GEOHYDROLOGY OF INDIAN RIVER COUNTY, FLORIDA

By G.R. Schiner and C.P. Laughlin, U.S. Geological Survey
and D.J. Toth, St. Johns River Water Management District

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ABSTRACT

The surficial aquifer system and the underlying Floridan aquifer system are the sources of all ground water used in Indian River County, Florida. The surficial aquifer system consists of a 100- to 150-foot-thick section of unconsolidated clastic deposits termed the "clastic zone" that overlies a 0- to 60-foot-thick section of mostly indurated carbonate rock termed the "shallow rock zone." The Floridan aquifer system consists of about 2,800 feet of carbonate rocks, subdivided on the basis of permeability, into the Upper Floridan aquifer (about 350-650 feet thick), the middle semiconfining unit (about 20-120 feet thick), and the Lower Floridan aquifer (roughly 2,000 feet thick). The surficial and Floridan aquifer systems are separated by a 100- to 200-foot-thick low permeability rock unit known as the intermediate confining unit.

Transmissivities of the surficial aquifer system range from 1,500 to 11,000 ft^2 /d (feet squared per day). Specific capacities range from 21 to 70 (gal/min)/ft (gallons per minute per foot) in eastern Indian River County, and range from 9 to 36 (gal/min)/ft in the Vero Beach well field.

Pumpage in the Vero Beach well field approximately doubled during the 10-year period from 1975 to 1985 and peaked at about 9.5 Mgal/d (million gallons per day) in the spring of 1981, during a major drought. A comparison of water levels in the Vero Beach well field area between April 1971 and May 1984 indicates a decline of about 15 to 19 feet since 1971.

Chloride concentrations in water from most wells that tap the surficial aquifer system in the Vero Beach well field have changed little in recent time. Between 1976 and 1983, the average chloride concentration in six production wells increased about 36 mg/L (milligrams per liter). However, chloride concentrations were unchanged in four others. The increase in chloride concentrations is probably related to the increase in well field pumpage from 5.44 Mgal/d in 1976 to 8.00 Mgal/d in 1983.

High yielding wells completed in the surficial aquifer system are most likely to be found along the coastal ridge west of U.S. Highway 1 in the eastern part of the county.

About 65 percent of all ground water used in the county is from the Floridan aquifer system. The hydrology of the Floridan aquifer system is complex. Considerable variation in yield and water quality may be found in nearby wells of equal depth. The permeability of the Upper Floridan aquifer generally is higher than that of the Lower Floridan aquifer.

Transmissivities of the Upper Floridan aquifer estimated from computer model simulations range from about 65,000 ft^2/d to 200,000 ft^2/d. However, much higher transmissivities have been determined from aquifer tests at a few sites. One such aquifer test at an injection well completed in the so-called "Boulder Zone" of the Lower Floridan aquifer yielded a transmissivity of 1.5×10^6 ft^2/d. Specific capacities of 37 wells in the Floridan aquifer system range from 1 to 200 (gal/min)/ft with a median of 67 (gal/min)/ft. Measured flow rates of wells that tap the Floridan aquifer system range from 30 to 2,000 gal/min (gallons per minute) with a median of 650 gal/min.

Most wells completed in the Floridan aquifer system flow. In heavily pumped areas and during "dry" years, water levels in May are as much as 15 feet lower than the levels in September. Water levels in the more developed eastern part of Indian River County have declined about 16 to 24 feet in the 50-year period 1934 to 1984. In the less developed western part of the county, water levels have declined about 8 to 10 feet. The countywide decline is probably mostly due to regional pumping. The water-level data indicate no significant water-level decline since the early 1970's outside of local heavily pumped areas.

Water from the Lower Floridan aquifer generally contains chloride and dissolved solids in concentrations that exceed 250 mg/L and 500 mg/L, respectively, but water from the Upper Floridan aquifer generally contains less than 250 mg/L chloride in much of the southwestern part of the county and in some areas along the Atlantic Coastal Ridge. High freshwater heads in the Floridan aquifer system (generally 10 to 30 feet above land surface) were, as of 1985, preventing saltwater in the Indian River, the Atlantic Ocean, and the saline aquifers that underlie the freshwater from migrating into the Floridan aquifer. The high heads also prevent contaminants on the land surface from moving downward into the Floridan aquifer system. In most of the county, chloride concentrations of wells that tap the Floridan aquifer system have not changed significantly in the 15-year period 1968-83. However, chloride concentrations in the water from two public-supply wells in the Floridan aquifer system at Vero Beach increased 35 and 60 percent in the past 6 and 9 years, respectively (1976 and 1979-85).

About 35 percent of the total area of Indian River County is in agricultural use, of which about 75 percent is irrigated. Irrigation withdrawals from the Floridan aquifer system amounted to 30 Mgal/d and constituted 22 percent of the total water used for irrigation in in the county in 1984. Inventoried irrigation wells range in depth from 233 to 1,272 feet--median depth is 700 feet. Changes in land use are affecting the pattern of irrigation. Urban development is replacing groveland along sections of U.S. Highway 1 and State Road 60 where irrigation water use is decreasing.

In 1984, about 8.5 Mgal/d of ground water were used for public supply in the county, mostly by Vero Beach. An additional 8 Mgal/d of ground water were used for domestic supply. In June 1985, the county-owned reverse osmosis treatment plant near Oslo has provided about 1 Mgal/d of water for public supply to its service area south and west of Vero Beach from two wells that tap the Floridan aquifer system.

INTRODUCTION

Background

The 1980 population of Indian River County (fig. 1) was about 60,000, an increase of 67 percent from the 1970 population of 36,000. The estimated 1985 population was about 76,000--a 300 percent increase in the 25-year period 1960-85 (University of Florida, 1986, p. 37). By the year 2000, the population is expected to reach about 104,000. Most new residents in the county have settled in the coastal areas, and this trend will probably continue. The predicted large population growth in the near future will cause a substantial additional demand for water from the shallow water-bearing surficial aquifer system, which underlies the coastal area and supplies much of the freshwater for public and private use. To augment supplies from the surficial aquifer system, additional substantial withdrawals from the commonly salty, deeper part of the Floridan aquifer system will probably be made for conversion to freshwater by the reverse osmosis process.

The surficial aquifer system and the Floridan aquifer system are the sources of all ground water used in Indian River County. The two systems contain ground water that ranges in salinity from fresh to brine. High chloride concentration is the chief water-quality problem in the county.

Prior to this study, little was known about the severity of stress imposed on the surficial and Floridan aquifer systems since large developments began in the 1970's. Drainage or diversion of surface water and changes in land use that accompany development may have altered the historical water balance that existed in the past. The effect of saline water flood irrigation on the water quality of the surficial aquifer system was not known.

High water levels, substantially above sea level, have historically kept saltwater in the coastal areas from moving laterally inland and infiltrating the potable water zones in the Floridan aquifer system. However, excessive pumping and diminishing recharge caused by changing land use can lower water levels enough to cause salty water to move into both the surficial and the Floridan aquifer systems.

The water-resources information needed to assess the effects of these changes was either lacking or outdated, so a comprehensive and current framework of water-resources information was needed to allow orderly planning and management, and use of the resource.

Purpose and Scope

The purpose of this report is to describe the principal water-bearing and water-quality features of the surficial and Floridan aquifer systems. The report includes descriptions of the geology and geography as they relate to the geohydrology of the county. It contains information on the water quality and hydraulic properties of the surficial and Floridan aquifer systems and describes trends in water levels and chloride concentrations in the aquifer systems.

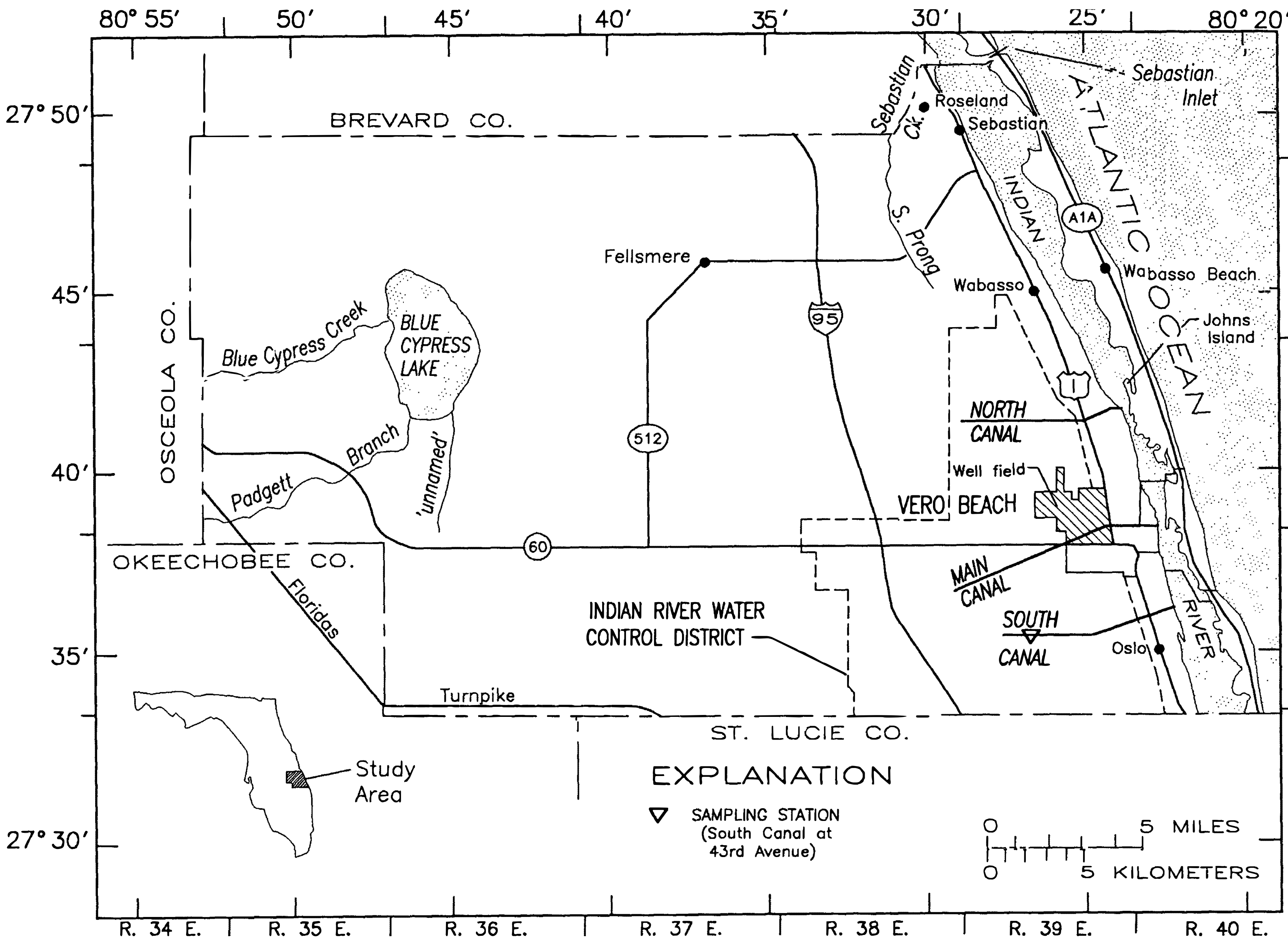


Figure 1.--Indian River County--the study area.

The section of the report describing the surficial aquifer system was prepared by D.S. Toth, St. Johns River Water Management; the section describing the Floridan aquifer system was prepared by Schiner and Laughlin of the U.S. Geological Survey. The description of the surficial aquifer system primarily describes the aquifer as it occurs in eastern Indian River County. This report includes data from reports and files of both of these agencies and from reports from other governmental agencies, and private consultants.

Study Approach

During this study, water levels were measured periodically in about 60 wells. Water-level recorders were installed on five new observation wells and reinstalled on two previously discontinued long-term observation wells. Wells were inventoried and well logs obtained from owners and drillers. Fifty-three geophysical well logs were run and 25 test wells were drilled. Specific capacity tests were run on 35 wells that tap the Floridan aquifer system. The water-quality characteristics of selected wells were determined and about 300 wells were sampled for chloride analysis. In addition, the existing water-quality data for about 125 wells were further analyzed. Wells sampled during the 1958 and 1975 studies were resampled for determination of chloride concentration. Specific conductance and field-determined chloride concentration measurements were periodically made at several sites on the canal system. Water-level and water-quality information provided by the city of Vero Beach was collated and analyzed.

Figures 2 and 3 show, respectively, the locations of wells in the surficial aquifer system and Floridan aquifer system used for data analyses in this report. Data on the physical characteristics of the wells are given in the sections Supplementary Data I (surficial aquifer system) and Supplementary Data II (Floridan aquifer system) at the end of the report.

Acknowledgments

The authors gratefully acknowledge the assistance given by many organizations and individuals during the study. Valuable assistance was provided by Hillman Goff, Vero Beach Water and Sewer Department; and Art Chalacombe, Planning and Human Resources, Indian River County. McLaughlin Well Drilling contributed valuable data. Cooperation of the many well owners who permitted access to their wells for testing and measuring is greatly appreciated.

Well-Numbering Systems

Three numbering systems are used to identify wells in this report. A number of up to three digits is used to identify wells and test holes in illustrations and tables. In the text, the well number is suffixed by the letters "S" or "F" to indicate an inventoried well in the surficial aquifer system or a well in the Floridan aquifer system, respectively. A 15-digit number based on latitude and longitude is used to identify wells in the U.S. Geological Survey data storage and retrieval systems. The St. Johns River Water Management District uses a similar identification system to the U.S. Geological Survey, using latitude and longitude as a primary identifier.

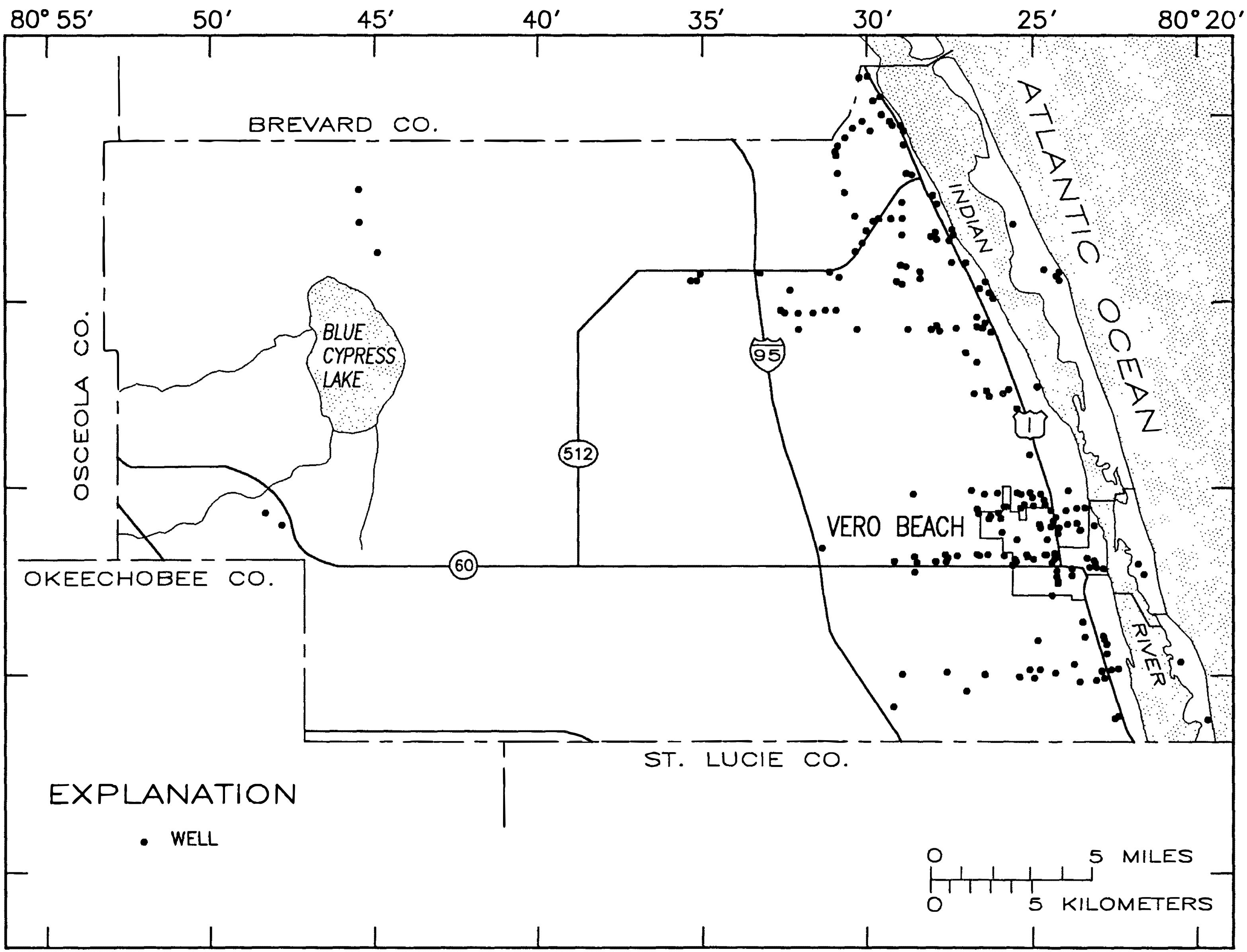


Figure 2.--Location of wells in the surficial aquifer system (listed in Supplementary Data table I).

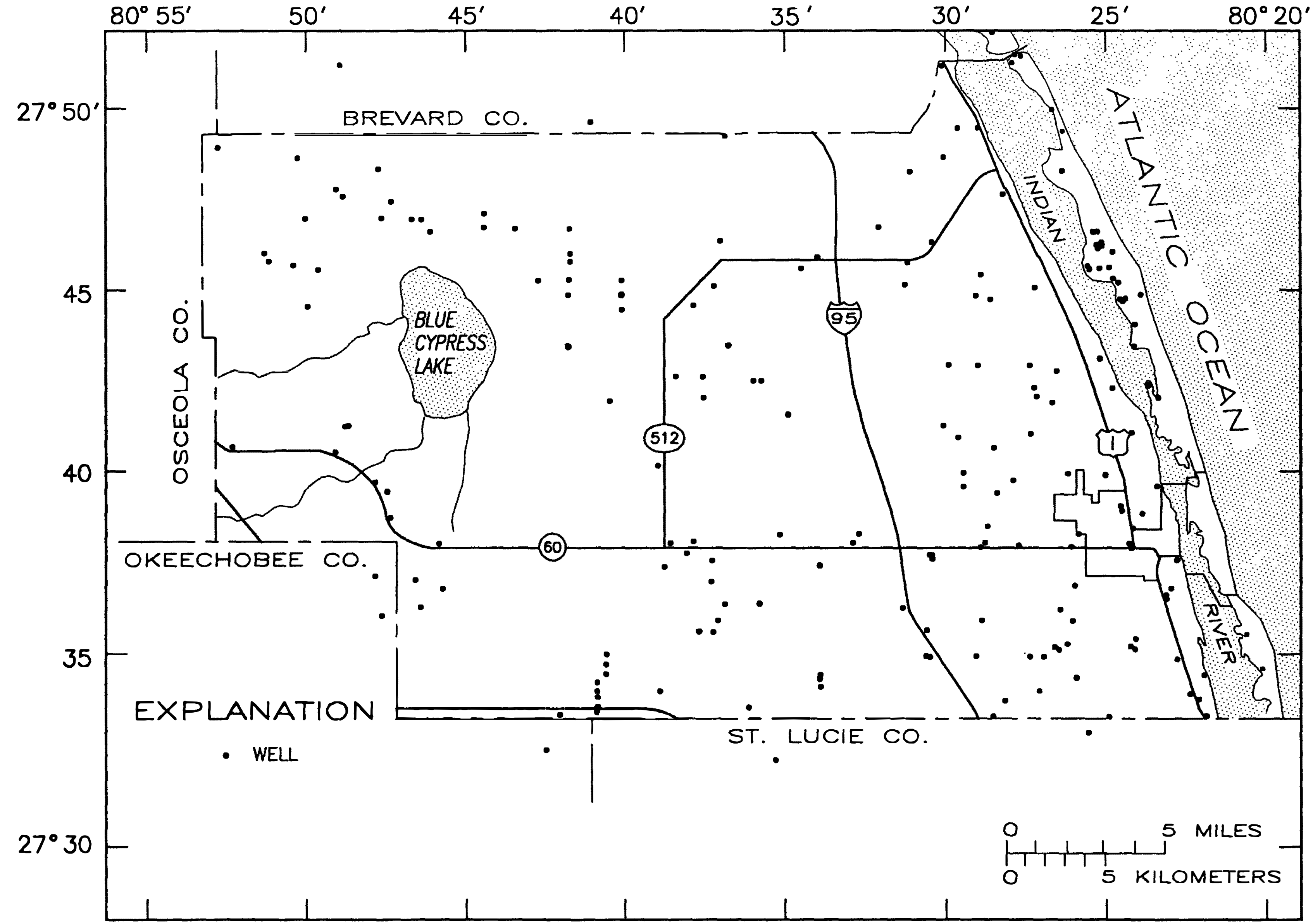


Figure 3.--Location of wells in the Floridan aquifer system (listed in Supplementary Data table II).

The 15-digit number is the customary ground-water site indentification system (GWSI) of the U.S. Geological Survey, providing a unique number for each station. The number consists of 15 digits, formed from the latitude and longitude of the station location. The first 6 digits denote the degrees, minutes, and seconds of latitude; the next 7 digits denote degrees (always 3 digits beginning with 0), minutes, and seconds of longitude; and the last 2 digits denote a sequential number for a station within a 1-second grid. Once assigned, a site identification number does not change even though the locations determined by latitude and longitude may be revised later. The site identification number is the major vehicle used in placing and retrieving data from the U.S. Geological Survey's data management system, the National Water Data Storage and Retrieval (WATSTORE) System.

GEOGRAPHY

Land Forms and Drainage

The major land forms in Indian River County evolved during Pleistocene time and are of two general types--extensive terraces, and much less commonly, ridges. Terraces are steplike flatlands and scarps that were formed by ancient seas that stood at several levels. The ridges represent shoreline features such as offshore bars and relict beaches of the ancient seas. The shape of the land surface has been little modified since Pleistocene time. Figure 4 shows the major land forms found in Indian River County.

The Silver Bluff terrace extends from the coast to the Atlantic Coastal Ridge. The terrace includes the Barrier Island and stands at altitudes ranging from about 0 to 10 feet. The Pamlico terrace extends from the eastern edge of the Atlantic Coastal Ridge inland about 24 miles to the western edge of the St. Johns Marsh at generally near the 25-foot altitude. The St. Johns Marsh covers the western half of the Pamlico terrace. The Talbot terrace rises from the western edge of the St. Johns Marsh to altitudes that range from about 25 to 75 feet but is generally near the 50-foot altitude.

The ridges from west to east are the Barrier Island, the Atlantic Coastal Ridge, and the Ten-Mile Ridge. The Barrier Island is a ridge that represents an ancient offshore bar in a section of the Atlantic Coastal Ridge system. The ridge on the Barrier Island ranges in altitude from 0 to about 25 feet but generally is less than 10 feet. The low area between the Barrier Island and the Atlantic Coastal Ridge is an ancient lagoon now occupied by the Indian River. The Atlantic Coastal Ridge ranges in altitude from about 5 to 50 feet--mostly 20 to 30 feet. The Ten-Mile Ridge ranges in altitude from 25 to 30 feet, and stands roughly 10 feet above the underlying Pamlico terrace. Descriptions of the geologic history and modes of occurrence of the terraces and ridges are given by Cooke (1945), MacNeil (1949), and White (1970).

Much of the surface drainage of Indian River County has been drastically modified since the 1900's and ongoing changes continue. Except for the Talbot terrace and the ridge areas, most of the county prior to development was marshland that drained northward. St. Johns Marsh comprised a large part of the headwaters of the St. Johns River. In recent decades, vast sections of the St. Johns Marsh and other marshy areas were diked,

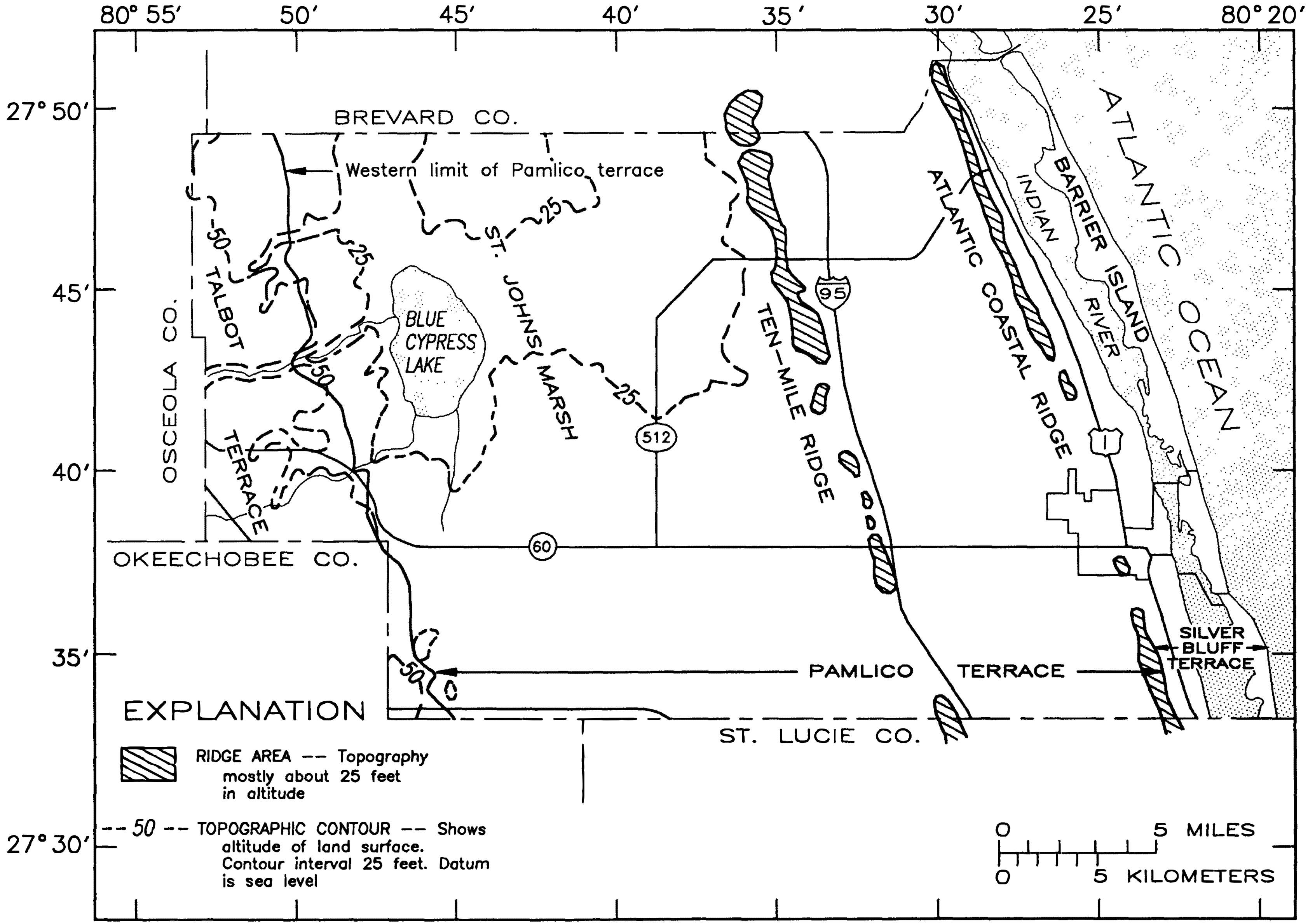


Figure 4.--Land forms in Indian River County (modified from Cook, 1939, and White, 1970).

channeled, and drained to accommodate agricultural use. A comparison of marsh areas in 1972 to predevelopment marsh areas (about 1900) is shown in figure 5.

Natural drainage in the county is sparse, but the following natural features were present in 1985. South Prong Sebastian Creek, paralleling the western side of the Atlantic Coastal Ridge, is tributary to Sebastian Creek that empties into the Indian River west of Sebastian Inlet. Blue Cypress Creek and Padgett Branch flow into Blue Cypress Lake from the highland of the Talbot Terrace west of the lake. Blue Cypress Lake has a surface area of 10.2 mi^2 (square miles) and has no defined natural outlet. Discharge from the northern end of the lake is controlled by a structure. A system of levees and drainage ditches that surround Blue Cypress Lake allows the adjacent land to be used for agriculture.

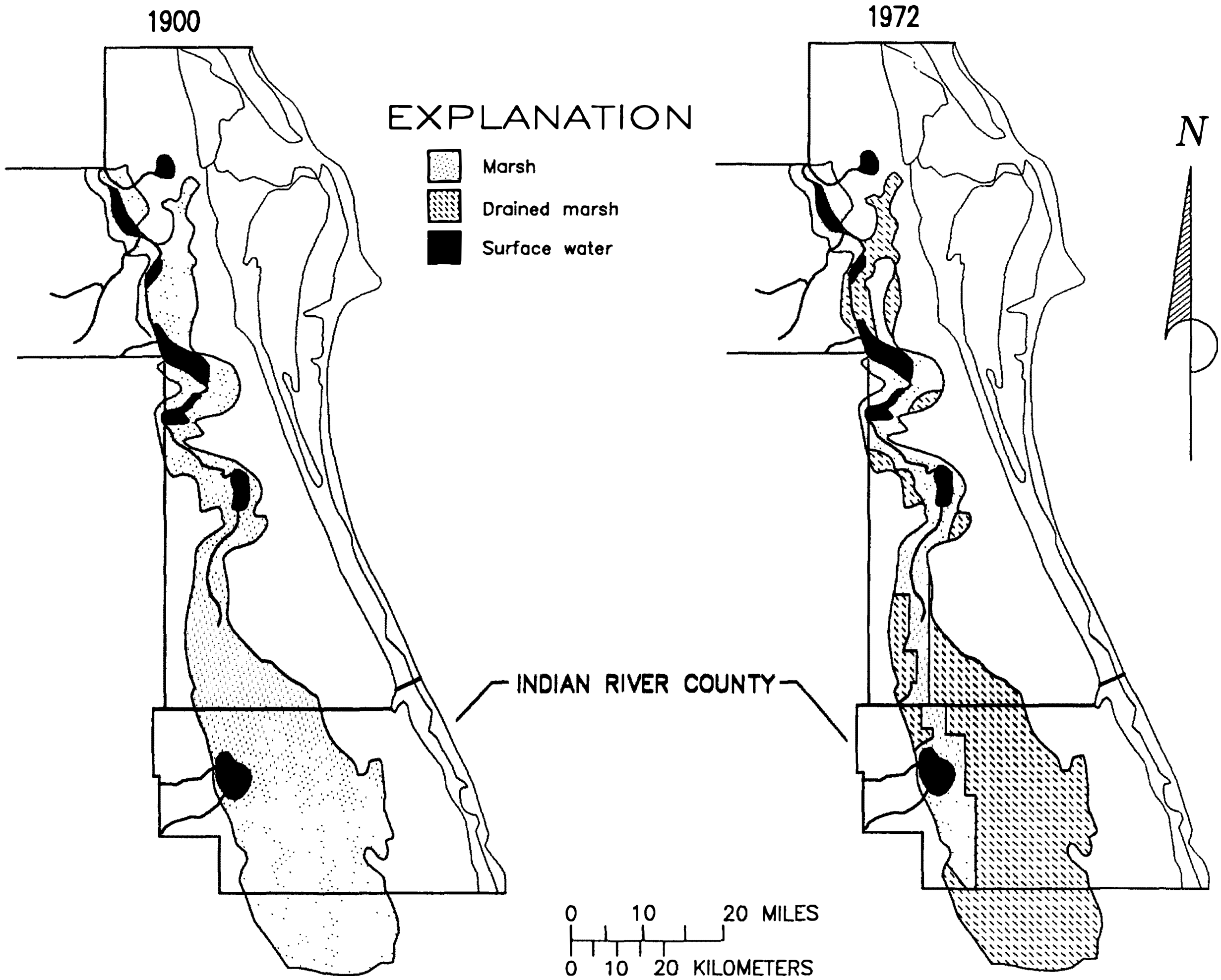


Figure 5.--Comparison of marsh areas in the Upper St. Johns River basin, predevelopment (1900) and 1972 (from Campbell and others, 1984).

Presently (1985), most of the drainage in the county flows to the Indian River through a system of drainage ditches connected to three large east-trending canals that discharge into the river (fig. 1).

Land Use

Indian River County has an area of 549 mi^2. Land use in the county is closely related to its land forms (fig. 4). The Barrier Island and Atlantic Coastal Ridge are generally citrus groves, residential, and commercial developments. Prior to the 1970's, the Atlantic Coastal Ridge and Barrier Island were chiefly in citrus groves, but because of urban growth these groves are being replaced by residential and commercial developments, primarily along the major roadways--State Roads A1A and 60, and U.S. Highway 1 (fig. 1). The Pamlico terrace is generally either in agricultural use (citrus and some vegetable farming) or natural marshland. The Ten Mile-Ridge is mostly in citrus groves. Large tracts of the St. Johns Marsh have been drained for citrus and vegetable farming and for cattle rangeland. Recently (1982-85) some of the drained rangeland is being developed for citrus production. The Talbot terrace is generally rangeland or undeveloped.

Climate

The climate of Indian River County is classified as subtropical humid, characterized by long, warm, mostly wet summers and mild, generally dry winters. The average annual air temperature is about 73 °F. High afternoon temperatures frequently exceed 90 °F during the summer months. Most years have a few days of frost or freezing temperatures with winter temperatures lowest inland.

Rainfall is unevenly distributed throughout the year. Summer rainfall is from local showers or thunderstorms that are random in occurrence. Winter rainfall is generally associated with large, cold, frontal-type air masses that move from the northern latitudes southward. These fronts cover large areas so winter rainfall is more widespread than the summer rains. Occasional tropical storms or hurricanes may add considerable amounts of rainfall to the yearly average total rainfall. About 60 percent of the annual rainfall occurs in the period June through October.

National Oceanographic and Atmospheric Administration records indicate that rainfall is unevenly distributed areally within the county. Average yearly rainfall at Fellsmere (about 55 inches) is about 3 inches more than the average yearly rainfall at Vero Beach (about 52 inches). Annual rainfall for a station at Blue Cypress Lake for the period 1979 through 1985 averaged about 49 inches. Rainfall data at Vero Beach, Fellsmere, and Blue Cypress Lake are shown in figures 6, 7, and 8. Drought conditions prevailed throughout Florida during parts of 1980 and 1981, causing a 2-year deficiency of about 19 inches from the average yearly at Vero Beach. At Avon Park, in Highlands County (fig. 14), the 2-year deficiency was about 26 inches.

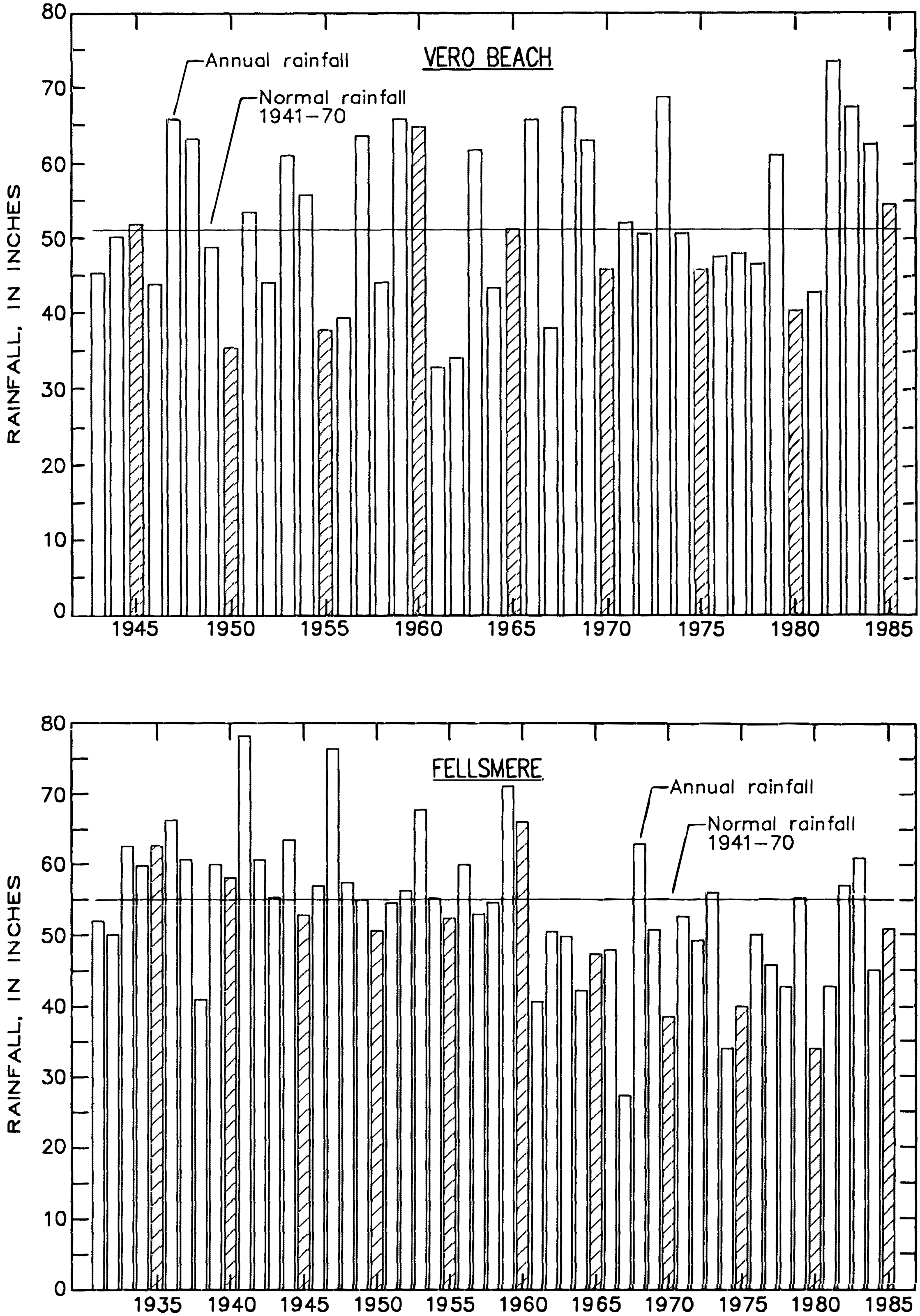


Figure 6.--Annual rainfall at Vero Beach, 1943–85, and Fellsmere, 1931–85.

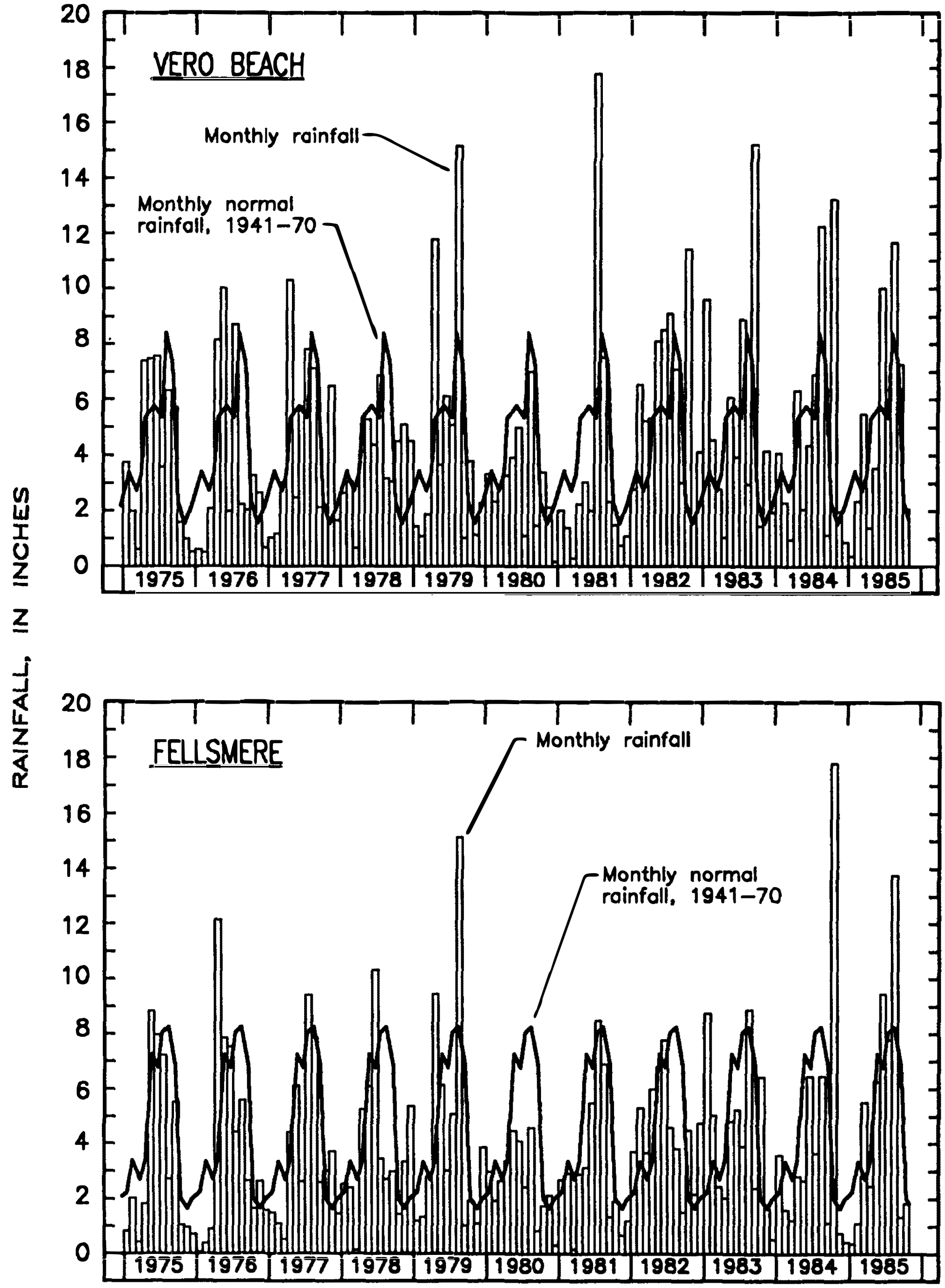


Figure 7.--Monthly rainfall at Vero Beach, 1975–85, and Fellsmere, 1975–85.

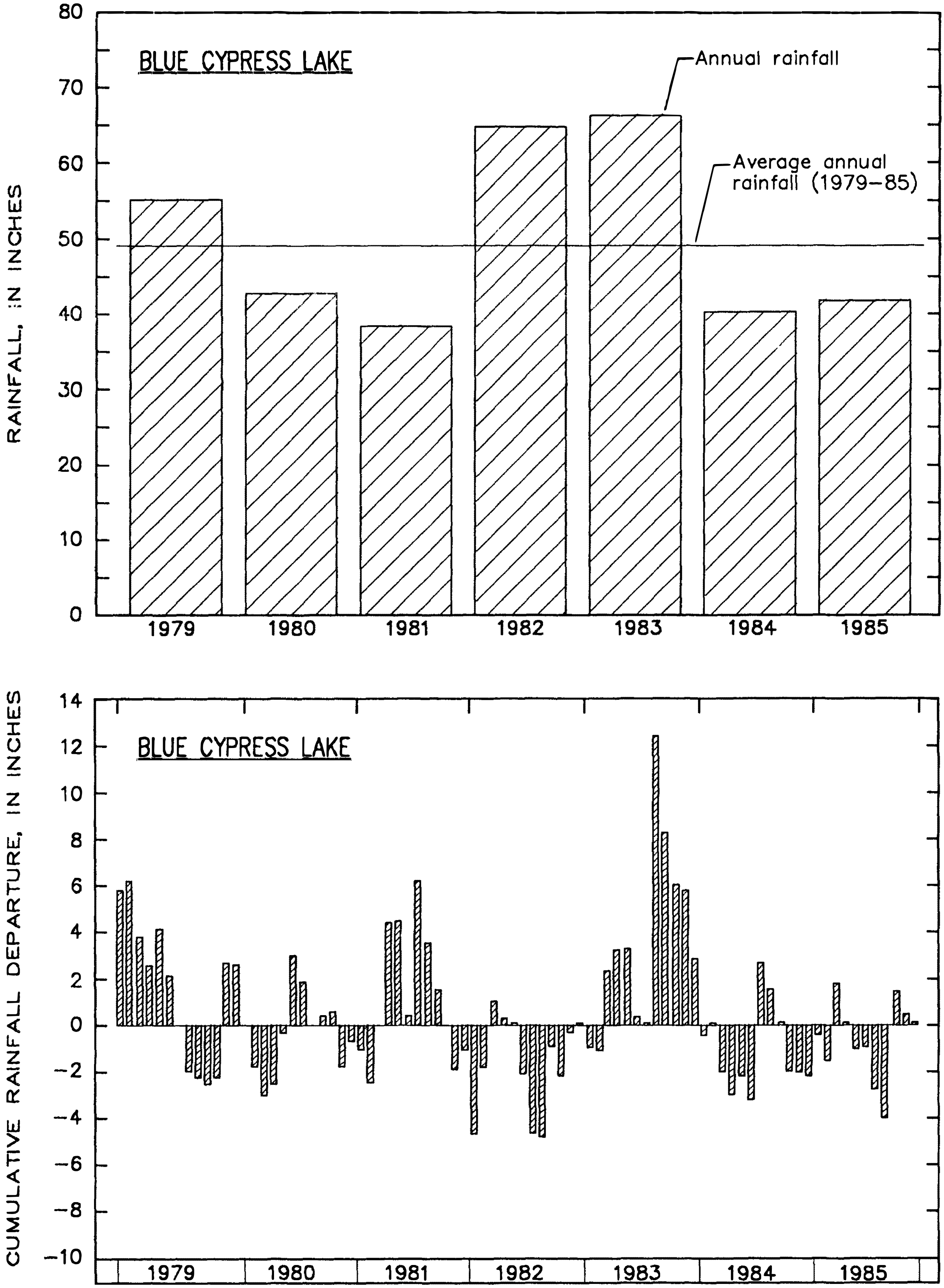


Figure 8.––Annual rainfall and cumulative departure from monthly average rainfall at Blue Cypress Lake, 1979–85.

GENERAL GEOHYDROLOGY OF THE GROUND-WATER SYSTEM

Geologic Framework

The availability and quality of ground water and surface water is closely related to the geologic framework that underlies Indian River County. Sedimentary rocks about 9,500 feet thick (Lloyd, 1985, p. 57) rest on a basement complex of pre-Mesozoic volcanic rock. The top 1,500 feet of sediments, significant to this study, are part of the Tertiary and Quaternary Systems that range in age from Eocene (oldest) to Holocene (youngest). The uppermost geologic deposits of the 1,500-foot section consist of unconsolidated post-Miocene deposits of sand, sandy clay, shell material and thin carbonate sediments that average about 150 feet in thickness. In descending order, the deposits consist of undifferentiated Holocene deposits, the Fort Thompson and Anastasia Formations of Pleistocene age, and the Tamiami Formation of Pliocene age. The unconsolidated deposits are underlain by fine clastic rocks of the Miocene Hawthorn Formation that range in thickness from about 70 to 250 feet in most of the study area. The fine clastic rocks are in turn underlain by either Oligocene or Eocene carbonate rocks about 1,000-feet thick that comprise the remainder of the 1,500-foot section. In descending order, the unit consists of the Suwannee Limestone, the Ocala Limestone, and the Avon Park Formation.

Descriptions of the geologic formations penetrated by wells in Indian River County are given in table 1. An interpretation of the subsurface geology, indicated by distinctive features of the gamma-ray log of well 46F, is shown in figure 9. (For location of well 46F, see fig. 47.) The hydrogeologic sections shown in figures 10, 11, and 12 indicate the thickness and extent of the geologic units located in the eastern part of the study area. (See figs. 22 and 47 for location of lines of section.)

Hydrogeologic Framework

The hydrogeologic framework, through which ground water moves and is stored, in the study area consists of two general types of rock units--consolidated carbonate rocks and the overlying unconsolidated rock. Each rock type contains aquifers with unique water-bearing properties that determine its utility as a source of water supply. The unconsolidated deposits contain the surficial aquifer system, commonly known as the surficial aquifer. The carbonate rocks contain the Floridan aquifer system, formerly known as the Floridan aquifer. The two aquifer systems are separated by a fine clastic unit that retards the exchange of water between them and is known as the intermediate confining unit (thickness is shown in fig. 13). The Floridan aquifer system has two major water-bearing zones separated by a less permeable confining unit (Tibbals, 1981, p. 7). In descending order, the aquifer system is divided into the Upper Floridan aquifer, the middle semiconfining unit, and the Lower Floridan aquifer (see fig. 9).

Geologic structure can be an important control in a ground-water flow system in Indian River County. The top of the Floridan aquifer system generally dips to the southeast and has an irregular, eroded surface. Consequently, the continuity of water-bearing zones that are structurally controlled may appear erratic in occurrence (fig. 41).

Table 1.--Water-bearing characteristics and descriptions of the geologic units in Indian River County

[gal/min = gallons per minute]

System	Series	Formation name	Thickness (feet)	Description	Yield of wells	Hydrogeologic unit	
QUATERNARY	Holocene	Undifferentiated deposits	0-25s	Variable mixture of sand, clay, coquina, and organic material	Varies widely but mostly less than 100 gal/min	SURFICIAL AQUIFER SYSTEM	Clastic zone
QUATERNARY	Pleistocene	Fort Thompson and Anastasia Formations	100-200s	Coquina with variable amounts of sand, silt and organic material	Varies widely, from less than 100 to about 700 gal/min)	SURFICIAL AQUIFER SYSTEM	Clastic zone
TERTIARY	Pliocene	Tamiami Formation	0-60s	Fragmented to cemented coquina and limestone	Generally 100 to 700 gal/min	SURFICIAL AQUIFER SYSTEM	Shallow rock zone
TERTIARY	Miocene	Hawthorn Formation	70-520	Silty to sandy clay, thin shell and limestone beds, phosphatic	Generally less than 100 gal/min	INTERMEDIATE CONFINING UNIT	
TERTIARY	Oligocene	Suwannee Limestone	0-190	Chalky to crystalline limestone	Generally less than 100 gal/min	FLORIDAN AQUIFER SYSTEM	Upper Floridan aquifer
TERTIARY	Eocene	Ocala Limestone	20-220s	Limestone, dolomitic near base in places	Varies widely, from about 100 to more than 700 gal/min	FLORIDAN AQUIFER SYSTEM	Upper Floridan aquifer
TERTIARY	Eocene	Avon Park Formation	100-500s	Limestone and dolomite	Generally more than 700 gal/min	FLORIDAN AQUIFER SYSTEM	Upper Floridan aquifer
TERTIARY	Eocene	Avon Park Formation	20-120	Dolomite, dolomitic limestone, limestone, and some gypsum	Probably much less than 100 gal/min	FLORIDAN AQUIFER SYSTEM	Middle semiconfining unit
TERTIARY	Eocene	Oldsmar Formation	600-700s	Limestone and dolomite	Generally 100 to more than 700 gal/min	FLORIDAN AQUIFER SYSTEM	Lower Floridan aquifer
TERTIARY	Eocene	Oldsmar Formation	About 1,000	Limestone and dolomite	Boulder zone used as receiving unit for injection wells	FLORIDAN AQUIFER SYSTEM	Lower Floridan aquifer

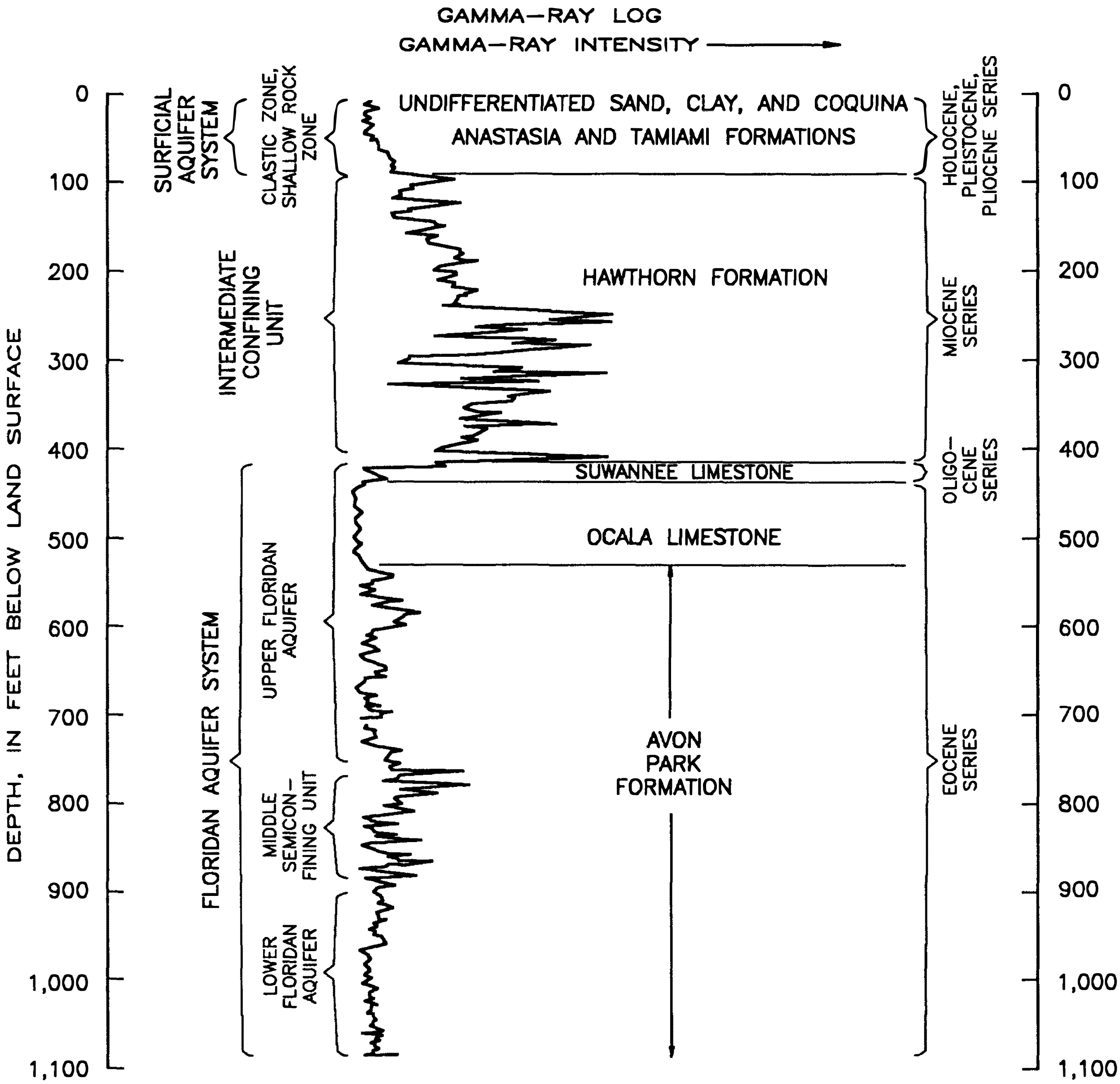


Figure 9.--Gamma-ray log of well 46F showing geologic formations and hydrologic units.

Miller (1982) reports that the small faults along Florida's east coast have the overall effect of thinning the Floridan aquifer system on the upthrown side of the fault, but because displacement is small, the ground-water flow system is little affected. Only one of several faults reported as present in Indian River County by Bermes (1958, p. 8) was confirmed on the evidence of geophysical and driller's logs collected during this study. The fault extends approximately from the south-county line northward along the Indian River to about Johns Island where it may trend northeast (fig. 41). The displacement in the carbonate rock section is roughly 350 feet (fig. 11). The effect of the fault on geohydrologic conditions identified in Indian River County is considerable. On the downthrown side (east of the fault trace), the upper part of the Floridan aquifer system contains brackish water. On the upthrown side, water from the upper part of the system is relatively fresh.

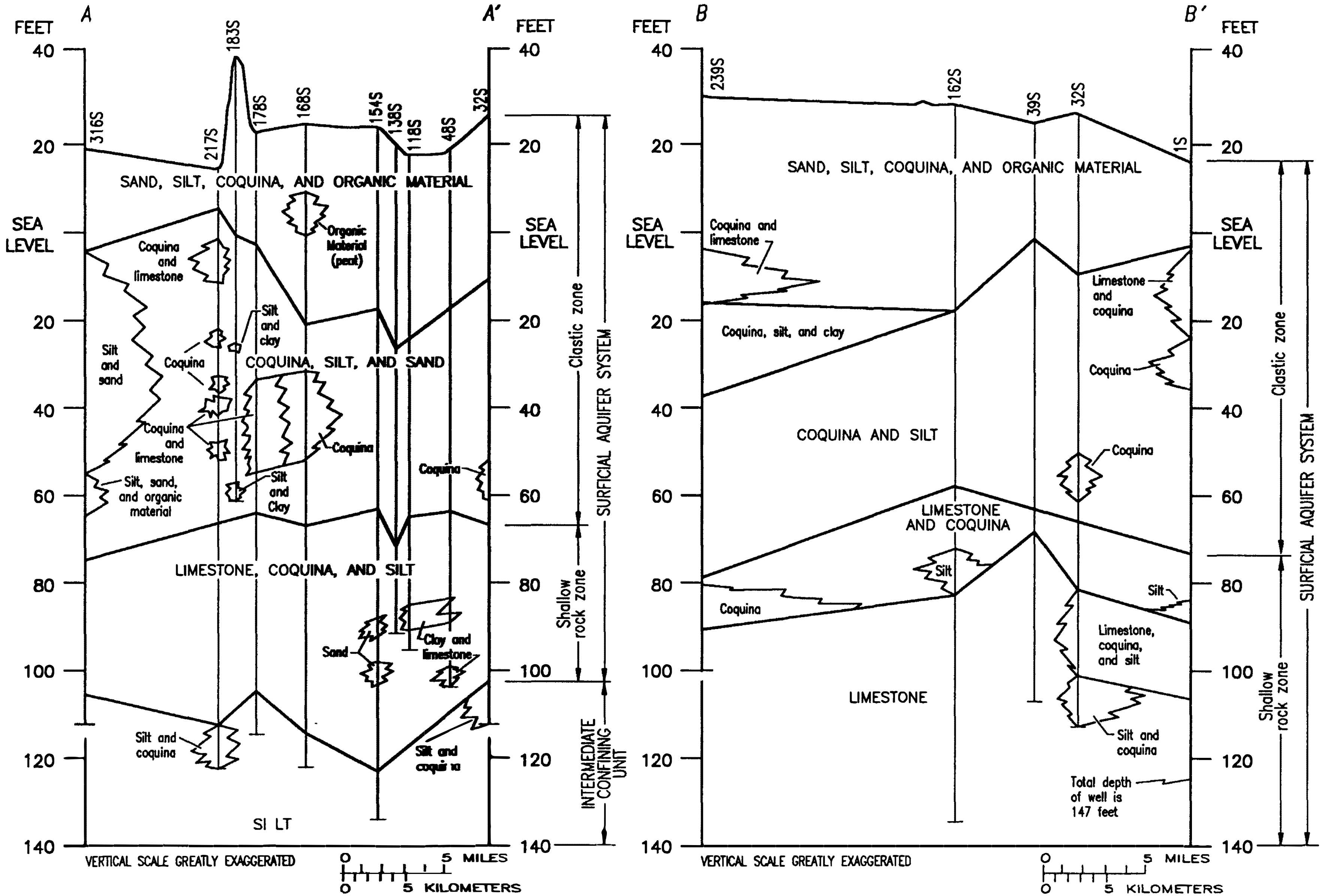


Figure 10.--**Hydrogeologic sections** *A–A'* and *B–B'* showing components of the surficial aquifer system (lines of section shown in fig. 22).

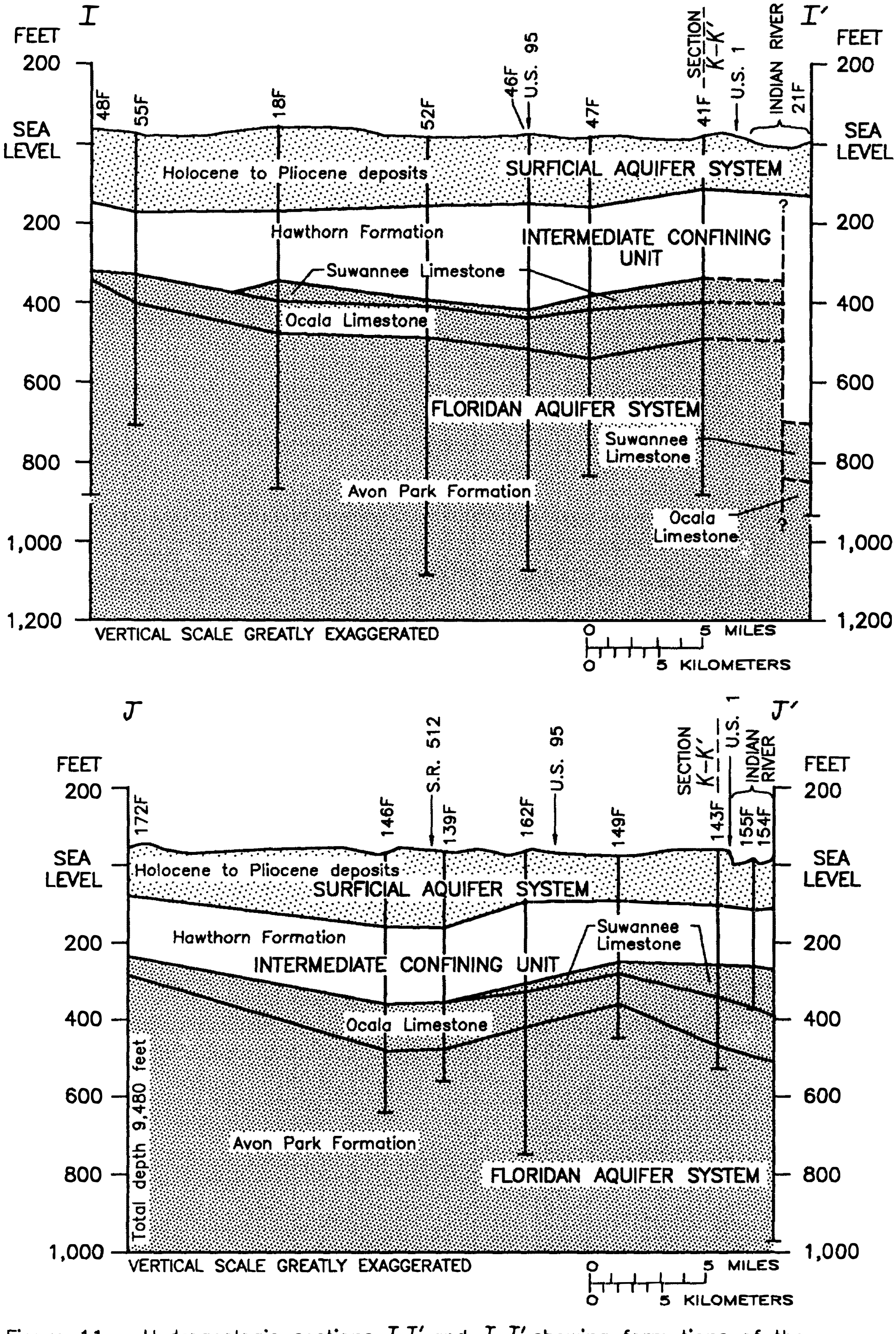


Figure 11.––Hydrogeologic sections *I–I′* and *J–J′* showing formations of the Floridan aquifer system (lines of section shown in fig. 47).

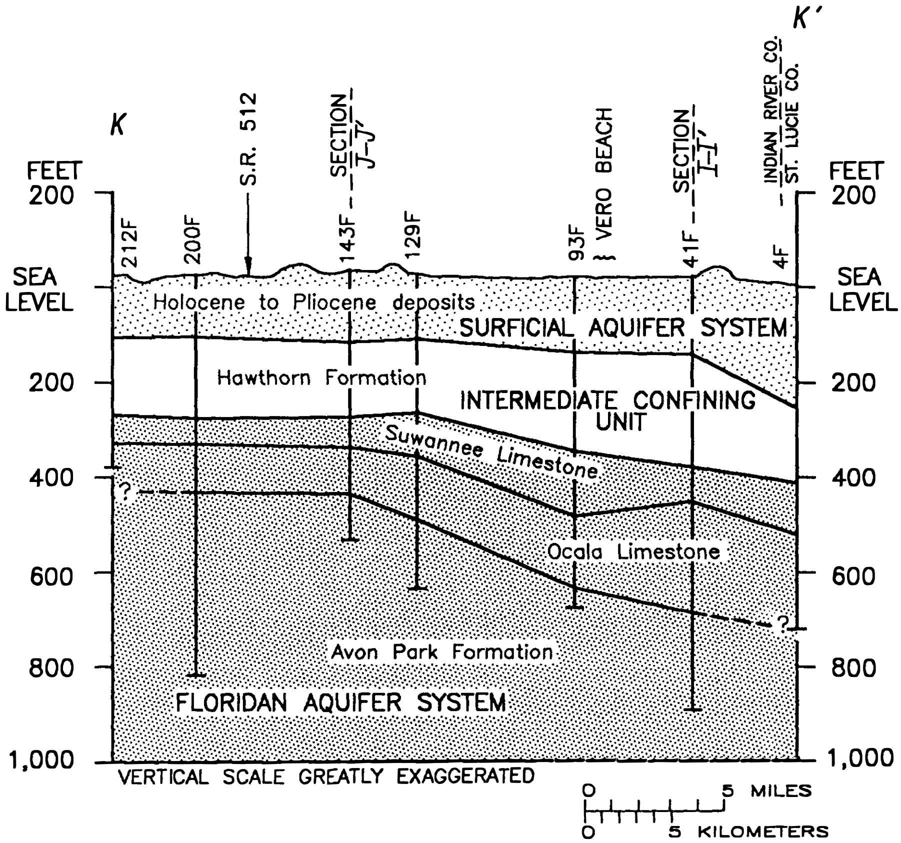


Figure 12.--Hydrogeologic section *K–K'* showing formations of the Floridan aquifer system (line of section shown in fig. 47).

Ground-Water Occurrence and Movement

Ground water in the surficial aquifer system is generally unconfined, but in the Floridan aquifer system the water is confined. The water table of the surficial aquifer system and the potentiometric surface of the Floridan aquifer system fluctuate continuously in response to changes in recharge and discharge. Most natural recharge to the surficial aquifer system is local precipitation in Indian River County, but most recharge to the Floridan aquifer system probably occurs in the Lake Wales Ridge area of eastern Polk and western Highlands Counties (fig. 14). Heads in the Floridan aquifer system are generally much higher than heads in the surficial aquifer system so recharge from the surficial to the Floridan aquifer system cannot occur in the county. Natural discharge from the surficial aquifer system generally occurs as evapotranspiration and subsurface flow into the Indian River and St. Johns Marsh. Most of the county is in the discharge area of the Floridan aquifer system. There, natural discharge is largely by way of upward leakage through the intermediate confining unit and probably some small amounts of discharge from the subcrop area beneath the Atlantic Ocean.

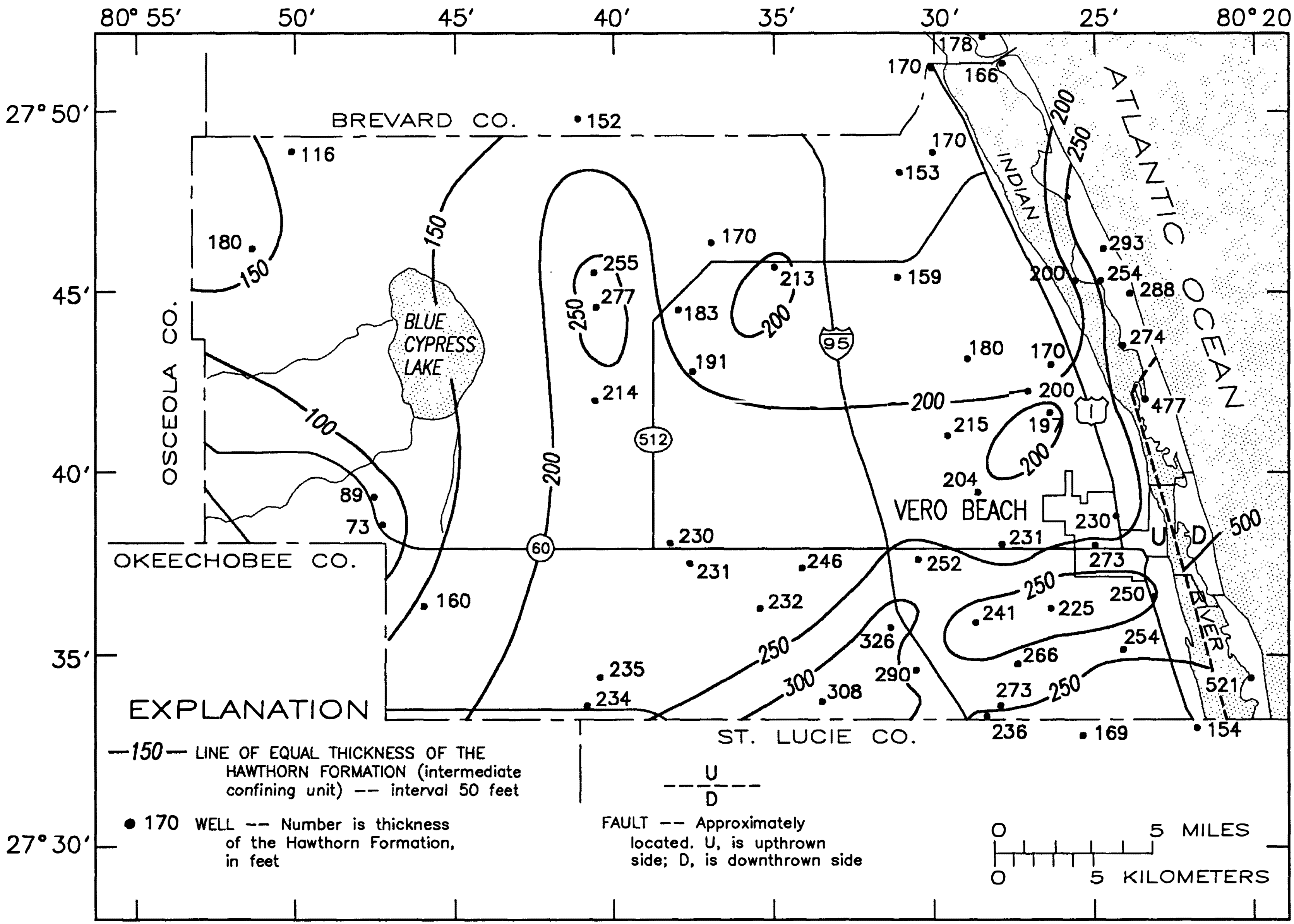
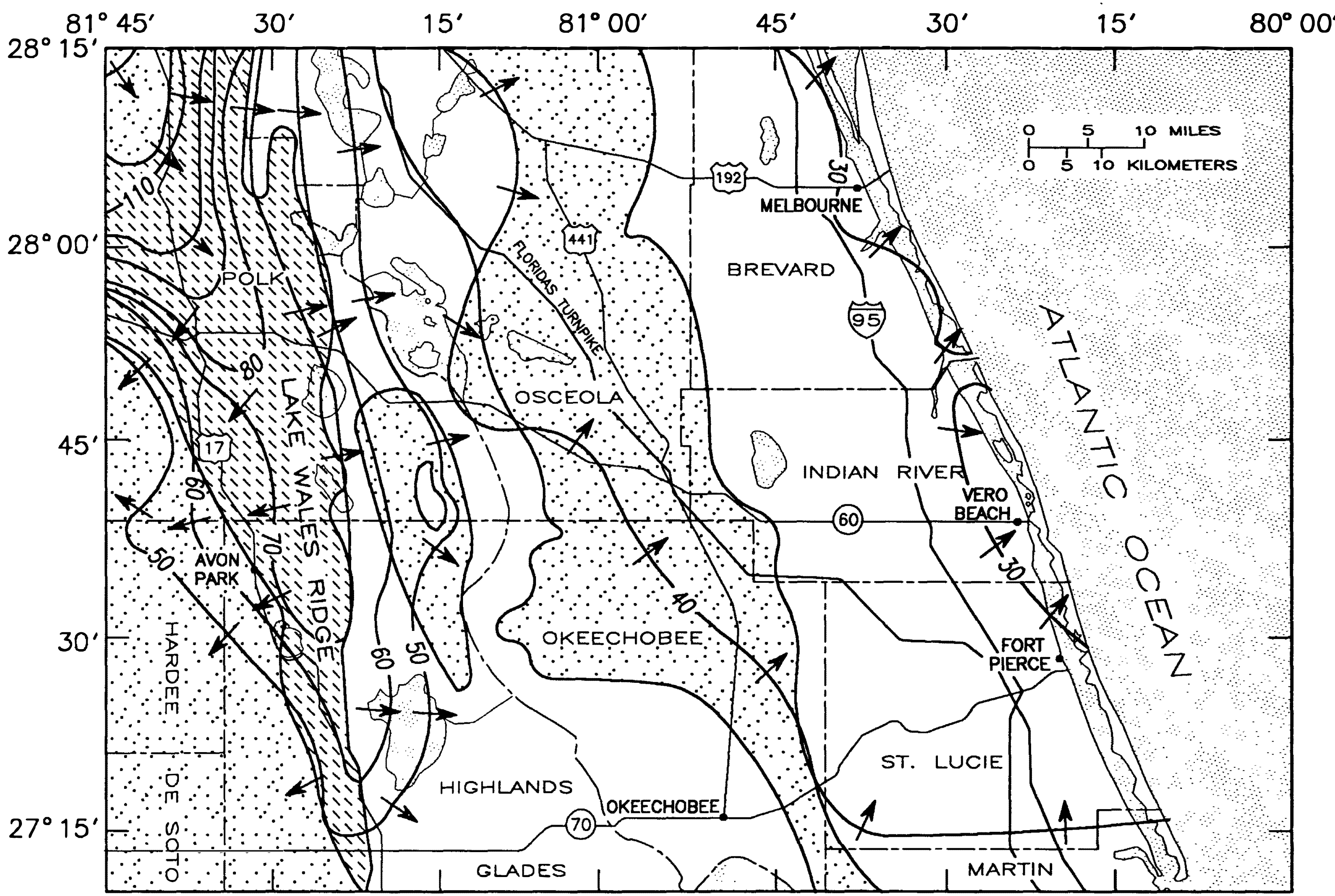


Figure 13.--Thickness of the Hawthorn Formation (intermediate confining unit).



EXPLANATION

—30→ POTENTIOMETRIC CONTOUR -- Shows altitude at which water level would have stood in tightly cased wells, May 1981 (Schiner and Hayes, 1981). Contour interval is 10 feet. Datum is sea level. Arrow indicates general direction of ground-water flow

Areas of high recharge

Areas of low to moderate recharge

Areas of discharge (most wells flow)

Figure 14.--Potentiometric surface, May 1981, and areas of natural recharge and discharge of the Upper Floridan aquifer (modifed from Phelps, 1984).

Water Quality

The amount, properties, and type of dissolved and suspended materials in water often control its use. Water suitable for one use may be unsatisfactory for other uses. For example, water having moderate amounts of dissolved solids may be used for irrigation purposes, but may not be suitable in the manufacture of high-grade paper which requires low dissolved solids. The chloride concentration and salinity of water in Indian River County are the most important limiting factors for public supply and agricultural use, which together account for more than 90 percent of the water used in the county. Chloride concentration is used in this report as an index to the overall quality of water in the county.

Chloride concentrations of water in the surficial and Floridan aquifer systems vary both areally and vertically because the geohydrologic conditions that control water quality differ to some degree from place to place. In this report, water with a chloride concentration of 250 mg/L or less is considered fresh; above 250 mg/L, the water is considered salty. Figure 15 is a graph showing the limiting concentrations of chloride recommended for plants, animals, and industrial uses.

The terminology used to describe the salinity of water in the county is a classification based on dissolved-solids concentration and uses the terminology of Krieger and others (1957).

Estimates of dissolved-solids and chloride concentrations can generally be obtained relatively easily and inexpensively by measuring an electrical property of the water called specific conductance, which is a measure of the capacity of water to conduct an electric current. Specific conductance varies with the concentration of dissolved mineral matter, the degree of ionization of the material, and the temperature of the water, and is reported in microsiemens per centimeter at 25 °C. Figures 16 and 17 show, respectively, the relation between chloride concentration, and specific conductance and between specific conductance and dissolved-solids concentration. Data from Indian River County and nearby areas were used in plotting the graphs. Note in figure 16 that specific conductance is roughly three times the chloride concentration and in figure 17, that specific conductance is about one-and-a-half times the dissolved-solids concentration. In some less-mineralized waters, chloride may not be a major element and conductance may be more closely related to other constituents. At the left side, or low-range end of figure 16, the group of data indicating a change in slope of this graph reflects waters not dominated by chloride concentration.

Hardness is expressed in terms of milligrams per liter of calcium carbonate ($CaCO_3$). Water is considered soft if its hardness value lies between 0 and 75 mg/L, moderately hard between 75 and 150 mg/L, hard between 150 and 300 mg/L, and very hard for values above 300 mg/L of $CaCO_3$ (U.S. Environmental Protection Agency, 1976).

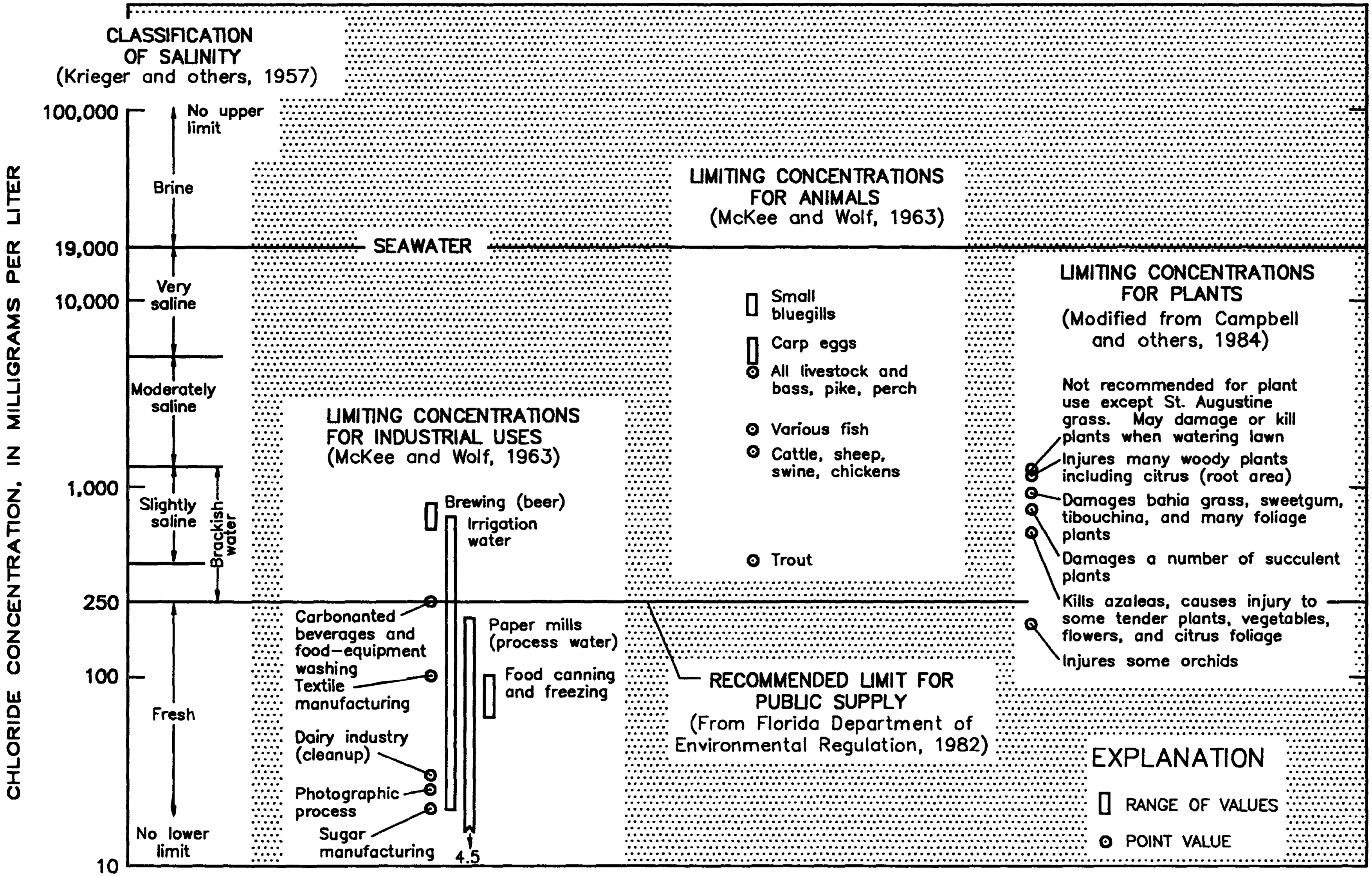


Figure 15.--Classification of salinity and limiting concentrations of chloride recommended for plants, animals, public supply, and industrial use.

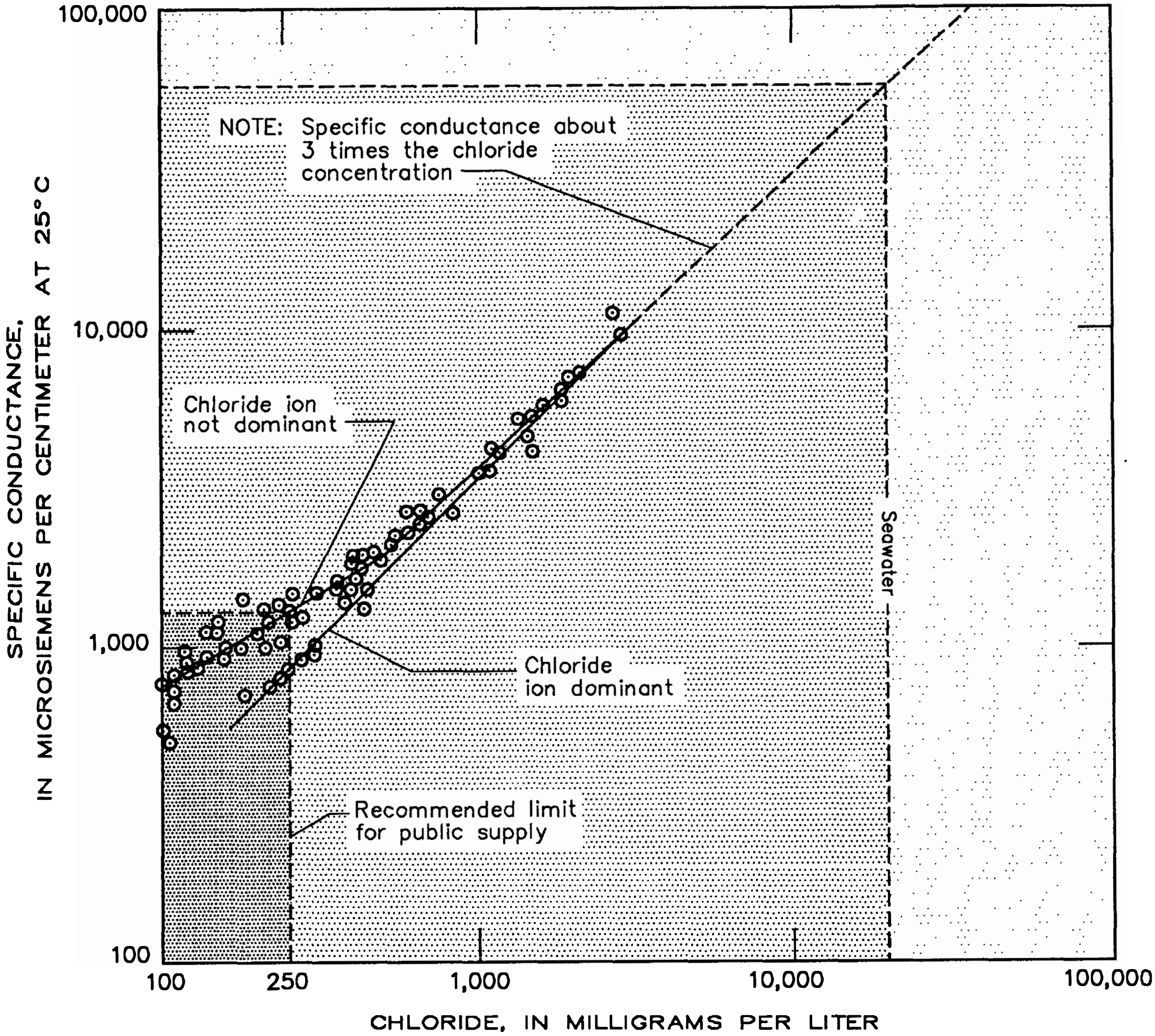


Figure 16.--Relation between chloride concentration and specific conductance.

GEOHYDROLOGY OF THE SURFICIAL AQUIFER SYSTEM

Hydrogeologic Framework

The surficial aquifer system consists of sediments of Pliocene age and younger that overlie the intermediate confining unit (Hawthorn Formation) of the Floridan aquifer system. In eastern Indian River County, the surficial aquifer system consists of a relatively thin, indurated carbonate unit, and an overlying relatively thick unit of unconsolidated clastic deposits. The surficial aquifer system generally is unconfined, but in places, may be semiconfined or confined where beds of low permeability are present. In this report, the surficial aquifer system is divided into two hydrogeologic units (table 1). The carbonate rock unit (Tamiami Formation) is termed the "shallow rock zone" and the unconsolidated clastic unit (combined Holocene deposits, Fort Thompson and Anastasia Formation) is termed the "clastic zone."

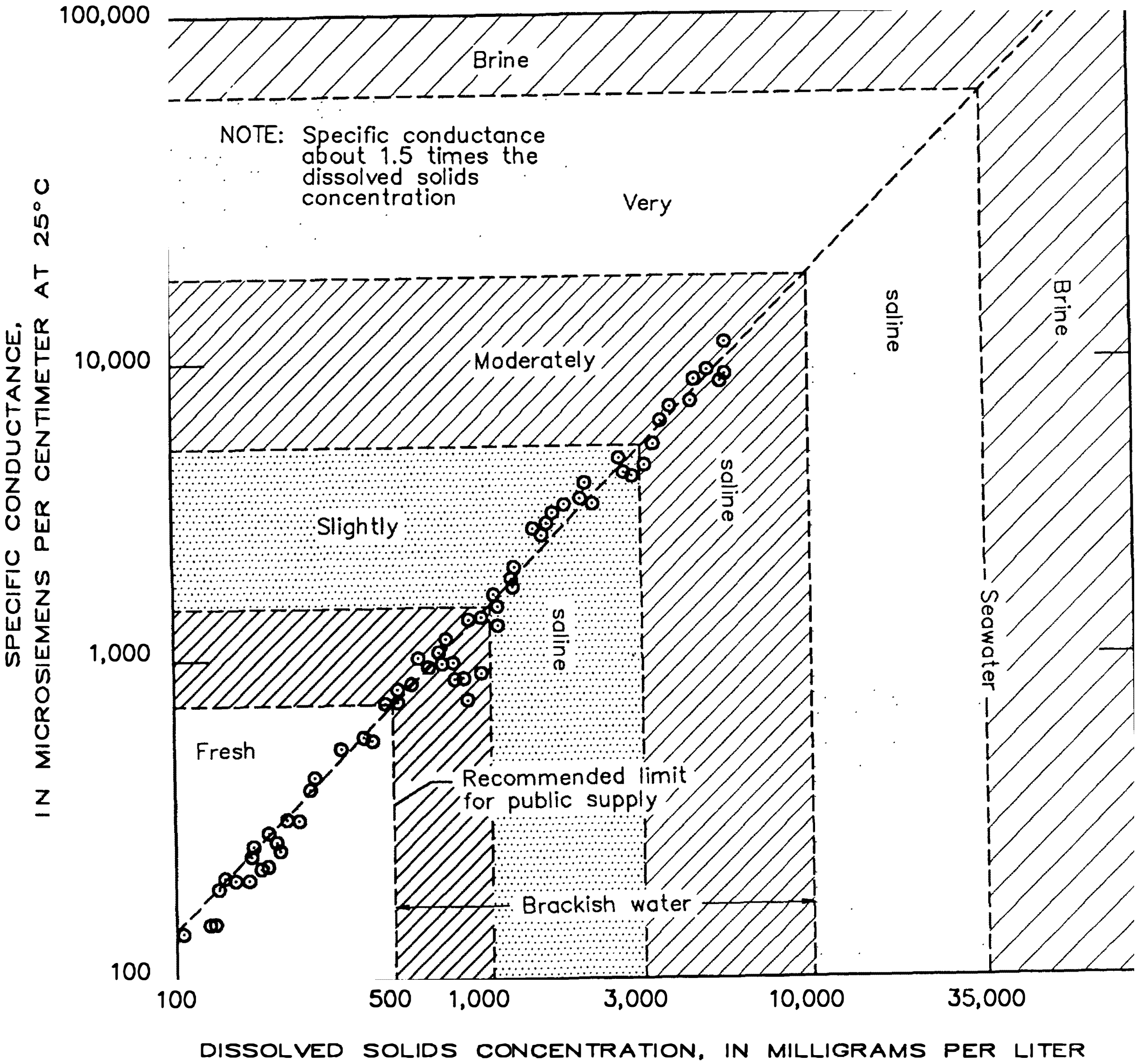


Figure 17.--Relation between specific conductance and dissolved-solids concentration, and the classification of salinity of water.

In eastern Indian River County, the thickness of the surficial aquifer system is related to the topography, so the system is thickest beneath the higher areas such as the Ten-Mile Ridge and the Atlantic Coastal Ridge. The system ranges in thickness from about 100 to 200 feet (fig. 18) and thickens southward to its maximum south of State Road 60. The hydrogeologic sections in figure 10 indicate the extent and thickness of the surficial aquifer system in eastern Indian River County.

The Tamiami Formation is composed of interbedded limestone, coquina, and sand and clay of Pliocene age. The formation, as much as 60 feet thick (fig. 19), overlies the Hawthorn Formation and is confined to the eastern part of the county. Its maximum thickness coincides with the Atlantic Coastal Ridge north of Vero Beach--thickness decreases east and west of the ridge. West of the Ten-Mile Ridge, the Tamiami grades into a "gray sand zone" that consists of gray sand and shell interbedded with clayey sands. The Tamiami Formation is often called "hardrock" by local well drillers.

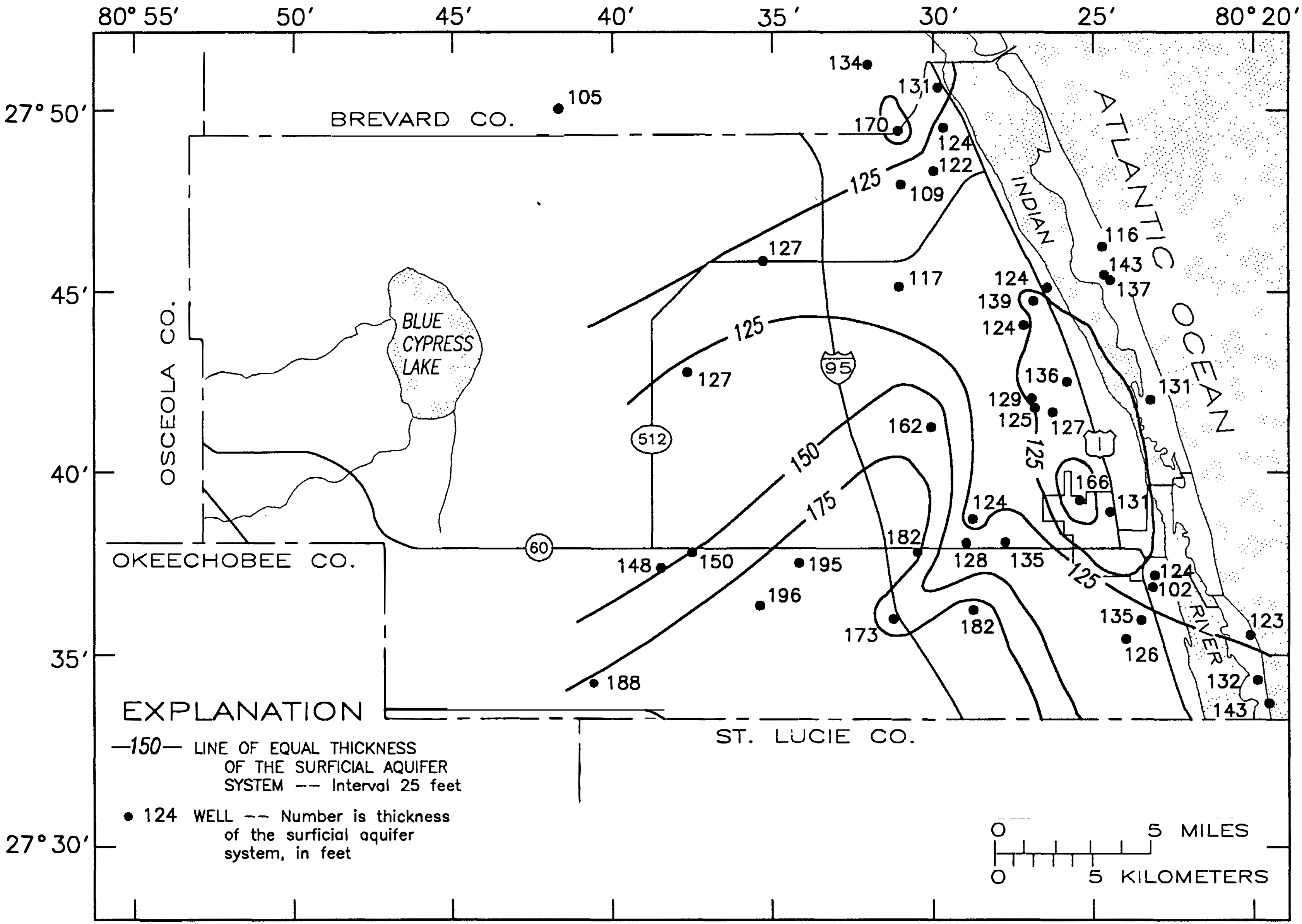


Figure 18.--Thickness of the surficial aquifer system.

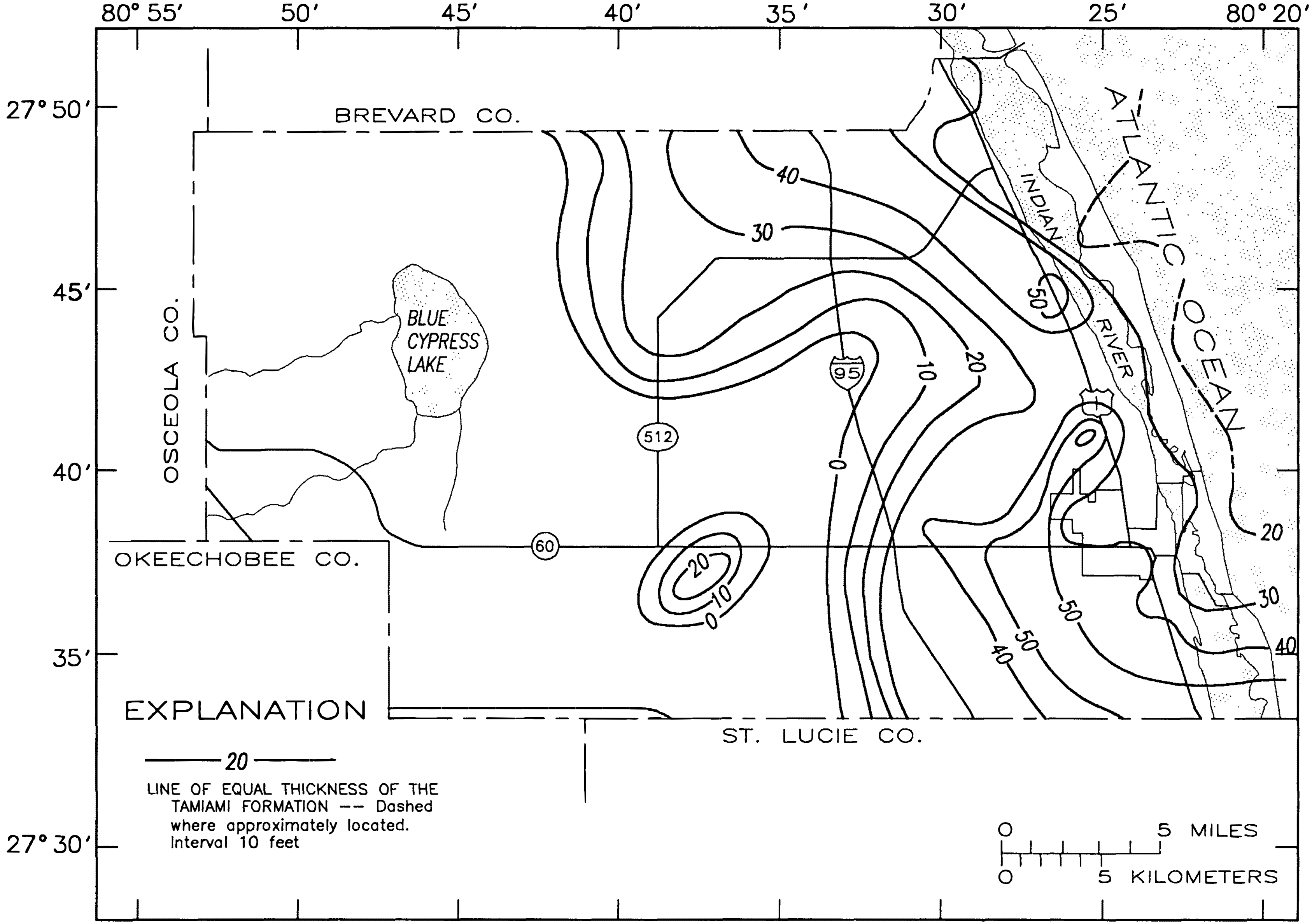


Figure 19.--Generalized thickness of the Tamiami Formation (from Frazee and Johnson, 1983).

The Anastasia Formation consists primarily of shellbeds of Pleistocene age that contain varying amounts of quartz sand, silt, and organic material. The shellbeds range from uncemented to a moderately hard coquina. The Anastasia Formation generally underlies the Barrier Islands and extends inland about 3 to 10 miles to the vicinity of the Ten-Mile Ridge. There, the composition of the Anastasia Formation changes from mostly shell to sand (Bermes, 1958; Crain and others, 1975). West of the Ten-Mile Ridge, the Fort Thompson Formation is equivalent to the Anastasia Formation and consists of less cemented coquina lenses and progressively greater percentages of sand and some very sandy limestone beds (Bermes, 1958).

The Anastasia Formation, and (or) the Fort Thompson Formation generally is covered by thin Holocene sands, silts, and clay. The combined thickness of Holocene and Anastasia or Fort Thompson deposits ranges from about 100 to 200 feet.

Hydraulic Properties

The hydraulic properties of the surficial aquifer system in eastern Indian River County vary considerably from place to place depending on characteristics such as grain size, sorting, packing, and cementation. These properties are reflected in values of transmissivity, storage, hydraulic conductivity and specific capacity that indicate the ability of an aquifer to yield water to wells. Transmissivity is a measure of the rate at which water moves through a unit width of an aquifer under a unit hydraulic gradient. The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. Leakance is the ratio of the vertical hydraulic conductivity and the thickness of the confining unit and is a measure of the ability of confining units to leak water to adjacent aquifers. Hydraulic conductivity is defined as the rate of water flow through a unit cross section of an aquifer under a unit hydraulic gradient. Generally, the larger the value for transmissivity and hydraulic conductivity, the more productive the aquifer.

Specific capacity is defined as the well discharge per unit of drawdown. Specific capacities of wells completed in the surficial aquifer system in eastern Indian River County range from 21 to 70 (gal/min)/ft (fig. 20). In the Vero Beach well field, specific capacities range from 9 to 36 (gal/min)/ft (fig. 21). Specific capacities tend to be highest in the areas south of Main Canal and west of the airstrip but decrease to the east and southwest.

Values of transmissivity, storage coefficient, and hydraulic conductivity for the surficial aquifer system at several locations are given in table 2. Transmissivities range from 1,500 ft^2/d at Winter Beach to 11,000 ft^2/d at Sebastian Highlands where the aquifer is mostly shell deposits. At Hobart Park, the aquifer also contains shell deposits, and the transmissivity is 7,900 ft^2/d. Transmissivity values tend to be lower in the shallow rock zone than in the clastic zone. At Vero Beach, where wells penetrate both zones, transmissivities range from 2,400 to 6,300 ft^2/d.

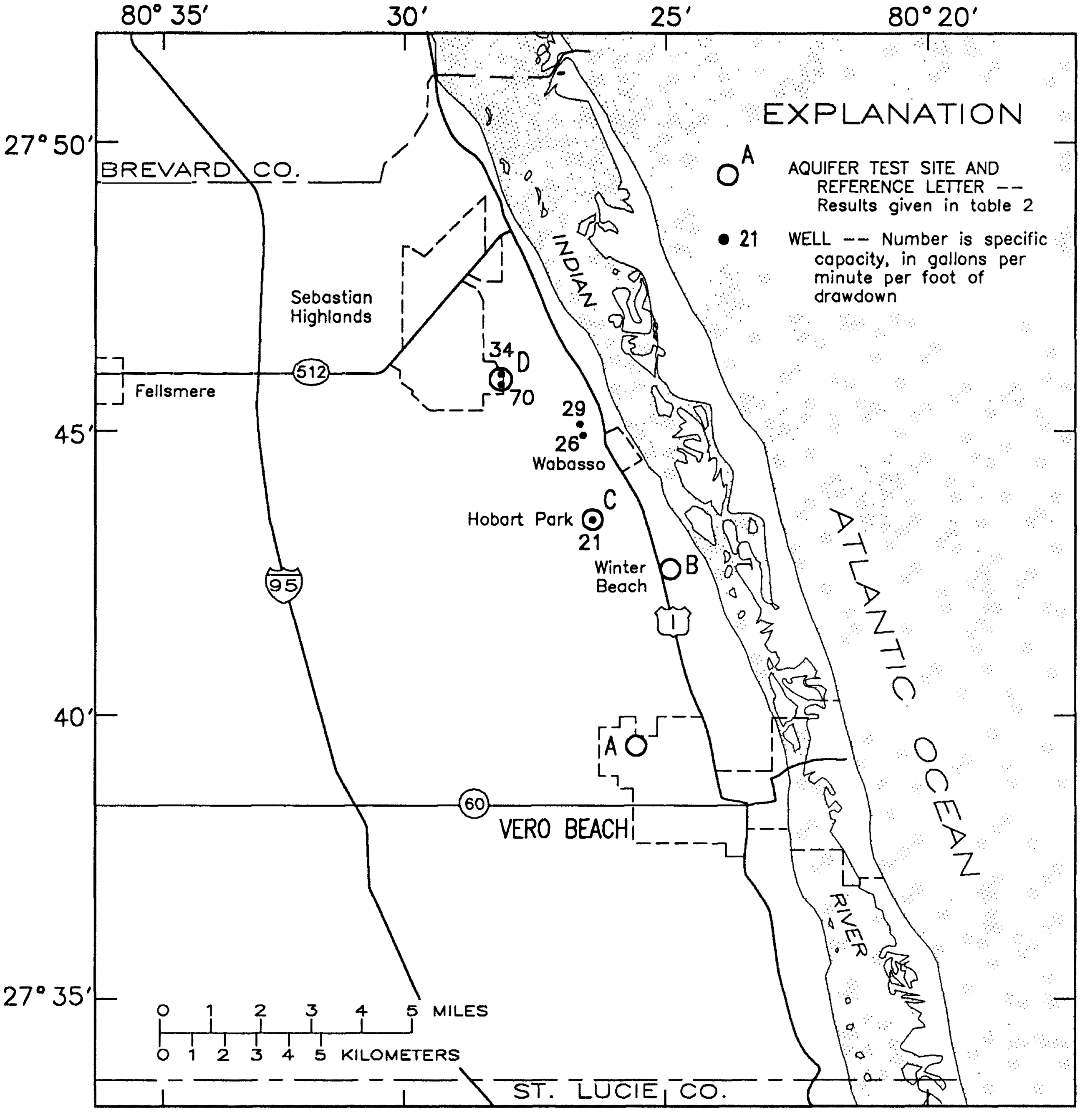


Figure 20.--Specific capacity of wells completed in the surficial aquifer system and location of aquifer test sites in eastern Indian River County.

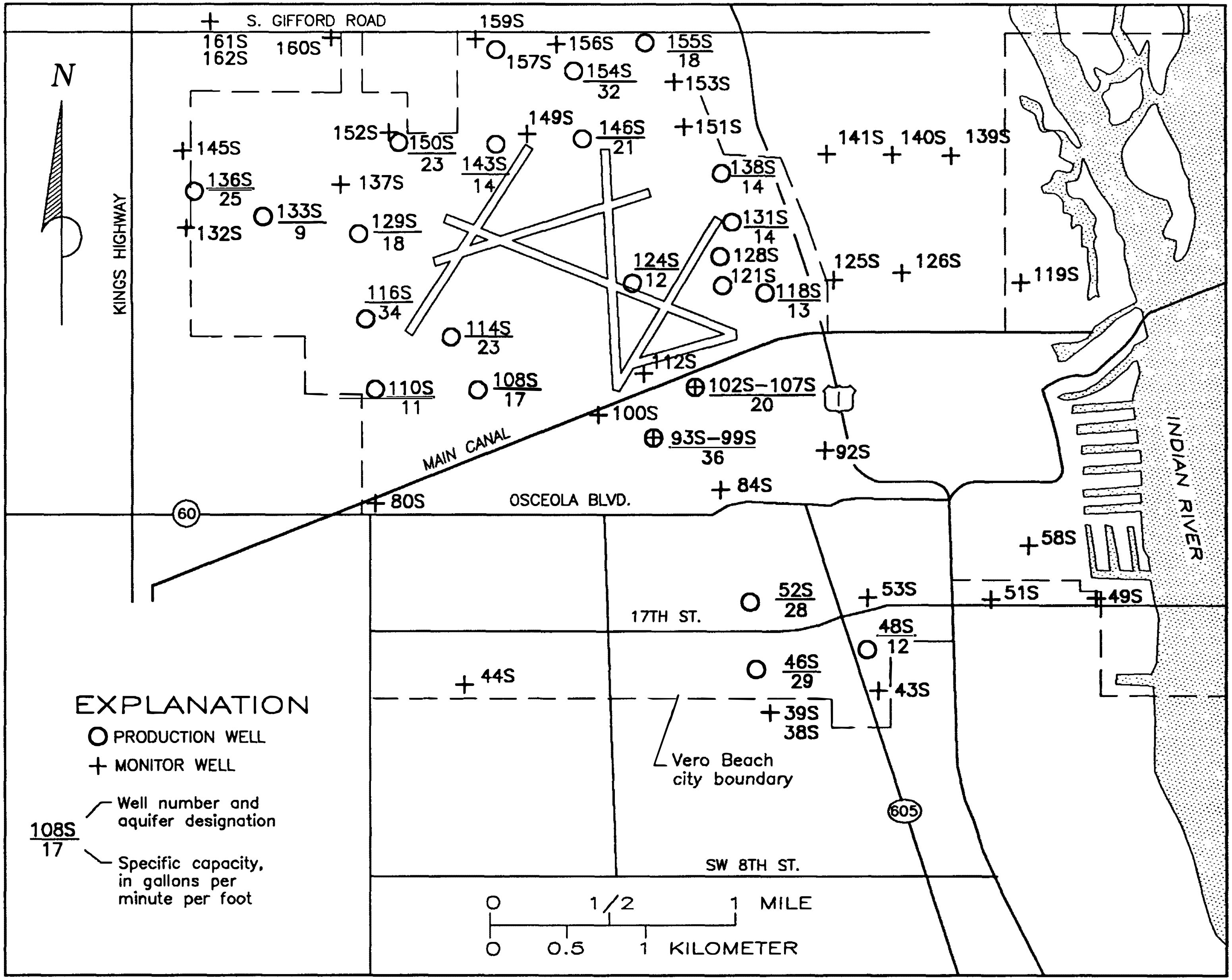


Figure 21.--Specific capacity of wells completed in the surficial aquifer system and locations of production wells and monitor wells in the Vero Beach well field.

Table 2.--Aquifer-test results for the surficial aquifer system at four sites in Indian River County

[ft²/d = feet squared per day; ft/d = feet per day]

Reference letter (fig. 20)	Site location	Transmissivity (T) (ft^2/d)	Storage coefficient (S)	Hydraulic conductivity[1] ft/d	Source of data[2]
A	Vero Beach	2,400-6,300	2.3×10^{-4}	33-80	1
		---	1.5×10^{-1}	---	
B	Winter Beach	1,500-1,900	1.9×10^{-4}	40-48	2
C	Hobart Park	7,900	1.4×10^{-2}	110	3
D	Sebastian Highlands	11,000	1.0×10^{-4}	348	4

[1]Hydraulic conductivity estimated from transmissivity and thickness of aquifer penetrated.

[2]Reference: (1) Gee and Jenson (1980).
(2) Estimated from the hydrograph of a cyclically pumped well (Brown, 1963) using a well at Winter Beach.
(3) Geraghty and Miller (1978).
(4) Geraghty and Miller (1981a).

Storage coefficients for the surficial aquifer system at four sites in Indian River County range from 1.0×10^{-4} at Sebastian Highlands to 0.15 at Vero Beach (table 2). At most of the sites, the zones tested in the surficial aquifer system responded as a leaky artesian aquifer. At Vero Beach, the aquifer at one of two sites tested in the surficial aquifer system acted as an unconfined aquifer (storage coefficient is 0.15).

Hydraulic conductivities of the surficial aquifer system in Indian River County are generally about 40 ft/d (feet per day), but some values may exceed 350 ft/d where shell deposits are extensive.

Description of Wells that Tap the System

For this study, 336 wells in the surficial aquifer system were inventoried (see Supplementary Data I and fig. 2). These wells represent only a small number of the surficial wells that exist in Indian River County. Uninventoried domestic and irrigation wells probably number in the thousands.

Wells that penetrate the clastic zone range from 35 to 90 feet in depth. Well casings generally extend to the top of a producing zone--the remaining depth of hole is commonly screened. Large-yield wells often tap both the clastic zone and the underlying shallow rock zone of the surficial aquifer system. The shallow rock zone is usually left as open hole in wells that penetrate both zones.

The location of production and monitor wells in the Vero Beach well field is shown in figure 21. Supply wells in the Vero Beach well field are 80 to 140 feet deep, have 40 to 65 feet of casing, and are typically completed as open-hole. Yields of wells in the Vero Beach well field range from 250 to 1,200 gal/min. The larger yields are from wells that are deep enough to tap both the clastic and the shallow rock zones, and where the surficial aquifer system is thickest. The lowest yields in the county (less than 10 gal/min) occur in marsh areas in the central part of the county.

Water Levels

Water levels in the surficial aquifer system in the eastern part of the county fluctuate in response to seasonal changes in precipitation, evapotranspiration, and pumping. Water levels also may fluctuate in response to manipulation of flows in these drainage network in the county.

Water levels have been monitored in several observation wells in the surficial aquifer system (fig. 22). Hydrographs showing long-term variations in water levels in the wells are shown in figure 24.

In the southwestern part of the county, at the western edge of the Pamlico terrace (fig. 4), water levels are near land surface. The land surface altitude is about 30 feet at well 134S (fig. 22) and during wet periods water levels may rise above the land surface. Water levels in this well fluctuate between 25 and 31 feet altitude but average about 28 feet (fig. 23).

Hydrographs of daily maximum water levels in wells 239S, 316S, and 217S are shown in figures 23 and 24. At well 239S near Fellsmere (fig. 22) the land surface altitude is about 27 feet. Water levels in that well fluctuate by as much as 2 feet monthly and declined from an altitude of about 26 feet to about 23 feet between September 1982 and May 1983. During the interval between September 1984 and May 1985, levels remained close to an altitude of 25 feet.

At well 316S in Roseland (fig. 22), water levels declined from above 17 to 15 feet altitude between September 1982 and July 1983. Since April 1984, the altitudes of water levels in this well have been above 14.5 feet. At Wabasso School (well 217S, figs. 22 and 24), the altitude of the water level declined from about 9 feet in May 1983 to near 6.5 feet in September 1984. Between March and May 1985, water-level altitudes fluctuated from below 7 to above 11 feet, and averaged 9 feet. The wells at Roseland and Wabasso School are located just west and east of the Atlantic Coastal Ridge where land surface altitudes are 19 and 12 feet, respectively.

The effect of nearby pumping on water levels in the surficial aquifer system was observed at well 39S (see fig. 22 for location). Water-level altitudes in well 39S averaged about 16 feet between May 1983 and April 1984, 14 feet between May and November 1984, and approximately 7.5 feet during January through March 1985. In April 1985, water levels had declined to an altitude of 4 feet. The 10-foot decline in the water level in this well coincided with the startup of a nearby well at Vero Beach (well 46S).

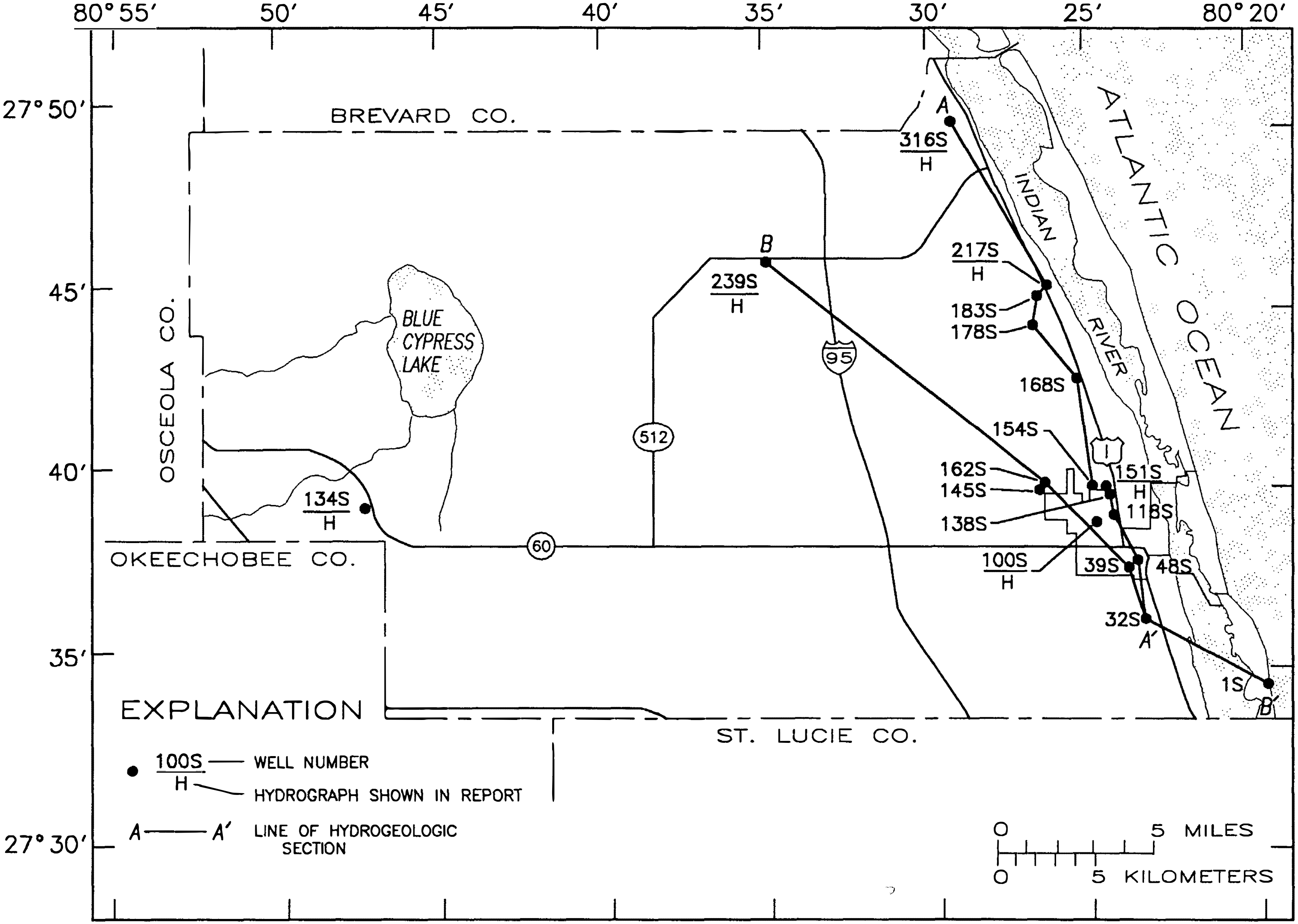


Figure 22.--Locations of wells in the surficial aquifer system for which hydrographs are shown, and lines of hydrogeologic section.

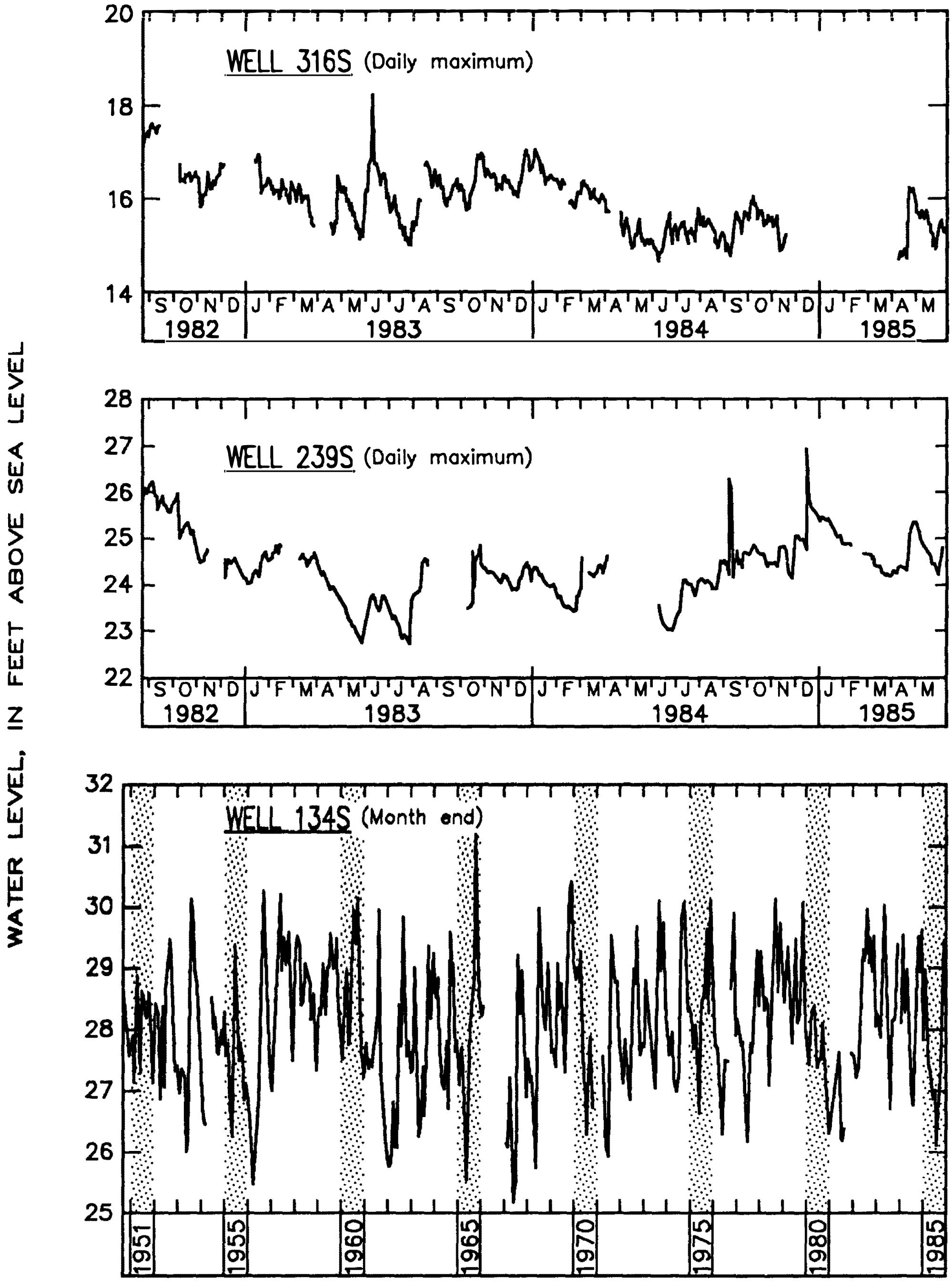


Figure 23.--Water level in wells 316S, 239S, and 134S.

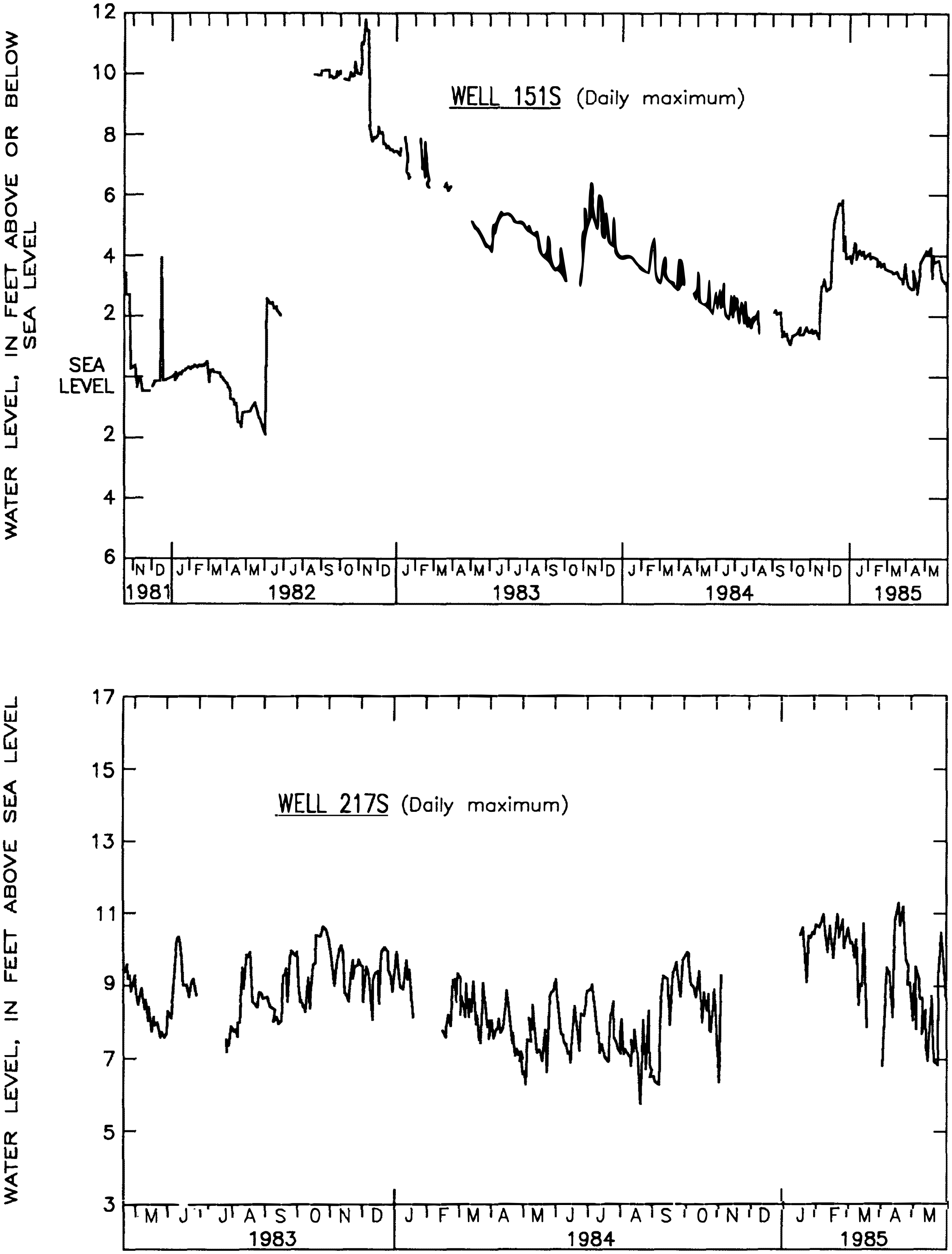


Figure 24.--Water level in wells 151S and 217S.

Water Levels in the Vero Beach Well Field

Water levels in the Vero Beach well field during May 1981 (an unusually dry year) and May 1984 (a year of about average rainfall) are shown in figures 25 and 26. Water levels were measured in monitor and production wells, when pumps were operating, and therefore illustrate the general pattern of the cone of depression caused by well-field pumping. In May 1981, water levels were as low as 39 feet below sea level (fig. 25). Water levels were lowest east and north of the airstrip. In May 1984 water levels at pumping centers were as much as 28 feet higher than in May 1981. Water levels continued to be lowest east and north of the airstrip. The difference in water levels between the first half of 1981 and 1984 is clearly shown in the hydrograph of well 121S in the Vero Beach well field (fig. 27). In 1981, water levels at production well 121S reached more than 37 feet below sea level, but rebounded to near sea level during periods of average rainfall (see rainfall graph in fig. 30). Part of the rise in water level is probably caused by a change in the pattern of pumping in the well field.

Some observation wells, such as 145S and 100S in the Vero Beach well field, are apparently little affected by pumping. Monitor well 145S is west of the well field and monitor well 100S is located adjacent to Main Canal (fig. 22). Water levels in monitor well 145S were lowest during the summer of 1981 and spring of 1985 (fig. 30). Both time intervals coincide with much below-average rainfall periods. Levels in 145S remained high in 1982 when rainfall was above average.

Yields of many wells in the Vero Beach well field decreased in 1981 due to the large drawdowns in the surficial aquifer system caused by long-term continuous pumping. The problem was alleviated by implementing a well-field management program that involved alternating withdrawals between sets of wells spaced far enough apart so as to minimize interfering drawdowns. In addition, a few wells were deepened to penetrate the shallow rock zone, and several wells were installed to replace wells previously abandoned because of low yield. The hydrograph of observation well 151S (fig. 24) illustrates the effect of nearby pumping from production wells prior to mid-1982, and the effect of well field expansion and management since mid-1982.

Figure 28 shows the average monthly daily pumpage for the Vero Beach well field from 1975 to 1985. Pumpage approximately doubled during the 10-year period from 1975 to 1985 and peaked to about 9.5 Mgal/d in the spring during the 1981 drought. Coinciding with the increase in pumpage, however, water levels have declined in the vicinity of the Vero Beach well field. A recent downward trend is shown by the hydrograph of well 151S also in the Vero Beach well field (fig. 24). Water levels reached a low of 5 feet below sea level in June 1982 but rebounded to an altitude of 9.5 feet in September 1982. Since December 1982 water levels have declined and by October 1984 were 1 foot below sea level. A comparison of water levels in the surficial aquifer in the vicinity of the Vero Beach well field in April 22, 1971, (Crain and others, 1975, fig. 28, p. 55) with water levels in May 1984 (fig. 26), indicates a decline of about 15 to 19 feet.

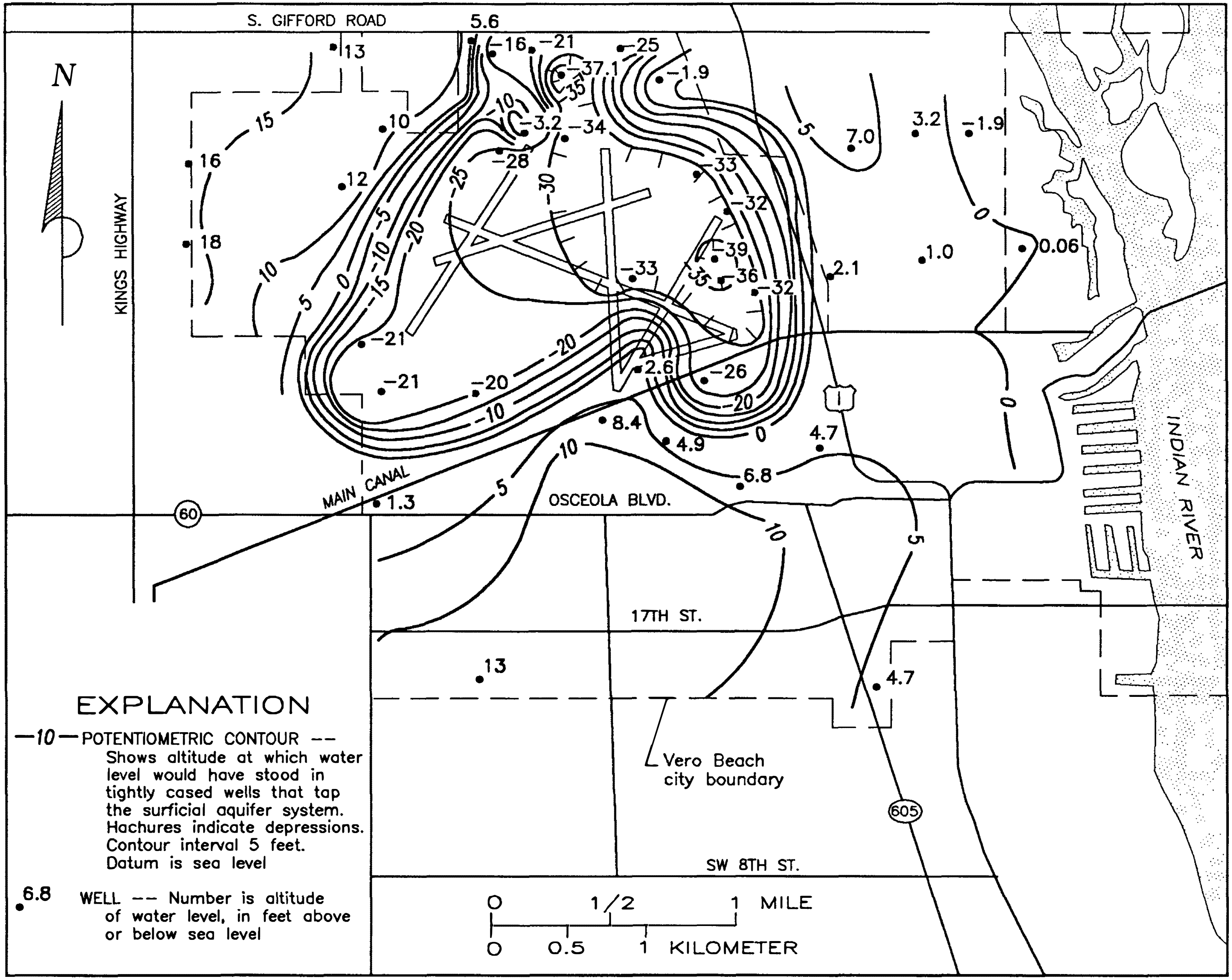


Figure 25.--Potentiometric surface of the surficial aquifer system in the Vero Beach well field, May 1981.

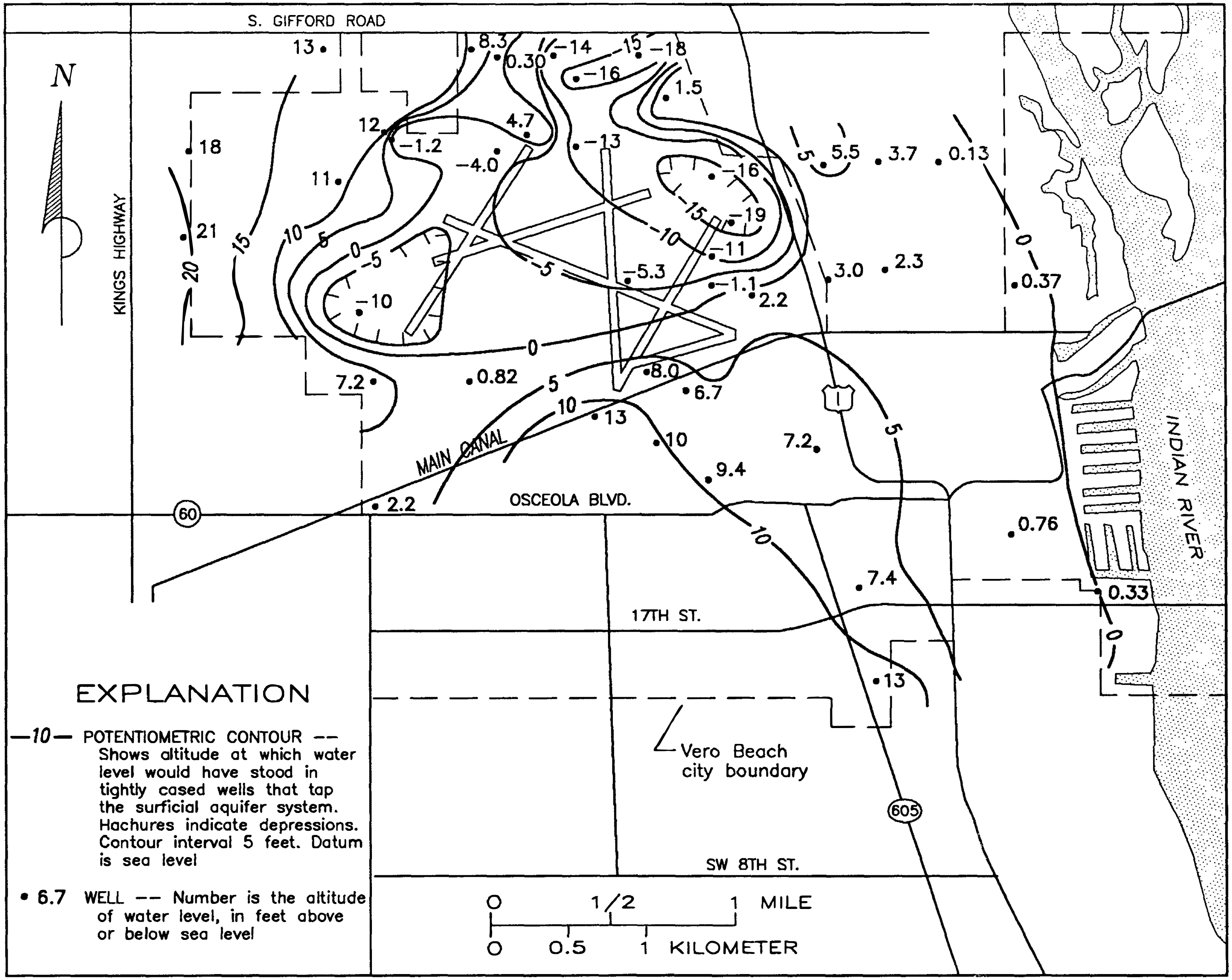


Figure 26.--Potentiometric surface of the surficial aquifer system in the Vero Beach well field, May 1984.

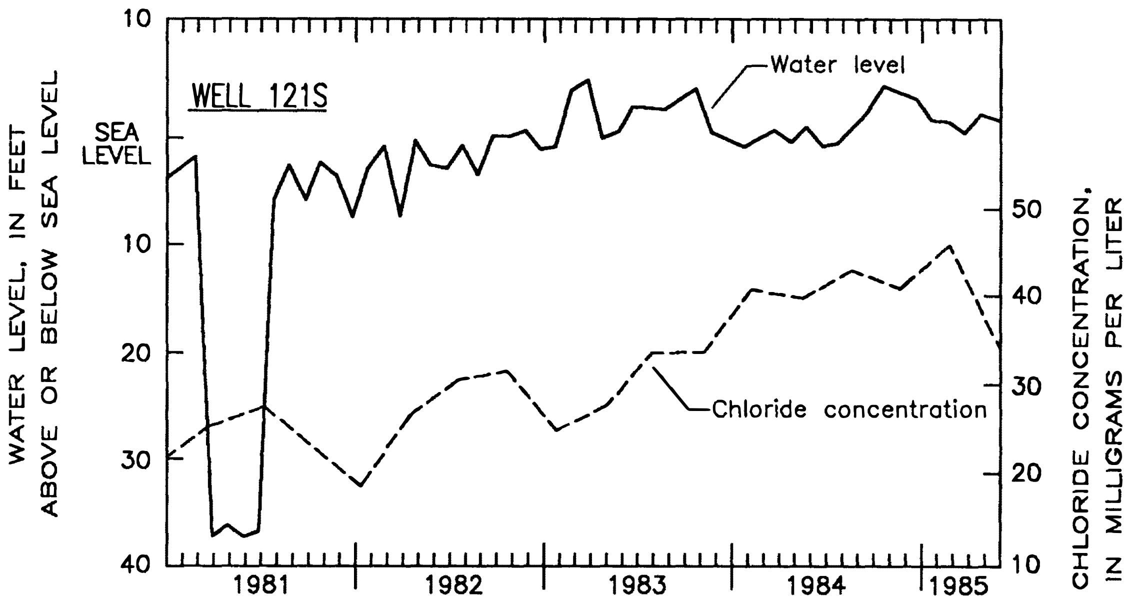


Figure 27.--Water level and chloride concentration of water in well 121S in the Vero Beach well field, 1981-85.

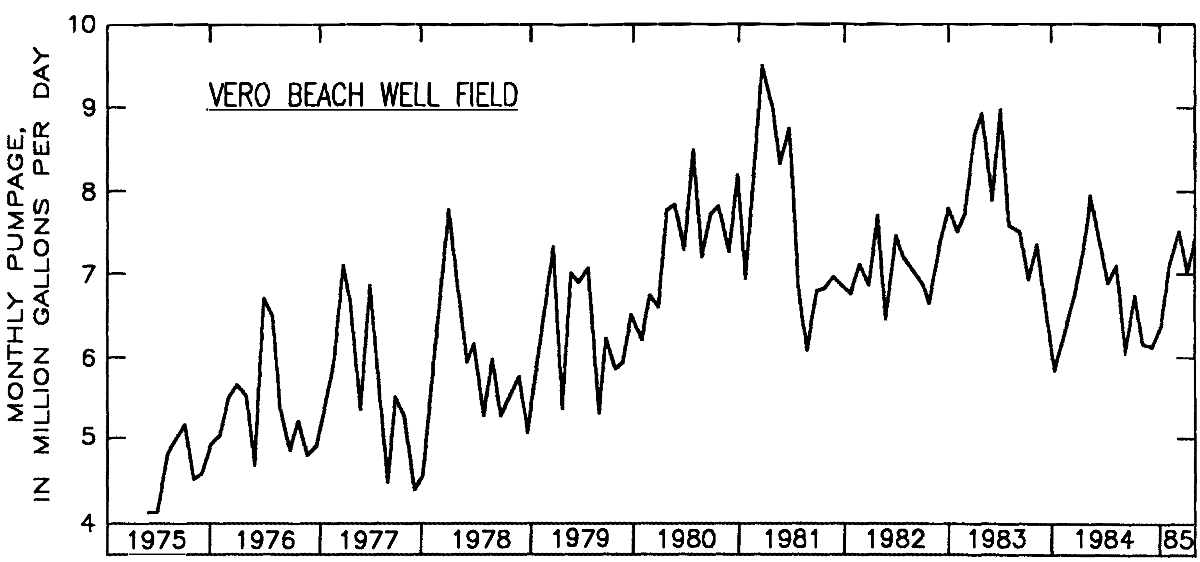


Figure 28.--Monthly pumpage from the Vero Beach well field, 1975-85.

Recharge and Discharge in the System

The surficial aquifer system in Indian River County is recharged mostly by infiltration of rainfall and by some downward percolation of irrigation water. The aquifer system receives little recharge from the underlying Floridan aquifer system because a thick confining unit of low permeability strata (the Hawthorn Formation) effectively separates the surficial and Floridan aquifer systems. Discharge from the surficial system occurs as seepage to the ocean, lakes, rivers, and canals, evapotranspiration, and withdrawals from wells.

Some recharge to the surficial aquifer system may occur from the canal system. For example, maximum stage fluctuations in Main Canal and water-level fluctuations of monitor well 100S (adjacent to Main Canal) are strikingly similar (fig. 29). When maximum stage is greater than the water level in well 100S, such as in the spring of 1981-82, water in Main Canal probably recharged the surficial aquifer.

The water level in the surficial aquifer system rises and declines during wet and dry periods in response to recharge and discharge. The hydrograph of well 145S (fig. 30) illustrates the relation between monthly rainfall at Vero Beach and water levels in the well. The water level in well 145S rose 5.7 feet in response to the rainfall of 16 inches in August 1981 and an attendant reduction in pumpage.

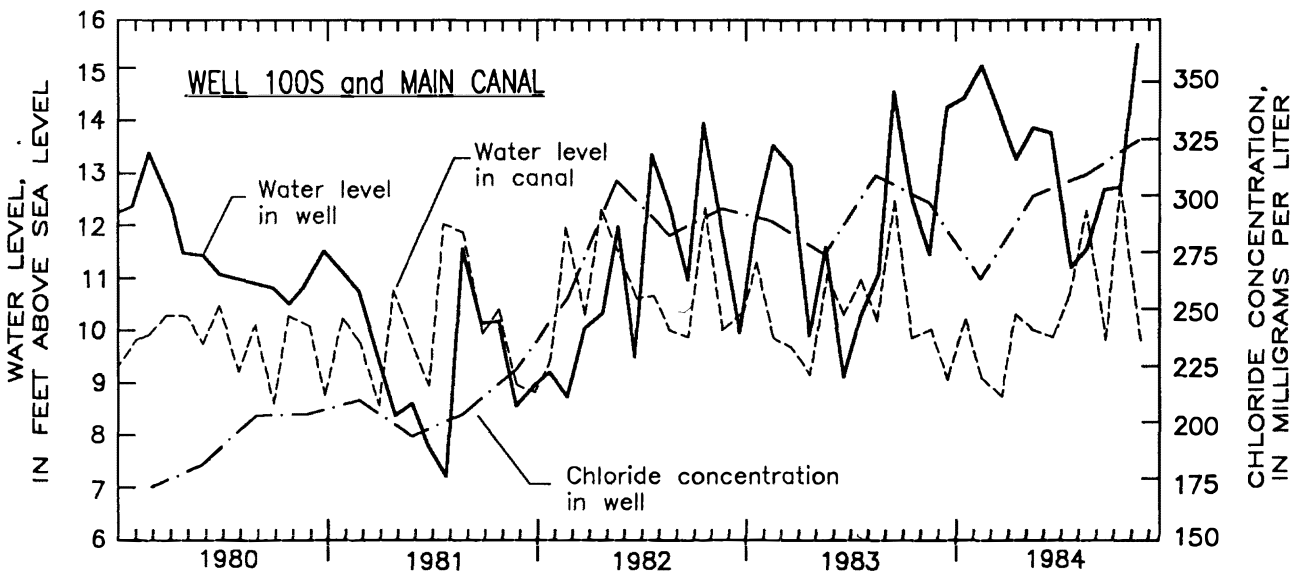


Figure 29.--Water level and chloride concentration of water in well 100S, and stage of Main Canal, 1980-84.

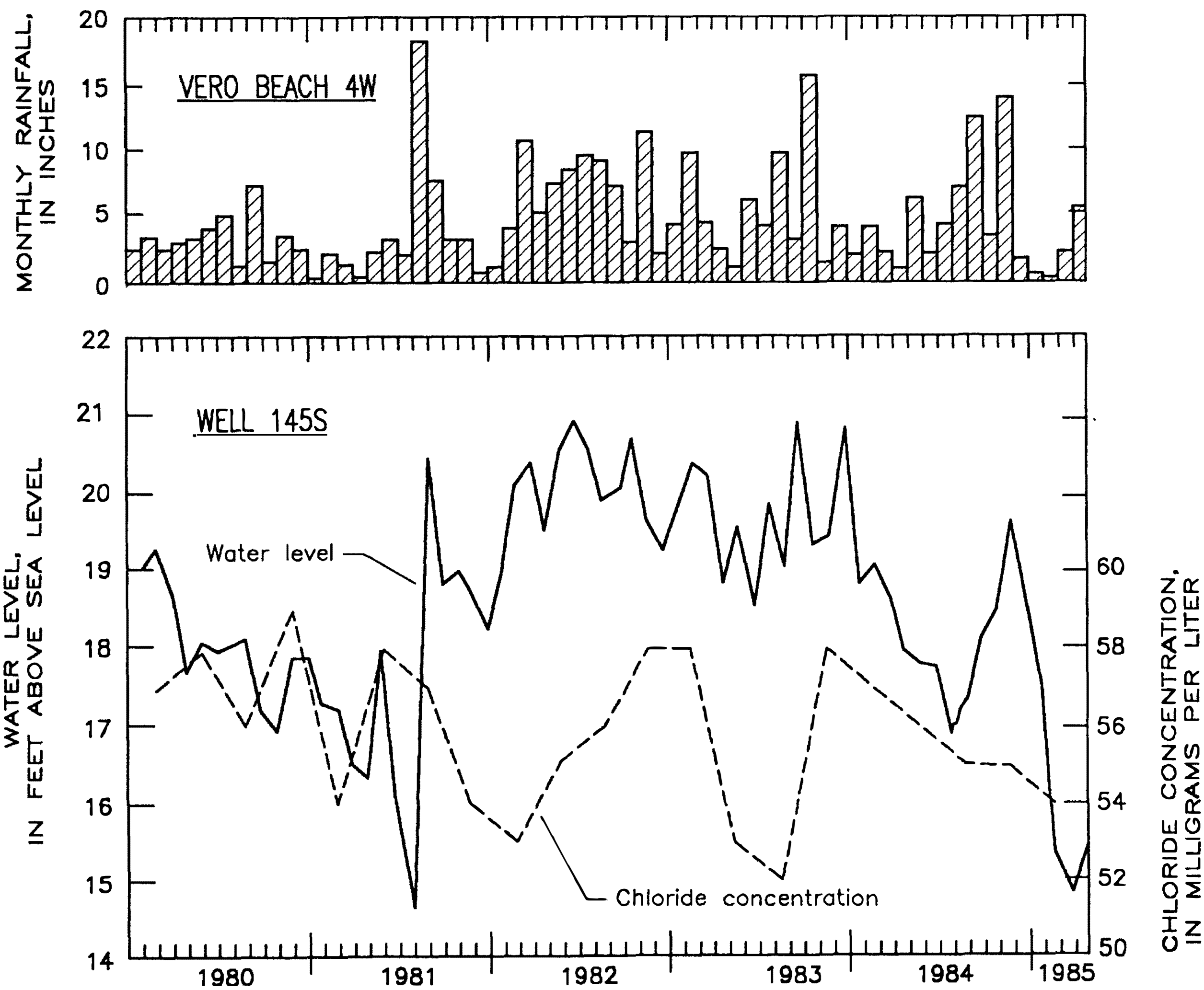


Figure 30.--Water level and chloride concentration of water in well 145S, and monthly rainfall at Vero Beach, 1980-85.

In places, head differences in the clastic and shallow rock zones allow ground-water movement from one zone to the other. To observe the head-difference relations, observation wells were installed in both the shallow rock zone and the clastic zone at several sites throughout the county. The well locations, well numbers, and selected water-level data are given in table 3 and figures 1 and 21. Comparison of water levels in the shallow rock and clastic zones at Vero Beach Elementary School (39S, 38S), South Gifford Road (162S, 161S), Wabasso (178S, 177S), and Roseland (316S, 317S) show little head difference (table 3). However, at the South Canal (31S, 32S), Winter Beach (168S, 167S), Wabasso School (217S, 216S), and Fellsmere (239S, 240S) the heads in the zones differ. This difference in head and location of wells can be used to define a pattern of recharge and discharge. West of the Atlantic Coastal Ridge, in wells 239S, 240S, 168S, and 167S, water levels are higher in the clastic zone than in the shallow rock zone; therefore, in this area, the clastic zone recharges the underlying shallow

Table 3.--Water levels in wells in the clastic zone and shallow rock zone

Well No.	Location	Aquifer	Water level, in feet above sea level: Feb-Mar 1983	Dec 1983	April 1984	March 1985
31S	South Canal	Shallow rock zone	9.8	9.6	8.1	6.6
32S		Clastic zone	7.8	6.7	6.1	5.4
39S	Vero Beach	Shallow rock zone	19.1	17.0	18.3	11.1
38S	Elementary School	Clastic zone	19.2	17.6	18.1	10.9
162S	South Gifford	Shallow rock zone	19.9	17.0	16.2	14.4
161S		Clastic zone	20.1	17.3	16.7	15.1
168S	Winter Beach	Shallow rock zone	16.4	14.7	14.8	13.8
167S		Clastic zone	18.1	16.1	17.0	15.3
178S	Wabasso	Shallow rock zone	18.2	16.5	16.7	15.0
177S		Clastic zone	19.9	16.7	17.3	15.2
217S	Wabasso School	Shallow rock zone	13.6	11.7	11.7	10.8
216S		Clastic zone	11.7	10.6	10.6	10.2
239S	Fellsmere	Shallow rock zone	25.6	24.1	24.9	23.6
240S		Clastic zone	--	24.7	25.9	24.3
316S	Roseland	Shallow rock zone	17.9	16.8	16.7	16.6
317S		Clastic zone	18.3	16.8	17.4	16.0

rock zone. East of the ridge, in wells 31S, 32S, 217S, and 216S, water levels are higher in the shallow rock zone than in the clastic zone; here the shallow rock zone discharges to the overlying clastic zone.

Water Quality

General

In coastal areas, ground water in the surficial aquifer system may be very saline as a result of lateral saltwater intrusion. In agricultural areas, the salinity of surficial ground water may be high because of the salinity of irrigation water or contamination of the shallow ground water with deeper, more saline water, through deteriorated or leaking well casings.

Table 4 lists representative analyses of water from 8 wells in the shallow rock zone, 7 wells in the clastic zone, and 1 well in the shallow rock zone (1S) that probably contains intruded saltwater. Also given in the table are ranges of concentrations of selected constituents in water from 39 wells in the shallow rock zone (depth >75 feet) and 51 wells in the clastic zone (depth <75 feet).

Table 4.--Representative analyses and ranges in concentrations of constituents in water from wells completed in the clastic and shallow rock zones of the surficial aquifer system

[Concentrations are in milligrams per liter]

REPRESENTATIVE ANALYSES

Well No.	Depth (feet)	Sodium	Potassium	Calcium	Magnesium	Iron	Hardness	Bicarbonate	Chloride	Sulfate
Clastic zone (<75 feet in depth)										
32S	53	26	0.7	105	6.5	0.92	289	330	48	21
38S	55	12	.6	76	4.3	.67	208	224	16	9
161S	53	39	13.3	158	7.9	2.9	428	540	51	<1
167S	53	32	2.4	54	3.2	1.6	148	464	65	20
177S	41	18	.4	87	2.5	.3	227	366	40	0
216S	49	67	.9	84	2.9	.05	222	310	120	40
317S	35	14	2.8	5.1	3.2	.13	25.9	26.8	26	1
Shallow rock zone (>75 feet in depth)										
1S[1]	147	14,000	500	630	1,900	22.0	9,393	922	30,250	4,000
31S	143	30	5.6	63	9	1.5	194	291	41	<1
39S	123	43	4.5	90	8.7	.5	261	322	60	<1
162S	150	44	1.9	112	8.4	2.9	315	372	73	<1
168S	144	19	3.7	84	3.9	8.2	226	464	25	0
178S	137	39	2.0	78	6.0	3.1	220	337	40	0
217S	133	26	7.1	26	18	.4	139	239	35	0
239S	140	44	10	27	16	.6	133	209	45	0
316S	134	35	2.9	36	21	1.2	176	197	50	0

RANGES OF CONCENTRATIONS

Range	Sodium	Potassium	Calcium	Magnesium	Iron	Hardness	Bicarbonate	Chloride	Sulfate
Clastic zone (51 wells <75 feet in depth)									
Low	11	2	21	2	0.3	180	169	20	0
High	520	13.3	158	76	8.1	328	540	535	280
Shallow rock zone (39 wells >75 feet in depth)									
Low	16	0.5	24	0.5	0.3	240	154	10	0
High	160	10	162	53	8.2	434	390	415	185

[1]Indicates lateral intrusion.

Occurrence of Chlorides

Chloride concentrations of water from wells more than 75 feet deep in the surficial aquifer system in eastern Indian River County are below 100 mg/L, except in an area along Sebastian Creek and along the Indian River near the Vero Beach well field, where concentrations are above 250 mg/L (fig. 31). In this figure, the 250 mg/L chloride line generally parallels the Indian River but bows inland toward the Vero Beach well field. Chloride concentrations increase from about 250 mg/L just east of the Vero Beach well field to more than 20,000 mg/L near the Indian River.

Chloride concentrations of water from wells 40 to 75 feet deep in the clastic zone also increase in an easterly direction, but values are not as high along the Indian River (fig. 32). Chloride concentrations west of the Indian River are generally less than 250 mg/L. Between the Vero Beach well field and the Indian River, chloride concentrations range from 50 to 100 mg/L. Concentrations greater than 250 mg/L occur in a small area bisected by Main Canal west of the Vero Beach well field, in the Sebastian Creek area, and on the Barrier Island.

Many wells in the Floridan aquifer system are cased to the top of the Hawthorn Formation, are more than 20 years old, and were constructed with steel casing that may be corroded through. Eastern Indian River County is a discharge area of the Floridan aquifer system and corroded-through casings of wells that tap the system could allow water from the Floridan aquifer system to intrude into the surficial aquifer system. Six cross sections in the eastern part of the county (fig. 33) show the relation between chloride concentration in ground water and the depths of wells (figs. 34-37). Interpretation of data shown in the cross sections indicates several patterns of chloride occurrence. Water from a few wells deeper than 80 feet have higher chloride concentrations than adjacent wells of near the same depth (figs. 34 and 35). The high concentrations may be due to intrusion of the shallow rock zone by more saline water from nearby wells in the Floridan aquifer system.

Sections E-E' and G-G' (figs. 35 and 36) show high chloride concentrations in water from a few wells less than about 80 feet deep. Along cross-section E-E' (fig. 35), chloride concentrations of water in three wells in the surficial aquifer system with depths less than 25 feet equal or exceed 180 mg/L. Along section G-G' (fig. 36), the lowest chloride concentration in water from the nine wells plotted in the Floridan aquifer system is 180 mg/L. The high chloride concentrations found in water from these relatively shallow wells in the surficial aquifer system may be due to downward seepage of irrigation water from the Floridan aquifer system or from wells in the Floridan aquifer system with corroded-through casings near the water table. The city of Vero Beach and the St. Johns River Water Management District have plugged several wells in the Floridan aquifer system that were leaking relatively high chloride concentration water into the surficial aquifer system through corroded casings. A common practice in the development of citrus groves into an urbanized area has been to bury existing wells in the Floridan aquifer system. As a consequence, the location of many wells in the Floridan aquifer system that potentially could cause intrusion problems is unknown.

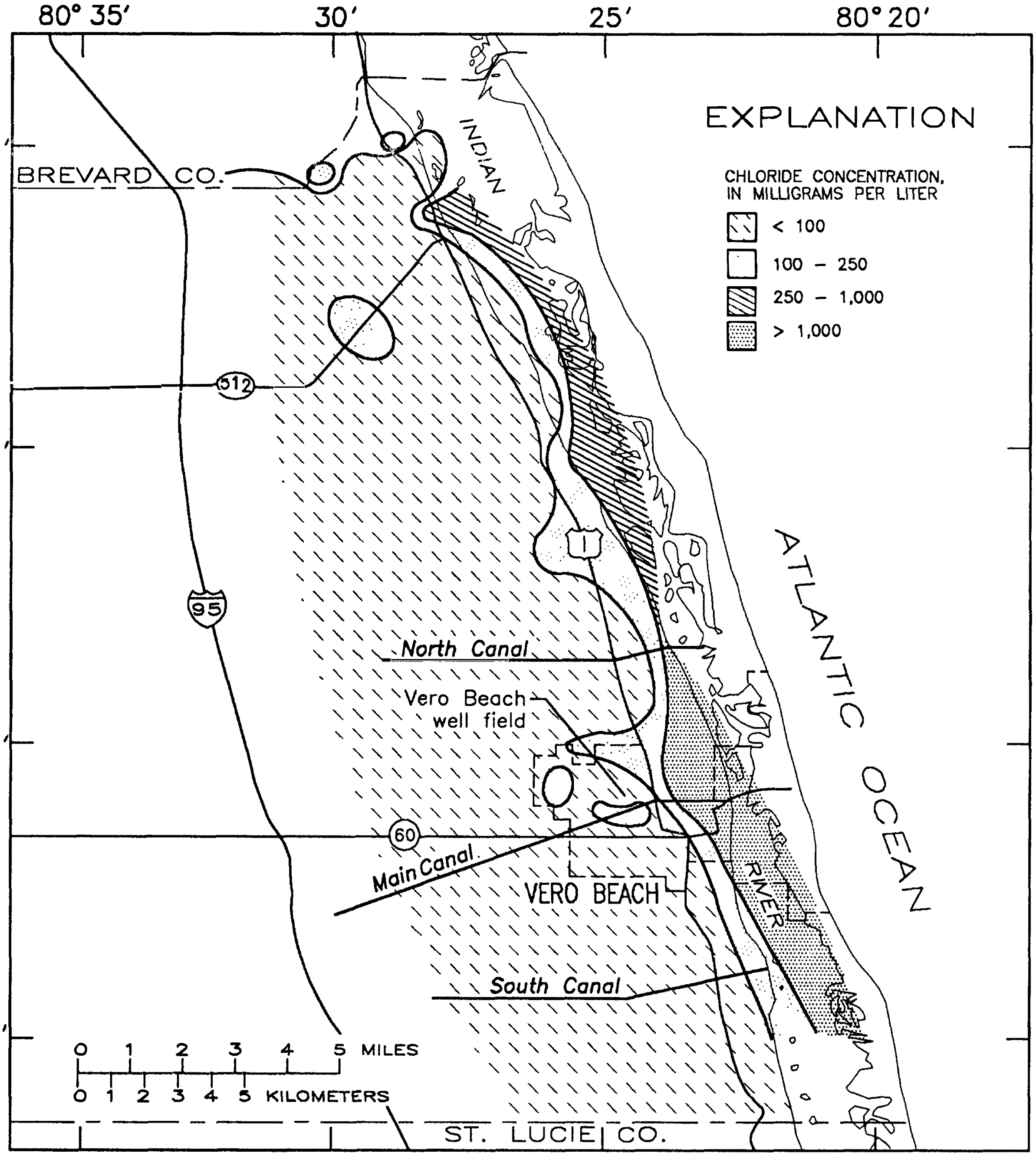


Figure 31.--Chloride concentrations in water from wells completed in the shallow rock zone (depths greater than 75 feet), 1982-83.

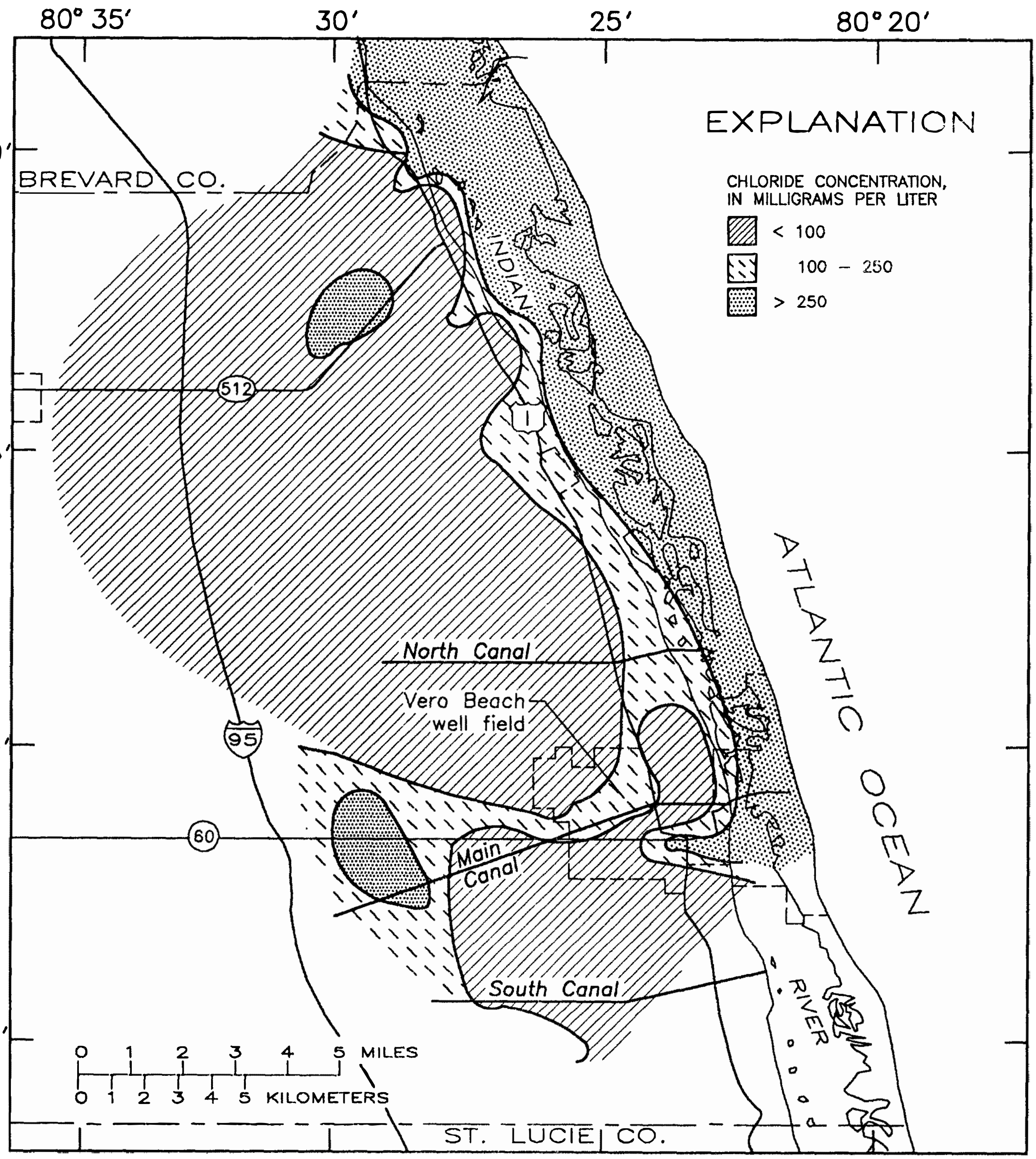


Figure 32.--Chloride concentrations in water from wells completed in the clastic zone (depths between 40 and 75 feet), 1982-83.

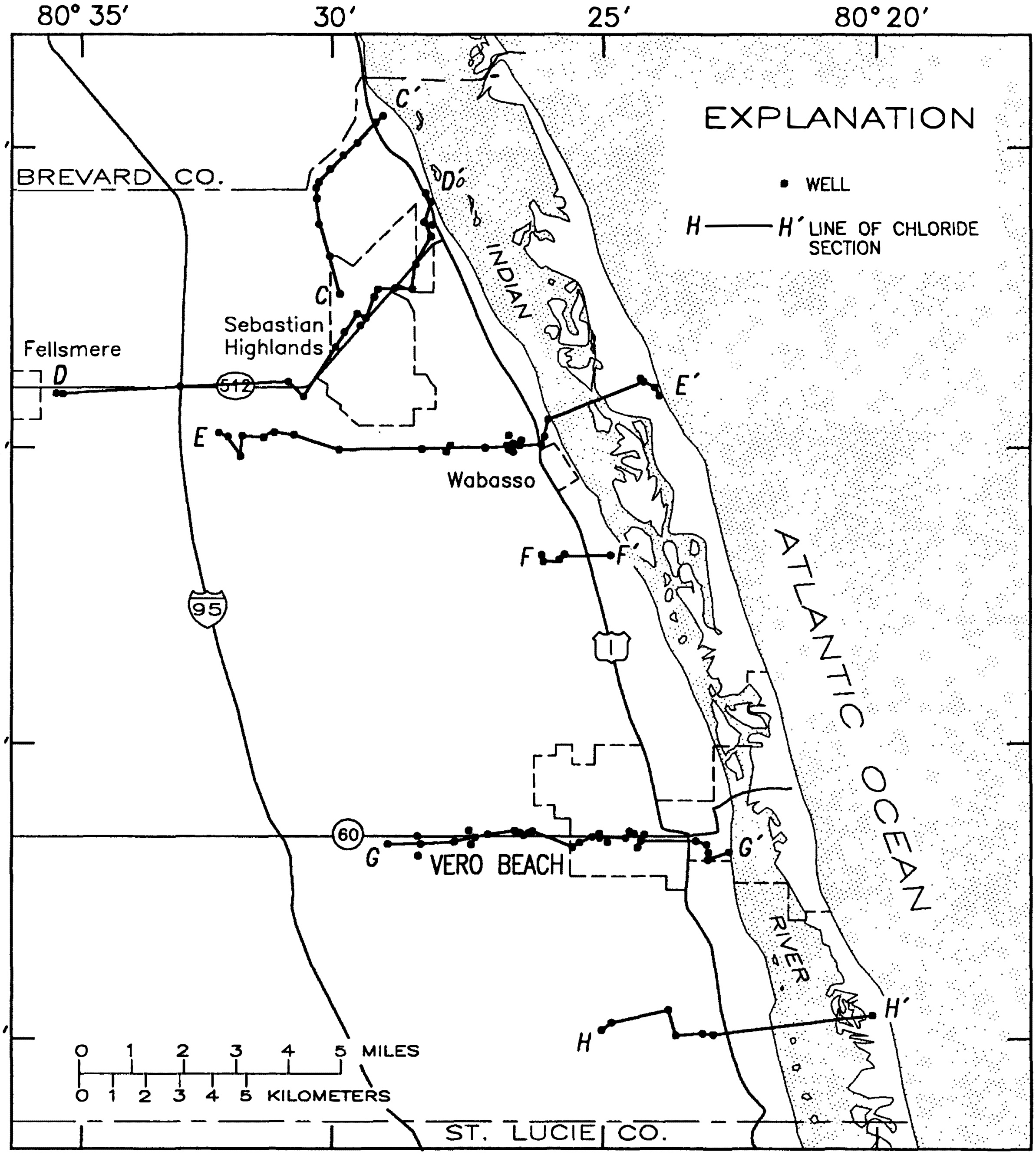


Figure 33.--Location of lines of chloride sections (sections shown in figs. 34-37).

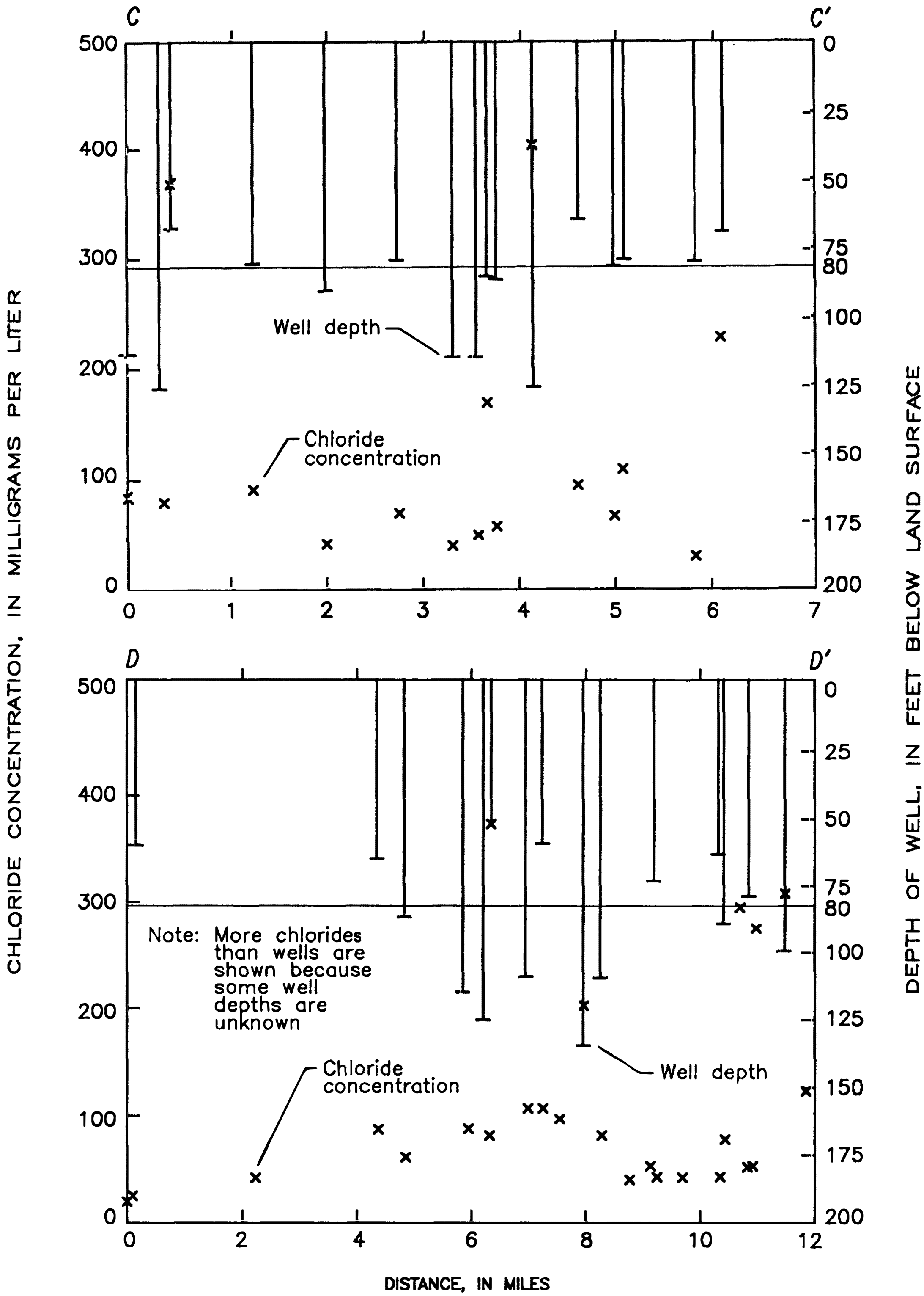


Figure 34.—Chloride concentrations in water and depth of wells in the surficial aquifer system along lines of section *C–C'* and *D–D'* (lines of section shown in fig. 33).

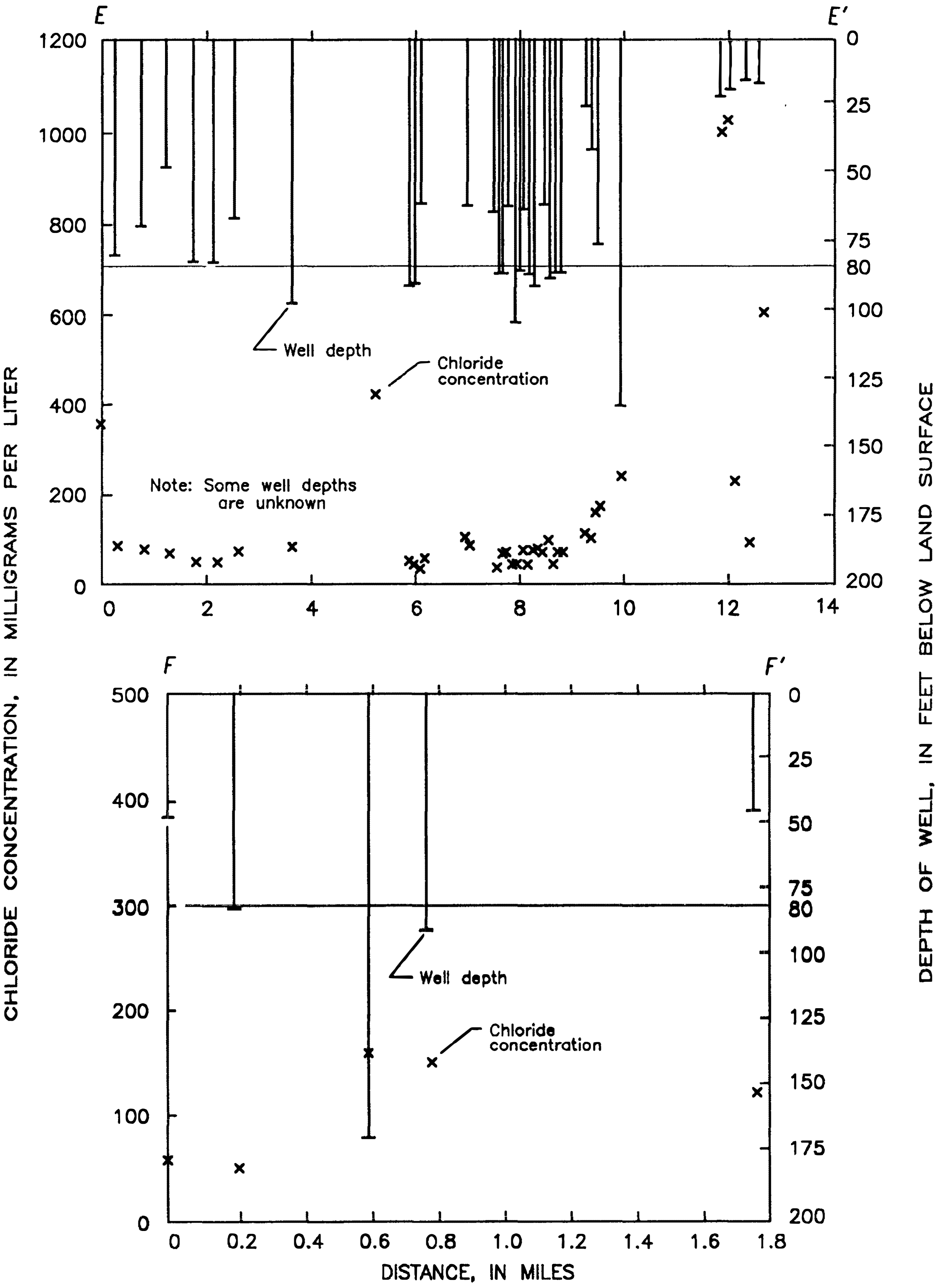


Figure 35.—Chloride concentrations in water and depth of wells in the surficial aquifer system along lines of section *E – E′* and *F – F′* (lines of section shown in fig. 33).

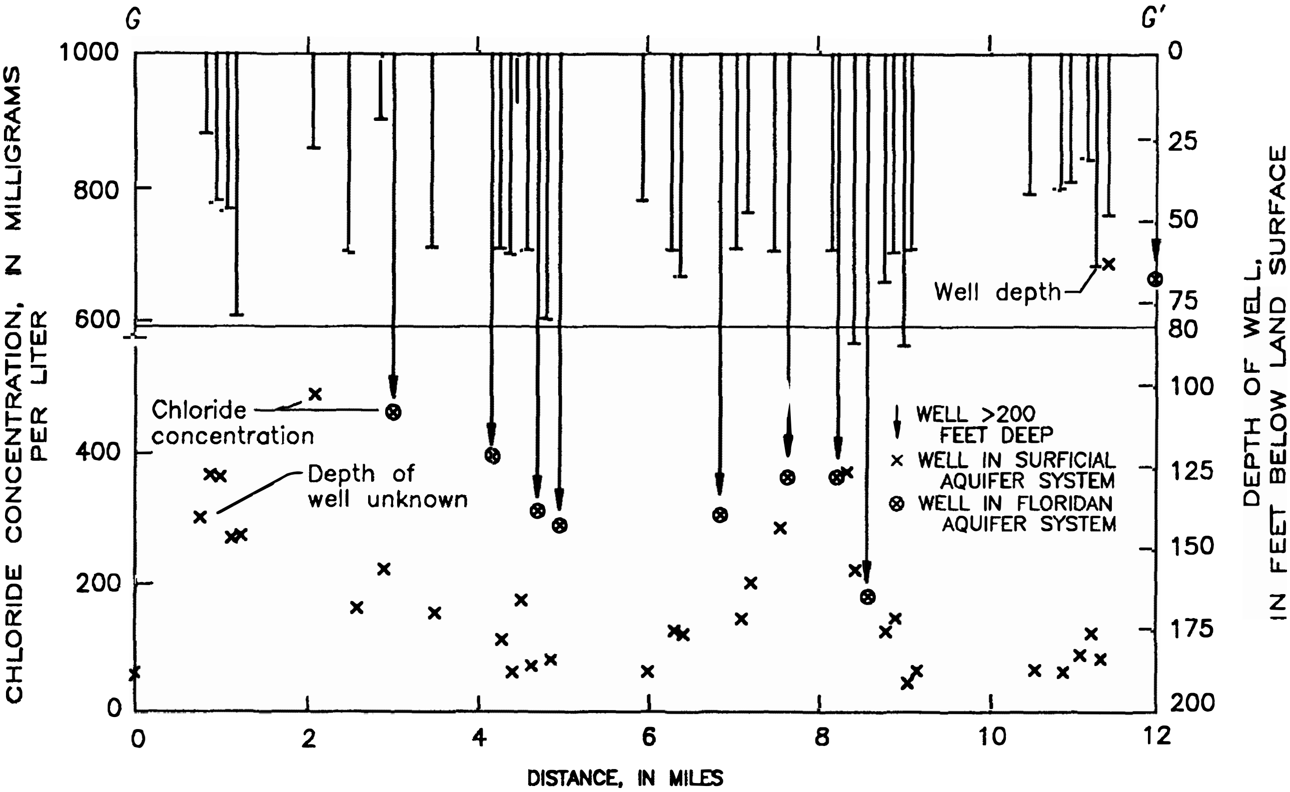


Figure 36.--Chloride concentration in water and depth of wells in the surficial and Floridan aquifer systems along line of section *G-G'* (line of section shown in fig. 33).

Areal patterns of occurrence and depth of occurrence of high chloride concentrations in water from wells often suggest a particular source for the high concentration. For example, when the chloride concentrations of water from wells increase with depth and are anomalously high, such as in the Sebastian Creek area, the cause may be intrusion by leakage, at depth, of water from wells that tap the Floridan aquifer system. Also, in areas where the chloride concentration of water is higher in a shallow well than in nearby deeper wells, such as west of Vero Beach straddling State Road 60, the cause is probably downward infiltration of Floridan aquifer system irrigation water or seepage from system wells. Along the coastal sections of Indian River County, the high chloride concentrations of water in many of the wells greater than 40 feet deep is probably due to the lateral intrusion of seawater.

Occurrence of Chlorides in the Vero Beach Area

Chloride concentrations in water from observation wells in the Vero Beach well field change in response to water-level fluctuations (see figs. 29 and 30) caused by pumping (discharge) and by recharge. Concentrations generally increase when water levels decline and decrease when water levels rise. However, in monitor well 100S, located just south of Main Canal, chlorides have increased though water levels are trending upward. Between

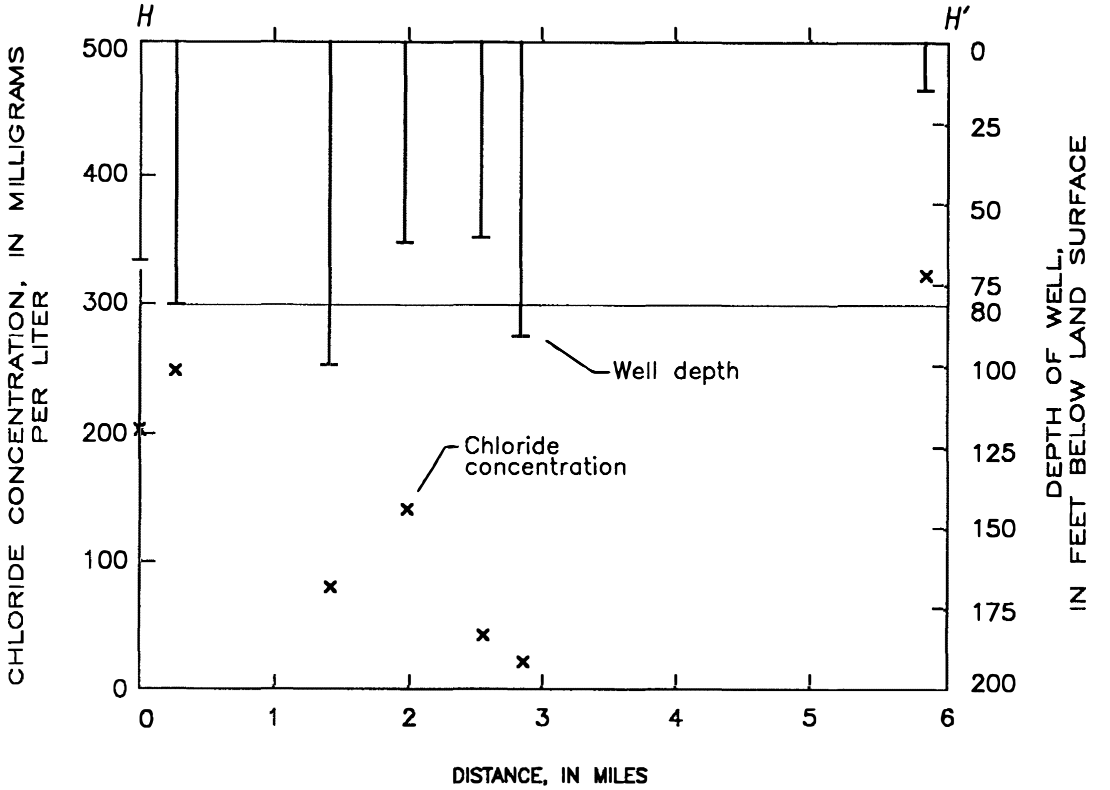


Figure 37.--Chloride concentration in water and depth of wells in the surficial aquifer system along line of section *H-H'* (line of section shown in fig. 33).

September 1981 and June 1982, chloride concentrations increased linearly to about 300 mg/L, and through 1983 and 1984 averaged about 300 mg/L (see figs. 39 and 40). The high chloride concentration found in well 100S and observation wells 84S and 95S may indicate a plume of high chloride water moving toward the southeast (fig. 39). Chloride concentrations of 320 and 144 mg/L also occurred south of Main Canal in observation wells 95S and 84S, respectively, (fig. 21) in June 1984 (fig. 40). The high chloride concentration in water from wells 100S, 95S, and 84S may be due to leakage from the corroded-through casings of wells in the Floridan aquifer system or recharge of high chloride concentration water from the canal when ground-water levels are periodically lower than the maximum stage of Main Canal (fig. 29).

Chloride concentrations during the period 1979 to 1984 are shown for three salinity observation wells (wells 119S, 125S, and 126S, fig. 23) in figure 38. In June 1981, water in salinity observation well 126S, located between the Vero Beach well field and the Indian River (fig. 21), had a chloride concentration of 4,900 mg/L. A year later, following the 1981 drought, the concentration increased to 14,000 mg/L. However, during above normal precipitation periods in 1983 and 1984, chloride concentrations were about 4,500 mg/L (fig. 38). The rise and fall of chloride concentrations in well 126S indicates that the position of the freshwater-saltwater interface probably fluctuates in response to rainfall and withdrawals from wells. During extremely dry periods, the interface moves toward the well field. The amount of movement, however, may be small. Chloride concentration in salinity observation well 125S, located 1,000 feet west of 126S, remained virtually unchanged between 1979 and 1984 (fig. 38).

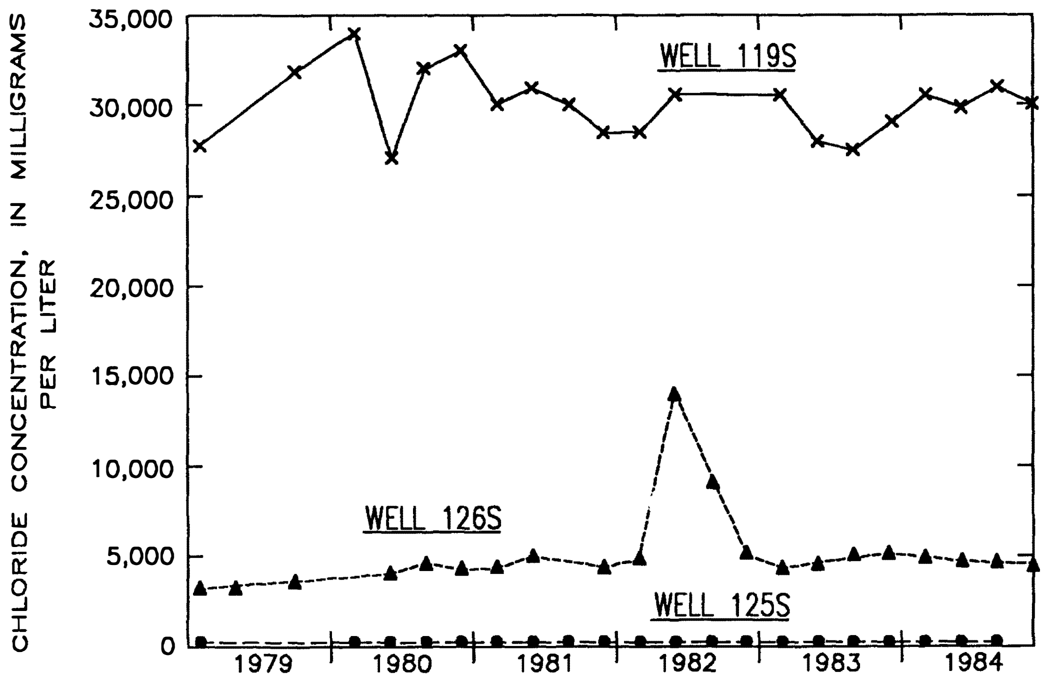


Figure 38.--Chloride concentrations in water from three salinity observation wells, 1979-84.

Chloride concentrations in the Vero Beach well field in June 1981 and June 1984 are shown in figures 39 and 40. Excluding the area east of the well field, the highest chloride concentrations generally occur south of Main Canal. Concentrations are lowest in the area of the airstrip (fig. 39), coincident with the area of maximum drawdown in the well field. The low chloride concentrations in the area of maximum drawdown may be due to a high recharge rate that captures relatively high quality rainfall in that area. Pumping, therefore, causes the water table to decline and thus provides room for fresh recharge water to be stored. A comparison of the chloride maps in figures 39 and 40 indicate that the position of the 1,000 mg/L chloride line did not change appreciably between 1981 and 1984.

Chloride concentrations of water in most wells in the Vero Beach well field have changed little in recent time, (see fig. 27 as an example). Between 1976 and 1983, the average chloride concentration increased about 36 mg/L in six production wells and was unchanged in four others. The increases in chloride concentrations were from scattered wells and are probably related to the increase in well field pumpage from 5.44 Mgal/d in 1976 to 8.00 Mgal/d in 1983 (fig. 27).

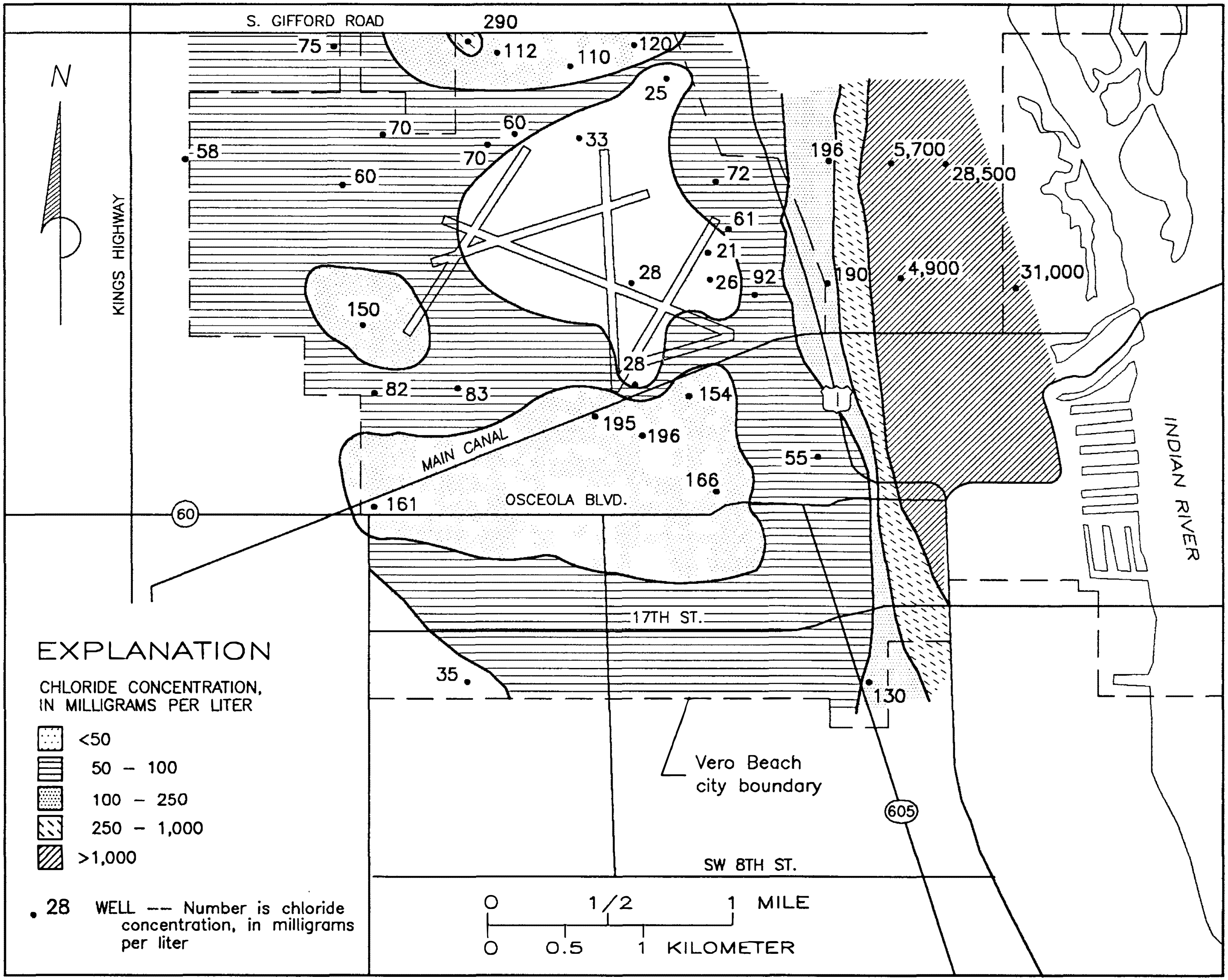


Figure 39.--Chloride concentrations in water from wells that tap the surficial aquifer system in the Vero Beach well field, June 1981.

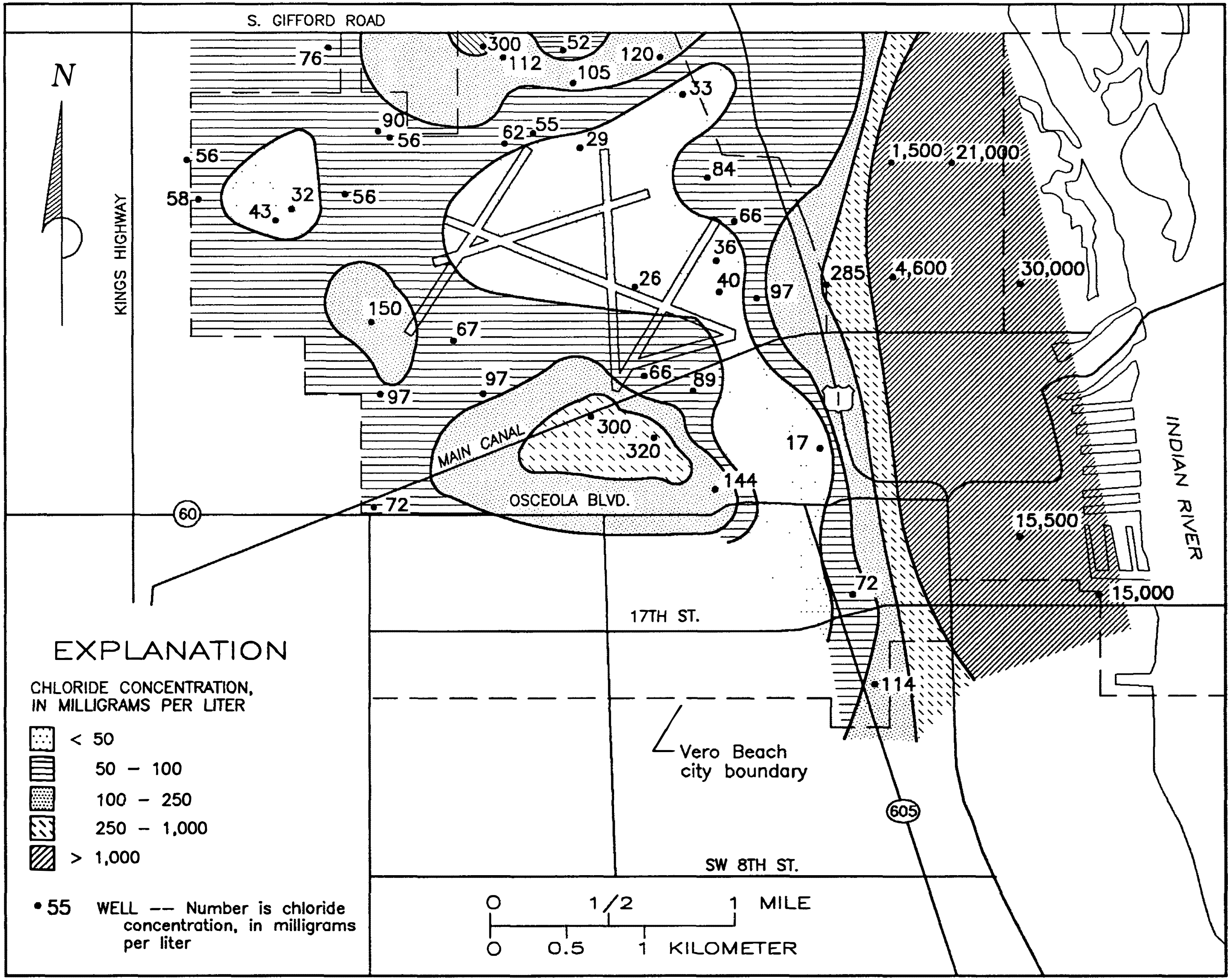


Figure 40.--Chloride concentration in water from wells that tap the surficial aquifer system in the Vero Beach well field, June 1984.

Potential Development

Tibbals (1978, p. 11) related evapotranspiration to the depth of the water table in east central Florida. Assuming this expression is valid for Indian River County where the water table averages 2 feet below land surface, evapotranspiration in the county is about 42 in/yr (inches per year). If the 42 in/yr of evapotranspiration is subtracted from an average rainfall of about 52 in/yr for eastern Indian River County, and assuming no runoff, the remainder of about 10 in/yr is net natural recharge to the surficial aquifer system in eastern Indian River County.

On the basis of hydrologic characteristics of the 140-mi^2 area that lies between U.S. Highway 1 and I-95, and assuming the surficial aquifer system receives 10 in/yr of natural recharge in that area, about 67 Mgal/d of water is theoretically available for withdrawal from the system in eastern Indian River County. It should be recognized that the estimate of availability was obtained from a simplified solution of a complex problem. The theoretical and actual amount of water available for withdrawal may differ considerably due to the many factors not considered. For example, not all the theoretical amount of water available can be withdrawn--some water is retained in the aquifer. Also, if the natural recharge rate is altered by development, additional or lesser amounts of water may be available. However, the amount indicated implies that sufficient water for public supply may be available for future use in the county if withdrawals are properly managed.

In east Indian River County, high-yielding wells completed in the surficial aquifer system are most likely to be found along the Atlantic Coastal Ridge west of U.S. Highway 1. In places, however, water quality there may not be acceptable because of high concentrations of undesirable constituents. Wells that tap both the clastic zone and the shallow rock zone will probably be the most productive.

In places, uncontrolled flowing wells that tap the Floridan aquifer system have apparently allowed high-chloride water to intrude into the surficial aquifer system. Some of these wells have been plugged by the St. Johns River Water Management District as part of their well plugging program. Problems relating to saltwater intrusion of the surficial aquifer system could possibly be avoided or lessened if (1) all new wells are tested for saltwater during installation and production, (2) all unused wells are plugged from bottom to top to prevent the upward migration of saltwater and, (3) the current (1985) monitoring program is continued.

GEOHYDROLOGY OF THE FLORIDAN AQUIFER SYSTEM

Description of the Hydrologic Units

About 65 percent of all ground water used in the county is from the Floridan aquifer system. In this report, the terminology and definitions relating to the Floridan aquifer system used by Miller (1986) are closely followed but with a few exceptions. The Floridan aquifer system consists of limestone and dolomite, about 2,800 feet thick, that commonly yields abundant supplies of water to wells. Previous to a recent study of the Tertiary limestone aquifer system in the southeastern states, the Floridan aquifer

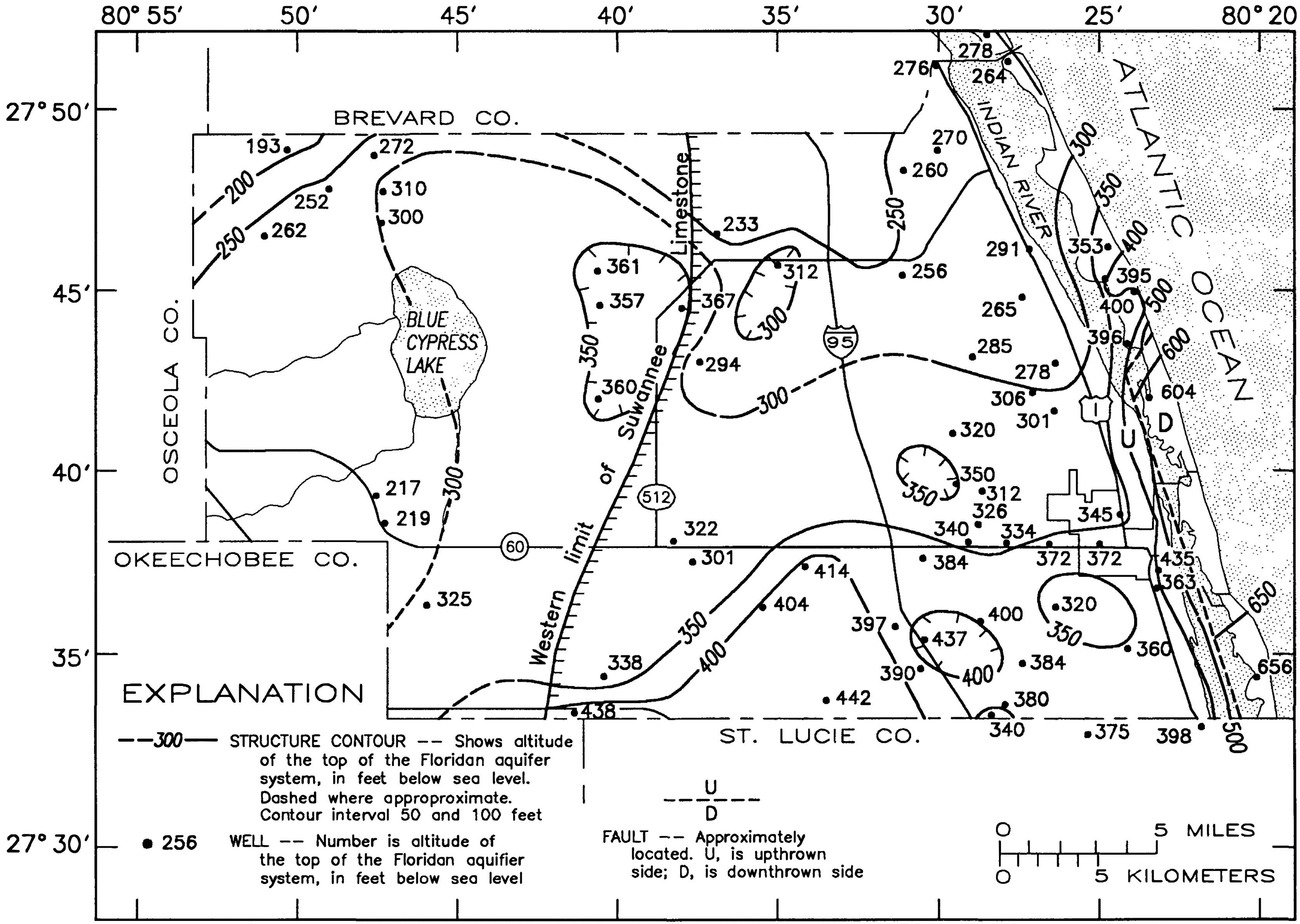


Figure 41.--Altitude of the top of the Floridan aquifer system and western limit of the Suwannee Limestone.

system was termed the "Floridan aquifer" (Miller, 1986, p. B44). Miller (1986, p. B45) describes the Floridan aquifer system as a vertically continuous sequence of generally high permeability carbonate rocks, mostly of middle and late Tertiary age, that are several orders of magnitude more permeable than the rocks that bound the system above and below.

Though the Floridan aquifer system is reported to generally cross formation and age boundaries, Miller (1986, p. B46) reports that, regionally, the top of the system is the Suwannee Limestone, but if absent, is the Ocala Limestone. Accordingly, in Indian River County, the Floridan aquifer system in descending order consists of the Suwannee Limestone (where present, fig. 41), Ocala Limestone, Avon Park Formation, Oldsmar Formation, and part of the Cedar Keys Formation (Miller, 1986, p. B46). The lower part of the Avon Park Formation was formerly known as the Lake City Limestone. Because of sparse control and the interfingering of key marker beds, the base of the Floridan aquifer system is difficult to ascertain. One oil test well (well 172F) drilled to basement rock, and one injection well (well 32F) finished in the Oldsmar Formation are the only wells known to penetrate below the Avon Park Formation in Indian River County.

Because less-permeable carbonate rocks consistently occur as a unit within the Floridan aquifer system in peninsular Florida, Miller (1986, p. B45) separated the system in descending order into the Upper Floridan aquifer, a middle semiconfining unit, and the Lower Floridan aquifer. The Upper Floridan aquifer ranges in thickness from about 350 feet in the southwestern part of the county to about 650 feet in the northeast. The top of the Upper Floridan is the Suwannee Limestone in the eastern part of Indian River County and the Ocala Limestone in the west (fig. 41). The top generally slopes to the southeast and ranges in altitude from about -200 to -500 feet. The surface is apparently irregular due to erosion and dissolution. East of the Indian River fault trace (fig. 41), the altitude of the top of the Floridan aquifer system is as low as -650 feet (in the southeast corner of the county)--about 250 feet lower than the surface west of the fault trace (fig. 11).

For this investigation, the middle semiconfining unit is identified as a dense dolomitic zone of variable thickness and low permeability and porosity that generally occurs near the middle of the Avon Park Formation. Geophysical logs indicate that the middle semiconfining unit ranges from about 20 to 120 feet in thickness. The logs also suggest that the top of the unit ranges widely in altitude (-613 to -1,450 feet).

According to Miller (1986, p. B65), the Lower Floridan aquifer consists of a zone of low and high permeability subzones that lie between the middle semiconfining unit and the Sub-Floridan confining unit (lower confining unit of Miller, 1986) that underlies the Lower Floridan aquifer. The Sub-Floridan confining unit is a massively bedded anhydrite of extremely low permeability that is in the upper part of the Cedar Keys Formation (Miller, 1986, p. B46). Little information is available on the thickness of the Lower Floridan aquifer. Miller (1986, pl. 32) shows that the Lower Floridan aquifer in Indian River County ranges from about 1,600 to 2,000 feet in thickness and thickens to the northwest. Well 172F is the only well known to completely penetrate the Cedar Keys. There, the altitude of the base of the Lower Floridan aquifer is about -3,100 feet.

Hydraulic Properties

The hydraulic properties of the middle semiconfining unit and the Lower Floridan aquifer of the Floridan aquifer system are poorly known, so discussion of these properties relates mostly to the better-known characteristics of the Upper Floridan aquifer. Variations in the hydrologic characteristics of the rock strata within the Floridan aquifer system are complex and are closely related to the geologic framework of the system. The porosity and permeability of the rock strata that comprise the system result from combinations of (1) the original texture of the rock; (2) processes that have acted on the rock, such as dolomitization and recrystallization; (3) joints, fractures, and faults; and (4) mineral solution or precipitation. Most of the hydraulic (and water-quality) variations found in the Floridan aquifer system in Indian River County probably occur because of one or a combination of the above factors. The combinations that are in effect may cause considerable variation in yield and water quality in nearby wells of equal depth. Flow-meter data show that water-producing zones within a borehole are typically discrete and may occur at different altitudes in adjacent boreholes. However, some boreholes contribute water throughout.

The permeability of the Upper Floridan aquifer is reported to be generally higher than that of the Lower Floridan (Miller, 1986, p. B54). The most productive water yielding zones are probably in the Avon Park Formation. The rate of ground-water circulation is relatively high in the Upper Floridan aquifer compared to circulation in the Lower Floridan aquifer, but flow logs indicate some wells that penetrate the Lower Floridan obtain a high percentage of their yield from that part of the aquifer system. Except east of the Indian River fault trace, (on the downthrown side of the fault), wells more than 700 feet deep in the eastern part of the county are probably completed in the Lower Floridan aquifer. These deeper wells were probably installed because the Upper Floridan could not supply sufficient water for a particular need (chiefly citrus irrigation).

Yields of wells that tap the Floridan aquifer system can be related to the specific capacity of the well, and in an approximate manner, to the transmissivity of the penetrated aquifer.

Transmissivity and associated data that can be used to determine hydraulic properties of the Floridan aquifer system are available for five test sites in Indian River County (fig. 42 and table 5). In addition, Tibbals (1981, fig. 6) determined a model-derived transmissivity range of 100,000 to 200,000 ft^2/d for the Upper Floridan aquifer in Indian River County based on a regional-scale model calibration. Planert and Aucott (1985, p. 19) reported a transmissivity of 10,000 ft^2/d for well site 216F in Brevard County near northwestern Indian River County. For a model calibration, the area bordering northern Indian River County was assigned a transmissivity value of 65,000 ft^2/d by Planert and Aucott (1985, p. 47) for both the Upper and Lower Floridan aquifers.

The highest transmissivity reported in the county (1.5×10^6 ft^2/d) was from an aquifer test run on an injection well (32F) completed in the Boulder Zone (Kohout, 1965)--a zone within the Lower Floridan aquifer consisting of high permeability, fractured, and cavernous dolomite near the base of the Oldsmar Formation. The Boulder Zone at that site occurs at a depth interval of about 2,400 to 3,000 feet. Miller (1986, p. B68), reports that the

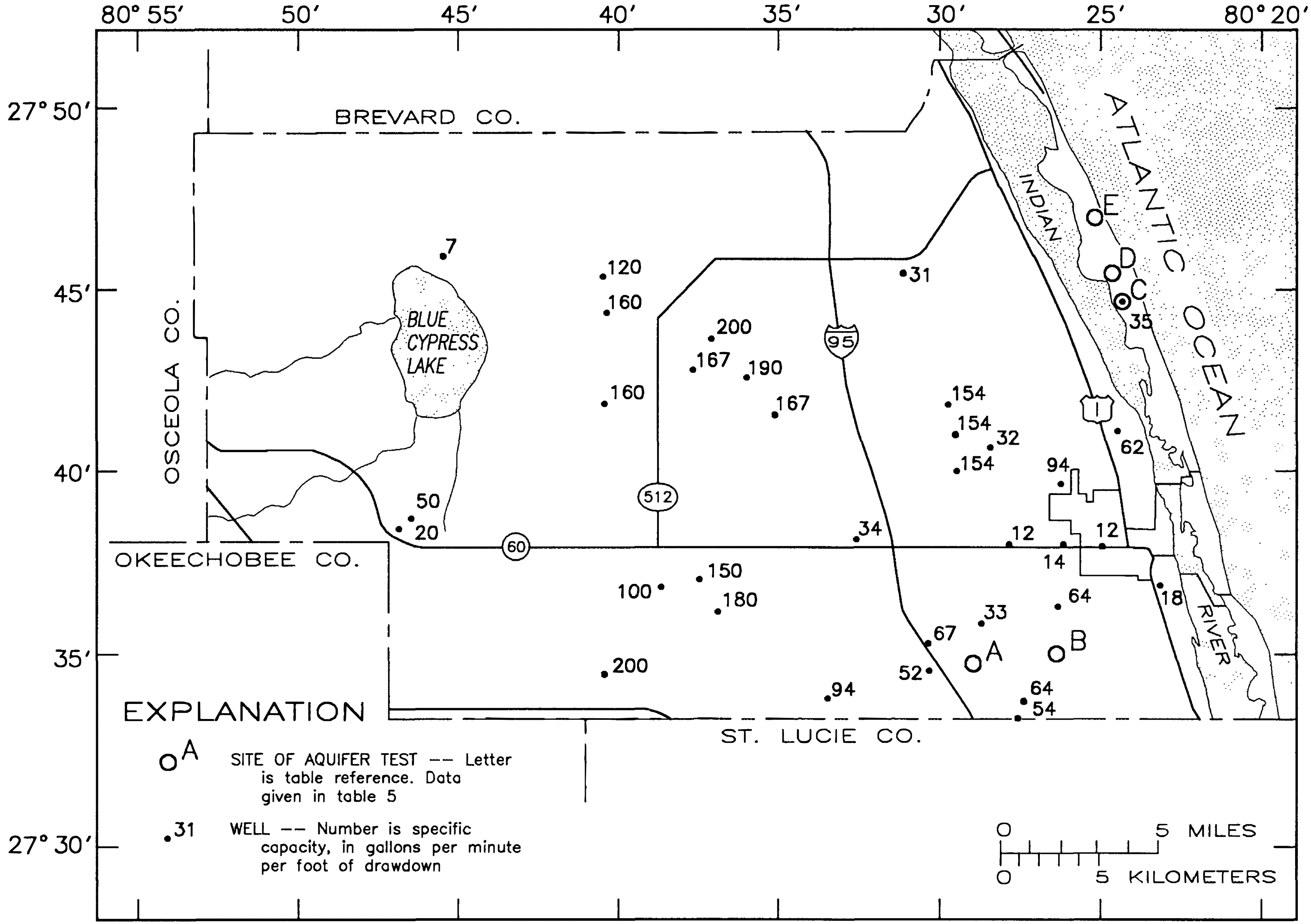


Figure 42.--Specific capacity of wells completed in the Floridan aquifer system and location of aquifer test sites.

Table 5.--Transmissivities of the Floridan aquifer system at five sites in Indian River County

[ft^2/d = feet squared per day]

Reference letter (fig. 42)	Well No.	Site identification No.	Transmissivity (ft^2/d)	Storage coefficient	Depth of well (feet below land surface)	Source of data
A	32F	273510080285502	1,500,000	---	[1]3,005	CH2M Hill (1979)
B	37F	273526080240701	50,000	4×10^{-4}	745	Geraghty and Miller (1981b)
	40F	273536080240101	56,800	3.9×10^{-4}	704	Do.
C	137F	274445080235901	7,500	5×10^{-4}	1,000	Bermes (1958)
	138F	274447080235301	4,800	1×10^{-3}	860	Do.
D	150F	274524080240801	17,600	6×10^{-4}	960	Seaburn and Robertson (1983a)
	154F	274532080241801	44,100	---	1,000	Do.
E	186F	274659080244301	19,400	1.4×10^{-3}	700	Bermes (1958)
	187F	274700080243901	20,100	1×10^{-3}	1,000	Do.
	188F	274700080245101	20,100	1.4×10^{-3}	860	Do.

[1]Interval tested was the 2,400- to 3,005-foot depth.

Boulder Zone is commonly found at depths of about 2,500 to 3,000 feet in south Florida, and that the transmissivity of the entire thickness of the zone may exceed 10^7 ft^2/d. The zone contains saline water, and is widely used as a receiving unit for municipal and other liquid wastes along the southeast coast of Florida.

Specific capacity data are more easily determined than transmissivity data, and are therefore more frequently available. The range of values of specific capacities of wells in the Floridan aquifer system in the county is large (fig. 42) and shows little areal pattern. The variability of specific capacity values is probably related to well diameter and depth of penetration but is probably due primarily to the irregular distribution and permeability of producing intervals in individual wells. Specific capacities of 37 wells range from 1 to 200 (gal/min)/ft and the median is 67 (gal/min)/ft (table 6). The map showing specific capacities (fig. 42) suggests lower than average specific capacities in the western part of the county, higher than average values in the central part, and probably low values east of the Indian River fault trace.

Flow rates of individual wells are usually indicative of the hydraulic characteristics of the aquifer penetrated, so high and low flow rates from wells of equivalent depth and diameter generally indicate correspondingly high and low specific capacities or transmissivities of the aquifer. Measured flow rates of wells that tap the Floridan aquifer system range from 30 to 2,000 gal/min with a median of 650 gal/min. The largest reported flow rate in the county is about 6,000 gal/min from an injection well (well 30F) at a depth of 1,350 feet (CH2M Hill, 1979). Flow rates of wells are not only related to hydraulic characteristics of the yielding zones of the

Table 6.--Specific capacity test data of selected wells that tap the Floridan aquifer system

[gal/min = gallon per minute; (gal/min)ft = gallon per minute per foot]

Well No.	Well identification No.	Casing diameter (inches)	Shut-in water level (feet above land surface)	Flowing water level (feet above land surface)	Drawdown (feet)	Flow-rate (gal/min)	Specific capacity [(gal/min)/ft]
7F	273335080280901	8	12	0	12	650	54
12F	273357080274901	8	12	1	11	700	64
20F	273423080332201	8	13	4	9	850	94
21F	273430080195601	6	30	0	30	30	1
26F	273459080401201	12	15	10	5	1,000	200
28F	273501080302101	8	12	1.5	10.5	1,600	152
42F	273539080301901	4	12	6	6	400	67
47F	273615080283501	8	10	1	9	300	33
53F	273633080364301	20	14	4	10	1,800	180
54F	273639080261501	6	8	1	7	450	64
57F	273710080230601	8	29	4	25	450	18
61F	273726080371501	10	16	4	12	1,800	150
64F	273741080382701	10	15	7	8	800	100
72F	273814080245201	4	10	6	4	50	12
76F	273819080260101	4	11	6	5	70	14
77F	273821080273901	4	9	5	4	50	12
80F	273827080322001	8	12	5	7	240	34
84F	273833080461901	6	12	10	2	40	20
95F	273927080465701	8	13	1	12	600	50
102F	274008080255301	8	9	1	8	750	94
104F	274023080291401	10	11	0	11	1,700	154
107F	274055080281301	5	13	4	9	285	32
110F	274115080291401	10	11	0	11	1,700	154
112F	274121080241701	6	28	16	12	750	62
115F	274156080344301	12	15	9	6	1,000	167
117F	274203080292901	12	13	0	13	2,000	154
119F	274210080400301	10	22	17	5	800	160
123F	274250080354401	12	13	8	5	950	190
126F	274302080371501	10	20	14	6	1,000	167
134F	274350080364501	12	16	11	5	1,000	200
136F	274436080395801	10	20	15	5	800	160
140F	274449080240001	5	24	16	8	280	35
149F	274522080304301	4	14	10	4	125	31
151F	274528080395801	10	20	15	5	600	120
155F	274534080251101	6	36	8	28	200	7
167F	274607080264001	6	21	1	20	150	7
180F	274642080453601	3	11	4	7	50	7
216F	275119080482401	12	--	--	8.9	280	32

wellbore, but also to pipe and wellbore hydraulics. Generally, the largest flow rates are from large-diameter wells (10 inches or more) and large diameter (8 inches or more) discharge pipes. Most wells that tap the Floridan aquifer system are capable of yielding several hundred gallons of water per minute without significant drawdown.

Description of Wells that Tap the System

The records of 250 wells in the Floridan aquifer system, which are stored in the Geological Survey computer files and shown in Supplementary Data II, represent only a small percentage of the wells that have been drilled in the study area. Uninventoried wells probably number several thousand. Some general observations pertaining to wells that tap the Floridan aquifer system in Indian River County can be made from field observations and from available records.

Depths of wells in the Floridan aquifer system in Indian River County are generally constrained by drilling costs and the potential of degradation of water quality with increased depth. The proposed use of water and the productivity of a well are the chief considerations for any well installation. Therefore, wells are generally drilled to meet or to most closely approximate required yields and water-quality needs within economic limits. Inventoried wells range in depth from 233 to 1,272 feet with a median depth of 700 feet. A report by Bermes (1958, p. 32) indicates that in about 1950 wells in the Floridan aquifer system on the mainland were about 600 to 700 feet deep. Records of new wells (drilled since the 1981 drought) indicate that typical depths have increased--many wells extend to depths of 900 feet or more. The probable reason for the deeper wells is the demand for higher yields.

Wells completed in the Floridan aquifer system that yield excessively saline water are usually plugged or abandoned. However, in places where a modest amount of acceptable water can be obtained from the upper part of the well, it may be more feasible to plug the bottom section of the well to seal off the lower saline zone rather than abandoning the well.

Well casings generally extend only to depths that allow the wellbore to remain open--usually into the Hawthorn Formation. Therefore, the bottom 600 to 800 feet of many wells in the Floridan aquifer system is frequently "open-hole" or uncased. Casing diameters range from 2 to 24 inches. Wells drilled since 1981 are generally 8 to 12 inches in diameter. Casings are made of steel, black iron, or plastic. Corrosion of metal well casings have caused many older wells to fail, so the use of plastic casing has become more prevalent in recent years. Burns (1983, p. 30) reports that in Lee County (southwest Florida) the life expectancy of steel-cased wells is 20 to 25 years, and that the corrosion of steel casing is most intensive at the upper part of the surficial aquifer system. As mentioned previously, corroded-through well casings could cause intrusion of water from the Floridan aquifer system into the surficial aquifer system.

More than 90 percent of the inventoried wells in the Floridan aquifer system are used for irrigation. Twelve wells are used as a source of water for reverse osmosis treatment for public-water supply. The city of Vero Beach blends water from two wells in the Floridan with water from the surficial aquifer system for public supply.

Few wells are equipped with pumps because water levels of most wells in the Floridan aquifer system stand above land surface. Water from the wells would discharge freely if not valved shut. Wells generally flow at sufficient rates to supply needed yields. In this report, wells that discharge freely are termed "flowing wells." When valved shut, flowing wells are termed "shut-in."

Potentiometric Surface

The potentiometric surface of the Upper Floridan aquifer fluctuates in response to changes in rates of recharge and rates of discharge. The major components that cause water-surface fluctuations are rainfall, pumpage, and, near the coast, tidal changes. Generally, short-term components are superimposed on long-term changes in the potentiometric surface of the Upper Floridan aquifer. Pumpage and rainfall can cause long- and short-term changes in the potentiometric surface.

The regional configuration of the potentiometric surface of the Upper Floridan aquifer in May 1981 is shown in figure 14. In Indian River County, the direction of water movement in the Upper Floridan aquifer is mainly eastward. Figures 43 and 44 show the potentiometric surface of the Upper Floridan aquifer in the county for May 1981 and May 1983. Comparison of the May 1981 potentiometric surface map (reflecting the 1980-81 drought) and the May 1983 map (reflecting above-average rainfall for 1982-83) shows that the potentiometric surface generally ranged 2 to 4 feet lower in May 1981 than in May 1983. The mound shown on the potentiometric surface in May 1981 (fig. 43) is probably residual from the previously high levels.

In the recharge area of the Floridan in Indian River County on the Lake Wales Ridge (fig. 14), September is normally the last month of the wet season and May is the last month of the dry season. Generally, the Upper Floridan aquifer is most stressed by pumping in May because, by then, the dry season has extended for about 7 months, and agricultural irrigation is heaviest. The potentiometric surface in May generally ranges in altitude from about 30 feet along the coastline to about 40 feet near the western county line. The depressions in the potentiometric surface in the eastern half of the county, as shown by the May 1983 potentiometric surface (fig. 44), reflect pumping stress from irrigation. In Indian River County, potentiometric contours generally shift slightly eastward toward the Atlantic Ocean between May and September because of the recharge from summer (wet season) rains and the associated curtailed local irrigation pumping.

Water Levels

General

Water levels in wells in discharge areas typically rise as the depth of penetration of the well increases, but few data are available to quantify differences in the levels in shallow and deeply penetrating wells in the Floridan aquifer system in the county. Geraghty and Miller, Inc. (1981b) reported that the water level of a well that is 901 feet deep (well 41F) was 3.5 feet higher in December 1980 than that in a nearby well 740 feet deep (well 37F). Water levels of wells cased into the Lower Floridan aquifer are probably at least several feet higher in altitude than the levels of wells

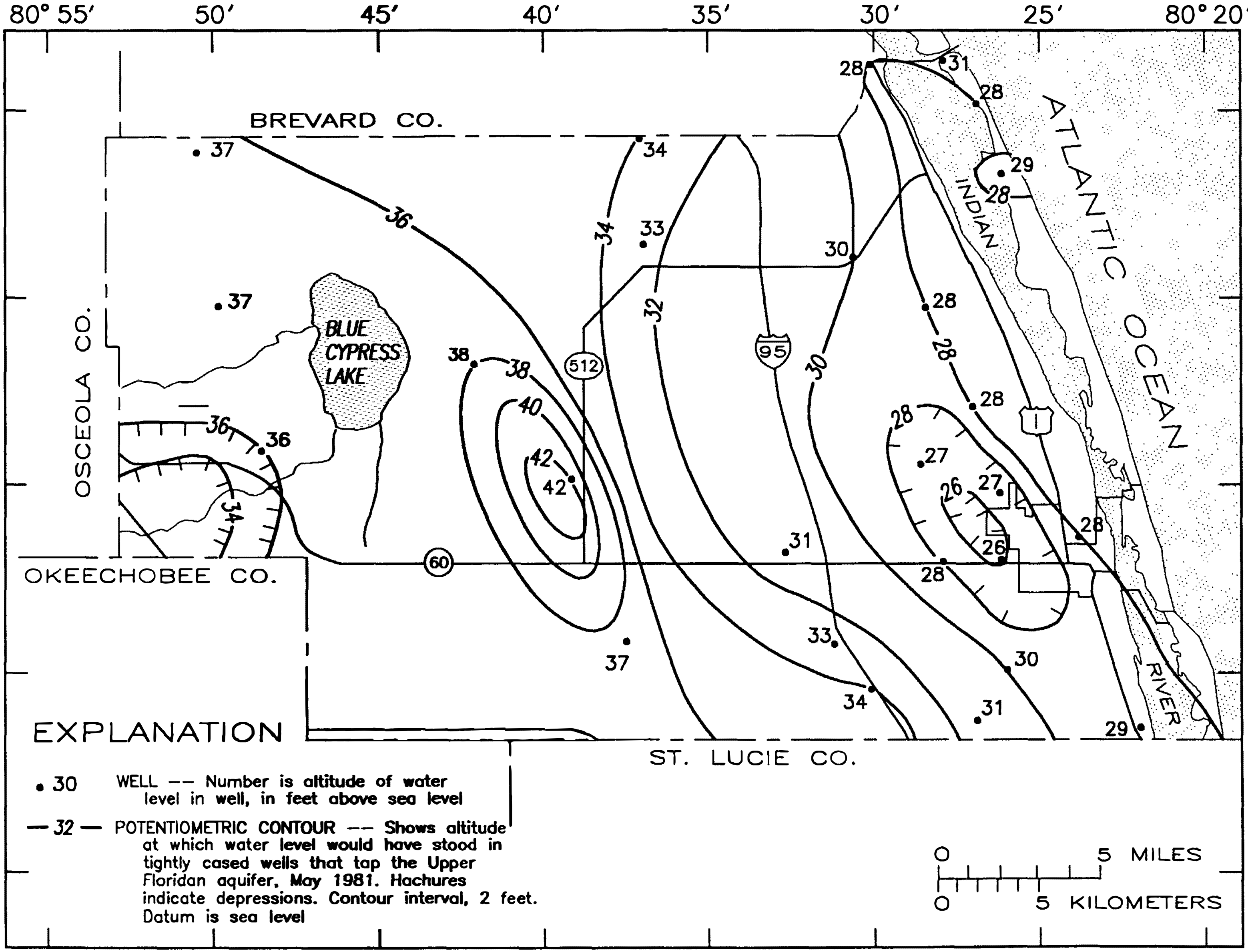


Figure 43.--Potentiometric surface of the Upper Floridan aquifer, May 1981.

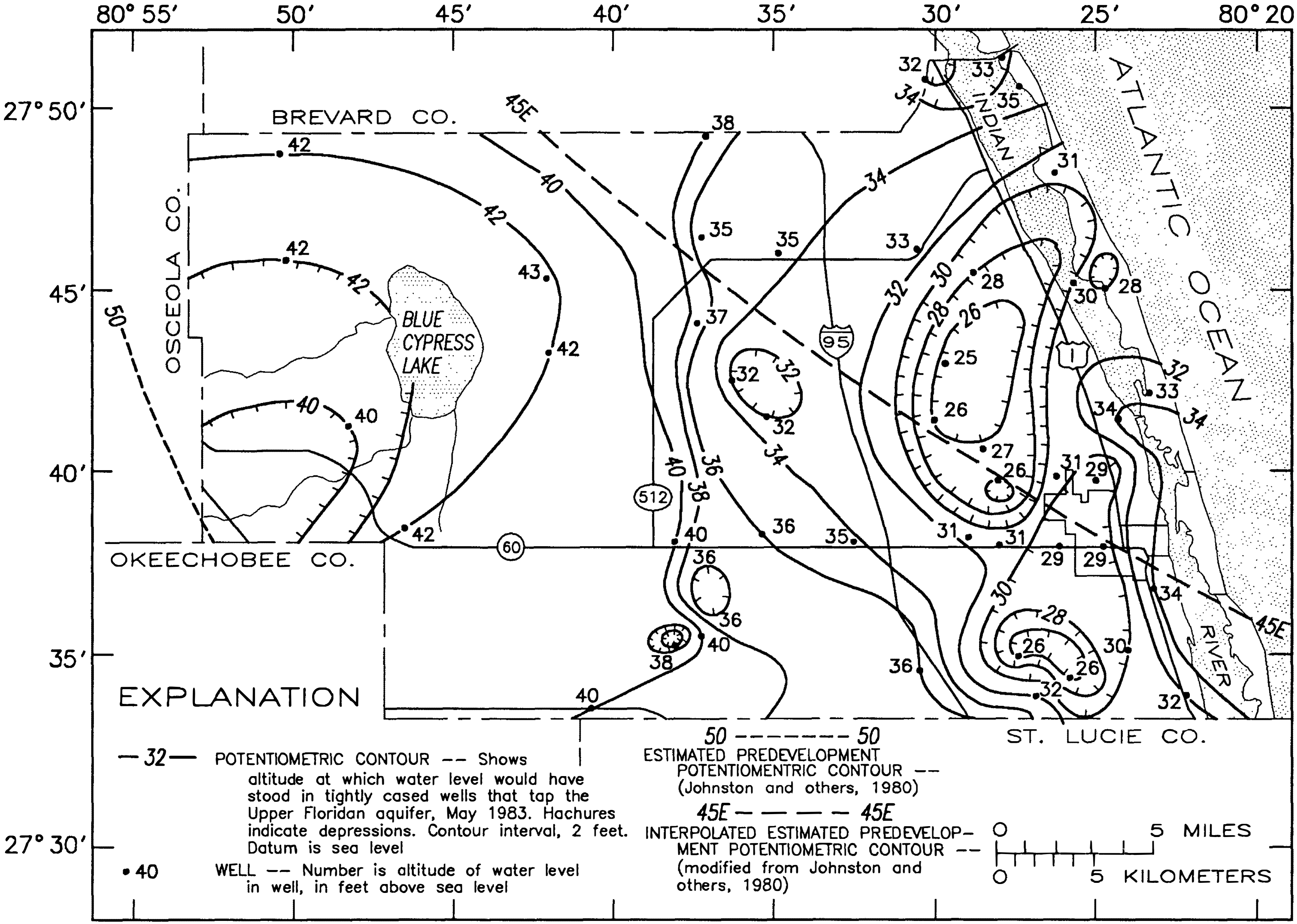


Figure 44.--Potentiometric surface of the Upper Floridan aquifer, May 1983, and predevelopment surface (estimated).

in the Upper Floridan aquifer. However, most wells in the Upper and Lower Floridan aquifers are cased only into the Hawthorn Formation; so water levels, particularly in the Lower Floridan, are resultant combination heads.

The hydrographs of two long-term observation wells completed in the Floridan aquifer system illustrate water-level fluctuations in a heavily irrigated area (well 23F in fig. 45) and the fluctuations in an area little affected by pumping (well 168F in fig. 46). (See fig. 47 for locations.) A comparison of the hydrographs and analysis of water-level data collected for compilation of biannual potentiometric surface maps show that September water levels generally range from 2 to 5 feet higher than May levels. However, in heavily pumped areas, water levels may decline as much as 15 feet between September and May if rainfall is deficient. The rainfall deficiencies of about 12 inches in 1980 and about 7 inches in 1981, and the probable effects of regional pumping, resulted in a record low May 1981 water level altitude (36.67 feet) in well 168F (fig. 46). Water levels in many other wells in the county also fell to record lows in May 1981.

Water-Level Trends

In Indian River County, long-term trends of water levels in the Floridan aquifer system are due to prolonged change in recharge and to water-use activities such as pumping for irrigation and public supply (development). Long-term trends due to development are difficult to ascertain because trends may be masked by the effect of variations in recharge. Water levels in the mostly undeveloped western part of the county are about 8 to 10 feet lower than those estimated for predevelopment time in the early 1930's.

Water-level data in table 7 shows that levels in the Floridan aquifer system in eastern Indian River County have declined about 16 to 24 feet in the 50-year period 1934 to 1984. The greatest decline occurred in the period 1934 to 1971. Since 1971, levels have apparently stabilized. At Avon Park in Highlands County, which is in a recharge area of the Floridan aquifer system, water levels show a similar, but greater, pattern of decline. There, water levels declined about 28 feet between 1934 and 1978. The hydrograph of well 168F (fig. 46) indicates no overall trend in the period 1976 to 1985. Brown and Reece (1979, pl. 3) reported no significant upward or downward trend of water levels in the Floridan aquifer system in the period 1970 to 1977 in adjacent St. Lucie County. The hydrograph of well 23F (fig. 45), in the Indian River Water Control District, suggests a downward trend from 1959 to 1971 and possibly an upward trend since 1972.

In the future, water levels in the Floridan aquifer system may decline in the Fellsmere area because of added stress on the system by planned expansion of agricultural irrigation. Water levels may also decline in the vicinity of the county's Oslo Road reverse osmosis plant as pumpage there for public supply increases. However, in some areas of the county water levels in the Floridan aquifer system probably will rise because of reduced irrigation pumpage due to urbanization. In the Indian River Water Control District and the Wabasso Beach area (fig. 1), for example, water levels will probably rise because irrigation pumpage will continue to decline as more citrus groves are replaced with urban-type developments that use public-supply systems. The amount of water used for public-water supply is not

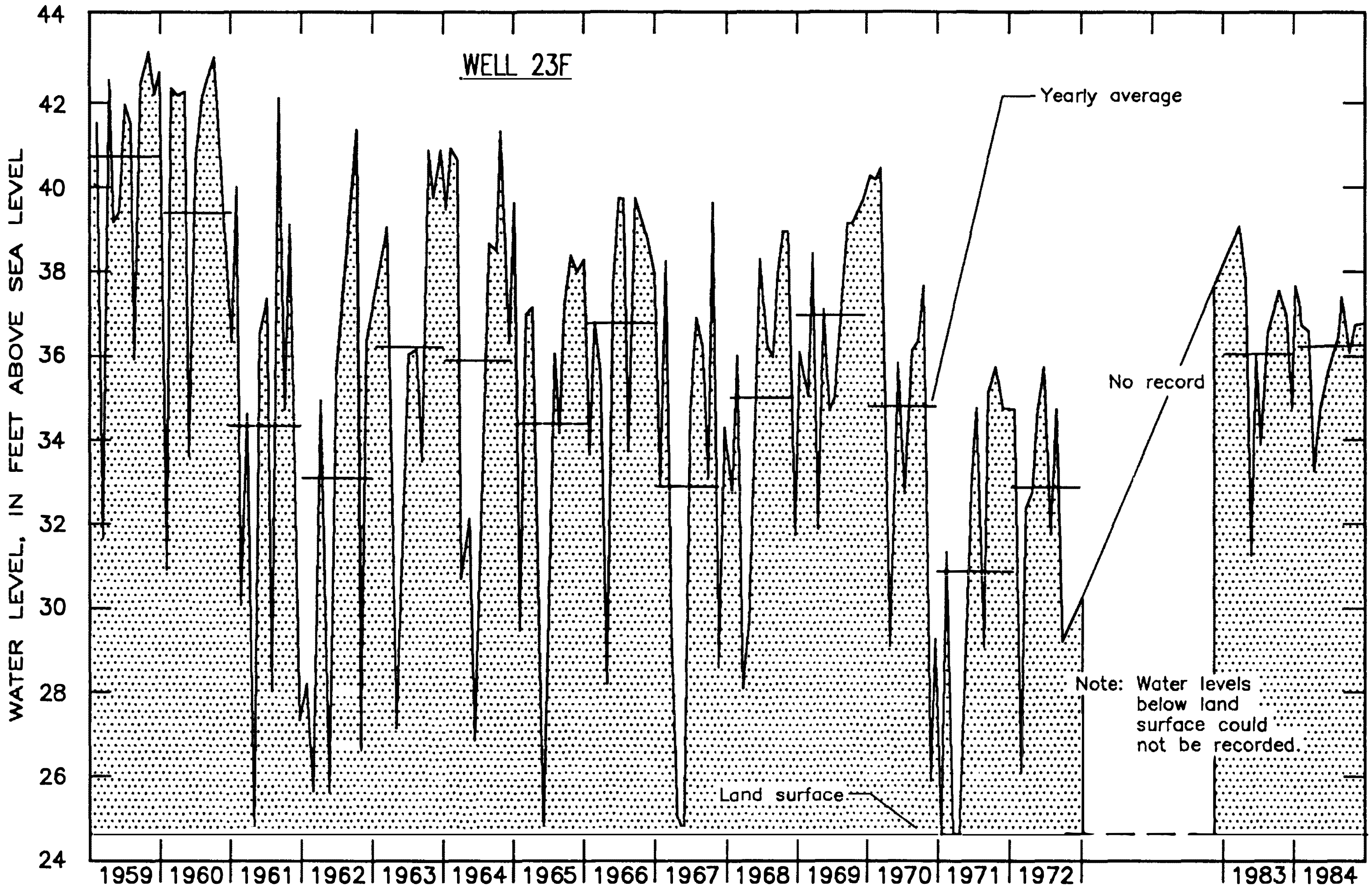


Figure 45.--Month-end water levels in well 23F (USDA South Well 43rd Avenue), 1959-84.

expected to equal the amount previously used for irrigation in the foreseeable future; so, in those places, water levels will probably rise unless additional demands are placed on the aquifer.

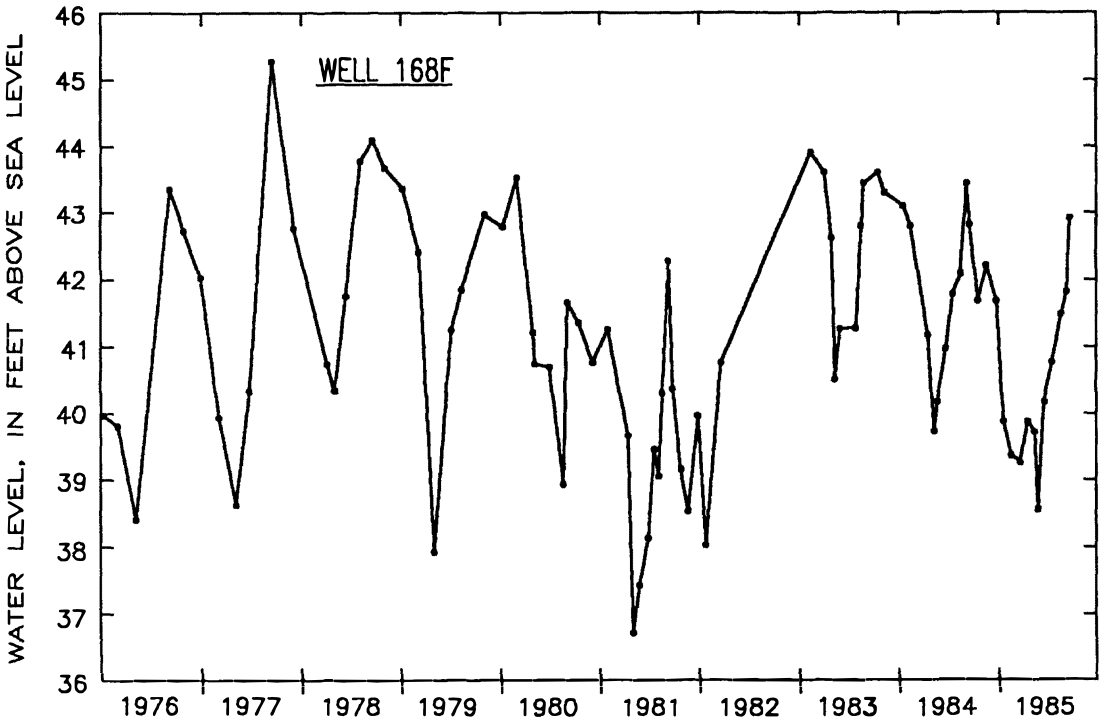


Figure 46.--Water level in well 168F (USGS Observation Well IR 189), 1976-85.

Water Quality

General

Most of the water that recharges the Floridan aquifer system in Indian River County originates as rainfall on the Lake Wales Ridge, to the west, in Polk County (fig. 14). The mineralization of the water increases as it moves eastward toward the coast and by the time it reaches the discharge area that includes Indian River County, the water quality in the Floridan aquifer system contains relatively high concentrations of dissolved-solids. Saline water ranging from slightly saline to brine is present at varying depths beneath the entire county. In places, water in the Upper Floridan aquifer is fresh, particularly in the upper part. Salinity increases with depth and is a function of flushing out of the ancient seawater trapped in the sediments during an earlier geologic time (Sprinkle, 1982). Water movement is generally sluggish (Miller, 1986, p. B63) in the Lower Floridan aquifer where little flushing has occurred and the water is briney.

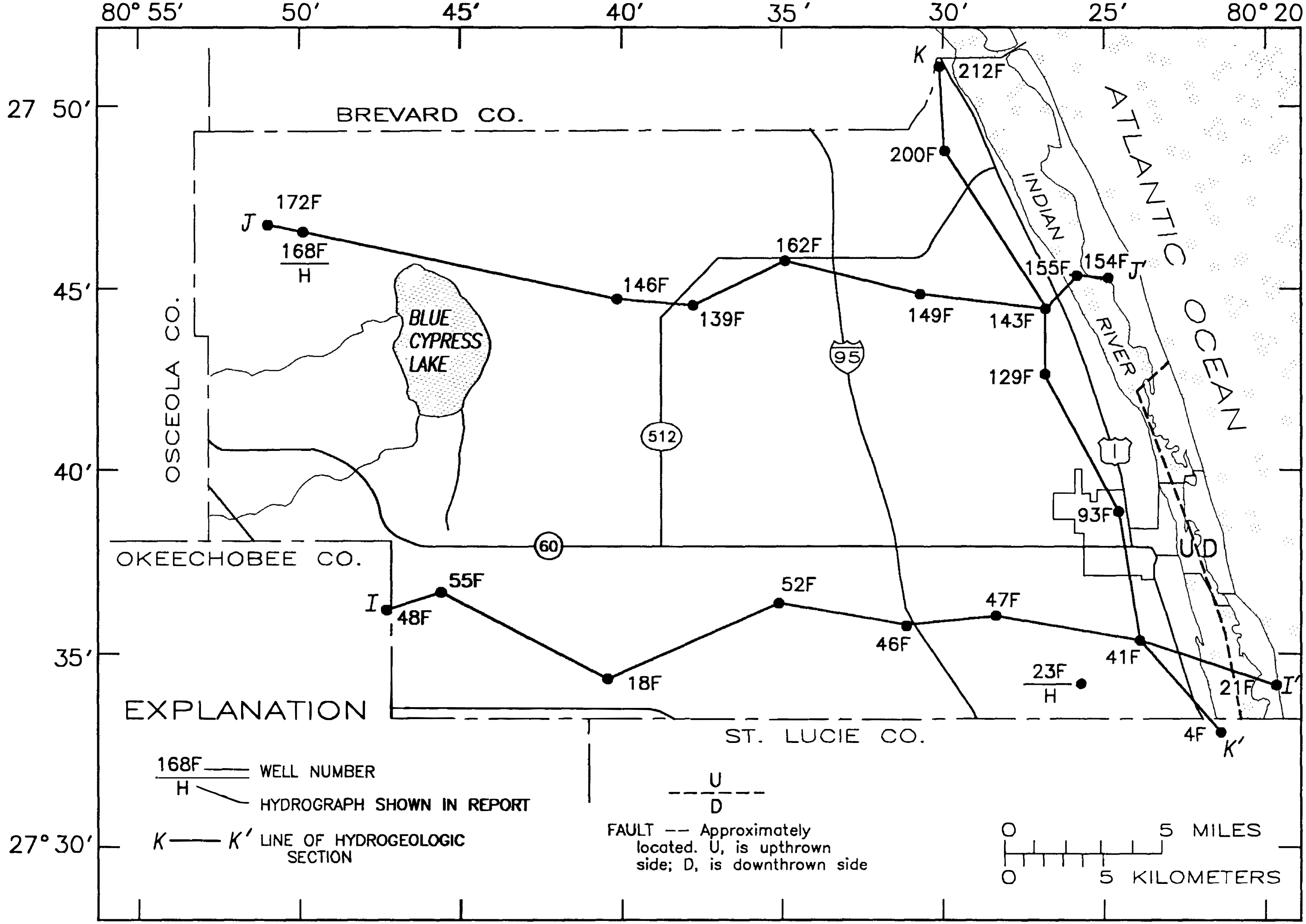


Figure 47.--Locations of wells in the Floridan aquifer system for which hydrographs are shown, and lines of hydrogeologic section.

Table 7.--Ground-water levels at selected sites in Indian River and Highlands Counties, [1]1934, 1951, 1971, and 1984

[Water levels are in feet above sea level]

Year	Vero Beach	Fellsmere	Sebastion	Avon Park (Highlands Co.)
1934	48 (Feb)[1]	55 (Aug)[1]	46 (Aug)[1]	105 (Feb)[2]
1951	40 (Oct)	48 (Oct)	37 (Oct)	92 (Apr)
1971	28 (May)	34 (May)	30 (May)	--
1984	30 (May)	31 (May)	30 (May)	78 (May)

[1]From Stringfield (1936).
[2]Estimated from nearby measurements made in Highlands and Polk Counties.

The water quality of a well completed in the Floridan aquifer system is a composite of the quality of water in the various producing zones penetrated by the open borehole. Water-quality data from Bermes (1958), Crain and others (1975), and unpublished data indicate that water from the Floridan aquifer system is generally hard and relatively high in dissolved solids. Most water is of the sodium chloride type. Chloride, bicarbonate, and sulfate are the major anions, and sodium, calcium, and magnesium the major cations. Potassium and strontium are common minor constituents. Trace amounts of other ions are also present. The distribution and values of salinity as measured by dissolved-solids concentrations are similar to chloride concentrations in the Floridan aquifer system. Concentrations of chloride and dissolved solids commonly exceed the Florida Department of Environmental Regulation (1982) maximum contaminant level for public drinking water systems (250 mg/L for chloride and 500 mg/L for dissolved solids where alternate supplies of lower concentration are available).

Lateral intrusion of saltwater from the Indian River or the Atlantic Ocean into the Floridan aquifer system is not possible under current conditions because of the aquifer's high head along the coast (at about the 30-foot altitude), and because the freshwater-saltwater interface is a considerable distance offshore. The high Floridan heads, responsible fore discharging conditions throughout the county, also prevent pollutants on thee land surface from moving downward into the Floridan. Pollutants could bee introduced into the aquifer from recharge areas, mostly outside the county,e or heavy pumping could cause local upconing of very saline water from depth.e

Variations of Chloride Concentration in Wells

Sprinkle (1982) reports that significant chemical differences may be found in the water from nearby wells, or from the same well from year to year, in the area that includes Indian River County. Therefore, recognition of a trend in chloride concentration in the water from individual wells is difficult to ascertain. An example is the water from well 20F (fig. 48) in which chloride concentrations of water from well 20F (fig. 48) ranged from

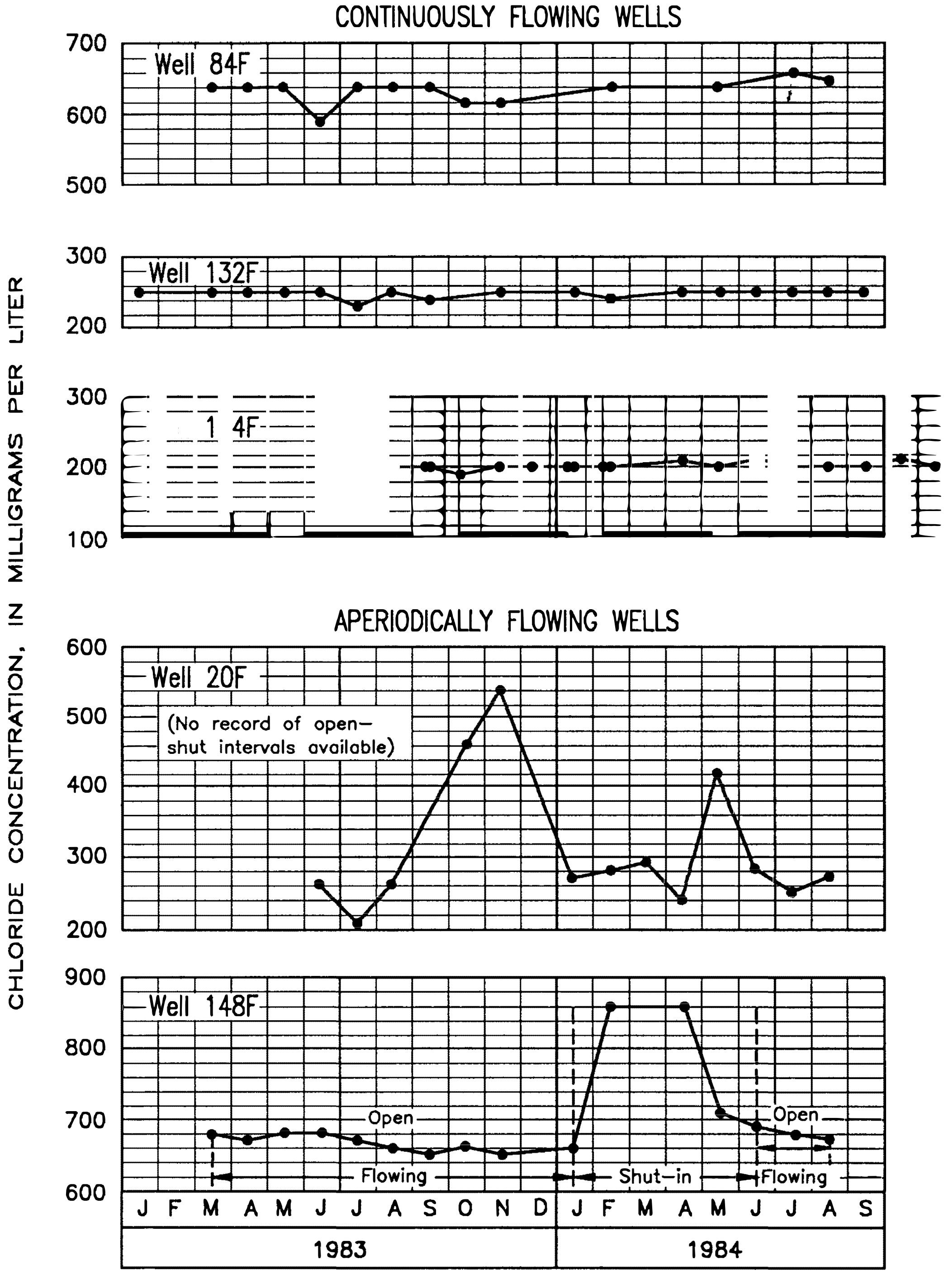


Figure 48.––Chloride concentrations in water from continuously flowing and aperiodically flowing wells.

210 to 540 mg/L during a 14-month sampling period. Fluctuations of chloride concentration in the water from a well may be related to head changes and changes in flow contributions of producing zones. Also, pumping during the dry season could lower heads enough to cause some upconing of saline water--particularly in wells completed in the Lower Floridan aquifer. Variations in the chloride concentration of water from a well sampled periodically may also be due to sampling technique or to the geohydrologic characteristics of the well.

Water-quality sampling techniques are designed to provide data that are representative of water in the aquifer. For this study, samples were taken from either shut-in or actively flowing wells. Samples from shut-in wells were taken at the wellhead by opening a valve and allowing water from the well to flow. Samples from flowing wells were taken from the discharge pipe or from a spigot on the well. Most sampling was done periodically--generally for chloride concentration determinations.

An important factor in sampling is to ensure that only native aquifer water is sampled. Barraclough (1962, p. 75) reports that in Seminole County (central Florida), the most important index of chloride concentration in water from some flowing wells is not changes in water level but the period the well is allowed to flow prior to sampling. Chloride concentrations of water from an observation well in Seminole County ranged from 65 mg/L at a flow period of 5 minutes to 290 mg/L for flows longer than 5 minutes.

For this study, prior to sampling, a shut-in well was allowed to discharge at least long enough to evacuate and replace the water stored in the wellbore with fresh formation water. For example, for an 8-inch-diameter well 1,000 feet deep that discharges 500 gals/min, the required time is about 5 minutes. Wellhead discharge waters that have attained a steady temperature or specific conductance generally indicate that the wellbore has been completely flushed.

Most wells that tap the Floridan aquifer system in Indian River County are periodically used during dry weather periods and freeze periods. When not in use, the wells are shut-in to prevent needless discharge. Chloride concentrations of water in these periodically shut-in wells appear to vary more than the concentration in wells that flow continuously.

Periodically, open wells may allow high chloride concentration water in a deep-producing zone of the Floridan aquifer system to invade an upper, better quality zone during shut-in periods. As mentioned previously, deep-producing zones in Floridan aquifer system have higher heads than the shallow producing zones. Many irrigation wells tap the Lower Floridan aquifer but are cased only to about the middle of the Hawthorn Formation. This can allow the higher head, more mineralized, water from a producing zone in the Lower Floridan aquifer to move into and contaminate a better quality producing zone in the Upper Floridan aquifer. Figure 49 illustrates the hypothetical paths of water movement in a periodically open well that penetrates the Upper and Lower Floridan aquifer. Head differentials indicate that a significant potential exists for water from the Floridan aquifer system to intrude into the surficial aquifer system through a break in a casing (fig. 49).

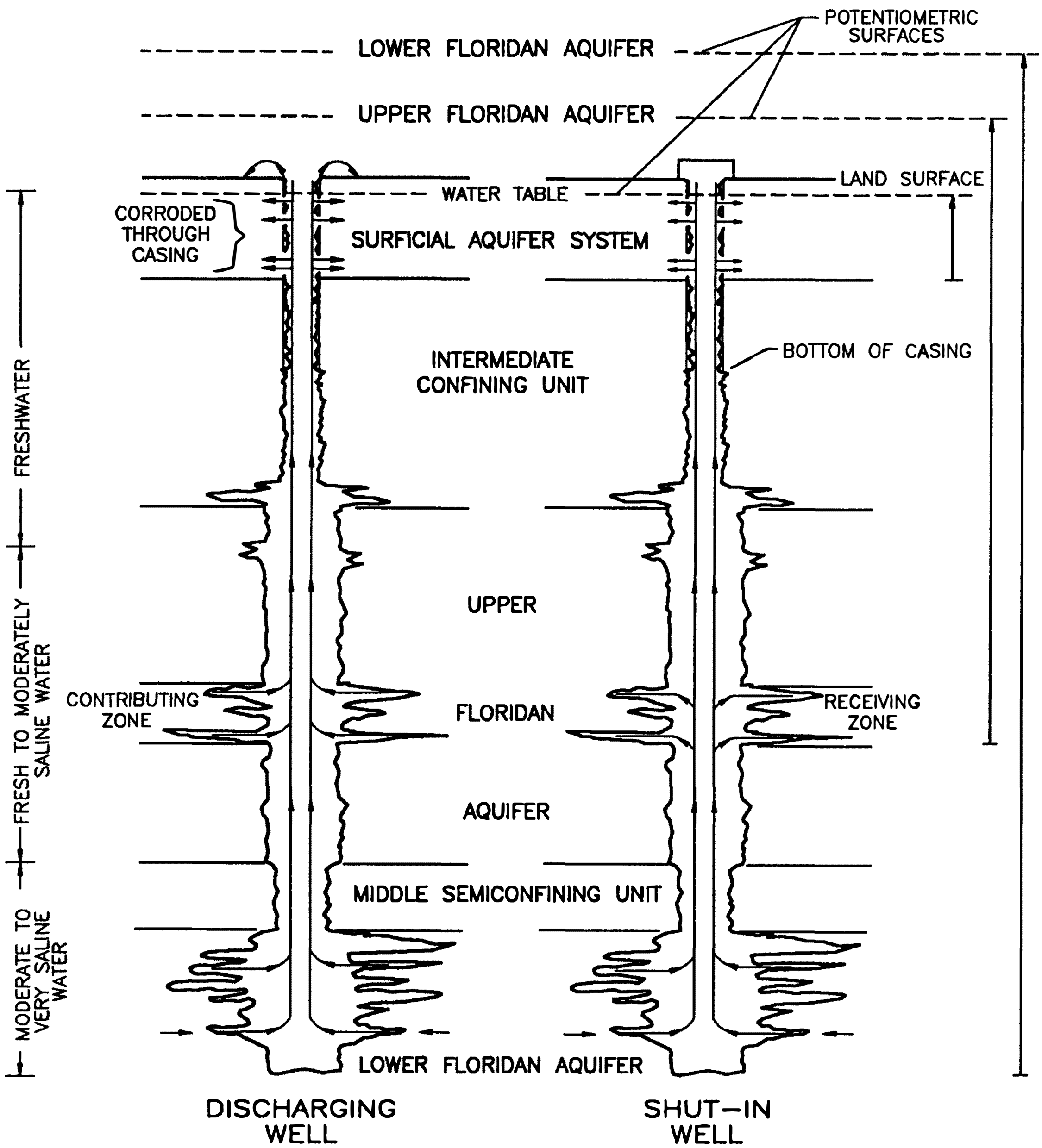


Figure 49.--Hypothetical paths of ground-water movement in wells that penetrate both the Upper and Lower Floridan aquifer.

The volume and quality of water that moves into or intrudes a receiving zone (fig. 49) in a shut-in or flowing well is directly related to head differentials, transmissivities, water density, the water quality of the producing zones, and to time. If a shut-in well is allowed to flow, the time required to evacuate the intruded zone in the Floridan will be longer than the time the well was shut-in. This is due to blending of the water in the intruded zone and the hydraulics of flow in the zone.

The plot of the chloride concentrations in water from well 148F (fig. 48) illustrates the effect of shutting-in a flowing well for a period of time. Prior to being shut-in, chloride concentrations ranged from 650 to 680 mg/L. But after the well was shut-in (January 1984), the chloride concentration began to rise, reaching 860 mg/L by mid-February. The chloride concentration remained at 860 mg/L for several months with the well shut-in. After the well was opened and allowed to flow, the chloride concentration declined rapidly to 710 mg/L and continued to decline with time thereafter until it reached the previous concentration of open conditions. The decline in chloride concentration is probably due to the slow release of mixed-quality water from an upper-producing zone that had been intruded by relatively high chloride water from a lower zone.

Many wells that flow continuously appear to reach an equilibrium of hydrologic conditions in which temporal and recharge-discharge changes have little influence on the chloride concentration of water in the wells. Chloride concentrations in water from flowing wells 84F, 132F, and 194F (fig. 48) show little fluctuation though their period of record covers several seasons and include seasonal variations in precipitation and pumpage. Water from wells periodically open and wells recently drilled may exhibit considerable variations in chloride concentration because equilibrium conditions have not been attained. (See well 20F in fig. 48, a relatively new well, for example.) Chloride concentrations of the water in recently drilled wells may often increase with time and concomitant decline in head. The period of time required for a well to reach water-quality constancy may vary with the hydrologic environment of the individual well and its use and could be years.

Distribution of Chlorides

Chloride concentrations of water in the Floridan aquifer system may vary considerably both areally and vertically as well as temporally. Predictions of chloride concentration at a particular location cannot be made with certainty, but generalizations can be made based on patterns of occurrence.

Figures 50 and 51 are highly generalized maps that show the distribution of chloride concentrations of water from wells that tap the Upper Floridan aquifer and both the Upper and Lower Floridan aquifers, respectively. Most of the data used to compile the maps were collected in 1983--some data are from the 1984-85 period. The wells that tap both the Upper and Lower Floridan aquifers probably derive most of their yield from the Lower Floridan which generally contains more highly mineralized water. Chloride concentrations generally increase slightly with depth in the Upper Floridan aquifer but may increase rapidly with depth in the Lower Floridan. Therefore, the concentrations shown for water mostly from the Lower Floridan

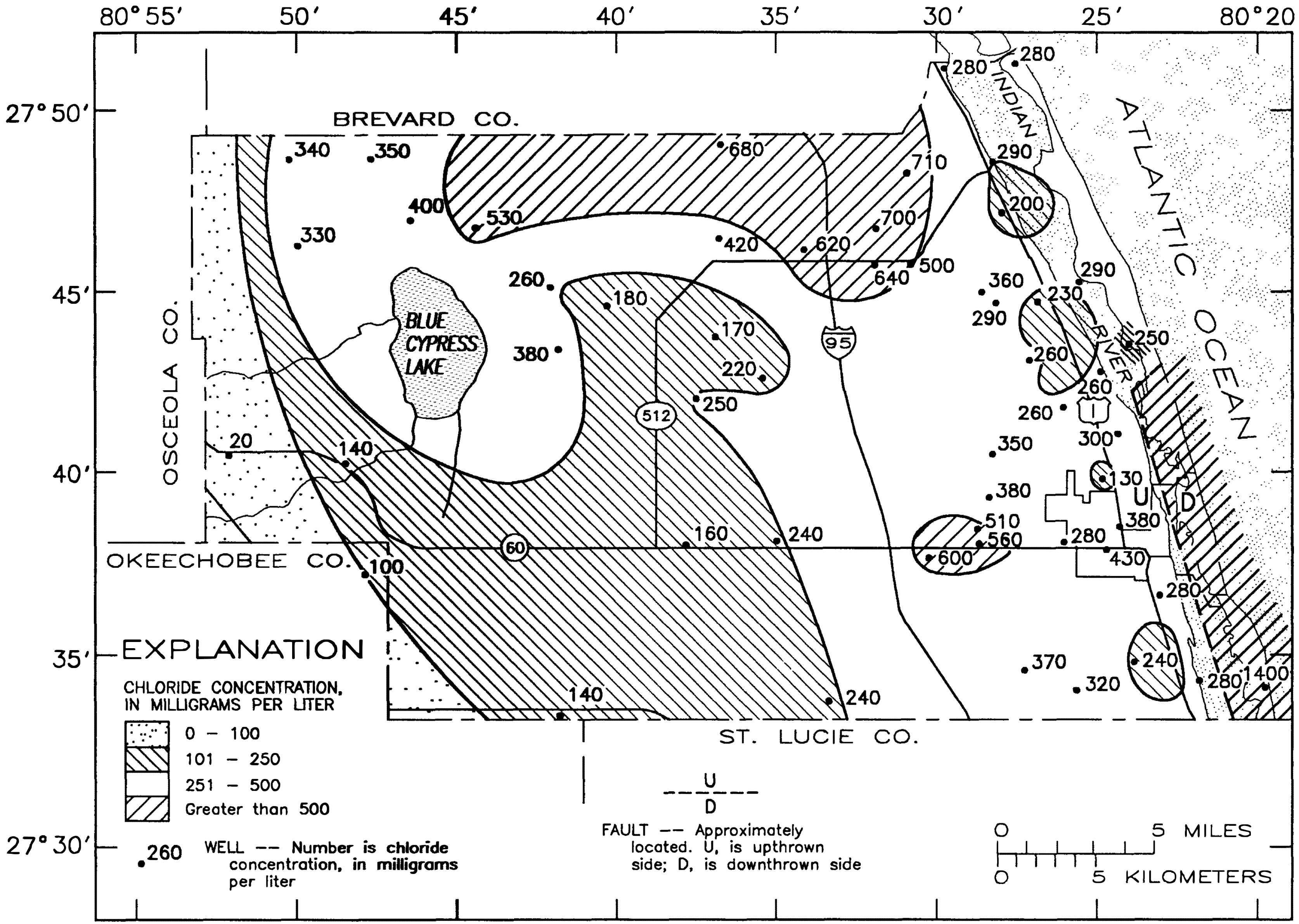


Figure 50.--**Chloride concentrations** in water from wells that tap the Upper Floridan aquifer.

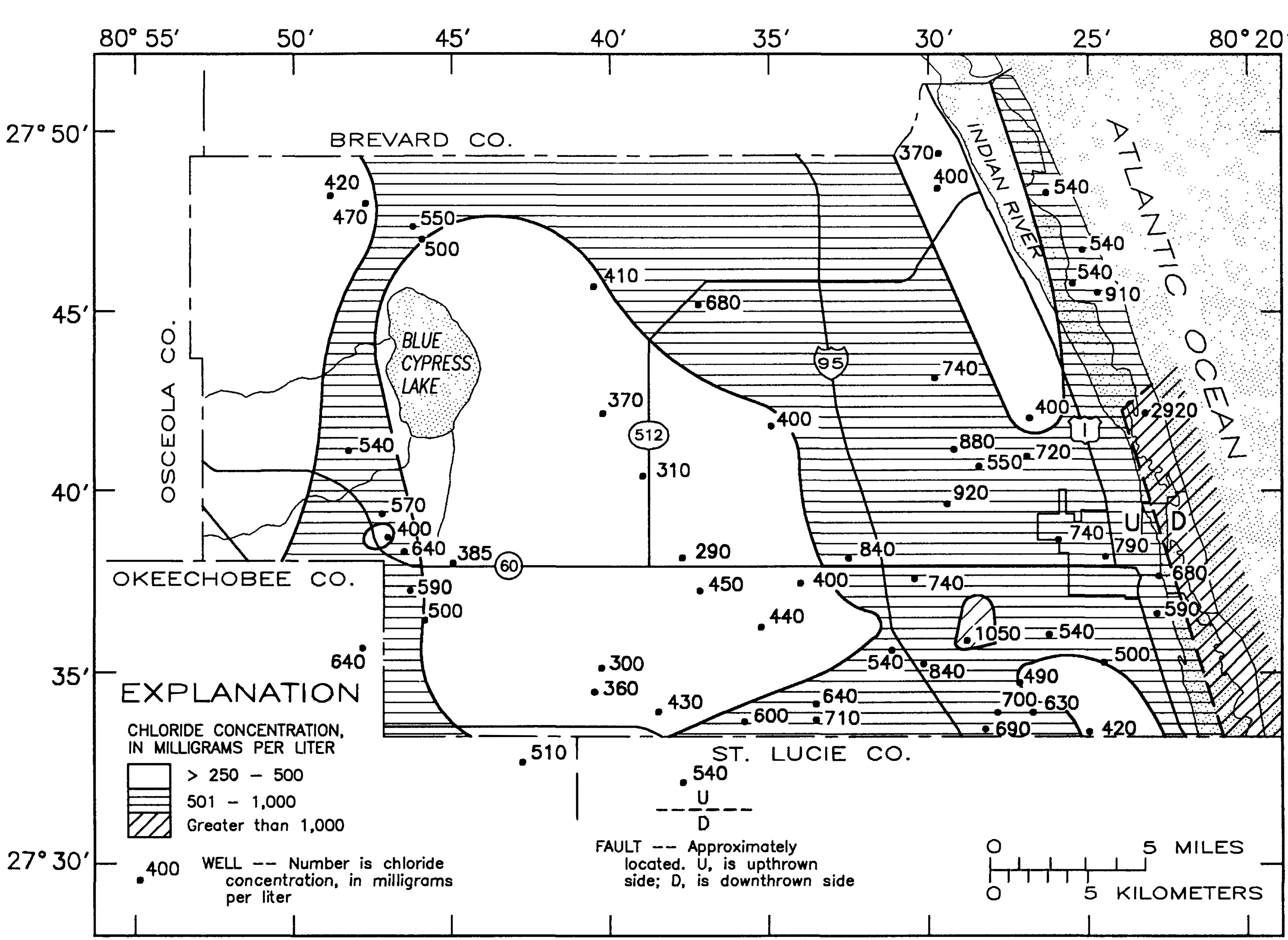


Figure 51.--Chloride concentrations in water from wells that tap the Upper and Lower Floridan aquifer.

aquifer are more variable than for water in the Upper Floridan aquifer because differences in well depths may cause large differences in chloride concentration. The highest concentrations for both aquifers are found on the east (downthrown) side of the fault along the Indian River.

Chloride concentrations in water from wells that yield mostly from the Upper Floridan aquifer range from 20 to about 1,400 mg/L. The lowest concentrations are in the area of the Talbot terrace (figs. 2 and 50). Concentrations less than 250 mg/L are found in about half the county--generally in the western, southwestern, and central part. Areas of less than 250 mg/L concentration occur as patches oriented parallel to the coast along the trace of the Atlantic Coastal Ridge (figs. 2 and 50). These patches may be pockets of freshwater that were trapped in the aquifer during a low stand of the sea during the Pleistocene Epoch (Tibbals, in press), or as theorized by Crain and others (1975, p. 49), may represent areas of recharge to the Upper Floridan aquifer. The highest concentration of chloride in water from the Upper Floridan is between the Talbot terrace and the Atlantic Coastal Ridge in the northern part of the county (figs. 2 and 50). The high chloride concentrations found in water from some Upper Floridan aquifer wells may be in those places where the underlying middle semiconfining unit is relatively permeable, thin, or breached. There, pumping could more readily cause upconing of high chloride concentration water from the Lower Floridan aquifer into the Upper Floridan aquifer.

Chloride concentrations in water from wells that yield mostly from the Lower Floridan aquifer range from 290 to 2,920 mg/L. In the eastern half of the county, water from these wells generally have chloride concentrations higher than 500 mg/L. Chloride concentrations ranging from 700 to 1,050 mg/L occur in a large area between the Atlantic Coastal Ridge and the Ten-Mile Ridge (fig. 51). Concentrations of 400 mg/L or less occur as a narrow band along the trace of the Atlantic Coastal Ridge in the northern half of the county and a northeast oriented band of 300 mg/L or less is centered at the junction of State Highways 60 and 512.

The high chloride concentrations of 910 mg/L in water from well 154F (near Wabasso Beach) and 1,050 mg/L in well 47F (south of State Highway 60 and east of I-95, figs. 1 and 51) may have been caused by their relatively heavy pumping and their greater depth than nearby wells.

Trends in Chloride Concentrations

The recognition of any time trend in chloride concentrations of water from wells is essential to management of the county's water resources. Figure 52 shows the chloride concentrations of water from 26 wells in the Floridan aquifer system. These same wells were sampled at three time intervals during the period 1951-84. The following table gives the average chloride concentrations for the time intervals.

Sampling period	Average chloride concentration (mg/L)
1951-52	369
1968-71	424 (increase of 15 percent)
1983-84	451 (increase of 6 percent from 1968-71 and 22 percent from 1951-52)

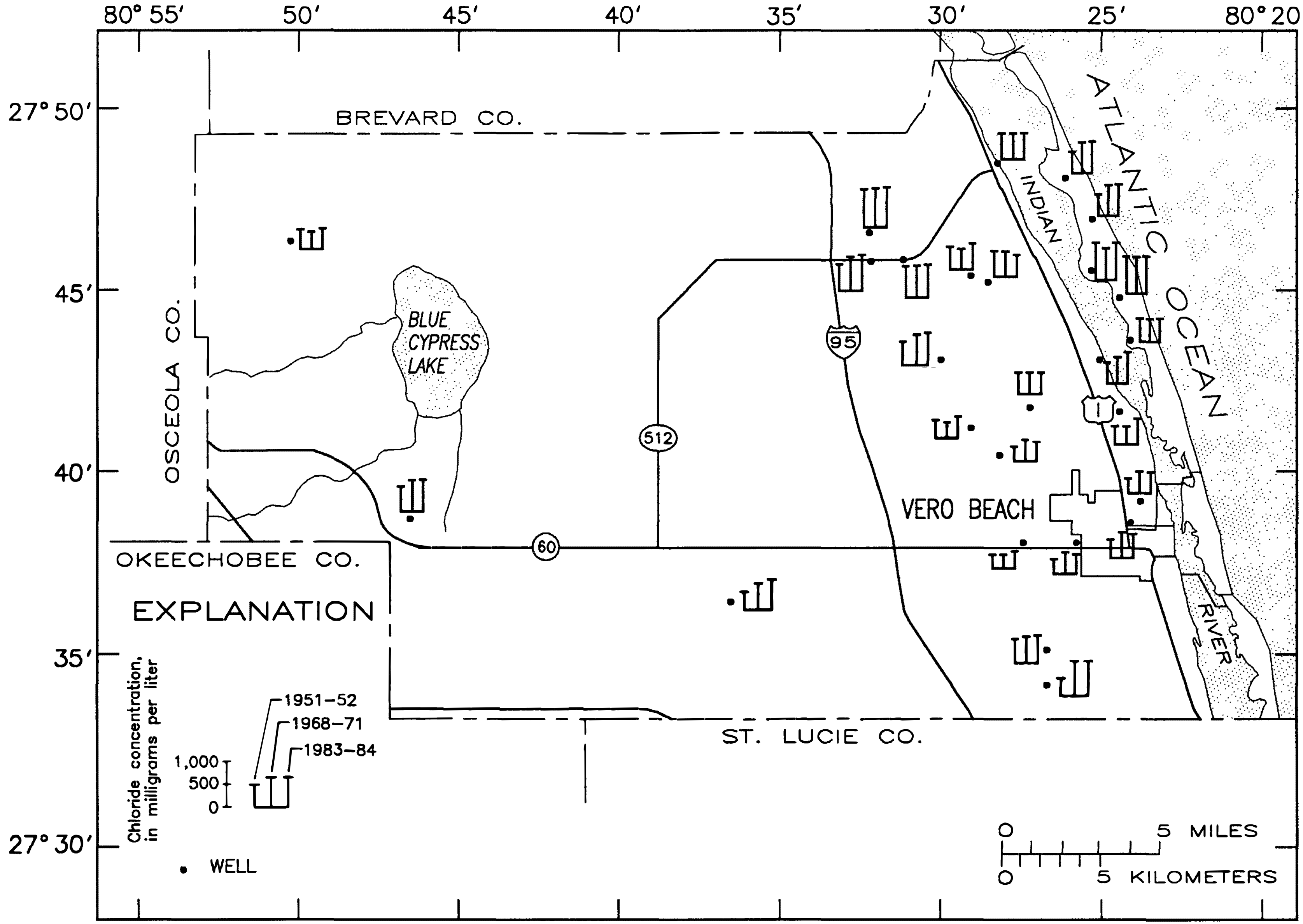


Figure 52.--Chloride concentrations in water from 26 wells that tap the Floridan aquifer system for the periods 1951-52, 1968-71, and 1983-84.

Chloride concentrations increased more than 10 percent in 11 of the 26 wells between the period 1951-52 and 1968-71, but concentrations increased more than 10 percent in only 5 wells between the period 1968-71 and 1983-84.

Crain and others (1975, p. 53) compared chloride concentrations of water from wells in the Floridan sampled in 1951-52 to that of samples collected in 1968-71 and found a small increase in chlorides in the eastern part of the county north of Winter Beach and a small decrease in chlorides south of Winter Beach. Data obtained for this study in 1983-84 shows that chloride concentrations increased about 25 percent in T33S (Township 33 South), R39E (Range 39 East), south of Vero Beach, between the periods 1951-52 and 1983-84. (See fig. 1 for Township and Range locations.) In T32S, R39E--the Vero Beach area--the increase was about 18 percent. In T31S, R39E--the Sebastian area--the chloride concentration decreased by 11 percent. The decrease may be due to the plugging of unused flowing wells. The overall increase in chloride concentration in the three townships was only 9 percent between the 1951-52 and the 1983-84 period. Average chloride concentrations in the townships for the three sampling periods are given in the following table.

Township and range	1951-52		1968-71		1983-84	
	Number of wells sampled	Average chloride (mg/L)	Number of wells sampled	Average chloride (mg/L)	Number of wells sampled	Average chloride (mg/L)
T31S, R39E	45	488	13	462	23	436
T32S, R39E	21	313	16	334	17	370
T33S, R39E	23	424	14	450	18	529
Total	89	---	43	---	58	---
Average of all samples		408		415		445

Data from four Floridan aquifer system wells in a grove at Wabasso Beach show no increase in chloride concentration from the 1940's to 1984. However, the chloride concentration of water from well 177F, completed in the Lower Floridan aquifer, rose from 378 mg/L in 1951 to 540 mg/L in 1983. The chloride concentration in 1969 was 535 mg/L.

Chloride concentrations of water in the Upper Floridan aquifer are increasing in the Vero Beach area. In the city well field, the chloride concentration of water from well 94F increased from 285 mg/L in November 1976 to 384 mg/L in May 1985 (35 percent increase). Chloride concentrations of water from well 93F increased from 300 mg/L in April 1979 to 476 mg/L in May 1985 (59 percent increase). Except for 1950, the following table shows a progressive upward trend in chloride concentration since 1921 in water from well 73F at the old Vero Beach Power Plant.

Year	1921		1924	1949	1950	1951	1983
Month	Aug.	Oct.	--	Oct.	Jan.	Dec.	July
Chloride (mg/L)	270	291	455	625	550	630	790

Well 73F has been out of service and shut-in for many years. High chloride concentration water from the lower part of the well may have substantially infiltrated the upper, better-quality zones.

On a countywide basis, the chloride concentrations of water from wells in the Floridan aquifer system have apparently not changed significantly in the 15-year period 1968 to 1983. Brown and Reece (1979, pl. 6) report that chloride concentrations of water from wells in the Floridan aquifer system did not change significantly during the 20-year period 1957-77 in the area that includes St. Lucie County--the adjacent county south of Indian River. A few localities and some individual wells have shown increases in chloride concentration, but the increases probably reflect a local condition rather than a general trend.

Effect of Irrigation Water from the Floridan Aquifer System on the Quality of Canal Water

Crain and others (1975, p. 53) reported that major canals that drain the eastern part of the county had similar water quality. Large quantities of relatively poor quality irrigation water from wells in the Floridan aquifer system commonly mix with higher quality surface water and water from the surficial aquifer system in the canals. However, the quality of water present in a canal at a given time varies widely with the relative proportions of rainfall, irrigation water from the Floridan aquifer system, and ground-water contribution from the surficial aquifer system. The variation in water quality, as indicated by specific conductance, was determined for South Canal at 43rd Avenue (fig. 53) from February 1983 to September 1984.

The specific conductance of canal water is generally highest during the dry season (November through June) because flow in the canal consists largely of irrigation water from the Floridan aquifer system. During the wet season, much of the canal water is rainfall and surface runoff, and specific conductance is relatively low.

Figure 53 shows the effects of discharge from Floridan aquifer system wells and rainfall on the water quality of South Canal. The specific conductance of water in the canal generally ranged from 900 to 1,700 μS/cm (about 250 mg/L and 450 mg/L chloride, respectively). The specific conductance was lowest (540 μS/cm) in October 1983 when the monthly rainfall totaled a record high 15.58 inches. The highest specific conductance of 2,880 μS/cm (about 850 mg/L chloride) was in May 1984 following a month with only 1.02 inches of rain. Large quantities of water from the Floridan aquifer system are apparently used for freeze protection of citrus groves. In December 1983, temperatures dropped below freezing for three consecutive days, December 25, 26, and 27. The conductance of canal water was 2,700 μS/cm on the 27th, but declined to 1,120 μS/cm on January 6th. During part of the dry season, generally about November through February, natural requirements for water by citrus trees diminishes as average daily temperatures decline, so little irrigation water is needed. For example, conductances remained comparatively low in November 1983 and January 1984, though rainfall was only 1.58 inches (average is 2.55 inches) and 2.02 inches (average is 2.43 inches), respectively.

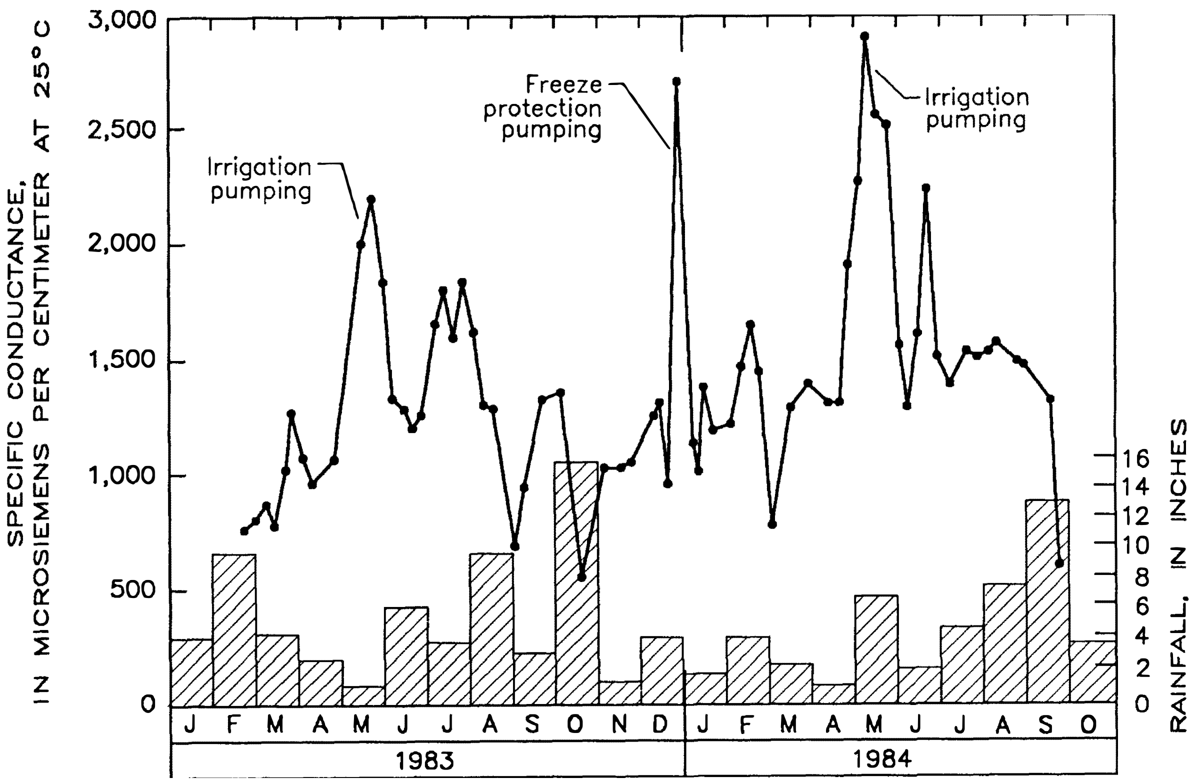


Figure 53.--Specific conductance of water in South Canal at 43rd Avenue and precipitation at Vero Beach.

WATER USE

General

The main public-water systems in the county are the cities of Vero Beach and Sebastian, and the county plant on Oslo Road. Figure 54 is a graph of the annual pumpage for Vero Beach, 1954-84. An undetermined amount of water used for irrigation originates from the dewatering of marshland. Large tracts of land previously part of the St. Johns Marsh east and south of Blue Cypress Lake are dewatered to grow citrus. Continuous pumping is needed to lower the near-surface water table enough to allow agriculture. Because dewatering is done throughout the year, including the dry season, the amount of water pumped may be large. Some of the water pumped from dewatering is ultimately used for irrigation.

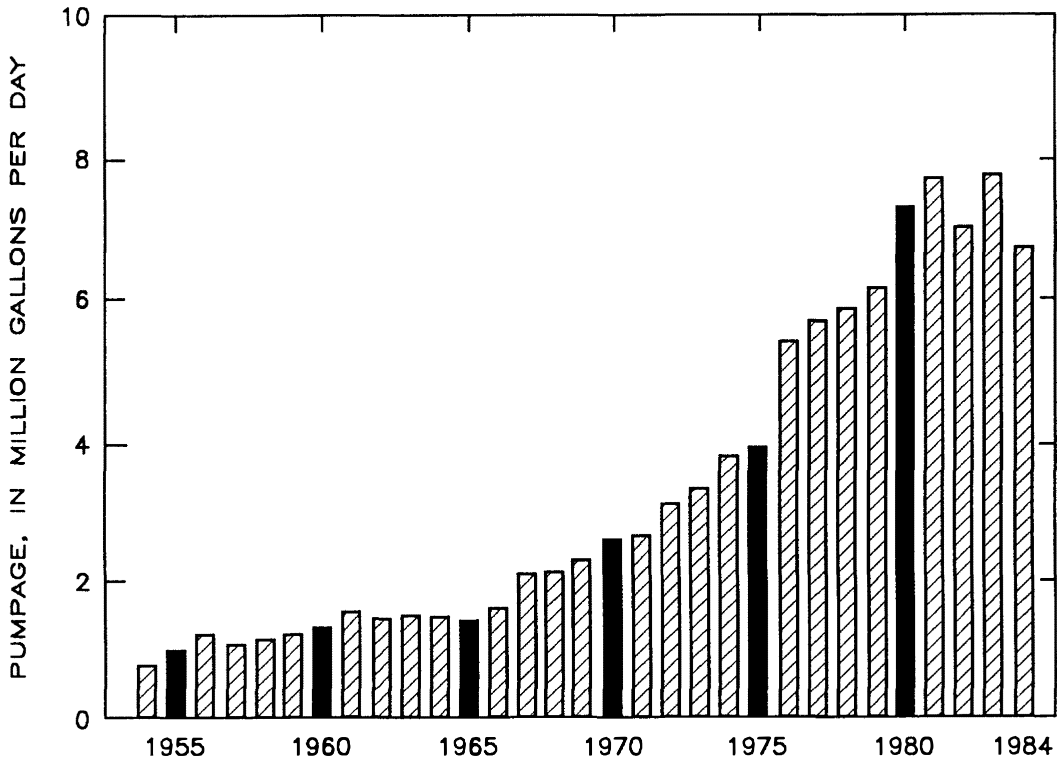


Figure 54.--Annual pumpage by the city of Vero Beach, 1954-84.

The following table gives the estimated water use in Indian River County for 1984.

Water use	Ground water (Mgal/d)	Surface water (Mgal/d)	Total (Mgal/d)	Total (percent)
Public	8.5	0	8.5	5.6
Domestic	8.0	0	8.0	5.3
Industrial	.23	0	.23	.1
Irrigation[1]	30	105	135	88.8
Thermoelectric	0	.24	.24	.2
Total	46.73	105.24	151.97	

[1]Excludes irrigation water obtained from dewatering.

Use of Water from the Floridan Aquifer System for Public-Water Supply

Prior to the 1980's, most water from the Floridan aquifer system could be used only for irrigation, because its high mineral content generally made the water nonpotable. However, with the advent of the reverse osmosis method of treatment that eliminates objectionable minerals, and with declining treatment cost, water from the Floridan aquifer system can be used as a source for the production of potable water. In places, particularly along the barrier beach, where the surficial aquifer system cannot provide enough freshwater for public supply, reverse osmosis facilities are often used. In June 1985, the county-owned reverse osmosis treatment plant near Oslo provided about 1 Mgal/d of water from two wells that tap the Floridan aquifer system to its service area south and west of Vero Beach. Another reverse osmosis treatment plant (North Beach Water Company) at Wabasso Beach has supplied about 0.06 Mgal/d of water from two wells in the Floridan aquifer system to the supply system on the Barrier Island between January and May 1985.

Irrigation Water Use

Approximately 124,000 acres (35 percent) of the total area of Indian River County (351,000 acres) are in agricultural use. About 94,000 acres (76 percent) are irrigated with large quantities of water from wells that tap the Floridan aquifer system. Agricultural land is used chiefly for citrus groves, pasture, and truck farming. Small acreages are used for other types of agriculture (nurseries and tropical-fish farming, for example). Irrigation is greatly reduced or ceases during rainy periods but commonly resumes shortly thereafter. Most irrigation is done during the latter part of the dry season, which extends from November through April or May, but with the approach of the rainy season (June through October), extended dry periods commonly occur and water use for crop irrigation may be considerable.

The changes in land use affecting the pattern of irrigation in the county will probably continue in the future. Along the main north-south road in the county (U.S. Highway 1), and along the main east-west road (State Road 60), urban development is replacing groves, so irrigation water use there is decreasing. In other areas, such as near Fellsmere, large areas of citrus groves are being planted. Irrigation water use in these places will increase accordingly.

On the Barrier Island, north of Vero Beach, land use is changing from citrus groves to mostly residential. Bermes (1958, p. 39) reported that 6.8 Mgal/d of irrigation water was withdrawn from about 90 wells in this area during 1951. If the current trend continues as predicted by county planners, most of the groves on the Barrier Island will probably be replaced with urban development in the next decade (1985-95), so irrigation water use will be minimal. Additional public-water supply systems using the reverse osmosis treatment will probably be installed. The amount of water used for public-water supplies will probably never exceed the amount that was previously used for irrigation.

Two types of irrigation systems are generally used in the county--flood and low volume (microjet); some overhead sprinkling is also done. In the flood system, water is applied by ditches or laterals that radiate from large open canals. In low-volume irrigation, water is typically distributed by pipeline and applied as a small jetspray to each tree in the grove. Flood irrigation, which currently uses mostly surface water, is still used by the majority of groves, but the low-volume system, which commonly uses ground water, is steadily increasing in use. The low-volume system is considered more efficient because evaporation is minimized during application. As the use of the low-volume system increases and replaces the flood-irrigation system, the use of ground water will increase and the use of surface water will decrease. However, ground-water use could possibly decline or remain about the same if large tracts of groves are converted to urban development. Data are currently (1985) not available on the amounts of water required for low-volume irrigation. In 1984, an estimated 78 percent of the water used for irrigation was surface water (105 Mgal/d) and 22 percent was ground water (30 Mgal/d).

The amount of water withdrawn from the Floridan aquifer system and used for irrigation in the county is difficult to ascertain. An irrigation-use inventory that shows areal and seasonal distribution of discharge from the Floridan does not exist. Pride (1973) reported that total irrigation use (surface water and ground water) in 1970 was 132 Mgal/d. Prior to 1985, many estimates of water use for irrigation in the county were based on permitted use which did not consider seasonal rainfall and surface-water storage. For example, contribution of water from the Floridan aquifer system in 1970 was reported as 100 Mgal/d--up 50 Mgal/d from 1951 (Crain and others, 1975 p. 28). After considering the factors of seasonal rainfall and surface-water storage, Marella (1986, p. 70) reported total agricultural-irrigation use in 1985 as 135.61 Mgal/d. Ground-water and surface-water uses were reported as 28.43 Mgal/d and 107.18 Mgal/d, respectively.

SUMMARY AND CONCLUSIONS

Indian River County has an area of 549 mi^2. Much of the drainage in the county has been drastically modified since the 1900's and is presently (1985) undergoing further change. Vast sections of the St. Johns Marsh that previously were part of the St. Johns River drainage area in the western half of the county have been diked and channeled for agricultural use. Most drainage is now eastward to the Indian River. In the eastern part of the county, residential and commercial developments are replacing citrus groves. The surficial aquifer system and the Floridan aquifer system are the sources of all ground water used in Indian River County. The two systems contain ground water that ranges in salinity from fresh to brine. High chloride concentration is the chief water-quality problem in the county.

In eastern Indian River County, the surficial aquifer system consists of a 100- to 150-foot-thick "clastic zone" (combined Holocene deposits and Fort Thompson and Anastasia Formations) and an underlying 0- to 60-foot-thick "shallow rock zone" (Tamiami Formation). The thickness of the surficial aquifer system generally increases in a southerly direction, from about a 100 feet in the northern part of the county to about 200 feet south of State Road 60.

The Floridan aquifer system consists of about 2,800 feet of carbonate rocks, subdivided on the basis of permeability, into the Upper Floridan aquifer (about 350-650 feet thick), the middle semiconfining unit (about 20-120 feet thick), and the Lower Floridan aquifer (about 2,000 feet thick). The surficial and Floridan aquifer systems are separated by a low permeability rock unit known as the intermediate confining unit.

Transmissivities of the surficial aquifer system range from 1,500 to 11,000 ft^2/d. Transmissivities tend to be lower in the shallow rock zone than in the clastic zone. At Vero Beach, where wells penetrate both zones, transmissivities range from 2,400 to 6,300 ft^2/d. Specific capacities range from 21 to 70 (gal/min)/ft in eastern Indian River County, and range from 9 to 36 (gal/min)/ft in the Vero Beach well field. Yields of wells that tap both the clastic and the shallow rock zones in the Vero Beach well field are as much as 1,200 gal/min. The lowest well yields in the county (less than 10 gal/min) occur in marsh areas in the central part of the county.

Water levels in the surficial aquifer system in eastern Indian River County may vary substantially from one location to another. Water levels generally fluctuate in response to seasonal changes in climate and pumping from wells but may also fluctuate in response to manipulation of flows in the drainage network in the county. Water levels in the Vero Beach well field during the May 1981 drought, were as low as 39 feet below sea level in wells that tap the surficial aquifer system; levels were lowest east and north of the airstrip. In May 1984, water levels had recovered substantially and were only 11 feet below sea level in some wells. However, water levels remained lowest near the airstrip.

Yields of many wells in the Vero Beach well field decreased in 1981 owing to the large drawdowns in the surficial aquifer system caused by long-term, continuous pumping. The problem was alleviated by implementing a well field management program that involved alternating withdrawals between sets of wells spaced far enough apart so as to minimize interfering drawdowns. In addition, a few wells were deepened to penetrate the shallow rock zone, and several new wells were installed to replace abandoned wells.

Pumpage in the Vero Beach well field approximately doubled during the 10-year period 1975-85 and peaked to about 9.5 Mgal/d in the spring of 1981, during a major drought. Coinciding with the increase in pumpage, however, water levels in the surficial aquifer system declined in the vicinity of the Vero Beach well field. Water-level measurements made in the surficial aquifer system near the Vero Beach well field in April 1971 and May 1984 indicate that water levels generally declined about 15 to 19 feet.

The surficial aquifer system in Indian River County is recharged mostly by infiltration of rainfall and by some periodic downward percolation of irrigation water. The aquifer receives little recharge from the underlying Floridan aquifer system because, though heads in the Floridan are generally higher than heads in the surficial aquifer system, a thick section of low permeability strata (the Hawthorn Formation) effectively separates the surficial and Floridan aquifer systems. Discharge from the surficial aquifer system is from seepage to the ocean, lakes, rivers, and canals; evapotranspiration; and withdrawals from wells.

Chloride concentrations in water from wells in the shallow rock zone in eastern Indian River County are generally below 100 mg/L except along Sebastian Creek and the Barrier Island where concentrations exceed 250 mg/L, and the east Vero Beach well field area where concentrations range from less than 100 to more than 1,000 mg/L. Water from observation wells east of the Vero Beach well field and approximately 1,000 feet west of the Indian River, have chloride concentrations greater than 20,000 mg/L.

Chloride concentrations in water from wells in the clastic zone also increase in an easterly direction, but concentrations are not as high as those in water from the shallow rock zone wells along the Indian River. Chloride concentrations in the clastic zone are generally less than 250 mg/L west of the Indian River but exceed 250 mg/L on the Barrier Island.

The high chloride concentration in some wells that tap the surficial aquifer system may be due to the intrusion of seawater or the intrusion of water from the Floridan aquifer system. Water from the Floridan aquifer system can be introduced into the surficial aquifer system by upward leakage around the casing of wells in the Floridan, corroded-through well casings, or by downward infiltration of irrigation water from the Floridan aquifer system.

Excluding the area east of the Vero Beach well field, the greatest chloride concentrations in water from wells in the surficial aquifer system generally occur south of Main Canal. Concentrations are lowest in the area of the airstrip coincident with the area of maximum drawdown in the Vero Beach well field. Chloride concentrations have increased in a few wells in the well field but changes have been relatively small. Between 1976 and 1983, the average chloride concentration in six production wells increased about 36 mg/L. However, average concentrations in four other wells were unchanged. The increases in chloride concentrations occurred in wells scattered throughout the area and were probably related to the increase in well-field pumpage from 5.44 Mgal/d in 1976 to 8.00 Mgal/d in 1983.

Assuming the surficial aquifer system receives 10 inches of natural recharge per year, about 67 Mgal/d of water is theoretically available for withdrawal in eastern Indian River County. This implies that sufficient water may be available for public-supply use in the foreseeable future in the county if development does not reduce the natural recharge rate and withdrawals are properly managed. In the eastern part of the county, high-yielding wells completed in the surficial aquifer system are most likely to be found along the Atlantic Coastal Ridge west of U.S. Highway 1.

Problems relating to saltwater intrusion of the surficial aquifer system can be minimized if all new wells are tested for saltwater during installation and production, and if all unused wells in the Floridan aquifer system are plugged from bottom to top. The occurrence and extent of saltwater intrusion into the surficial aquifer can be assessed only if long-term water-quality-monitoring programs are maintained.

About 65 percent of all ground water used in the county is from the Floridan aquifer system. The system, which is about 2,800 feet thick, in descending order, consists of the Upper Floridan aquifer, the middle semiconfining unit, and the Lower Floridan aquifer. The hydrology of the

Floridan aquifer system is complex, and considerable variation in yield and water quality may be found in nearby wells of equal depth. The permeability of the Upper Floridan aquifer generally is higher than the Lower Floridan aquifer. The most productive water-yielding zones are in the Avon Park Formation in the Upper Floridan aquifer. The Lower Floridan aquifer may also be productive in places. Wells more than 700 feet deep in the eastern part of the county are probably completed in the Lower Floridan aquifer. Transmissivities of the Floridan aquifer system as determined from individual aquifer tests range from about 10,000 ft^2/d from a well in the Upper Floridan aquifer to 1.5×10^6 ft^2/d from an injection well completed in the Boulder Zone in the Lower Floridan aquifer. However computer model simulations of the regional ground-water system, indicate that, generally, transmissivities are in the range of 65,000 to 200,000 ft^2/d. Specific capacities of 37 wells that tap the Floridan aquifer system range from 1 (gal/min)/ft to 200 (gal/min)/ft), with a median of 67 (gal/min)/ft. Specific capacity data indicate lower than average specific capacities in western Indian River County, higher than average values in the central part, and probably low values east of a fault trace along the Indian River.

Most wells completed in the Floridan aquifer system flow. Measured flow rates range from 30 to 2,000 gal/min with a median of 650 gal/min. A flow of 6,000 gal/min is reported from a well completed at a depth of 1,350 feet. Wells in the Floridan aquifer system are generally capable of yielding several hundred gallons of water per minute. Inventoried irrigation wells range from 233 feet to 1,272 feet in depth--median depth is 700 feet. Average well depths have increased from about 650 feet in 1950 to about 900 feet in 1985 in response to a demand for higher well yields. Well casings generally extend only into the intermediate confining unit (Hawthorn Formation), which directly overlies the Floridan aquifer system. Many wells are uncased at depths below about 200 feet. Corroded-through steel well casings are a significant problem, and the use of plastic (polyvinyl-chloride) casing is becoming common. More than 90 percent of inventoried wells in the Floridan aquifer system are used for irrigation. In those places where yields or water quality from wells in the surficial aquifer system is a problem, water from wells in the Floridan aquifer system has been successfully used for public water supply after reverse osmosis treatment. The public supply system at Vero Beach utilizes water from two wells in the Floridan aquifer system to supplement the yield from a well field that taps the surficial aquifer system.

The regional ground-water movement in the Upper Floridan aquifer is east from the recharge area in eastern Polk and western Highlands County. Natural discharge is mostly upward leakage through the intermediate confining unit. The potentiometric surface of the Upper Floridan aquifer, when most stressed in May, generally ranges from an altitude of about 30 feet along the coastline to about 50 feet on the Talbot terrace in the western part of the county. Potentiometric contours shift slightly eastward toward the Atlantic Ocean between May and September because of the recharge from summer (wet season) rains and curtailment of irrigation pumping. Water levels in September are generally 2 to 5 feet higher than levels in May, but if rainfall is deficient, levels in May can be as much as 15 feet lower than in September in heavily pumped areas. The rainfall deficit of about 19 inches during the 1980-81 drought caused record low water levels in many wells in May 1981. Water levels in wells in the Lower Floridan aquifer probably stand several feet higher than wells in the Upper Floridan aquifer, so wells that penetrate both units have resultant combination heads of the producing zones penetrated.

Long-term trends that may indicate declining water levels due to development are difficult to ascertain because variations in natural recharge may mask the trend. Water levels in the Floridan aquifer system in the generally undeveloped western part of the county declined 8 to 10 feet in the period between the 1930's and 1978, due to the effects of regional pumping. In the eastern part of the county, levels declined about 16 to 24 feet in the 50-year period 1934 to 1984, but most of the declines occurred prior to 1976.

In the future, water levels in the Floridan aquifer system may decline locally in those areas of the county where pumpage is increasing, such as in the Fellsmere area and in the area of the reverse osmosis treatment plant near Oslo. Curtailed water use in other parts of the county may allow water levels to rise, in areas such as the Indian River Water Control District where irrigation use is declining due to urban development.

Water from the Floridan aquifer system is relatively highly mineralized and the predominant constituents are sodium and chloride. Salinity increases with depth and is a function of flushing out of the ancient seawater trapped in the sediments during an earlier geologic time. Water from the Floridan aquifer system commonly exceeds the Florida Department of Environmental Regulation maximum contaminant levels for public drinking water systems of 250 mg/L for chloride and 500 mg/L for dissolved-solids concentration.

In places, corroded-through casings of wells in the Floridan aquifer system have allowed high chloride concentration water to intrude the surficial aquifer system. High heads, generally 10 to 30 feet above land surface, at present (1985) prevent saltwater contamination of the Floridan aquifer system from the Indian River or the Atlantic Ocean. The high heads also prevent surface pollution from moving downward into the aquifer. However, pollutants could be introduced into the Floridan aquifer system from recharge areas mostly outside the county, and heavy pumping can cause upconing of highly saline water. Periodic sampling of monitor wells would be needed to recognize incipient quality-of-water changes that could cause problems.

Chloride concentrations may vary considerably both areally and vertically. Chloride concentrations in water from wells in the Floridan aquifer system that flow continuously have less yearly variation than concentrations from wells that are periodically allowed to flow. Water in the Upper Floridan aquifer is fresher and less variable in quality than water in the Lower Floridan aquifer. Concentrations generally increase slightly with depth in the Upper Floridan aquifer but may increase rapidly with depth in the Lower Floridan. Chloride concentrations in water from the Upper Floridan aquifer range from 20 to 1,400 mg/L. Concentrations less than 250 mg/L occur primarily in the western, southwestern, and central part of the county.

Chloride concentrations in water from wells that yield mostly from the Lower Floridan aquifer range from 250 to 2,920 mg/L. In the eastern half of the county, concentrations generally exceed 500 mg/L. Water with chloride concentrations of 400 mg/L or less occurs in a narrow band along the trace of the Atlantic Coastal Ridge in the northern half of the county. Anomalously high chloride concentrations in water from some wells probably are a site-specific condition caused by heavy pumping from a relatively deep well.

Average chloride concentrations of water in the Floridan aquifer system throughout the county have increased only about 6 percent in the 15-year period 1968-83. However, chloride concentrations in water from 26 wells sampled during a 1951-52 study increased an average of about 20 percent between the early 1950's and 1985. Chloride concentrations in the Vero Beach area are apparently increasing; concentrations in water from well 93F increased from 300 mg/L in 1975 to 476 mg/L in 1985, and concentrations in well 94F increased from 285 mg/L in 1976 to 384 mg/L in 1985. At the old Vero Beach Power Plant, chloride concentrations in water from well 73F increased from 291 mg/L in 1921 to 790 mg/L in 1983.

Large quantities of moderately mineralized irrigation water from wells in the Floridan aquifer system commonly mix with less mineralized surface water and water from the surficial aquifer system in the canals that are used to drain or irrigate cropland.

The specific conductance of water in a typical canal, South Canal, during the water year 1984 ranged between 900 to 1,700 μS/cm (about 250-450 mg/L chloride, respectively). The highest conductance of 2,880 μS/cm (about 850 mg/L chloride) was in May 1984 when only 1.02 inches of rain fell, and the lowest conductance of 540 μS/cm (about 150 mg/L chloride) was in October 1983 which had a record high rainfall of 15.58 inches.

About 8.5 Mgal/d of ground water is used for public supply in the county, mostly by Vero Beach. In June 1985, the county-owned reverse osmosis treatment plant near Oslo provided about 1 Mgal/d of public-supply water to its service area south and west of Vero Beach from two wells that tap the Floridan aquifer system. Another reverse osmosis plant at Wabasso Beach (North Beach Water Company) supplied about 0.06 Mgal/d of water from two wells in the Floridan aquifer system to services on the Barrier Island between January and May 1985. The largest use of ground water in the county is for irrigation. An additional 8 Mgal/d of ground water is used for domestic supply. Industrial and thermoelectric use of ground water is minimal. In 1984, an estimated 22 percent of the water used for irrigation in the county was ground water (30 Mgal/d).

About 35 percent of the total area of Indian River County is in agricultural use, of which about 75 percent is irrigated with large quantities of water from wells that tap the Floridan aquifer system. Most agricultural land use is citrus groves--some is in pasture and truck farming. Changes in land use are affecting the pattern of irrigation. Urban development is replacing groves along sections of U.S. Highway 1 and State Road 60, so there irrigation water use is decreasing. In other areas, such as near Fellsmere, large areas of citrus groves are being developed--irrigation-water use will probably increase, accordingly. On the Barrier Island,

land use is changing from citrus groves to residential. Most of the groves on the Barrier Island may be replaced by urban development by 1995. At that time, water use there will probably be mostly for public supply and the amount of water used for that purpose is not likely to equal or exceed the amount that has been used for irrigation in the past.

SELECTED REFERENCES

Barraclough, J.T., 1962, Ground-water resources of Seminole County, Florida: Florida Geological Survey Report of Investigations 27, 91 p.

Bermes, B.J., 1958, Interim report on geology and ground-water resources of Indian River County, Florida: Florida Geological Survey Information Circular 18, 74 p.

Brown, M.P., and Reece, D.E., 1979, Hydrogeologic reconnaissance of the Floridan aquifer system Upper East Coast Planning Area: West Palm Beach, South Florida Water Management District Technical Map Series 79-1, plates 1-10B.

Brown, R.H., 1963, Drawdowns resulting from cyclic intervals of discharge, in Bentall, Ray, compiler, Methods of determining permeability, transmissibility, and drawdown: U.S. Geological Survey Water Supply Paper 1536-I, p. 324-330.

Burns, W.S., 1983, Well plugging applications to the inter-aquifer migration of saline groundwater in Lee County, Florida: West Palm Beach, South Florida Water Management District Technical Publication 83-8, 77 p., appendix I-III.

Campbell, Dean, Munch, D.A., Johnson, Richard, Parker, M.P., Parker, Bruce, Rao, D.V., Marella, Richard, and Albanesi, Edward, 1984, Section III Water administration and regional management, Chapter 13, St. Johns River Water Management District, in Fernald, E.A., and Patton, D.J., eds., Water Resources Atlas of Florida, Tallahassee, Florida State University, p. 158-177.

CH2M Hill, 1979, Injection test well and multizone monitor well Indian River Plant: Hydrogeologic Report, project no. GN 54801.80; consultant's report prepared for Hercules Inc., in files of U.S. Geological Survey, Orlando, Fla., 6 chapters, appendix A-K.

Cooke, C.W., 1939, Scenery of Florida: Florida Geological Survey Bulletin 17, 118 p.

----- 1945, Geology of Florida: Florida Geological Survey Bulletin 29, 339 p.

Crain, L.J., Hughes, G.H., and Snell, L.J., 1975, Water resources of Indian River County, Florida: Florida Bureau of Geology Report of Investigations 80, 75 p.

Florida Department of Environmental Regulation, 1982, Public drinking water systems: Chapter 17-22 in Florida Administrative Code.

Florida Department of Natural Resources, 1970, Florida water and related land resources-St. Johns River basin: Tallahassee, Fla., 205 p.

Florida Department of State, 1978, Rules of the Department of Environmental Regulation, Water-Quality Standards, Chapter 17-3, in Florida Administrative Code: Tallahassee, Fla.

Frazee, J.M., and Johnson, R.A., 1983, The hydrology of the post Hawthorn shallow rock zone of Brevard and Indian River Counties: Paper presented at the Southeastern Section of the Geological Society of America, Tallahassee, Fla.

SELECTED REFERENCES--Continued

Gee and Jenson, 1980, Future water supply development for the City of Vero Beach, Florida: Consultant's report prepared for City of Vero Beach, in files of St. Johns River Water Management District, Palatka, Fla., 167 p.

Geraghty and Miller, Inc., 1978, Availability of ground water at Hobart Park, Indian River County, Florida: Consultant's report prepared for Indian River County Commissioners, in files of St. Johns River Water Management District, Palatka, Fla., 40 p.

----- 1981a, Drilling and testing for public water supply from the shallow aquifer, Sebastian Highlands, Indian River County, Florida: Consultant's report prepared for General Development Corp., Miami, Fla., in files of St. Johns River Water Management District, Palatka, Fla., 45 p.

----- 1981b, Installation and testing of production and monitoring wells, South Taxing District, Indian River County, Florida: Consultant's report prepared for Indian River County Commissioners, in files of St. Johns River Water Management District, Palatka, Fla., 138 p.

Johnston, R.H., Krause, R.E., Meyer, R.W., Ryder, P.D., Tibbals, C.H., and Hunn, J.D., 1980, Estimated potentiometric surface for the Tertiary limestone aquifer system, southeastern United States, prior to development: U.S. Geological Survey Open-File Report 80-406, scale 1:1,000,000, 1 sheet.

Kohout, F.A., 1965, A hypothesis concerning cyclic flow of salt water related to geothermal heating in the Floridan aquifer: Transactions of the New York Academy of Sciences, ser. II, 28, no. 2, p. 249-271.

Krieger, R.A., Hatchett, J.L., and Poole, J.L., 1957, Preliminary survey of the saline-water resources of the United States: U.S. Geological Survey Water-Supply Paper 1374, 172 p.

Lloyd, J.M., 1985, Annotated bibliography of Florida basement geology and related regional and tectonic studies including an appendix of Florida deep well data: Florida Bureau of Geology Information Circular 98, 72 p.

MacNeil, F.S., 1949, Pleistocene shorelines in Florida and Georgia: U.S. Geological Survey Professional Paper 221-F, p. 91-107.

Marella, Richard, 1986, Annual water use survey: 1985: Palatka, Fla., St. Johns River Water Management District Technical Publication SJ86-5, 117 p.

McKee, J.E., and Wolf, H.W., 1963, Water quality criteria (2d ed.): California State Water Quality Control Board Publication 3-A, 548 p.

Miller, J.A., 1982, Thickness of the upper permeable zone of the Tertiary limestone aquifer system, southeastern United States: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-1179, scale 1:1,000,000, 1 sheet.

----- 1986, Hydrogeologic framework of the Floridan aquifer system in Florida and parts of Georgia, Alabama, and South Carolina: U.S. Geological Survey Professional Paper 1403-B, 91 p.

National Oceanographic and Atmospheric Administration, Climatological data, Florida, annual summaries.

Parker, G.G., Ferguson, G.E., Love, S.K., and others, 1955, Water resources of southeastern Florida: U.S. Geological Survey Water-Supply Paper 1255, 965 p.

Phelps, G.G., 1984, Recharge and discharge areas of the Floridan aquifer in the St. Johns River Water Management District and vicinity, Florida: U.S. Geological Survey Water-Resources Investigations 82-4058, 1 sheet.

Planert, Michael, and Aucott, W.R., 1985, Water-supply potential of the Floridan aquifer in Osceola, eastern Orange, and southwestern Brevard Counties, Florida: U.S. Geological Survey Water-Resources Investigations Report 84-4135, 69 p.

Pride, R.W., 1973, Estimated use of water in Florida, 1970: Florida Bureau of Geology Information Circular 83, 31 p.

Seaburn and Robertson, Inc., 1983a, The North Beach Water Company reverse osmosis supply well no. 2 construction and aquifer testing report: Consultant's report prepared for the North Beach Water Co., Vero Beach, Fla., in files of St. Johns River Water Management District, Palatka, Fla., 34 p.

----- 1983b, Marsh Island reverse osmosis supply well completion report: Consultant's report prepared for Florida Communities of Vero Beach, in files of U.S. Geological Survey, Orlando, Fla., 31 p.

Sprinkle, C.L., 1982, Chloride concentration in water from the upper permeable zone of the Tertiary limestone aquifer system, southeastern United States: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-1103, scale 1:1,000,000, 1 sheet.

Stringfield, V.T., 1936, Artesian water in the Florida peninsula: U.S. Geological Survey Water-Supply Paper 773-C, p. 115-195.

----- 1966, Artesian water in Tertiary limestone in the southeastern states: U.S. Geological Survey Professional Paper 517, 226 p.

Tibbals, C.H., 1978, Effects of paved surfaces on recharge to the Floridan aquifer in east-central Florida--a conceptual model: U.S. Geological Survey Water-Resources Investigations 78-76, 42 p.

----- 1981, Computer simulation of the steady-state flow system of the Tertiary limestone (Floridan) aquifer system in east-central Florida: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-681, 31 p.

----- in press, Hydrology of the Floridan aquifer system in east-central Florida: U.S. Geological Survey Professional Paper 1403-E.

U.S. Environmental Protection Agency, 1976, Quality criteria for water: U.S. Environmental Protection Agency report EPA-44019-76-023, 501 p.

University of Florida, 1986, Florida estimates of population, April 1, 1985, states, counties and municipalities: Gainesville, University of Florida Bureau of Economic and Business Research, Population Program, 48 p.

White, W.A., 1970, The geomorphology of the Florida peninsula: Florida Bureau of Geology Bulletin 51, 164 p.

SUPPLEMENTARY DATA I

Wells in the surficial aquifer system used for data analysis

[Altitude refers to distance above sea level]

Well No.	Latitude	Longitude	Well name	Altitude of land surface (feet)	Well depth (feet)	Casing Depth (feet)	Casing Diameter (inches)
1S	273348	0801930	SJRWMD	9.88	147	108	4
2S	273356	0802232	Vero Beach Highlands	42	127	--	--
3S	273356	0802237	Vero Beach Highlands	37	127	--	--
4S	273418	0802909	I.R. Correctional Inst.	25	65	--	--
5S	273448	0802658	USGS	20	62	--	--
6S	273457	0802336	Randy Saxton	--	--	--	2
7S	273459	0802254	Morgan Thomas	--	70	--	2
8S	273459	0802307	Shirley McDougald	--	--	--	1.25
9S	273505	0802458	Holiday Village	--	65	--	4
10S	273508	0802419	James Whalen	--	--	--	2
11S	273508	0802523	John Metherall	--	80	--	2
12S	273509	0802257	Father & Son Appl.	--	65	--	2
13S	273509	0802258	Father & Son Appl.	37	45	--	--
14S	273511	0802448	John Streeter	--	--	--	--
15S	273512	0802625	Barbara Nolte	--	73	--	2
16S	273513	0802223	Entomological Inst.	--	--	--	2
17S	273513	0802240	Undetermined	10	90	--	--
18S	273513	0802851	Ocean Spray Industries	26	63	--	--
19S	273514	0802240	Undetermined	10	90	--	--
20S	273515	0802505	Oaks Paradise MHP	21	87	--	--
21S	273518	0801959	Smith	13	14	11	2
22S	273518	0802731	Hyatt Fruit Co.	21	65	--	--
23S	273518	0802731	USGS	21	120	--	--
24S	273523	0802346	Earl McGiff	--	98	--	2
25S	273539	0802246	Vista Royale	11	100	--	--
26S	273543	0802247	Vista Royale	9	100	--	--
27S	273556	0802250	Vista Royale	11	91	--	--
28S	273558	0802303	Knights of Columbus	--	--	--	2
29S	273603	0802250	Vista Royale	9	91	--	--
30S	273604	0802449	Undetermined	23	100	--	--
31S	273607	0802328	SJRWMD	22.37	143	101	4
32S	273607	0802328	SJRWMD	--	53	43	2
33S	273608	0802252	Vista Royale	11	92	--	--
34S	273629	0802328	F.H. Buffington	24	86	--	--
35S	273713	0802422	H.E. Chappel	22	80	--	--

Wells in the surficial aquifer system used for data analysis--Continued

Well No.	Latitude	Longitude	Well name	Altitude of land surface (feet)	Well depth (feet)	Casing Depth (feet)	Casing Diameter (inches)
36S	273713	0802422	H.E. Chappell	22	33	--	--
37S	273731	0802122	S. Valentino	4	20	--	--
38S	273732	0802410	SJRWMD	19.37	55	45	2
39S	273732	0802410	SJRWMD	21.27	123	108	4
40S	273734	0802329	Mid-Fla Utilities	13	93	--	--
41S	273736	0802327	Mid-Fla Utilities	12	100	--	--
42S	273737	0802330	Mid-Fla Utilities	13	93	--	--
43S	273737	0802342	City of Vero Beach	--	130	50	2
44S	273739	0802525	City of Vero Beach	--	131	50	2
45S	273741	0802320	Vero Palms Motel	11	67	--	--
46S	273741	0802412	City of Vero Beach	17.80	120	55	12
47S	273743	0802131	C. Smith	3	8	--	--
48S	273745	0802346	City of Vero Beach	14.40	117	55	12
49S	273756	0802248	City of Vero Beach	4.90	100	10	2
50S	273756	0802301	Bertha Boettcher	--	50	--	--
51S	273756	0802314	City of Vero Beach	6.70	125	10	2
52S	273756	0802413	City of Vero Beach	20.30	140	55	12
53S	273757	0802345	City of Vero Beach	13.70	140	10	2
54S	273759	0802301	Marcell St. Thomas	--	65	--	1.5
55S	273759	0802827	L. Laney	--	--	--	1.5
56S	273801	0802301	Melvin J. Scheidt	--	33	30	1.25
57S	273807	0802533	John D. Grice	--	45	40	2
58S	273808	0802305	City of Vero Beach	5.10	100	10	2
59S	273808	0802420	Bernice Meyer	--	60	--	1.25
60S	273809	0802303	Anthony Mirabito	--	40	--	2
61S	273811	0802306	B. Pfleiderer	--	42	--	1.25
62S	273811	0802524	C.J. Neilsen	--	60	--	2
63S	273811	0802824	C. Schmaltz	--	25	--	1.5
64S	273812	0802727	Fran Price	--	20	--	1.25
65S	273812	0802901	Dave Gagliardi	--	85	--	1.5
66S	273813	0802454	D.K. Richardson	--	60	--	2
67S	273814	0802314	Earl Mathiak	--	44	40	2
68S	273814	0802415	A.R. Jones	--	90	--	3
69S	273814	0802526	Elmer Grant	--	68	63	2
70S	273814	0802745	Bertram Bach	--	29	--	2

Wells in the surficial aquifer system used for data analysis--Continued

Well No.	Latitude	Longitude	Well name	Altitude of land surface (feet)	Well depth (feet)	Casing Depth (feet)	Casing Diameter (inches)
71S	273814	0802824	Major Surles	--	45	--	1.5
72S	273814	0802828	C.H. Murtaugh	--	47	--	--
73S	273815	0802418	Edith MacLean	--	70	--	2
74S	273817	0802828	Wm. L. Shelton	--	47	--	1.5
75S	273818	0802434	John Detrick	--	60	--	3
76S	273818	0802503	John Stone	--	50	--	2
77S	273818	0802724	E.A. Hobbs	--	600	--	3
78S	273818	0802826	L. Layman	--	40	--	1.5
79S	273819	0802429	Jerry VanKeulen	--	87	--	2
80S	273819	0802545	City of Vero Beach	24	130	65	2
81S	273821	0802413	1st United Methodist	--	60	--	3
82S	273821	0802628	Haller LaRue	--	15	--	1.25
83S	273821	0802708	Charles Reschakh	--	60	--	1.25
84S	273822	0802420	City of Vero Beach	19.30	130	40	2
85S	273822	0802503	Mrs. David Evans	--	60	--	--
86S	273822	0802623	A.J. Brackins	--	60	--	2
87S	273822	0802632	Philip Junkins	--	60	--	--
88S	273823	0802618	C. Stecher	--	80	--	2
89S	273823	0802631	Kathy Beatty	--	60	--	1.25
90S	273823	0803115	USGS	25	120	--	--
91S	273824	0802729	M.J. Long	--	60	--	1.25
92S	273829	0802355	City of Vero Beach	14.60	141	50	2
93S	273833	0802437	City of Vero Beach	20	135	65	20
94S	273833	0802437	USGS	--	90	--	--
95S	273833	0802437	City of Vero Beach	21.90	135	65	2
96S	273833	0802437	City of Vero Beach	22.90	135	65	2
97S	273833	0802437	City of Vero Beach	21.90	135	65	2
98S	273833	0802437	City of Vero Beach	22.30	102	77	2
99S	273833	0802437	City of Vero Beach	23.00	53	5	2
100S	273838	0802450	City of Vero Beach	30.60	103	--	--
101S	273842	0802447	USGS	21	55	--	--
102S	273844	0802426	City of Vero Beach	20	105	65	20
103S	273844	0802426	City of Vero Beach	19.20	105	65	2
104S	273844	0802426	City of Vero Beach	19.40	105	65	2
105S	273844	0802426	City of Vero Beach	20.20	105	65	2

Wells in the surficial aquifer system used for data analysis--Continued

Well No.	Lati-tude	Longi-tude	Well name	Altitude of land surface (feet)	Well depth (feet)	Casing Depth (feet)	Casing Diameter (inches)
106S	273844	0802426	City of Vero Beach	20	90	77	4
107S	273844	0802426	City of Vero Beach	20.20	50	5	2
108S	273844	0802520	City of Vero Beach	22	93	53	10
109S	273844	0802544	City of Vero Beach	21	90	52	10
110S	273844	0802544	City of Vero Beach	21	127	60	12
111S	273846	0802609	City of Vero Beach	--	130	75	2
112S	273847	0802438	City of Vero Beach	22	80	--	--
113S	273853	0802410	USGS	15	48	--	--
114S	273856	0802527	City of Vero Beach	25.30	130	55	12
115S	273858	0802330	USGS	6	54	--	--
116S	273900	0802547	City of Vero Beach	22	130	60	12
117S	273903	0802548	USGS	22	61	--	--
118S	273905	0802409	City of Vero Beach	21	112	60	12
119S	273907	0802305	City of Vero Beach	5	92	--	2
120S	273907	0802305	USGS	4	120	--	--
121S	273907	0802419	City of Vero Beach	20.75	112	60	12
122S	273907	0802422	USGS	20	58	--	--
123S	273907	0802422	USGS	20	120	--	--
124S	273907	0802440	City of Vero Beach	21	130	60	12
125S	273908	0802352	City of Vero Beach	9.10	116	18	2
126S	273910	0802335	City of Vero Beach	7.30	120	10	2
127S	273910	0802442	City of Vero Beach	21	130	63	12
128S	273913	0802420	City of Vero Beach	17	81	49	10
129S	273919	0802549	City of Vero Beach	23.90	125	55	12
130S	273920	0802549	USGS	20	120	--	--
131S	273921	0802416	City of Vero Beach	15	84	50	10
132S	273921	0802632	City of Vero Beach	26	81	--	2
133S	273923	0802612	City of Vero Beach	22.70	140	60	12
134S	273923	0804718	USGS	32.21	19	13	6
135S	273925	0802609	City of Vero Beach	23	--	--	--
136S	273929	0802630	City of Vero Beach	21.40	130	50	12
137S	273930	0802553	City of Vero Beach	23.40	96	--	--
138S	273932	0802419	City of Vero Beach	20	112	60	12
139S	273935	0802321	City of Vero Beach	2.40	135	10	2
140S	273935	0802336	City of Vero Beach	7.70	140	10	2

Wells in the surficial aquifer system used for data analysis--Continued

Well No.	Lati- tude	Longi- tude	Well name	Altitude of land surface (feet)	Well depth (feet)	Casing Depth (feet)	Casing Diameter (inches)
141S	273935	0802353	City of Vero Beach	10	140	10	2
142S	273937	0802335	USGS	8	66	63	2
143S	273938	0802514	City of Vero Beach	21	122	60	12
144S	273938	0802631	City of Vero Beach	--	136	75	2
145S	273938	0802632	City of Vero Beach	21.70	136	75	2
146S	273939	0802452	City of Vero Beach	21	100	60	12
147S	273940	0802508	City of Vero Beach	21	125	62	12
148S	273940	0804750	USGS	32.21	19	13	6
149S	273941	0802506	City of Vero Beach	22	92	--	--
150S	273941	0802540	City of Vero Beach	22.70	135	55	12
151S	273942	0802427	City of Vero Beach	22.08	105	--	6
152S	273942	0802542	USGS	22	58	55	2
153S	273951	0802430	City of Vero Beach	14.70	100	77	4
154S	273955	0802455	City of Vero Beach	20	127	60	12
155S	274000	0802437	City of Vero Beach	21	102	62	10
156S	274000	0802459	City of Vero Beach	20.50	127	60	12
157S	274000	0802514	City of Vero Beach	21.70	120	43	10
158S	274001	0802349	USGS	6	66	--	--
159S	274002	0802519	City of Vero Beach	22.60	95	--	--
160S	274002	0802554	City of Vero Beach	25.30	91	--	--
161S	274002	0802619	SJRWMD	25.74	53	43	2
162S	274002	0802619	SJRWMD	--	150	84	4
163S	274004	0802827	USGS	19	92	--	--
164S	274007	0802640	USGS	22	87	--	--
165S	274025	0802437	Quality Fruit Packers	--	80	--	2
166S	274055	0802505	USGS	20	54	--	--
167S	274240	0802532	SJRWMD	24.56	53	43	2
168S	274240	0802532	SJRWMD	24.39	144	95	4
169S	274301	0802605	Freta Brumley	--	80	--	2
170S	274302	0802548	Brenda Tucker	--	169	--	3
171S	274307	0802450	George Hamilton	--	45	--	2
172S	274307	0802542	Dennis Proctor	--	90	--	--
173S	274307	0802607	Gerald Gravenmier	--	45	--	3
174S	274312	0802633	Hobart Park	--	70	--	--
175S	274352	0802258	USGS	10	5	--	--

Wells in the surficial aquifer system used for data analysis--Continued

Well No.	Lati-tude	Longi-tude	Well name	Altitude of land surface (feet)	Well depth (feet)	Casing Depth (feet)	Casing Diameter (inches)
176S	274400	0802633	USGS	20	68	--	--
177S	274414	0802650	SJRWMD	23.61	41	31	2
178S	274414	0802650	SJRWMD	24.49	137	88	4
179S	274422	0803828	USGS	23	67	--	--
180S	274448	0802618	Graves Bros. Co.	20	888	--	--
181S	274448	0803146	Stanley Frontzek	--	66	--	2
182S	274451	0802639	Lost Tree Village	27.53	85	--	2
183S	274453	0802638	Lost Tree Village	37	90	50	18
184S	274453	0802752	N.B. Ryall	--	60	--	1.25
185S	274454	0802636	David Eldell	--	60	--	2
186S	274454	0802643	Minnie Collins	--	60	--	2
187S	274454	0802711	Florance Johnson	--	60	--	2
188S	274454	0802756	Annabelle E. Smith	--	--	--	4
189S	274454	0802822	Mrs. Minnie Jones	--	--	--	--
190S	274454	0802957	Burrell Lynn	--	95	80	1.25
191S	274455	0802639	Queen Johnson	--	60	--	2
192S	274455	0802640	Lost Tree Village	33	85	45	4
193S	274455	0802646	Lost Tree Village	26.40	85	--	2
194S	274456	0802711	Rosebud Jones	--	--	--	2
195S	274457	0802637	Lost Tree Village	46.83	85	--	2
196S	274457	0802751	Philip Newton	--	90	--	2
197S	274457	0802752	H. Wilson	--	90	--	1.5
198S	274458	0802630	Lost Tree Village	21.01	85	--	2
199S	274458	0802640	Lost Tree Village	34	104	50	18
200S	274458	0802647	Thomas Ealy	--	62	--	2
201S	274459	0802606	R.W. Aughtman	--	--	--	1.5
202S	274502	0802627	Lost Tree Village	20.03	85	--	2
203S	274503	0802631	George Sessions	--	87	--	2
204S	274505	0802603	Harry N. Mills	--	24	24	1.25
205S	274506	0802601	John Resanka	--	40	--	1.5
206S	274506	0802603	Steve Dyalk	--	42	--	1.5
207S	274506	0802603	Harry N. Mills	--	75	--	1.5
208S	274507	0803123	William R. Gammill	--	80	--	2
209S	274507	0803202	Joel McDaniel	--	77	--	2
210S	274508	0802644	Lost Tree Village	34.86	85	--	2

Wells in the surficial aquifer system used for data analysis--Continued

Well No.	Latitude	Longitude	Well name	Altitude of land surface (feet)	Well depth (feet)	Casing Depth (feet)	Casing Diameter (inches)
211S	274508	0803144	Francis Betz	--	45	--	2
212S	274509	0803048	Edward Brown	--	65	--	2
213S	274511	0803109	Sharon Moon	--	80	--	2
214S	274511	0803211	David Finch	--	--	--	2
215S	274515	0802537	USGS	2	53	--	--
216S	274517	0802618	SJRWMD	11.95	49	39	2
217S	274517	0802618	SJRWMD	13.89	133	85	4
218S	274518	0802618	Tropical Travel Tr. Pk.	11.80	72	67	2
219S	274525	0802559	Olga C. Williams	--	135	--	2
220S	274533	0802616	Lowe	--	70	--	2
221S	274535	0803154	USGS	21	67	--	--
222S	274538	0802833	Undetermined	--	75	--	--
223S	274142	0802607	Joe Tomberg	--	70	--	2
224S	274542	0802841	Undetermined	--	72	--	--
225S	274547	0802352	John Escobedo	--	600	--	2
226S	274548	0802808	Sebastian Highlands	23.34	102	65	18
227S	274548	0803037	Undetermined	--	87	--	--
228S	274549	0802350	William Carnill	--	--	--	2
229S	274549	0802355	William Hickey	--	15	--	2
230S	274552	0803505	W.L. Austin	--	60	--	1.5
231S	274552	0803511	Frank McManus	--	--	--	--
232S	274554	0802808	Sebastian Highlands	23.65	102	65	18
233S	274557	0802359	Larry Lang	--	14	--	2.5
234S	274601	0803258	Stuckey's Rest. I-95	--	--	--	4
235S	274602	0802823	Undetermined	--	75	--	--
236S	274602	0803054	Harry Givens	--	65	--	2
237S	274603	0802411	Richard Gillespie	--	18	--	2
238S	274603	0802415	Peter Gasperini	--	20	--	2
239S	274603	0803457	SJRWMD	30.75	140	105	4
240S	274603	0803457	SJRWMD	--	45	20	2
241S	274604	0802829	Undetermined	--	65	--	--
242S	274604	0802831	Undetermined	--	40	--	--
243S	274607	0802415	Gerald Horan	--	--	--	--
244S	274615	0802710	R. Anderson	--	25	26	1.5
245S	274616	0802703	Nolan Askins	--	22	20	1.5

Wells in the surficial aquifer system used for data analysis--Continued

Well No.	Latitude	Longitude	Well name	Altitude of land surface (feet)	Well depth (feet)	Casing Depth (feet)	Casing Diameter (inches)
246S	274617	0802707	Johns Piliponis	--	21	17	1.5
247S	274618	0802710	John C. Villarose	--	44	42	1.5
248S	274619	0802641	R.C. Wilborn	--	75	--	1.2
249S	274636	0803001	Noel Donais	--	115	--	1.5
250S	274650	0802951	P.E. Lemmon	--	68	--	2
251S	274650	0802951	P.E. Lemmon	--	128	105	2
252S	274650	0804402	Undetermined	--	--	--	--
253S	274658	0802933	H.J. Munson	--	60	--	2
254S	274706	0802718	Cooley	--	50	--	1.25
255S	274706	0802925	R. Hammond	--	--	--	2
256S	274708	0802704	Sam Baugh	--	115	--	1.2
257S	274709	0802708	J.C. Kopeck	--	64	--	1.2
258S	274709	0802708	J.C. Kopeck	--	400	--	2.5
259S	274709	0802711	J.C. Kopeck	--	64	--	1.2
260S	274709	0802740	Max Bressler	--	70	--	2
261S	274709	0802743	Arthur Pederquist	--	120	--	2
262S	274710	0802936	Ray Nudo	--	110	--	1.25
263S	274711	0802658	A. Stuprich	--	78	--	1.5
264S	274711	0802713	Harrel Riddle	--	45	--	2
265S	274711	0802737	John Thompson	--	72	50	2
266S	274711	0802747	Henry Cwik	--	65	--	2
267S	274712	0802502	D'Albora	9	40	--	1.5
268S	274713	0802701	William Dalrymple	--	80	--	1.5
269S	274714	0802739	James Forward	--	80	--	2
270S	274716	0802705	Bill Schardt	--	90	--	1.5
271S	274716	0802725	B. Parker	--	--	--	2
272S	274716	0802743	Norris Cox	--	85	--	2
273S	274717	0802739	W.H. Phelan	--	90	--	2
274S	274717	0802740	Arthur Hughes	--	85	--	2
275S	274717	0802832	Sue Guynel	--	90	--	2
276S	274719	0802704	G. Roarty	--	90	--	1.5
277S	274725	0802918	Tracy Faulkner	--	135	--	2
278S	274731	0802955	Carl Mullen	--	80	--	1.25
279S	274733	0802913	M. Dunn	--	110	--	2
280S	274735	0802832	L.R. White	--	74	--	1.25

Wells in the surficial aquifer system used for data analysis--Continued

Well No.	Latitude	Longitude	Well name	Altitude of land surface (feet)	Well depth (feet)	Casing Depth (feet)	Casing Diameter (inches)
281S	274735	0802833	Pearl White	--	74	--	1.25
282S	274735	0802835	Fredrick Trexler	--	--	--	1.25
283S	274736	0802848	John Walker	--	--	--	1.25
284S	274736	0802853	Paul Crichton	--	--	--	--
285S	274747	0804434	USGS	16	35	--	--
286S	274750	0802733	John Timinsky	--	82	--	2
287S	274758	0802736	Kroegel	--	520	--	4
288S	274759	0802830	Victor Pelletier	--	--	--	1.25
289S	274809	0803007	Thomas J. Pepi	--	90	--	1
290S	274823	0802747	Helen Tennyson	--	53	--	1.5
291S	274823	0802747	Helen Tenyson	--	53	--	1.5
292S	274827	0802811	Oscar R. Pedigo	--	65	--	2
293S	274830	0802812	Golem	--	90	84	2
294S	274835	0804435	USGS	12	32	--	--
295S	274840	0802811	Ethal Kinsell	--	--	--	2
296S	274841	0803018	J. Clinton Scott	--	80	--	1.25
297S	274843	0802814	Berti Conner	--	65	--	2
298S	274843	0802818	Carl Lazzeri	--	--	--	--
299S	274844	0802814	Sylvia Flood	--	--	--	4
300S	274906	0802810	Mrs. Helen Boone	--	100	97	2
301S	274908	0803019	Lester Vander Meer	--	115	100	1.25
302S	274917	0803021	Charles W. Calkins	--	115	100	1.25
303S	274918	0802816	Amos J. Simons	--	--	--	2
304S	274918	0803018	Ray Pospisil	--	85	--	2
305S	274922	0803018	Robert Tanksley	--	87	--	2
306S	274925	0802825	William Wihstutz	--	40	--	2
307S	274925	0802825	William Wihstutz	--	40	--	2
308S	274927	0802824	R.G. Bergbom	--	--	--	2
309S	274932	0802828	Swan	--	--	--	2
310S	274937	0803006	Henry Mesec	--	126	--	1.25
311S	274942	0802835	Blizman	--	67	62	2
312S	274946	0802842	John Crumrine	--	90	--	2
313S	274946	0802843	Charles Rhodes	--	400	--	1.5
314S	274946	0802843	Charles Rhodes	--	90	--	2
315S	274947	0802844	David Burns	--	85	--	2

Wells in the surficial aquifer system used for data analysis--Continued

Well No.	Lati- tude	Longi- tude	Well name	Altitude of land surface (feet)	Well depth (feet)	Casing Depth (feet)	Casing Diameter (inches)
316S	274948	0802916	SJRWMD	20.60	134	105	4
317S	274948	0802916	SJRWMD	20.68	35	25	2
318S	274949	0802846	Tim Brussel	--	120	--	2
319S	274951	0802843	Irvin Foss	--	86	--	2
320S	274951	0802950	Christena Garry	--	65	--	2
321S	274952	0802845	John Radzinsky	--	85	--	2
322S	274953	0802953	A.G. Fletcher	--	87	--	1.25
323S	274954	0802843	Bruce Robert	--	85	--	--
324S	274955	0802848	Ernest Sherwin	--	94	--	2
325S	274955	0802848	Ernest Sherwin	--	74	--	2
326S	274958	0802845	Ruth R. Miller	--	--	--	--
327S	274958	0802850	Mary Bolton	--	127	--	--
328S	274959	0802848	Nino Bertini	--	125	--	2
329S	275002	0802935	Daniel Baker	--	80	--	3
330S	275003	0802936	C.W. King	--	82	--	2
331S	275010	0802858	Joseph Lutz	--	123	--	2
332S	275011	0802856	Thor Tobiason	--	85	--	--
333S	275026	0802911	Vergie Herbert	--	80	--	2
334S	275031	0802901	W.C. Tebay	--	60	--	2
335S	275052	0802911	Phillip Garcia	--	65	--	2
336S	275052	0802928	R.L. Brown	--	60	--	2
337S	275056	0802916	Allen Anderson	--	--	--	1.2
338S	275059	0802926	S.D. Mason	--	--	--	2

SUPPLEMENTARY DATA II

Wells in the Floridan aquifer system used for data analysis

[Altitude refers to distance above sea level]

Well No.	Site identification No.	Well name	Altitude of land surface (feet)	Depth of well (feet)
1F	273212080351101	SLF-Green Ranch	20	946
2F	273238080421401	OKF-2 Evans Groves	28.07	686
3F	273304080255101	StL 44 McDonald	20	691
4F	273323080214201	StL 48 Dolenick	2	714
5F	273331080412701	Evans Groves 158W	27	960
6F	273332080245001	Paramont Aquarium 27th Ave.	22	1,000
7F	273335080280901	Edwin Prange 66th Ave.	23	940
8F	273336080403001	Evans Groves 15AE	27	900
9F	273342080403001	Evans Goves 14AE	27	900
10F	273355080355601	Brady Groves West of Oslo	24	--
11F	273357080220201	Midway MHP South of Oslo	5.36	--
12F	273357080274901	Vernon Fromarg 66th Ave.	23	900
13F	273401080384101	Evans Groves 11DE	23	--
14F	273402080332001	Morrison Groves 3 JIMROD 7	25	992
15F	273402080403001	Evans Groves 12AE	27	940
16F	273405080222601	Ruth Hallstrum Old Dixie Road	20	--
17F	273409080265201	IR 252 Kings Highway	20	660
18F	273416080403001	Evans Groves 10AE	27	900
19F	273417080332201	Morrison Goves 2 JIMROD 2	24	1,010
20F	273423080332201	Morrison Groves	24	--
21F	273430080195301	Seminole Shores	2.01	943
22F	273430080403001	Evans Groves 8AE	27	960
23F	273435080255101	USDA South Well 43rd Ave.	24.60	--
24F	273445080401201	Evans Groves 6AE	27	900
25F	273446080215201	River Shores South of Oslo	5	720
26F	273459080401201	Evans Groves 4AE	27	900
27F	273501080301501	Dr. Moore Alternate Oslo Road	24	--
28F	273501080302101	Dr. Moore Oslo Road	24	880
29F	273510080225301	Phillip Helseth Oslo Road	19.95	450
30F	273510080271901	Albert Helseth Oslo Road	19	--
31F	273510080285501	Ocean Spray injection monitor	25	1,960
32F	273510080285502	Ocean Spray injection well	25	3,000
33F	273513080265201	IR 254 SR 505A & Oslo Road	21	760
34F	273513080401201	Evans Groves 2AE	27	920
35F	273522080235801	Oslo Nursery Oslo Road	22	800

Wells in the Floridan aquifer system used for data analysis--Continued

Well No.	Site identification No.	Well name	Altitude of land surface (feet)	Depth of well (feet)
36F	273524080262401	Albert Helseth Oslo Road	19	700
37F	273526080240701	County RO well No. 2	22	745
38F	273526080261001	Albert Helseth Oslo Road	19	--
39F	273527080263001	Phillip Helseth Oslo Road	19	750
40F	273536080240101	County RO well No. 1	22.29	704
41F	273536080240201	County RO monitor well	22	901
42F	273539080301901	Graves Groves Oslo Road	25	836
43F	273542080372001	Tech-ohm Groves	25	--
44F	273543080374101	Rancho Santa Maria 122 Ave.	24	--
45F	273559080370301	Tech-ohm Groves 122 Ave.	24	--
46F	273607080310301	Ball Groves 90th Ave.	24	1,100
47F	273615080283501	Jackson Groves Carter Ave.	21	860
48F	273616080470501	Latt Maxcy	36	912
49F	273629080260401	IR 256 Lillian Lockwood	20	700
50F	273630080460601	Latt Maxcy K-4	31	--
51F	273632080364501	IR 266 Citrus Road & 90th Ave.	24.06	--
52F	273633080351001	Gracewood Groves Heritage Road	24	1,100
53F	273633080364301	Rio Groves McClelland Road	25	--
54F	273639080261501	L. Gollnick Groves 4th Street	22	900
55F	273649080452701	IR 202 Latt Maxcy F-7	28	730
56F	273656080230701	Tropic Villas No. 2	8	703
57F	273710080230601	Tropic Villas No. 1	8	660
58F	273719080225601	IR 243 12th Street	3	941
59F	273722080455901	Latt Maxcy K-11	27	--
60F	273723080255401	IR 255 Mr. Young 43rd Ave.	21	575
61F	273726080371501	Talmadge Brothers Groves	24	960
62F	273726080471701	Latt Maxcy	32	--
63F	273740080335701	Lykes Pasco No. 6	26	1,100
64F	273741080382701	Eder Groves 122nd Ave.	26	570
65F	273756080371401	Talmedge Bros. Groves	24	1,000
66F	273758080301501	Village Green Southwest	22	766
67F	273801080301701	Village Green South 90 Ave.	23	704
68F	273802080375701	Cardinal Groves 122 Ave.	26	540
69F	273805080223901	Vero Beach Power Plant No. 2	3	--
70F	273807080450201	K. Prince St. Johns Marsh	24	750

Wells in the Floridan aquifer system used for data analysis--Continued

Well No.	Site identification No.	Well name	Altitude of land surface (feet)	Depth of well (feet)
71F	273812080382701	Eder Groves 122nd Ave.	26	800
72F	273814080245201	IR 24 1st Christ Church	20	671
73F	273815080235101	IR 10/241 old VB Power Plant	20	665
74F	273818080235201	IR 200 old VB Power Plant	15	700
75F	273818080284801	Williams Groves SR 60	22	725
76F	273819080260101	IR 228 F Pollock SR 60	23.35	750
77F	273821080273901	Chauncey Hatch Jr. SR 60	21	746
78F	273822080374401	Cardinal Groves Pond Well	24	--
79F	273822080374402	Cardinal Groves unused	23.00	604
80F	273827080322001	SR 60 West of I-95	23	--
81F	273828080283801	Village Green No. 2 SR 60	23	780
82F	273828080283901	Village Green No. 1 SR 60	23	760
83F	273833080233901	IR 23 Episcopal Church	10	690
84F	273833080461901	IR 205 K Prince	28.06	--
85F	273835080345801	Kromhout Groves SR 60	24	600
86F	273839080244101	Village Green MHP SR 60	20	--
87F	273840080320701	Lambeth Groves SR 60	26	975
88F	273846080254701	USDA North Well 43rd Ave.	22	--
89F	273852080283601	Village Green 26th St. aban.	20	562
90F	273854080464401	Eatmon Ranch	26	920
91F	273859080235101	30th Street Vero Beach	8.51	--
92F	273900080232301	IR 240 Royal Palm Golf Club	5	550
93F	273905080241101	Vero Beach No. 21 Airport	20	688
94F	273912080241401	Vero Beach No 14 Airport	15	688
95F	273927080465701	Eatmon Ranch West	27	960
96F	273940080472101	Leroy Pressley SR 60	29	--
97F	273945080281801	J. Johnson Barber Ave.	20	760
98F	273947080230501	Mosquito Control Well	5	--
99F	273953080274801	IR 208 Frank Bates	20	700
100F	273957080291501	Takaho Groves Block 13 & 14	19	882
101F	274005080244901	IR 230 South Gifford Road	19.34	720
102F	274008080255301	Jackson Groves S. Gifford Road	23.57	960
103F	274016080481601	K.D. Eatmon SR 60	36	--
104F	274023080291401	Takaho Groves Blk 9 & 10	20	966
105F	274028080384301	Diamond G Farm SR 512	22	--

Wells in the Floridan aquifer system used for data analysis--Continued

Well No.	Site identification No.	Well name	Altitude of land surface (feet)	Depth of well (feet)
106F	274047080513701	USGS TH Site near Yeehaw	58	305
107F	274055080281301	IR 210 Walter Pool	19	650
108F	274113080475501	IR 185 W. Surrency	33	700
109F	274114080474901	L. Pressley Blue Cypress Road	31	550
110F	274115080291401	Takaho Groves Blk 1 & 2	20	886
111F	274116080265001	IR 216 SR #505A	21	635
112F	274121080241701	IR 233 Kennedy Grove	6.65	635
113F	274142080294301	IR 226 Ranch Road	21	--
114F	274150080260901	Kings Highway	22	472
115F	274156080344301	Jack Berry Grove Blk 99	23	700
116F	274157080263801	Kings Highway	22	556
117F	274203080292901	Gracewood Groves	22	890
118F	274206080225501	Johns Island Well	2.90	2,020
119F	274210080400301	Fellsmere JV Ditch 33	18	700
120F	274216080264301	Kings Highway	22	579
121F	274223080371501	Fellsmere JV Ditch 32	24	600
122F	274226080242501	IR 234 North of Gifford	4	500
123F	274250080354401	Jack Berry Groves Blk 55	23	700
124F	274250080355001	Jack Berry Groves Blk 54	23	700
125F	274302080260901	Bruce Chalker	18	405
126F	274302080371501	Fellsmere JV Ditch 29	24	650
127F	274303080380401	Fellsmere JV Ditch 8	22	760
128F	274309080245001	IR 235 George Hamilton	5	500
129F	274309080265301	CIBA Geigy Co.	24.32	651
130F	274310080293301	IR 58 Graves Bros.	20	400
131F	274313080283701	H. Prange	20	800
132F	274337080233901	IR 116 Jungle Trail	3	650
133F	274345080413201	Fellsmere JV Lat 26	20	460
134F	274350080364501	Jack Berry Groves Blk 11	24	708
135F	274404080233601	IR 114 R. Jones Jungle Trail	3	586
136F	274436080395801	Fellsmere JV Ditch 22	20	650
137F	274445080235901	IR 104 Deerfield Groves	3	1,000
138F	274447080235301	IR 108 Deerfield Groves	7	860
139F	274448080373201	IR 203 Dietz Well	22	590
140F	274449080240001	IR 107 Deerfield Groves	3	991

Wells in the Floridan aquifer system used for data analysis--Continued

Well No.	Site identification No.	Well name	Altitude of land surface (feet)	Depth of well (feet)
141F	274450080232401	Baytree A1A	8.30	1,050
142F	274452080275501	IR 147 A.S. Pfarr	21	620
143F	274455080263701	Johns Island Golf Course	37	560
144F	274459080490501	Rollins Ranch North of Yeehaw	31	416
145F	274501080282101	IR 160 West of Wabasso	20	600
146F	274502080395801	Fellsmere JV Ditch 20	20	650
147F	274503080413001	Fellsmere JV Lat 20	20	399
148F	274514080365601	Harold Platt	23	--
149F	274522080304301	SR 510 South of River Bridge	20	465
150F	274524080240801	North Beach Water Co. No. 2	3	960
151F	274528080395801	Fellsmere JV Ditch 18	20	650
152F	274528080412901	Fellsmere JV Lat 18	22	--
153F	274529080423001	Fellsmere JV Lat 18 & Q Canal	22	400
154F	274532080241801	North Beach Water Co. No. 1	3	1,000
155F	274534080251101	Marsh Island	3	390
156F	274538080281601	IR 155 Sebastian Highlands	21.52	--
157F	274549080245201	IR 73 Deerfield Groves	3	800
158F	274552080242201	IR 82 Deerfield Groves	5	950
159F	274553080243801	IR 69 Deerfield Groves	3	550
160F	274553080245801	IR 72 Deerfield Groves	3	800
161F	274556080412901	Fellsmere JV Lat 16	20	405
162F	274557080343001	Carol City Aquarium	28	786
163F	274558080304201	John Bradley River Bridge	19	540
164F	274601080313801	IR 175 SR 510	19	600
165F	274603080485201	Rollins Ranch North of Yeehaw	28	--
166F	274606080335401	Schiner Memorial Well	31	--
167F	274607080264001	Pelican Pointe	9	357
168F	274607080493001	USGS Observation Well IR 189	33.66	630
169F	274608080412901	Fellsmere JV Lat 15	20	405
170F	274609080502801	Rollins Ranch No. 1	42	605
171F	274621080300901	Roseland Acres	17.66	--
172F	274623080503201	Oil Test Rollins Ranch	60	9,480
173F	274625080242101	Kohl at Wabasso Beach	7	1,272
174F	274635080244501	IR 60 Deerfield Groves	6	550
175F	274635080363001	IR 183 Joe Screws	24	640

Wells in the Floridan aquifer system used for data analysis--Continued

Well No.	Site identification No.	Well name	Altitude of land surface (feet)	Depth of well (feet)
176F	274636080244001	IR 59 Deerfield Groves	6	650
177F	274640080243401	IR 201 Deerfield Groves	8	883
178F	274640080243801	IR 52 Deerfield Groves	7	750
179F	274641080244701	IR 51 Deerfield Groves	20	800
180F	274642080453601	Rollins Ranch pumphouse	27	600
181F	274646080243801	IR 50 Deerfield Groves	7	750
182F	274647080313401	IR 169 C L'Orange	18	525
183F	274650080413001	IR 186 Fellsmere JV Lat 12	20	--
184F	274650080425901	Fellsmere JV Lat 12	20	340
185F	274650080440201	Fellsmere JV Lat 12 No. 1	20	380
186F	274659080244301	IR 49 B.F. Bailey	7	760
187F	274700080243901	IR 46 B.F. Bailey	8	850
188F	274700080245101	IR 47 B.F. Bailey	6	700
189F	274705080460301	Rollins Ranch Silage Road	20	600
190F	274705080470201	Rollins Ranch Silage Road No.1	20	600
191F	274706080454901	Rollins Ranch Silage Road No.2	20	600
192F	274712080491101	Rollins Ranch North of Yeehaw	28	--
193F	274718080440201	Fellsmere JV Lat 10	20	360
194F	274719080274301	General Development Co.	25	510
195F	274744080465001	Blue Cypress Ranch	23	--
196F	274751080480801	Blue Cypress Ranch nr old shop	23	--
197F	274801080482001	Blue Cypress Ranch unused	24	--
198F	274814080303301	Carl L'Orange Sebastian River	2	491
199F	274815080254101	IR 33 A.J. Byrd	3	540
200F	274837080293501	Sebastian Country Club	22	840
201F	274838080275501	IR 131 P.R. Stevenson	7	--
202F	274843080471401	Blue Cypress Ranch near shop	23	--
203F	274857080493401	Yates Well near Sebastian	28	233
204F	274915080362501	IR 180 A. Beckman	25	425
205F	274916080520701	USGS TH Mace Ranch	53	260
206F	274921080254201	Indian River County AIA	5	--
207F	274927080290601	B and S Fish Co.	22	700
208F	274935080282601	Sembler Well Sebastian	6	475
209F	274942080404001	Fellsmere Joint Venture	25	500
210F	275018080261201	McLarty Museum	4.96	--

Wells in the Floridan aquifer system used for data analysis--Continued

Well No.	Site identification No.	Well name	Altitude of land surface (feet)	Depth of well (feet)
211F	275047080292401	Kip Wagner Roseland	25	600
212F	275057080292301	Bob's Inn Roseland	26	409
213F	275108080271001	State Park Sebastian Inlet	5	480
214F	275114080265401	Mosquito Control Well Seb. Inlet	3	--
215F	275117080270401	State Park Seb. Inlet unused	4.96	480
216F	275119080482401	Gilbert Tucker	21	594
217F	275210080272201	DR0624 Seb. Inlet Test Well	2	650

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