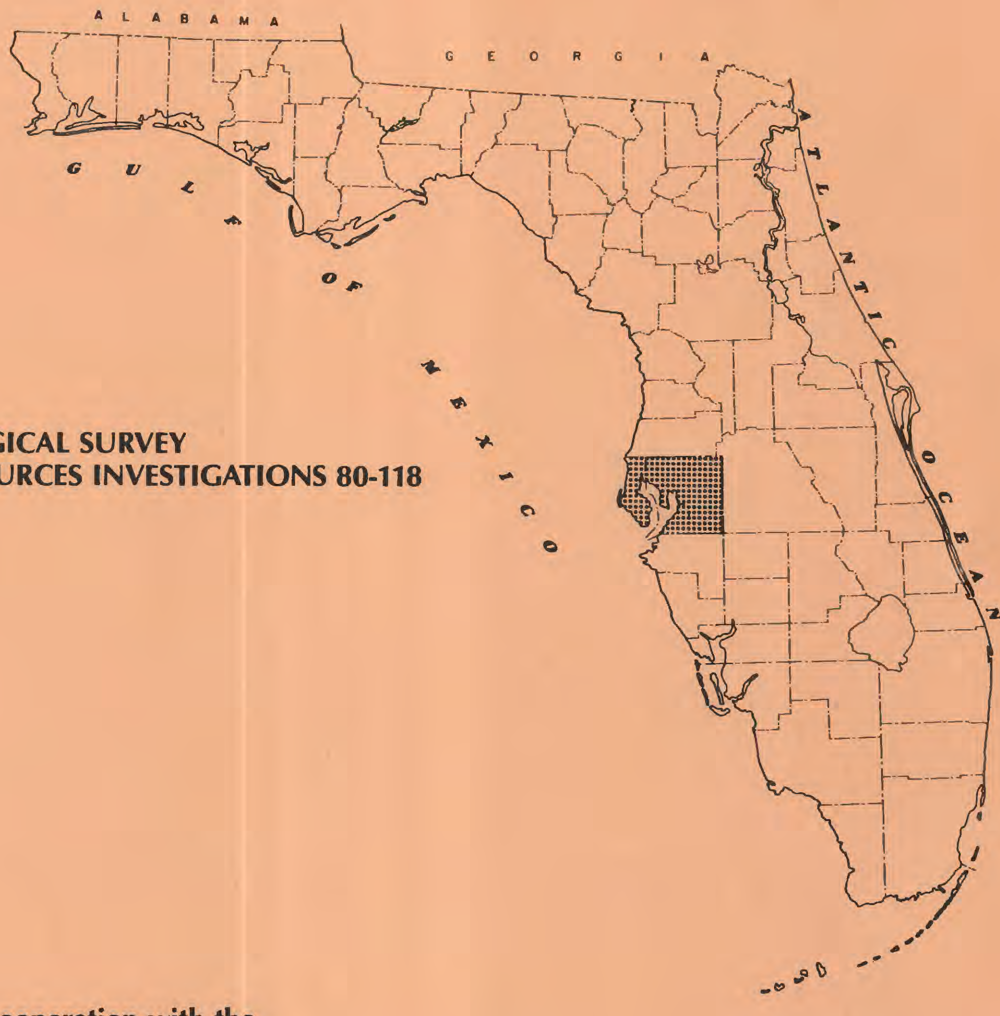
HYDROGEOLOGY, ESTIMATED IMPACT, AND REGIONAL WELL MONITORING OF EFFECTS OF SUBSURFACE WASTEWATER INJECTION, TAMPA BAY AREA, FLORIDA



U.S. GEOLOGICAL SURVEY
WATER-RESOURCES INVESTIGATIONS 80-118

Prepared in cooperation with the

SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT

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The injection zone at the proposed sites is a persistently dolomitized section of the Avon Park Limestone in the lower part of the Floridan aquifer. The injection zone contains ground water with chloride concentration of 19,000 to 20,000 milligrams per liter.

Pressure changes and velocity that could result from injection were computed for selected regional locations. Results of model computations suggest that the regional impact during 20 years of injection within the Tampa Bay area will be small.

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1981

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

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

Multiply inch-pound unit	By	To obtain SI unit
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Volume	
gallon (gal)	3.785	liter (L)
	0.003785	cubic meter (m^3)
	Flow	
gallon per minute (gal/min)	.06309	liter per second (L/s)
million gallons per day (Mgal/d)	3,785.412	cubic meters per day (m^3/d)
	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)
	Pressure	
pound per square inch (lb/in^2)	6,894.8	Newton per square meter (N/m^2)
pound per square foot (lb/ft^2)	47.8803	Newton per square meter (N/m^2)
	Hydraulic Conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Density	
slug per foot cubed ($slug/ft^3$)	0.5154	grams per milliliter (g/mL)

* * * *

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."

HYDROGEOLOGY, ESTIMATED IMPACT, AND REGIONAL WELL MONITORING OF EFFECTS OF SUBSURFACE WASTEWATER INJECTION, TAMPA BAY AREA, FLORIDA

By John J. Hickey

ABSTRACT

The potential impact on freshwater resources in the Tampa Bay area from subsurface injection of waste treatment plant effluent at six proposed sites located in Pinellas County, including the city of St. Petersburg, is of some concern. Projected maximum injection rate, when all sites become operational, will be about 40 million gallons per day.

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INTRODUCTION

The Tampa Bay area, located in west-central Florida (fig. 1), is experiencing rapid population growth. In 1960 the population of Pinellas, Hillsborough, and Manatee Counties, surrounding Tampa Bay, was about 840,000, in 1970 it was about 1,100,000, and by 2000 it may exceed 2,000,000 (Thompson, 1977). Water supply in this region is largely dependent upon ground water. Efforts by regulatory agencies to improve the hydrologic environment have led to regulation of withdrawals from well fields and to increased regulatory standards for discharges from wastewater treatment plants. To respond to these standards and to reduce costs for treating wastewater, Pinellas County and the city of St. Petersburg are considering subsurface injection of treatment plant effluent. The permeable zone that will receive injected wastewater contains saltwater. However, the zone also contains freshwater about 16 to 18 miles north and east of the proposed injection sites. Because of this, the Southwest Florida Water Management District is concerned about potential degradation of freshwater resources in the Tampa Bay area by the inland movement of saltwater that could be caused by injection.

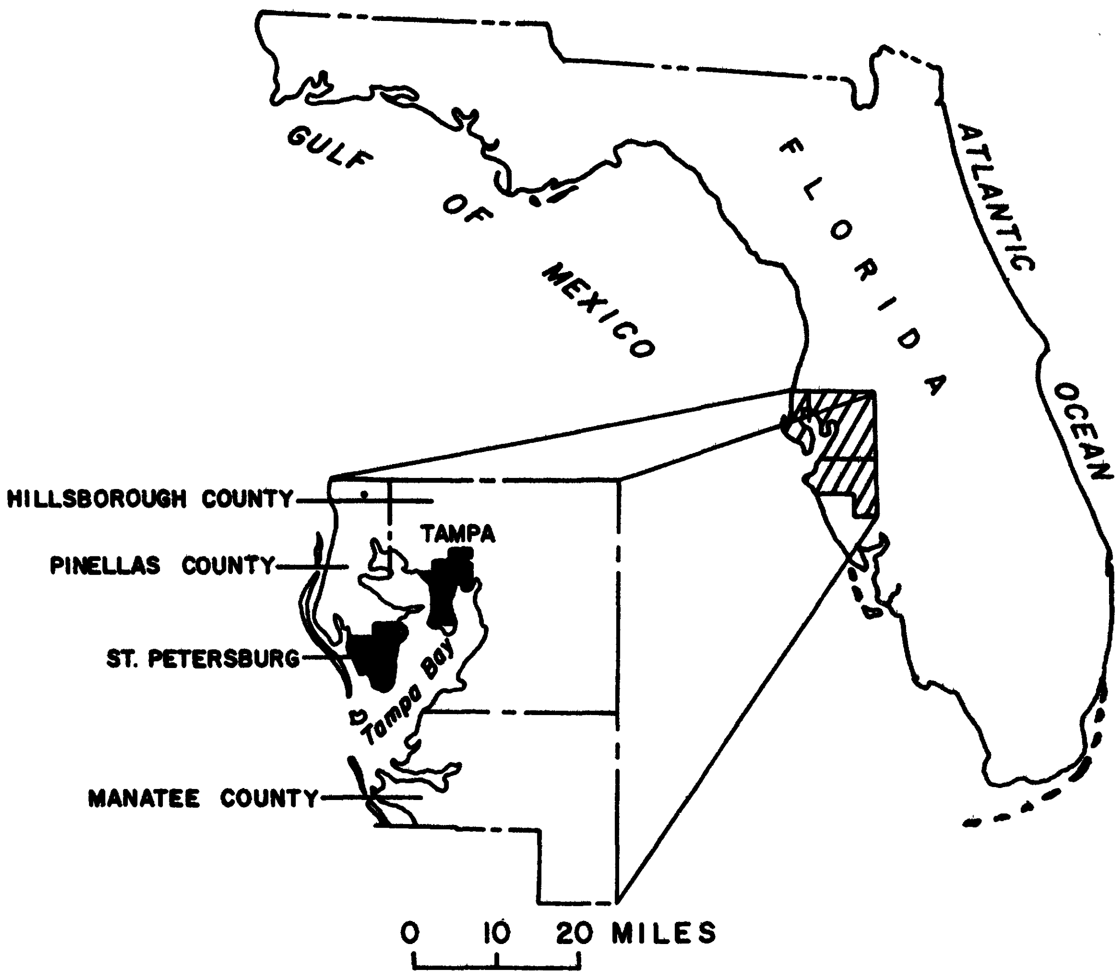


Figure 1.--Location of Tampa Bay area.

Projected maximum injection rate, when proposed injection sites (fig. 2) become fully operational, will be about 40 Mgal/d. Pinellas County plans to inject all the effluent from their wastewater treatment plants. At the Pinellas County South Cross Bayou site, the county's expected maximum average injection rate is 20 Mgal/d; and at their McKay Creek site, the expected maximum is 4 Mgal/d.

The city of St. Petersburg plans to use their injection facilities as a secondary disposal method, the primary method being spray sites, which includes irrigation of golf courses. The city anticipates using the injection wells only during periods of wet weather when primary disposal method becomes ineffective. The city plans to have four injection sites: southwest St. Petersburg, Albert Whitted, northeast St. Petersburg, and northwest St. Petersburg. Maximum average injection rate expected by the city of St. Petersburg at each site is 4 Mgal/d or a total of 16 Mgal/d for all four sites.

Purpose and Scope

Proposed sites for the injection of wastewater treatment plant effluent in Pinellas County and the city of St. Petersburg will have a network of monitoring wells that will be used to evaluate the local environmental impact of waste injection. Regional effects, however, might result from operating the six proposed injection facilities at one time that could impact on the freshwater resources in the Tampa Bay area.

The U.S. Geological Survey, in cooperation with the Southwest Florida Water Management District, has undertaken a study to determine sites where the regional effects of subsurface injection could be monitored most effectively. Such sites would provide information to evaluate the integrated impact of six proposed injection sites on the fresh ground-water resources of the Tampa Bay area. This investigation was also supported by the U.S. Geological Survey's subsurface-storage statewide research study.

The objective of this study is to develop a regional well network for monitoring the effects of subsurface injection in the Tampa Bay area. In this report, the hydrogeology of the Tampa Bay area is described, estimated impact of injection is computed at selected sites, and, based upon these analyses, a regional monitoring network is proposed.

Acknowledgments

The author wishes to thank Robert Shultz of the Southwest Florida Water Management District for his thoughtful comments during the course of this investigation. Thanks are also extended to William Steinkampf and James Gerhart of the U.S. Geological Survey whose diligent efforts in the modeling part of this investigation went beyond their normal assignments.

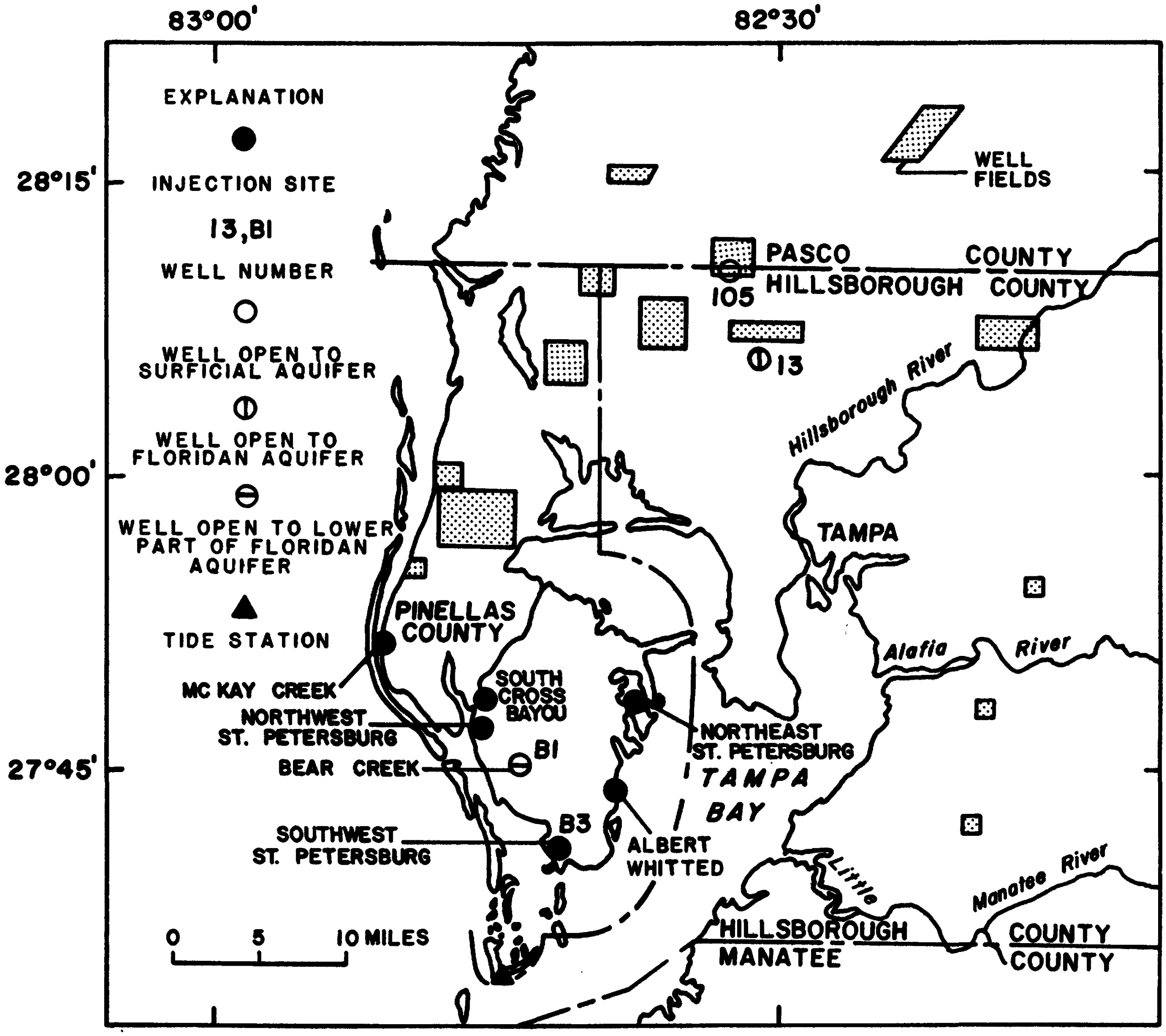


Figure 2.--Location of proposed wastewater injection sites.

GEOLOGIC FRAMEWORK

The Tampa Bay area is underlain by a sequence of sedimentary rocks whose lithology, structure, and geologic history control the occurrence and movement of fresh and saline ground water. Principal elements of the geologic framework are described below; a more detailed discussion is contained in the "hydrogeology" section of this report. The stratigraphic nomenclature used in this report was determined from several sources and may not necessarily follow the usage of the U.S. Geological Survey.

Table 1 shows the time-stratigraphic units and formations underlying the Tampa Bay area. These units include sedimentary rocks ranging in age from Cretaceous to Pleistocene, probably overlying a pre-Mesozoic basement complex of igneous and metamorphic rocks (Applin, 1951). Limestone and dolomite are the principal sedimentary rocks in this column and range in thickness from about 10,000 to 12,000 feet (Applin, 1951). Formations of principal interest are of Pleistocene to Eocene age and from youngest to oldest are surficial sand, Hawthorn Formation (middle Miocene), Tampa Limestone (lower Miocene), Suwannee Limestone (Oligocene), Ocala Limestone (upper Eocene), Avon Park Limestone (middle Eocene), Lake City Limestone (middle Eocene), and Oldsmar Limestone (lower Eocene) (fig. 3).

Structurally, the Tampa Bay area is on the southwest flank of the peninsular arch and is southwest of the Ocala uplift. The peninsular arch is the dominant subsurface structure and forms the axis of the Florida peninsula. The Ocala uplift is a gentle, anticlinal flexure in north-central Florida (Puri and Vernon, 1964). Axes of both structural features approximately parallel each other and trend northwest to southeast. Puri and Vernon (1964) describe the carbonate rocks associated with the Ocala uplift as being extensively fractured. Fracture patterns mapped by Vernon (1951) show preferred fracture orientation with azimuths from 301° to 325° just north of Tampa Bay (J. A. Miller, written commun., 1978). Vernon (1951) shows fracture patterns in the northern part of Pinellas County and no fractures in the southern part. Vernon shows a small number of fractures in southern Hillsborough County.

HYDROGEOLOGY OF THE TAMPA BAY AREA

Fresh and saline ground water occur in the rocks underlying the Tampa Bay area. Saline ground water is relatively abundant in the coastal margins and in Pinellas County. Fresh ground water typically occurs inland in Hillsborough and Manatee Counties. Sources of fresh ground water are locally infiltrating rainwater and lateral movement of ground water into the area. Sources of saline ground water are the Gulf of Mexico, Tampa Bay, and residual seawater from the geologic past. The injection zone at all test sites contains water similar in composition to seawater.

There are three principal lithologic sequences in the Tampa Bay area: (1) unconsolidated sand, clay, and marl; (2) limestone and dolomite; and (3) gypsiferous limestone and dolomite. Sand, clay, and marl are the principal sediments in the upper part of the section in middle Miocene and younger rocks. Limestone and dolomite are the principal rocks in the middle part of the section in

Table 1.--Time-stratigraphic units and formations underlying the Tampa Bay area, Florida

[Nomenclature after Applin and Applin (1944), Heath and Smith (1954), and Puri and Vernon (1964)]

Erathem	System	Series		Formation
Cenozoic	Quaternary	Pleistocene		Surficial sand
	Tertiary	Miocene	Middle	Hawthorn Formation
			Lower	Tampa Limestone
		Oligocene		Suwannee Limestone
		Eocene	Upper	Ocala Limestone
			Middle	Avon Park Limestone
				Lake City Limestone
			Lower	Oldsmar Limestone
		Paleocene		Cedar Keys Limestone
Mesozoic	Cretaceous	Undifferentiated for this report		
Pre-Mesozoic	Undifferentiated for this report			

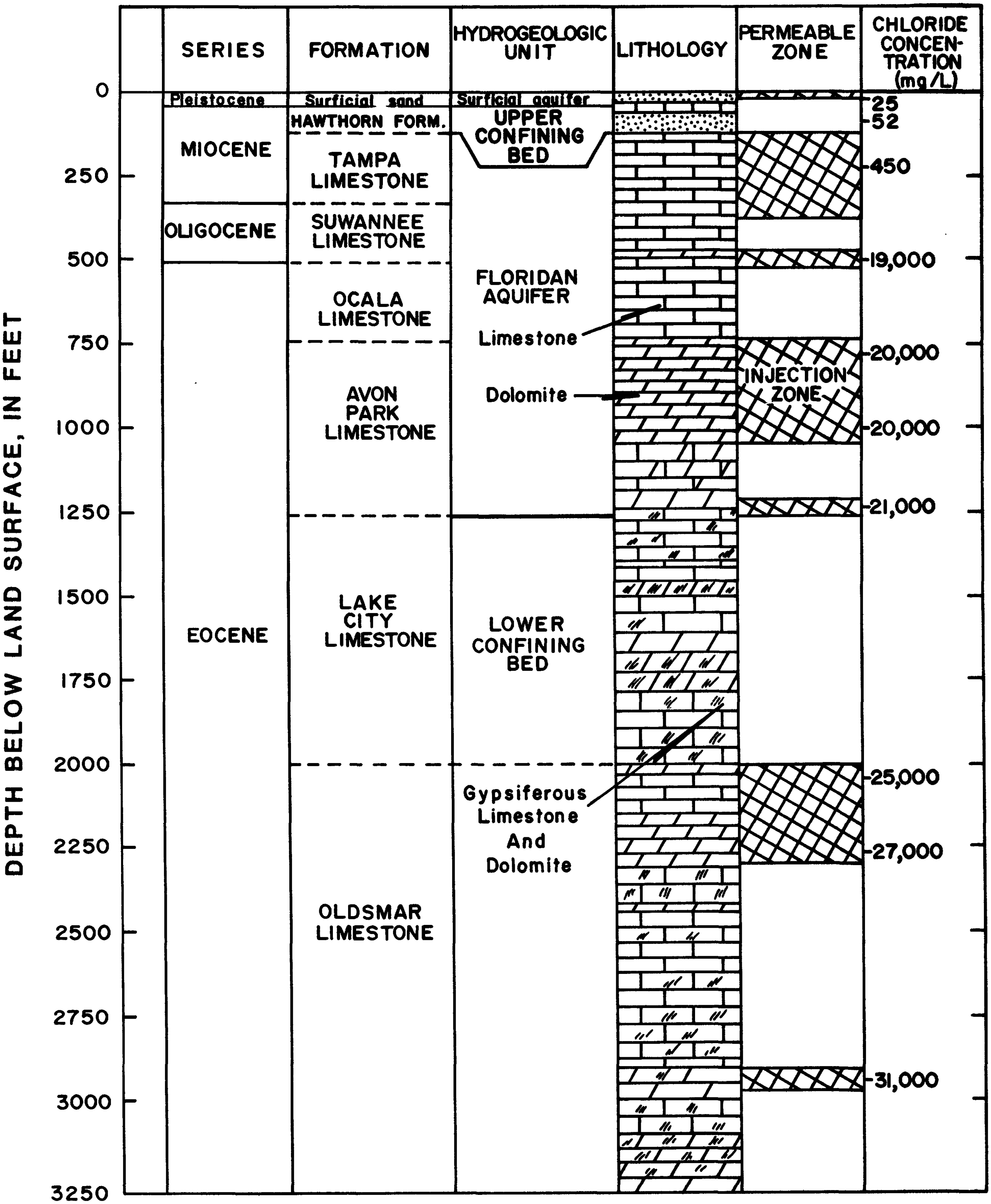


Figure 3.--Stratigraphic and hydrogeologic section, South Cross Bayou test injection site.

lower Miocene to late middle Eocene rocks. Gypsiferous limestone and dolomite are the principal rocks in the lower part of the section of early middle Eocene rocks. The test injection zone at all sites is in a persistently dolomitized section of late middle Eocene rocks.

In the Tampa Bay area, two aquifers have been identified, the surficial aquifer and the Floridan aquifer (Parker and others, 1955). Also, two confining beds have been identified, the upper and lower confining beds of the Floridan aquifer.

All rocks underlying the Tampa Bay area are permeable in some degree, but their ability to yield water to wells differs considerably. Therefore, they have been categorized hydrogeologically as being either aquifers or confining beds. Lohman and others (1972) define an aquifer to be a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. They define a confining bed to be a body of "impermeable" material stratigraphically adjacent to one or more aquifers. Confining beds are relatively less permeable than aquifers and restrict flow of water between aquifers. Their effectiveness to restrict flow varies, depending upon confining-bed thickness, head differences between aquifers, and the vertical hydraulic conductivity of the confining bed. Under suitable conditions, moderate to large volumes of water can flow through confining beds. In this report, the ratio of hydraulic conductivities used to distinguish aquifers from confining beds is 100 to 1.

The term semiconfining bed is used in the following text to describe the carbonate confining strata within the Floridan aquifer and to distinguish these strata from the still less permeable confining beds overlying and underlying the aquifer. The term permeable zone is used to describe the most permeable strata within the Floridan aquifer. Ratio of hydraulic conductivities used to distinguish permeable zones from semiconfining beds is 100 to 1, the same as between aquifers and confining beds.

Surficial Aquifer

The surficial aquifer typically consists of a sand deposit that is generally less than 85 feet thick. Except for minor to abundant shell and minor phosphate, the sand is composed principally of fine- to medium-sized quartz grains. The aquifer is used mainly as a source of water for lawn irrigation. The water table in the aquifer is easily reached by shallow wells and is near land surface during wet periods and is about 5 to 10 feet below land surface during dry periods.

The water table fluctuates seasonally, as illustrated by the hydrograph for a well in south Pasco County (fig. 4). Peak water levels occur during rainy seasons, commonly in late summer and mid-winter. Minimum water levels occur during dry seasons, commonly in May. The seasonal range is 2 to 5 feet. Significant trends are not noted for the 1973-79 period, indicating that recharge from summer rains was adequate to replenish the aquifer.

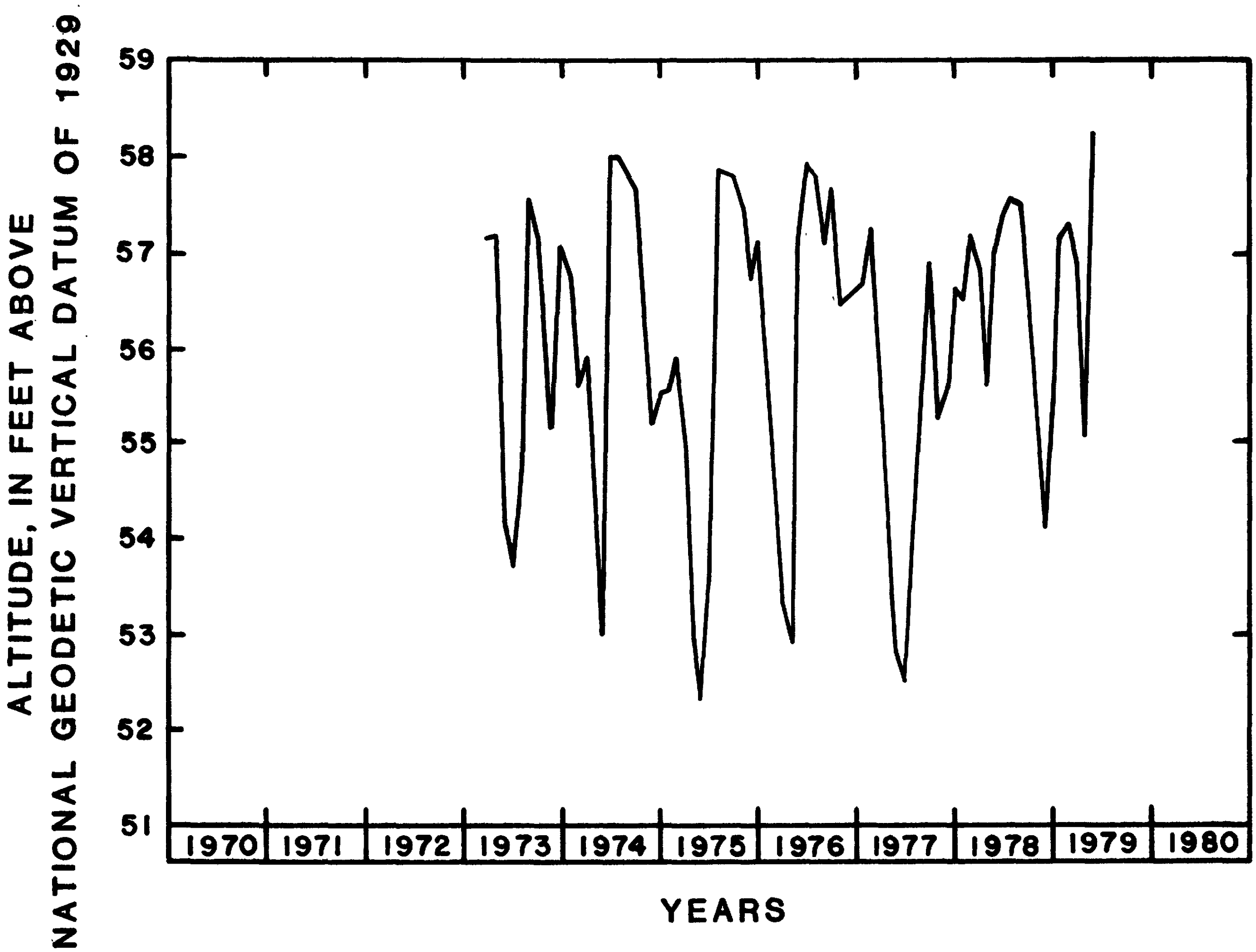


Figure 4.--Water levels of well 105 near Land O'Lakes open to the surficial aquifer (see figure 2 for location).

Hydraulic properties of the surficial aquifer in Pinellas County and northwest Hillsborough County have been determined. Hutchinson and Stewart (1978) and Sinclair (1974) report vertical hydraulic conductivities (from laboratory tests) ranging from 0.36 to 13 feet per day (ft/d) and averaging 2.6 ft/d. Horizontal hydraulic conductivity, derived from pumping test interpretations, are reported by Cherry and Brown (1974) to be 250 gallons per day per square foot [(gal/d)/ft^2] or 33 ft/d and by Sinclair to be 100 (gal/d)ft^2 or 13 ft/d. Four specific yield determinations from laboratory tests ranged from 33.7 to 37.6 percent (Sinclair, 1974). Storage coefficients (specific yield) for sand aquifers are typically within the range of 0.1 to 0.3.

Floridan Aquifer

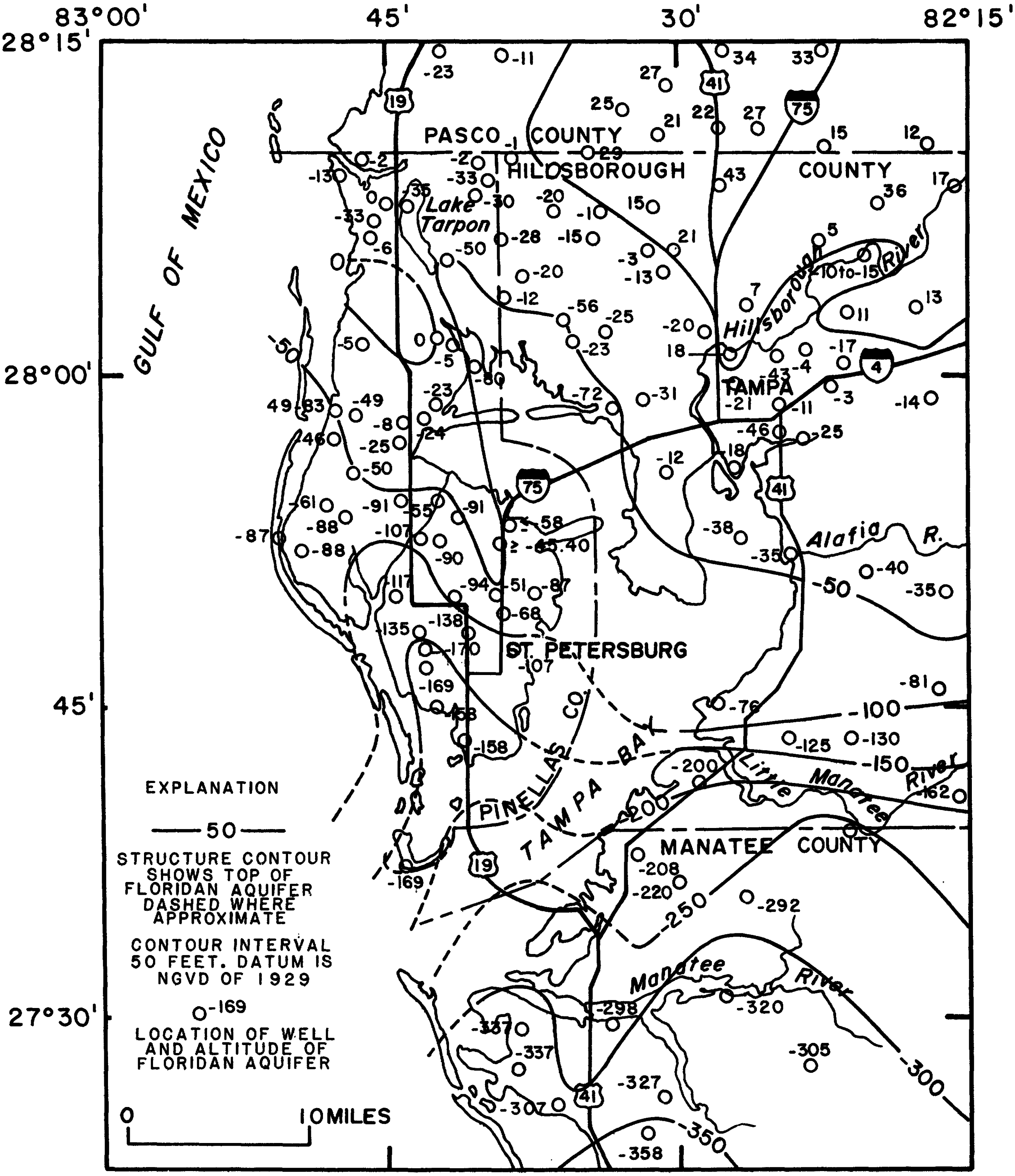
Parker and others (1955) define the Floridan aquifer to include all or parts of the Lake City Limestone, Avon Park Limestone, Ocala Limestone, Suwannee Limestone, Tampa Limestone, and permeable parts of the Hawthorn Formation that are in hydrologic contact with the rest of the aquifer. In this report, the top of the aquifer is considered to be the top of the persistent carbonate sequence below which clay, marl, and sand make up a very small percentage of the rocks. The top of the aquifer may include limestones of the Hawthorn Formation and the Tampa Limestone. The base of the aquifer is considered to be the beginning of the presence of gypsum occurring below the persistently dolomitized sequence in the lower part of the aquifer. Typically, gypsum is present within pores and as occasional thin beds; when first encountered, it is in trace amounts.

The Floridan aquifer in the Tampa Bay area is composed of limestone, dolomitic limestone, and dolomite. Limestone is the principal rock type in the upper 600 feet of the aquifer, comprising the Tampa Limestone, Suwannee Limestone, and Ocala Limestone. Dolomite and dolomitic limestone are the principal rock types in the lower 500 feet of the aquifer, comprising the Avon Park Limestone.

Most water-supply investigations of the Floridan aquifer have treated the aquifer as a single hydrogeologic unit, as proposed by Parker and others (1955). This viewpoint has yielded satisfactory analyses of the fresh groundwater flow regime in the aquifer. A few authors have subdivided the Floridan aquifer on the west coast of Florida into "units" (Wilson, 1977) and "zones" (Sutcliffe, 1975) based upon the ability of different rock sections to yield water. Rosenshein and Hickey (1977) subdivided the aquifer in Pinellas County into zones of relative hydraulic conductivity, also based upon the water-yielding ability of the rocks. Hickey, in a report presently in press, discusses the detailed hydraulic character of the Floridan aquifer and results of injection tests in Pinellas County.

Characteristics

A contour map of the top of the Floridan aquifer is shown in figure 5. This map is an adjusted version of one produced by Buono and Rutledge (1979). The altitude of the top of the aquifer ranges from zero National Geodetic



BASE FROM U.S. GEOLOGICAL SURVEY
STATE OF FLORIDA MAP 1967

Figure 5.--Altitude of top of the Floridan aquifer (modified from Buono and Rutledge, 1979).

Vertical Datum of 1929 (NGVD of 1929) just southwest of Lake Tarpon in north Pinellas County to about 350 feet below the datum in south Manatee County. Figure 5 shows the top to be somewhat irregular, except in the northernmost part of the area where it is relatively flat.

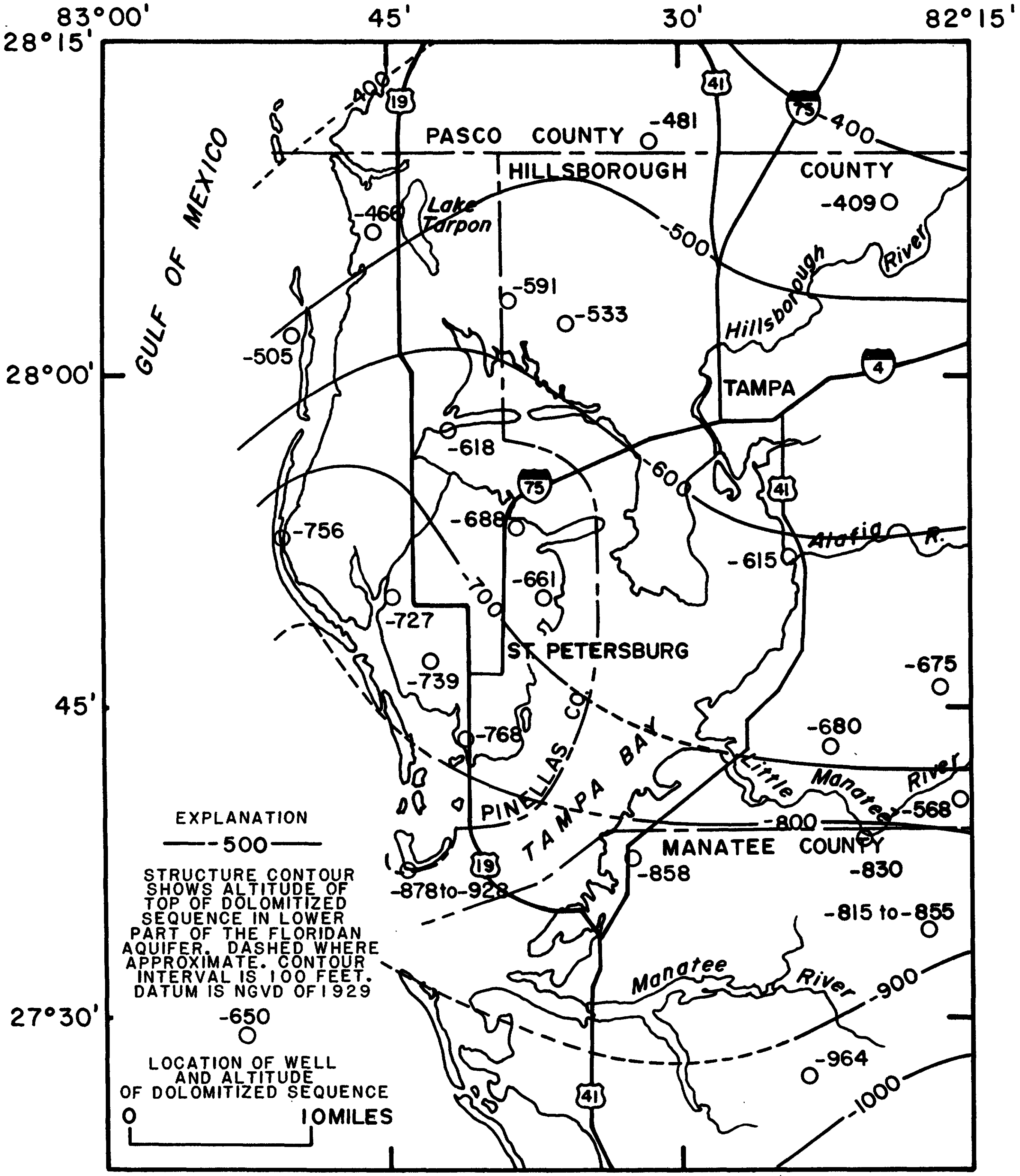
Figure 6 is a contour map of the top of the persistently dolomitized sequence in the lower part of the aquifer. The surface dips to the south and ranges in altitude from 400 feet below NGVD of 1929 in north Hillsborough County to about 1,000 feet below the datum in south Manatee County. Because of sparse control, the map is highly generalized. In Pinellas County, this map corresponds to the top of the injection zone.

At least three, and possibly four, widespread and readily identified permeable zones occur within the Floridan aquifer in the Tampa Bay area. A permeable zone occurs in the upper part of the aquifer and probably is comprised of the Tampa Limestone and, in places, parts of the Hawthorn Formation and Suwannee Limestone. The most productive permeable zone generally occurs in the dolomitized sequence in the lower part of the aquifer, which is a very dense dolomite that has been fractured. This zone is within the Avon Park Limestone and, in places, may include the lower section of the Ocala Limestone. In Pinellas County, this zone comprises about 60 percent of the thickness of the dolomitized sequence found in the lower part of the aquifer. The other permeable zones within the aquifer are generally less permeable than the two zones just mentioned and for the purpose of this investigation are ignored as separate entities.

Figure 7 shows a vertical section illustrating the simplified hydrogeologic model used in this report. The term water-producing interval shown in figure 7 refers to discrete intervals within boreholes that yield water during pumping. Water-producing intervals that occur at similar stratigraphic positions within widely separated boreholes indicate the presence of permeable zones. One of the permeable zones ignored in this investigation occurs in about the middle of the semiconfining beds shown in figure 7; the other is near the basal contact of the aquifer in the southwest St. Petersburg well (fig. 7).

Transmissivity of the Floridan aquifer, determined from aquifer tests, is shown in figure 8. These data suggest vertical and lateral variation of transmissivity. In Pinellas County, transmissivity differs as much as 40 times between the upper and lower parts of the aquifer. A comparison between Pinellas and Hillsborough Counties suggests that transmissivity differs laterally by about 3 times in the upper part of the aquifer and by about 10 times in the lower part of the aquifer.

Available data suggest that limestone semiconfining beds separate the upper and lower parts of the Floridan aquifer in the Tampa Bay area (fig. 7). Stewart (1966), Hickey (1977; 1979), Black, Crow, and Eidsness, Inc. (1978), and Hickey and Barr (1979) report 13 laboratory-determined vertical hydraulic conductivities of cores taken from the Suwannee Limestone and Ocala Limestone. These hydraulic conductivities range from about 0.0013 to 2.5 ft/d and average 0.6 ft/d. Results of short-term injection tests at three of the injection sites in Pinellas County suggest that the limestone semiconfining beds are present above the injection zone (Briley, Wild and Associates, 1977; Black, Crow, and Eidsness, Inc., 1978; Seaburn and Robertson, 1979). William F. Guyton and Associates (1976) report on a model simulation of an aquifer test in northeast Manatee County and suggest that the Ocala Limestone could have a vertical hydraulic conductivity of about 1 ft/d.



BASE FROM U.S. GEOLOGICAL SURVEY
STATE OF FLORIDA MAP 1967

Figure 6.--Altitude of top of dolomitized sequence in lower part of the Floridan aquifer (from Wolansky and others, 1979).

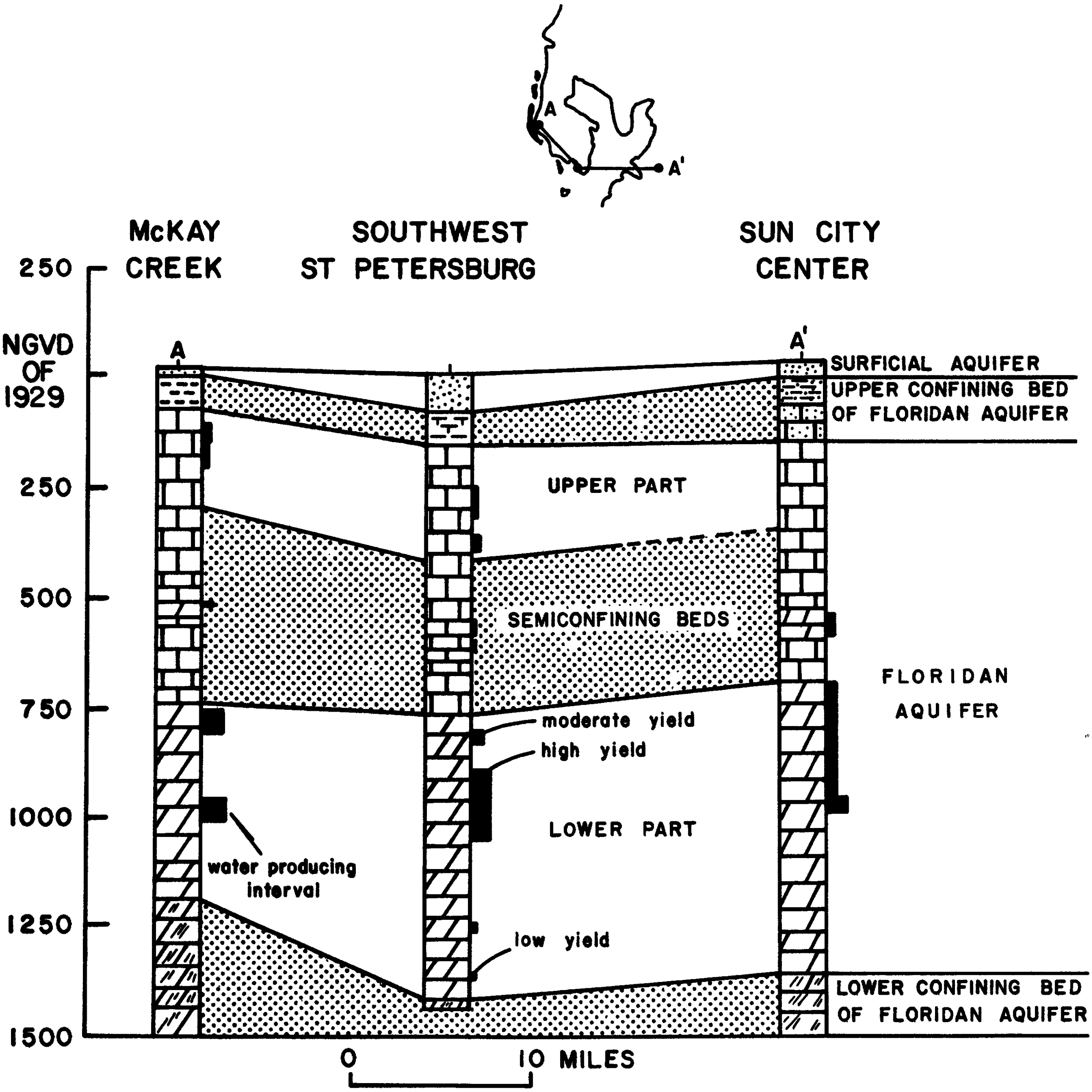
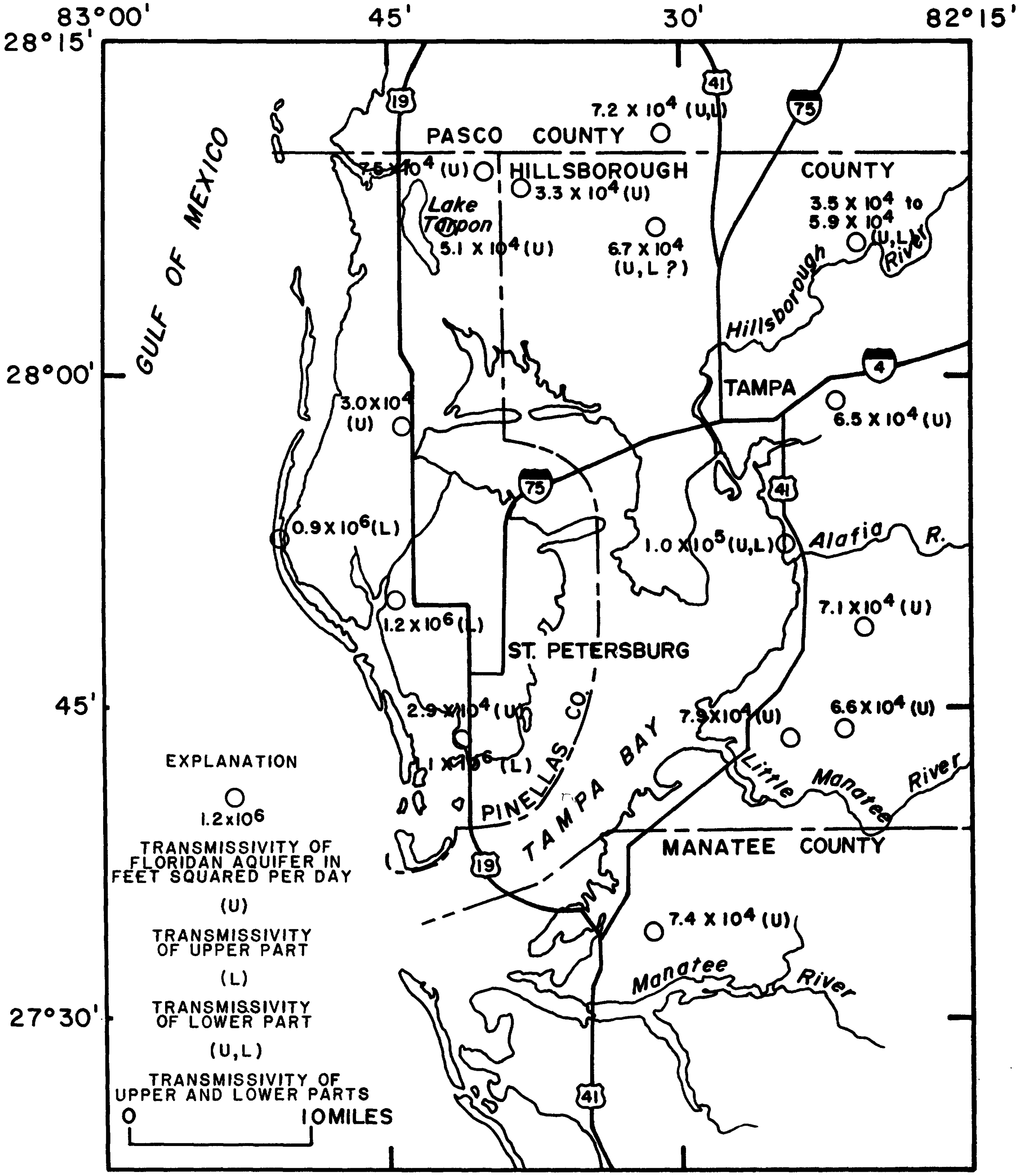


Figure 7.-Hydrogeologic section A-A'. (Width of water-producing interval reflects relative yield.)



BASE FROM U.S. GEOLOGICAL SURVEY
STATE OF FLORIDA MAP 1967

Figure 8.--Transmissivity of the Floridan aquifer at selected locations.

Pressure or head pulses will travel rapidly across the limestone semiconfining beds because of their large hydraulic diffusivity. Hydraulic diffusivity is defined as hydraulic conductivity divided by specific storage. Using laboratory determinations of compressibilities of limestone cores (Hickey, 1977; 1979; Hickey and Barr, 1979) and an estimated porosity for the limestone of 30 percent, specific storage was computed to range from 5.5 x 10^{-7} ft^{-1} to 5.3 x 10^{-6} ft^{-1} and to average 3.2 x 10^{-6} ft^{-1}. Diffusivity of these beds could be as large as 4.5 x 10^{6} ft^{2}/d using the largest hydraulic conductivity and the smallest calculated specific storage, or conversely, as small as 4 x 10^{2}. Diffusivities reported by Wolff (1970) for clay range from about 0.2 to 2.7 ft^{2}/d. Comparison between diffusivities of clay and limestone shows that limestone values are many times larger. Regional importance of the less permeable limestone beds lies not in their ability to retard a pressure or head pulse, but in their ability to retard ground-water flow in the Floridan aquifer.

Confining Beds

Confining beds occur above and below the Floridan aquifer. The upper confining bed, as considered in this report, is a clastic and carbonate sequence between the surficial aquifer and the Floridan aquifer. The carbonates in the sequence are generally underlain and overlain by clays and marls of relatively low permeability. The lower confining bed of the Floridan aquifer is the section of carbonate rock containing gypsum that underlies the aquifer.

Upper Confining Bed

The upper confining bed is composed of clay, marl, and limestone with rare occurrences of dolomite (Hickey, 1979). Clay and marl generally predominate and are very sandy in places; occasionally, limestone predominates. The upper confining bed comprises the Hawthorn Formation and, in places, the upper part of the Tampa Limestone. For mapping purposes, the thickness of the upper confining bed was chosen to be the difference between the depth to the base of the surficial aquifer and the depth to the top of the persistent occurrence of limestone (Floridan aquifer). Figure 9 is a thickness map of the upper confining bed, as adjusted from Buono and others (1979). The upper confining bed thickens to the south and does not exceed a thickness of 400 feet. North of Tampa Bay, the upper confining bed is relatively thin, not exceeding a thickness of 50 feet, and is absent in places.

Cherry and Brown (1974), Sinclair (1974), Black, Crow, and Eidsness, Inc. (1978), and Hutchinson and Stewart (1978) report laboratory determinations of vertical hydraulic conductivities for the confining bed sediments. Thirteen conductivities reported for sandy clay and marl range from about 1 x 10^{-2} to 1 x 10^{-4} ft/d and average about 8 x 10^{-3} ft/d; 16 conductivities for clay range from about 3 x 10^{-3} to 7 x 10^{-5} ft/d and average about 8 x 10^{-4} ft/d.

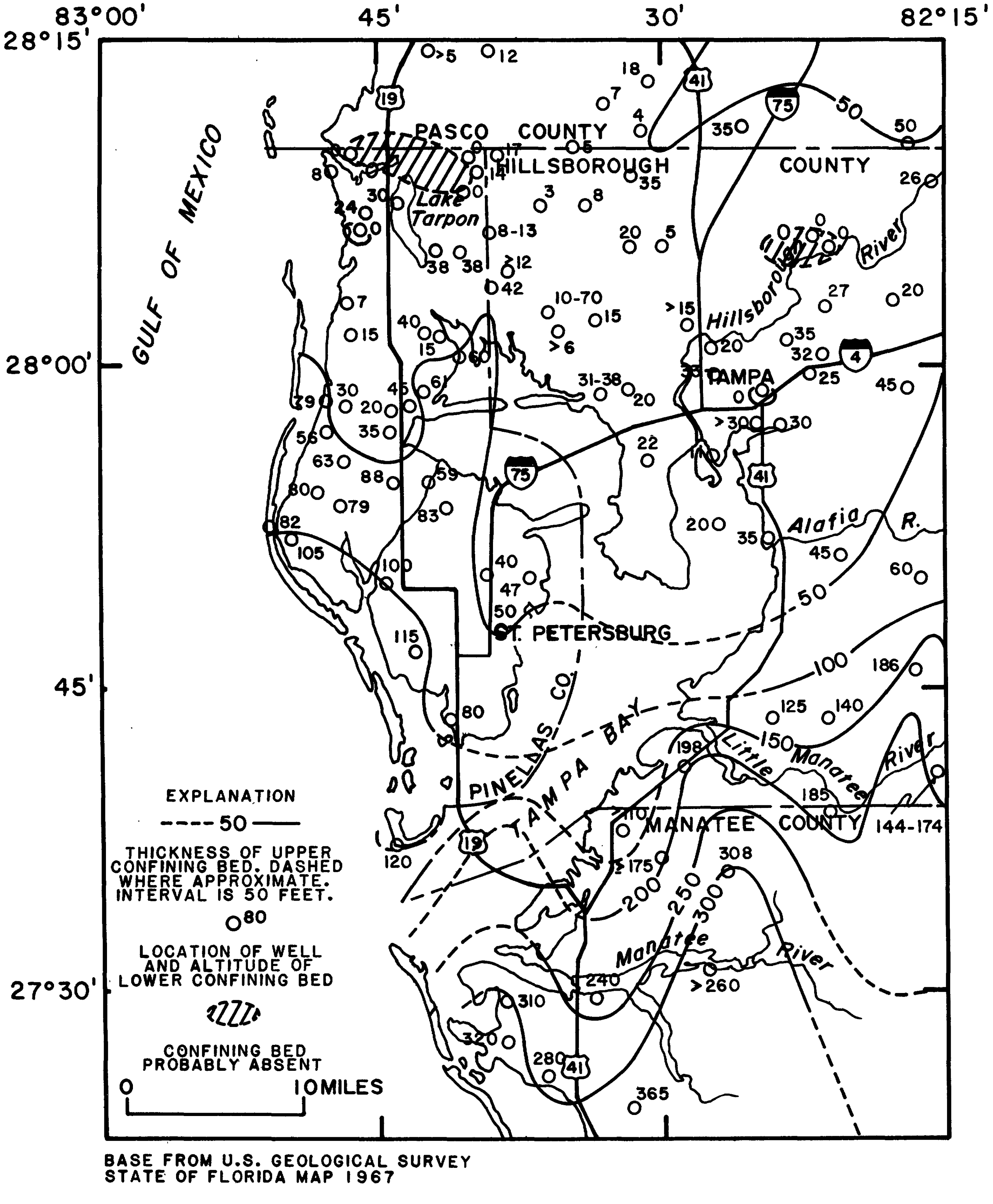


Figure 9.--Thickness of upper confining bed (modified from Wolansky and others, 1979).

Reported vertical hydraulic conductivities were determined at atmospheric conditions. Because of this, they are probably greater than if determined in place. Sinclair (1974) reports one clay vertical hydraulic conductivity determined from a consolidation test to be 1.3×10^{-4} ft/d. A comparison of this with the previously determined average for clay (8×10^{-4} ft/d) shows that the consolidation test result is about six times smaller. Therefore, it is assumed that most reported hydraulic conductivities are probably high.

Specific storage data for the upper confining bed in the Tampa Bay area are not available. A limited amount of information is available from other locations in Florida. About 50 miles southeast of the area, laboratory determinations of specific storage for five clay cores range from 3.4×10^{-5} to 3.2×10^{-4} ft^{-1} and average 1.2×10^{-4} ft^{-1} (Geraghty and Miller, Inc., 1978). Miller and others (1978) reported laboratory determinations of specific storage for one clay core and for one calcareous sandstone core from the upper confining bed in north Florida. In their study area, the confining bed consisted of the Hawthorn Formation. Specific storage for the clay core was 1.8×10^{-5} ft^{-1} and for the calcareous sandstone core was 2.2×10^{-6} ft^{-1}.

Lower Confining Bed

The lower confining bed of the Floridan aquifer, as considered in this report, is composed of limestone and dolomite with intergranular and some thin-bedded gypsum and anhydrite. It probably comprises the Lake City Limestone. For mapping purposes, the top of the confining bed was chosen as the first presence of intergranular gypsum in the carbonate rocks below a dark brown, microcrystalline dolomite in the lower part of the Floridan aquifer. The first presence of gypsum is typically a trace, but its occurrence increases with depth, although it seldom exceeds 10 percent of a given sample of rock cuttings. Figure 10 shows the altitude of the top of the lower confining bed. The surface is highly generalized and not mapped outside of Pinellas County because of sparse data. It tends to dip to the south and ranges in altitude from about 1,000 feet below NGVD of 1929 in north Pinellas and Hillsborough Counties to about 1,400 feet below the datum in south Manatee County.

A few vertical hydraulic conductivities for the lower confining bed have been determined by laboratory tests on cores. Three conductivities determined on cores taken in Pinellas County are 6.0×10^{-7} ft/d, 3.3×10^{-3} ft/d, and 1.1 ft/d (city of St. Petersburg, unpublished data; Black, Crow, and Eidsness, Inc., 1978). Stewart (1966) reports vertical hydraulic conductivities derived from cores taken in Polk County as 4.0×10^{-5} ft/d, 3.0×10^{-3} ft/d, 5.2×10^{-2} ft/d, and 2.0 ft/d. William F. Guyton and Associates (1976) report the results of testing the lower confining bed in northeastern Manatee County. They concluded that the confining bed was significantly less permeable than the overlying strata of the Floridan aquifer.

Specific storage of the lower confining bed should be smaller in magnitude than the specific storage of the carbonates in the Floridan aquifer because of gypsum filling intergranular spaces in the rock, thus reducing porosity.

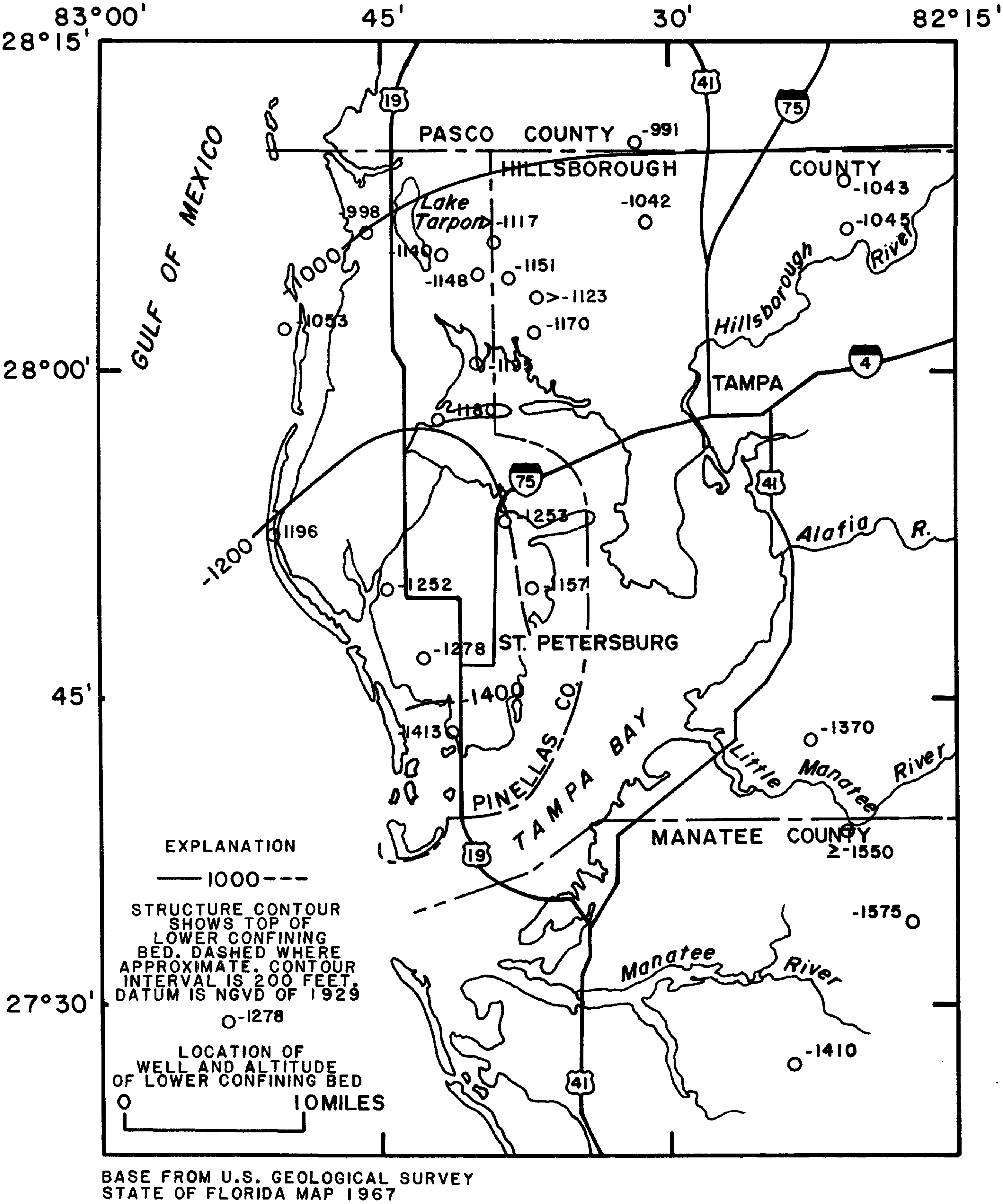


Figure 10.--Altitude of top of lower confining bed.

Ground-Water Level Fluctuations and Movement

Fluctuations in ground-water levels in the Floridan aquifer are caused by tidal variations in the Gulf of Mexico and Tampa Bay, seasonal variations in water pumped from the aquifer, precipitation, barometric pressure changes, and earth tides. In coastal margins, daily tidal variations are the most important cause of daily fluctuations in ground-water levels. Daily hydrographs of water levels at the Mullet Key tide station and at a well open to the lower part of the Floridan aquifer containing saltwater at the southwest St. Petersburg test injection site are shown in figure 11. As shown, fluctuations in ground-water levels are a subdued expression of fluctuations in tides.

Seasonal fluctuations of ground-water levels in the freshwater zone within the Floridan aquifer are illustrated in figure 12. As shown, water levels vary irregularly during any year, but generally levels are highest in late summer and autumn and lowest in spring. Water levels, as illustrated, are significantly affected by pumpage during the spring. The steep decline of the potentiometric surface is halted in May or June when the rainy season begins. The overall decline in water levels from 1960 to 1972 probably reflects both deficient rainfall and increasing pumpage; whereas the overall upward trend from 1972 to 1977 probably reflects decreasing pumpage from the adjacent well fields in Hillsborough County (fig. 2) as a result of well fields being developed further to the north in Pasco County (fig. 2). It should be noted that there was a net reduction in the potentiometric surface for the period illustrated. Elsewhere in west-central Florida, water levels began to decline in the early 1960s, corresponding to the beginning of a period of deficient rainfall (Palmer and Bone, 1977) and also to the beginning of the widespread use of deep turbine pumps. One probable effect of the downward trend in the potentiometric surface is reduction of freshwater flow to coastal areas.

Seasonal variations in water levels also occur in permeable zones that contain saltwater within the Floridan aquifer. Figure 13 shows a comparison of 1977-78 water levels from the Mullet Key tide station and well B-1, which is open to the lower part of the aquifer, at the Bear Creek injection test site in Pinellas County. The lowest ground-water levels at the Bear Creek site occur during late spring; the highest water levels occur during late summer. These do not correspond to the seasonal variation in tide level, but do correspond to periods of maximum and minimum withdrawals of fresh ground water.

The potentiometric surface of the Floridan aquifer in southwest Florida has been mapped semiannually since 1975 to show water levels during late spring (May) and late summer (September). In Pinellas County and the coastal margins of Hillsborough, Manatee, and Sarasota Counties, the May and September maps represent hydraulic conditions in the upper part of the aquifer, whereas inland, the maps represent average hydraulic conditions for both the upper and lower parts of the aquifer. A persistent feature in the May potentiometric maps is a depression in water levels that occurs within Hillsborough, Manatee, and Sarasota Counties. Water levels in the depression in May 1976 were below NGVD of 1929 in an area of about 700 mi^2 (W. E. Wilson, written commun., 1979). In the September maps, the depression is absent except for a small residual in Manatee and Hillsborough Counties.

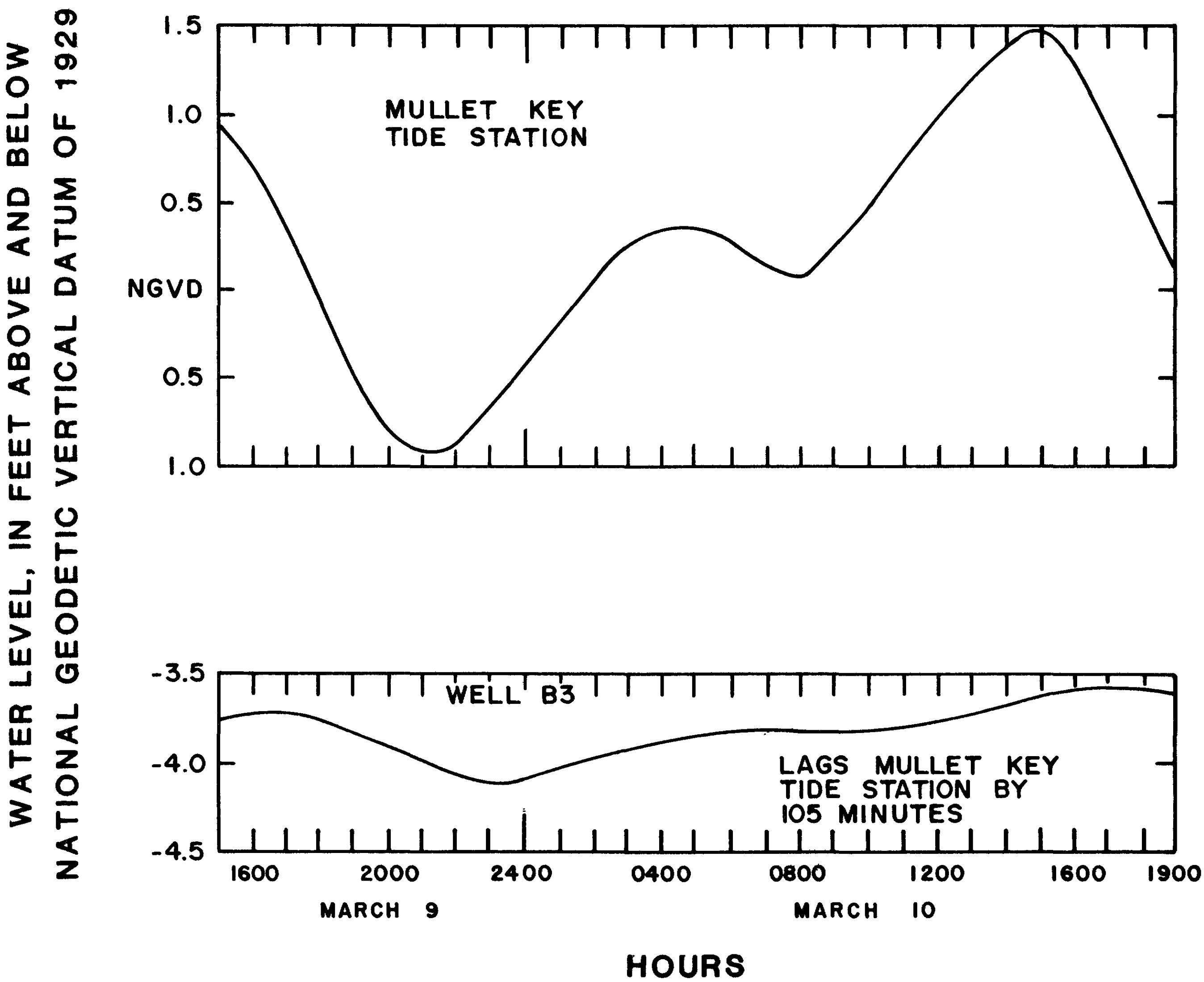


Figure 11.--Water levels at the Mullet Key tide station and in well B3 at southwest St. Petersburg open to lower part of the Floridan aquifer, March 9-10, 1977 (see figure 2 for location).

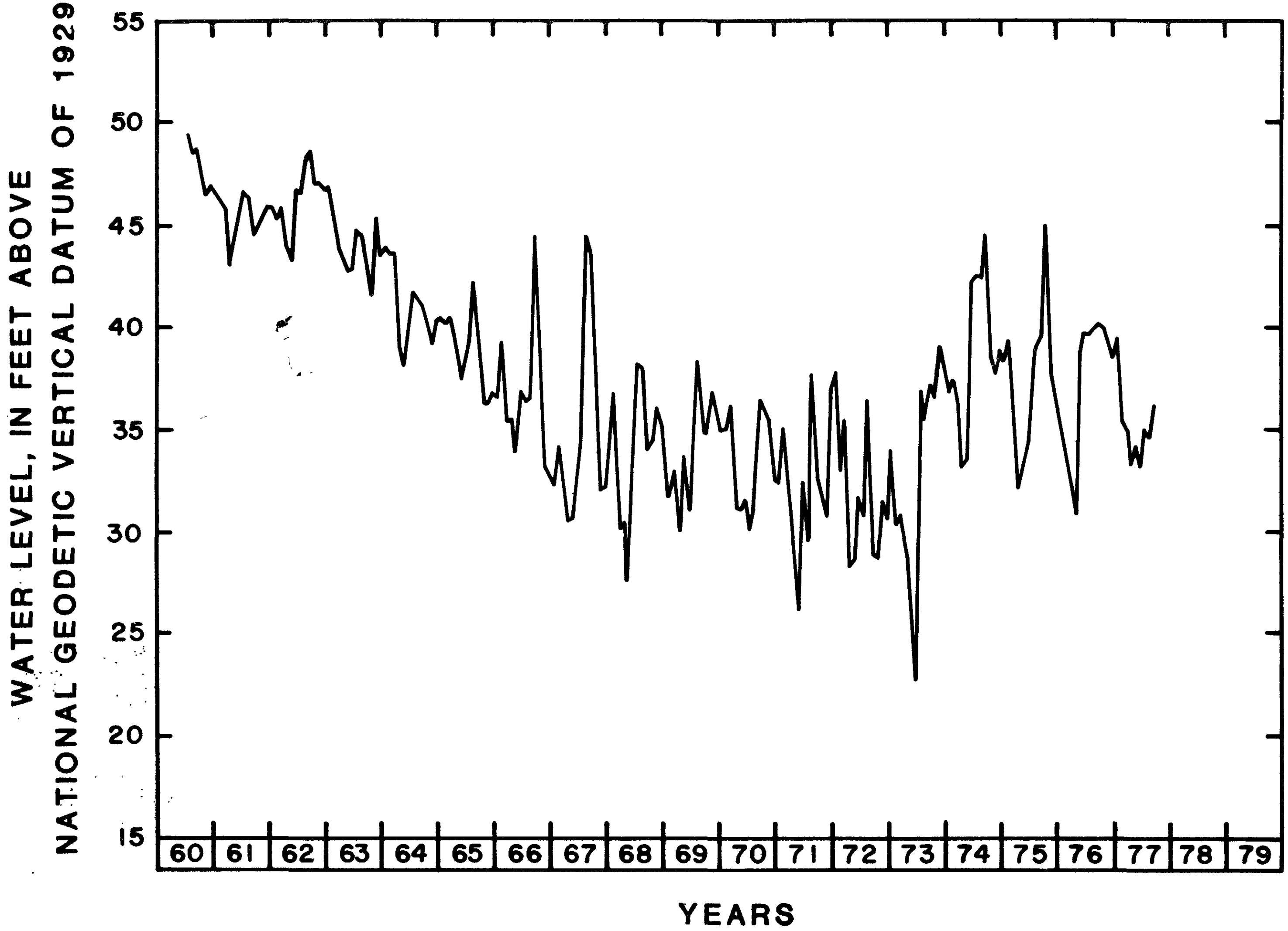


Figure 12.--Water levels in Hillsborough deep well 13, near Citrus Park, open to the Floridan aquifer (see figure 2 for location).

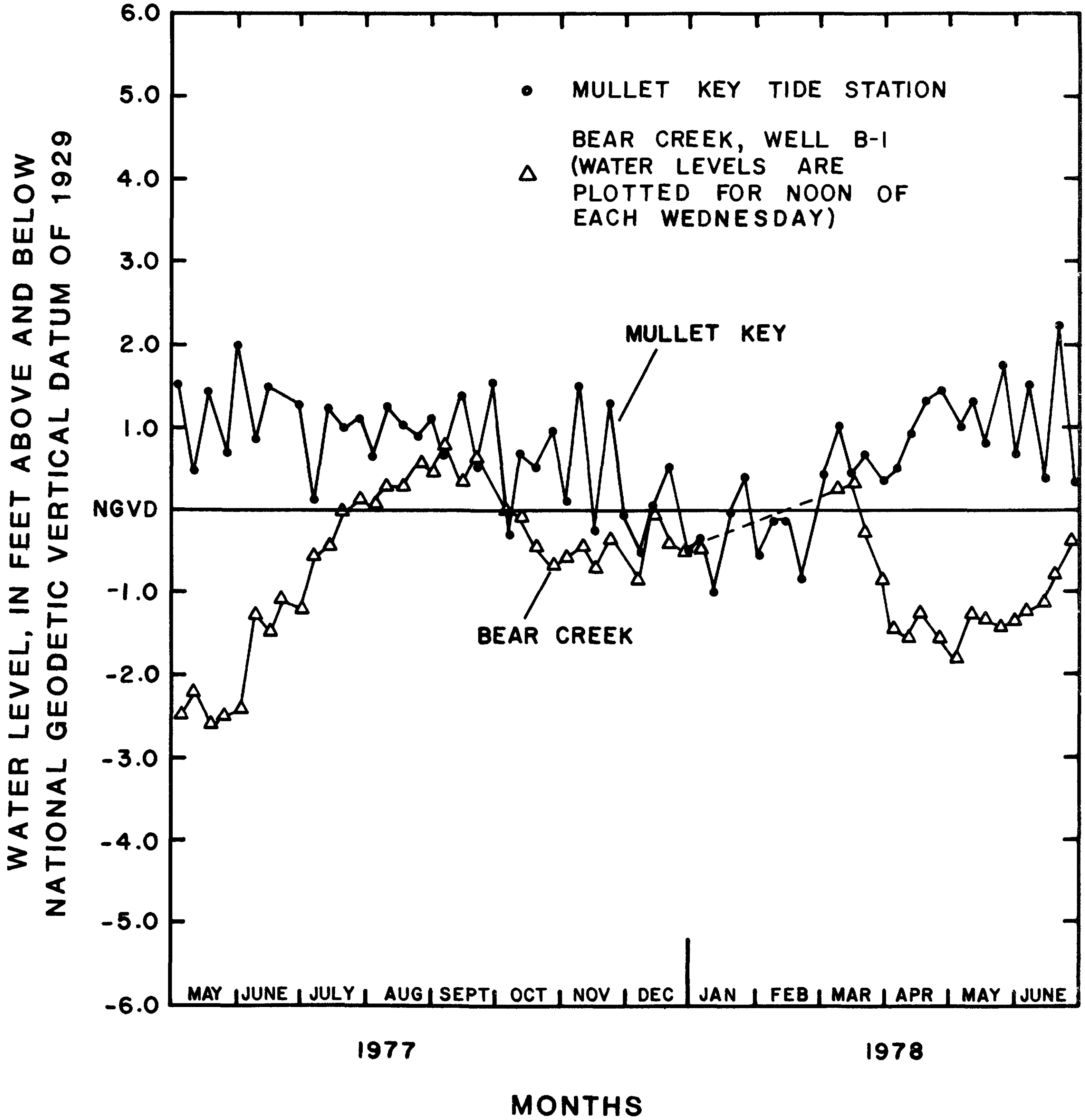


Figure 13.--Water levels at Mullet Key tide station and in well B1 at Bear Creek open to saltwater in the lower part of the Floridan aquifer, 1977-78 (see figure 2 for locations).

Comparison of the May and September potentiometric maps indicates reversals in ground-water flow directions. In September, ground water throughout the area generally flows towards Tampa Bay. In May, ground-water flow generally landward into Hillsborough and Manatee Counties. An exception to this generalization occurred in May 1979 when only a part of Hillsborough County experienced landward movement of ground-water flow. Landward movement suggests the possibility of saltwater encroachment.

Saltwater-Freshwater Transition Zone

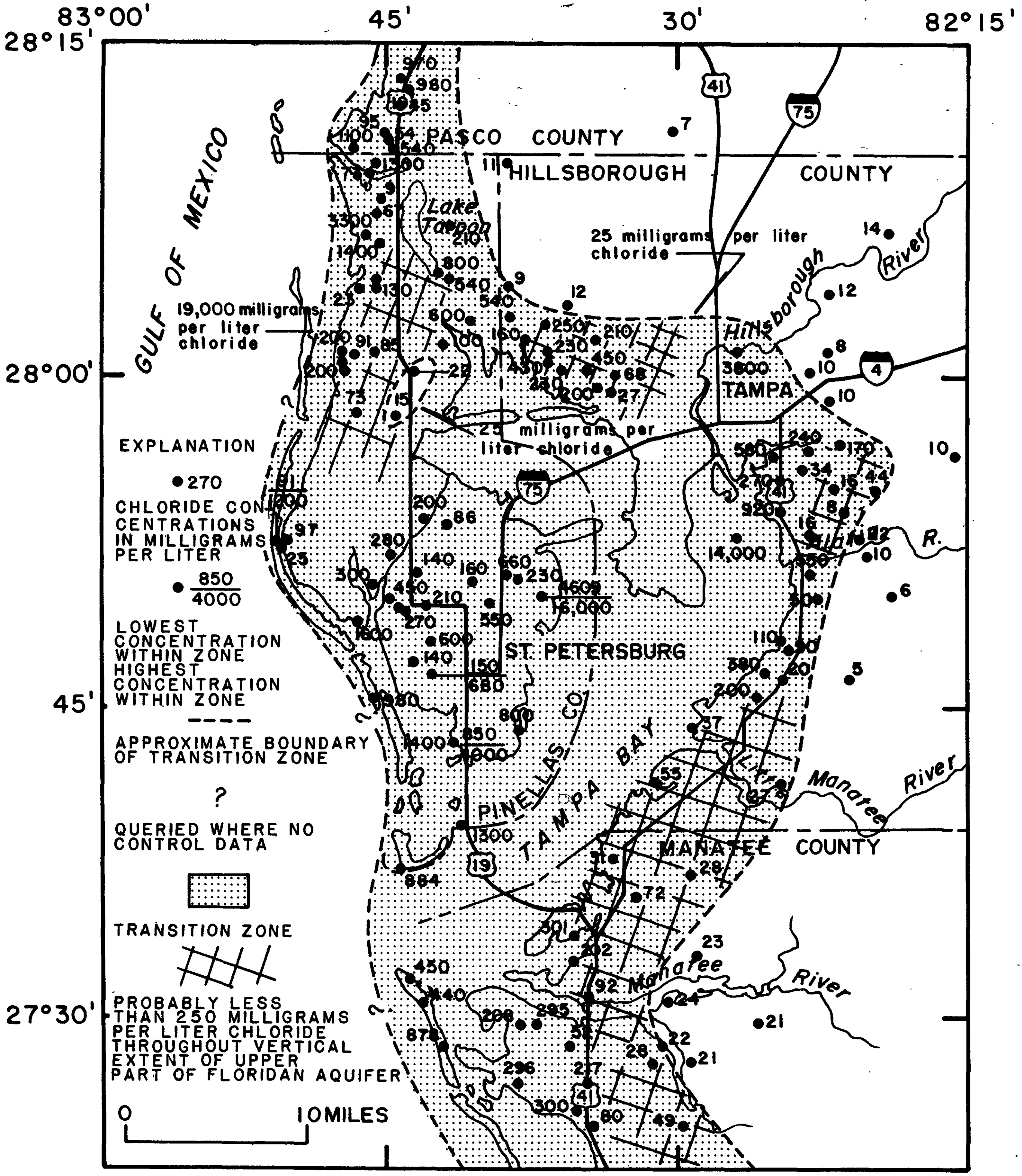
Freshwater in the coastal margins of the Tampa Bay area is bounded by a transition zone in which freshwater and saltwater are mixed in varying proportions. As considered in this report, the seaward boundary of the transition zone within the upper and lower parts of the Floridan aquifer is where all ground water in a vertical section contains chloride concentrations of 19,000 mg/L, which is equal to that of seawater. The landward boundary is considered to be where all ground water in a vertical section contains chloride concentrations equal to 25 mg/L. The highest background chloride concentration in ground water from the Floridan aquifer at locations several miles landward from Tampa Bay and the Gulf of Mexico is about 25 mg/L.

Chloride concentrations in water from selected wells open to the upper part of the Floridan aquifer are shown in figure 14. All wells are open to depths not exceeding the upper 200 feet of the aquifer. Analyses are generally for the period 1973-75 and are from publications and files of the U.S. Geological Survey.

The landward boundary of the transition zone in the upper part of the aquifer is generally less than 10 miles inland from Tampa Bay in Hillsborough and Manatee Counties. Most of Pinellas County is within the transition zone with the exception of a small area in the northeast where chloride concentration in ground water is less than 25 mg/L (fig. 14). This area is the approximate location of the "Coachman High" identified by Heath and Smith (1954) as the principal recharge area in Pinellas County. The seaward boundary of the transition zone probably underlies the Gulf of Mexico west of Pinellas and Manatee Counties.

Areas where ground water containing less than 250 mg/L chloride concentration throughout the vertical extent of the upper part of the Floridan aquifer occur in places adjacent to the landward boundary of the transition zone (fig. 14). In Pinellas County, this occurs in the north-central part of the county in the vicinity of the Clearwater and Dunedin well fields. Ground water containing less than 250 mg/L chloride concentration also occurs in Hillsborough County north and east of Tampa Bay and in Manatee County. In north Pinellas County and in Hillsborough County northeast of the city of Tampa, this condition also probably occurs, but could not be represented on figure 14 because of the absence of data.

Underlying Tampa Bay, in the vicinity of the city of Tampa, ground water having a chloride concentration of 14,000 mg/L occurs in the upper part of the aquifer (fig. 14). In Pinellas County, adjacent to the bay, ground water having a chloride concentration of 16,000 mg/L occurs (fig. 14). Both sites are



BASE FROM U.S. GEOLOGICAL SURVEY
STATE OF FLORIDA MAP 1967

Figure 14.--Chloride concentration in water from selected wells open to upper part of the Floridan aquifer.

located within the north Tampa Bay area. In the south Tampa Bay area and underlying the bay, ground water having a chloride concentration of 1,300 mg/L occurs in the upper part of the aquifer (fig. 14). These data suggest a lesser flow of fresh ground water into the transition zone in the upper part of the aquifer underlying north Tampa Bay than in south Tampa Bay.

Chloride concentration in water from selected wells open to the transmissive dolomitized sequence in the lower part of the Floridan aquifer is shown in figure 15. Most of these wells in Hillsborough and Manatee Counties are also open to the upper part of the Floridan aquifer. Therefore, chloride concentrations in water from these wells represent a blend. Because of this, the seaward and landward position of the transition zone on figure 15 may not be positioned far enough inland. Another factor affecting placement of the boundaries in Hillsborough and Manatee Counties is that wells do not fully penetrate the lower part of the aquifer.

The seaward and landward boundaries of the transition zone in the lower part of the Floridan aquifer generally underlie the coastal margins of Hillsborough and Manatee Counties. Ground water containing chloride concentrations of 19,000 mg/L or more occurs throughout Pinellas County and Tampa Bay in the lower part of the aquifer. Width of the transition zone varies from about 3 miles in north Hillsborough County to about 20 miles in south Manatee County.

Comparison of figures 14 and 15 shows that the 25 mg/L boundary in the lower part of the aquifer is generally further inland than in the upper part.

ESTIMATED IMPACT OF INJECTION

A radial flow model was used to compute time-varying pressure and velocity changes at selected locations in the Floridan aquifer caused by wastewater injection in Pinellas County. The model utilizes a finite difference method in which partial differential equations describing radial ground-water flow are solved numerically. The model was described by INTERCOMP Resource Development and Engineering, Inc. (1976).

A radial finite difference grid was superimposed on a generalized hydrogeologic section (fig. 16) representing the injection test sites. Eleven vertical blocks were used and ranged in thickness from 15 to 265 feet. All of the hydrogeologic units with their thickness shown in figure 16 were subdivided into two equally thick blocks with the exception of the injection zone, which was subdivided into three blocks. From top to bottom, the injection zone blocks were 50, 215, and 265 feet thick, respectively. Eighty-five radial blocks were used and ranged in radial length from 0.15 to 5,282 feet. From the test well to 31,612 feet or approximately 6 miles, a logarithmic expansion was used for the radial blocks, and from 31,612 feet to 158,400 feet or 30 miles, radial block sizes were all 5,282 feet in radial length.

The Carter-Tracy influence function (INTERCOMP Resource Development and Engineering, Inc., 1976) was applied at a radial distance of 30 miles in the model. This function is a device for simulating a radially infinite aquifer when only part of the aquifer is explicitly represented in a finite difference form.

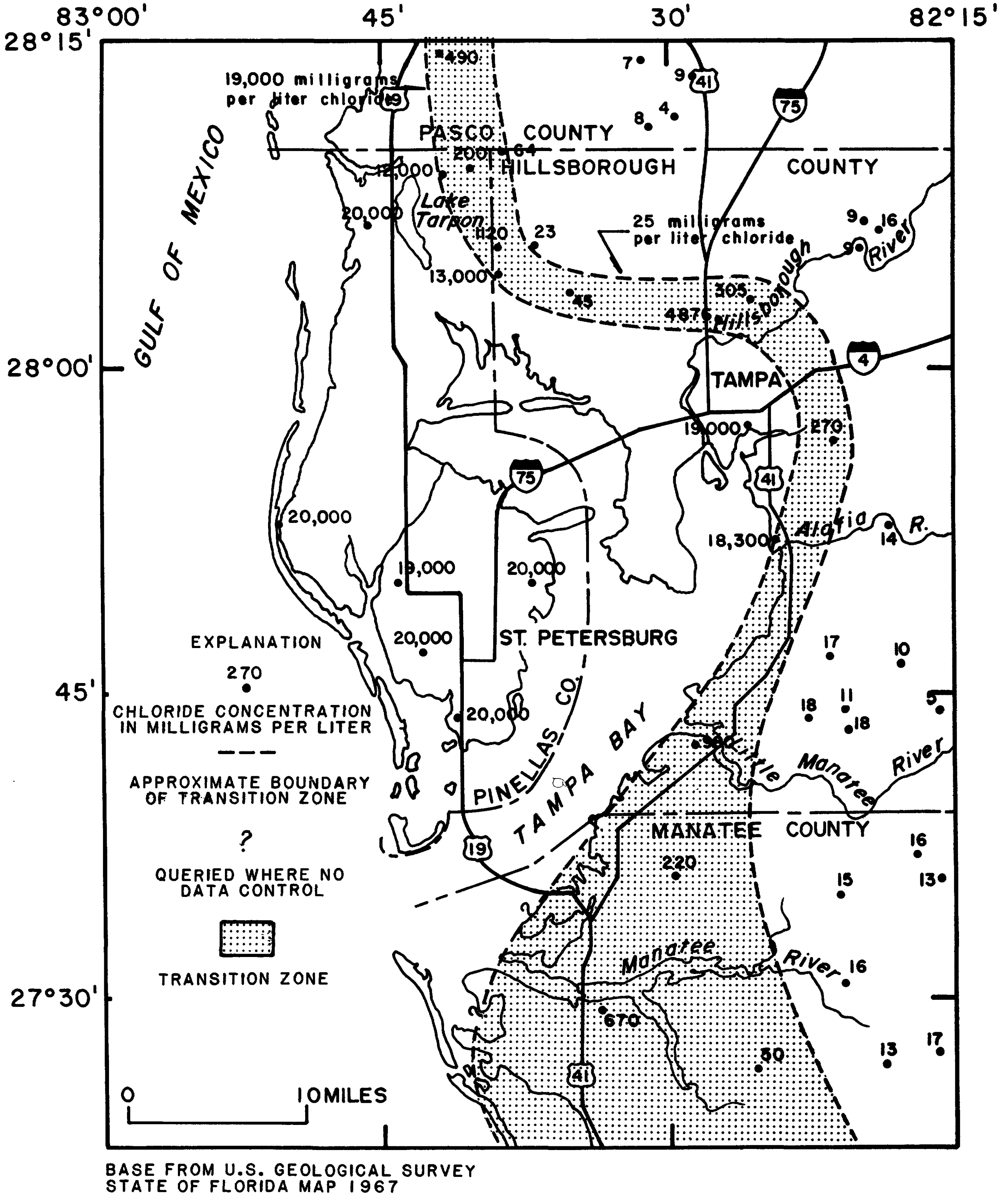


Figure 15.--Chloride concentration in water from selected wells open to lower part of the Floridan aquifer.

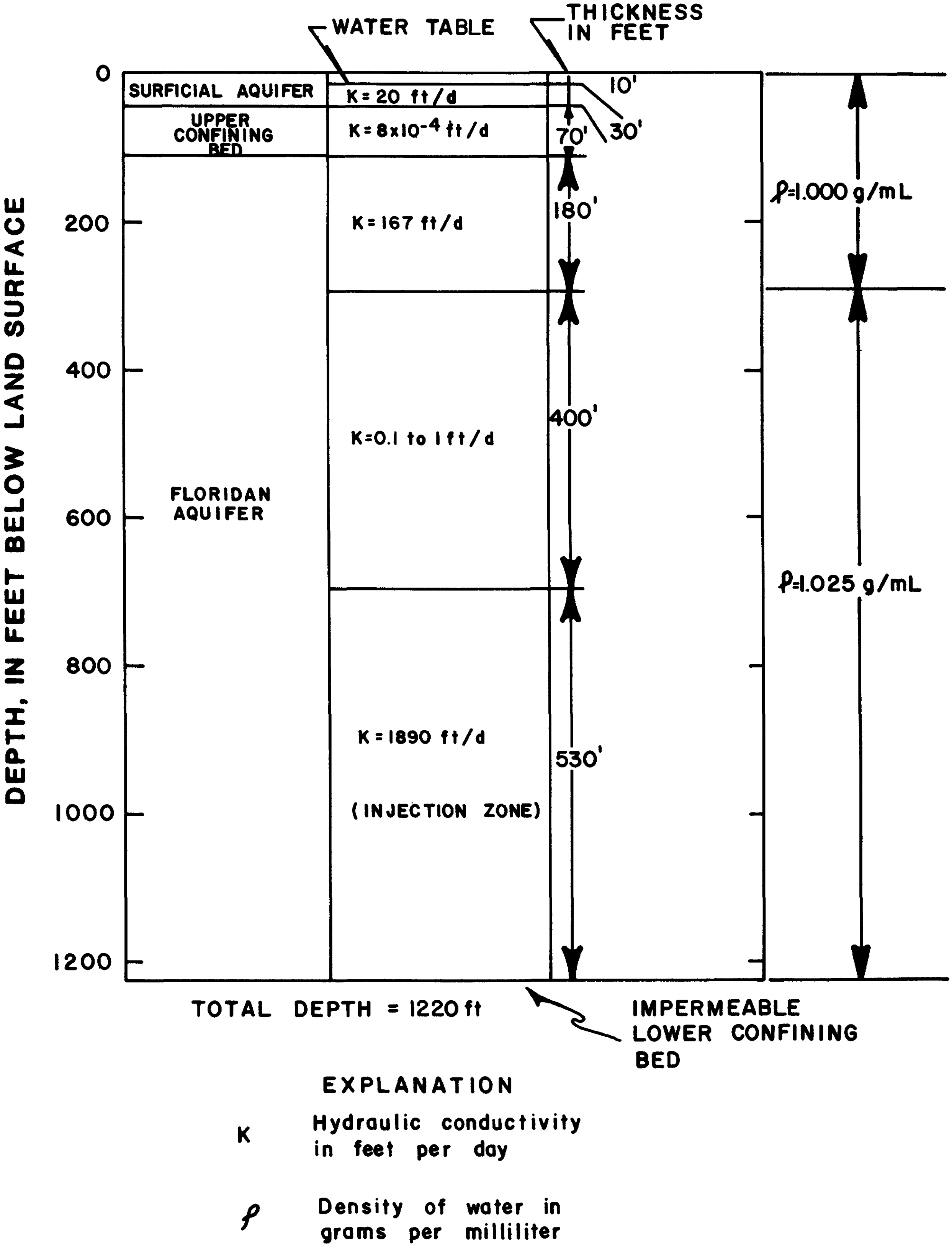


Figure 16.--Generalized hydrogeologic section of injection sites used to construct digital model.

Hydraulic characteristics used in the model were chosen to be representative of the injection test sites. For the most part, these characteristics were interpreted from data collected at the test sites (Hickey, 1977; Hickey, 1979; Hickey and Barr, 1979; Hickey and Spechler, 1979). The vertical distribution of hydraulic conductivity and water density are shown in figure 16. Rock compressibility in the model was 1.32 x 10^{-5} lb/in^2 and represents an estimated average of all of the rocks comprising the modeled section. Porosity in the model was 0.30 with the exception of the upper confining bed and the injection zone, which were 0.40 and 0.20, respectively. The injection zone porosity is smaller than the other rocks in the column because it is composed principally of fractures in a dense or low-porosity dolomite. Porosity of the other parts of the rock column is composed principally of voids between the grains that comprise the rocks along with some solution features that occur mainly in the upper part of the aquifer.

Major assumptions in the model analysis are as follows:

1. Hydrostatic conditions prevail in the Floridan aquifer at the inception of injection.
2. Hydrogeologic conditions at the injection sites in Pinellas County are radially extensive.
3. Injected water has the same density as native formation water.

The first assumption restricts model computations to effects caused solely by injection. Model results would have to be added to an existing flow system before the integrated behavior of the system could be ascertained. Because the exact nature of the future behavior of the freshwater-saltwater flow system in the Tampa Bay area to stresses other than injection is unknown, this cannot be accomplished. Model results, however, can be compared regionally to define areas where the impact of injection will be greatest. This information, coupled with knowledge of existing and planned areas of major ground-water withdrawals landward or within the saltwater-freshwater transition zone, can be used to develop an observation-well network that considers the probable integrated behavior of the system. As a means of gaining some quantitative insight into the integrated impact of injection, model results in this study are added to hydrologic conditions existing in May 1979 at a selected location.

The second assumption is the most restrictive in the model analysis. Hydrogeologic conditions in the Floridan aquifer are not uniform, particularly in the lower part of the aquifer. To test the effects of the assumption upon computed velocity, the model was run using two transmissivity distributions for the lower part. One analysis considered the high transmissivity found in Pinellas County to be radially extensive. The other analysis considered the transmissivity to be a magnitude smaller at a distance of about 12.5 miles from the test well and from there on to be radially extensive. The smaller transmissivity is representative of west-central Hillsborough County.

Results of the two model computations indicate that using a uniformly high transmissivity causes velocity to be greater in the lower part of the aquifer in comparison to the case where transmissivity becomes smaller at a distance. Therefore, the assumption of radially extensive high transmissivity provides computed velocities that overestimate the impact of injection in the lower part. Thus, the assumption of radially extensive hydrogeologic conditions is not as restrictive as it would first appear, and the computed velocities can be considered as high values in the lower part of the aquifer.

The third assumption was also tested to determine its effect on computed pressure and velocity changes regionally. Two model runs were made injecting 20 Mgal/d. One run injected water that was less dense than formation water; the other injected water that had the same density as formation water. Major difference in computed pressure and velocity changes between the two model runs was within the zone where less dense injected water was mixed with the formation water. At points selected for regional impact computations in this study, that is more than 6 miles from the injection sites and beyond the zone of mixing, pressure and velocity changes calculated in both runs were similar. Again, the model assumption is not as restrictive as it would first appear.

Computation Procedures

Transient model analyses were used to compute, at selected regional locations, pressure and velocity changes resulting from 20 years of projected wastewater injection at six sites in Pinellas County. The effect of injection caused by each site was computed separately and then all results were added at the selected locations. Computed pressure changes were added algebraicly and velocities were added vectorially.

Locations were selected for model computations in the following manner. In the upper part of the aquifer, several sites were chosen as potential candidates for pressure and velocity computations on the coastal margins of Hillsborough and Manatee Counties and in Pinellas County where all ground water vertically in the upper part of the aquifer probably contains chloride concentrations less than 250 mg/L (fig. 17). In the lower part of the aquifer, several sites were selected near the seaward boundary of the transition zone (fig. 18). All sites chosen as potential candidates for computations were identified generally on the basis of closeness to the injection wells. Then, the radius from the center of injection to each chosen candidate site was calculated (center of injection is analogous to center of gravity). Two sites, one in each part of the aquifer having the smallest radius to the center of injection, were selected as the locations for model computations. These selected locations, site 2 in the upper part and site 4 in the lower part of the aquifer, represent the sites from among the initially chosen candidate sites at which the greatest impact of injection would occur.

Injection rates assumed in the model analyses were as follows: 20 Mgal/d at South Cross Bayou; and, 4 Mgal/d each at McKay Creek, southwest St. Petersburg, Albert Whitted, northeast St. Petersburg, and northwest St. Petersburg. Injection rates are the projected maximum for each site expected by the city of St. Petersburg and Pinellas County. Maximum rates may occur once all sites become operational; however, injection at each site will not start at the same time. For the model, however, injection at each site is assumed to start at the same time and to continue for a period of 20 years. Modeling in this manner causes computed pressure and velocity changes to occur earlier and at larger magnitudes than would occur when the injection wells become operational in Pinellas County.

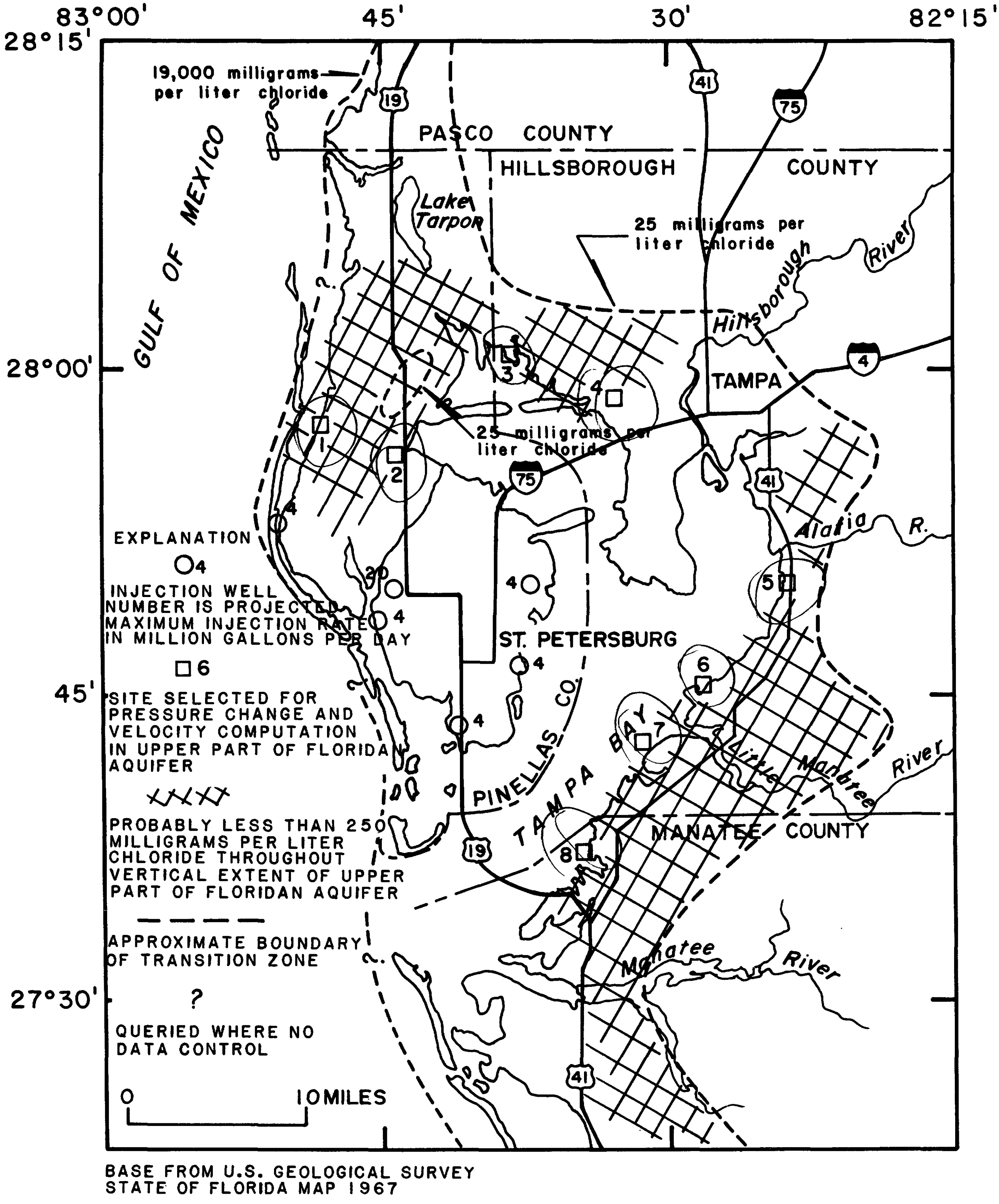


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Figure 17.--Location of sites selected as potential candidates for pressure change and velocity computations, upper part of the Floridan aquifer.

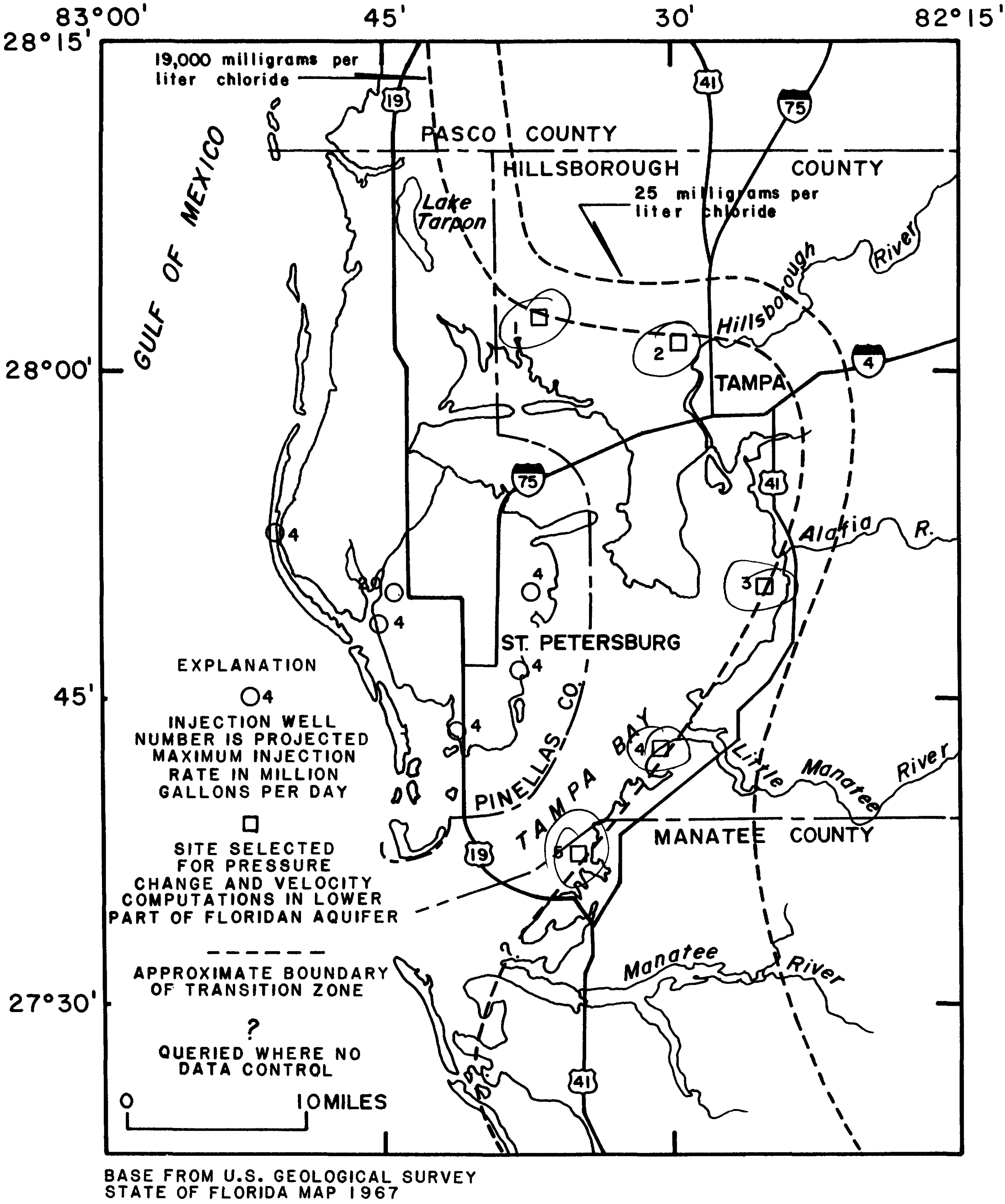

Figure 18.--Location of sites selected as potential candidates for pressure change and velocity computations, lower part of the Floridan aquifer.

Two model analyses were run using different hydraulic conductivities for the semiconfining beds between the upper and lower parts of the Floridan aquifer. In the first analysis, the semiconfining beds were assumed to have a vertical hydraulic conductivity of 1 ft/d for the purpose of computing maximum impact in the upper part of the aquifer. In the second analysis, vertical hydraulic conductivity was assumed to be 0.1 ft/d for the purpose of computing maximum impact in the lower part of the aquifer. Computed maximum impact at the locations selected in the upper and lower parts of the aquifer are presented, in part, as graphs showing pressure change versus time and velocity versus time.

Results

Figure 19 shows computed pressure changes and velocity at site 2 in the upper part of the Floridan aquifer. These results represent maximum impact computations using 1 ft/d vertical hydraulic conductivity for the semiconfining beds between the upper and lower parts of the aquifer. Site 2 is closest to the center of injection of all the potential computational sites shown in figure 17.

The pressure buildup at site 2 (fig. 19), in the upper part of the aquifer after 20 years (7,300 days) of injection, is 1.46 lb/in^2 or about 3.4 feet of freshwater head change. Computed radial ground-water velocity did not exceed 0.02 ft/d with an azimuth of about 33°.

The May 1979 potentiometric map of the Floridan aquifer (Wolansky and others, 1979) indicates a head of about 5 feet in the vicinity of site 2. Using the May 1979 head as initial conditions and using superposition, after 20 years of injection, the head at site 2 would be about 8 feet.

The May 1979 potentiometric map also suggests a head gradient at site 2 of about 2.4×10^{-4} ft/ft directed along an azimuth of about 90°. Assuming the same parameters as the digital model, the May 1979 ground-water velocity at site 2 was about 0.13 ft/d. Using the May 1979 velocity and direction as initial conditions, after 20 years of injection, the ground-water velocity at site 2 would be about 0.14 ft/d directed along an azimuth of about 84°.

Figure 20 shows computed pressure changes and velocity at site 4 in the lower part of the Floridan aquifer. These results represent maximum impact computations using 0.1 ft/d hydraulic conductivity for the semiconfining beds between the upper and lower parts of the aquifer. Site 4 is closest to the center of injection of all the potential computational sites shown in figure 18.

The largest pressure buildup at site 4 (fig. 20) in the lower part of the aquifer is 1.26 lb/in^2, or about 2.9 feet of head change. Computed radial velocity did not exceed 0.1 ft/d and had an azimuth of about 119°.

Water levels used to construct the May 1979 potentiometric map for the coastal margin of Hillsborough County are from wells open to the upper part of the aquifer. Thus, the map is not representative of ground-water conditions in the lower part of the aquifer in the vicinity of site 4. Therefore, computations using the map to gain some quantitative insight into the integrated impact of injection in the lower part of the aquifer cannot be performed.

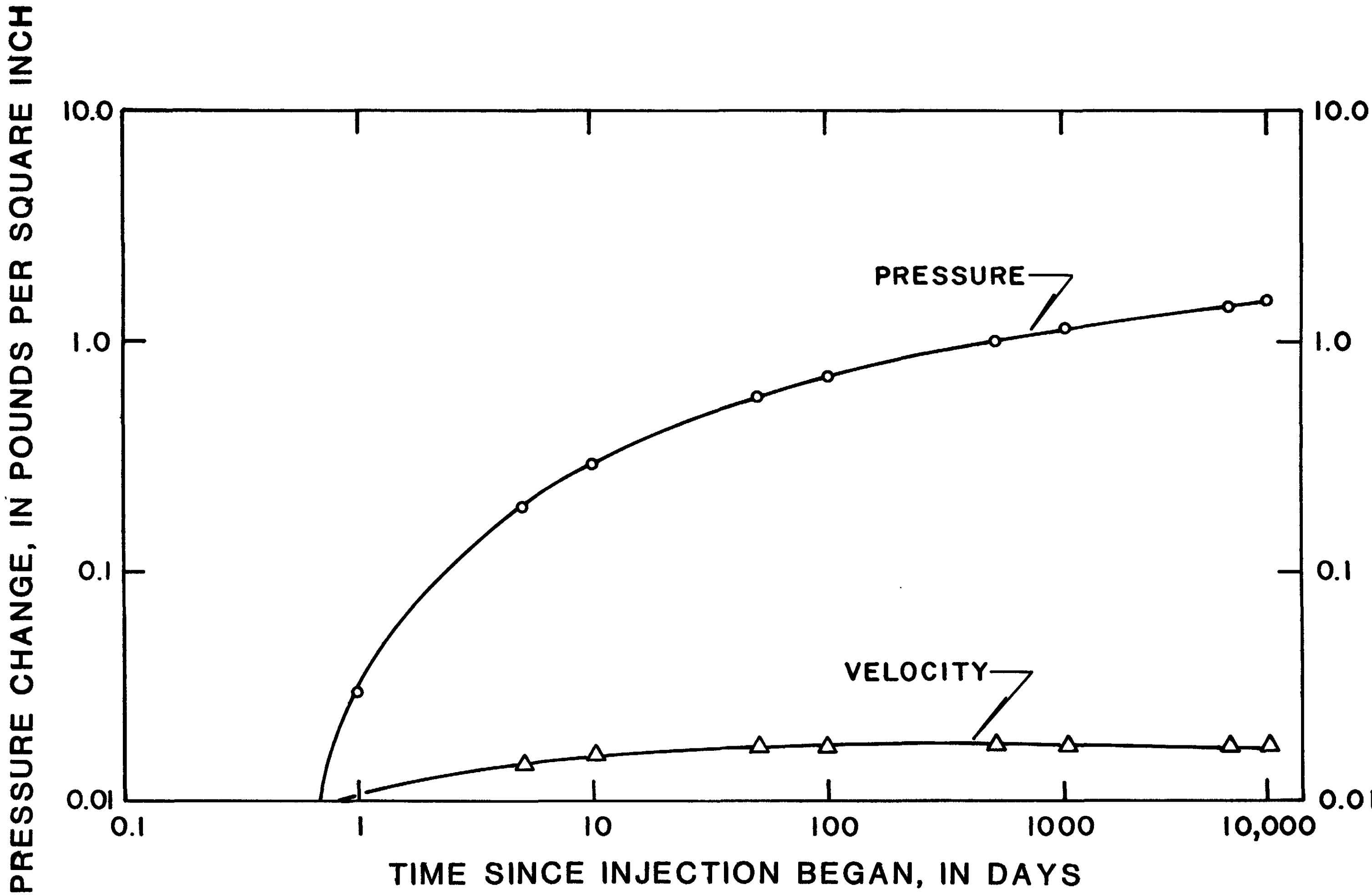

Figure 19.--Computed pressure change and velocity at site 2, upper part of the Floridan aquifer.

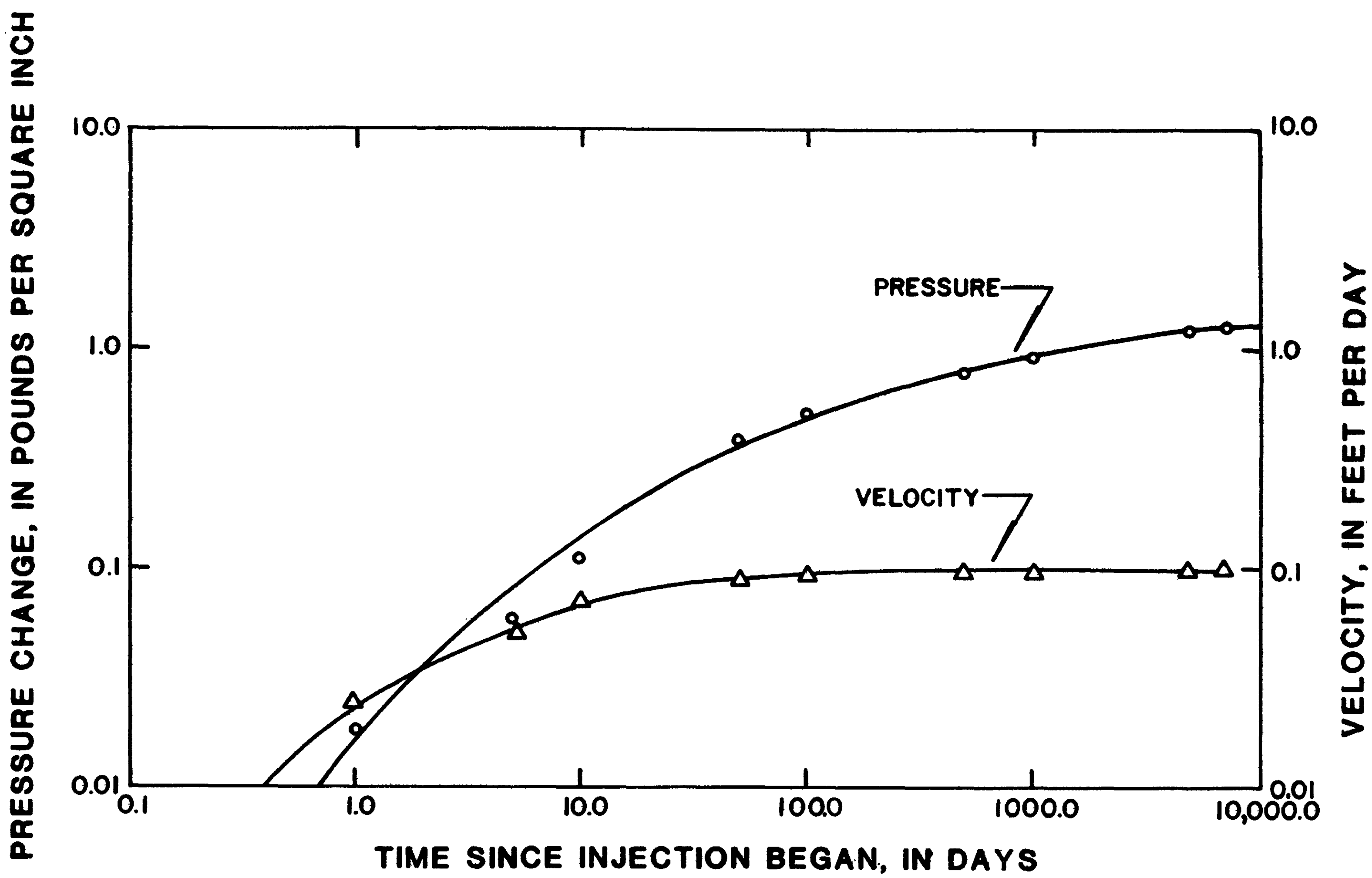

Figure 20.--Computed pressure change and velocity at site 4, lower part of the Floridan aquifer.

Discussion

The computational activity and results represent an effort to bring together the principal hydrogeologic parameters that affect the regional impact of wastewater injection. The computational method used was the most advanced one available. Nevertheless, certain assumptions associated with use of the model and with present knowledge of the hydrogeology of the area introduces uncertainty into computed results. For example, hydraulic parameters of the Floridan aquifer are not radially extensive, and evidence supporting the regional presence of semiconfining beds separating the upper and lower part of the aquifer is sparse.

Model results can be used to obtain a "worst case" sense of the magnitude of regional changes in pressure and ground-water velocity that could be anticipated if the proposed wastewater injection sites are used as planned. By assuming very high and radially extensive transmissivity in the lower part of the aquifer and the presence of semiconfining beds separating the upper and lower parts of the aquifer, effects of injection are more regionally extensive and more representative of "worst case" changes.

Even considering the "worst case," it appears that the regional impact of injection on freshwater resources of the Tampa Bay area will, in general, be small. However, at least three regional locations should be monitored for detection of the effects of subsurface injection because of the computational simplifications and assumptions, sparse hydrogeologic data, and lack of knowledge about the precise manner in which saltwater and freshwater flow systems are interacting.

PROPOSED REGIONAL WELL MONITORING FOR SUBSURFACE INJECTION

Proposed regional well monitoring locations are as follows:

1. In the vicinity of the intersection of highways U.S. 19 and U.S. 60, Pinellas County;
2. In the vicinity of Sun City, Hillsborough County; and
3. In the vicinity of the intersection of Sheldon Road and Gunn Highway, Hillsborough County.

The first proposed location is in the vicinity of site 2 in figure 17, which is the location of maximum computed impact in the upper part of the aquifer. The second proposed location is east of site 4 in figure 18, which is the site of maximum computed impact in the lower part of the aquifer. The third proposed location is just northwest of site 1 in figure 18 and lies between the municipal well fields in Hillsborough and Pinellas Counties and the injection sites.

Two monitoring wells at each location are proposed: one well open to about the upper 200 feet of the Floridan aquifer to monitor the upper part of the aquifer and the other well open to the dolomitized sequence in the lower 500 feet of the aquifer to monitor the injection zone. Figures 5 and 6 can be used to determine the approximate depths of these two zones at the sites of the proposed monitoring wells. During the drilling of these wells, lithologic, water-quality, hydraulic, and borehole geophysical data should be collected for the purpose of describing in detail the hydrogeologic setting of the wells.

All of the proposed monitoring wells will probably be open to the saltwater-freshwater transition zone with the exception of the well open to the lower part of the aquifer in the vicinity of the intersection of U.S. 19 and U.S. 60. Because of this, water-quality changes caused by the landward movement of saltwater should be detectable and apparent.

The monitoring program should include the collection of water-level and water-quality data to determine any changes in the aquifer as the result of injection. A continuous water-level recorder is recommended for each well. The chemical characteristics of water from each well should be determined four times a year for chloride, sulfate, dissolved solids, specific conductance, density, alkalinity, pH, and temperature, parameters that are most likely to indicate changes due to the injection of wastewater. After a few years, if interpretation of the data warrants, water-quality sampling could be reduced to two times a year.

All proposed monitoring locations will be affected by present and projected increases in freshwater pumpage. The U.S. 19-U.S. 60 site is just south of the Clearwater well field. The Sun City site is adjacent to an area of intense agricultural irrigation withdrawals. The Sheldon Road-Gunn Highway site is south of the principal municipal well fields serving the Tampa Bay area. Data collected from the wells at the proposed monitoring locations will represent the integrated impact of subsurface wastewater injection and fresh ground-water supply development.

SUMMARY

Hydrogeology of the Floridan aquifer in the Tampa Bay area and computations of regional impact of wastewater injection were studied to identify locations for regional well monitoring for subsurface injection.

Six proposed injection sites are located in Pinellas County, including the city of St. Petersburg. Projected maximum injection rate, if all sites become operational, will be about 40 Mgal/d.

The Floridan aquifer is composed of rocks ranging from lower Miocene to middle Eocene and comprises the following formations from youngest to oldest: Tampa Limestone, Suwannee Limestone, Ocala Limestone, and Avon Park Limestone. The proposed receiving zone at the wastewater injection sites is within the lower part of the Floridan aquifer in a persistently dolomitized section of the Avon Park Limestone.

At the proposed injection sites, semiconfining beds lie above the injection zone. Sparse data suggest that these beds occur regionally.

Overlying the Floridan aquifer are clays, marls, and limestones of the Hawthorn Formation that comprise the upper confining bed of the Floridan aquifer. Underlying the aquifer are the limestones and dolomites with intergranular gypsum of the Lake City Formation that comprise the lower confining bed of the aquifer.

Most of the coastal margins of Hillsborough and Manatee Counties and nearly all of Pinellas County are within the saltwater-freshwater transition zone in the upper part of the Floridan aquifer. In the lower part of the aquifer, the transition zone underlies the coastal margins of Hillsborough and Manatee Counties and saltwater underlies Pinellas County and Tampa Bay.

Computations of the regional impact of injection suggests that pressure and velocity changes will be small, generally not exceeding 3 feet of head change and 0.1 ft/d of velocity change. Because of uncertainties in the computational results, however, three locations are proposed for monitoring the regional impact of injection. They are in the vicinity of the intersection of highways U.S. 19 and U.S. 60 in Pinellas County, Sun City in Hillsborough County, and the intersection of Sheldon Road and Gunn Highway in Hillsborough County.

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