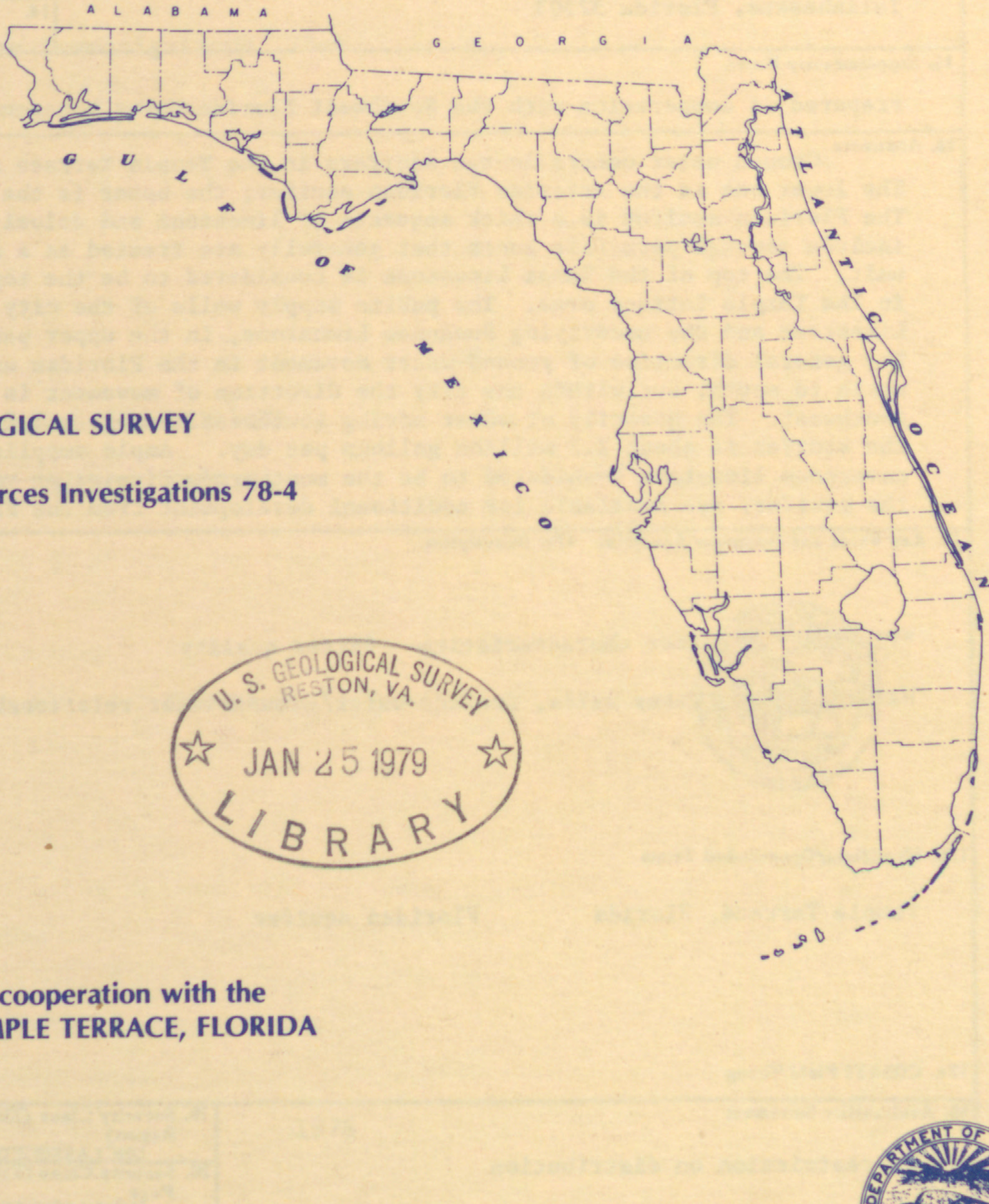
HYDROGEOLOGIC FACTORS AFFECTING THE AVAILABILITY AND QUALITY OF GROUND WATER IN THE TEMPLE TERRACE AREA, HILLSBOROUGH COUNTY, FLORIDA



U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 78-4

Prepared in cooperation with the
CITY of TEMPLE TERRACE, FLORIDA

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle HYDROGEOLOGIC FACTORS AFFECTING THE AVAILABILITY AND QUALITY OF GROUND WATER IN THE TEMPLE TERRACE AREA, HILLSBOROUGH COUNTY, FLORIDA			5. Report Date October 1978
			6.
7. Author(s) J.W.Stewart, C.L.Goetz, and L.R.Mills			8. Performing Organization Rept. No. USGS WRI 78-4
9. Performing Organization Name and Address U.S.Geological Survey, Water Resources Division 325 John Knox Road, F-240 Tallahassee, Florida 32303			10. Project/Task/Work Unit No.
			11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S.Geological Survey, Water Resources Division 325 John Knox Road, F-240 Tallahassee, Florida 32303			13. Type of Report & Period Covered
			14.

15. Supplementary Notes

Prepared in cooperation with the Southwest Florida Water Management District

16. Abstracts

Ground water occurs in two aquifers in the Temple Terrace area. The lower one is the artesian Floridan aquifer; the upper is the water-table aquifer. The Floridan aquifer is a thick sequence of limestone and dolomite layers which include several permeable zones that generally are treated as a single hydrologic unit. The top of the Tampa Limestone is considered to be the top of the Floridan in the Temple Terrace area. The public supply wells of the city tap the Tampa Limestone and the underlying Suwannee Limestone, in the upper part of the Floridan. The general direction of ground-water movement in the Floridan aquifer is from north to south, but within the city the direction of movement is from northeast to southwest. The quantity of water moving southwest through a 1.8 mile section of the aquifer is about 2.7 million gallons per day. Ample supplies of water in a cavernous limestone considered to be the most productive water-yielding zone in the aquifer, are available for additional development from the Floridan aquifer.

17. Key Words and Document Analysis. 17a. Descriptors

*Florida *Aquifer characteristics *Water quality

Water sources, Water wells, Surface-water/Ground-water relationships

17b. Identifiers/Open-Ended Terms

Temple Terrace, Florida Floridan aquifer

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution	UNCLASSIFIED	44
	20. Security Class (This Page) UNCLASSIFIED	22. Price

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1978

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For use of those readers who may prefer metric units rather than U.S. customary units, the conversion factors for the terms used in this report are listed below:

U.S. customary unit	Multiply by	Metric units
	Length	
inches (in)	2.54	centimeters (cm)
inches (in)	25.4	millimeters (mm)
feet (ft)	0.304	meters (m)
miles (mi)	1.609	kilometers (km)
	Area	
square miles (mi^2)	2.590	square kilometers (km^2)
	Flow	
cubic feet per second (ft^3/s)	.02832	cubic meters per second (m^3/s)
gallons per minute (gal/min)	.06309	liters per second (L/s)
gallons per day (gal/d)	3.785	liters per day (L/d)
million gallons per day (Mgal/d)	.003785	cubic meters per day (m^3/d)
	Gradient	
feet per mile (ft/mi)	.1894	meters per kilometer (m/km)
	Hydraulic Conductivity	
feet per day (ft/d)	.3048	meters per day (m/d)
	Transmissivity	
square feet per day (ft^2/d)	.09290	square meters per day (m^2/d)
	Specific Capacity	
gallons per minute per foot of drawdown [(gal/min)/ft]	.207	liters per second per meter [(L/s)/m]

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By

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ABSTRACT

Ground water occurs in two aquifers in the Temple Terrace area. The lower one is the artesian Floridan aquifer; the upper is the water-table aquifer.

The Floridan aquifer is a thick sequence of limestone and dolomite layers which includes several permeable zones that generally are treated as a single hydrologic unit. The top of the Tampa Limestone is considered to be the top of the Floridan aquifer in the Temple Terrace area. There, the top of the Tampa Limestone generally ranged from 20 feet above mean sea level to 60 feet below. The public supply wells of the city of Temple Terrace tap the Tampa Limestone and the underlying Suwannee Limestone, in the upper part of the Floridan aquifer. The transmissivity of the Floridan aquifer is estimated to be about 1.3×10^5 square feet per day and the storage coefficient to be about 3.4×10^{-4} on the average. The general direction of ground-water movement in the Floridan aquifer is from north to south but within the city the direction of movement is from northeast to southwest. The quantity of water moving southwest through a 1.8-mile-wide section of the aquifer is about 2.7 million gallons per day. Ample supplies of water are available for additional development from the Floridan in the Temple Terrace area.

The water-table aquifer consists of fine to medium sand, sandy clay, clayey sand, and clay. The thickness of the water-table aquifer generally ranges from 20 to 80 feet. The vertical hydraulic conductivity of the material making up the water-table aquifer ranges from 5.2×10^{-5} to 8.4 feet per day, and the horizontal hydraulic conductivity is about 13 feet per day. The aquifer is not used as a source of water for public supplies.

Coliform bacteria indicate degradation of water quality in the Floridan aquifer at three of the city wells. The specific source of the coliform bacteria in water from these three wells was not determined; however, disposal of sewage by septic tank systems introduces large quantities of coliform bacteria into the surficial sediments and into the water-table aquifer. High concentrations of these organisms also are found in surface waters, including sinkholes, in the Temple Terrace area. Colored water has also degraded the quality of the water supplies from these three wells. The source of the color is surface water which enters the Floridan aquifer and moves through solution channels in the interval between 120 and 180 feet below land surface, in a cavernous limestone considered to be the most productive water-yielding zone in the aquifer.

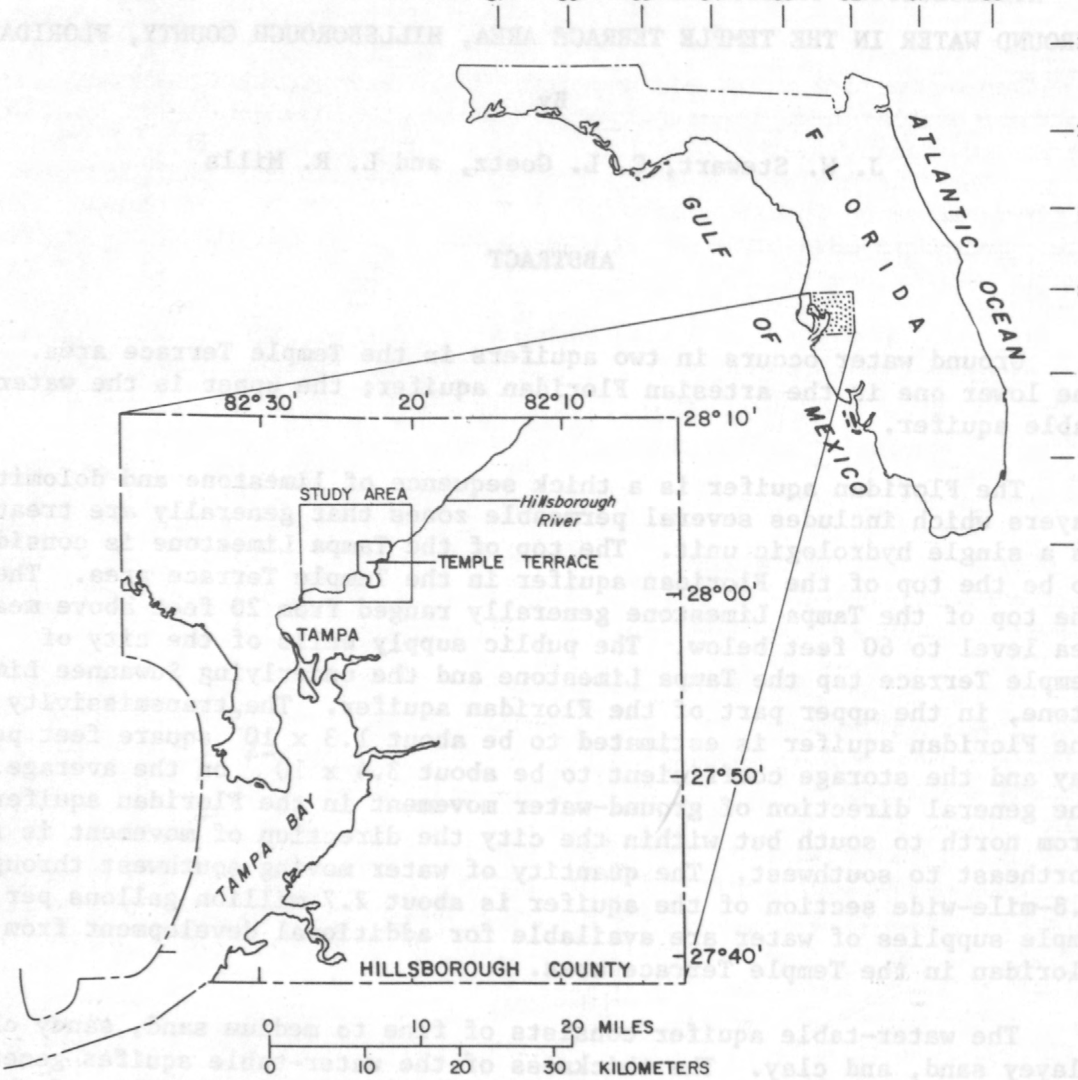


Figure 1. --Location map.

INTRODUCTION

Temple Terrace is in north-central Hillsborough County in west-central Florida (fig. 1). The city is bounded on the south and east by the Hillsborough River, and on the west and southwest by Tampa. Temple Terrace obtains its water supply from six wells that tap the Floridan aquifer and range in depth from 185 to 480 ft. The estimated amount of water pumped in 1974 from the six wells averaged 1.2 Mgal/d, for an average per capita use of 112 gal/d. Two additional wells were drilled in 1974 but were not in service as of May 1975. Water demands are expected to more than double within the next few years because of a rapid population increase in the area. Thus, Temple Terrace is faced with the task of augmenting its ground-water supply to insure enough water for its expanding population.

Water of poor bacteriological quality has been pumped from three of the city wells on several occasions. Also, water of a noticeably yellow color appeared in the homes being served by these three wells in April 1968 and again in June 1968. During 1969-74, the bacteriological quality of the water from the three wells continued to be a problem, but the color had disappeared.

Temple Terrace is situated along sharp bends of the Hillsborough River. Numerous deep sinks occur in the flood plain. The area north of the city also contains large sinks, several of which are more than 200 ft deep. The deep sinks are partly filled with trees and other debris, part of which was deposited at the time of collapse. Some of the sinks are open to the Floridan aquifer and at times may receive overflow from encompassing marshy areas or from the Hillsborough River. The marshy areas and the Hillsborough River often contain highly colored water of poor bacteriological quality.

Purpose and Scope

The purpose of this study was to provide hydrologic and geologic information to aid in developing additional water supplies and in minimizing problems with water of poor quality. To provide this information required the determination of the probable source of the poor quality water and factors influencing its movement through the aquifer.

The investigation included the following activities.

1. Collecting and analyzing information pertinent to water quality and water-quality problems in the area.

2. Making an inventory of wells and sinks.

3. Conducting an aquifer test of city supply well 2.

4. Establishing a water-quality monitoring network to assess the quality of water in the surficial aquifer and the Floridan aquifer during the period of the project.

5. Sampling of a pilot well adjacent to a city supply well by installing packers to determine if water within the section of the well open to the Floridan aquifer is stratified.

6. Conducting a dye tracer test to determine if there is a hydraulic connection between a nearby filled sinkhole and the Floridan aquifer.

7. Geophysical logging of several test and supply wells in the area to evaluate the geologic and hydrologic characteristics of the Floridan aquifer and the surficial materials.

8. Construction of potentiometric maps of surficial and Floridan aquifers.

Acknowledgments

This study was conducted by the U.S. Geological Survey in cooperation with the city of Temple Terrace. Special acknowledgment is made to William B. Nungester, former City Manager, and to Robert Fernandez, Water Superintendent, Temple Terrace. Roy Parham, Sanitary Engineer of Tomasino and Associates, consultants to the city, also provided valuable information about city wells. Property owners in the area are also due a note of thanks for allowing access to their wells at various times during the study.

GEOGRAPHY

Urban Development

Temple Terrace has grown from a small town with a population of 433 in 1950 to a city of 10,751 in 1974 (Pamela Jones, City Clerk, Temple Terrace, oral commun., 1975) and presently (1976) covers about 4 mi^2. This growth has involved a transition in land use, from predominantly agricultural in 1950 to commercial and residential in 1975.

Topography and Drainage

Temple Terrace is on a local topographic high; land-surface altitude is 90 ft along the western limits of the city, more than 80 ft along the north-northwest limits of the city, and less than 20 ft at the Hillsborough River. The average altitude of Temple Terrace is about 50 ft.

The city is bounded by the Hillsborough River on two sides of a roughly rectangular-shaped area. Both springs and sinks occur in the city.

Temple Terrace is in the Hillsborough River drainage basin. Urban drainage within the city is routed to a series of storm-water retention basins in the northwestern part of the city (fig. 2). Many of these basins are equipped with pumps to remove excess water which is discharged into the Hillsborough River by pipeline.

Hillsborough River

The Hillsborough River flows along the eastern and southern boundaries of Temple Terrace. The river drains about 320 mi^2 of the north-central part of the county. Total drainage area of the river above Tampa Dam (fig. 2) is 650 mi^2. Average annual flow at the dam for a 35-year period ending September 30, 1973, was 625 ft^3/s or 13.05 in over the entire basin.

The river meanders abruptly in the study area, apparently because of the fracture patterns in the underlying limestone. The river flows in the direction of the regional dip of the buried limestone.

Tampa obtains most of its water supply (50 Mgal/d in 1974) from the Hillsborough River at Tampa Waterworks (fig. 2), about 1.5 mi downstream from Temple Terrace. Tampa experiences a water shortage every year during dry periods, owing partly to inadequate flow of the Hillsborough River and partly to inadequate reservoir storage.

Precipitation

Daily precipitation records are available beginning in 1972 for Temple Terrace, and beginning in 1890 for Tampa. The Tampa record is available from NOAA (National Oceanic and Atmospheric Administration). The records show that the average annual rainfall in the Tampa area for the 28-year period 1948-74 was 49.32 in. About 60 percent of precipitation falls during June through early September. August is the wettest month, with about 17 percent of the annual rainfall; November is the driest month, with slightly less than 4 percent.

GROUND-WATER HYDROLOGY

Ground water occurs below the surface of the earth in the saturated zone under water-table (unconfined) conditions and under artesian (confined) conditions. Water-table conditions exist where the upper surface

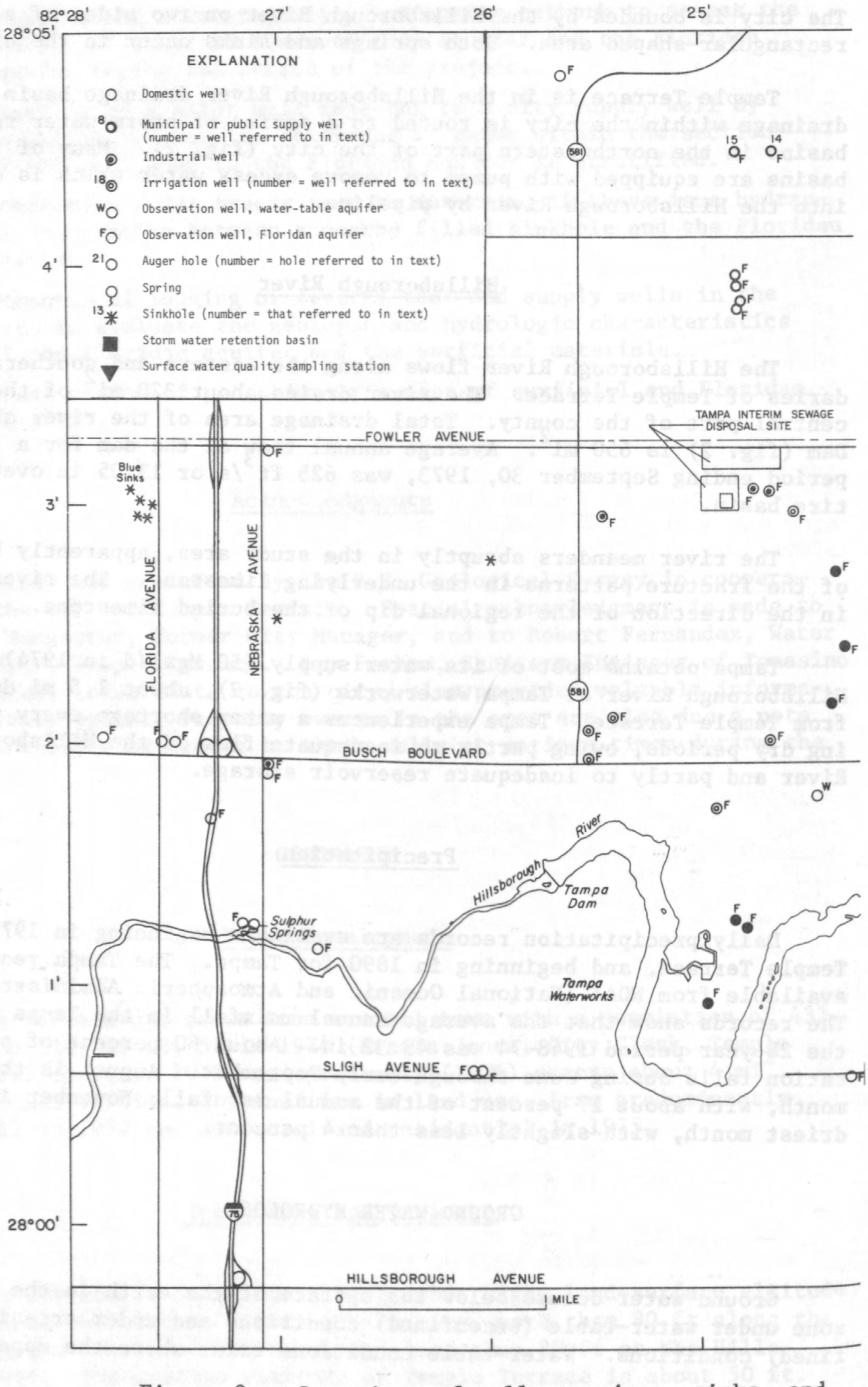
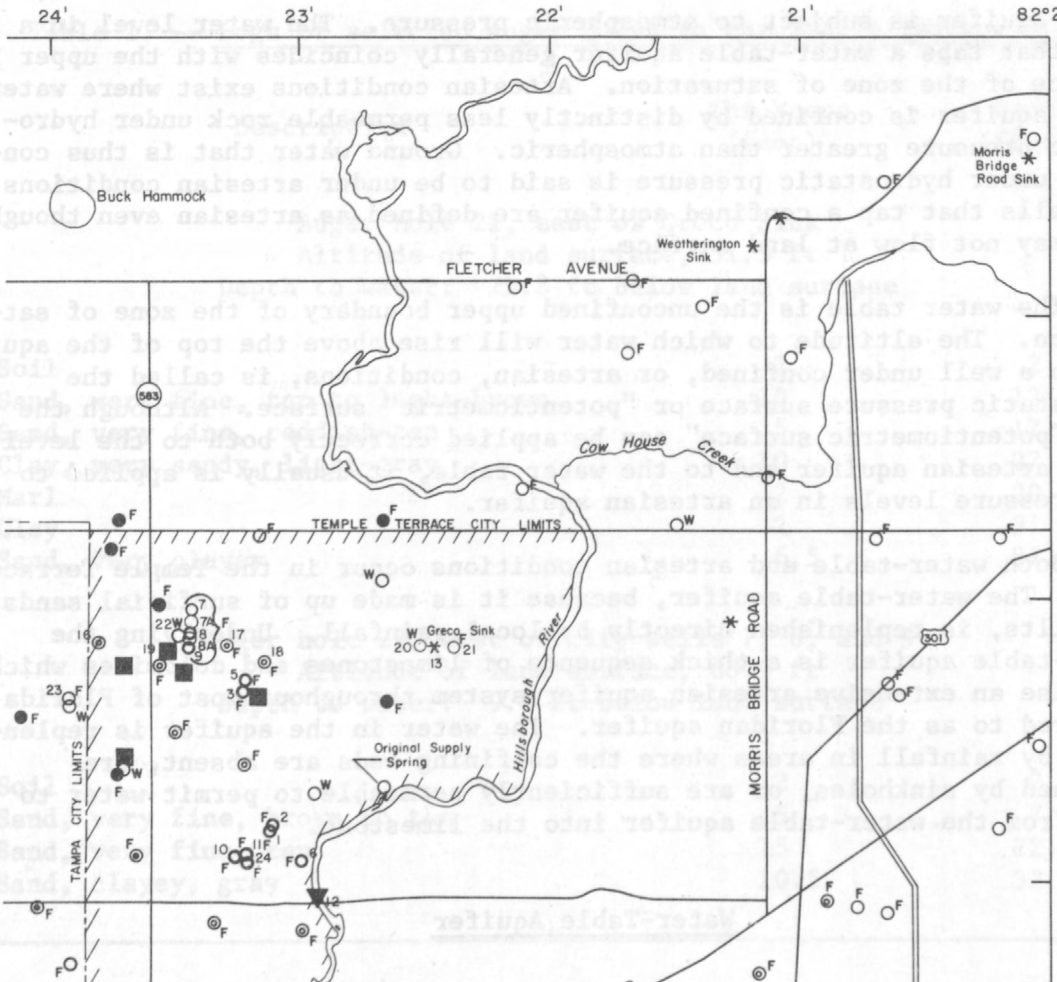


Figure 2. --Locations of wells, springs, sinks, and



storm-water retention basins, Temple Terrace area.

of an aquifer is subject to atmospheric pressure. The water level in a well that taps a water-table aquifer generally coincides with the upper surface of the zone of saturation. Artesian conditions exist where water in an aquifer is confined by distinctly less permeable rock under hydrostatic pressure greater than atmospheric. Ground water that is thus confined under hydrostatic pressure is said to be under artesian conditions and wells that tap a confined aquifer are defined as artesian even though they may not flow at land surface.

The water table is the unconfined upper boundary of the zone of saturation. The altitude to which water will rise above the top of the aquifer in a well under confined, or artesian, conditions, is called the hydrostatic pressure surface or "potentiometric" surface. Although the term "potentiometric surface" can be applied correctly both to the level in an artesian aquifer and to the water table, it usually is applied to the pressure levels in an artesian aquifer.

Both water-table and artesian conditions occur in the Temple Terrace area. The water-table aquifer, because it is made up of surficial sands and silts, is replenished directly by local rainfall. Underlying the water-table aquifer is a thick sequence of limestones and dolomites which comprise an extensive artesian aquifer system throughout most of Florida, referred to as the Floridan aquifer. The water in the aquifer is replenished by rainfall in areas where the confining beds are absent, are breached by sinkholes, or are sufficiently permeable to permit water to move from the water-table aquifer into the limestone.

Water-Table Aquifer

The near-surface deposits that make up the water-table aquifer consist of fine to medium sand, sandy clay, clayey sand, and clay, and form a sequence ranging in thickness from 20 to 80 ft. The type of material penetrated in two auger holes is shown in table 1. (See fig. 2 for locations.) In general, the sediments are thickest--greater than 20 ft--in the area west of the city (fig. 3) where the altitude of the land surface is highest. As expected, the section of sediments is thinnest--less than 20 ft thick--along the Hillsborough River. The saturated thickness of the sediments throughout the area ranges from about 20 to 70 ft.

During construction of auger holes in the area, undisturbed samples of surficial materials were collected for laboratory analyses of total porosity and hydraulic conductivity. The samples were also analyzed mechanically for particle-size distribution, sediment classification, and pore-size distribution.

The quantity of water that the surficial material will yield and the rate at which water will move through the material are governed by the porosity, effective porosity, specific yield, storage coefficient, hydraulic conductivity, and transmissivity of the aquifer. Porosity relates to

Table 1. -- Logs of selected auger holes in the Temple Terrace area

Description	Thickness (feet)	Depth (feet)
Auger hole 21, east of Greco Sink Altitude of land surface, 51.3 ft Depth to water: 25.8 ft below land surface		
Soil	2	2
Sand, very fine, tan to light-brown	10	12
Sand, very fine, reddish-tan	5	17
Clay, very sandy, light-gray	10	27
Marl	2	29
Clay	2	31
Sand, very clayey	6.5	37.5
Auger hole 22, west of city wells 7, 8, and 9 Altitude of land surface, 68.9 ft Depth to water: 9.6 ft below land surface		
Soil	2	2
Sand, very fine, brown to tan	5	7
Sand, very fine, tan	15	22
Sand, clayey, gray	10.5	32.5

Table 2. -- Laboratory analyses of core samples, Temple Terrace

Sample depth (ft)	Total porosity (percent)	Vertical hydraulic conductivity at 60°F (ft/d)
Auger hole 21, east of Greco Sink		
12.0-12.5	38.6	0.0016
17.0-17.5	34.1	.00052
22.0-22.5	28.8	.000052
32.0-32.5	45.6	.000085
37.0-37.5	--	.39
Auger hole 22, west of city wells 7, 8, and 9		
12.0-12.5	37.6	2.6
22.0-22.5	34.2	.047
32.0-32.5	35.1	.059

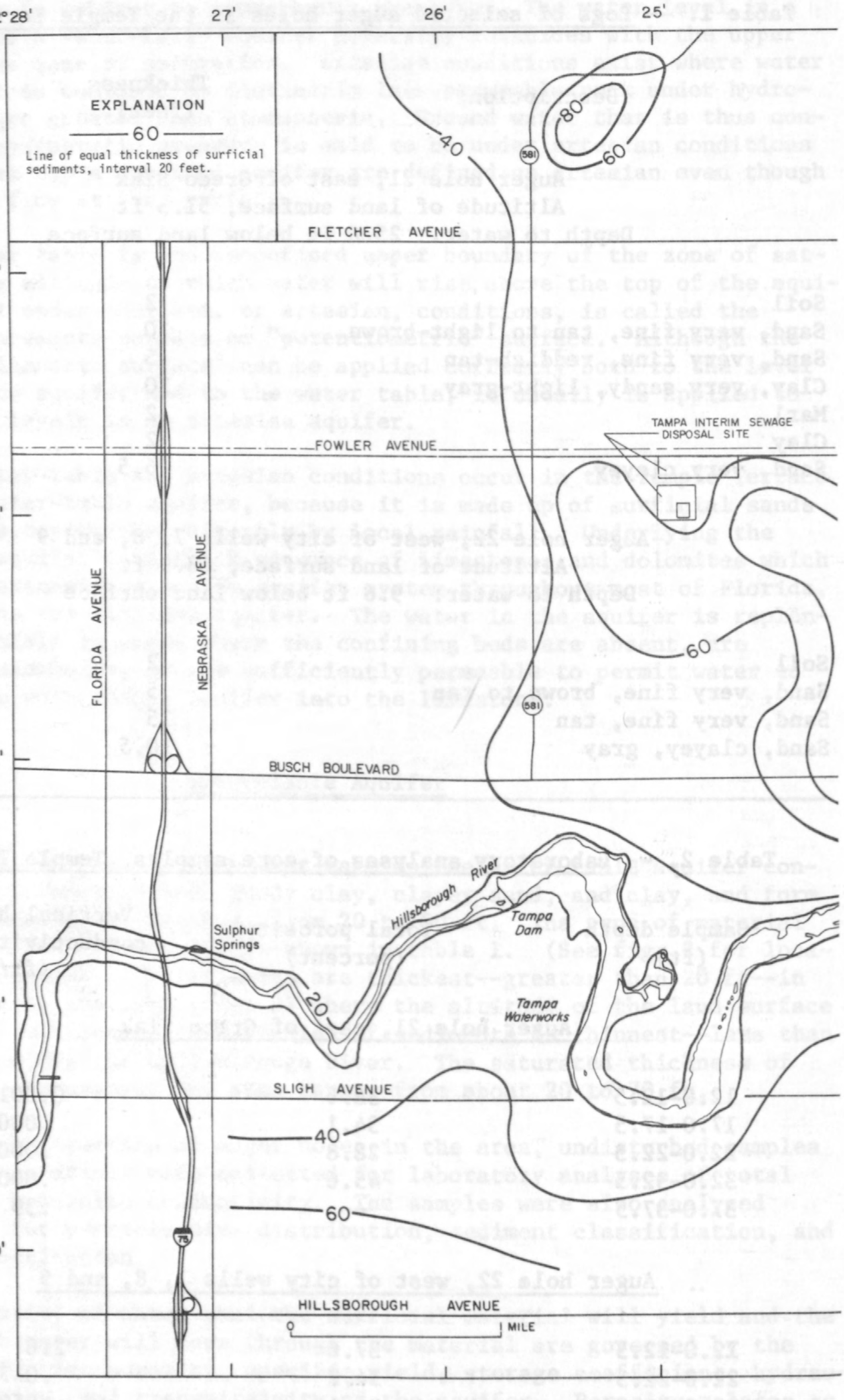
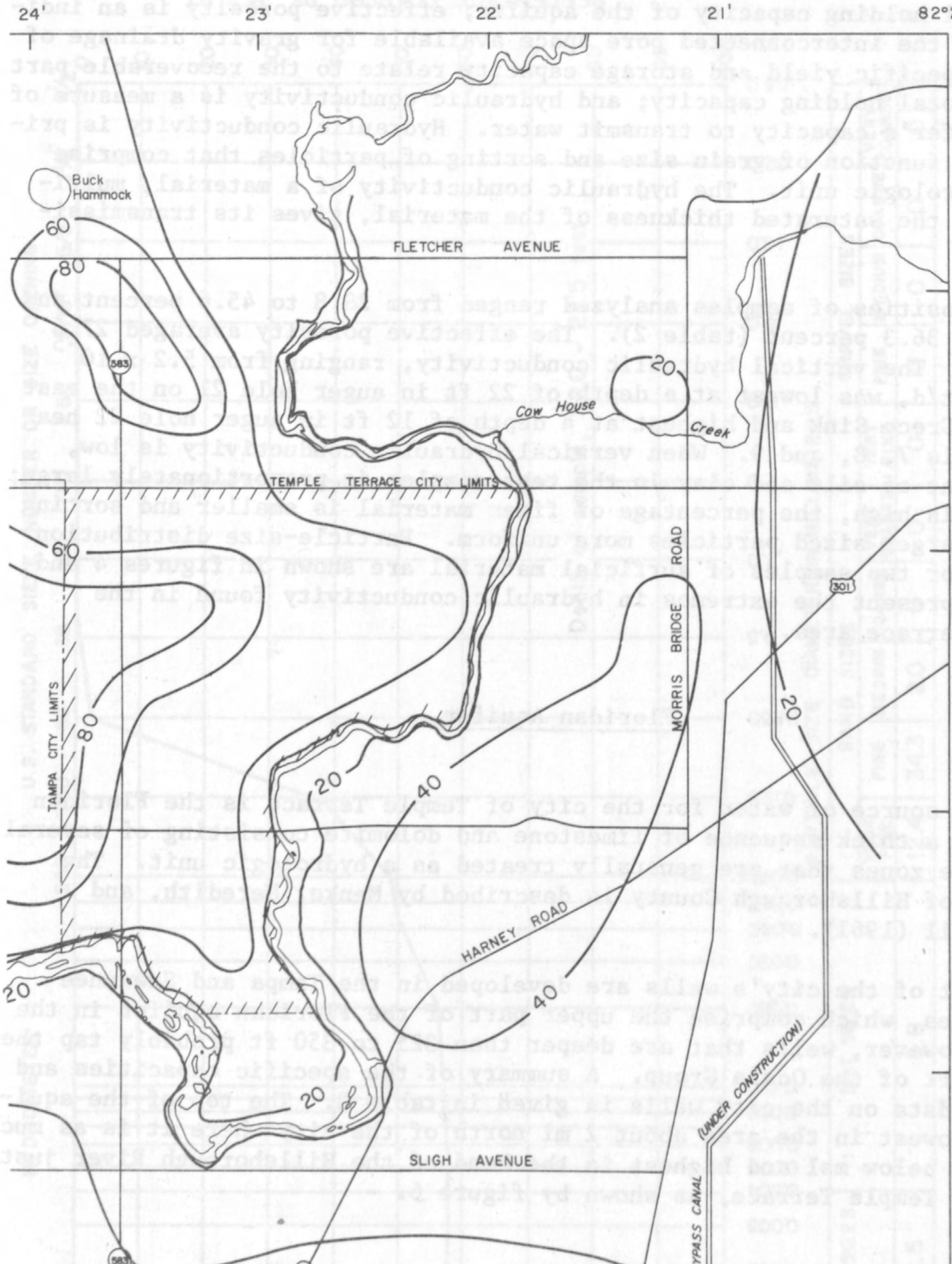


Figure 3. --Generalized thickness of



surficial sediments, Temple Terrace area.

the total holding capacity of the aquifer; effective porosity is an indicator of the interconnected pore space available for gravity drainage of fluid; specific yield and storage capacity relate to the recoverable part of the total holding capacity; and hydraulic conductivity is a measure of the aquifer's capacity to transmit water. Hydraulic conductivity is primarily a function of grain size and sorting of particles that comprise each hydrologic unit. The hydraulic conductivity of a material, multiplied by the saturated thickness of the material, gives its transmissivity.

Porosities of samples analyzed ranged from 28.8 to 45.6 percent and averaged 36.3 percent (table 2). The effective porosity averaged 27.6 percent. The vertical hydraulic conductivity, ranging from 5.2×10^{-5} to 2.6 ft/d, was lowest at a depth of 22 ft in auger hole 21 on the east side of Greco Sink and highest at a depth of 12 ft in auger hole 22 near city wells 7, 8, and 9. When vertical hydraulic conductivity is low, the amount of silt and clay in the test samples is proportionately large; when it is high, the percentage of finer material is smaller and sorting of the larger sized particles more uniform. Particle-size distribution curves for two samples of surficial material are shown in figures 4 and 5 and represent the extremes in hydraulic conductivity found in the Temple Terrace area.

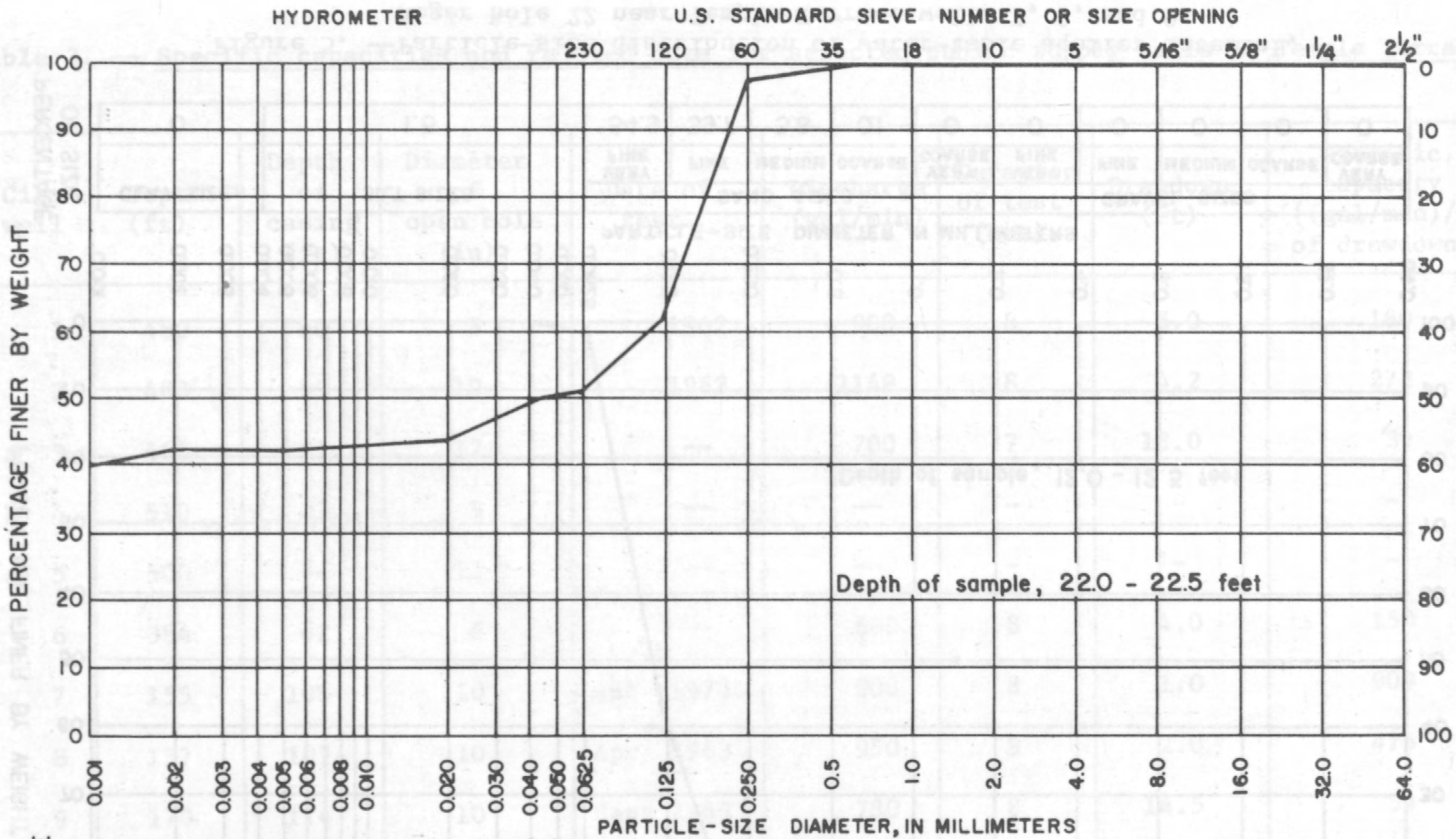
Floridan Aquifer

The source of water for the city of Temple Terrace is the Floridan aquifer, a thick sequence of limestone and dolomite consisting of several permeable zones that are generally treated as a hydrologic unit. The geology of Hillsborough County is described by Menke, Meredith, and Wetterhall (1961).

Most of the city's wells are developed in the Tampa and Suwannee Limestones, which comprise the upper part of the Floridan aquifer in the area. However, wells that are deeper than 325 to 350 ft probably tap the upper part of the Ocala Group. A summary of the specific capacities and related data on the city wells is given in table 3. The top of the aquifer is lowest in the area about 2 mi north of the city where it is as much as 60 ft below msl and highest in the bend of the Hillsborough River just south of Temple Terrace, as shown by figure 6.

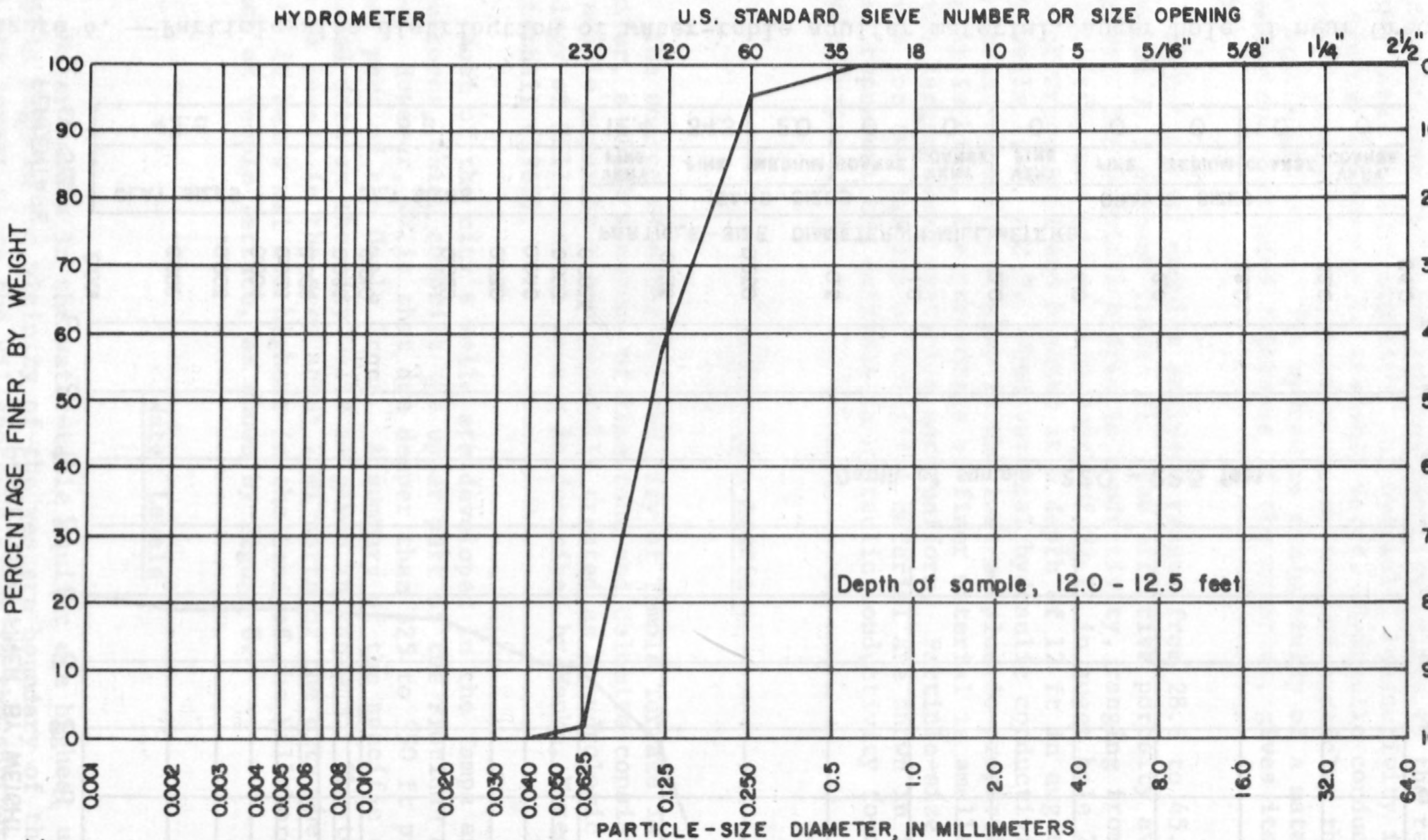
Water Levels

Water levels in the water-table aquifer are highest under the topographic high in the vicinity of the western boundary of the city limits and are lowest along the Hillsborough River in the southern and eastern parts of the city (fig. 7). On September 16, 1974, the water level in the area mapped ranged from less than 25 ft to more than 60 ft above msl.



PERCENTAGE OF SIZE	CLAY SIZES	SILT SIZES	SAND SIZES: VERY FINE	SAND SIZES: FINE	SAND SIZES: MEDIUM	SAND SIZES: COARSE	SAND SIZES: VERY COARSE	GRAVEL SIZES: VERY FINE	GRAVEL SIZES: FINE	GRAVEL SIZES: MEDIUM	GRAVEL SIZES: COARSE	GRAVEL SIZES: VERY COARSE
	42.5	8.8	12.4	34.3	2.0	0	0	0	0	0	0	0

Figure 4. --Particle-size distribution of water-table aquifer material, Auger hole 21 near Greco sink.



PERCENTAGE OF SIZE	CLAY SIZES	SILT SIZES	SAND SIZES					GRAVEL SIZES				
			VERY FINE	FINE	MEDIUM	COARSE	VERY COARSE	VERY FINE	FINE	MEDIUM	COARSE	VERY COARSE
	0	1.5	54.9	39.7	3.8	0.1	0	0	0	0	0	0

Figure 5. --Particle-size distribution of water-table aquifer material, Auger hole 22 near Temple Terrace wells 7, 8, and 9.

Table 3. -- Specific capacities and related data for selected public supply wells in Temple Terrace

City well	Depth (ft)	Depth of casing (ft)	Diameter of open hole (in)	Date of test	Discharge (gal/min)	Duration of test (hrs)	Drawdown (ft)	Specific capacity ([(gal/min)/ft] of drawdown)
1	480	80	8	1962	900	8	5.0	180
2	480	93	10	1962	1148	8	4.2	273
a 3	465	97	12	--	700	7	18.0	39
b 4	510	87	8	--	--	-	-	-
a 5	500	--	12	--	--	-	-	-
6	384	42	8	--	600	8	4.0	150
7	155	108	10	Apr 1973	900	8	1.0	900
8	157	107	10	Apr 1963	950	8	2.0	475
9	170	114	10	Sept 1963	780	8	14.5	54
c 10	313	58	12	Oct 1974	1678	8	3.0	559
c 11	390	45	12	Nov 1974	1013	8	5.7	178

a Not in service.
b Well plugged.
c Drilled 1974; not in service in May 1975.

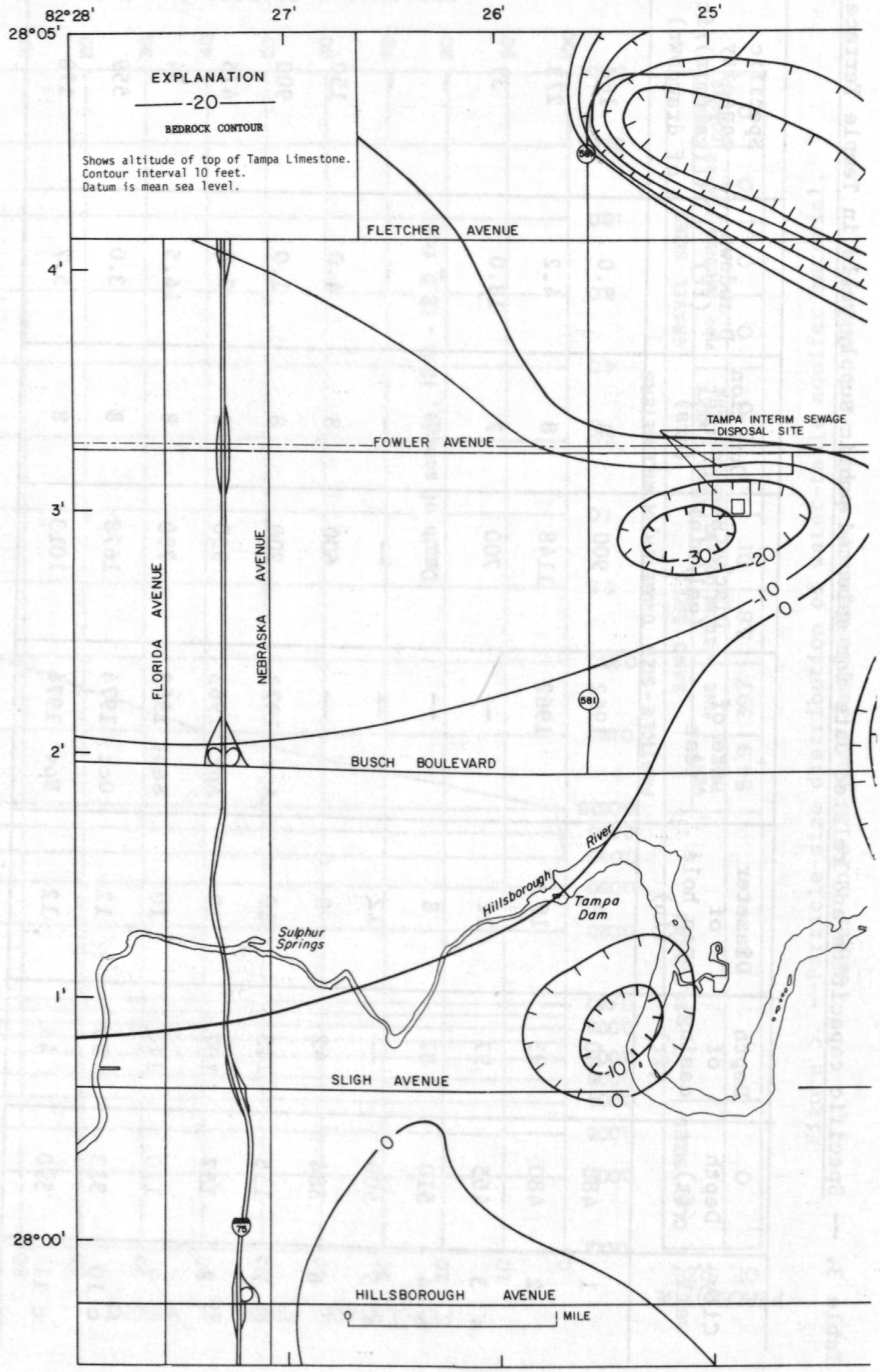
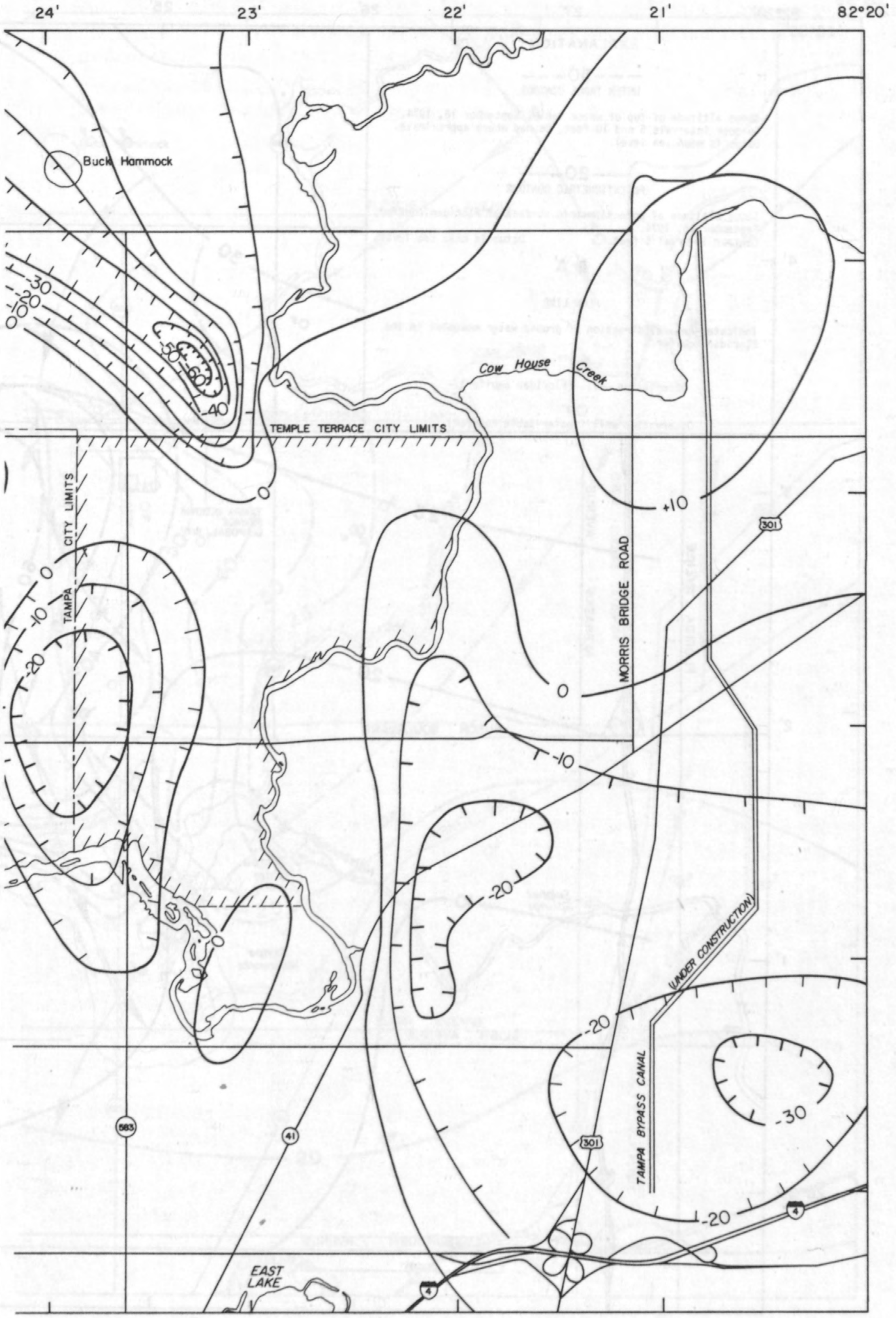


Figure 6. --Generalized contours on top



of Tampa Limestone, Temple Terrace area.

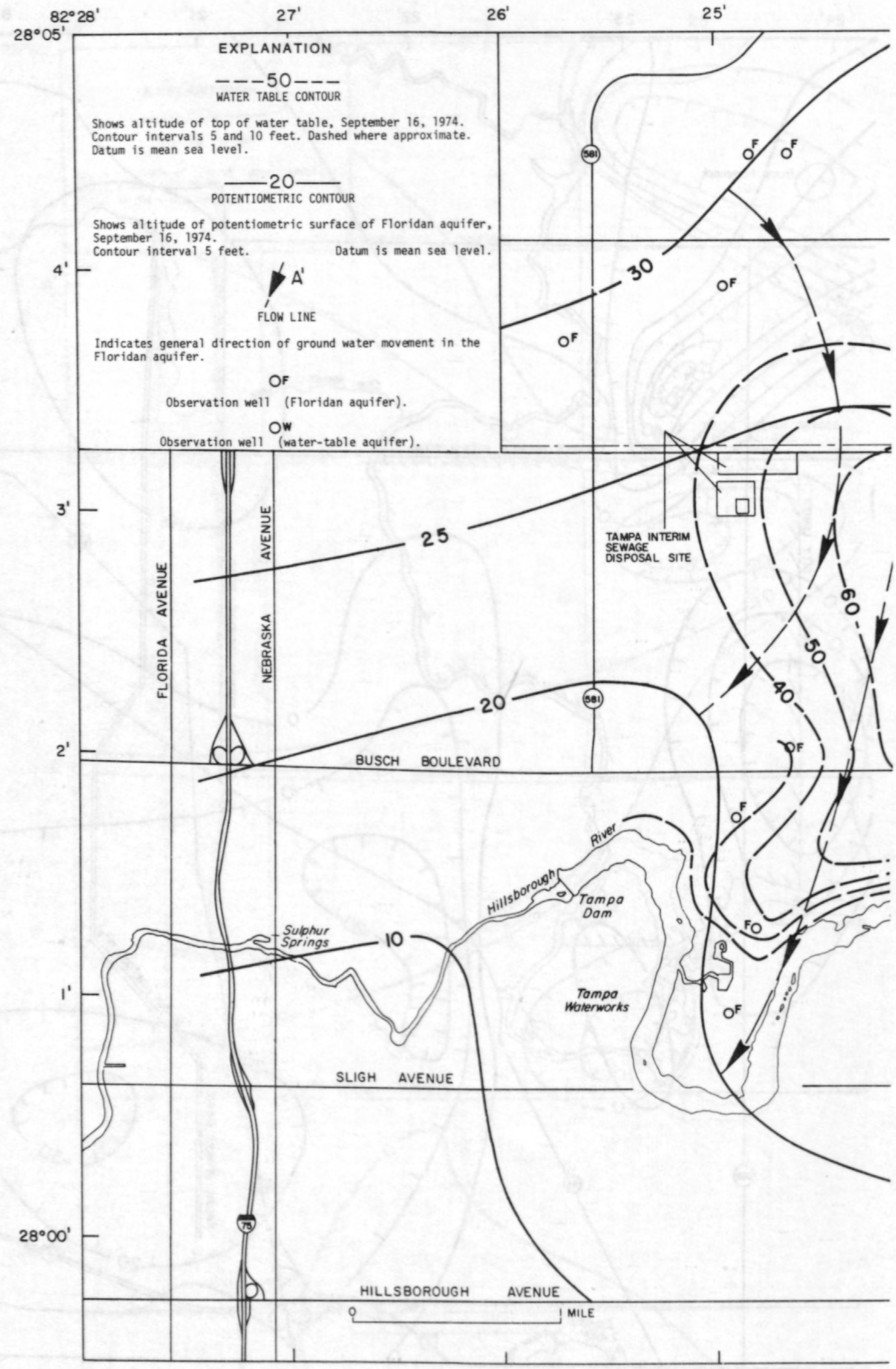
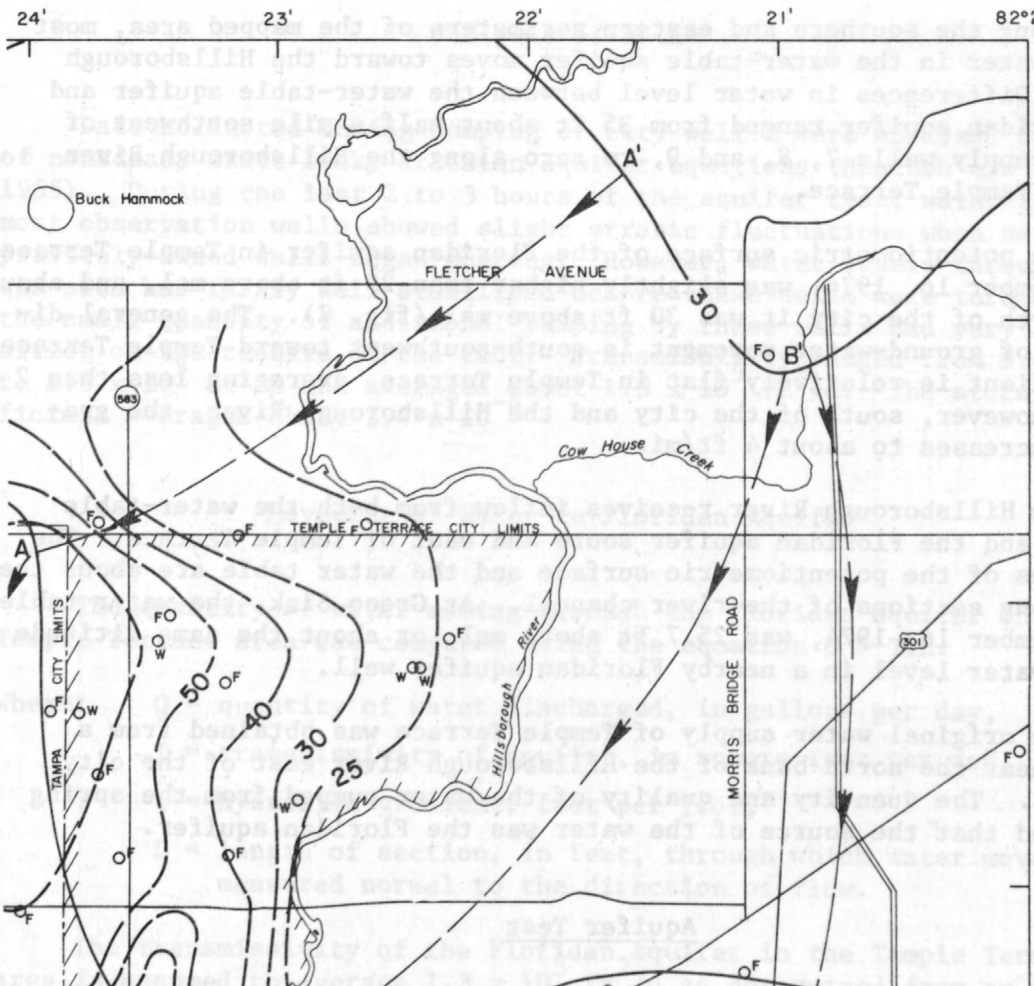


Figure 7. --Configuration of water table and



potentiometric surface of Floridan aquifer, September 16, 1974.

Along the southern and eastern perimeters of the mapped area, most of the water in the water-table aquifer moves toward the Hillsborough River. Differences in water level between the water-table aquifer and the Floridan aquifer ranged from 35 ft about half a mile southwest of public supply wells 7, 8, and 9, to zero along the Hillsborough River east of Temple Terrace.

The potentiometric surface of the Floridan aquifer in Temple Terrace on September 16, 1974, was slightly higher than 25 ft above msl, and about 2 mi north of the city it was 30 ft above msl (fig. 7). The general direction of ground-water movement is south-southwest toward Temple Terrace. The gradient is relatively flat in Temple Terrace, averaging less than 2 ft/mi; however, south of the city and the Hillsborough River, the gradient increases to about 4 ft/mi.

The Hillsborough River receives inflow from both the water-table aquifer and the Floridan aquifer south and east of Temple Terrace. The altitudes of the potentiometric surface and the water table are about the same along sections of the river channel. At Greco Sink, the water table on September 16, 1974, was 25.7 ft above msl, or about the same altitude as the water level in a nearby Floridan aquifer well.

The original water supply of Temple Terrace was obtained from a spring near the north bank of the Hillsborough River east of the city (fig. 2). The quantity and quality of the water pumped from the spring indicated that the source of the water was the Floridan aquifer.

Aquifer Test

An aquifer test at city supply well 2 (well 2, fig. 2) was made in March 1975. The well was pumped at an average rate of 900 gal/min for 25 hours. About 12 hours before pumping began, all city supply wells and privately-owned wells in the area were shut down to allow water levels to recover. Automatic water-level recorders were installed and operated on four of seven wells observed during the test. Water levels were measured in the pumped well for only 8 hours after the pump was turned off. The time available for measuring water-level recovery was minimal because the city needed to turn some of the wells on--water storage facilities available in the city are limited.

The principal hydraulic characteristics determined from aquifer tests are transmissivity and storage coefficient. The transmissivity is defined as the rate at which water of the prevailing viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. The storage coefficient is the volume of water that the aquifer releases from storage per unit surface area of the aquifer per unit change in head.

Analysis of Data

Data collected during pumping of city well 2 were analyzed by means of nonsteady state leaky artesian aquifer equations (Hantush and Jacob, 1955). During the last 2 to 3 hours of the aquifer test, water levels in most observation wells showed slight erratic fluctuations when several privately-owned wells began pumping. However, water levels throughout the area had fairly well stabilized before these wells were turned on and the small quantity of additional pumping by these wells had very little effect on the results of the test. Transmissivity ranged from 9.4×10^4 to 1.6×10^5 ft^2/d and averaged about 1.3×10^5 ft^2/d. The storage coefficient averaged about 3.4×10^{-4}.

Movement of Water in Floridan Aquifer

The quantity of water moving through the Floridan aquifer into the Temple Terrace area was computed using the equation Q = TIL.

Where: Q = quantity of water discharged, in gallons per day,

T = transmissivity of aquifer, in square feet per day,

I = hydraulic gradient, feet per foot,

L = length of section, in feet, through which water moves measured normal to the direction of flow.

The transmissivity of the Floridan aquifer in the Temple Terrace area is assumed to average 1.3×10^5 ft^2/d as determined from an aquifer test of city supply well 2. The hydraulic gradient I, in feet per foot, was calculated using the formula $I = \frac{C}{W}$ in which C is the contour interval in feet and $W = \frac{A}{L}$ where A is the area in square feet between two limiting flow lines (A-A' and B-B', fig. 7) and the potentiometric contours. The hydraulic gradient (I) in the area as defined by flow lines A-A' and B-B' is 0.0003. The length (L) in feet, obtained from the potentiometric map is 9,345 ft, the average length of the 25-ft and 30-ft contours between the limiting flow lines. Substituting these values in the equation yields:

$$Q = (1.3 \times 10^5)(0.0003)(9,345) = 365,450 \ ft^3/d, \text{ or } 2.7 \ Mgal/d.$$

This represents the quantity of water flowing through the section of the aquifer between the 25-ft and 30-ft contours and flow lines A-A' and B-B'. The estimated quantity of water pumped from industrial, irrigation, and public supply wells in the area in 1974 probably exceeded 4 Mgal/d.

Rate of Movement in Water-Table Aquifer

Ground water moves from areas of high hydraulic head to areas of low hydraulic head, normal to the contour lines in an isotropic aquifer. The rate of movement is controlled by the hydraulic conductivity and hydraulic gradient of the aquifer through which the water moves. In a water-table aquifer, such as that which occurs in the surficial sediments, the hydraulic graident is a measure of the slope of the water table. In an artesian aquifer, such as the Floridan aquifer, the gradient is determined by the slope of the potentiometric surface. In general, the water moves slowly where the slopes are gentle, and faster where the slopes are steeper, providing the hydraulic conductivity of the aquifer is constant or nearly constant.

The velocity of ground-water movement in the surficial aquifer toward Greco Sink and the Hillsborough River east of Temple Terrace was calculated using the following form of Darcy's equation:

$$V = KI/P_e$$

Where: V = velocity of flow through the surficial aquifer in feet per day,

K = horizontal hydraulic conductivity of the aquifer in feet per day,

I = hydraulic gradient, in feet per foot,

P_e = effective porosity, a nondimensional fraction.

On the basis of the particle-size data for samples collected from test holes drilled during this study and similar data obtained from test holes in the Tampa area, the horizontal hydraulic conductivity of the water-table aquifer is estimated to be about 13 ft/d. On September 16, the hydraulic gradient was 0.006, computed by dividing the change in head (35 ft) by 6,000 ft, the distance between the 25- and 60-ft contours east of 56th Street and west of Greco Sink. The average effective porosity of the material is 0.276 determined from samples from auger holes drilled in the area. Substituting the above values in the equation just cited, the velocity of ground-water movement toward Greco Sink and the Hillsborough River is computed to be 0.28 ft/d. At this rate of movement it would take more than 50 years for water to move from the supply wells to Greco Sink. However, an increase in the hydraulic gradient in the area will produce a proportional increase in ground-water velocity. For example, a two-fold increase in gradient--from 0.006 to 0.012--would increase the velocity from 0.28 to 0.56 ft/d, assuming, of course, that all other factors remained unchanged.

Sinkholes in the Area

Sinkholes are fairly common throughout the Temple Terrace area. Some are potential sources of ground-water degradation because of surface-water inflow and for this reason a brief discussion of several selected sinkholes follows:

Greco Sink

The Greco Sink is near the northeastern limits of the city, about half a mile west of the Hillsborough River (fig. 2). In December 1971 its greatest depth was only 18 ft below a stage of about 25 ft above msl. Its diameter is 110 ft. In September 1974, the altitude of the water surface in the sinkhole was 0.2 ft above that of the water table of the shallow aquifer, indicating that the sinkhole may be hydraulically connected with the Floridan aquifer.

Analysis of a water sample collected at a depth of 18 ft in the southwest part of the sinkhole also suggests a hydraulic connection between the sinkhole and the Floridan aquifer. The concentration of calcium (37 mg/L), bicarbonate (128 mg/L), alkalinity (105 mg/L as $CaCo_3$) and dissolved solids (144 mg/L) indicate a mixture of water from surface runoff and water from the Floridan aquifer. A nitrate concentration of 0.77 mg/L as nitrogen indicates degradation of water in the sinkhole from surface-water inflow or possibly from introduction of solid waste into the sinkhole over a period of years. This sinkhole is important hydrologically because ground-water movement from the sink is generally west-southwest toward the city supply wells.

Harney Sink

Harney Sink is about 250 ft east of the Hillsborough River and about one-third mi north of Sligh Avenue on Harney Road (fig. 2). This sinkhole probably does not influence the quality of the ground water in the Temple Terrace supply wells because it is 1 to 2 mi downgradient from these wells. The sinkhole is more than 200 ft deep as measured by scuba divers in February 1971. It is cited in this report because of its proximity to Temple Terrace and to show the wide distribution of deep sinkholes in the area.

Morris Bridge Road Sink

Morris Bridge Road Sink is about 3 mi northeast of Temple Terrace in the extreme northeastern corner of the study area (fig. 2). This sinkhole is 135 ft in diameter at a water-surface altitude of 25 ft and more than

200 ft deep as measured by scuba divers. A second deep sinkhole (not shown on fig. 2) is 750 ft east of Morris Bridge Road Sink; this sinkhole is 80 ft in diameter and 245 ft deep. The sinkholes are open to both the Tampa Limestone and the Suwannee Limestone.

Both sinkholes receive water from surface runoff and are possible sources of ground-water quality degradation. The sinkholes are upgradient from Temple Terrace, and in general, ground water moves southwest toward the city supply wells. In September 1974, the altitude of the potentiometric surface of the Floridan aquifer in the vicinity of the sinkholes was slightly more than 30 ft, and the altitude of the potentiometric surface at Temple Terrace was slightly more than 25 ft.

Water in the Morris Bridge Road Sink is a mixture of water from surface runoff and water from the Floridan aquifer. A water sample collected in July 1972 had a pH of 7.8. The concentration of calcium was 212 mg/L; sulfate, 100 mg/L; hardness, 250 mg/L; dissolved solids, 340 mg/L; and specific conductance, 500 umhos/cm.

Weatherington Sink

Weatherington Sink is about 500 ft west of Morris Bridge Road and about 1 mi south of the Hillsborough River (fig. 2). The sinkhole is more than 500 ft in diameter; its depth is not known. The sinkhole is near the bottom of a high ridge, and receives surface-water runoff from the surrounding high areas.

About 600 ft northeast of Weatherington Sink, on the south side of Morris Bridge Road, is a large topographic depression containing a sinkhole. The depression is not of recent origin as indicated by the large-diameter trees growing on the sides and near the bottom of the sinkhole. The bottom of the sinkhole contains some water. The sinkhole has not been sounded.

Ground water in the Floridan aquifer moves generally southwest from these sinkholes toward Temple Terrace.

Blue Sinks

A concentrated group of 5 to 6 small sinkholes, less than 50 ft in diameter and less than 25 ft deep, about 4 mi west of Temple Terrace (fig. 2), are referred to, collectively, as "Blue Sinks". These sinkholes are partly filled with solid waste dumped into them over a period of years. The sinkholes are hydraulically connected with the Floridan aquifer as is indicated by the large quantities of water which flow into and are dispersed by the sinkholes during very heavy rains. Before the sinkholes were partly filled with solid waste, water could be observed moving across the bottoms of the sinkholes during dry periods.

The Blue Sinks probably do not influence the quality of the ground water in the Temple Terrace area. However, they may influence the quality elsewhere. In 1958, when the city of Tampa injected dye into the northernmost sinkhole in the group (fig. 2), the dye was detected in water from wells finished in the Floridan aquifer as far as 2 mi east-southeast of the sinkholes.

Miscellaneous Sinkholes

Several small unnamed sinkholes less than 10 ft deep and averaging less than 25 ft in diameter are found throughout the study area. However, it is not known whether any of these sinkholes are hydraulically connected with the Floridan aquifer.

WATER QUALITY

Network Sampling

Water samples were collected from selected wells, sinkholes, and the Hillsborough River at various times throughout the period of the investigation and analyzed by the U.S. Geological Survey laboratory. The quality of water in wells, in Greco Sink, and in the Hillsborough River is shown in table 4. (See figure 2 for location of sampling sites listed in table 4.) The data show that water quality in the aquifer is related to depth. Water from the two deepest wells, 358 and 530 ft deep, has the highest specific conductance and the highest hardness. That these are high is due to the increasing quantities of dissolved solids with increased well depth. In water from both Greco Sink and the Hillsborough River near Temple Terrace, total coliform bacteria counts are in the hundreds per 100 ml. The water in the storm-water retention basin, about 425 ft southwest of city wells 7, 8, and 9, had a total coliform bacteria count of 100 per 100 ml, low specific conductance, low hardness, high color, and high total organic carbon. The quality of the water at sampling site 17 (fig. 2, table 4) is similar to the quality of the water in the nearby storm retention basin except in coliform bacteria count. The similarity in water quality at the two sites may indicate recharge to nearby wells downgradient from the storm retention basins. The quality of the water at city wells 7, 8, and 9 is characterized by low color, low total organic carbon, high total inorganic carbon, specific conductances between 269 and 423 micromhos per centimeter (umhos/cm), and a hardness between 120 and 200 mg/L.

Table 4. -- Chemical and microbiological analyses of water samples from selected sites in the Temple Terrace area

[Analyses in milligrams per liter except as noted. Analyses by U.S. Geological Survey.]

Site	Sampling site number	Date	Time of collection	Well depth (ft)	Casing depth (ft)	Color (Pt-Co units)	Tannin and lignin
Temple Terrace well 7	7	3-05-74	0930	155	108	-	-
		7-15-74	1100	155	108	0	-
Temple Terrace well 7A	7A	10-09-74	1330	(a)	-	0	0.07
		10-07-74	1400	(b)	-	5	.53
		10-08-74	1100	(c)	-	0	.35
Temple Terrace well 8	8	3-05-74	0945	157	107	-	-
		7-15-74	1115	157	107	0	-
Temple Terrace well 8A	8A	7-16-74	1000	158	154	0	-
Temple Terrace well 9	9	3-05-74	0950	170	114	-	-
		7-15-74	1130	170	114	0	-
Hillsborough River near SR 580 at Temple Terrace	12	3-05-74	1030	-	-	-	-
Greco Sink, Temple Terrace	13	3-05-74	1015	(d)	-	-	-
Tampa well at 46th Street	14	7-15-74	1015	358	183	5	-
Tampa well at 42nd Street	15	7-15-74	1000	530	101	5	-
Temple Terrace Village Apartments well	16	7-16-74	1220	160	85	0	-
Cuylon Barker well	17	7-17-74	1000	170	85	0	-
E. D. Shidden well	18	7-17-74	0930	127	42	5	-
Storm water basin	19	10-08-74	1000	(e)	-	45	.54

a Packer sample, 100-118 ft.
b Packer sample, 120-130 ft.
c Packer sample, 130-153 ft.
d Maximum sounded depth of sink, 18 ft.
e Depth of storm water retention basin, 4 ft.

Table 4. -- Chemical and microbiological analyses of water samples from selected sites in the Temple Terrace area - continued

Site	Total organic carbon	Total inorganic carbon	Total carbon	Specific conductance (umho/cm at 25°C)	Chloride (Cl)	Iron (Fe)	Total hardness (as $CaCo_3$)
Temple Terrace well 7	-	-	-	-	-	-	-
	-	-	-	335	8.8	-	150
Temple Terrace well 7A	0	17	17	269	8.5	0.00	120
	3	19	22	279	8.6	.26	130
	3	18	21	274	8.0	.02	120
Temple Terrace well 8	-	-	-	-	-	-	-
	-	-	-	352	9.8	-	160
Temple Terrace well 8A	-	-	-	360	9.0	-	170
Temple Terrace well 9	-	-	-	-	-	-	-
	-	-	-	423	9.6	-	200
Hillsborough River near SR 580 at Temple Terrace	-	-	-	-	-	-	-
Greco Sink, Temple Terrace	-	-	-	-	-	-	-
Tampa well at 46th Street	-	-	-	1010	7.5	-	570
Tampa well at 42nd Street	-	-	-	860	10	-	480
Temple Terrace Village Apartments well	-	-	-	151	4.0	-	80
Cuylon Barker well	-	-	-	391	15	-	170
E. D. Shidden well	-	-	-	275	10	-	120
Storm water basin	15	11	26	137	5.0	.02	66

Table 4. -- Chemical and microbiological analyses of samples from selected sites in the Temple Terrace area - continued

Site	Bacteria (Colonies per 100 ml)		
	Total coliform	Fecal coliform	Fecal streptococci
Temple Terrace well 7	11	1	1
	7	1	1
Temple Terrace well 7A	33	1	1
	1	1	47
	4	1	1
Temple Terrace well 8	3	1	1
	1	1	1
Temple Terrace well 8A	1	1	1
Temple Terrace well 9	1	1	1
	5	1	1
Hillsborough River near SR 580 at Temple Terrace	180	27	5
Greco Sink, Temple Terrace	730	36	560
Tampa well at 46th Street	1	1	1
Tampa well at 42nd Street	1	1	1
Temple Terrace Village Apartments well	1	1	1
Cuylon Barker well	1	1	1
E. D. Shidden well	1	1	1
Storm water basin	100	1	1

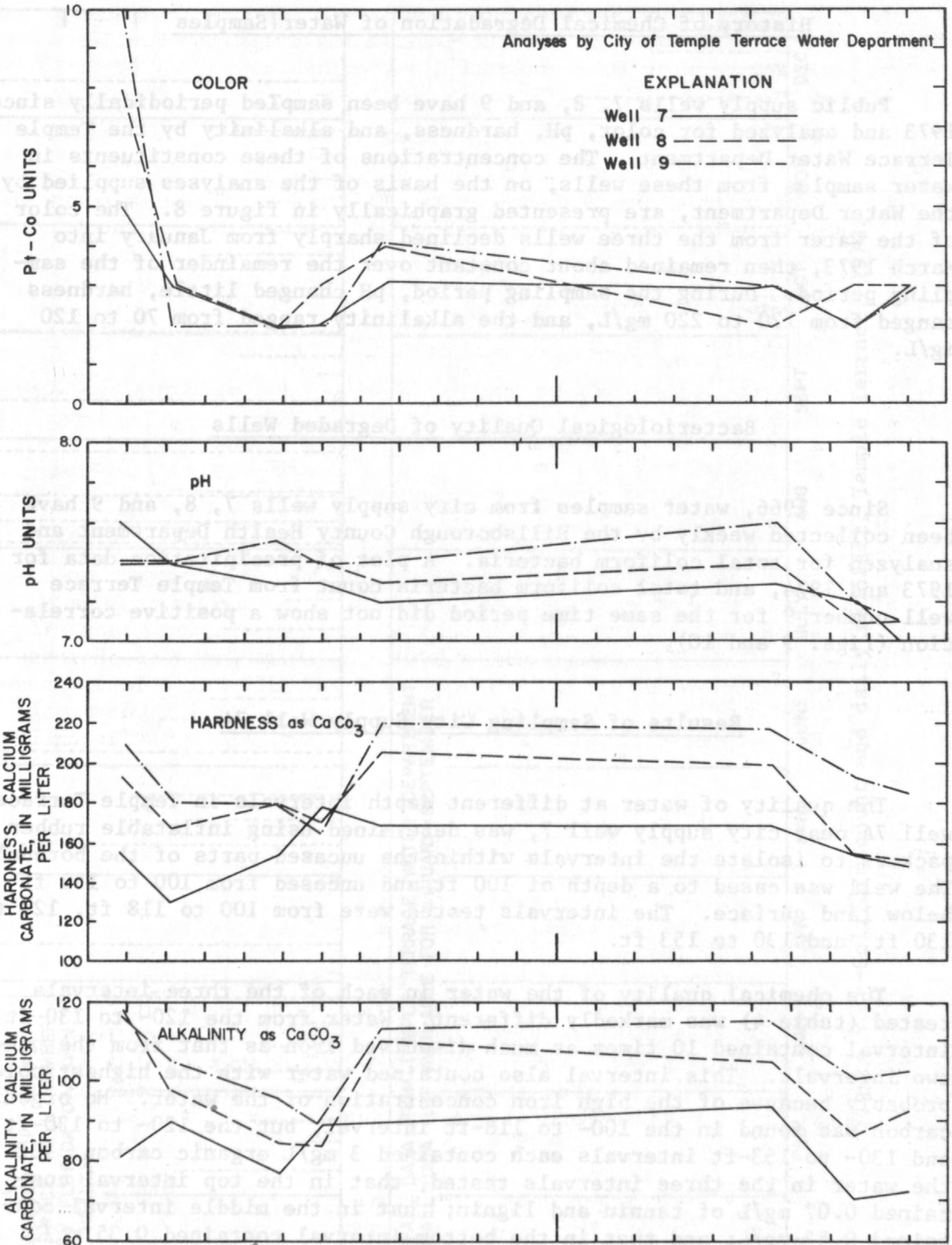


Figure 8. --Color, pH, hardness, and alkalinity, Temple Terrace wells 7, 8, and 9.

History of Chemical Degradation of Water Samples

Public supply wells 7, 8, and 9 have been sampled periodically since 1973 and analyzed for color, pH, hardness, and alkalinity by the Temple Terrace Water Department. The concentrations of these constituents in water samples from these wells, on the basis of the analyses supplied by the Water Department, are presented graphically in figure 8. The color of the water from the three wells declined sharply from January into March 1973, then remained about constant over the remainder of the sampling period. During the sampling period, pH changed little, hardness ranged from 120 to 220 mg/L, and the alkalinity ranged from 70 to 120 mg/L.

Bacteriological Quality of Degraded Wells

Since 1966, water samples from city supply wells 7, 8, and 9 have been collected weekly by the Hillsborough County Health Department and analyzed for total coliform bacteria. A plot of precipitation data for 1973 and 1974, and total coliform bacteria count from Temple Terrace well number 9 for the same time period did not show a positive correlation (figs. 9 and 10).

Results of Sampling City Supply Well 7A

The quality of water at different depth intervals in Temple Terrace well 7A near city supply well 7, was determined using inflatable rubber packers to isolate the intervals within the uncased parts of the borehole. The well was cased to a depth of 100 ft and uncased from 100 to 153 ft below land surface. The intervals tested were from 100 to 118 ft, 120 to 130 ft, and 130 to 153 ft.

The chemical quality of the water in each of the three intervals tested (table 4) was markedly different. Water from the 120- to 130-ft interval contained 10 times as much dissolved iron as that from the other two intervals. This interval also contained water with the highest color probably because of the high iron concentration of the water. No organic carbon was found in the 100- to 118-ft interval, but the 120- to 130-ft and 130- to 153-ft intervals each contained 3 mg/L organic carbon. Of the water in the three intervals tested, that in the top interval contained 0.07 mg/L of tannin and lignin; that in the middle interval contained 0.53 mg/L; and that in the bottom interval contained 0.35 mg/L.

A difference in bacterial quality of the water was found within the three intervals. Total coliform bacterial organisms were most numerous in the 100- to 118-ft interval with a count of 33 colonies per 100 ml. The 120- to 130-ft interval had a count of less than 1 colony per 100 ml,

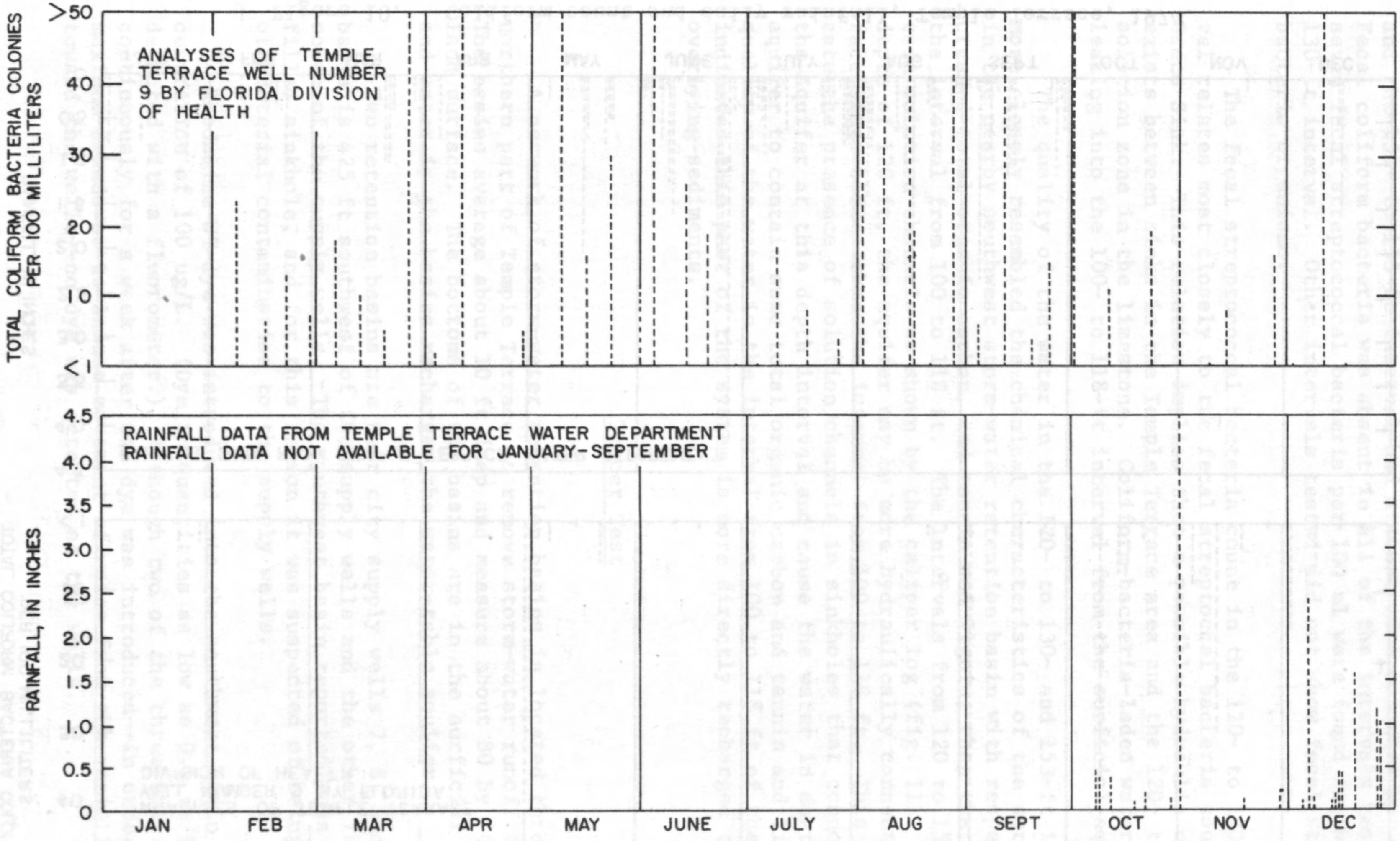


Figure 9. --Coliform count and daily rainfall, Temple Terrace, 1973.

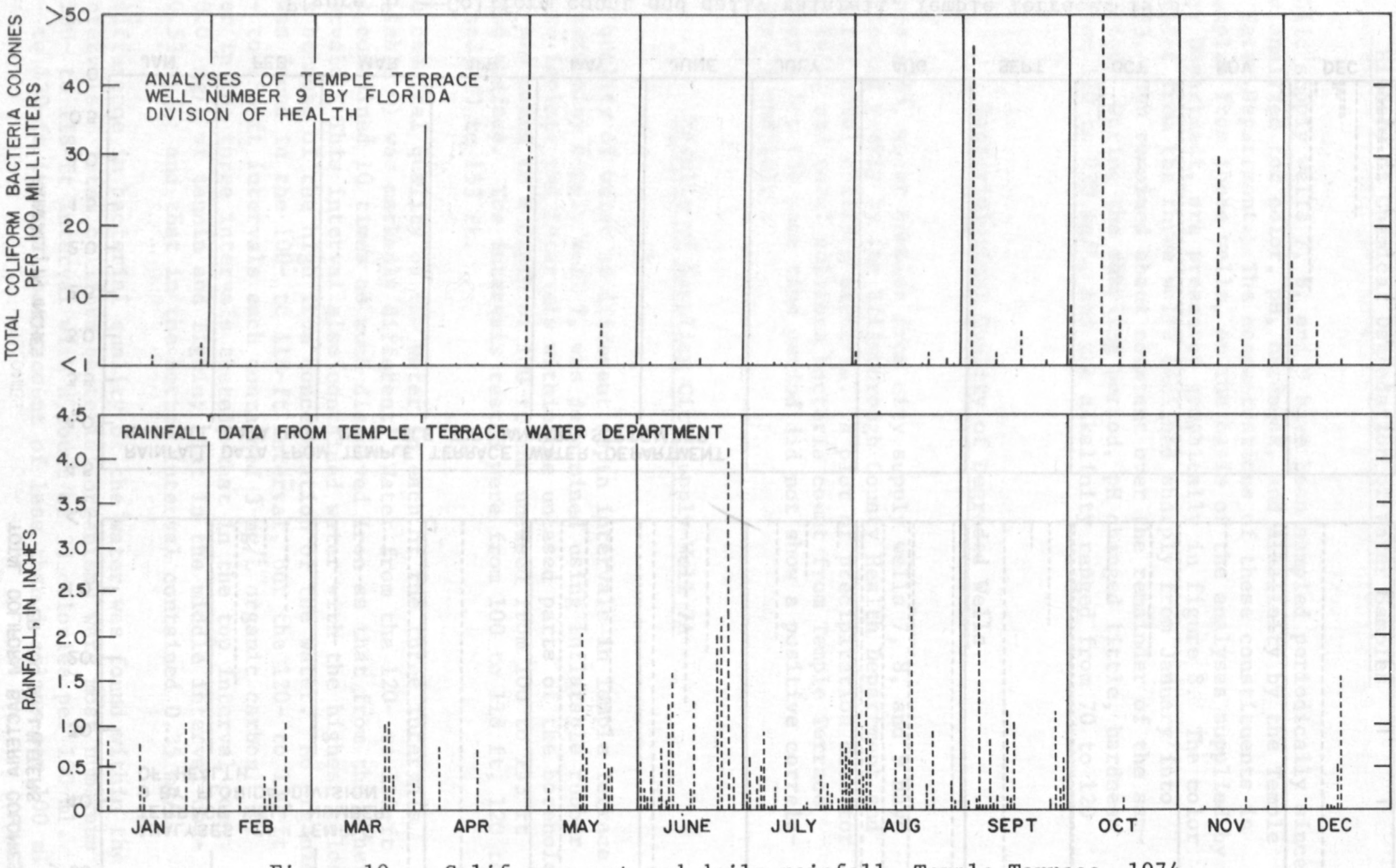


Figure 10. --Coliform count and daily rainfall, Temple Terrace, 1974.

and the 130- to 153-ft interval had a count of 4 colonies per 100 ml. Fecal coliform bacteria was absent in all of the intervals tested. Forty-seven fecal streptococcal bacteria per 100 ml were found in the 120- to 130-ft interval. Other intervals tested did not show fecal streptococcal bacteria organisms.

The fecal streptococcal bacteria count in the 120- to 130-ft interval relates most closely to the fecal streptoccal bacteria count found in Greco Sink. This relation implies that a possible hydraulic connection exists between sinks in the Temple Terrace area and the 120- to 130-ft solution zone in the limestone. Coliform-bacteria-laden water may be leaking into the 100- to 118-ft interval from the surficial aquifer.

The quality of the water in the 120- to 130- and 153-ft intervals more closely resembled the chemical characteristics of the surface water in the nearby southwest storm-water retention basin with respect to increased total organic carbon, and tannin and lignin, than that found in the interval from 100 to 118 ft. The intervals from 120 to 153 ft contain solution channels as shown by the caliper log (fig. 11). Below a depth of 120 ft, the aquifer may be more hydraulically connected to surface-water bodies than the interval from 100 to 118 ft. This may indicate the presence of solution channels in sinkholes that connect with the aquifer at this depth interval and cause the water in most of the aquifer to contain some total organic carbon and tannin and lignin. The quality of the water in the interval from 100 to 118 ft of the aquifer indicates this part of the system is more directly recharged through the overlying sediments.

Tracer Test

A network of storm-water retention basins is located throughout the northern part of Temple Terrace to remove storm-water runoff (fig. 2). The basins average about 10 ft deep and measure about 80 by 140 ft at land surface. The bottoms of the basins are in the surficial sediments, and water in the basins recharges the water-table aquifer.

Two retention basins are near city supply wells 7, 8, and 9. One basin is 425 ft southwest of the supply wells and the other is 500 ft south of the supply wells. The southwest basin reportedly is an old filled sinkhole, and for this reason it was suspected of being a source of bacterial contamination to the supply wells.

Rhodamine WT dye was introduced into the southwest basin at a concentration of 100 ug/L. (Dye in quantities as low as 0.1 ug/L can be detected with a fluórometer.) Although two of the three wells were pumped continuously for a week after the dye was introduced--in order to produce maximum drawdowns to induce movement of water from the retention basin toward the wells--no dye was detected at the wells.

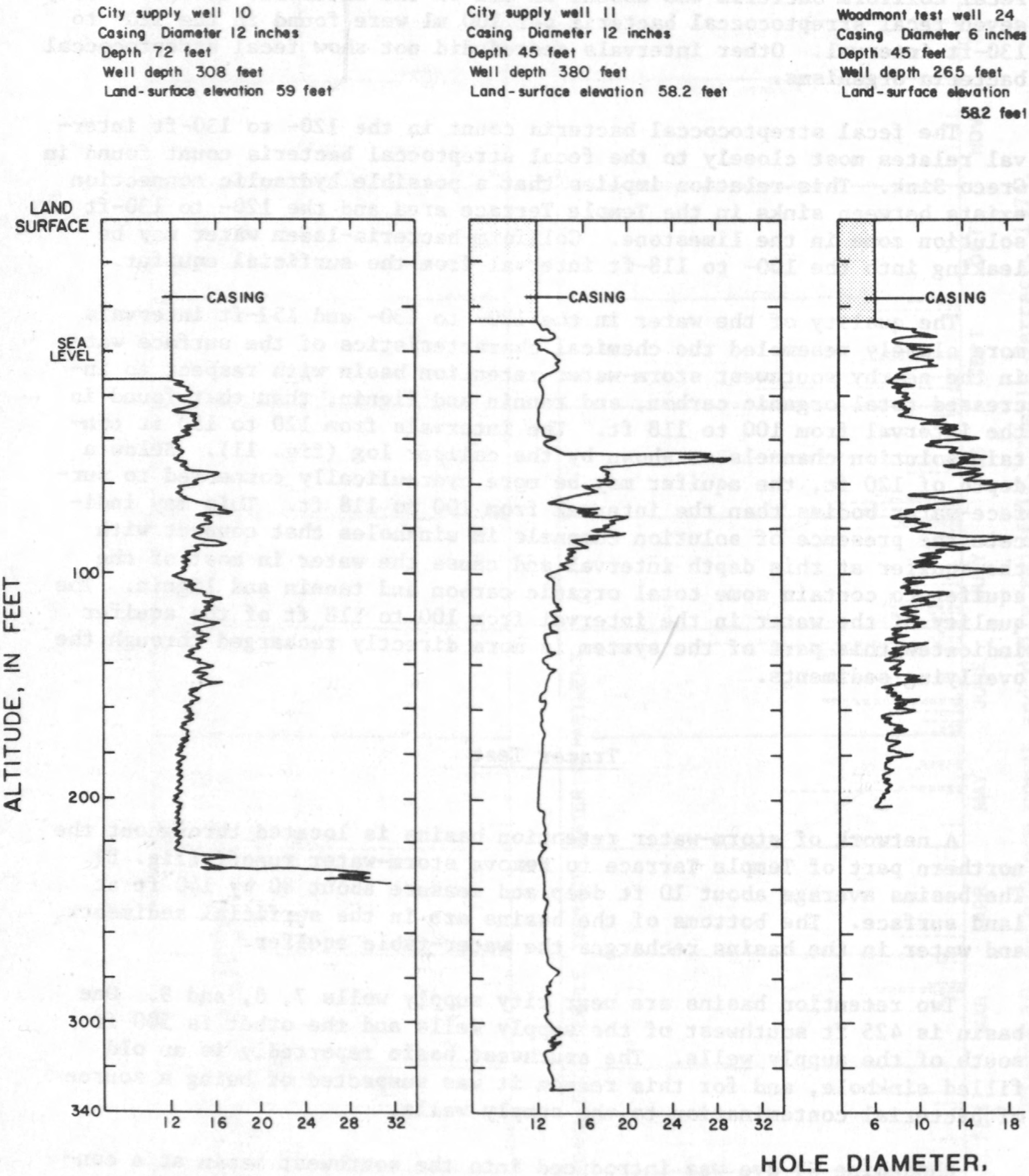
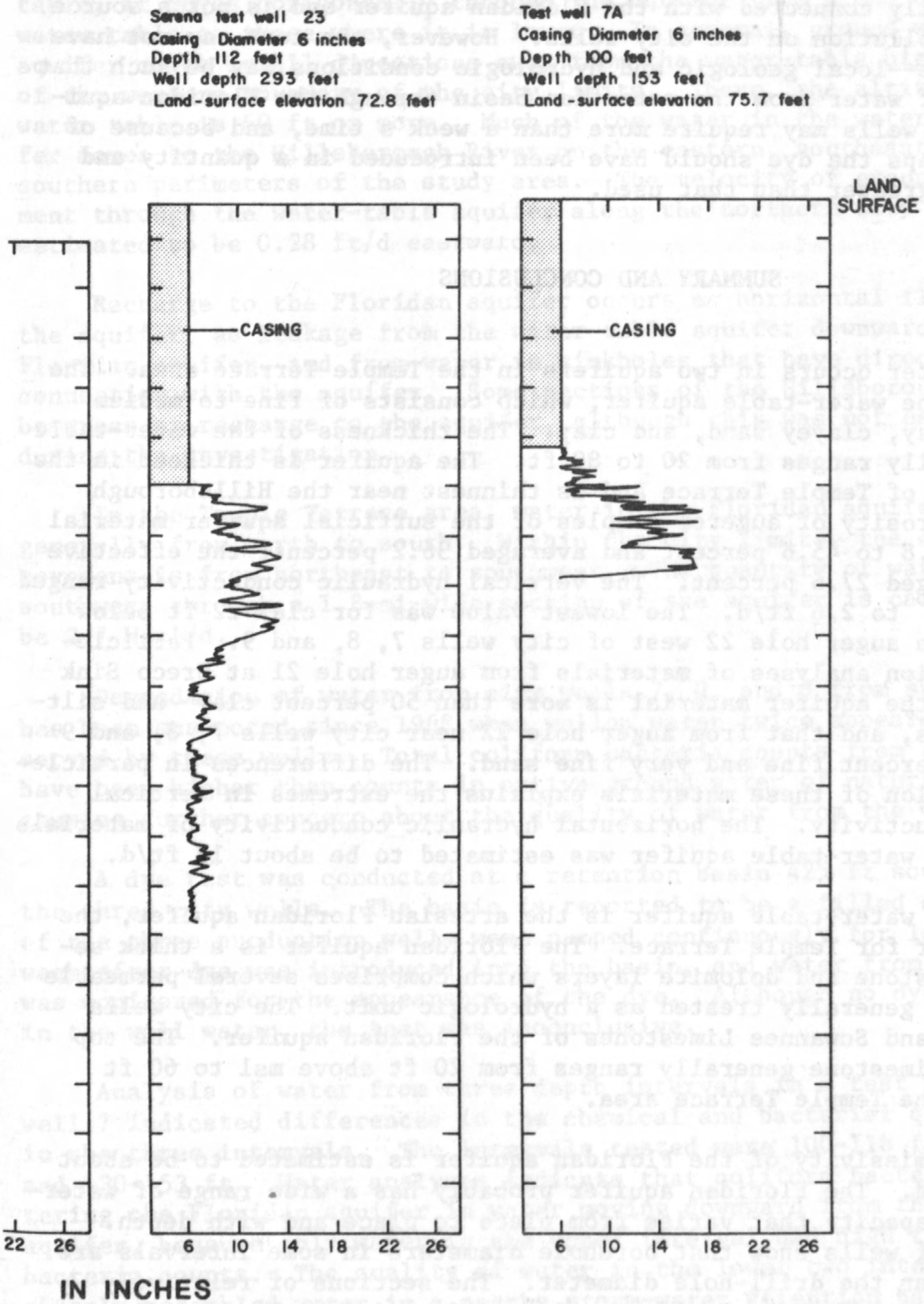


Figure 11.--Caliper logs of selected wells in



Temple Terrace showing bore-hole diameters.

On the basis of the dye test, it appears that the retention basin is not hydraulically connected with the Floridan aquifer and is not a source of bacterial pollution on the city wells. However, the test may not have been conclusive--local geologic and hydrologic conditions may be such that any movement of water from the retention basin through the Floridan aquifer and to the wells may require more than a week's time, and because of dilution, perhaps the dye should have been introduced in a quantity and concentration greater than that used.

SUMMARY AND CONCLUSIONS

Ground water occurs in two aquifers in the Temple Terrace area. The upper one is the water-table aquifer, which consists of fine to medium sand, sandy clay, clayey sand, and clay. The thickness of the water-table aquifer generally ranges from 20 to 80 ft. The aquifer is thickest in the northwest part of Temple Terrace and is thinnest near the Hillsborough River. The porosity of augered samples of the surficial aquifer material ranged from 28.8 to 45.6 percent and averaged 36.2 percent; the effective porosity averaged 27.6 percent. The vertical hydraulic conductivity ranged from 5.2×10^{-5} to 2.6 ft/d. The lowest value was for clay 22 ft below land surface in auger hole 22 west of city wells 7, 8, and 9. Particle-size distribution analyses of materials from auger hole 21 at Greco Sink indicate that the aquifer material is more than 50 percent clay- and silt-sized particles, and that from auger hole 22 near city wells 7, 8, and 9 is nearly 95 percent fine and very fine sand. The differences in particle-size distribution of these materials explains the extremes in vertical hydraulic conductivity. The horizontal hydraulic conductivity of materials comprising the water-table aquifer was estimated to be about 13 ft/d.

Below the water-table aquifer is the artesian Floridan aquifer, the source of water for Temple Terrace. The Floridan aquifer is a thick sequence of limestone and dolomite layers which comprises several permeable zones that are generally treated as a hydrologic unit. The city wells tap the Tampa and Suwannee Limestones of the Floridan aquifer. The top of the Tampa Limestone generally ranges from 20 ft above msl to 60 ft below msl in the Temple Terrace area.

The transmissivity of the Floridan aquifer is estimated to be about 1.3×10^{5} ft^{2}/d. The Floridan aquifer probably has a wide range of water-transmitting capacity that varies from place to place and with depth. Caliper logs of wells show that borehole diameters in some intervals are much larger than the drill-hole diameter. The sections of relatively large diameter represent solution openings and cavities that were intercepted by the wells. Most of these occur in an interval between 120 and 180 ft below land surface.

Wells in the Floridan aquifer in Temple Terrace, ranging from about 150 to 500 ft in depth, yield as much as 1,500 gal/min. The most productive water-yielding part of the aquifer is the cavernous zone 120 to 180 ft below land surface.

When rainfall infiltrates the shallow deposits and reaches the water table, it moves horizontally through the aquifer from areas of higher water table to those where it is lower. In general, ground water in this aquifer moves in all directions away from the water-table high in the area of the western boundary of the city limits. There, the altitude of the water table is 60 ft or more. Much of the water in the water-table aquifer moves to the Hillsborough River on the eastern, southeastern, and southern perimeters of the study area. The velocity of ground-water movement through the water-table aquifer along the northern city limit is estimated to be 0.28 ft/d eastward.

Recharge to the Floridan aquifer occurs as horizontal flow through the aquifer, as leakage from the water-table aquifer downward into the Floridan aquifer, and from water in sinkholes that have direct hydraulic connection with the aquifer. Some sections of the Hillsborough River may be areas of recharge to the aquifer, although this was not established during the investigation.

In the Temple Terrace area, water in the Floridan aquifer moves generally from north to south. Within the city limits, the direction of movement is from northeast to southwest. The quantity of water moving southwest through a 1.8-mi-wide section of the aquifer is calculated to be 2.7 Mgal/d.

Degradation of water from city wells 7, 8, and 9 from surface water has been suspected since 1968 when yellow water twice appeared in homes served by these wells. Total coliform bacteria counts from these wells have been higher than counts in native ground water of natural quality, causing further concern about the quality of water from the wells.

A dye test was conducted at a retention basin 425 ft southwest of the three city wells. The basin is reported to be a filled sinkhole. Two of the three production wells were pumped continuously for longer than a week after dye was introduced into the basin, and water from the wells was monitored for the appearance of the dye. Although no dye was detected in the well water, the test was inconclusive.

Analysis of water from three depth intervals in a test well near city well 7 indicated differences in the chemical and bacterial quality of water in the three intervals. The intervals tested were 100-118 ft, 120-130 ft, and 130-153 ft. Water analyses indicate that coliform bacteria may be entering the Floridan aquifer in water moving downward from the water-table aquifer, because only water in the upper interval had high total-coliform bacteria counts. The quality of water in the lower two intervals more closely resembled water in a nearby storm-water retention basin with respect to concentrations of total organic carbon, and tannin and lignin.

Results of analyses for color, pH, hardness, and alkalinity of water from wells 7, 8, and 9 during 1973-74 indicate an unusual variation only in the color. Color, which was more than 5 platinum-cobalt units in water from all three wells in January 1973, has not exceeded this value since then.

A comparison of weekly total coliform bacteria counts in water from well 9 with precipitation records indicates no apparent direct correlation between these counts and the occurrence of large amounts of rainfall.

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