HYDROGEOLOGY OF THE SARASOTA-PORT CHARLOTTE AREA, FLORIDA

By Richard M. Wolansky

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Factors for converting inch-pound units to International System of units (SI) and abbreviation of units

Multiply	By	To obtain
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
cubic foot per minute (ft^3/min)	0.02827	cubic meter per minute (m^3/min)
gallon per minute (gal/min)	0.00378	cubic meter per minute (m^3/min)
	Transmissivity	
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
gallon per day per foot [(gal/d)/ft]	0.0124	meter squared per day (m^2/d)
	Hydraulic Conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Leakance Coefficient	
foot per day per foot [(ft/d)/ft]	1.0	meter per day per meter [(m/d)/m]
gallon per day per cubic foot [$(gal/d)/ft^3$]	0.1337	meter per day per meter [(m/d)/m]
	Specific Capacity	
cubic foot per minute per foot [$(ft^3/min)/ft$]	0.008616	cubic meter per minute per meter [$(m^3/min)/m$]
gallon per minute per foot [(gal/min)/ft]	0.001152	cubic meter per minute per meter [$(m^3/min)/m$]

* * * * * * * * * * * *

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in the text of this report.

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ABSTRACT

The surficial and intermediate aquifers are the major sources of public water supplies in the Sarasota-Port Charlotte, Florida, area because water in the Floridan aquifer, the principal aquifer in most of the State, yields relatively poor quality water in the area. The hydrogeologic framework consists of the surficial aquifer, intermediate aquifers (Tamiami-upper Hawthorn and lower Hawthorn-upper Tampa aquifers) and confining beds, Floridan aquifer, and lower confining bed (or base of the Floridan aquifer).

The quality of ground water in the surficial and intermediate aquifers is generally good, except in the western (coastal) and southern parts where saltwater intrusion or incomplete flushing of residual seawater has occurred. The mineral content of ground water generally increases with depth and increases areally from the northeast toward the west and south. Water from intermediate aquifers is widely used for domestic and public supplies. The Floridan aquifer is a major source of water for agricultural irrigation.

A water budget for the study area shows that an average annual rainfall of 51.0 inches minus an evapotranspiration of 38.0 inches per year and streamflow of 12.5 inches per year leaves 0.5 inch per year of recharge to the surficial aquifer. Combined pumpage from the aquifers is 1.06 inches per year and pumpage returned to the surficial aquifer is 0.01 inch per year. Ground-water inflow to the aquifers is 1.20 inches per year and ground-water outflow is 0.64 inch per year.

A quasi-three-dimensional model was applied to the study area and served as a check on the reasonableness of the defined hydrogeologic framework and of aquifer parameters. The preliminary steady-state model was considered calibrated when the final head matrix was within plus or minus 5 feet of the starting head.

INTRODUCTION

In much of Sarasota, southwestern De Soto, and Charlotte Counties (fig. 1), the surficial aquifer and intermediate aquifers overlying the Floridan aquifer are the principal sources of potable ground water. The Floridan aquifer, the major source of water in most of west-central Florida, does not contain potable ground water in these counties. The surficial and intermediate aquifers include the surficial deposits, Caloosahatchee Marl, Bone Valley, Tamiami, and Hawthorn Formations, and the part of the Tampa Limestone that is not in hydraulic connection with the Floridan aquifer. In several previous investigations, these water-bearing zones have been identified; however, regional delineation or hydrologic evaluation of the zones and their occurrence within the surficial and intermediate aquifers has not been made.

This report presents the results of a cooperative investigation with the Southwest Florida Water Management District to define the hydrogeologic framework for the Sarasota-Port Charlotte area. This framework definition could aid in systematic and proper development of the shallow ground water of the area.

The investigation was based on an evaluation of extensive existing data in reports of the U.S. Geological Survey, other government agencies, and consultants. These reports include geologic and geophysical logs, water-quality analyses, and aquifer-test data. Where needed, existing data were supplemented by selected well inventory, geophysical logging, surface geophysics, examination of well cuttings, and sampling for water-quality analyses. Results of previous local investigations were incorporated with new findings in previously unstudied areas to provide an integrated regional framework of the aquifer system.

Purpose and Scope

The objective of this investigation was to define the hydrogeologic framework of the surficial, intermediate (Tamiami-upper Hawthorn aquifer and lower Hawthorn-upper Tampa aquifer), and Floridan aquifers in the Sarasota-Port Charlotte area, including their regional extent, thickness, hydraulic properties, water quality, and their interrelation in the regional ground-water flow system.

The study area includes all of Sarasota County, the southwestern part of De Soto County, and that part of Charlotte County that is within the Southwest Florida Water Management District (fig. 1). The study area is named for the two principal communities within it, the cities of Sarasota and Port Charlotte. Geologic, geophysical, water-level, and water-quality data were collected and interpreted to define the hydrogeologic framework of the surficial and intermediate aquifers.

The report presents the thickness, structure, water quality, and water levels of the four aquifers mapped. The results of aquifer tests and the probable range of aquifer characteristics of the aquifers are reported. A water budget for the study area was verified using a digital ground-water flow simulation model.

Acknowledgments

Valuable assistance in conducting this investigation was provided by many organizations and individuals. Personnel of the Florida Bureau of Geology, Florida Department of Transportation, and the Southwest Florida Water Management District provided access to well records and cuttings.

F. P. Haeni, U.S. Geological Survey, Connecticut, and Richard Sylvester, U.S. Geological Survey, Massachusetts, assisted in conducting a continuous marine seismic survey and in interpreting the seismic data.

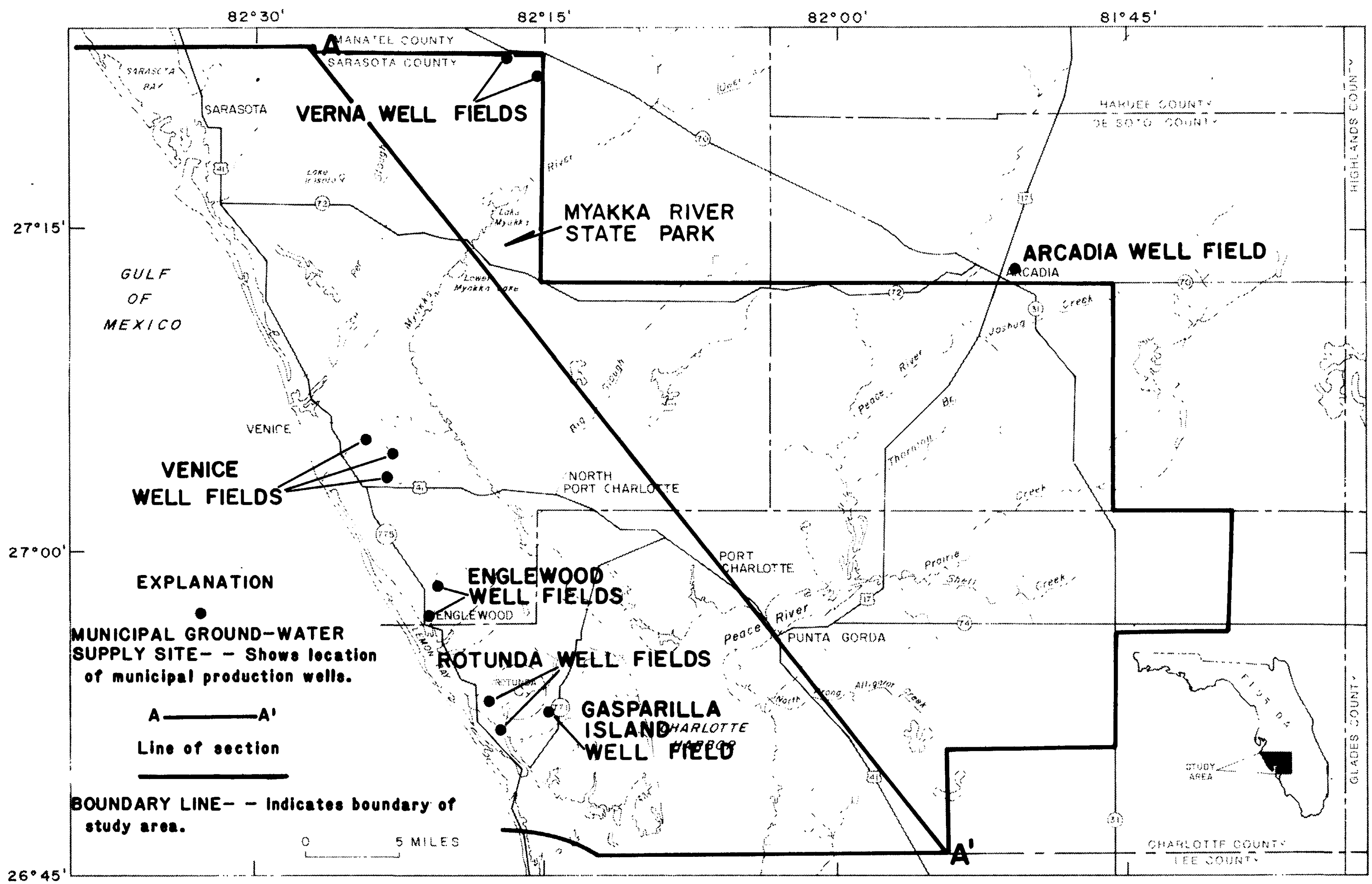


Figure 1.--Location of the Sarasota-Port Charlotte area and public water-supply systems that obtain water from the surficial and intermediate aquifers.

Previous Investigations

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

Investigations that report geologic and ground-water information include the following: Stringfield (1933a; 1933b) described the geology and ground-water conditions and yields of water-bearing strata in Sarasota County. Parker and Cooke (1944) discussed the geology and ground water in Charlotte County. The stratigraphy of shallow deposits in De Soto County was reported by Bergendahl (1956). Clark (1964) discussed local geology, water quality, and aquifer tests in the Venice area. Eppert (1966) reported on the stratigraphy of the late Miocene deposits in Sarasota County. Sutcliffe and Joyner (1968) gave the results of packer tests in wells in Sarasota County. Kaufman and Dion (1968) presented ground-water resources data of Charlotte and De Soto Counties. Sutcliffe (1975) presented an appraisal of the water resources of Charlotte County that identified water-bearing zones overlying the Floridan aquifer. Wilson (1977) provided information on the ground-water resources of De Soto and Hardee Counties that included the geology and hydrology of the surficial and intermediate aquifers. Joyner and Sutcliffe (1976) identified and described water resources in the Myakka River basin and included a description of the water-bearing zones overlying the Floridan aquifer. Hutchinson (1977) gave an appraisal of shallow ground-water resources in the upper Peace and eastern Alafia River basins. Wolansky (1978) presented the feasibility of water-supply development from the surficial aquifer in Charlotte County.

Other reports that pertain mainly to water-supply development, but include information on shallow aquifers, are as follows: Bishop (1960) presented water-resource problems in Sarasota County, and Smith and Gillespie, Inc. (1960) reported on alternative ground-water supplies near Sarasota. Smally, Wellford and Nalvin, Inc. (1963) addressed the water supplies of Sarasota County. Russel and Axon, Inc. (1965) presented an investigation of future sources of water supply in the Venice area. Joyner and Sutcliffe (1967) reported on saltwater contamination in wells on Siesta Key. Wells (1969) reported on water demands and water-supply alternatives for the Port Charlotte area. Black, Crow and Eidsness, Inc. (1974) presented a plan to increase water production of the Venice Gardens Utility. Geraghty and Miller, Inc. (1974) reported on the engineering and financial feasibility of water-supply alternatives available to Venice Gardens. Geraghty and Miller, Inc. (1975a) addressed the safe yield of wells at the Verna well field. Smith and Gillespie, Inc. (1975) reported on the safe yield and water quality of the surficial and intermediate aquifers in the Verna well-field area. Smalley, Wellford and Nalvin, Inc. (1977) presented a literature assessment of the Manasota Basin (Sarasota and Manatee Counties).

DESCRIPTION OF THE AREA

Land and bay area in Sarasota County and parts of Charlotte and De Soto Counties within the study area encompass approximately 1,400 mi^2 in west-central Florida (fig. 1). The counties include parts of the Peace and Myakka River basins and adjacent coastal drainage areas.

Geographic Setting

The Sarasota-Port Charlotte area lies in the midpeninsular physiographic zone that includes the Gulf Coastal Lowlands, the Gulf Coastal Lagoons, and the Gulf Barrier Chain subdivisions (White, 1970). As described by White, the Gulf Coastal Lowlands are a broad, gently sloping marine plain, and the Gulf Barrier Chain and Gulf Coastal Lagoons are a system of barrier lagoons and spits that were formed by erosion of divides between estuaries. The lowlands are characterized by broad flatlands with many sloughs and swampy areas, including some that have been drained by ditches and canals. Topography in the study area ranges from more than 100 feet above sea level along the northwestern boundary to less than 25 feet above sea level in coastal areas (fig. 2).

Water Use

The surficial and intermediate aquifers are the major sources of water supplies in the Sarasota-Port Charlotte area because of the relatively poor quality of water from the deeper-lying Floridan aquifer. The Floridan aquifer contains potable water only in the northeastern part of the study area. Although water from the Floridan aquifer is used for irrigation in many places and the upper part of the aquifer is used for municipal supply at the Verna well field, the aquifer generally contains highly mineralized water (greater than 1,000 mg/L dissolved solids).

Total pumpage of ground water from all sources in the study area in 1979 was estimated to be 41.7 Mgal/d (table 1). About 64 percent (26.5 Mgal/d) of the water used was for irrigation of citrus, vegetables, and pastureland. Public water supply was about 23 percent of the total use (9.7 Mgal/d), rural domestic use was about 12 percent (5.1 Mgal/d), and industrial use was less than 1 percent (0.4 Mgal/d).

In 1979, six major public-supply systems with well fields within or adjacent to the study area obtained water from the surficial and intermediate aquifers (H. Sutcliffe, Jr., written commun., 1980). Average daily pumpage for the systems was as follows:

County	Public supply system	Pumping rate (Mgal/d)
Sarasota	Sarasota	5.7
	Venice	1.6
	Englewood	1.3
Southwest De Soto	Arcadia	0.7
Charlotte	Gasparilla Island	0.2
	Rotunda	0.2

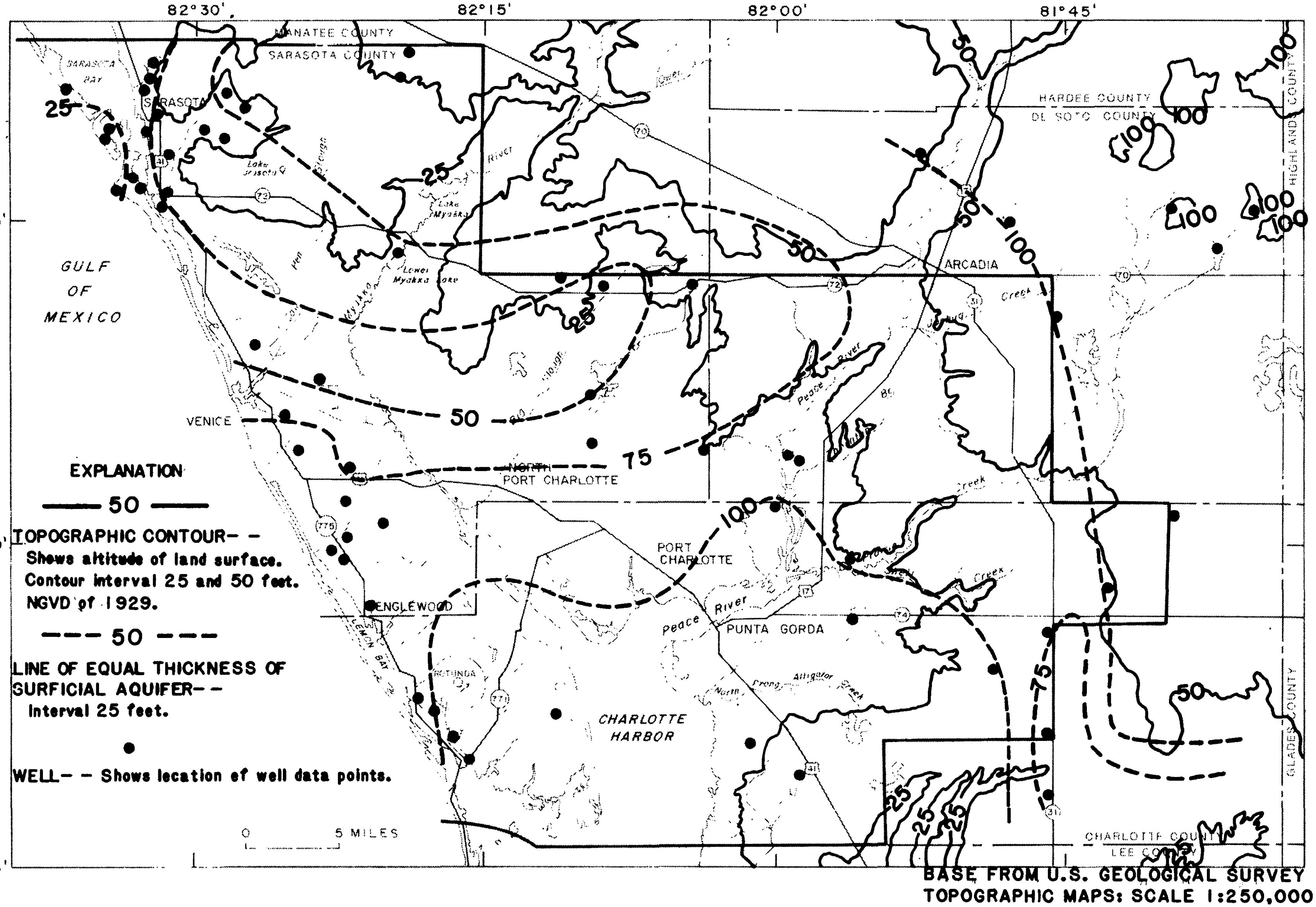


Figure 2.--Topography of the Sarasota-Port Charlotte area and generalized thickness of the surficial aquifer.

Table 1.--Ground-water pumpage in 1979

[All values are in million gallons per day. Modified from Duerr and Trommer, 1981]

Type of use	Charlotte County	Southwest De Soto County	Sarasota County	Total
Irrigation	14.8	1.7	10.0	26.5
Public supply	.4	.7	8.6	9.7
Rural domestic	1.0	.1	4.0	5.1
Industrial	0	.1	.3	.4
Total	16.2	2.6	22.3	41.7

Rainfall and Evapotranspiration

Long-term rainfall data have been collected by the National Weather Service at five sites within and adjacent to the study area: Arcadia, Myakka River State Park, Punta Gorda, Sarasota, and Venice. The average of the normal annual rainfall at these sites, based on data for the period 1951-80, is 51.0 inches. For the 10-year period 1971-80, average annual rainfall at these sites was 47.7 inches (fig. 3). Joyner and Sutcliffe (1976) reported that for the 33-year period 1933-65, the average annual rainfall based on stations at Arcadia, Myakka River State Park, Punta Gorda, and Sarasota was 54.3 inches.

Rainfall is greatest during the summer; about 60 percent of the annual rainfall occurs in June through September. The dry season, October through May, is the peak irrigation season.

Mean daily temperatures range from 84°F in summer to 61°F in winter. The mean annual temperature is about 73°F. The moderately high temperatures result in a large amount of rainfall being lost to evapotranspiration, which will vary depending on rainfall, temperature, distribution of vegetation communities, and land-use patterns. In areas where water is standing in ponds and depressions, evapotranspiration almost equals yearly potential evapotranspiration, about 54 inches annually (Visher and Hughes, 1969). Utilizing a method described by Dohrenwend (1977) that is based on temperature, vegetation communities, land use, and rainfall, an evapotranspiration rate of about 38 in/yr was determined for the study area. This compares favorably with evapotranspiration rates presented in other reports for areas within or adjacent to the study area:

Area	Report	Evapotranspiration (in/yr)
Upper Peace and eastern Alafia River basins	Hutchinson (1977)	41.2
Myakka River basin	Joyner and Sutcliffe (1976)	35-40
Charlotte County	Wolansky (1978)	37

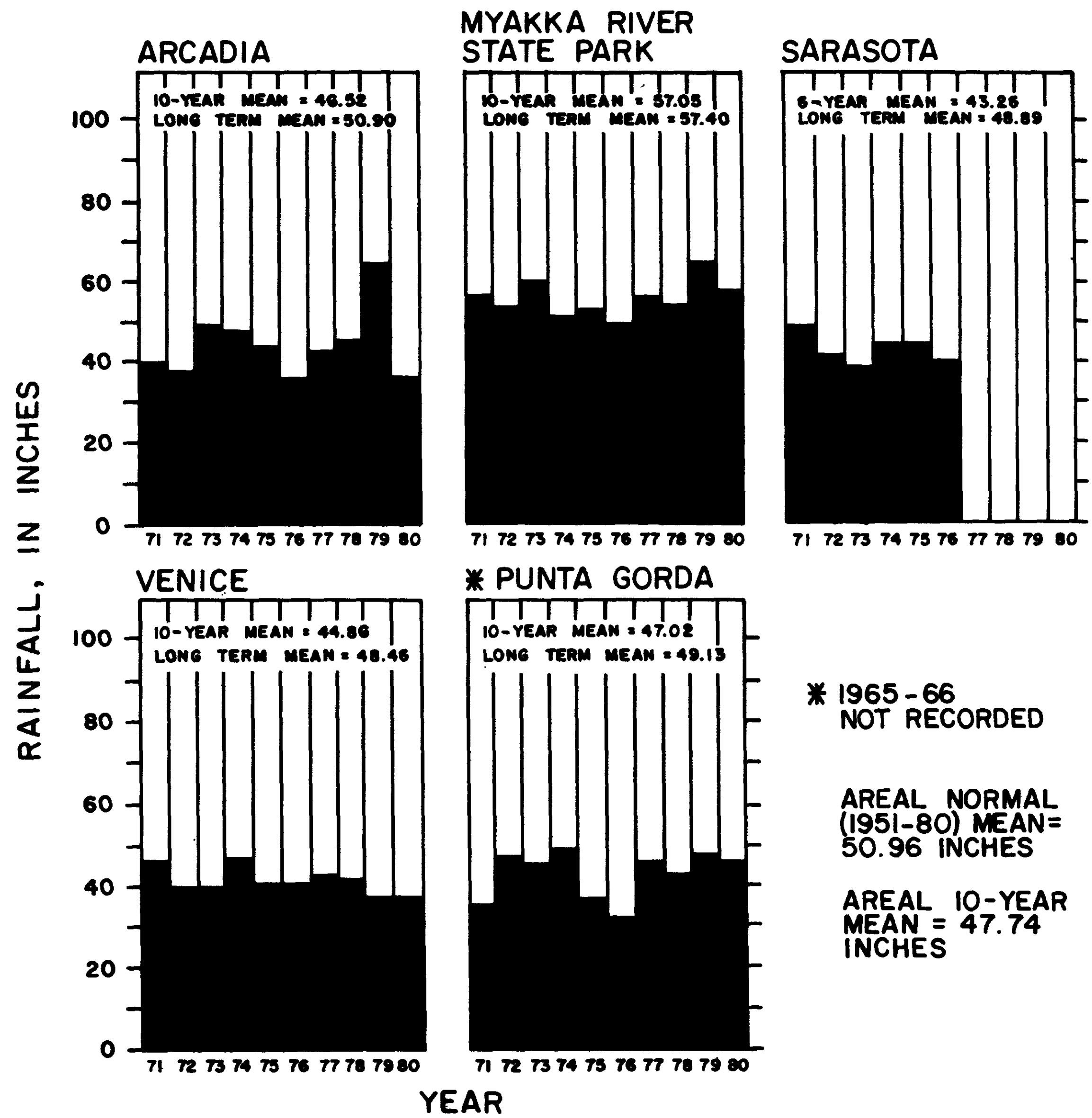


Figure 3.--Annual rainfall, 1971-80.

HYDROGEOLOGIC FRAMEWORK

The hydrogeologic framework consists of the following units: surficial aquifer, two intermediate aquifers (herein called the Tamiami-upper Hawthorn and lower Hawthorn-upper Tampa aquifers) and confining beds, Floridan aquifer, and the lower confining bed or base of the Floridan aquifer. The aquifers and confining beds (fig. 4 and table 2) range from about 1,800 to 2,500 feet in total thickness and consist of sedimentary rock and surficial deposits whose lithology and structure control the occurrence and movement of ground water. The surficial and intermediate aquifers and confining beds thicken toward the south and range in thickness from about 400 to 700 feet. Limestone and dolomite beds that make up the Floridan aquifer also thicken toward the south and range in thickness from 1,200 to 1,800 feet.

The sequence of ground-water levels from shallowest to deepest includes the water table in the surficial aquifer and the potentiometric surfaces of the Tamiami-upper Hawthorn, lower Hawthorn-upper Tampa, and Floridan aquifers (fig. 4). The relation of head in this sequence of aquifers is generally one of increasing head in the deeper aquifers. In areas where this relation does not hold, the cause is generally variable discharge from the aquifers.

Geologic formations that comprise the surficial aquifer and intermediate aquifers and confining beds are the surficial deposits, undifferentiated Caloosahatchee Marl, Bone Valley Formation, Tamiami and Hawthorn Formations, and parts of the Tampa Limestone that are not included with the Floridan aquifer. Underlying these formations is the Floridan aquifer which consists of the rest of the Tampa, Suwannee, Ocala, and Avon Park Limestones and parts of the Lake City Limestone. Underlying the Floridan aquifer is the lower confining bed; the top of which is the first occurrence of vertically persistent intergranular evaporites in the Lake City Limestone (table 2). Hydrologic designations presented in this report and previous reports on the study area that described the hydrogeologic framework are shown in table 3.

Surficial Aquifer

The surficial aquifer consists primarily of permeable units of the surficial deposits, Caloosahatchee Marl, and Bone Valley Formation. Permeable units near the top of the Tamiami Formation may be hydraulically connected to the surficial aquifer. The units are predominantly layers of fine to medium sand, shell, and phosphate gravel intermixed with stringers of limestone and marl. Except for the limestone, the deposits are unconsolidated. The aquifer is generally unconfined; however, lenses of sand, marl, and limestone contain water under confined conditions in some areas. The thickness of the surficial aquifer ranges from 50 feet in the northwest to more than 100 feet in the east and south. Regionally, the aquifer increases in thickness toward the south (fig. 2). The base of the surficial aquifer generally consists of clayey sand and sandy clay in the upper part of the Tamiami Formation in the south or similar lithologies in the lower part of the Caloosahatchee Marl or the Bone Valley Formation in the north.

Table 2.--Generalized stratigraphic section and hydrogeologic description

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

Oligocene	Suwannee Limestone	Floridan aquifer	200-300	Marine, cream to buff, often soft, granular limestone composed of loosely cemented foraminifers.
Upper Eocene	Ocala Limestone		200-300	Marine, white to cream, often soft and finely granular limestone, grading near the bottom into tan limestone with beds of grayish-brown dolomite.
Middle Eocene	Avon Park Limestone		600-700	Marine, cream to tan, soft to hard, granular to chalky, highly fossiliferous limestone interbedded with grayish-brown to dark-brown, highly fractured dolomite; some carbonaceous and clayey zones; some intergranular gypsum and anhydrite near the bottom in places.
	Lake City Limestone	Lower confining bed	300-500	Marine, cream to tan, slightly carbonaceous and cherty limestone and grayish- to dark-brown dolomite; both with varying amounts of intergranular gypsum and anhydrite.

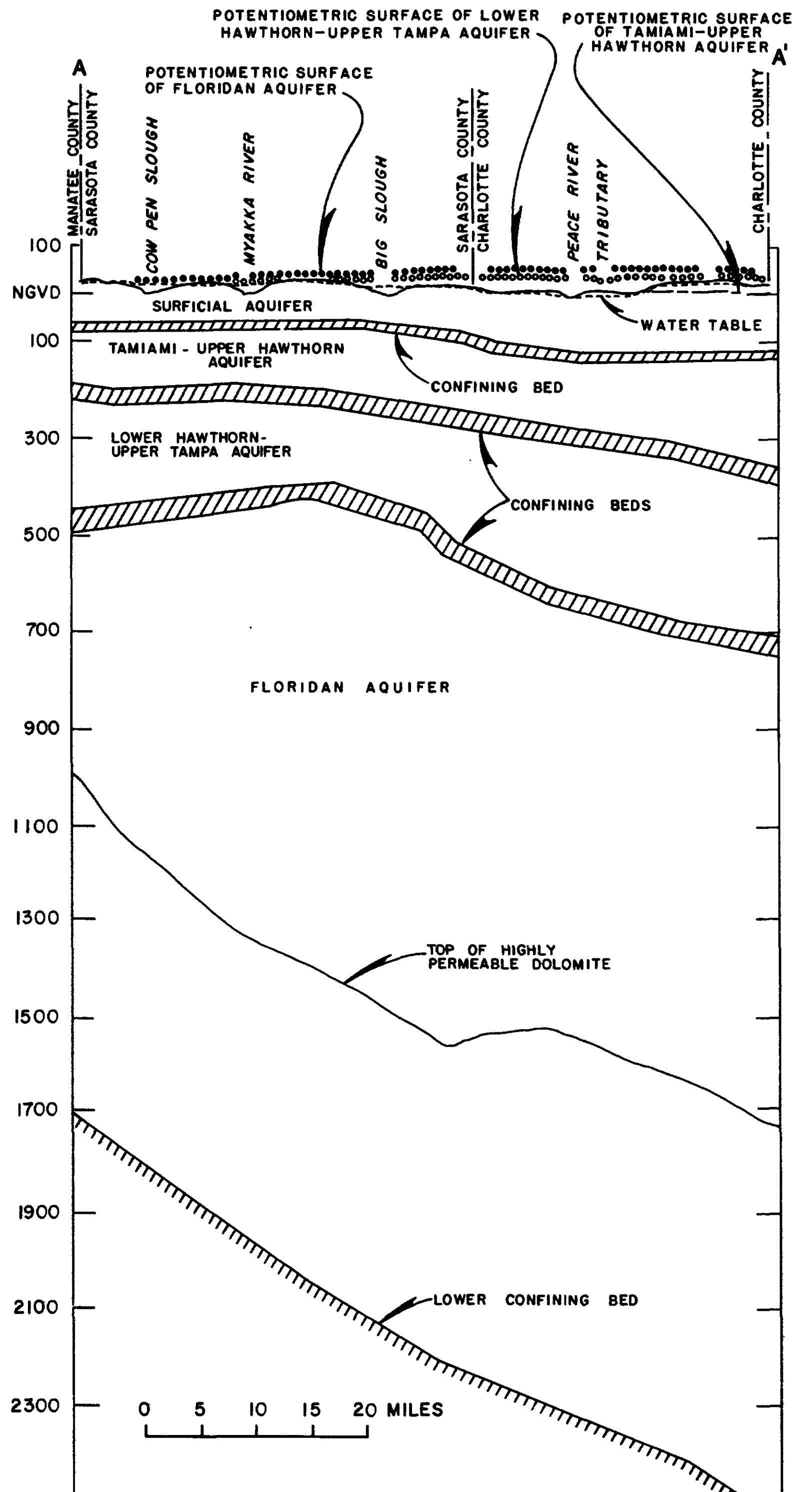
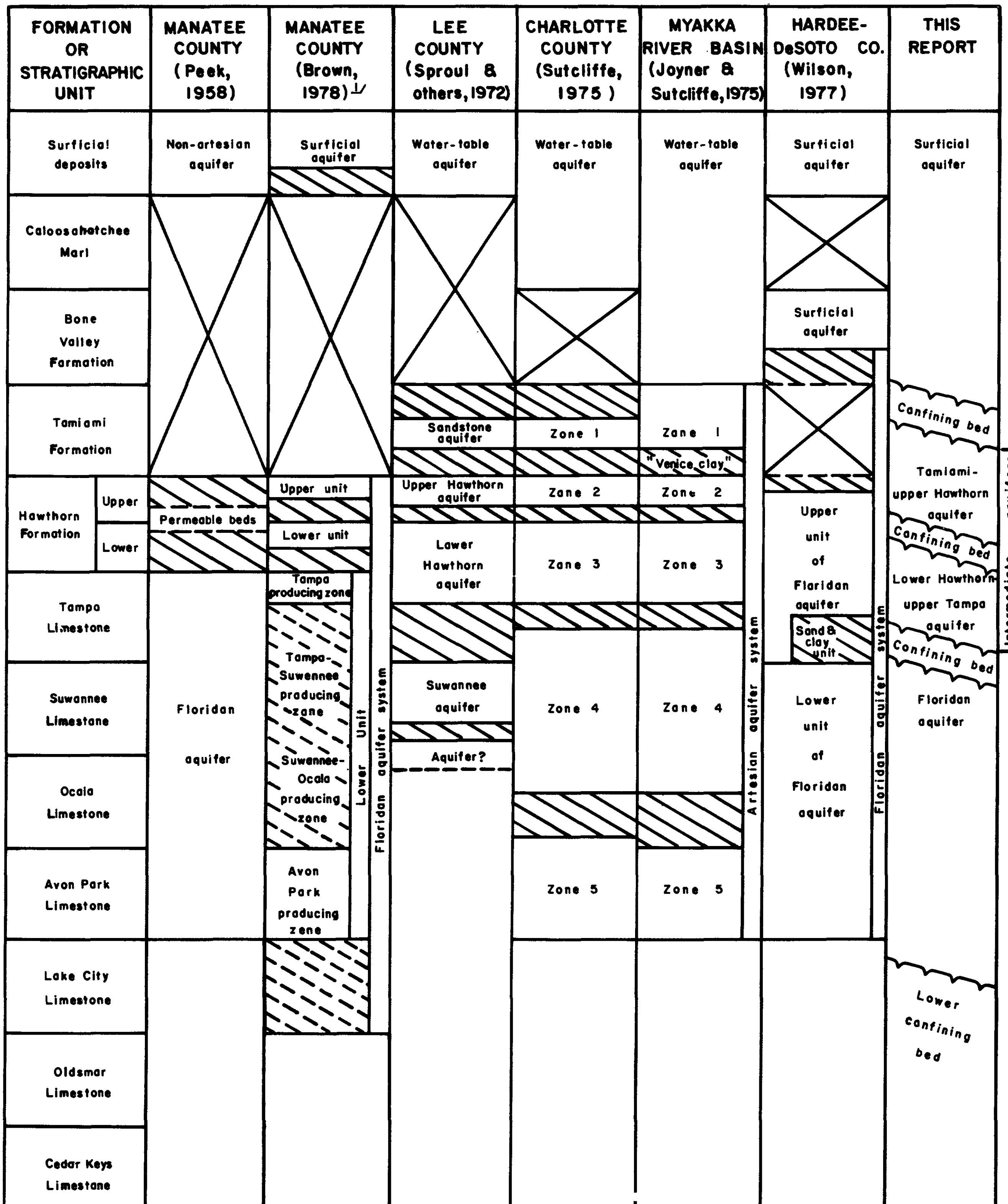


Figure 4.--Generalized hydrogeologic section. (For line of section, see figure 1.)

Table 3.--Hydrogeologic designations from previous studies



1/ written commun.

Geology

The surficial aquifer includes deposits of Holocene, Pleistocene, and Pliocene age (table 2). Holocene deposits consist of fine, light gray, quartz; surficial sand; and alluvium. The deposits are present throughout most of the area and may be as much as 20 feet in thickness. Pleistocene terrace deposits unconformably underlie the Holocene sand and alluvium. The terrace deposits are predominantly fine to medium, well-sorted, pale yellow-orange sand with some clay and shell. Thickness and areal distribution of the terrace deposits are more variable than the Holocene deposits. They range from zero to 40 feet in thickness.

The Caloosahatchee Marl of Pliocene and Pleistocene age unconformably underlies the terrace deposits and is present only in the southern part of the area. Typically, the Caloosahatchee Marl sediments consist of unconsolidated shell beds; light gray, sandy, shelly marl; marl; and thin beds of hard, sandy limestone. The marl varies laterally from very shelly to very sandy and silty. The Caloosahatchee Marl generally ranges from zero to 50 feet in thickness.

The Bone Valley Formation of Pliocene age unconformably underlies the Caloosahatchee Marl. It is present in the northern part of the area and probably is not present in the south. The formation consists of an upper unit that is predominantly clayey sand with minor amounts of phosphate nodules and a lower unit composed of phosphate nodules, sand, and clay. The formation ranges from zero to 20 feet in thickness.

The Bone Valley Formation and Caloosahatchee Marl are unconformably underlain by the Tamiami Formation of Pliocene age. The formation is comprised of clays, marls, sands, and thin beds of limestone. All the units, except the limestone, are slightly consolidated and slightly phosphatic. The formation ranges in thickness from zero to 150 feet and is present in most of the area.

Water Table and Movement, Recharge, and Discharge of Ground Water

The depth to the water table of the surficial aquifer is generally about 5 to 10 feet. In areas of high altitude (greater than 40 feet) and well-defined drainage channels, such as in northeastern Sarasota County and eastern Charlotte County, the water table may be more than 15 feet below land surface; in areas of low topographic relief and near the coast, the water table may be less than 1 foot below land surface. Fluctuations in the water table in the surficial aquifer are generally seasonal and vary within a 5-foot range. The lowest water table occurs during the dry spring months, and it recovers generally during the wet summer months to the annual high in September or October.

The general shape of the water table in the surficial aquifer is shown in figure 5. The altitude of the water table ranges from a high of 90 feet in the extreme northeastern part of Sarasota County to less than 10 feet near the coast and near Charlotte Harbor. The direction of flow of the water is downgradient and normal to the contour lines. The water flows generally southwestward except near stream channels where water flows laterally to the streams.

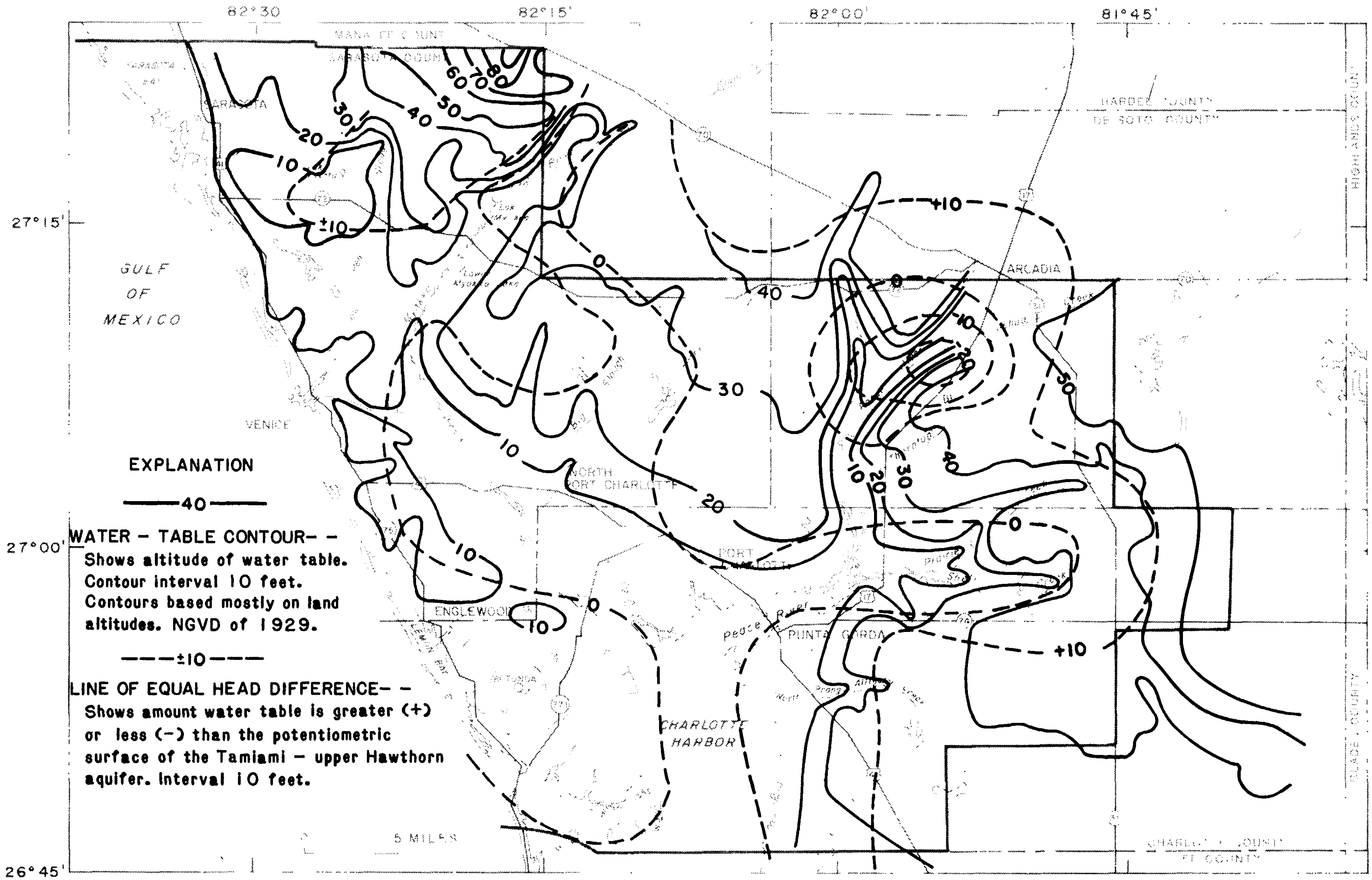


Figure 5.--Generalized altitude of the water table in the surficial aquifer and head difference between the water table and potentiometric surface of the Tamiami-upper Hawthorn aquifer.

Major sources of recharge to the surficial aquifer are: (1) rainfall; (2) upward leakage along the Peace and Myakka Rivers where the altitude of the potentiometric surface of the Tamiami-upper Hawthorn aquifer is higher than the water table; and (3) infiltration of pumpage return. Major types of discharge from the surficial aquifer are: (1) evapotranspiration, (2) seepage into streams and the Gulf canals, (3) downward leakage in the northern and western parts of the study area where the altitude of the water table is higher than the potentiometric surface of the Tamiami-upper Hawthorn aquifer, and (4) pumping from wells.

Hydraulic Properties

The quantity of water that an aquifer will yield to wells depends upon the hydraulic characteristics of the aquifer. The principal hydraulic characteristics are: transmissivity, storage coefficient, and leakage coefficient.

The hydraulic properties of the surficial aquifer vary from place to place because of the large range of hydraulic conductivity of individual lithologic units and the heterogeneity in their distributions. Hydraulic properties have been estimated from six aquifer tests of wells that penetrated sections of the aquifer. For the six tests, transmissivity ranged from 600 to 8,000 ft^2/d, and storage coefficient determined from two tests ranged from $5x10^{-2}$ to 0.16 (fig. 6).

Table 4 gives the estimated range in hydraulic conductivity for surficial aquifer materials. By assigning values of hydraulic conductivity to layers of known thickness described in lithologic logs, transmissivities of individual layers can be summed to estimate aquifer transmissivity at well sites. The estimated range of aquifer and well characteristics for the surficial aquifer is shown in table 5.

Table 4.--Estimated range of hydraulic conductivity for surficial aquifer materials[1/]

Lithologic unit	Hydraulic conductivity range (ft/d)
Fine to medium sand	5-35
Silty sand	1-10
Clayey sand	0.01-2
Shell bed and sandy shells	50-1,000
Shelly marl	0.1-15
Sandy marl	0.1-15
Limestone	0.01-15
Sandy clay	$3x10^{-4}$-$3x10^{-2}$
Clay	10^{-5}-10^{-4}

[1/] Modified from Freeze and Cherry, 1979.

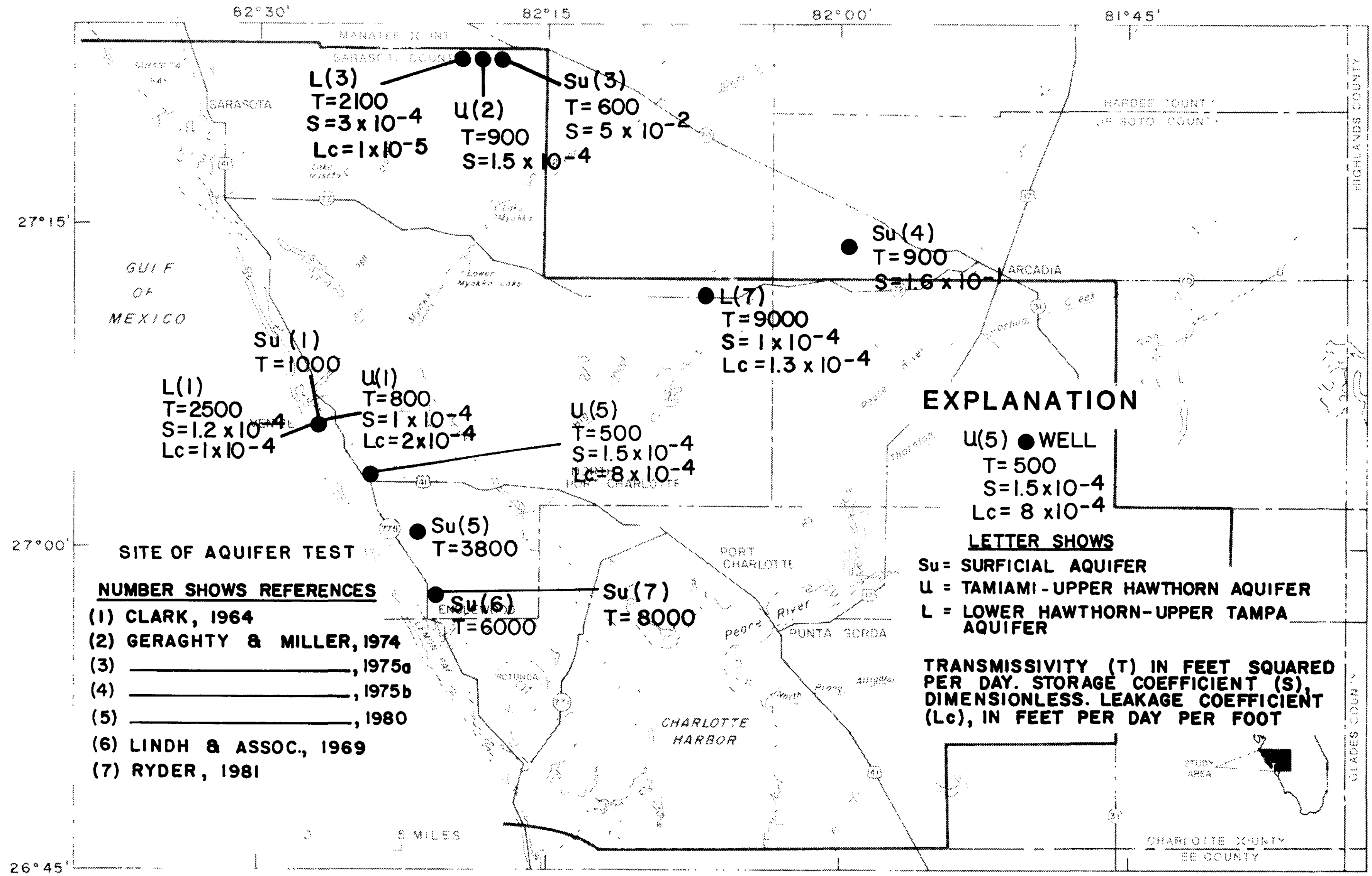


Figure 6.--Test sites and aquifer characteristics.

Table 5.--Estimated range of aquifer and well characteristics for the surficial, Tamiami-upper Hawthorn, lower Hawthorn-upper Tampa, and Floridan aquifers[1/]

Aquifer	Thickness (feet)	Transmissivity (ft^2/d)	Storage coefficient	Leakage coefficient [(ft/d)/ft]
Surficial	75 (50-100)	1,300 (500-10,000)	0.2 (0.05-0.25)	---
Tamiami-upper Hawthorn	115 (75-150)	2,600 (500-3,500)	$1x10^{-4}$ $(0.5\text{-}1.5x10^{-4})$	$1.3x10^{-5}$ $(1x10^{-6}\text{-}1x10^{-4})$
Lower Hawthorn-upper Tampa	250 (200-350)	2,600 (500-10,000)	$2x10^{-4}$ $(0.5\text{-}3x10^{-4})$	$1.5x10^{-6}$ $(0.5\text{-}5x10^{-6})$
Floridan	1,700 (1,400-1,900)	130,000 (100,000-500,000)	$1.3x10^{-3}$ $(1.1\text{-}1.7x10^{-3})$	$5x10^{-6}$ $(1\text{-}10x10^{-6})$

Aquifer	Horizontal hydraulic conductivity (ft/d)	Vertical hydraulic conductivity (ft/d)	Yield of wells (gal/min)	Specific capacity [(gal/min)/ft]
Surficial	17 (7-133)	2 (1.5-15)	30 (10-750)	10 (3-60)
Tamiami-upper Hawthorn	23 (4-30)	1 (0.5-1.5)	75 (20-250)	10 (3-15)
Lower Hawthorn-upper Tampa	10 (2-40)	1 (0.5-1.5)	150 (20-500)	10 (3-30)
Floridan	75 (60-300)	1 (0.1-10)	2,000 (500-5,000)	350 (250-1,000)

[1/] Upper number is the average and lower number is the range.

The estimated range of aquifer characteristics is based on the results of aquifer tests and laboratory tests of the various lithologies that comprise the surficial aquifer. Transmissivity of the surficial aquifer is estimated to range from 500 ft^2/d for areas where fine and clayey sand predominate to 10,000 ft^2/d for areas where clean shell predominate. The average transmissivity is probably about 1,300 ft^2/d. The storage coefficient is estimated to range from 0.05 to 0.25, and the average is probably about 0.2. Because of aquifer stratification and local lenses of clay, the short-term testing of the aquifer may indicate an artesian storage coefficient on the order of $1x10^{-5}$; however, the long-term storage coefficient of the aquifer is probably within the above stated range. The specific capacity of the surficial aquifer ranges from about 3 to 60 (gal/min)/ft, and the average is about 10 (gal/min)/ft.

Development

Many hundreds of wells tap the surficial aquifer. Most are 2-inch diameter, drive-point wells that yield as much as 30 gal/min and are used to obtain water for domestic supply, lawn irrigation, or for watering livestock. Some 3- to 6-inch diameter irrigation wells, finished as open hole through limestone stringers or cemented sand and shell, yield about 100 gal/min.

The surficial aquifer supplies water to wells at the Venice, Englewood, and Rotunda well fields (fig. 1). The capacity of these wells is generally less than 50 gal/min; however, wells that tap part of the intermediate aquifers, as well as the surficial aquifer, have higher yields.

Chemical Quality of Water

The quality of ground water depends on the composition of the rocks and soil through which rain passes and the length of time it remains in contact with the soil and rocks. Thus, the chemical quality of water from an aquifer usually depends upon lithology of the aquifer. Quartz sand, the major constituent of the surficial aquifer, is relatively insoluble. The sandy and clayey limestone and dolomite of the intermediate aquifers are more soluble than the quartz sand of the surficial aquifer, but less soluble than the limestone and dolomite of the Floridan aquifer.

The principal constituents in ground water that affect potability in the study area are chloride, sulfate, dissolved solids, and fluoride. Iron and color often affect the potability of water from the surficial aquifer; however, both can be easily removed during water treatment by aeration and filtration. The concentration of iron and amount of color in water from the surficial aquifer are usually highest near marshes where decaying plants release iron and organic compounds that can be taken into solution by water infiltrating into the aquifer. Recommended or permitted maximum concentrations for these constituents in public water supplies are as follows:

Constituent	U.S. Environmental Protection Agency (EPA) standard for public supply (mg/L)[1/]
Dissolved solids	500
Sulfate (SO_4)	250
Chloride (Cl)	250
Fluoride (F)	1.4[2/]
Iron (Fe)	0.3
Color (Pt-Co units)	15 (75[3/])

1/ U.S. Environmental Protection Agency, 1975, 1977.

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

3/ Standard source of supply.

Water from the surficial aquifer is generally of acceptable quality for potable use except near the coast, along tidally affected streams and canals, and in the vicinity of the Myakka and Peace River estuaries where seawater has intruded into the aquifer or poorer quality water from flowing wells has contaminated the aquifer (fig. 7). The concentrations of constituents shown generally increase to the southwest. The concentrations of chloride range from less than 25 milligrams per liter (mg/L) in the northeast to more than 250 mg/L near the coast. The concentrations of sulfate are less than 25 mg/L in the eastern half of the study area and more than 250 mg/L in the northwestern coastal area. The concentration of dissolved solids is less than 500 mg/L in the northeast and is more than 1,000 mg/L near the coast. The concentration of dissolved solids is between 500 to 1,000 mg/L in the southwest. The U.S. Environmental Protection Agency recommended limit for dissolved solids is 500 mg/L; however, water with concentrations of less than 1,000 mg/L in dissolved solids is commonly used for public supply in this area. Concentrations of fluoride vary considerably, but are usually less than the 1.4 mg/L U.S. Environmental Protection Agency limit (U.S. Environmental Protection Agency, 1975).

Intermediate Aquifers and Confining Beds

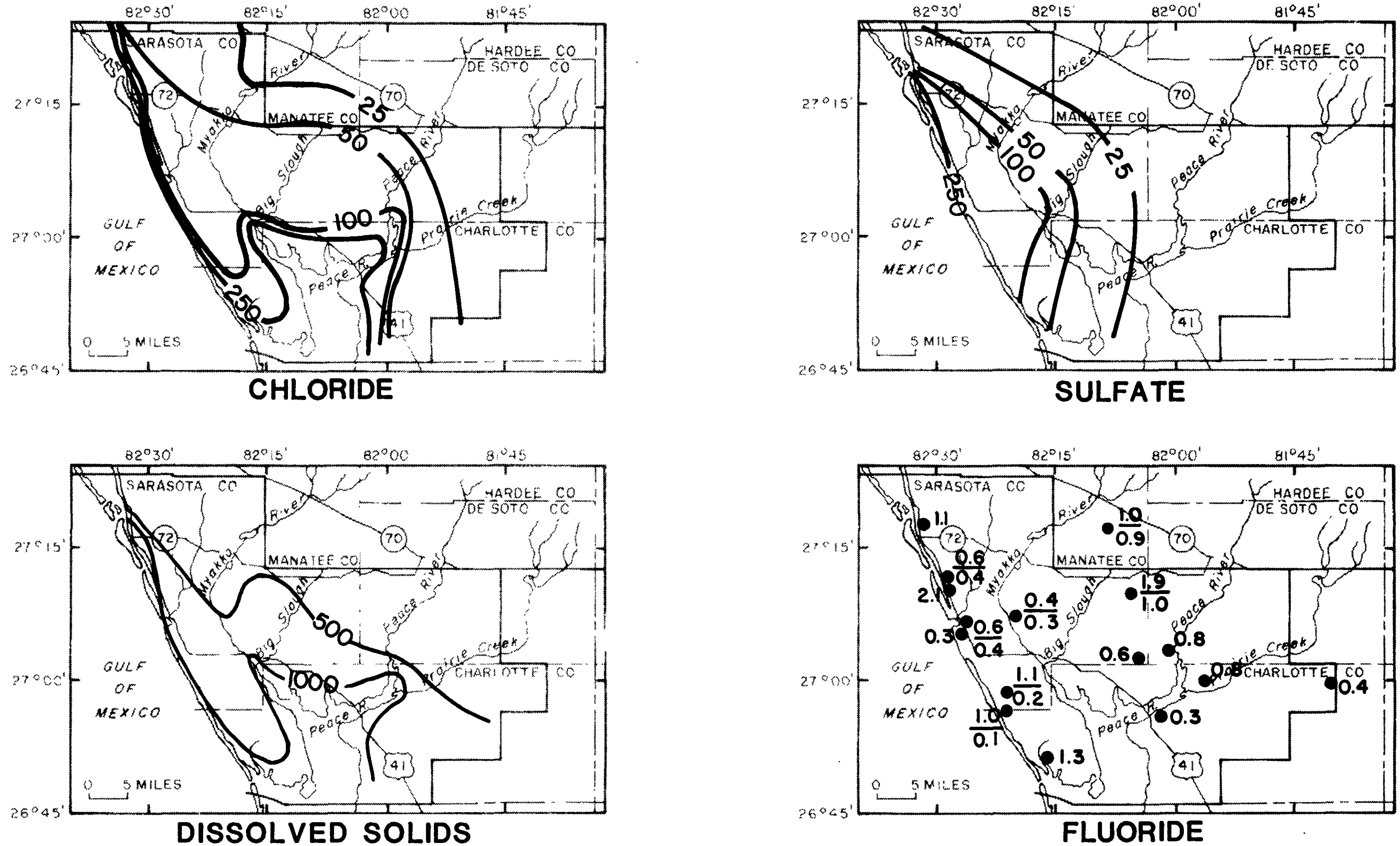
The two intermediate aquifers consist of discontinuous permeable sand, gravel, shell, and limestone and dolomite beds in the Tamiami Formation, the upper and lower parts of the Hawthorn Formation, and the Tampa Limestone where it is in hydraulic connection with the Hawthorn Formation.

Intermediate confining beds consist of sandy clay, clay, and marl at the base of the surficial aquifer in the upper part of the Tamiami Formation; between the upper and lower parts of the Hawthorn Formation; and in the study area, a sand and clay generally present 50 to 100 feet below the top of the Tampa Limestone (Wilson, 1977). The intermediate confining beds retard vertical movement of ground water between the surficial and the Floridan aquifers. The thickness of the intermediate aquifers and confining beds ranges from about 325 feet in the northern part of the study area to about 550 feet in the southern part.

Tamiami-Upper Hawthorn Aquifer

The Tamiami-upper Hawthorn aquifer is the uppermost intermediate aquifer. The aquifer consists of semiconsolidated deposits of phosphatic marl, shell, sand and clayey sand, and thin beds of phosphatic limestone. The top of the aquifer ranges from about 50 feet below sea level in the north to about 125 feet below sea level in the south. Its thickness ranges from about 75 to 150 feet with thickness increasing from the northeast toward the southwest (fig. 8). Generally, clayey materials above and below confine the aquifer; however, many facies changes within the aquifer cause local hydraulic connection with overlying and underlying aquifers.

The top of the aquifer is generally below the clayey sands and sandy clay in the upper part of the Tamiami Formation. The bottom of the aquifer is at beds of limestone and dolomite in the upper part of the Hawthorn Formation that have poor permeability because fracture porosity is low or the fractures are filled with clay.



EXPLANATION

——250——

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

● $\frac{1.0}{0.1}$ MAXIMUM / MINIMUM

WELL NUMBER INDICATES FLUORIDE CONCENTRATION IN MILLIGRAMS PER LITER. ONE NUMBER SHOWS ONE SAMPLING

Figure 7.--Concentrations of chloride, sulfate, dissolved solids, and fluoride in water from the surficial aquifer.

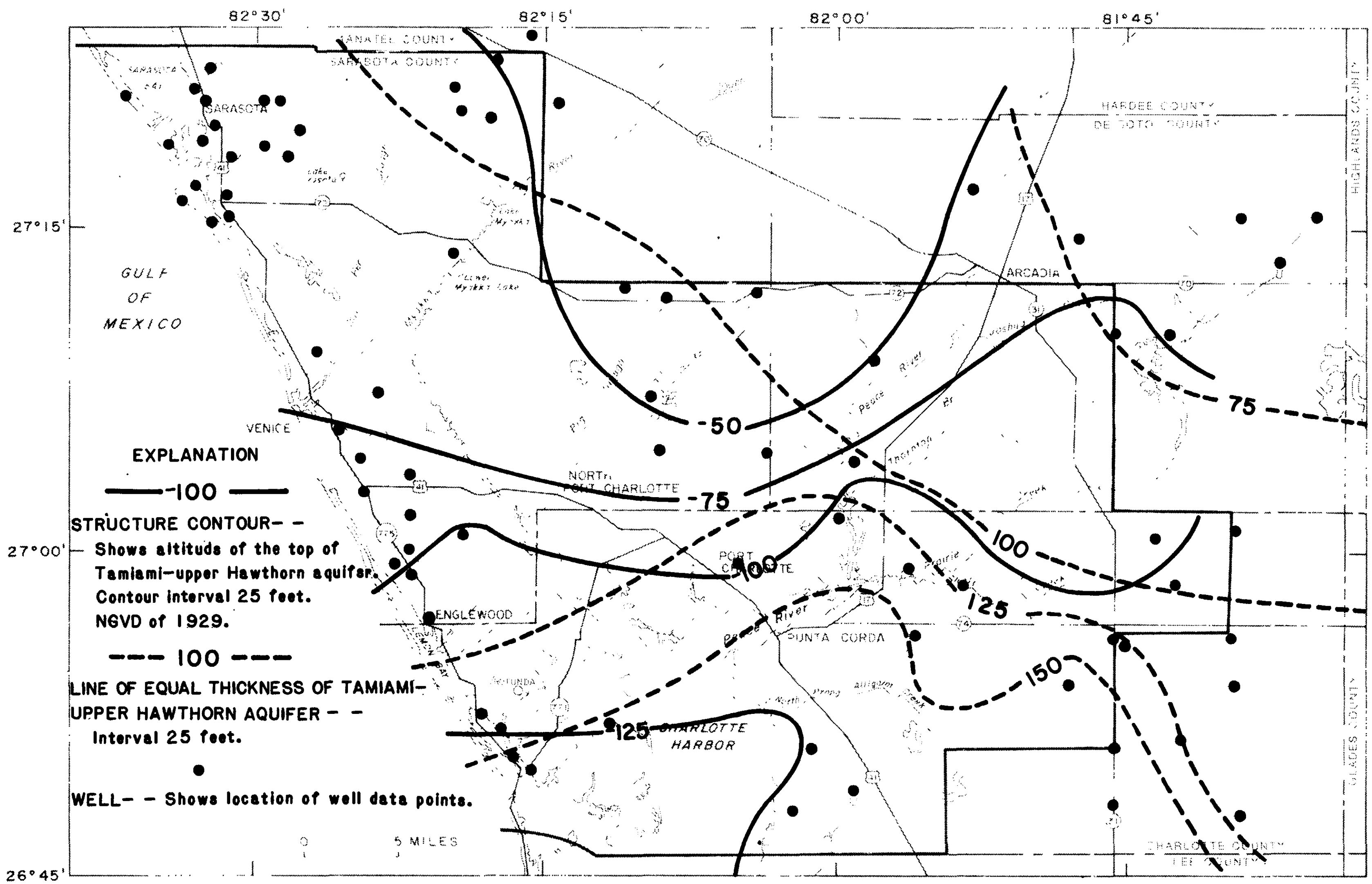


Figure 8.--Altitude of the top and the thickness of the Tamiami-upper Hawthorn aquifer.

The Tamiami-upper Hawthorn aquifer or parts of it has also been referred to as: "artesian zones 1 and 2," Sutcliffe (1975), Joyner and Sutcliffe (1976); "shallow aquifer," McCoy (1967; 1972), Sherwood and Klein (1961); "shallow artesian aquifer," Klein (1954), Boggess (1974); "surficial aquifer phosphorite unit," Wilson (1977); "sandstone aquifer" and "upper Hawthorn aquifer," Sproul and others (1972); "sandstone aquifer," Missimer and Gardner (1976); "uppermost artesian aquifer," Stewart (1966); "beds of shell and sand of Pliocene and Pleistocene age," Peek (1958); and "first artesian aquifer," Clark (1964).

Geology

The Tamiami-upper Hawthorn aquifer includes deposits of Pliocene and middle Miocene age. The Tamiami Formation of Pliocene age unconformably underlies the Bone Valley Formation and Caloosahatchee Marl. The formation consists of clay, marl, sand, and thin beds of limestone. All units, except the limestone, are only slightly consolidated and all are slightly phosphatic. The Tamiami Formation ranges in thickness from zero to 150 feet and is present in most of the area except in the northeast.

The Hawthorn Formation of middle Miocene age disconformably underlies the Tamiami Formation. The upper part of the formation consists principally of beds of sandy, phosphatic limestone, dolomite, and sandy, chalky to granular phosphatic marl and clay.

Potentiometric surface and movement, recharge, and discharge of ground water

Fluctuations in the potentiometric surface in the Tamiami-upper Hawthorn aquifer are seasonal and generally vary within a 5-foot range. Similar to the water table of the surficial aquifer, the potentiometric surface is lowest during the dry spring months, and it recovers during the wet summer months to a seasonal high. In local areas where the aquifer is stressed by pumpage, such as for housing subdivisions with irrigation wells tapping the aquifer, declines in the potentiometric surface of 20 feet or more occur during extended dry periods.

The general shape of the potentiometric surface of the Tamiami-upper Hawthorn aquifer is shown in figure 9. The altitude of the potentiometric surface ranges from a high of about 30 feet above sea level in the northeastern part to less than 10 feet above sea level near the coast. Water generally moves from the northeast to the southwest.

The aquifer is recharged by downward leakage from the overlying surficial aquifer and upward leakage from the underlying lower Hawthorn-upper Tampa aquifer. The primary source of recharge in areas surrounding Charlotte Harbor, along the Peace and Myakka Rivers, and along Big Slough Canal is from the lower Hawthorn-upper Tampa aquifer. In these areas, the water table in the surficial aquifer is below the potentiometric surface of the Tamiami-upper Hawthorn aquifer (fig. 5). Recharge from the lower Hawthorn-upper Tampa aquifer to the Tamiami-upper Hawthorn aquifer is areawide because the lower Hawthorn-upper Tampa aquifer has a higher potentiometric surface than the Tamiami-upper

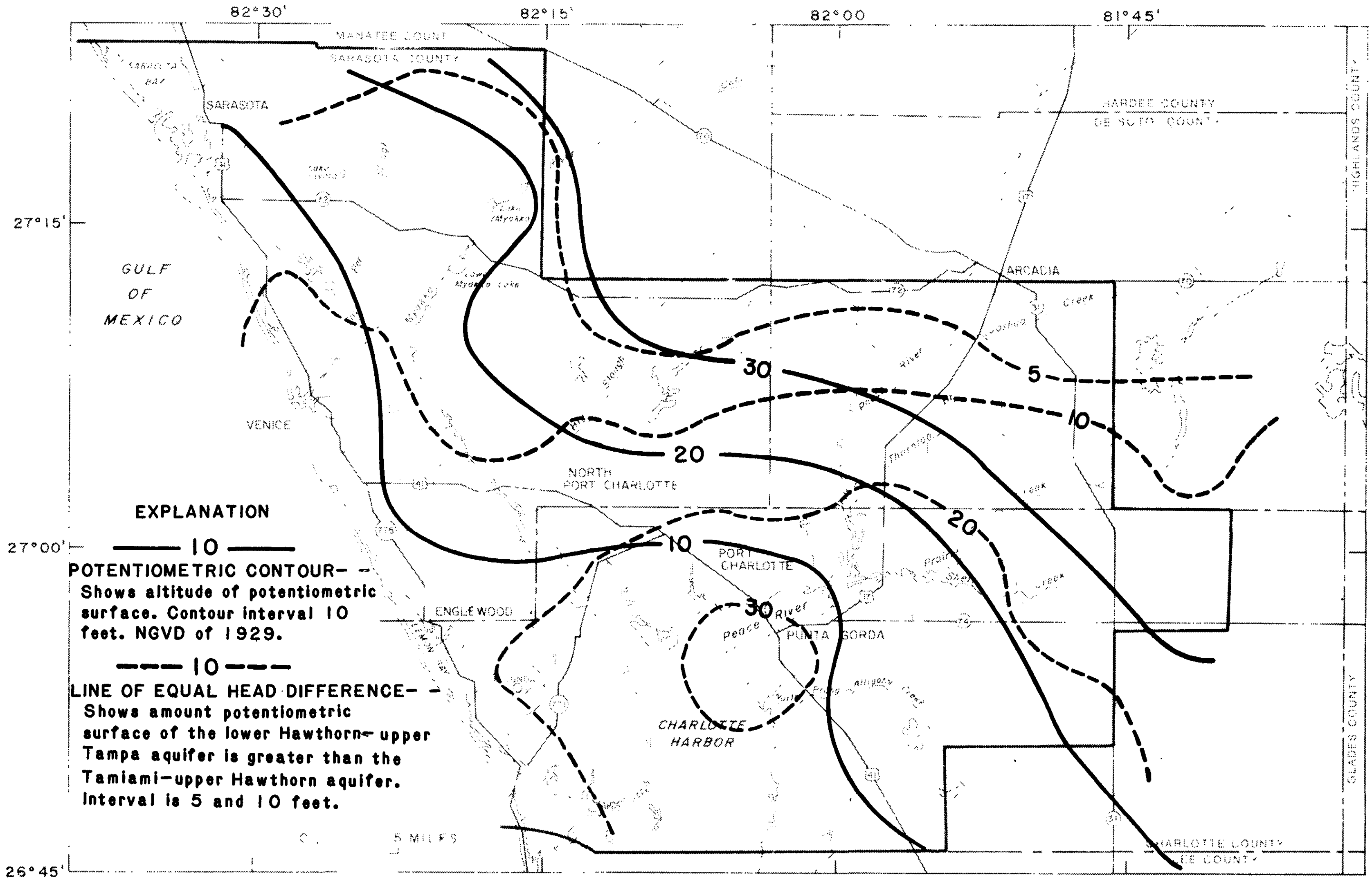


Figure 9.--Altitude of the potentiometric surface of the Tamiami-upper Hawthorn aquifer and head difference between the aquifer and that for the underlying lower Hawthorn-upper Tampa aquifer.

Hawthorn throughout the study area. The potentiometric surface in the lower Hawthorn-upper Tampa aquifer ranges from 5 feet higher than the Tamiami-upper Hawthorn aquifer in the northeast to 30 feet in the southwest (fig. 9). Natural discharge from the Tamiami-upper Hawthorn aquifer occurs as ground-water flow into Charlotte Harbor and along the Peace and Myakka River stream valleys where the potentiometric surface of the aquifer is higher than the water table (fig. 5).

Hydraulic properties

The hydraulic properties of the Tamiami-upper Hawthorn aquifer vary according to its lithology and to solution development within limestone and dolomite units more so than to variation in thickness. Hydraulic properties estimated from three aquifer tests and location of the tests are shown in figure 6. For the three tests, transmissivity ranged from 500 to 900 ft^2/d, storage coefficient from $1x10^{-4}$ to $1.5x10^{-4}$, and leakage coefficient from $2x10^{-4}$ to $8x10^{-4}$ (ft/d)/ft.

Table 5 presents the estimated range of aquifer and well characteristics for the Tamiami-upper Hawthorn aquifer. The estimated range of aquifer characteristics is based on the results of aquifer tests, laboratory tests of the various lithologies that comprise the aquifer, and adjustments to aquifer characteristics resulting from model calibration. Because of aquifer heterogeneity, aquifer or well characteristics from additional aquifer tests may fall outside the estimated range.

Development

The Tamiami-upper Hawthorn aquifer is the most highly developed aquifer in the populous coastal area. It supplies most of the water used for domestic and home irrigation use. The Verna, Venice, Englewood, and Rotunda well fields have wells that tap the aquifer.

Wells 2 to 4 inches in diameter, open to the upper part of the aquifer, usually yield about 25 gal/min. Larger wells (6 to 8 inches in diameter), open to the full thickness of the aquifer, yield as much as 200 gal/min.

Chemical quality of water

Water in the Tamiami-upper Hawthorn aquifer is generally of acceptable quality for potable use, except near the coast and most of the western half of Charlotte County where water from the aquifer is salty. The chemical quality of water from wells that penetrate the aquifer may vary greatly depending upon whether the well intercepts solutional features, because water moving through solutional features is not in contact with soluble minerals for as long a time as water in less permeable parts of the aquifer. The approximate regional distribution of selected chemical-quality parameters is shown in figure 10. Chloride concentrations range from less than 50 mg/L in the northeastern part to more than 1,000 mg/L in the southwestern part. In the western half of Charlotte

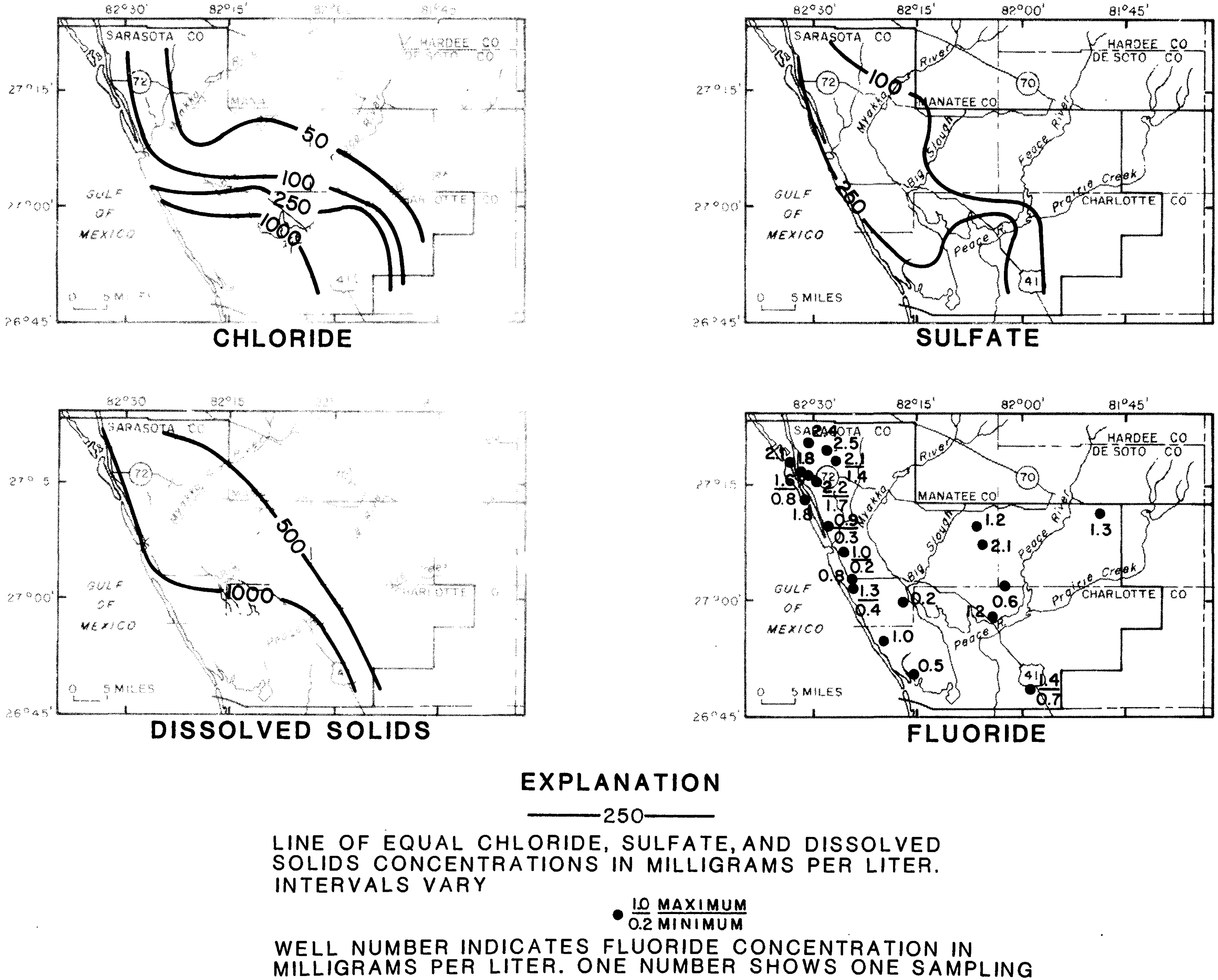


Figure 10.--Concentrations of chloride, sulfate, dissolved solids, and fluoride in water from the Tamiami-upper Hawthorn aquifer.

County and southern Sarasota County, chloride concentrations are more than 250 mg/L. Sulfate concentrations range from less than 100 mg/L in the northeast to more than 250 mg/L near the coast and the southwestern part of Charlotte County. Dissolved solids range from less than 500 mg/L in the northeast to more than 1,000 mg/L along the coast, and in southwestern Charlotte and southwestern Sarasota Counties. Fluoride concentrations in water from wells penetrating the aquifer range from 0.2 to 2.5 mg/L.

Lower Hawthorn-Upper Tampa Aquifer

The lower Hawthorn-upper Tampa aquifer is the lowermost intermediate aquifer. The aquifer consists of permeable limestone and dolomite beds in the lower part of the Hawthorn Formation and parts of the upper Tampa Limestone that are in hydrologic connection with those beds of the Hawthorn Formation. The top of the aquifer occurs at depths ranging from about 200 feet below sea level in the north to more than 300 feet below sea level in the south (fig. 11). The aquifer is present throughout the study area and thickens from north to south. Its thickness ranges from 200 feet in the north to 350 feet in the south.

The top of the aquifer is generally below the beds of clayey limestone and dolomite near the middle of the Hawthorn Formation. The bottom of the aquifer is generally a clayey sand and sandy clay unit 50 to 100 feet below the top of the Tampa Limestone.

The lower Hawthorn-upper Tampa aquifer has also been called: "lower Hawthorn aquifer," Sproul and others (1972); "artesian zone 3," Sutcliffe (1975), Joyner and Sutcliffe (1976); and "upper unit of Floridan aquifer," Wilson (1977).

Geology

The lower Hawthorn-upper Tampa aquifer includes deposits of middle and early Miocene age. The contact between the Hawthorn Formation and the Tampa Limestone is an erosional unconformity. The lower part of the Hawthorn Formation is usually a more dolomitized and crystalline limestone with less clayey sand and sandy clay than the upper part. The sandy limestone of the Tampa Limestone unconformably underlies the Hawthorn Formation. The sand and clay unit that occurs about 50 to 100 feet below the top of the Tampa Limestone throughout most of the study area is the base of the lower Hawthorn-upper Tampa aquifer.

Potentiometric surface and movement, recharge, and discharge of ground water

Fluctuations in the potentiometric surface in the lower Hawthorn-upper Tampa aquifer are seasonal, declining to a low during the dry spring months and recovering to a seasonal high during the wet summer months. The seasonal fluctuations are generally less than 5 feet except near well fields that tap the aquifer where seasonal fluctuations of greater than 20 feet are common.

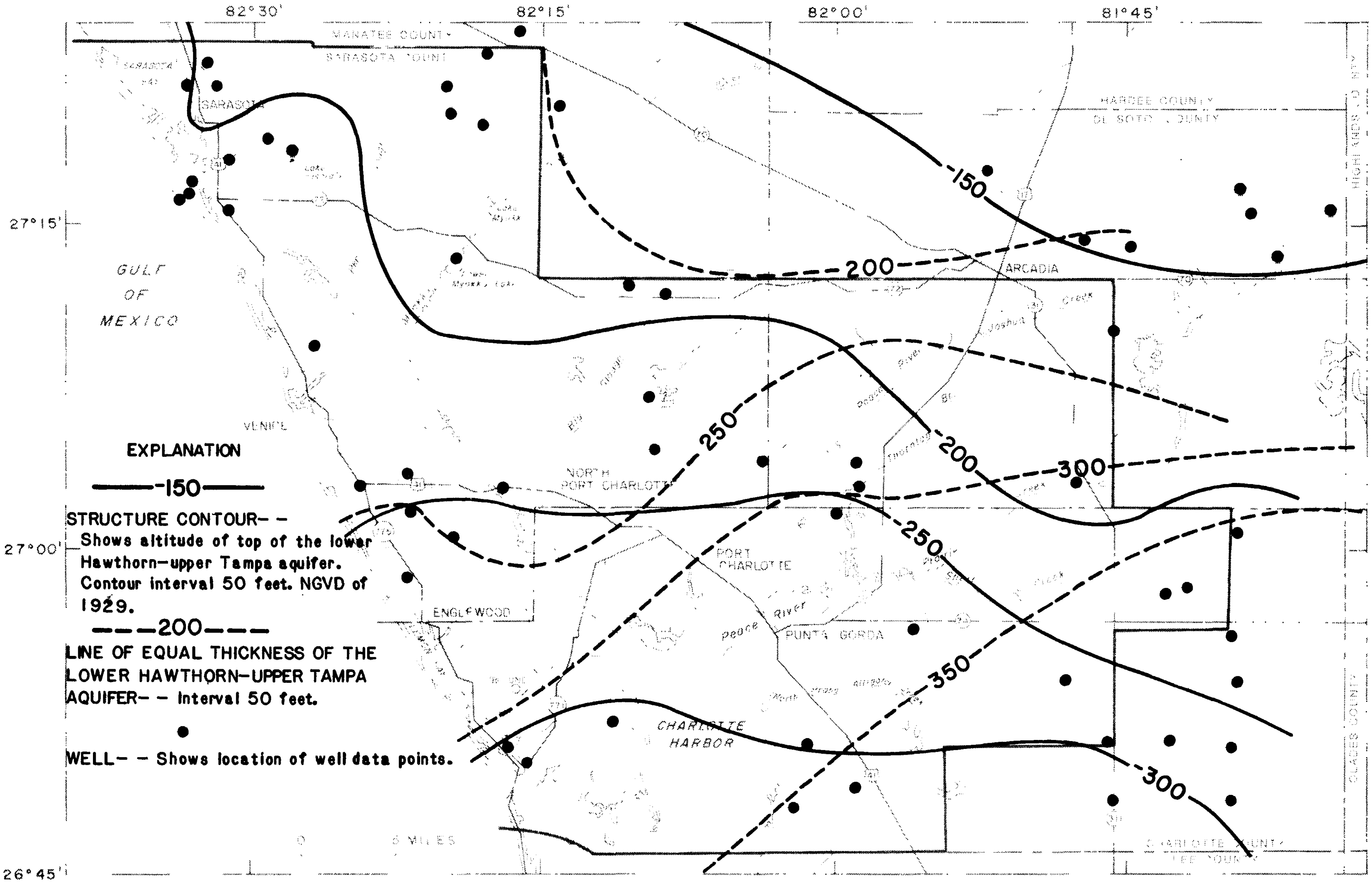


Figure 11.--Altitude of the top and thickness of the lower Hawthorn-upper Tampa aquifer.

The general shape of the potentiometric surface of the aquifer is shown in figure 12. The altitude of the potentiometric surface ranges from a high of 40 feet above sea level in the east to less than 10 feet above sea level in the northwestern coastal area. Water in the aquifer flows from east to west.

The aquifer is recharged by upward leakage from the underlying Floridan aquifer, except in northeastern Sarasota County. North of the study area a depression occurs in the potentiometric surface of the Floridan aquifer because of pumping from irrigation wells. The depression has changed the direction of leakage in that area so that, instead of water moving upward from the Floridan aquifer it moves downward from the lower Hawthorn-upper Tampa aquifer to the Floridan.

Discharge from the lower Hawthorn-upper Tampa aquifer to the overlying Tamiami-upper Hawthorn aquifer occurs throughout the study area. The head difference between the two aquifers ranges from 5 feet in the north to 30 feet in the south (fig. 9).

Hydraulic properties

The hydraulic properties of the lower Hawthorn-upper Tampa aquifer are more variable than those of the overlying aquifers. Permeability is probably directly related to the degree of solution development within the limestone and dolomite beds. Aquifer hydraulic properties have been estimated from three aquifer tests of wells that penetrated sections of the aquifer (fig. 6). Transmissivity ranges from 2,100 to 9,000 ft^2/d; storage coefficient (three tests), $1x10^{-4}$ to $3x10^{-4}$; and leakage coefficient (three tests) from $1x10^{-5}$ to $1.3x10^{-4}$ (ft/d)/ft.

The estimated range of aquifer characteristics for the lower Hawthorn-upper Tampa aquifer is presented in table 5. The estimated range of aquifer characteristics is based on the results of aquifer tests, laboratory tests of the various lithologies that comprise the aquifer, and adjustments to aquifer characteristics resulting from model calibration. The range of characteristics is wide due to aquifer heterogeneity, anisotropy, and to variations of solution development.

Development

The lower Hawthorn-upper Tampa aquifer is widely used as a source of water for irrigation. The aquifer contributes water to wells for public supply at the Verna, Venice, Englewood, Rotunda, and Arcadia well fields. At the Verna and Arcadia well fields, the aquifer supplies more than half the water pumped from each field. At the Venice, Englewood, and Rotunda well fields, the water from the aquifer is mineralized and is treated in reverse-osmosis treatment plants.

Wells open to the aquifer yield as much as 500 gal/min. Many large diameter irrigation wells open to the underlying Floridan aquifer are also open to the lower Hawthorn-upper Tampa aquifer. The aquifer probably contributes about 20 percent of the yield of these wells.

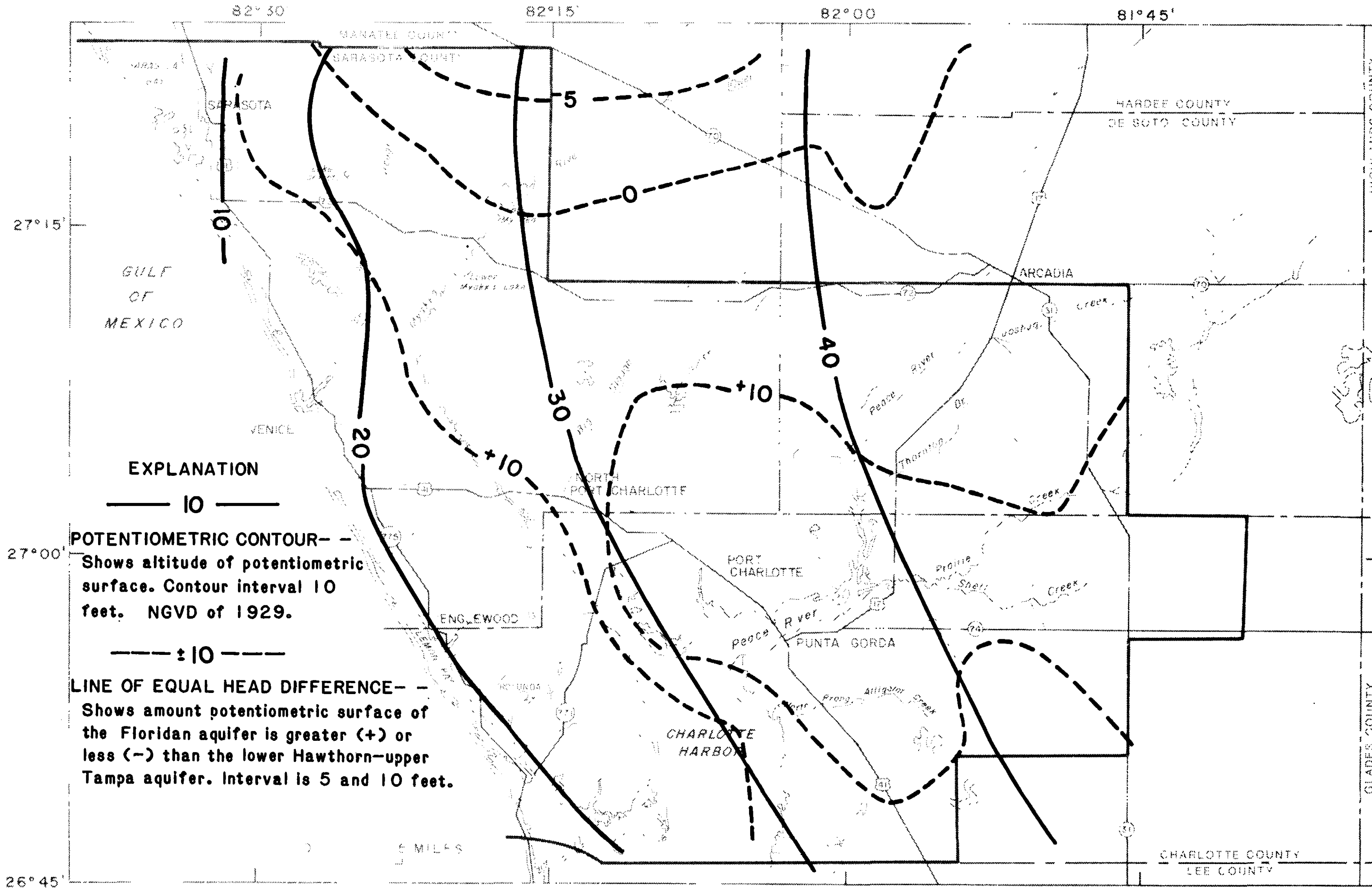


Figure 12.--Altitude of the potentiometric surface of the lower Hawthorn-upper Tampa aquifer and head difference between the aquifer and the underlying Floridan aquifer.

Chemical quality of water

Water from wells that tap the lower Hawthorn-upper Tampa aquifer is generally of potable or nearly potable quality except in the coastal and southeastern parts of the area. Chloride concentrations range from about 50 to 1,000 mg/L. Chloride concentrations greater than 250 mg/L occur in the coastal and southern parts of the study area (fig. 13). Sulfate concentrations range from 100 to 500 mg/L, generally increasing from the northern part toward the south and west. Concentrations greater than 250 mg/L are limited to coastal areas and to an area in central-northeastern Sarasota County and southwestern De Soto County. The concentration of dissolved solids is less than 500 mg/L in the northeast and is more than 2,000 mg/L near the coast and southwestern Charlotte County. Fluoride concentrations in water from the aquifer vary areally and vertically and range from 0.3 to 3.2 mg/L.

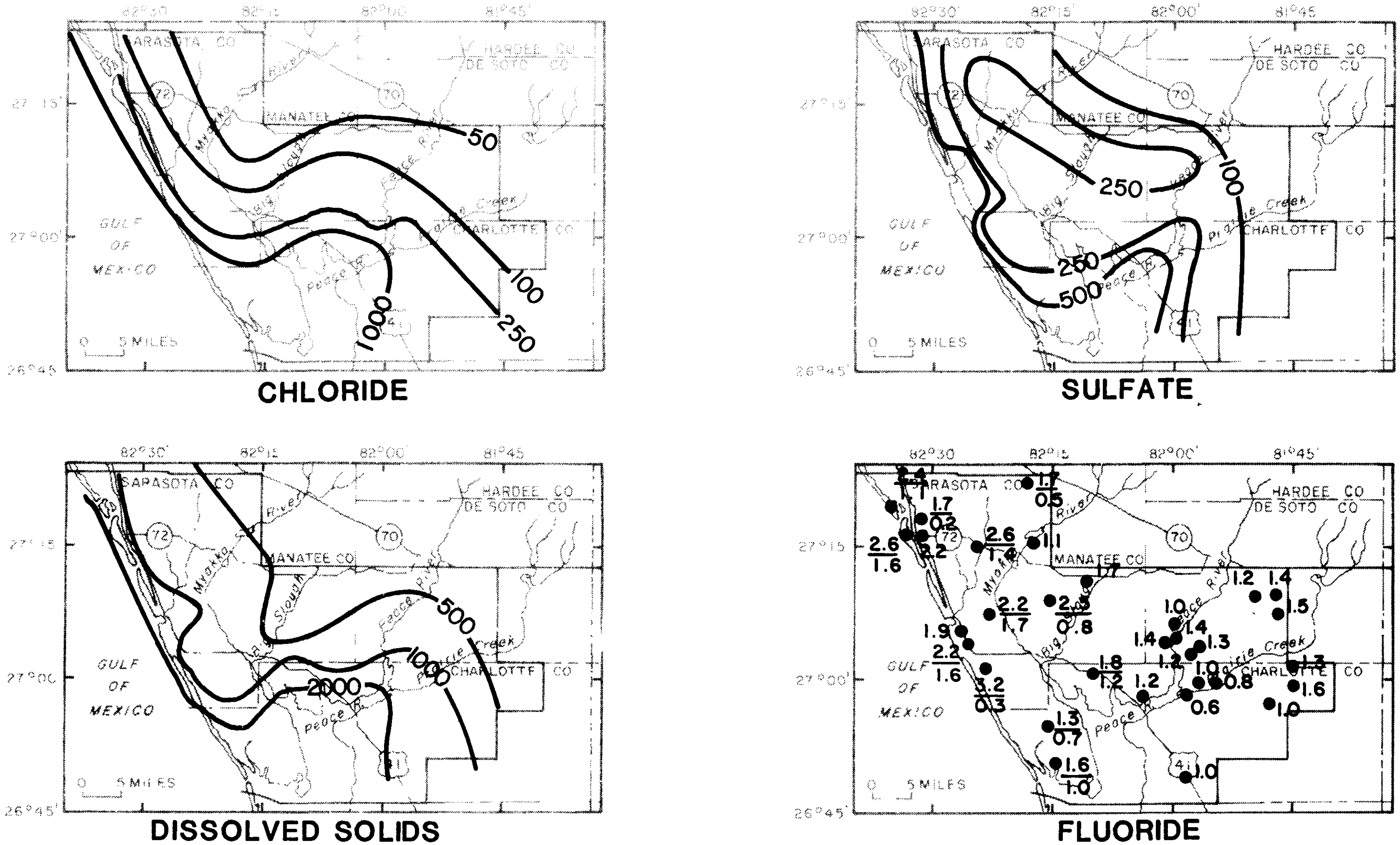
Floridan Aquifer

The Floridan aquifer is the most productive aquifer in the study area; however, its use is generally restricted because of the poor quality of the water produced. The aquifer is composed of a thick, stratified sequence of limestone and dolomite. The Floridan aquifer was originally defined by Parker (Parker and others, 1955) to include, in ascending order, all or parts of the Lake City, Avon Park, Ocala, and Tampa Limestones and permeable parts of the Hawthorn Formation that are in hydrologic connection with the rest of the aquifer. In this report, the top of the Floridan aquifer is a limestone defined as the first persistent rock of early Miocene age, or older, below which clay confining beds do not occur. This surface generally coincides with the lower part of the Tampa Limestone or the top of the Suwannee Limestone. Underlying the Floridan aquifer is the lower confining bed that generally occurs in the Lake City Limestone where persistent intergranular anhydrite and gypsum occur.

The limestone and dolomite sequence generally functions regionally as a single hydrogeologic unit; however, two distinct water-bearing zones are known to exist in the sequence in the study area. They are the upper zone (parts of the Tampa Limestone and the Suwannee and Ocala Limestones) and the lower zone (the Avon Park Limestone). In the southern and southwestern areas, water in the lower zone is distinctly more mineralized than that in the upper zone. These zones were designated as artesian zones 4 and 5, respectively, by Joyner and Sutcliffe (1976). The altitude of the top of the Floridan aquifer ranges from about 400 feet below sea level in the northeast to about 650 feet below sea level in the southwest, and its average thickness is about 1,700 feet (figs. 4 and 14).

Geology

The Tampa Limestone of early Miocene age is a sandy, phosphatic limestone with varying amounts of interbedded sand and clay. Its thickness ranges from 150 to 300 feet. The Suwannee Limestone of Oligocene age is a granular limestone that ranges from 200 to 300 feet in thickness. The Ocala Limestone of



EXPLANATION

——250——

LINE OF EQUAL CHLORIDE, SULFATE, AND DISSOLVED SOLIDS CONCENTRATIONS IN MILLIGRAMS PER LITER. INTERVALS VARY

● $\frac{1.3}{0.7}$ $\frac{\text{MAXIMUM}}{\text{MINIMUM}}$

WELL NUMBER INDICATES FLUORIDE CONCENTRATION IN MILLIGRAMS PER LITER. ONE NUMBER SHOWS ONE SAMPLING

Figure 13.--Concentrations of chloride, sulfate, dissolved solids, and fluoride in water from the lower Hawthorn-upper Tampa aquifer.

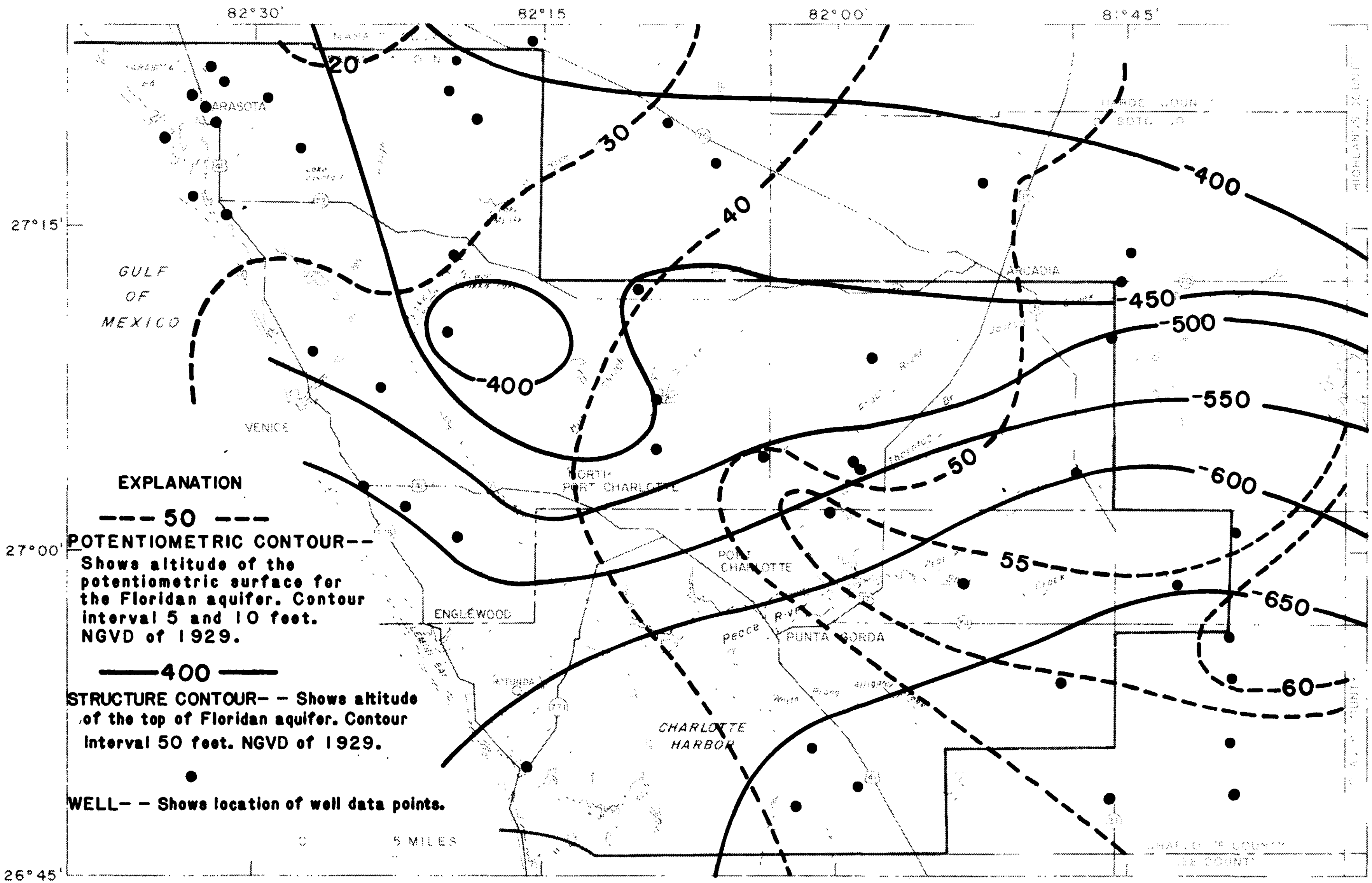


Figure 14.--Top of and generalized altitude of the potentiometric surface of the Floridan aquifer (modified from Yobbi and others, 1980).

late Eocene age is a relatively pure limestone that grades into a dolomite near the bottom. It ranges from 200 to 300 feet in thickness. The Avon Park of middle Eocene age consists primarily of limestone interbedded with dark brown, highly fractured dolomite that ranges from 600 to 700 feet in thickness. The Lake City Limestone of middle Eocene age consists primarily of limestone and dolomite with varying amounts of evaporites. The Lake City ranges from 300 to 500 feet in thickness.

Potentiometric Surface and Movement, Recharge, and Discharge of Ground Water

The potentiometric surface in the Floridan aquifer fluctuates 20 feet or more in the northeastern part of the area in response to large seasonal withdrawals for irrigation. In the southern and southwestern parts, fluctuations in water level are generally less than 5 feet because pumpage from this aquifer for irrigation is minimal in these areas.

The altitude of the potentiometric surface of the Floridan aquifer is shown in figure 14. It ranges from about 60 feet above sea level in eastern Charlotte County to about 20 feet above sea level in northern Sarasota County. The regional gradient and direction of flow is west and northwest. The northwesterly flow is due to the depression in the potentiometric surface in Manatee County. Prior to development of the depression, the direction of flow was generally from east to west (Johnston and others, 1981).

Within the study area, recharge to the Floridan aquifer from the overlying aquifer occurs only in northwest Sarasota County where the altitude of the potentiometric surface of the Floridan aquifer is lower than the overlying aquifer. Elsewhere, discharge occurs from the Floridan aquifer to the overlying aquifer.

Hydraulic Properties

Areal variation of transmissivity of the Floridan aquifer is primarily controlled by the occurrence of solution features and fractures. The aquifer storage coefficient is controlled by thickness, and confining bed lithology and thickness control leakage. The estimated range of aquifer characteristics is based on the results of aquifer tests reported by Ryder (1981), laboratory tests of the various lithologies that comprise the aquifer, and adjustments to aquifer characteristics resulting from model calibrations (table 5).

Development

Large diameter (12-inch) wells that tap the Floridan aquifer yield as much as 5,000 gal/min. In the past, smaller diameter wells that would yield 1,500 gal/min were used to obtain water for irrigation in the southern and southwestern parts of the study area. Presently, large withdrawals for irrigation occur primarily in northeastern Sarasota County and southwestern De Soto County. At the Verna well field (fig. 1), the upper part of the Floridan aquifer is the source of about 20 percent of the water pumped from the intermediate and Floridan aquifers. Within the city limits of Sarasota, production wells that tap the upper part of the Floridan aquifer provide mineralized water that is treated in a reverse-osmosis plant.

Chemical Quality of Water

Water in the Floridan aquifer is generally more mineralized than water from the surficial aquifer and intermediate aquifers (figs. 7, 10, 13, and 15). The mineralization of the water varies vertically and areally, generally increasing with depth and towards the coast and south. Water from wells open to the upper zone (Tampa Limestone) of the Floridan aquifer is generally less mineralized than water from wells open to the middle zone (Suwannee and Ocala Limestones). Water in the lower zone (Avon Park Limestone) has the highest mineralization.

Chloride concentrations of water in the Floridan aquifer are greater than 250 mg/L, except near the central and northeastern parts where flushing of residual seawater has been more complete (fig. 15). In the northeast, chloride concentrations are generally less than 50 mg/L and there is little change with depth. In the coastal and southern parts, chloride concentrations generally exceed 1,000 mg/L and tend to increase seaward and with depth.

Concentrations of sulfate in water from the Floridan aquifer range from 250 to more than 1,000 mg/L, generally increasing with depth and toward the west and south. Only in parts of eastern Sarasota and southern De Soto Counties are concentrations of sulfate less than 250 mg/L. The linear zone of high sulfate along the Peace River is attributed to deep ground-water circulation and active solution of evaporites by Kaufman and Dion (1968).

Dissolved solids in water from the Floridan aquifer generally increase with depth and toward the west and south. Dissolved solids concentrations range from 500 mg/L in the northeastern part to 5,000 mg/L in the southwestern part.

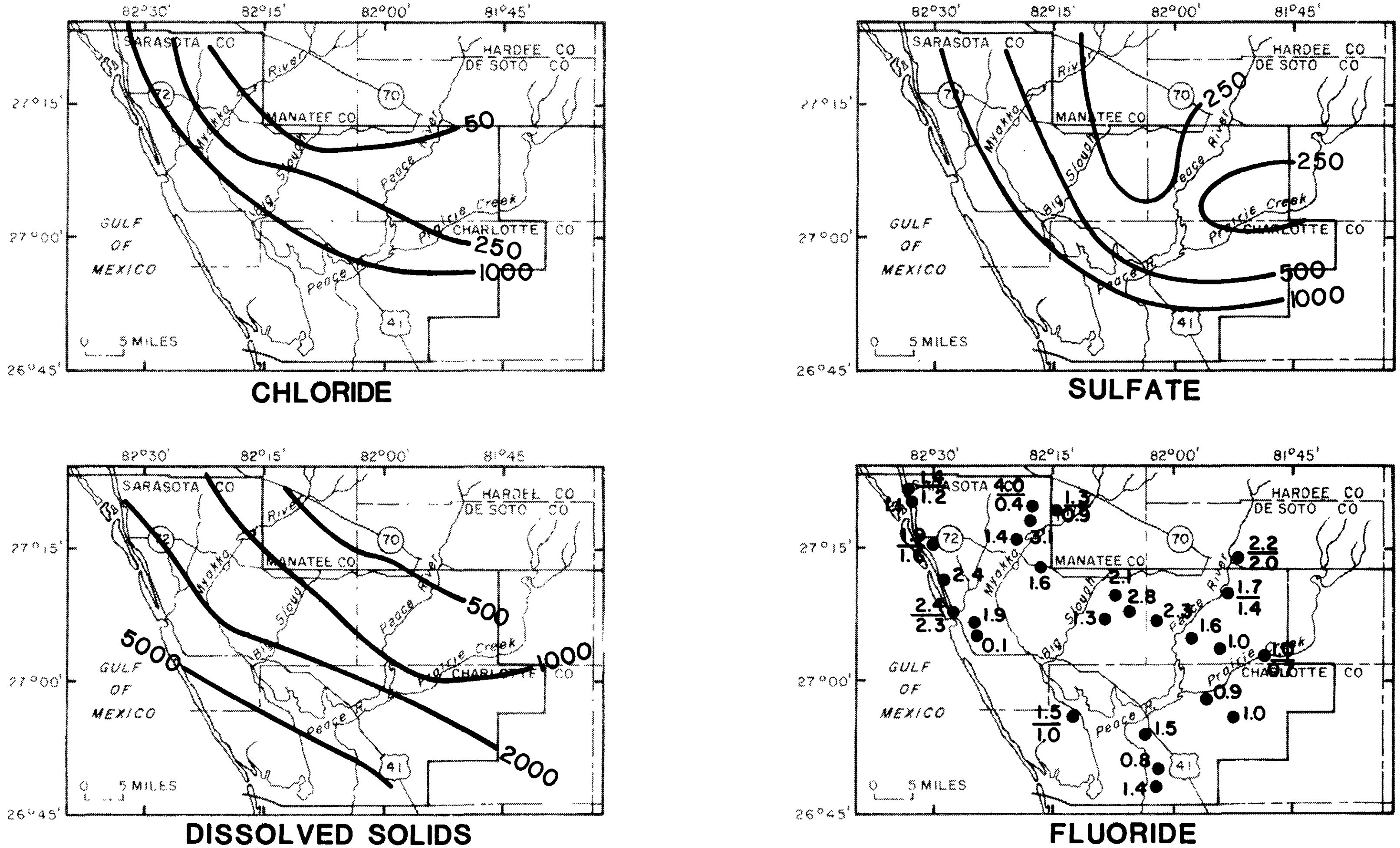
Fluoride concentrations in water from the Floridan aquifer vary areally and vertically and range from 0.1 to about 4.0 mg/L. Concentrations of fluoride in water from wells penetrating lower zones are generally higher than from the upper zone.

WATER BUDGET

A water budget is a quantitative accounting of water entering and leaving a hydrologic system for a specific period of time. When applying a water budget to a long period of time, it can be assumed that water entering and leaving the ground-water system is equal, so long as a change in level of the water table and potentiometric surface does not occur. For example, water levels are the same at the beginning and at the end of the time period.

A generalized annual water budget for the 1,300-mi^2 land area of the Sarasota-Port Charlotte study area is shown in figure 16. The figure is a diagrammatic presentation of the area hydrologic system. Inputs to and outputs from the system are:

Inputs	Outputs
Rainfall	Evapotranspiration
Pumpage return	Streamflow
Ground-water inflow	Pumpage
	Ground-water outflow



EXPLANATION

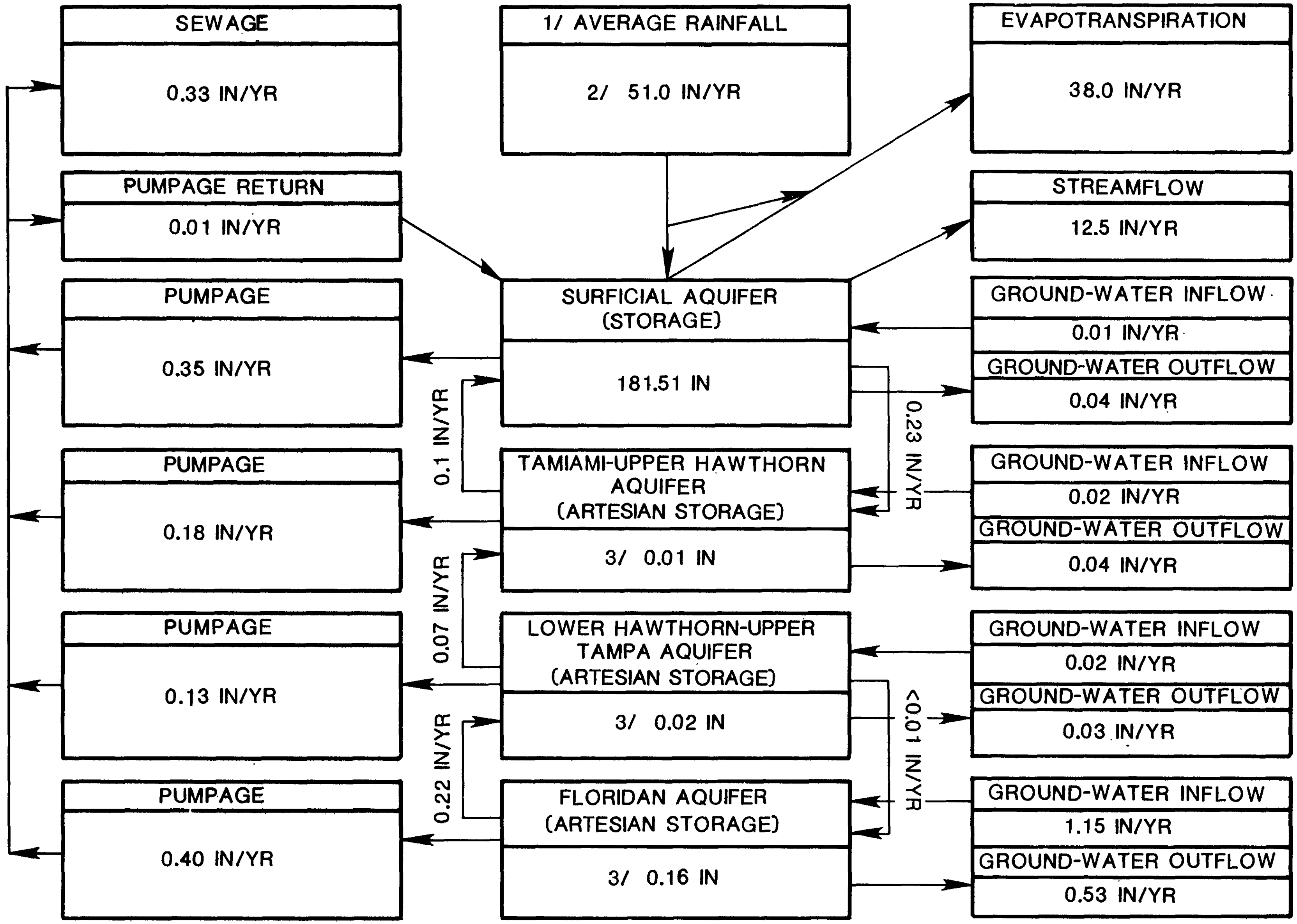
——2000——

LINE OF EQUAL CHLORIDE, SULFATE, AND DISSOLVED SOLIDS CONCENTRATIONS IN MILLIGRAMS PER LITER. INTERVALS VARY

● $\frac{1.5}{1.0}$ $\frac{\text{MAXIMUM}}{\text{MINIMUM}}$

WELL NUMBER INDICATES FLUORIDE CONCENTRATION IN MILLIGRAMS PER LITER. ONE NUMBER SHOWS ONE SAMPLING

Figure 15.--Concentrations of chloride, sulfate, dissolved solids, and fluoride in water from the Floridan aquifer.



1/ LAND AREA = 1300 MI^2

2/ TO CONVERT TO BILLION GALLONS PER YEAR MULTIPLY BY 22.59

3/ BASED UPON A HEAD DECLINE OF 10 FEET

Figure 16.--Generalized water budget for the Sarasota-Port Charlotte area.

Rainfall is the primary input and evapotranspiration and streamflow are the primary outputs. Secondary inputs into the system are pumpage return and ground-water flow into the aquifer from outside the area. Secondary outputs from the system are pumpage and ground-water outflow from the aquifers. An average annual rainfall of 51.0 in/yr minus evapotranspiration of 38.0 in/yr and streamflow of 12.5 in/yr leaves an average of 0.5 in/yr of recharge to the surficial aquifer. Streamflow equals the average annual runoff for those parts of the Peace River, Myakka River, Charlotte Harbor and coastal area, and coastal area between Myakka and Manatee Rivers basins that are within the study area for the period of record (U.S. Geological Survey, 1981). Combined pumpage from the aquifers is 1.06 in/yr and pumpage returned to the surficial aquifer that is recharged is 0.01 in/yr. Ground-water inflow to the aquifers is 1.20 in/yr and ground-water outflow is 0.64 in/yr.

The ground-water inflow and outflow were determined by the "gradient method" which utilizes the following form of Darcy's Law to calculate flow across an open contour when the transmissivity of the aquifer is known:

$$Q = TIL \tag{1}$$

where

Q = discharge (ground-water inflow or outflow), in cubic feet per day;
T = transmissivity, in feet squared per day;
I = hydraulic gradient, in feet per foot;
L = width of the cross section through which the discharge takes place, in feet.

The hydraulic gradient was interpolated along flow sections that correspond approximately to the 50-foot water-table contour for inflow and the 10-foot water-table contour for outflow for the surficial aquifer, to the 30-foot potentiometric contour for inflow and the 10-foot potentiometric contour for outflow for the Tamiami-upper Hawthorn aquifer, to the 40-foot potentiometric contour for inflow and the 10-foot potentiometric contour for outflow for the lower Hawthorn-upper Tampa aquifer, and to the 50-foot potentiometric contour for inflow and the 10-foot potentiometric contour for outflow for the Floridan aquifer. Table 6 lists the Q, T, I, and L for the surficial, intermediate (Tamiami-upper Hawthorn and lower Hawthorn-upper Tampa), and Floridan aquifers. Ground-water inflow into the surficial aquifer is 0.01 in/yr and outflow is 0.04 in/yr. The greater outflow is due to the steep hydraulic gradient along streams in the coastal outflow area. The inflow to the Tamiami-upper Hawthorn aquifer is 0.02 in/yr and outflow is 0.04 in/yr. This greater outflow is due to numerous canals that breach the aquifer. Inflow into the lower Hawthorn-upper Tampa aquifer is 0.02 in/yr and outflow is 0.03 in/yr. Inflow to the Floridan aquifer is 1.15 in/yr and outflow is 0.53 in/yr. Because the altitude of the Floridan aquifer potentiometric surface is higher than the altitude of the potentiometric surface of the intermediate aquifers in all but the northwestern part, the excess inflow leaks upward to the intermediate aquifers.

Table 6.--Ground-water inflow and outflow in the surficial, intermediate, and Floridan aquifers

Aquifer	Q[1/] (Mgal/d / in/yr)	T (ft^2/d)	I (ft/ft)	L (ft)	Ground-water flow
Surficial	0.62 / 0.01	1,300	1/5,803	3.7×10^5	Inflow.
	2.48 / 0.04	1,300	1/2,141	5.46×10^5	Outflow.
Tamiami-upper Hawthorn	1.24 / 0.02	2,600	1/4,972	3.17×10^5	Inflow.
	2.48 / 0.04	2,600	1/4,141	5.28×10^5	Outflow.
Lower Hawthorn-upper Tampa	1.24 / 0.02	2,600	1/4,219	2.69×10^5	Inflow.
	1.86 / 0.03	2,600	1/2,760	2.64×10^5	Outflow.
Floridan	71.3 / 1.15	400,000	1/11,288	2.69×10^5	Inflow.
	32.9 / 0.53	130,000	1/10,847	3.17×10^5	Outflow.

[1/]Upper number is leakage in million gallons per day and lower number is leakage in inches per year.

Leakage between the surficial, intermediate, and Floridan aquifers was determined using the following equation:

$$Q = (K'/b')\ \Delta h\ A \qquad (2)$$

where

Q = leakage through confining beds, in cubic feet per day;
K'/b' = leakage coefficient of confining unit, in feet per day per foot;
Δh = average head difference between potentiometric surfaces of aquifers, in feet;
A = area of confining beds through which leakage occurs, in feet squared.

Table 7 lists estimates of Q, K'/b', Δh, and A for the surficial, intermediate, and Floridan aquifers. Leakage between aquifers is in the direction of lower altitude of the potentiometric surface or water table.

As can be determined from figure 5, downward leakage occurs between the surficial aquifer and Tamiami-upper Hawthorn aquifer except for areas along the Peace and Myakka Rivers where the water table is lower because it is a discharge area. Downward leakage between the aquifers is 0.23 in/yr and upward leakage is 0.10 in/yr. The net leakage from the surficial aquifer to the Tamiami-upper Hawthorn aquifer is 0.13 in/yr.

Table 7.--Parameters used to determine leakage between aquifers

Leakage direction	$Q^{1/}$ (Mgal/d / in/yr)	K'/b' [(ft/d)/ft]	Δh (ft)	A_2 (ft^2)
Surficial aquifer to Tamiami-upper Hawthorn aquifer.	14.1 / 0.23	$1.3x10^{-5}$	5	$2.9x10^{10}$
Tamiami-upper Hawthorn aquifer to surficial aquifer.	6.0 / 0.10	$1.3x10^{-5}$	7.5	$8.2x10^{9}$
Lower Hawthorn-upper Tampa aquifer to Tamiami-upper Hawthorn aquifer.	4.2 / 0.07	$1.3x10^{-6}$	12	$3.6x10^{10}$
Lower Hawthorn-upper Tampa aquifer to Floridan aquifer.	0.24 / <0.01	$4.0x10^{-6}$	4	$2.0x10^{9}$
Floridan aquifer to lower Hawthorn-upper Tampa aquifer.	13.6 / 0.22	$5.3x10^{-6}$	10	$3.43x10^{10}$

1/ Land area = 1,300 mi^2.

Leakage between the Tamiami-upper Hawthorn aquifer and the lower Hawthorn-upper Tampa aquifer occurs only in the upward direction because the altitude of the lower Hawthorn-upper Tampa aquifer potentiometric surface is higher throughout the area (fig. 9). Upward leakage between the two aquifers is 0.07 in/yr.

The altitude of the potentiometric surface of the Floridan aquifer is higher than that of the lower Hawthorn-upper Tampa aquifer except in the northwest where irrigation pumpage has caused a depression in the potentiometric surface of the Floridan aquifer. Upward leakage from the Floridan aquifer to the lower Hawthorn-upper Tampa aquifer is 0.22 in/yr and downward leakage in the northwest is less than 0.01 in/yr.

The 0.22 in/yr of upward leakage from the Floridan aquifer to the lower Hawthorn-upper Tampa aquifer and the 0.23 in/yr of downward leakage from the surficial aquifer to the Tamiami-upper Hawthorn aquifer are primary inputs to the intermediate aquifers. The 0.23 in/yr of leakage from the surficial aquifer is derived from 0.5 in/yr recharge from rainfall, 0.01 in/yr of pumpage return, 0.09 in/yr of upward leakage from the Tamiami-upper Hawthorn aquifer, less 0.35 in/yr of pumpage from the aquifer and 0.03 in/yr that ground-water outflow is greater than inflow. The 0.22 in/yr of upward leakage from the Floridan aquifer is derived from ground-water inflow of 1.15 in/yr and downward leakage from the lower Hawthorn-upper Tampa aquifer of less than 0.01 in/yr minus ground-water outflow of 0.53 in/yr and pumpage of 0.40 in/yr.

PRELIMINARY DIGITAL MODEL OF THE SURFICIAL AQUIFER, INTERMEDIATE AQUIFERS, AND FLORIDAN AQUIFER

A preliminary digital ground-water flow simulation model was constructed to check the reasonableness of the defined hydrogeologic framework and of estimated aquifer parameters. If the hydraulic properties, water-level maps, and aquifer boundaries determined for the aquifers and the water-budget values are within reasonable limits, a steady-state calibration that duplicates water levels of the aquifers within their limits of accuracy should be possible. The model is considered preliminary because only a coarse steady-state calibration was made and additional adjustment of parameters may result in an improved model.

The ground-water flow model described by Trescott (1975) computes the hydraulic-head changes in an aquifer in response to applied hydrologic stresses. The model utilizes a finite-difference method that solves differential equations that describe ground-water flow numerically. To solve the equations, hydraulic properties, boundaries, and stresses of the aquifers being modeled must be defined. The three-dimensional digital model developed by Trescott was used because a multi-aquifer system was to be modeled. A quasi-three-dimensional form of the model was applicable because the confining layers have negligible horizontal flow. In this form of the model, effects of vertical leakage through the confining layer are incorporated into the vertical component of the hydraulic conductivity of adjacent aquifers.

A grid consisting of 16 rows and 20 columns with a grid spacing of 4 miles was used to discretize the area for modeling purposes (fig. 17). Four layers of varying thickness were used to represent the four aquifers. Hydrologic parameters were assigned to each three-dimensional block according to the values in table 5. Model boundaries of each aquifer were selected to coincide with hydrologic boundaries; they are generally perpendicular to the potentiometric contours of each aquifer. The boundaries of each aquifer were simulated using either a no-flow condition or a constant-head condition at the boundaries.

Calibration of Steady-State Model

Steady-state conditions are those in which there are no changes in ground-water storage with time, that is, the system has reached equilibrium. Under steady-state conditions the storage term in the flow equation is set to zero during model calibration.

In the calibration of the steady-state model, aquifer parameters were adjusted in steady-state computer runs until the computed potentiometric surfaces approximated the input potentiometric surfaces. The match between computed and input potentiometric surfaces was improved by adjusting the values of transmissivity, leakance, and head, while staying within the estimated range of these parameters.

Because the calibration is preliminary and the generalized potentiometric surface of the modeled aquifers have limits of accuracy of about 5 feet, the model was considered calibrated when the final head matrix was within 5 feet

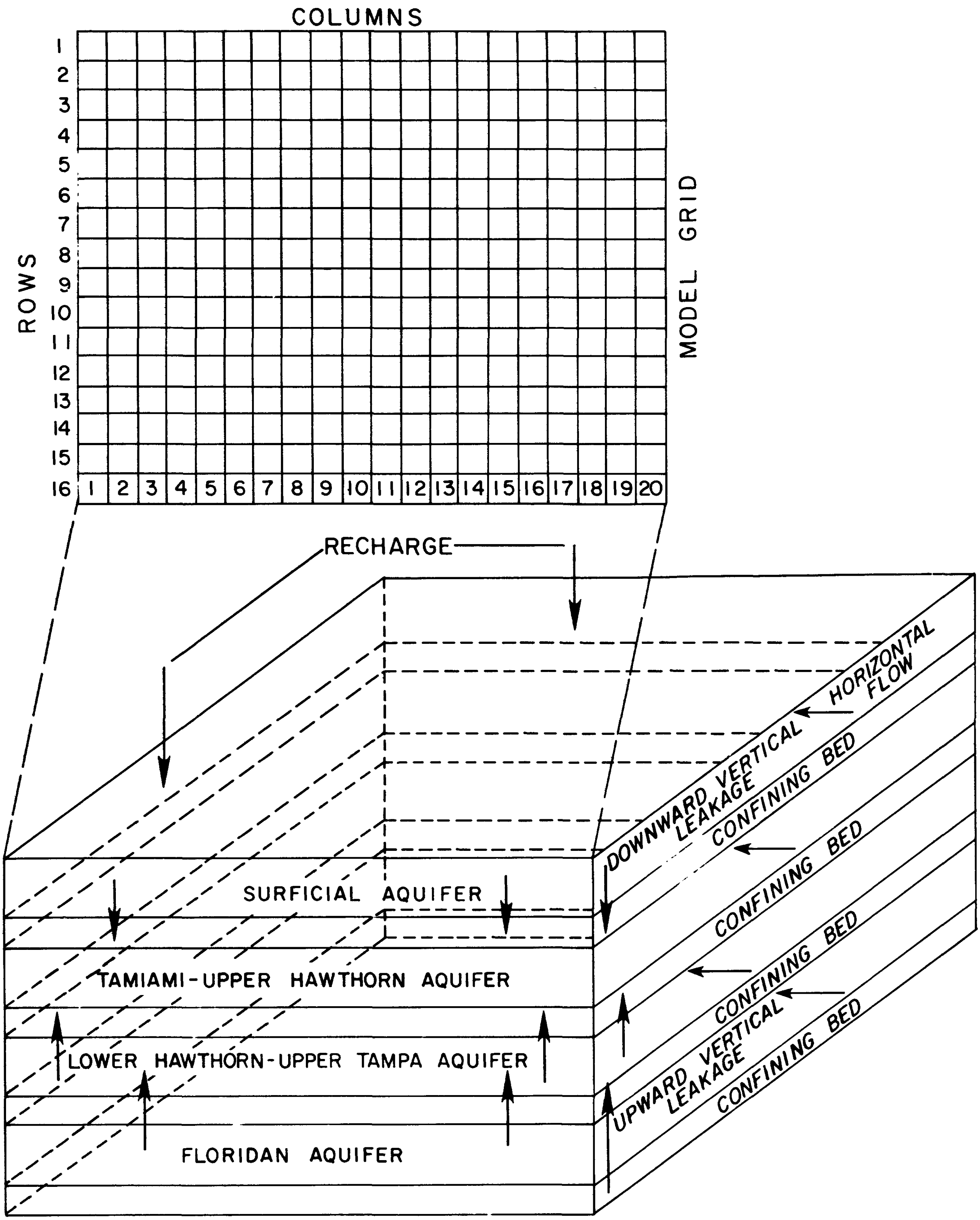


Figure 17.--Schematic illustration of aquifers modeled.

of the starting head matrix. It should be noted that the calibration is not unique. For example, the same final head configuration can be generated by changing parameter values in one matrix and making compensating changes in one or more other matrices.

Digital modeling of ground-water flow in the study area shows that recharge rates calculated for the water budget are sufficient to balance the natural discharge of the regional ground-water system. The model calibration supports the reasonableness of the hydraulic properties, water-level maps, and aquifer boundaries determined for the aquifers.

SUMMARY

Land and bay area in Sarasota County and parts of Charlotte and De Soto Counties in the study area encompass an area of approximately 1,400 mi^2 in west-central Florida. The surficial and intermediate aquifers are the major source of public water supplies because of the relatively poor quality of water in the Floridan aquifer. Total pumpage of ground water in 1979 was estimated to be 41.7 Mgal/d.

The average annual rainfall is about 51 inches. About 60 percent of the rainfall occurs from June through September. The dry season, October through May, is the peak irrigation season. Evapotranspiration is about 38 in/yr.

The hydrogeologic framework in the Sarasota-Port Charlotte area consists of the surficial aquifer, intermediate aquifers (Tamiami-upper Hawthorn and lower Hawthorn-upper Tampa aquifers) and confining beds, Floridan aquifer, and lower confining bed (or base of the Floridan aquifer). Limestone and dolomite beds that make up the Floridan aquifer thicken toward the south and range in thickness from 1,400 to 1,900 feet. The altitude of the top of the aquifer ranges from 400 feet below sea level in the north to 650 feet below sea level in the south. The surficial and intermediate aquifers and confining beds also thicken toward the south and range in thickness from 400 to 700 feet.

Geologic formations that comprise the surficial and intermediate aquifers and confining beds are the surficial deposits, undifferentiated Caloosahatchee Marl, Bone Valley Formation, the Tamiami and Hawthorn Formations, and parts of the Tampa Limestone that are not in hydraulic contact with the Floridan aquifer. Underlying these formations are the rest of the Tampa, Suwannee, Ocala, and Avon Park Limestones of the Floridan aquifer. Underlying the Floridan aquifer is the Lake City Limestone that is the lower confining bed where it is impregnated with evaporites.

The surficial aquifer ranges in thickness from about 50 feet in the north to about 100 feet in the south. The depth to the water table of the surficial aquifer is generally about 7 feet, ranging from about 15 feet to less than 1 foot below land surface. Fluctuations in water level in the surficial aquifer generally vary within a 5-foot range. The seasonal low occurs during spring months and the seasonal high occurs in late summer. The altitude of the water table ranges from a high of 90 feet in northeastern Sarasota County to less than 10 feet near the coast. The hydraulic properties of the surficial aquifer are variable because of the large range of hydraulic conductivity for the lithologic units that make up the aquifer. Water from the surficial aquifer is generally of potable quality except near the coast, along tidally affected streams and canals, and in the vicinity of the Myakka and Peace River estuaries.

The Tamiami-upper Hawthorn aquifer is the uppermost intermediate aquifer. It consists of phosphatic marl, shell, sand, clayey sand, and phosphatic limestone. The top of the aquifer ranges from about 50 feet below sea level in the north to about 125 feet below sea level in the south. Its thickness ranges from about 75 to 150 feet with thickness increasing from the northeast toward the southwest. Fluctuations in water level are seasonal and generally vary within a 5-foot range similar to the seasonal variations of the water table of the surficial aquifer. The hydraulic properties of the aquifer vary with lithology and degree of solution development within limestone and dolomite rather than with aquifer thickness. Water in the aquifer is generally potable except near the coast and most of the western half of Charlotte County where saltwater intrusion has occurred or seawater has not been completely flushed from the aquifer.

The lower Hawthorn-upper Tampa aquifer is the lowermost intermediate aquifer. The aquifer consists of permeable limestone and dolomite beds in the lower part of the Hawthorn Formation and upper part of the Tampa Limestone. The top of the aquifer ranges in altitude from less than 200 feet below sea level in the north to about 300 feet below sea level in the south. Its thickness ranges from 200 feet in the north to about 350 feet in the south. Fluctuations in water level are generally less than 5 feet except near well fields and are seasonal. The altitude of the potentiometric surface ranges from about 40 feet above sea level in the east to about 10 feet above sea level in the northwestern coastal area. Hydraulic properties of the aquifer are more variable than overlying aquifers. Permeability of the limestone and dolomite is related to the degree of solution development. Water from the aquifer is generally potable or close to potable in quality, except in coastal and southwestern areas.

The Floridan aquifer is the most productive aquifer in the study area. Except for the northeastern area, water from the aquifer is not of acceptable quality for public water supplies. The altitude of the potentiometric surface of the Floridan aquifer ranges from about 60 feet above sea level in eastern Charlotte County to about 20 feet above sea level in northern Sarasota County. Water in the Floridan aquifer is generally more mineralized than water from the surficial aquifer and intermediate aquifers.

A water budget shows that rainfall is the primary input to the hydrologic system, and evapotranspiration and streamflow are the primary outputs. Secondary inputs into the system are ground-water flow into the aquifer from outside the study area and pumpage return. Secondary outputs from the system are ground-water outflow and pumpage from the aquifers. An average annual rainfall of 51.0 inches minus an evapotranspiration of 38.0 in/yr and streamflow of 12.5 in/yr leaves 0.5 in/yr of recharge to the surficial aquifer in an average year. Combined pumpage from the aquifers is 1.06 in/yr, and pumpage returned to the surficial aquifer that is recharged is 0.01 in/yr. Ground-water inflow to the aquifers is 1.20 in/yr while ground-water outflow is 0.64 in/yr.

A quasi-three-dimensional model was used to check the reasonableness of the hydrogeologic framework defined and of aquifer parameters. The model was considered calibrated when the final head matrix was within ±5 feet of the starting head. Digital modeling of ground-water flow in the study area shows that recharge rates calculated for the water budget are sufficient to balance the natural discharge of the regional ground-water system.

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