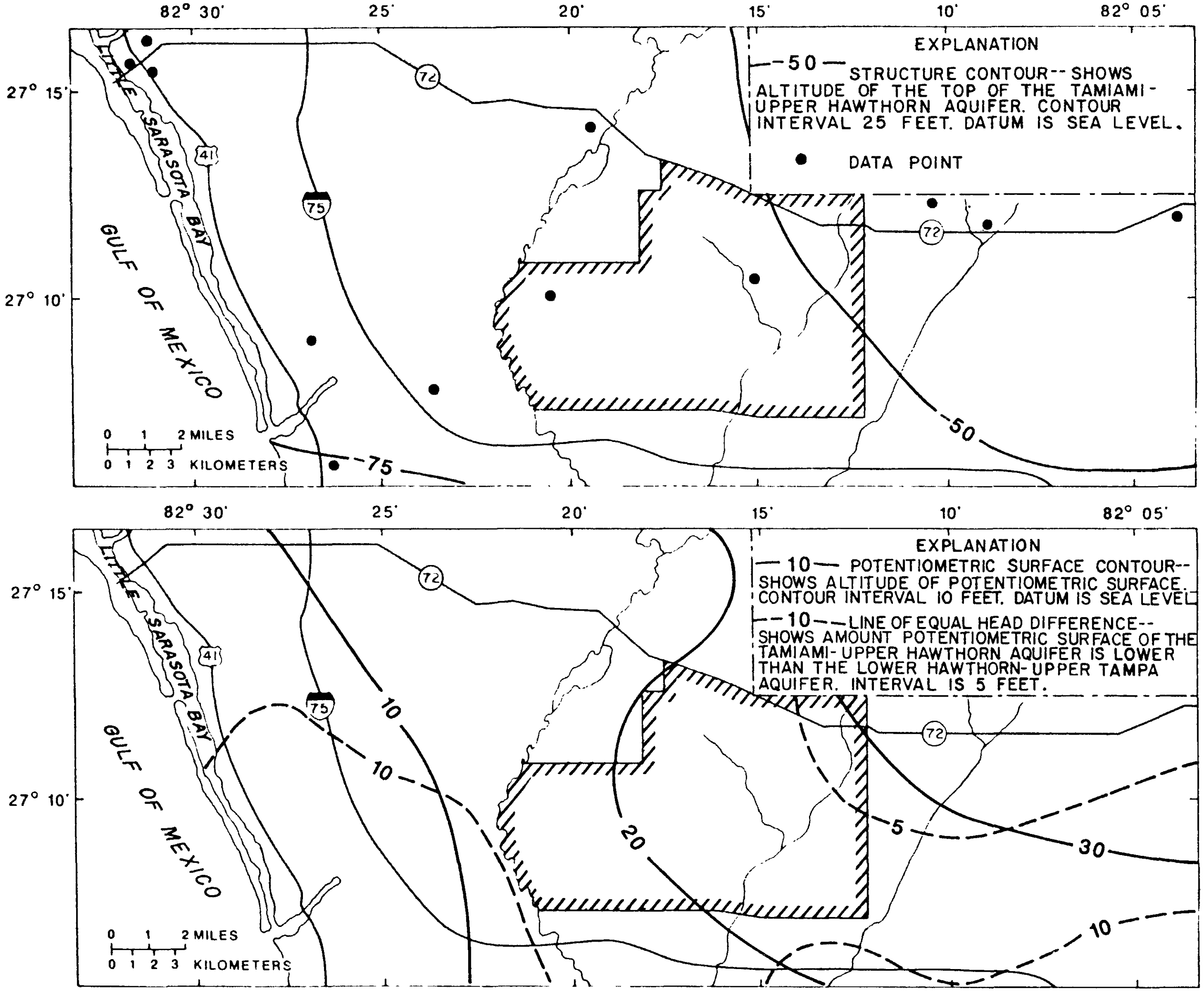
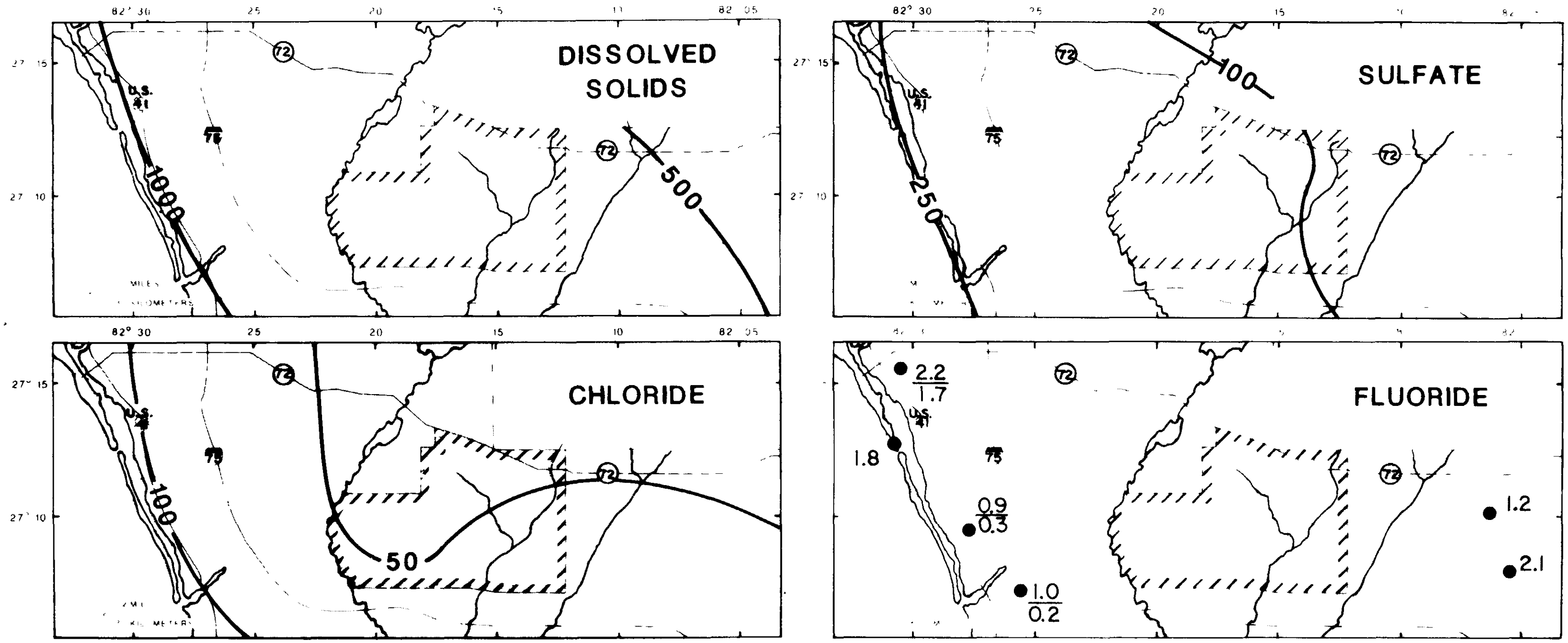


Figure 3.--Altitude of the top and altitude of the potentiometric surface of the Tamiami-upper Hawthorn aquifer and head difference between the aquifer and the underlying lower Hawthorn-upper Tampa aquifer (modified from Wolansky, 1983).



EXPLANATION

—— 50 ——

LINE OF EQUAL DISSOLVED SOLIDS, CHLORIDE, OR SULFATE CONCENTRATION IN MILLIGRAMS PER LITER. INTERVALS VARY

● 1.0 MAXIMUM
0.2 MINIMUM

NUMBER INDICATES MAXIMUM AND MINIMUM FLUORIDE CONCENTRATION IN MILLIGRAMS PER LITER. A SINGLE NUMBER INDICATES ONE SAMPLE

Figure 4.--Concentrations of dissolved solids, chloride, sulfate, and fluoride in water from the Tamiami-upper Hawthorn aquifer (modified from Wolansky, 1983).

less than 50 mg/L in the northeast to more than 100 mg/L near the coast. Sulfate concentrations range from less than 100 mg/L in the east to more than 250 mg/L near the coast. Fluoride concentrations range from 0.2 to 2.2 mg/L.

Lower Hawthorn-Upper Tampa Aquifer

The lower Hawthorn-upper Tampa aquifer is the lowermost intermediate aquifer. The aquifer consists of permeable limestone and dolomite beds in the lower part of the Hawthorn Formation and upper parts of the Tampa Limestone. The altitude of the top of the aquifer ranges from about 190 to 220 feet below sea level, decreasing in altitude from north to south (fig. 5). Its thickness ranges from about 200 feet in the north to 250 feet in the south.

The top of the lower Hawthorn-upper Tampa aquifer is generally below the beds of clayey limestone and dolomite that occur near the middle of the Hawthorn Formation. Beneath the aquifer is generally a unit that is comprised of clayey sand and sandy clay that occurs 50 to 100 feet below the top of the Tampa Formation. The lower Hawthorn-upper Tampa aquifer has also been called "lower Hawthorn aquifer" (Sproul and others, 1972) and "artesian zone 3" (Sutcliffe, 1975; Joyner and Sutcliffe, 1976). The general shape of the potentiometric surface of the lower Hawthorn-upper Tampa aquifer is shown in figure 5. The altitude of the potentiometric surface ranges from less than 10 feet above sea level in the northwestern coastal area to about 35 feet above sea level in the east. Water in the aquifer generally flows from east to west.

The aquifer is recharged by upward leakage from the underlying Floridan aquifer system and by ground-water inflow from adjacent areas. Discharge from the lower Hawthorn-upper Tampa aquifer to the overlying Tamiami-upper Hawthorn aquifer occurs throughout the study area. The head difference between these two aquifers ranges from 5 to about 10 feet (fig. 3).

Hydraulic properties from two aquifer tests of wells that penetrate sections of the lower Hawthorn-upper Tampa aquifer are shown in table 2. Computed transmissivities were 2,500 and 9,000 ft^2/d, storage coefficients were $1x10^{-4}$ and $1.2x10^{-4}$, and leakage coefficients were $1x10^{-4}$ and $1.3x10^{-4}$ (ft/d)/ft. The transmissivity of a third well that was open to both the Tamiami-upper Hawthorn and lower Hawthorn-upper Tampa aquifers was 2,740 ft^2/d.

Water from wells that tap the lower Hawthorn-upper Tampa aquifer is generally of potable quality, except in the coastal area. Concentrations of dissolved solids in water from the aquifer are less than 500 mg/L in the northeast and increase to more than 2,000 mg/L near the coast (fig. 6). Chloride concentrations range from about 50 to 1,000 mg/L, with concentrations more than 250 mg/L occurring near the coast. Sulfate concentrations range from 250 to 500 mg/L. Concentrations greater than 250 mg/L are limited to coastal areas and to an area in central-northeastern Sarasota County. Fluoride concentrations vary areally and vertically and range from 0.8 to 2.6 mg/L.

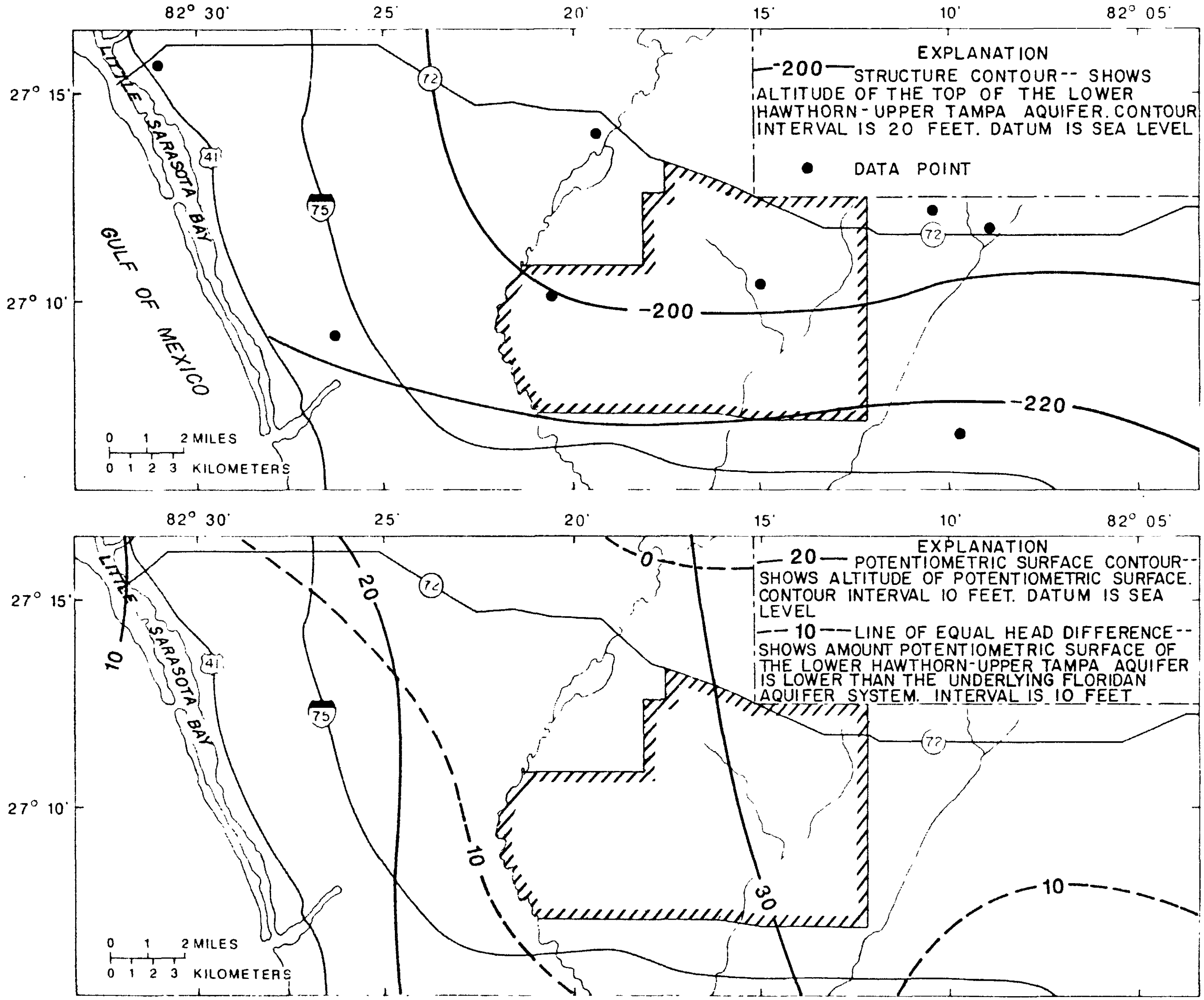


Figure 5.--Altitude of the top of and altitude of the potentiometric surface of the lower Hawthorn-upper Tampa aquifer and head difference between the aquifer and the underlying Floridan aquifer system (modified from Wolansky, 1983).

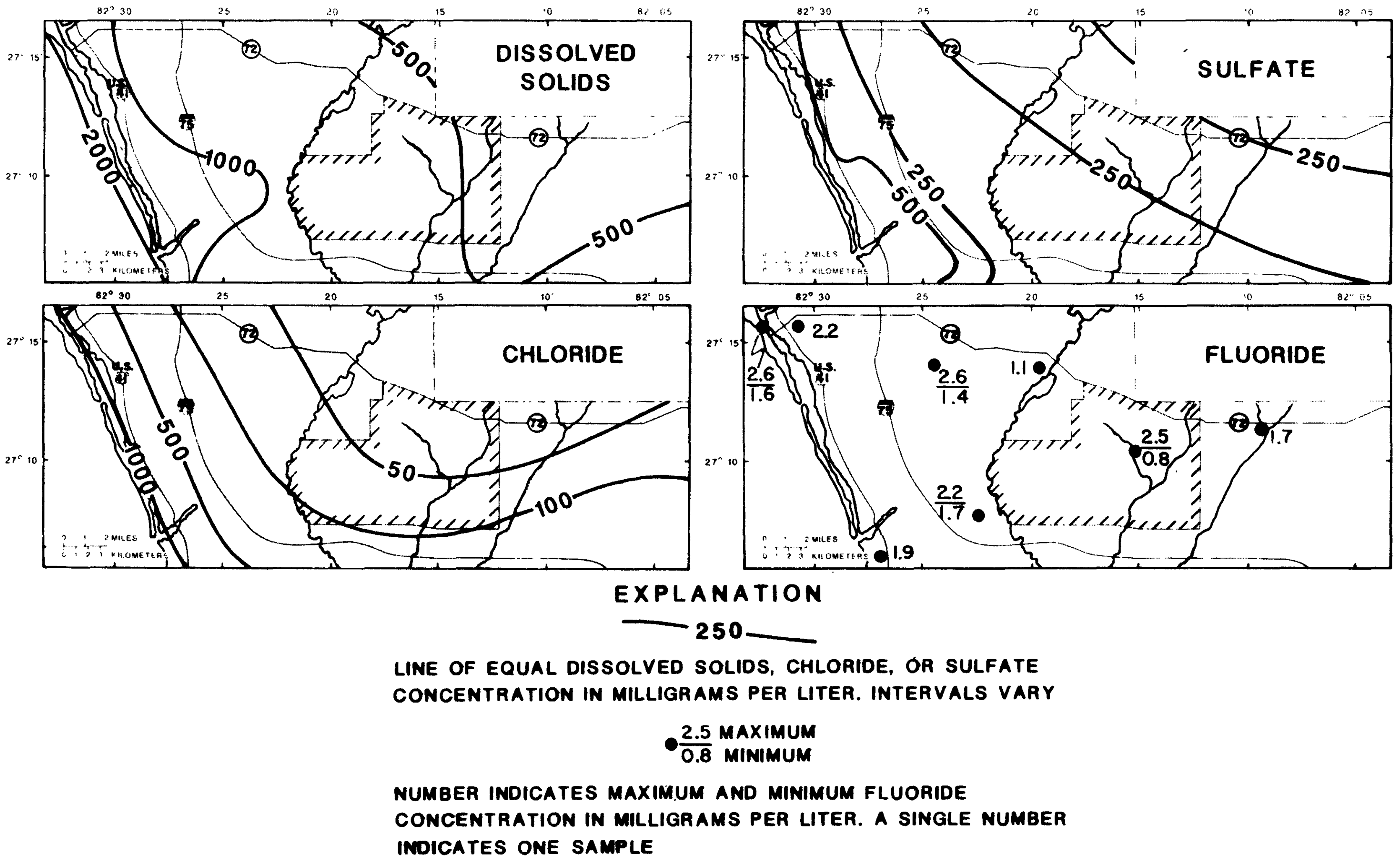


Figure 6.--Concentrations of dissolved solids, chloride, sulfate, and fluoride in water from the lower Hawthorn-upper Tampa aquifer (modified from Wolansky, 1983).

HYDROGEOLOGY OF THE RINGLING-MACARTHUR RESERVE

The Ringling-MacArthur Reserve encompasses approximately 51 mi^2 in the central part of the study area (figs. 1 and 7). The Reserve consists of broad flatlands with many sloughs and swampy areas. Land-surface altitudes range from about 10 feet above sea level along the Myakka River to almost 35 feet along the northeastern boundary. Principal drainage is by the Myakka River and Deer Prairie Slough. Discharge of the Myakka River averaged 254 ft^3/s for 47 years of record (1937-84). The stream is measured at a site slightly upstream from the Reserve (fig. 1). Discharge at a gage on Deer Prairie Slough that drains the eastern part of the Reserve (total drainage area 33.2 mi^2) averaged 32.5 ft^3/s in 1982 and 43.7 ft^3/s in 1983, the 2 years for which record is available. The slough is an intermittent stream and was completely dry during the winter of 1984-85. Another small stream, Big Slough, drains the extreme southeastern part of the Reserve (fig. 1). Its total drainage area is 36.5 mi^2, and average discharges during 1982 and 1983 were 44.6 and 56.7 ft^3/s, respectively.

The depth to the water table in the surficial aquifer ranges areally from land surface to about 4 feet below land surface. Seasonal fluctuations in the water table are generally within a 3-foot range (fig. 8). Water levels in two representative wells in figure 8 show that the water table is generally higher than the potentiometric surface of the Tamiami-upper Hawthorn aquifer in the western part of the Reserve and lower in the eastern part. The water table is at or near land surface for several months during the wet season. The depth to the water table at a relatively wet period during the dry season (February 1-3, 1984) is shown in figure 9. The water table ranged from land surface in the east to about 2 feet below land surface in the south and west. Figure 10 shows the depth to the water table during a drier period (May 29-31, 1984). Water levels were generally about 1 to 2 feet lower in May than in February and ranged from land surface in the east to about 4 feet below land surface in the north.

Figure 11 shows the altitude of the top of the first clay. The top ranges from 15 feet below sea level in the extreme east to about 25 feet above sea level in the northeast. Figure 12 shows the thickness of the surficial deposits overlying the first clay. The thickness ranges from about 5 feet in the northeast to about 50 feet in the northwest. In some areas, surficial sand deposits underlie the first clay layer. These deposits are part of the surficial aquifer and contribute to the yield of the aquifer. Table 3 shows data for the 51 surficial-aquifer test wells drilled to the first occurrence of clay. Many of the wells were originally drilled to depths greater than those shown in table 3.

The stratigraphic and hydrogeologic units, lithology, and concentrations of chloride and sulfate for water from wells 19E and 19W are shown in figures 13 and 14, respectively. Generally, the concentrations of sulfate in water from the Floridan aquifer system are higher than recommended limits, whereas sulfate concentrations in water from the intermediate and surficial aquifers are generally within recommended limits.

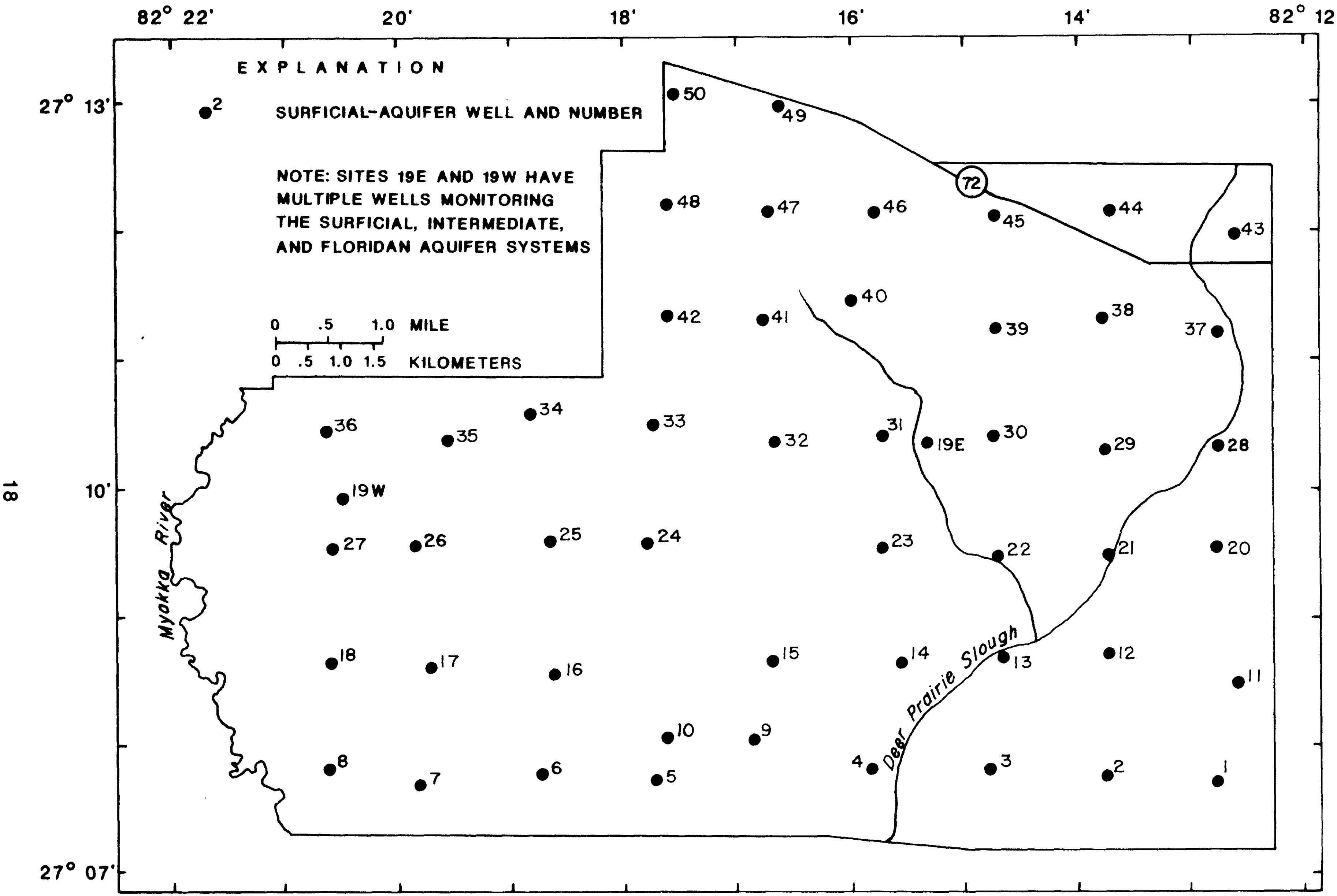


Figure 7.--Location of wells and streams in the Ringling-MacArthur Reserve.

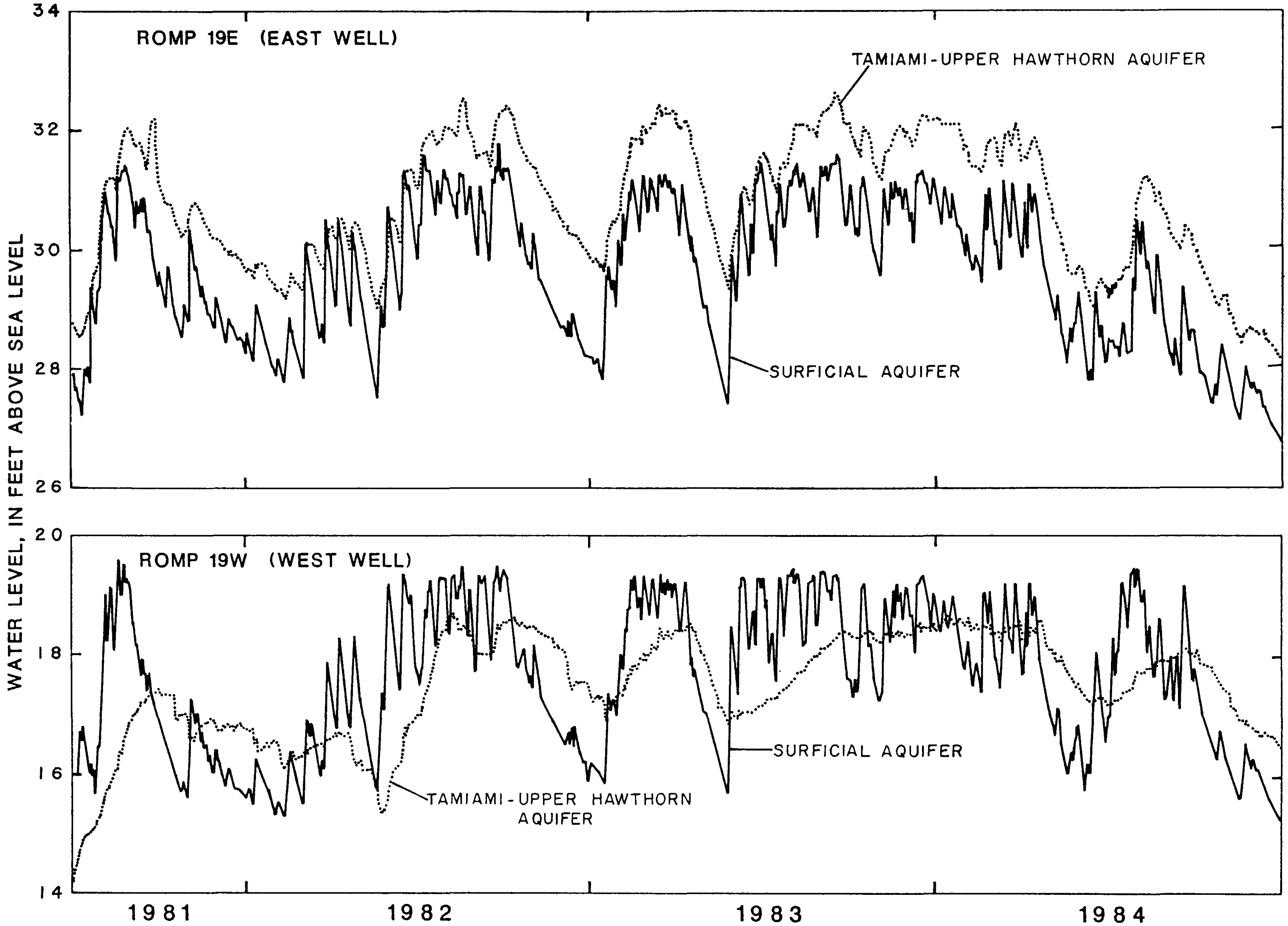


Figure 8.--Water levels in ROMP wells 19E and 19W.

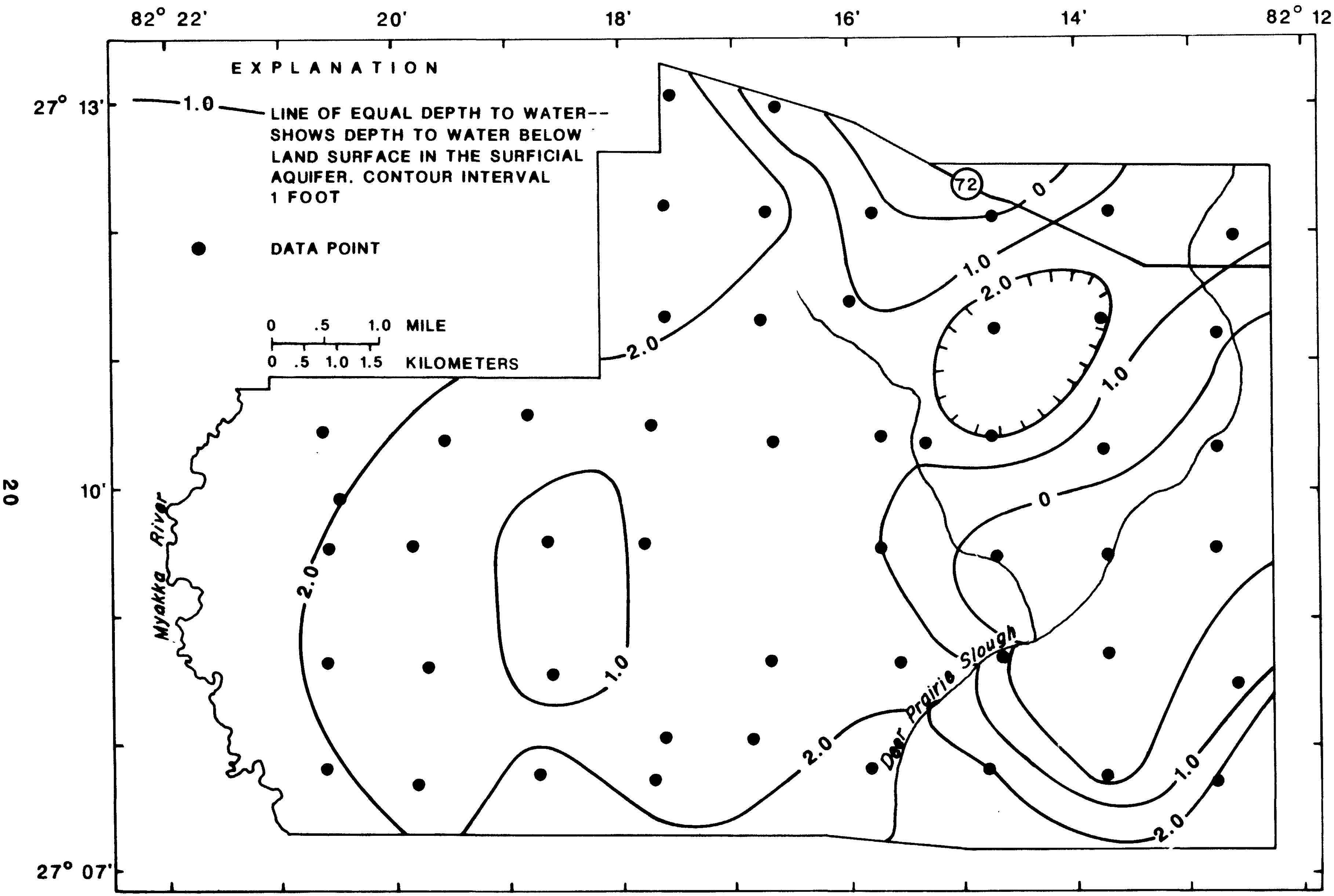


Figure 9.--Depth to water in the surficial aquifer, February 1-3, 1984, Ringling-MacArthur Reserve.

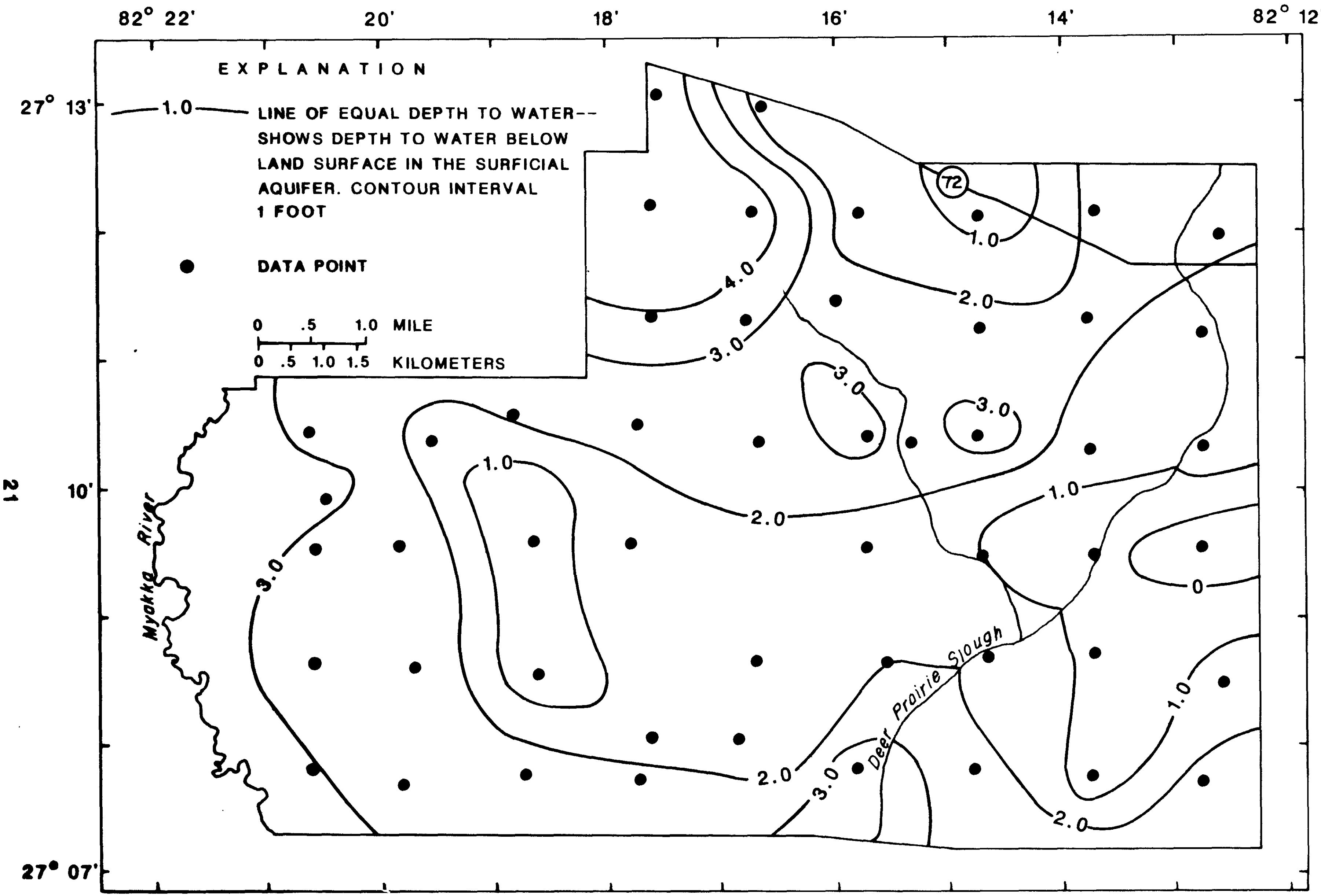


Figure 10.--Depth to water in the surficial aquifer, May 29-31, 1984, Ringling-MacArthur Reserve.

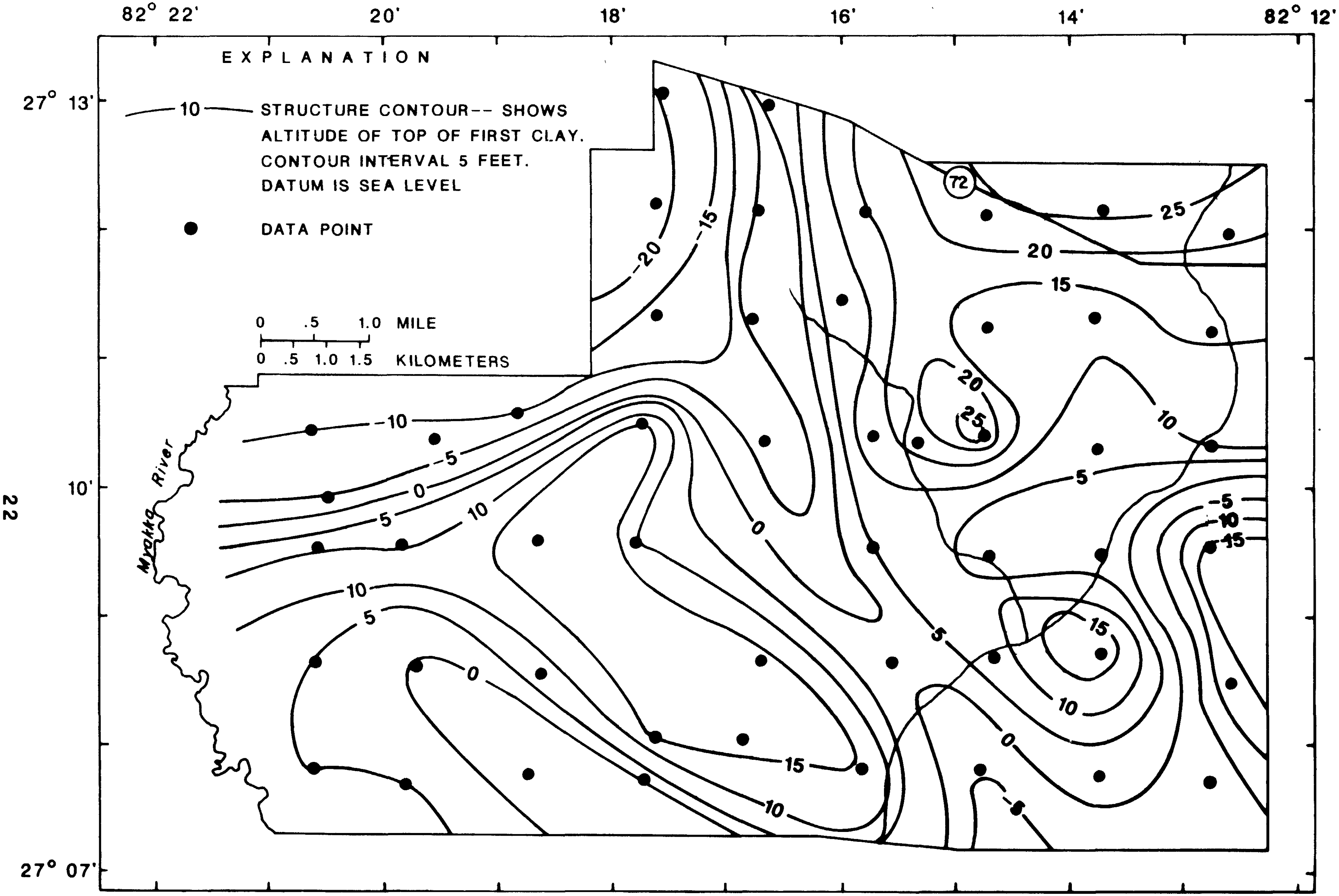


Figure 11.--Altitude of the top of the first clay, Ringling-MacArthur Reserve.

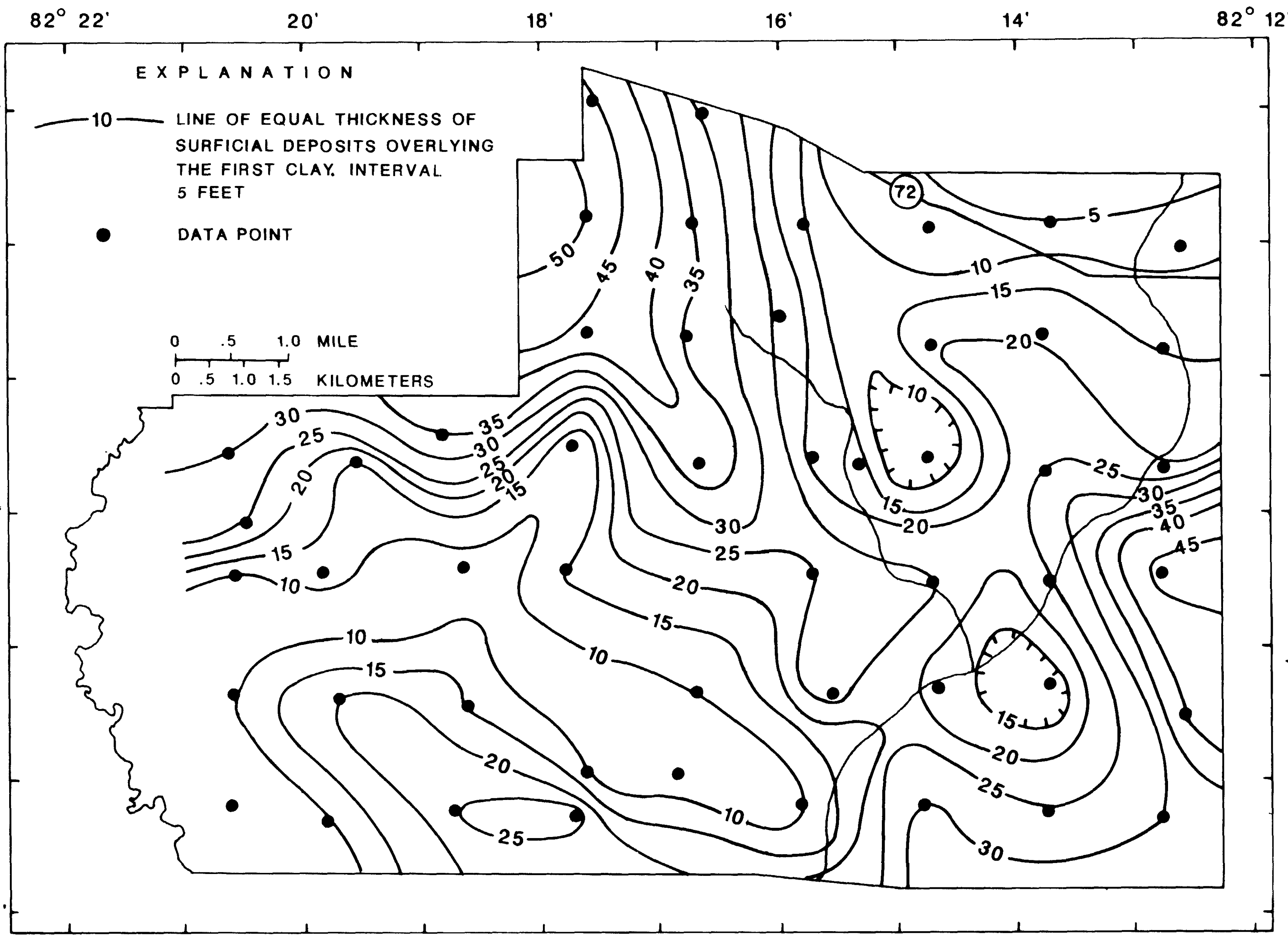


Figure 12.--Thickness of surficial deposits overlying the first clay, Ringling-MacArthur Reserve.

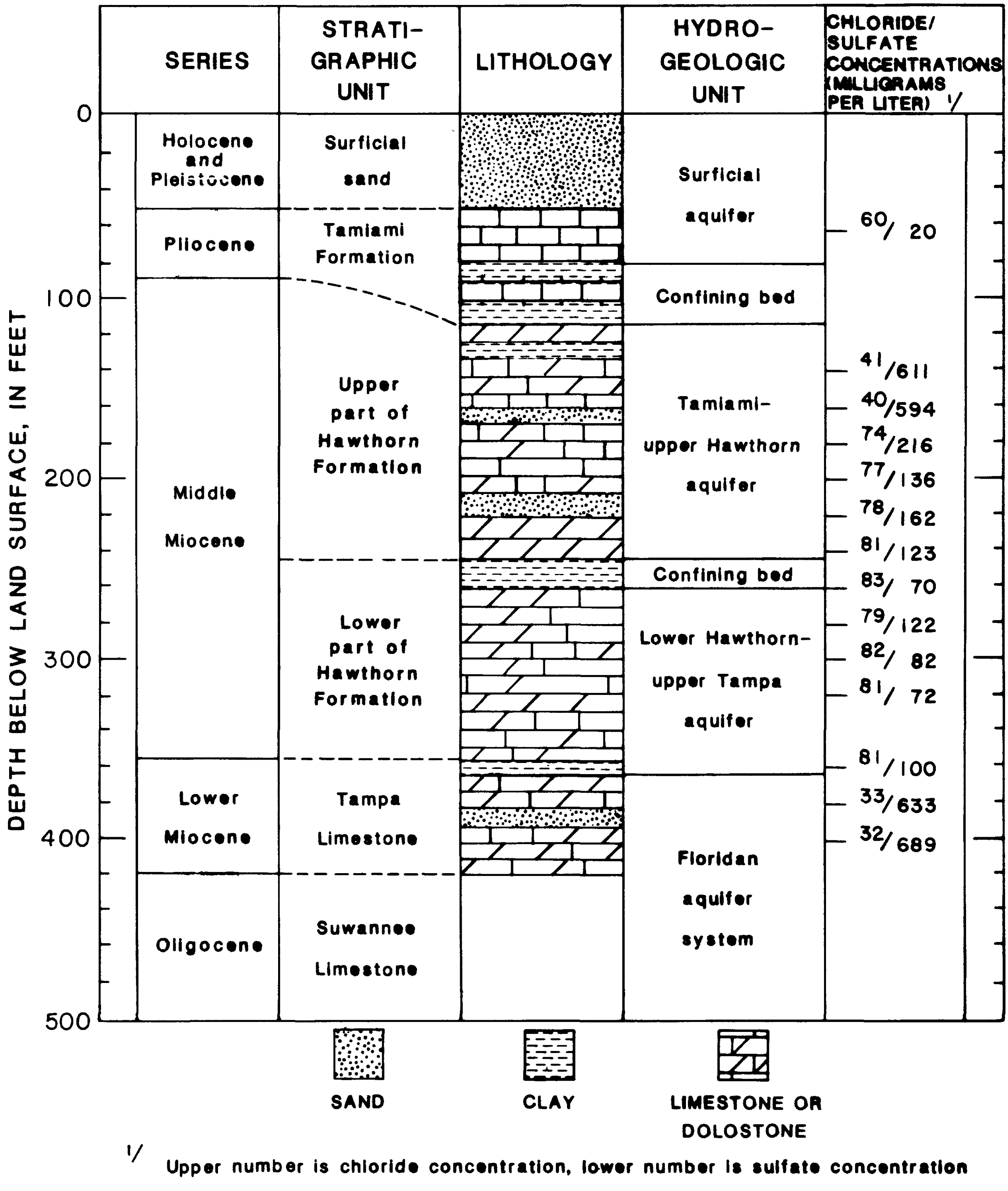


Figure 13.--Hydrogeologic section and chloride and sulfate concentrations of water obtained during drilling of well 19W.

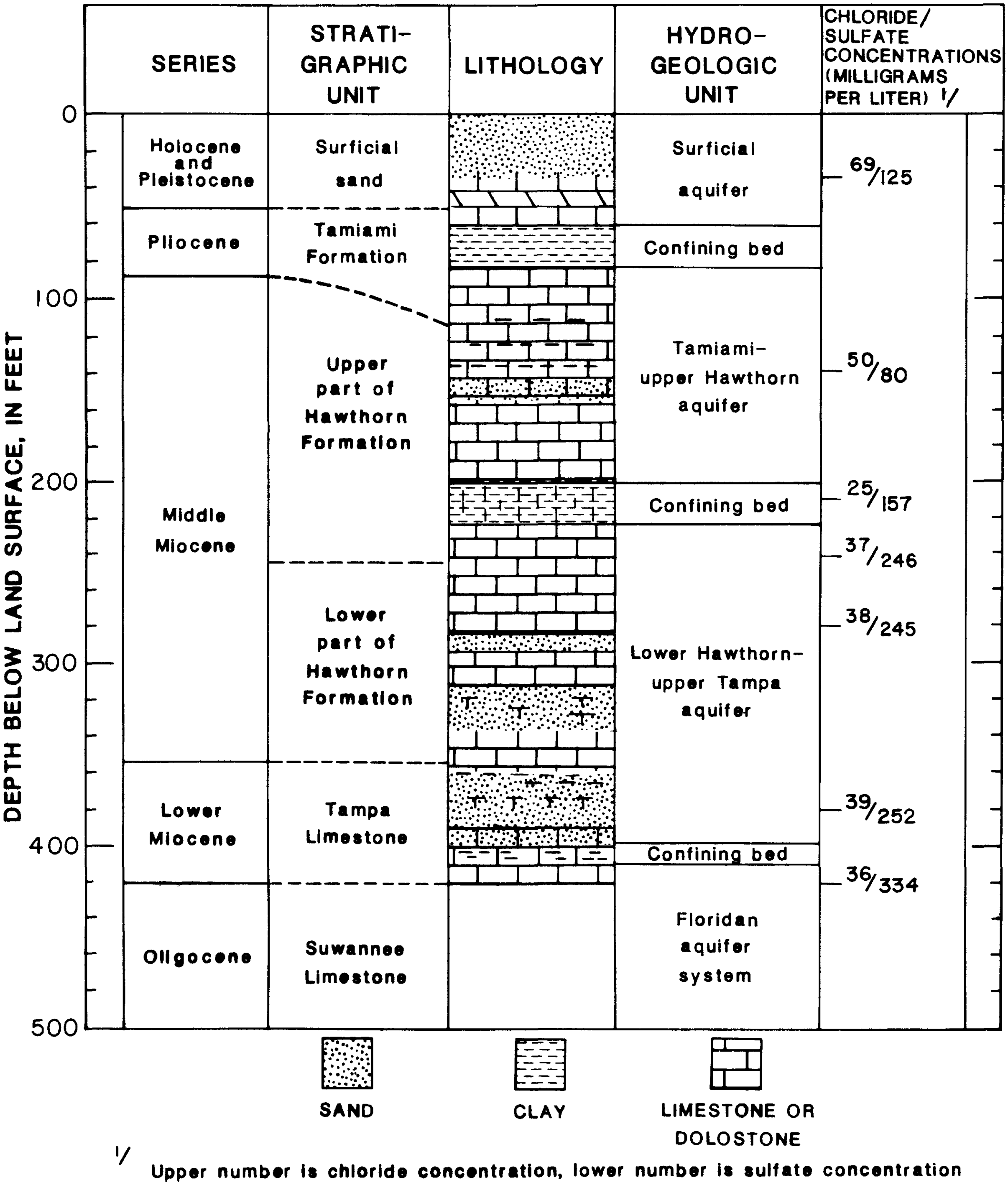


Figure 14.--Hydrogeologic section and chloride and sulfate concentrations of water obtained during drilling of well 19E.

Table 3.--Records of wells in the Ringling-MacArthur Reserve

[Well yield, in gallons per minute, good indicates 1 gallon per minute and poor indicates 1 gallon per minute; first clay, top of first clay, in feet above (+) or below (-) sea level (SL); ALT LSD, altitude of land surface, in feet; ALT MP, altitude of measuring point, in feet; well depth, all wells screened from bottom of casing to bottom of hole except for wells WLAM, WUAM, ELAM, and EUAM]

Well (fig. 7)	ID number	Local number	Well depth (ft)	Casing Depth (ft)	Casing Diameter (in.)	Well yield	First clay	ALT LSD
1	270742082124601	18-33	35	30	2	good	-1	29.0
2	270742082134601	15-32	25	20	2	--	+1	26.0
3	270752082144401	15-31	23	18	2	--	-5	25.0
4	270752082154401	11-36	20	5	2	4	+15	25.0
5	270746082174001	7-34	11	6	2	5	0	25.0
6	270748082184401	7-33	22	17	2	5	-2	23.0
7	270744082194901	3-32	10	5	2	1	+5	15.0
8	270751082203801	3-31	10	5	2	poor	+5	10.0
9	270807082164701	11-35	10	5	2	--	+16	25.0
10	270807082173301	7-27	15	10	2	3	+15	25.0
11	270828082123301	18-28	48	43	2	poor	-14	26.0
12	270840082134401	15-29	18	13	2	good	+17	29.0
13	270838082143901	15-30	18	13	2	poor	+6	25.0
14	270839082152901	11-25	26	21	2	poor	+2	29.0
15	270842082163901	11-26	23	18	2	1	+16	26.0
16	270832082183801	7-28	13	8	2	--	+7	22.0
17	270838082194301	3-29	16	11	2	3	0	20.0
18	270839082203701	3-30	9	4	2	2	+5	15.0
19W	270959082203001	WLAM	425	410	4	--	--	20.0
19W	270959082203002	WUAM	205	87	18	--	--	20.0
19W	270959082203003	WS	67	32	6	--	+5	20.0
19E	271021082151601	ELAM	419	410	4	--	--	31.0
19E	271021082151602	EUAM	121	80	18	--	--	31.0
19E	271021082151603	ES	35	15	6	--	+16	31.0
20	270932082124601	17-21	42	37	2	good	-16	30.0
21	270929082134101	14-20	29	24	2	good	+2	27.0
22	270926082144201	14-19	12	7	2	--	+3	28.0
23	270934082154101	10-24	20	15	2	4	+5	30.0
24	270934082174401	6-22	18	12	2	poor	+10	25.0
25	270936082183801	6-21	9	4	2	1	+17	25.0

Table 3.--Records of wells in the Ringling-MacArthur Reserve--Continued

Well (fig. 7)	ID number	Local number	Well depth (ft)	Casing Depth (ft)	Casing Diameter (in.)	Well yield	First clay	Alt LSD
26	270932082195201	2-20	11	6	2	poor	+9	22.0
27	270933082203601	2-19	13	8	2	poor	+10	20.0
28	271019082124701	17-16	21	16	2	4	+10	30.0
29	271018082134601	14-17	24	20	2	good	+7	32.0
30	271025082144401	14-18	13	8	2	poor	+25	30.0
31	271024082154101	10-13	14	9	2	--	+12	30.0
32	271021082163901	10-14	25	20	2	--	-8	30.0
33	271028082174101	6-15	13	9	2	poor	+15	28.0
34	271035082185001	6-16	22	17	2	--	-10	25.0
35	271023082193701	2-17	13	8	2	4	-7	22.0
36	271026082204001	2-18	21	16	2	1	-10	20.0
37	271111082125101	16-9	24	19	2	10	+16	30.0
38	271117082134701	13-8	20	15	2	5	+11	30.0
39	271116082144401	13-7	20	15	2	2	+12	31.0
40	271127082155701	9-12	24	19	2	--	+6	30.0
41	271117082164401	9-11	32	27	2	poor	-4	30.0
42	271121082173501	5-10	34	24	2	good	-14	30.0
43	271152082123701	16-4	29	19	2	--	+22	30.0
44	271208082134401	13-5	14	9	2	poor	+26	31.0
45	271205082144501	13-6	14	9	2	3	+24	30.0
46	271207082154301	9-1	24	19	2	good	+15	31.0
47	271208082164201	9-2	35	25	2	--	-5	30.0
48	271212082173501	5-3	49	39	2	--	-24	25.0
49	271301082163801	8-35	20	15	2	--	+1	30.0
50	271303082173401	4-34	48	32	2	--	-19	25.0

Table 3.--Records of wells in the Ringling-MacArthur Reserve--Continued

Well (fig. 7)	Date measured	ALT MP	Water level, in feet below or above (+) MP	LSD	SL	Remarks
1	2-03-84	32.5	5.7	2.2	+26.8	
	5-30-84	32.5	6.0	2.5	+26.5	
2	2-03-84	29.7	3.6	+ .1	+26.1	
	5-30-84	29.7	3.9	.2	+25.8	Standing water 0.2 ft above LSD.
3	2-03-84	27.6	4.6	2.0	+23.0	
	5-30-84	27.6	5.2	2.6	+22.4	
4	2-03-84	28.1	5.6	2.5	+22.5	
	5-30-84	28.1	6.6	3.5	+21.5	
5	2-03-84	27.9	4.7	1.8	+23.2	
	5-30-84	27.9	5.0	2.1	+22.9	
6	2-03-84	25.9	5.4	2.5	+20.5	
	5-30-84	25.9	5.4	2.5	+20.5	
7	2-03-84	16.2	1.4	.2	+14.8	
	5-30-84	16.2	1.4	.2	+14.8	
8	2-03-84	13.5	5.7	2.2	+7.8	
	5-30-84	13.5	6.6	3.1	+6.9	
9	2-03-84	26.8	3.3	1.5	+23.5	
	5-30-84	26.8	3.0	1.2	+23.8	
10	2-03-84	27.7	4.2	1.5	+23.5	
	5-30-84	27.7	4.2	1.5	+23.5	
11	2-03-84	28.6	3.4	.8	+25.2	
	5-30-84	28.6	3.9	1.3	+24.7	
12	2-03-84	32.3	3.5	.2	+28.8	Standing water 0.1 ft above LSD.
	5-30-84	32.3	4.2	.9	+28.1	
13	2-03-84	27.8	2.7	+ .1	+25.1	Standing water 0.3 ft above LSD.
	5-30-84	27.8	4.2	1.4	+23.6	
14	2-03-84	31.1	3.6	1.5	+27.5	
	5-30-84	31.1	4.1	2.0	+27.0	
15	2-03-84	28.8	4.6	1.7	+24.2	
	5-30-84	28.8	5.6	2.7	+23.2	
16	2-03-84	25.4	3.8	.4	+21.6	At edge of pond.
	5-30-84	25.4	3.4	0	+22.0	

Table 3.--Records of wells in the Ringling-MacArthur Reserve--Continued

Well (fig. 7)	Date measured	ALT MP	Water level, in feet below or above (+) MP	LSD	SL	Remarks
17	2-02-84	23.2	5.1	1.9	+18.1	
	5-31-84	23.3	5.8	2.5	+17.5	Casing repaired, new MP.
18	2-02-84	18.4	4.7	1.3	+13.7	
	5-31-84	18.7	6.0	2.3	+12.7	Casing repaired, new MP.
19W	--	32.5	-	-	--	SWFWMD ROMP well.
19W	--	32.5	-	-	--	SWFWMD ROMP well.
19W	2-15-84	22.9	5.1	2.2	+17.8	SWFWMD ROMP well.
	5-29-84	22.9	6.4	3.5	+16.5	
19E	--	40.0	-	-	--	SWFWMD ROMP well.
19E	--	39.8	-	-	--	SWFWMD ROMP well.
19E	2-01-84	34.3	4.4	1.1	+29.9	SWFWMD ROMP well.
	5-29-84	34.3	5.4	2.1	+28.9	
20	2-01-84	36.2	5.9	+ .3	+30.3	Standing water 0.5 ft above LSD.
	5-30-84	36.2	5.9	+ .3	+30.3	
21	2-01-84	30.5	-	-	--	Could not locate.
	5-30-84	30.5	3.6	.1	+26.9	Wet area.
22	2-01-84	31.3	2.7	+ .6	+28.6	Standing water 0.6 ft above LSD.
	5-27-84	33.5	6.3	.8	+27.2	Casing repaired, new MP.
23	2-03-84	30.0	1.0	1.0	+29.0	
	5-30-84	32.7	4.4	1.7	+28.3	Casing repaired, new MP.
24	2-02-84	28.1	4.7	1.6	+23.4	
	5-31-84	28.1	4.9	1.8	+23.2	
25	2-02-84	28.0	3.6	.6	+24.4	Never cleared up.
	5-31-84	28.0	3.4	.4	+24.6	
26	2-02-84	24.3	4.0	1.7	+20.3	
	5-31-84	24.3	4.9	2.6	+19.4	
27	2-02-84	23.1	3.9	.8	+19.2	
	5-31-84	23.1	5.2	2.1	+17.9	
28	2-01-84	33.5	4.3	.8	+29.2	
	5-30-84	33.5	4.9	1.4	+28.6	
29	2-01-84	35.4	3.7	.3	+31.7	Standing water 0.5 ft above LSD.
	5-29-84	35.4	4.9	1.5	+30.5	

Table 3.--Records of wells in the Ringling-MacArthur Reserve--Continued

Well (fig. 7)	Date measured	ALT MP	Water level, in feet below or above (+) MP	LSD	SL	Remarks
30	2-01-84	32.4	4.5	2.1	+27.9	
	5-29-84	32.4	5.7	3.3	+26.7	
31	2-02-84	32.9	4.9	2.0	+28.0	
	5-29-84	32.9	6.3	3.4	+26.6	
32	2-02-84	34.1	5.2	1.1	+28.9	
	5-29-84	34.1	6.9	2.8	+27.2	
33	2-02-84	31.0	4.4	1.4	+26.6	
	5-31-84	31.0	5.6	2.6	+25.4	
34	2-02-84	27.9	4.7	1.8	+23.2	
	5-31-84	27.9	5.0	2.1	+22.9	
35	2-02-84	24.8	4.4	1.6	+20.4	
	5-31-84	24.8	4.2	1.4	+20.6	
36	2-02-84	22.9	5.1	2.2	+17.8	Pumped for 60 minutes.
	5-31-84	22.9	5.7	2.8	+17.2	
37	2-01-84	32.1	2.0	+ .1	+30.1	Standing water 0.5 ft above LSD.
	5-30-84	32.1	2.3	.2	+29.8	
38	2-01-84	32.3	4.4	2.1	+27.9	
	5-29-84	32.3	4.6	2.3	+27.7	
39	2-01-84	32.2	4.8	2.6	+27.4	
40	2-02-84	32.6	3.7	1.1	+28.9	
	5-29-84	33.7	6.3	2.6	+27.4	
41	2-02-84	32.8	4.2	1.4	+28.6	
	5-29-84	32.8	5.9	3.1	+26.9	
42	2-02-84	33.5	5.7	2.2	+27.8	
	5-29-84	33.5	7.5	4.0	+26.0	
43	2-01-84	32.4	3.9	1.5	+28.5	Pitcher pump on well.
	5-29-84	32.4	5.2	2.8	+27.2	
44	2-06-84	33.8	4.6	1.8	+29.2	
	5-29-84	33.8	5.0	2.2	+28.8	
45	2-01-84	32.6	2.6	0	+30.0	Standing water 0.2 ft above LSD.
	5-29-84	32.6	2.9	.3	+29.7	
46	2-02-84	33.6	2.8	.2	+30.8	
	5-29-84	33.6	4.0	1.4	+29.4	
47	2-02-84	33.8	6.8	3.0	+27.0	
	5-29-84	33.8	8.2	4.4	+25.6	

Table 3.--Records of wells in the Ringling-MacArthur Reserve--Continued

Well (fig. 7)	Date measured	ALT MP	Water level, in feet below or above (+)			Remarks
			MP	LSD	SL	
48	2-02-84	27.0	4.1	2.1	+22.9	
	5-29-84	27.0	6.1	4.1	+20.9	
49	2-02-84	33.4	3.6	.2	+29.8	
	5-29-84	33.4	5.2	1.8	+28.2	
50	2-02-84	27.7	5.3	2.6	+22.4	
	5-29-84	27.7	7.2	4.5	+20.5	

Concentrations of chemical constituents in water from the surficial aquifer within the Ringling-MacArthur Reserve are shown in table 4. Concentrations of dissolved solids range from 82 (well 17) to 1,090 mg/L (well 21). Most concentrations are between 200 and 500 mg/L. Concentrations of chloride range from 13 (wells 15 and 24) to 220 mg/L (well 25). Most concentrations are between 25 and 50 mg/L. Concentrations of sulfate range from zero (well 40) to 430 mg/L (well 21). Concentrations are generally less than 15 mg/L. Concentrations of fluoride range from zero (well 17) to 1.4 mg/L (well 47). Concentrations are generally less than 0.5 mg/L in the western half of the area and greater than 0.5 mg/L in the rest of the area. Concentrations of hardness range from 25 (well 17) to 704 mg/L (well 21). Most concentrations are between 100 and 300 mg/L.

SUMMARY

The study area in central Sarasota County encompasses approximately 300 mi^2. The average annual rainfall for the area is 56.0 inches. About 60 percent of the rainfall occurs from June through September. The evapotranspiration rate is about 42 in/yr.

The hydrogeologic framework of the central Sarasota County potable aquifers consists of the surficial aquifer and intermediate aquifers (Tamiami-upper Hawthorn and lower Hawthorn-upper Tampa aquifers) and confining units. Geologic units that comprise the surficial aquifer and intermediate aquifers are the surficial deposits, undifferentiated Caloosahatchee Marl, Bone Valley Formation, the Tamiami and Hawthorn Formations, and parts of the Tampa Limestone that are not in hydraulic connection with the Floridan aquifer system. The artesian pressure of the various confined aquifers generally increases with depth.

The surficial aquifer saturated thickness ranges from about 40 to 75 feet. The altitude of the water table ranges from about zero to 10 feet near the coast to 40 feet in the northeast. For three aquifer tests, transmissivities ranged from 1,000 to 1,800 ft^2/d, and storage coefficients determined

Table 4.--Water-quality data for water from surficial-aquifer wells in the Ringling-MacArthur Reserve

[Concentrations are in milligrams per liter]

Well (fig. 7)	Well depth (ft)	Date sampled	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Hardness (as $CaCO_3$)	Dissolved solids
1	35	11-24-82	38	0.6	0.1	253	355
2	25	11-24-82	29	3.3	.7	257	397
3	23	11-24-82	92	8.6	.4	119	399
4	20	7-08-82	22	.6	.3	245	324
5	11	none	--	-	-	-	-
6	22	7-07-82	33	2.1	.2	184	328
7	10	7-07-82	23	15	.4	151	209
8	10	7-07-82	28	41	.5	-	432
9	10	7-08-82	20	.4	.3	258	344
10	15	7-08-82	51	2.1	.5	249	395
11	48	11-24-82	44	7.4	.4	284	407
12	18	11-22-82	30	.1	.7	102	258
13	18	11-22-82	82	280	.5	553	885
		2-01-83	80	280	.5	565	824
14	26	7-08-82	26	.2	.4	244	333
15	23	7-08-82	13	14	.2	237	302
		7-19-82	80	45	.5	416	640
16	13	7-07-82	37	.4	.2	279	420
17	16	7-07-82	22	2.4	0	25	82
18	9	7-07-82	110	54	.4	524	765
		2-03-83	160	150	.5	645	914
19E	35	6-14-82	62	110	.4	382	611
		5-05-83	62	110	.4	246	-
19W	67	2-18-82	56	.1	.4	276	439
20	42	8-26-82	59	45	.5	296	438
21	29	11-22-82	70	430	.8	704	1,090
22	12	7-19-82	29	2.4	.8	161	270
23	20	7-19-82	69	1.8	.4	239	476
24	18	6-30-82	13	4.8	.4	27	97
25	9	2-03-83	220	3.8	.6	286	750
26	11	7-06-82	61	1.4	.2	135	363
27	13	7-06-82	25	2.8	.3	134	221
28	21	8-26-82	38	2.0	.5	180	334
29	24	2-01-83	31	.8	.7	43	159
30	13	7-19-82	45	1.8	.4	94	378

Table 4.--Water-quality data for water from surficial aquifer wells in the Ringling-MacArthur Reserve--Continued

Well (fig. 7)	Well depth (ft)	Date sampled	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Hardness (as $CaCO_3$)	Dissolved solids
31	14	7-19-82	25	16	0.2	37	-
32	25	7-19-82	20	180	.3	239	398
33	13	6-30-82	49	120	.2	209	439
34	22	7-06-82	15	3.6	.4	105	186
35	13	7-06-82	17	.2	.2	191	274
36	21	7-06-82	40	1.5	.4	98	269
37	24	2-01-83	40	.8	.6	142	312
38	20	7-12-82	24	.2	1.0	46	132
39	20	7-12-82	47	.2	1.3	127	296
40	24	6-30-82	15	0	.6	194	247
42	34	6-29-82	45	7.0	.4	115	261
43	29	7-12-82	120	78	.7	374	676
		2-01-83	120	77	.7	387	642
44	14	2-01-83	89	1.6	.8	107	320
45	14	7-12-82	86	1.5	.9	234	422
46	24	6-30-82	36	17	.5	292	406
47	35	6-29-82	16	.8	1.4	67	141
48	49	6-29-82	15	.6	.9	245	307
49	20	6-30-82	37	3.2	1.2	56	182
50	48	6-29-82	37	1.0	.9	304	404

from two tests were 1.5×10^{-1} and 1.9×10^{-1}. The concentrations of chloride, sulfate, and fluoride are generally within the U.S. Environmental Protection Agency's recommended standards, except near the coast.

The Tamiami-upper Hawthorn aquifer is the uppermost intermediate aquifer. The top of the aquifer ranges from about 50 feet below sea level in the northeast to about 75 feet below sea level in the southwest. Its thickness averages about 100 feet, increasing slightly to the southwest. The altitude of the potentiometric surface ranges from about 10 feet above sea level near the coast to about 30 feet above sea level in the northeast. Transmissivity was computed to be 800 ft^2/d, storage coefficient was 1×10^{-4}, and leakage coefficient was 2×10^{-4} (ft/d)/ft. Dissolved-solids concentrations range from less than 500 mg/L in the northeast to more than 1,000 mg/L along the coast. Chloride concentrations range from less than 50 mg/L in the northeast to more than 100 mg/L near the coast. Sulfate concentrations range from less than 100 mg/L in the east to more than 250 mg/L near the coast. Fluoride concentrations range from 0.2 to 2.2 mg/L.

The lower Hawthorn-upper Tampa aquifer is the lowermost intermediate aquifer. The top of the aquifer occurs at depths that range from 190 to about 220 feet below sea level, increasing in depth from north to south. Its thickness ranges from about 200 feet in the north to 250 feet in the south. The altitude of the potentiometric surface ranges from less than 10 feet above sea level in the northwestern coastal area to about 35 feet above sea level in the east. Transmissivities from two aquifer tests were 2,500 and 9,000 ft^2/d, and storage coefficients were $1x10^{-4}$ and $1.2x10^{-4}$. Dissolved-solids concentrations range from less than 500 mg/L in the northeast to more than 2,000 mg/L near the coast. Chloride concentrations range from about 50 mg/L in the northeast to 1,000 mg/L near the coast. Sulfate concentrations range from 250 to 500 mg/L, generally increasing from the northeast to the southwest. Fluoride concentrations vary areally and vertically and range from 0.8 to 2.6 mg/L.

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SUPPLEMENTAL DATA

Lithologic Logs of Wells in the Ringling-MacArthur Reserve

Lithologic description	Thickness (ft)	Depth (ft)
Well 1		
Sand, brown at surface, turning yellow	4.5	4.5
Sand, yellow to gray, fine-grained	5	9.5
Sand, brown, very fine-grained, silty	5	14.5
Sand, brown, sticky, silty	5	19.5
Sand, brown, sticky, quartz grains, with phosphate, large grains	5	24.5
Sand, brown, silty, clayey	5	29.5
Sand, light-green, clayey, with phosphate	5	34.5
Well 2		
Sand, yellow	4.5	4.5
Sand, gray, silty	5	9.5
Sand, gray, silty, with phosphate	5	14.5
Sand, tan to light gray, sticky; phosphate	5	19.5
Sand, gray, clayey, with phosphate	5	24.5
Well 3		
Sand, surface, fine-grained turning to white fine-grained	4.5	4.5
Sand, dark-brown, fine-grained, silty	5	9.5
Sand, light-tan	5	14.5
Sand, light-brown, very silty	5	19.5
Sand, greenish-gray, sticky, with phosphate	5	24.5
Sand, greenish-gray, very sticky, silty	5	29.5
Well 4		
Sand, brown (surface), yellow	4.5	4.5
Sand, light-tan, fine-grained; clay, sandy, green	5	9.5
Clay, light-green, sandy, with shells	10	19.5
Well 5		
Sand, light-tan	4.5	4.5
Sand, yellow turning light-gray, sticky	5	9.5
Sand, tan, clean, fine- to medium-grained	5	14.5
No return, drilled as above	5	19.5
Sand, with shells	1.5	21
Sand, gray, with shells, sticky, with phosphate	3.5	24.5

NOTE: Well may not have been completed to first clay.

Lithologic description	Thickness (ft)	Depth (ft)
Well 6		
Sand, black (muck), very silty	4.5	4.5
Sand, dark-brown, fine-grained	5	9.5
Sand, brown, fine-grained (clean)	10	19.5
Sand, brown, fine-grained, some large quartz grains, with phosphate	5	24.5
Clay, light-green, sandy	5	29.5
Well 7		
Sand, light-tan, clean, medium- to fine-grained	4.5	4.5
Sand, brown, shell, with phosphate	5	9.5
Marl, white, sandy, limestone streaks, light-tan	5	14.5
Well 8		
Sand, white changing to dark-brown	4.5	4.5
Marl, white, limestone, sandy	5	9.5
Well 9		
Sand, dark-brown at surface, turning to light-tan to yellow at bottom	4.5	4.5
Sand, light-tan, fine-grained	4	8.5
Clay, gray, sandy	1	9.5
Clay, green, very sandy	5	14.5
Well 10		
Sand, black at surface to light-tan to bright-yellow at bottom of auger	4.5	4.5
Sand, light-green turning to dark-brown, very sticky (first time this type of material was found)	5	9.5
Clay, dark-brown, (muck) changing to green at bottom of bit	5	14.5

Lithologic description	Thickness (ft)	Depth (ft)
Well 11		
Sand, brown, dark to tan at surface, turning light-tan with depth	4.5	4.5
Sand, dark-brown to tan, silty	5	9.5
Sand, tan, silty, fine-grained	10	19.5
Sand, brown, silty, fine-grained, little sticky	5	24.5
Sand, brown, silty, with phosphate	5	29.5
Sand, light-brown, medium- to fine-grained, cleaner, with phosphate	5	34.5
Sand, light-brown, coarse, with phosphate pebbles	3.5	38
Shell bed, with phosphate pebbles	1.5	39.5
Clay (Very difficult to bring up sample. Drilled like possibly still in shell bed and gravel.)	5	44.5
Drill still vibrating. No return sample taken from bottom of bit, indicates possible clay zone	5	49.5
Well 12		
Sand, dark-brown at surface, changing to yellow	4.5	4.5
Sand, light-brown, very silty	5	9.5
Sand, light-gray, clayey	2.5	12
Clay, dark-gray	1	13
Sand, gray, clayey	1.5	14.5
Clay, green, sandy	5	19.5
Well 13		
Sand, dark-brown to yellow, silt	4.5	4.5
Sand, light-gray, fine-grained, sticky	5	9.5
Sand, light-brown, fine-grained, clayey	5	14.5
Sand, light-green; clay, light-green, sandy	5	19.5
Well 14		
Sand, dark-brown at surface, changing to yellow	4.5	4.5
Sand, light-gray, very silty, sticky	5	9.5
Sand, light-gray to brown, very silty	5	14.5
Sand, gray, clayey, silty, with phosphate	5	19.5
Same (sticky)	5	24.5
Sand, coarse to medium shells, with phosphate pebbles	2.5	27
Sand ran up and plugged augers.		
Clay	2.5	29.5

Lithologic description	Thickness (ft)	Depth (ft)
Well 15		
Sand, dark-brown to yellow, fine-grained	4.5	4.5
Sand, gray; clay, gray, very sticky	5	9.5
Clay, plastered side of hole, no return	5	14.5
Clay, light green, sandy, no return	5	19.5
Clay, seemed to be pretty firm, gray, 10 feet up on augers. Very sticky, pure clay	5	24.5
Well 16		
Sand, white to gray turning to yellow, fine-grained	4.5	4.5
Sand, gray, fine-grained, clayey	5	9.5
Sand, gray, sticky, with shells	5	14.5
Well 17		
Sand, white at surface turning dark-brown, fine-grained	4.5	4.5
Sand, dark-brown to light-brown, fine grained	5	9.5
Sand, light-brown, fine-grained	5	14.5
Sand, light-brown, very sticky	5	19.5
No clay on bottom of bit. Clay not reached although sand was very sticky.		
Well 18		
Sand, dark-brown to light-brown	4.5	4.5
Sand, dark-gray, very sticky, with shells	5	9.5
Clay, light-green, very sandy, with shells	5	14.5
Well 20		
Sand, dark-brown, silty, fine-grained	4.5	4.5
Sand, brown, clayey	5	9.5
Sand, light-tan to green (water)	5	14.5
Sand, light-green, silty, with phosphate	5	19.5
Sand, light-gray, clean, medium- to fine-grained, with phosphate	5	24.5
Sand, light-gray, clean, with phosphate (heavy)	5	29.5
Sand, dark-gray, medium-grained, with phosphate (very heavy)	10	39.5
Sand, gray, coarse- to medium-grained, with shells (heavy, cemented together), with phosphate pebbles. Very difficult to sample	6	45.5
Clay, green; limestone, black, large pebbles	1	46.5

Lithologic description	Thickness (ft)	Depth (ft)
Well 21		
Sand, black to light-brown, fine-grained	4.5	4.5
Sand, grayish-green, fine-grained; clay, light-green, sandy	5	9.5
Sand, light-green, fine- to medium-grained, clayey, with phosphate	5	14.5
Sand, coarse-grained, large quartz grains, with phosphate	5	19.5
Sand, coarse-grained, with phosphate pebbles, heavy	5	24.5
Sand; clay, gray at bottom of auger	5	29.5
Well 22		
Sand, tan changing to yellow silt, sticky at 4.5 feet	4.5	4.5
Sand, gray, silty, fine-grained, little sticky	5	9.5
Sand, light-brown, fine-grained, silty (sticky)	5	14.5
Sand, light-brown, fine-grained	5	19.5
Sand, light-brown, sticky, with phosphate	5	24.5
Clay, light-gray to green, sandy, with phosphate, shells	5	29.5
Well 23		
Sand, black (muck) to orange (bright)	4.5	4.5
Sand, light-gray, clayey, sticky, silt	5	9.5
Sand, light-gray to brown, not as sticky, silty	5	14.5
Sand, light-gray, very silty, with phosphate	10	24.5
Sand, gray, with phosphate; clay, gray	5	29.5
Well 24		
Sand, black, silt turning gray back to dark-brown, very fine-grained	4.5	4.5
Sand, dark-brown, fine-grained, silty	5	9.5
Sand, dark-brown, very silty, fine-grained	5	14.5
Well 25		
Sand, (surface) turning yellow, fine-grained	4.5	4.5
Sand, tan	3.5	8
Clay, blue, sandy	1.5	9.5

Lithologic description	Thickness (ft)	Depth (ft)
Well 26		
Sand, brown, very silty	4.5	4.5
Sand, light-brown, clean	8	12.5
Clay, gray, sandy	2	14.5
Water 6 inches deep over entire area.		
Well 27		
Sand, brown, fine-grained; clay, brown, silty at surface	4.5	4.5
Sand, light-green, very sticky, clayey	5	9.5
Clay, light-green	5	14.5
Well 28		
Sand, yellow, fine-grained	4.5	4.5
Sand, light-gray, silty	5	9.5
Sand, light-gray to green, fine- to coarse-grained (water)	5	14.5
Sand, light-gray, clayey	5	19.5
Sand, light-gray; clay, light-green, and phosphate	5	24.5
Well 29		
Sand, black to gray, silty	4.5	4.5
Sand, light-gray to tan, silty	5	9.5
Sand, brown, very silty (water)	5	14.5
Sand, gray (dark), silty	5	19.5
Sand, light-green, with phosphate; clay, light-green	5	24.5
Well 30		
Sand, black at surface to dark-brown, very silty	4.5	4.5
Clay, light-gray, very sandy	5	9.5
Clay, gray, very sandy	5	14.5
Well 31		
Sand, black, hard pan at 3.5 feet, white sand below	4.5	4.5
Sand, dark-brown, silty, dry	5	9.5
Sand, light-tan, clean, fine- to medium-grained	8	17.5
Clay, light-green, sandy	2	19.5

Lithologic description	Thickness (ft)	Depth (ft)
Well 32		
Sand, black to dark-brown, silt	4.5	4.5
Sand, dark-brown, fine-grained	5	9.5
No return, drilled the same as last 5 feet	5	14.5
Sand, brown, dark, very silty, fine-grained	5	19.5
Sand, brown, fine- to medium-grained (no clay)	5	24.5
Set screen at 25 feet below LSD, 20 feet of 2-inch PVC, 5 feet of 0.010-mm screen. Moved rig 10 feet, drilled down to 40 feet.		
Sand, gray, coarse-grained, with phosphate	5	29.5
Same, sampled off augers	5	34.5
Sand, grayish-green, coarse- to medium-grained, phosphate, heavy, large shells at bottom of bit	3	37.5
Clay, dark-gray to green, very sandy (sampled off bit)	2	39.5
Well 33		
Sand, black to dark-brown, silt	4.5	4.5
Sand, gray, fine-grained, silty	8.5	13.0
Clay, bluish-green (pure)	1.5	14.5
Well 34		
Sand, black (surface), dark-brown	4.5	4.5
Sand, light-brown, fine-grained	5	9.5
Sand, light-brown, sticky	5	14.5
Sand, light-brown, fine-grained	5	19.5
Sand, tan, fine-grained, some large quartz grains	5	24.5
Sand, light-gray, fine-grained, shells, with phosphate	5	29.5
Sand, tan, fine-grained, shells, with phosphate	5	34.5
Clay, very soft, difficult to determine	1.5	36.0
Clay, green	3.5	39.5
Well 35		
Sand, brown, fine-grained	4.5	4.5
Sand, light-tan, fine-grained, silty	5	9.5
Sand, brown, fine-grained, clayey	5	14.5
Sand, light-brown, with shells; clay, gray ???	5	19.5
Very difficult to determine clay layer. Bit contained gray sandy clay.		

Lithologic description	Thickness (ft)	Depth (ft)
Well 36		
Sand, black (muck) to dark-brown	4.5	4.5
Sand, brown to gray, very silty, fine-grained	5	9.5
Sand, gray, fine-grained	5	14.5
Sand, gray, very fine-grained, silty	5	19.5
Very difficult to bring up cuttings from bottom. Samples may not accurately represent depth as noted.		
Same (very sticky)	5	24.5
Sand, greenish-gray, very sticky, with phosphate	5	29.5
May not have drilled to clay, although it appears that clay streaks are all through the sand.		
Well 37		
Sand, black	4.5	4.5
Sand, light-gray to green, clayey	5	9.5
Sand, light-green; clay, light-green	5	14.5
Clay, light-green, sandy	5	19.5
Sand, medium- to fine-grained, clayey, with phosphate (light-green clay on bit)	5	24.5
Well 38		
Sand, dark-brown at surface to light-brown	4.5	4.5
Sand, dark-brown, fine-grained	10	14.5
Sand, dark-green, clayey	5	19.5
Well 39		
Sand, dark-brown	1	1
Sand, yellow, fine- to medium-grained	3.5	4.5
Sand, light-tan, silty	5	9.5
Sand, light-gray, silty, clayey, with phosphate	5	14.5
Sand, light-gray; clay, green, with phosphate	5	19.5
Well 40		
Sand, dark-brown to yellow	4.5	4.5
Sand, light-tan; clay, light-green, sandy	5	9.5
Sand, light-green, clayey	5	14.5
Sand, light-gray, sticky, with phosphate and shell fragments	10	24.5
Clay, light-green; limestone, hard	2.5	27

Lithologic description	Thickness (ft)	Depth (ft)
Well 41		
Sand, brown and black, fine-grained	4.5	4.5
Sand, light-tan, silty, fine-grained	5	9.5
Sand, light-tan, silty, with shell fragments	10	19.5
Sand, light-brown	5	24.5
Sand, light-brown, silty, not much water	10	34.5
Same, clayey, not much water	5	39.5
Sand, clayey, with phosphate	5	44.5
Well 42		
Sand, white, silty	4.5	4.5
Sand, dark-brown to light-tan	5	9.5
Sand, tan, fine- to medium-grained, silty (water)	5	14.5
Sand, light-brown, silty; quartz, medium- to large-grained	5	19.5
Sand, light-brown, very silty, clay, green to gray	10	29.5
Sand, quartz, medium-grained	5	34.5
Sand, with phosphate pebbles	5	39.5
Sand, coarse-grained, with phosphate; clay, gray	5	44.5
Clay, light-green to gray	5	49.5
Well 43		
Muck, black	1	1
Sand, yellow, fine-grained	3.5	4.5
Sand, yellow, clayey	3.5	8
Clay, light-green, sandy	1.5	9.5
Clay, light-green, turning yellow, sandy, with limestone, broken	5	14.5
Clay, yellow to light-green, sandy (no water)	5	19.5
Clay, yellow to light-green, with limestone, broken, sandy	5	24.5
Clay, light-green (some water)	5	29.5
Clay, light-green, with limestone, broken	5	34.5
Clay, light-green, with shells; limestone	5	39.5
Well 44		
Sand, dark-brown	4.5	4.5
Clay, green, sandy	3	7.5
Clay, light-gray, sandy	2	9.5
Clay, gray, sandy	5	14.5

Lithologic description	Thickness (ft)	Depth (ft)
Well 45		
Sand, dark-brown to yellow	3	3
Sand, yellow	3	6
Clay, light-green, sandy	3.5	9.5
Clay, light-gray, sticky (water)	5	14.5
Well 46		
Sand, dark-brown to light-tan, fine-grained	4.5	4.5
Sand, brown, fine-grained	5	9.5
Sand, brown to light-gray, fine-grained, with phosphate	5	14.5
Same, appears to be in clay	5	19.5
Clay, light-green, with shells (large pieces), with phosphate	5	24.5
Well 47		
Sand, black to brown, silt	4.5	4.5
Sand, light-tan, silty	5	9.5
Sand, medium- to fine-grained (water)	5	14.5
Sand, medium- to fine-grained, silty	5	19.5
Sand, silty	5	24.5
Sand, medium- to fine-grained, clean	5	29.5
Sand, light-brown, medium- to fine-grained	5	34.5
Sand, light-green; clay, light-green	5	39.5
Well 48		
Sand, white	4.5	4.5
Sand, dark-brown	5	9.5
Sand, dark-brown (water)	5	14.5
Sand, light-brown, clayey	5	19.5
Sand, light-brown, clayey and silty	5	24.5
Sand, light-brown, silty	5	29.5
Same, some coarser-grained	5	34.5
Same, fine- to medium-grained; clay, green	5	39.5
Sand, fine- to medium-grained; quartz, some large pebbles, phosphate	5	44.5
Sand, fine- to medium-grained; large quartz, with phosphate, little clayey	5	49.5
Clay, green, sandy	5	54.5

Lithologic description	Thickness (ft)	Depth (ft)
Well 49		
Sand, brown to tan	4.5	4.5
Sand, light-gray, silty	10	14.5
Sand, gray, very little clay, silty	5	19.5
Sand, light-tan; quartz, some large pebbles	5	24.5
Sand, light-green; clay, green	5	29.5
Well 50		
Sand, brown to black, hard pan at 4 feet	4.5	4.5
Sand, gray, silty	5	9.5
Sand, gray, clayey, with phosphate (water)	5	14.5
Sand, very coarse-grained, with shells and phosphate pebbles	5	19.5
Same, very coarse-grained	10	29.5
Sand, fine-grained; gravel, coarse-grained, with phosphate (salt and pepper sand)	5	34.5
Sand, salt and pepper, fine-grained, with shell fragments	5	39.5
Sand, fine- to coarse-grained, with phosphate shells, with limestone, brown; clay, gray	5	44.5
Sand, silty, with phosphate, shells; clay, dark-gray	5	49.5
Clay, gray; sand, medium- to coarse-grained, with phosphate	5	54.5

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