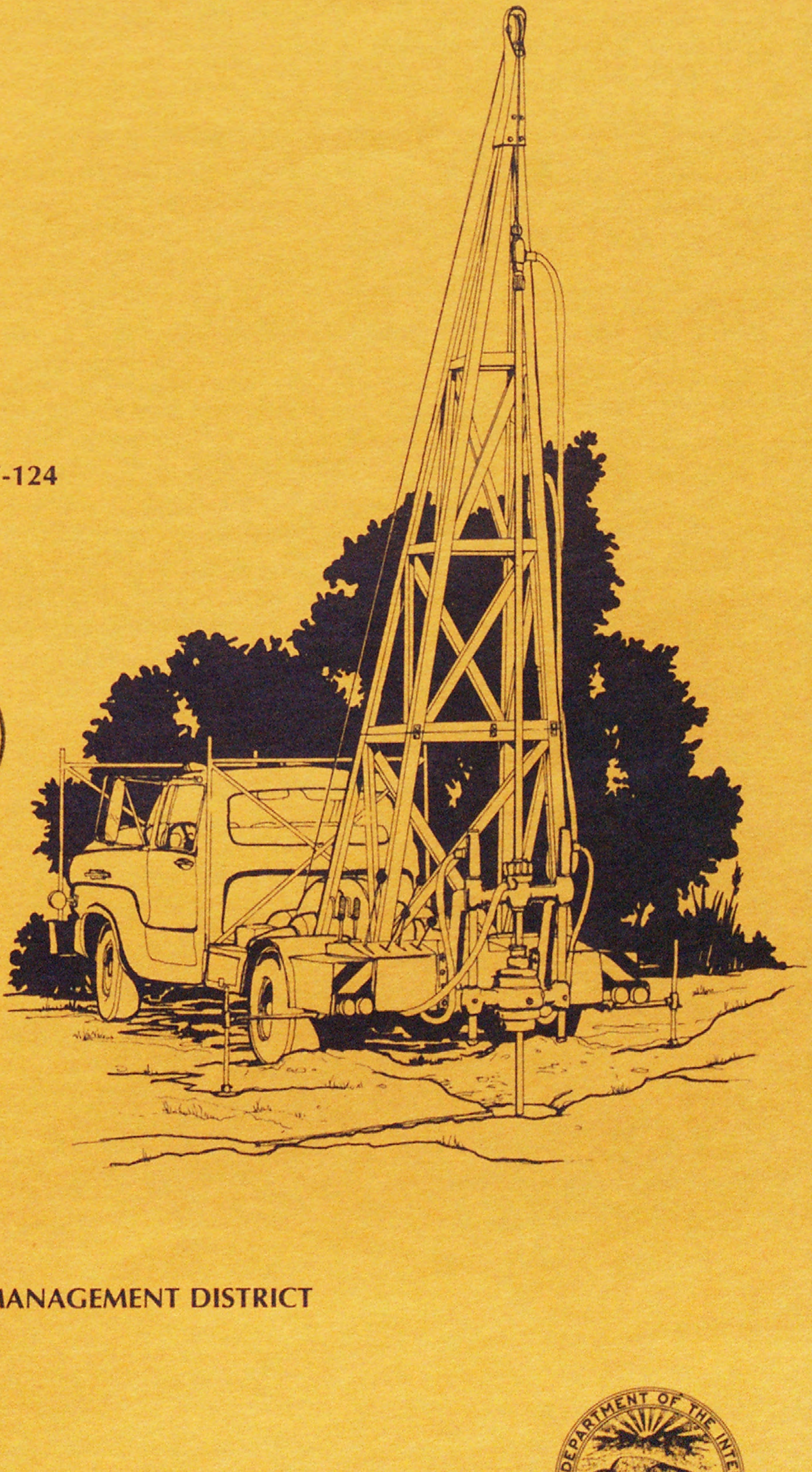
APPRAISAL OF SHALLOW GROUND-WATER RESOURCES AND MANAGEMENT ALTERNATIVES IN THE UPPER PEACE AND EASTERN ALAFIA RIVER BASINS, FLORIDA



U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 77-124

Prepared in cooperation with the
SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

BIBLIOGRAPHIC DATA SHEET

1. Report No.

2.

3. Recipient's Accession No.

4. Title and Subtitle

APPRAISAL OF SHALLOW GROUND-WATER RESOURCES AND MANAGEMENT ALTERNATIVES IN THE UPPER PEACE AND EASTERN ALAFIA RIVER BASINS, FLORIDA

5. Report Date

February 1978

6.

7. Author(s)

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8. Performing Organization Rept. No USGS WRI 77-124

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

The shallow aquifer system underlying the 1,250-square-mile upper Peace and eastern Alafia River basins is a relatively untapped source of supply. The shallow aquifer system ranges between 50 and 300 feet thick and is composed of a surficial sand unit underlain by a limestone unit. Sand and clay confining beds separate the shallow aquifer system from the highly productive, extensively developed deep aquifer system. The hydrologic budget of the area indicates that annual leakage of water from the shallow to the deep aquifer system is 2.6 inches while annual pumpage from the deep aquifer system averages 5.5 inches.

Management alternatives to be considered for efficient use of the shallow ground-water resources include development by withdrawal wells or connector wells for recharge. One solution for a gridded network of wells consists of 540 wells spaced 7,000 feet apart, each producing 453 gallons per minute. The network would derive water to meet demand by capturing water that would normally have run off evapotranspired.

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

*Water resources development, ground-water movement, hydrologic budget, aquifer characteristics, Florida

17b. Identifiers/Open-Ended Terms

Connector wells

17c. COSATI Field/Group

18. Availability Statement

No restriction on distribution

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page)
UNCLASSIFIED

21. No. of Pages
58

22. Price

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February 1978

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

TABLES

APPRAISAL OF SHALLOW GROUND-WATER RESOURCES AND MANAGEMENT ALTERNATIVES IN THE UPPER PEACE AND EASTERN ALAFIA RIVER BASINS, FLORIDA

By

C. B. Hutchinson

ABSTRACT

The shallow aquifer underlying the 1,250-square-mile upper Peace and eastern Alafia River basins range between 50 and 300 feet thick and occur in two distinct hydrogeologic units: (1) the unconfined surficial sand aquifer, and (2) the underlying confined upper unit of the Floridan aquifer, composed of limestone and dolomite. Over most of the area the shallow aquifers are hydraulically separated from the lower unit of the Floridan aquifer by sand and clay confining beds. The shallow aquifers form a supply for small-scale use such as individual households, while the more productive deep aquifer supplies large-scale users, including industry and agriculture.

Transmissivities of 1,600 and 2,200 feet squared per day were obtained from two pumping tests of the surficial aquifer. Laboratory determinations of the storage coefficient averaged 0.29. The total volume of water in storage within the surficial aquifer is estimated at 14.4 million acre-feet.

Based on three aquifer tests, nine specific capacity tests, and six slug tests, transmissivity of the upper unit of the Floridan aquifer ranges between 10 and 13,300 feet squared per day, storage coefficient ranges between 1.0×10^{-4} and 4.2×10^{-5}, and the leakage coefficient of overlying semiconfining beds within the surficial aquifer is 2.5×10^{-4} feet per day per foot. Total volume of water stored in the aquifer is estimated at 31.6 million acre-feet. Apparently the upper, weathered part of the aquifer is the most transmissive section. Transmissivity is probably related more to local variations in solution development within the limestone than to changes in thickness, lithology, or stratigraphy of the aquifer.

The hydrologic budget of the area indicates that annual leakage of shallow ground water to the deep aquifer is 2.6 inches. Annual pumpage from the deep aquifer averages 5.5 inches. The deficit is accounted for by removal of water from storage and a decrease in ground-water discharge, and has resulted in progressive declines in the potentiometric surface of the lower unit of the Floridan aquifer.

In light of increasing demands of municipal, agricultural, and industrial users, development of the shallow ground-water resources appears imminent. Two water-management alternatives seem particularly suited:

(1) installation of a network of supply wells which would supplement pumpage from the lower unit of the Floridan aquifer; (2) installation of a network of gravity-flow connector wells that would connect the surficial aquifer and (or) the upper unit of the Floridan aquifer to the lower unit of the Floridan, recharging the lower unit by gravity flow.

On the basis of criteria set forth in the report, about 730 square miles of the surficial aquifer and about 990 square miles of the upper unit of the Floridan aquifer are suitable for development. A gridded network including a combination of a few hundred supply and connector wells in selected areas could produce enough shallow ground water to alleviate the hydrologic stress imposed by present pumping of the lower unit of the Floridan aquifer. However, as a result of large-scale withdrawals of shallow ground water, streamflow in the area could be drastically reduced during dry spells.

The adverse effects of withdrawing shallow ground water from aquifers in the upper Peace and eastern Alafia River basins perhaps could best be minimized if the shallow ground water and the deep ground water were developed conjunctively, maximizing the use of shallow ground water during wet spells and reserving the deep ground water for dry spells. Further investigations would be required to establish whether appreciable net benefits could result from such a proposal and whether the associated adverse effects could be tolerated.

INTRODUCTION

During the last three decades, withdrawal of water from the lower unit of the Floridan aquifer in the upper Peace and eastern Alafia River basins (fig. 1) has resulted in a continued long-term water-level decline. A map of the changes in the potentiometric surface indicated that water levels declined as much as 60 ft from 1949 to 1969 (Stewart and others, 1971). The declines had necessitated the lowering of the bowls of nearly every deep turbine pump in the area by 1969. By 1975 the potentiometric surface had declined an additional 20 ft below the 1969 level in some areas (Mills and Laughlin, 1976).

The deposits that overlie the lower unit of the Floridan aquifer are as much as 300 ft thick and include the surficial aquifer--composed of sand, sandy clay, clay, and marl--and the upper unit of the Floridan aquifer--composed of limestone and dolomite. Prior to this report, the hydrogeology of this shallow ground-water zone and its water-resource potential has not been described in detail, and little consideration has been given to its use as a major source of water supply.

Purpose and Scope

This report presents the results of a 27-month investigation by the U.S. Geological Survey, in cooperation with the Southwest Florida Water Management District, to determine the thickness and areal extent of the surficial aquifer and the upper unit of the Floridan aquifer, to determine their hydraulic properties and water quality, and to evaluate their potential as a source of supply. The thickness, structure, and water levels of two aquifers are mapped; the results of 20 aquifer tests and 23 analyses of chemical quality are presented; and an examination is made of hydrogeologic controls on the potential development of ground water in the area. Although the project is limited in areal extent to the Peace and Alafia River basins in parts of Hillsborough, Polk, and Hardee Counties, results will be transferable to surrounding areas and other parts of the state having similar hydrologic conditions.

Methods of Collection and Analysis of Data

Data for this investigation were obtained from State and Federal reconnaissance reports, consulting engineers' reports, published and unpublished geologic logs and water-quality analyses from various sources, and information supplied by the phosphate industry. In areas where data from these sources were lacking, a field program of obtaining well records, test drilling, aquifer testing, and water-quality sampling was conducted.

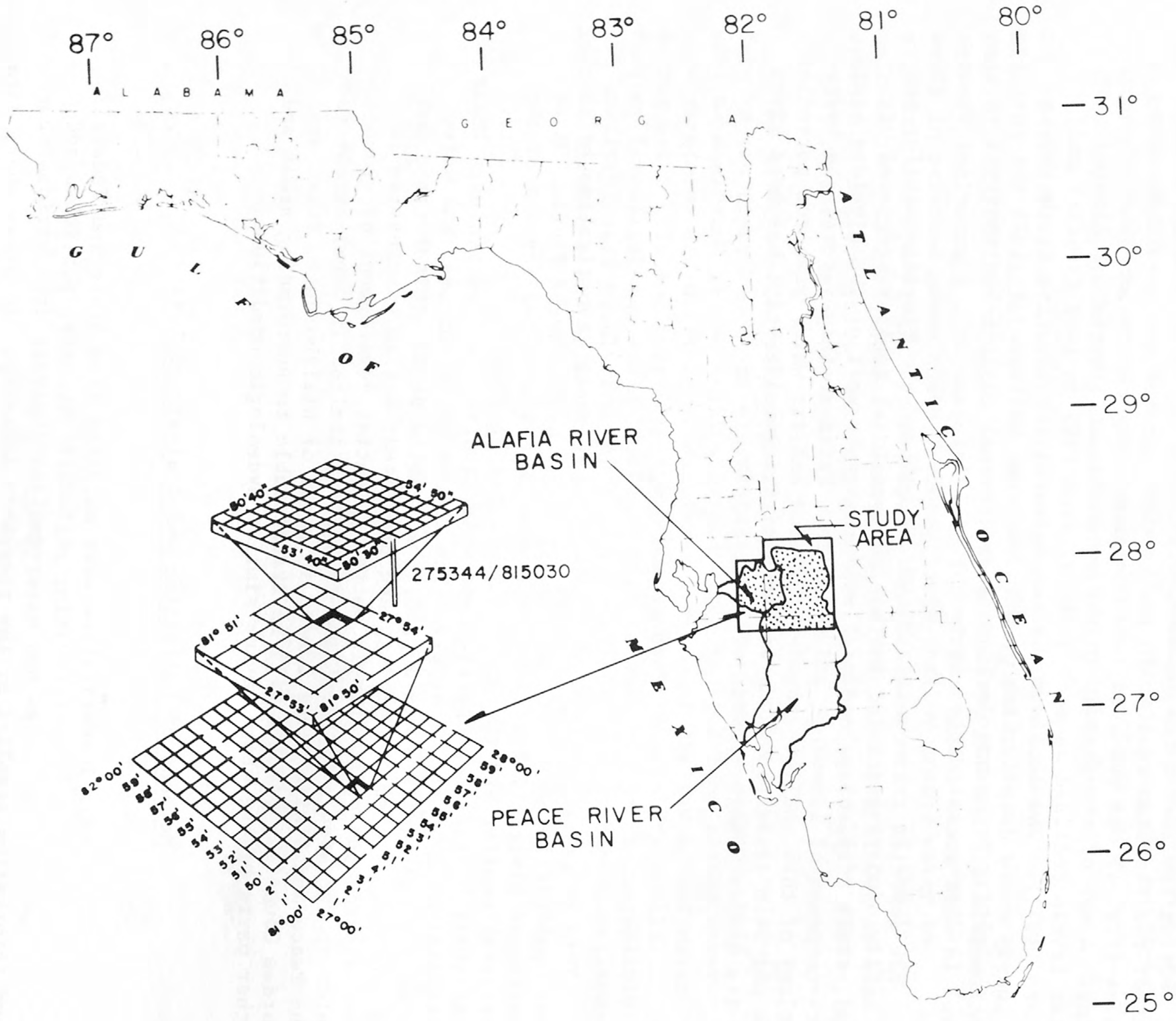

Figure 1 -- Location of the study area in the upper Peace and eastern Alafia River basins, and the latitude-longitude well-numbering system

A truck-mounted power auger was used in the test drilling to install shallow wells for monitoring both water quality and water levels. Prior to installation of the well at selected sites, a split-spoon core sample was taken at the bottom of the test hole where the well screen would be placed. The samples were analyzed for lithology and physical characteristics at the U.S. Geological Survey's Hydrologic Laboratory in Denver, Colorado.

Aquifer tests were conducted on wells for which records were obtained and characteristics were either known or could be determined using geophysical logging techniques. Aquifer characteristics including transmissivity, storage coefficient, and leakage coefficient were determined from pumping tests, specific capacity tests, and slug tests.

Water from 23 wells and surface-water bodies was analyzed for a suite of chemical quality constituents at the Geological Survey's Water Quality Laboratory in Atlanta, Georgia, and for radiochemical quality at the Survey's Analytical Services Unit in Denver, Colorado. Concentrations of selected constituents at each site are compared using Stiff diagrams. The concentrations are also compared to recommended drinking water standards of the National Academy of Sciences and National Academy of Engineering (1973).

For convenience of reference, all 321 data sites analyzed in this study are numbered serially on the figures and on the tables of supporting data. In addition to the serial numbers, all sites are keyed to the generally familiar section-township-range grid of the Federal land survey. Where possible, the exact location of the site is also given by a 12-character number that defines the latitude and longitude. An example of the latitude-longitude well number is illustrated in figure 1. The designation 275344/815030 indicates that the site is in the 1-second quadrangle bounded by lat 27°53'44" N. on the south and long 81°50'30" W. on the east.

Acknowledgments

The assistance and cooperation of the engineering and technical personnel of phosphate mining companies who provided information and aided in field work is sincerely appreciated. These include the International Minerals and Chemicals Corp., American Cyanamid Co., Agrico Chemical Co., Borden Chemical Co., W. R. Grace and Co., Mobil Chemical Co., Swift Chemical Co., C. F. Industries, and Gardenier, Inc. Special thanks are also extended to numerous well drillers in the area who made their time and experience available.

Grateful acknowledgment is here made to Barbara Boatwright, Southwest Florida Water Management District, for many beneficial discussions involving the exchange of ideas and concepts.

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

Multiply English unit	By	To obtain metric unit
feet (ft)	0.3048	meters (m)
square feet (ft^2)	.0929	square meters (m^2)
cubic feet (ft^3)	.0283	cubic meters (m^3)
gallons per day (gal/d)	.00004381	liters per second (L/s)
million gallons per day (Mgal/d)	.04381	cubic meters per second (m^3/s)
gallons per minute (gal/min)	.06309	liters per second (L/s)
inches (in)	25.4	millimeters (mm)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.589	square kilometers (km^2)
feet squared per day (ft^2/d)	.0929	meters squared per day (m^2/d)
tons, short (2,000 lb)	.907	metric tons (t)
acre-feet (acre-ft)	1,234	cubic meters (m^3)

DESCRIPTION OF THE AREA

Topography and Drainage

The upper Peace and eastern Alafia River basins comprise an area of 1,250 mi^2 in the heart of central Florida's land-pebble phosphate mining district (fig. 2). The Alafia River basin occupies the western 375-mi^2 section and the Peace River basin occupies the eastern 875-mi^2 section of the study area. Topography in the two basins ranges from more than 250 ft above msl (mean sea level) along northwest-southeast trending ridges, through a broad flatland ranging from 100-150 ft above msl, to the river valleys which are less than 100 ft above msl.

Much of the topography has been altered by strip mining (fig. 2). Phosphate pebbles were first discovered in 1884 and mining began along the river valleys where overburden had been thinned or removed by erosion. By the early 1900's the deeper lying phosphate ore beneath the flatlands and ridges was being mined. In 1968 Florida produced 39,000,000 tons of phosphate, most of which came from the land-pebble district (Florida Phosphate Council, personal commun., 1976). Many of the mined-out areas have not been reclaimed and stand as spoil piles and large basins filled with water and clay byproducts of the phosphate processing.

The drainage patterns are well developed in the valleys and flatlands of the upper Peace and eastern Alafia River basins, although in some areas drainage is poor due to low relief and swampy conditions. The normally dendritic pattern has been modified greatly by strip mining. The ridges are dissected by sinkholes and drainage patterns in these areas are not well developed.

Population

Population is used to estimate the water use of the shallow aquifers in the upper Peace and eastern Alafia River basins. Principal population centers in the upper Peace River basin are along the ridges and include the cities of Lakeland, Winter Haven, and Auburndale to the north, and Lake Wales to the east. The towns of Bartow, Fort Meade, and Bowling Green lie along the Peace River valley. The sole population center in the eastern Alafia River basin is the mining town of Mulberry. Total population of 23 incorporated and unincorporated places of 1,000 or more in the study area was 127,290, according to the 1970 census. Rural population of the area is about 67,000, or little more than one third the total population.

Climate

The area has a humid subtropical climate. Long-term climatological data are collected by the National Weather Service at 5 sites; Lake Alfred, Lakeland, Bartow, Winter Haven, and Mountain Lake. The average of the normal annual precipitation at these sites, based on the period 1941-70, is 52.48 in; however, during 1966-75 the annual rainfall at these sites averaged about 48 in. The average of the normal annual temperature at these sites is 72.3°F (Fahrenheit), or 22.4°C (Celcius). The average annual evaporation from a Class A pan at Lake Alfred was 68.99 in during 1966-75. Rainfall is greatest, temperatures highest, and evaporation rates highest during the summer. During the rainy season the aquifers are recharged by rainfall, stream discharge is greatest, the stress on the aquifers lessens owing to a reduction of ground-water pumpage for irrigation and municipal supply, and water levels recover.

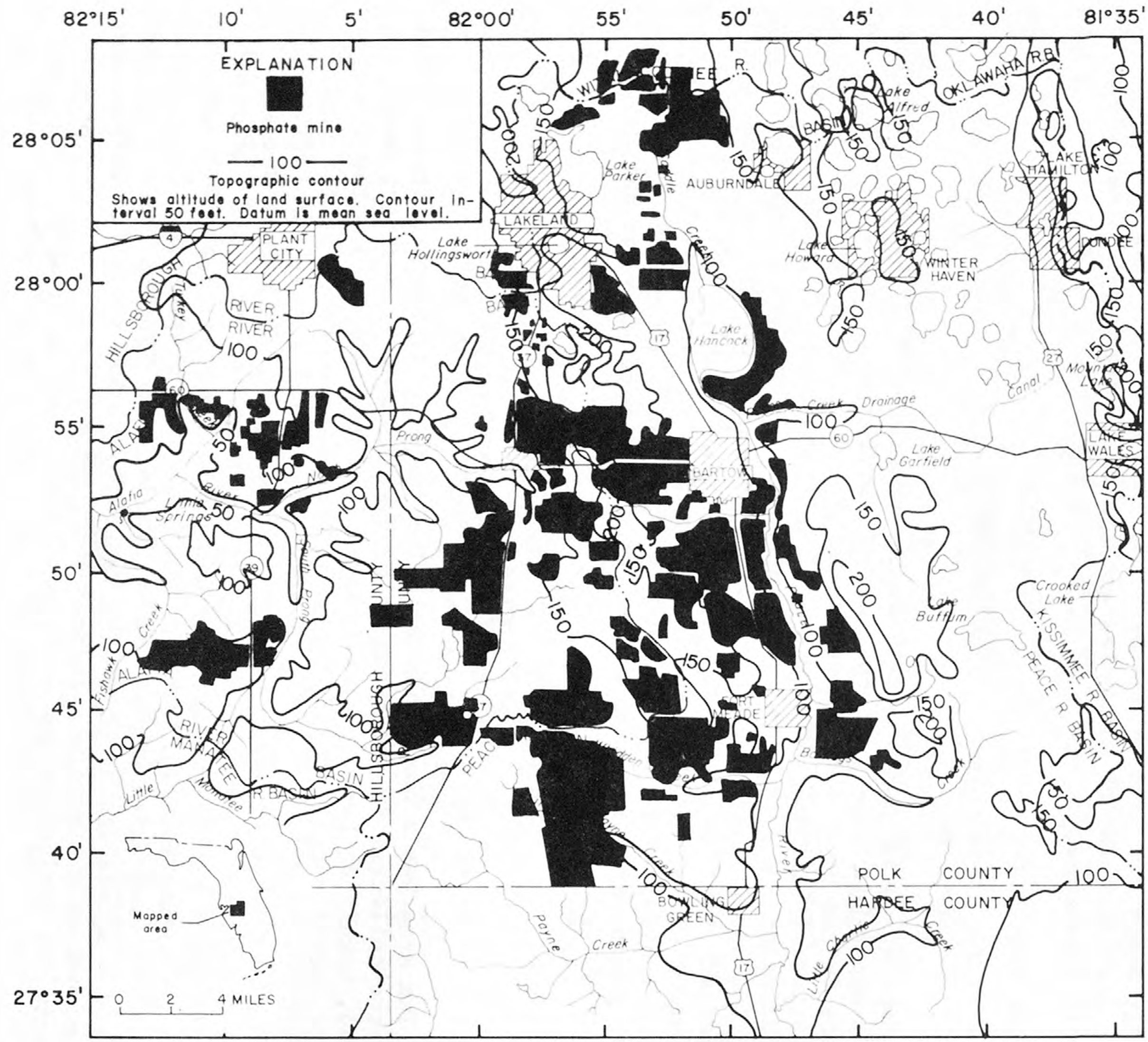

Figure 2.--Topography and mining areas, 1975.

Streamflow

The U.S. Geological Survey monitors the flow of the Peace and Alafia Rivers and their tributaries at several stations. Stations with long periods of record selected for analysis are the Alafia River at Lithia, about 2 mi upstream from the western boundary of the study area, and the Peace River at Zolfo Springs, about 4 mi downstream from the southern boundary of the study area. Records are current through the 1975 water year, October 1974 to September 1975 (U.S. Geological Survey, 1976).

Average discharge at the Peace River station for the 42-year period of record was 703 ft^3/s, or 11.56 in/yr from the basin, and average discharge for the 10-year period 1966-75 was 510 ft^3/s, or 8.39 in/yr from the basin. Average discharge at the Alafia River station for the 43-year period of record was 373 ft^3/s, or 15.12 in/yr from the basin, and average discharge for the 10-year period 1966-75 was 338 ft^3/s, or 13.74 in/yr. The reduction in streamflow during 1966-75 is largely due to the general deficiency of the regional rainfall during this same period.

Water Use

Both ground and surface water are used consumptively in the upper Peace and eastern Alafia River basins, although use of ground water greatly exceeds use of surface water. Average annual water use in this area is estimated at 398,000 acre-ft. Use is greatest during the dry spring as demand for irrigation and industrial make-up water is increased, and is least during the wet summer when irrigation ceases and most of the make-up water is supplied by rainfall.

During 1971 ground-water pumpage from the lower unit of the Floridan aquifer for industrial, irrigation, and municipal supplies totaled 369,000 acre-ft (Robertson and Mills, 1974). Industrial pumpage averaged 208 Mgal/d and was centered in active mining areas of the flatlands along the Peace-Alafia drainage basin divide; irrigation pumpage averaged 89.6 Mgal/d and was concentrated along the ridge areas where large citrus groves have been planted on the well-drained soil; and municipal pumpage averaged 31.9 Mgal/d and was in the population centers. Pumpage is small from the shallow aquifer compared to that from the lower unit of the Floridan aquifer. The shallow aquifers are used primarily for domestic and small-scale irrigation purposes in rural areas where municipal supplies are not available. Based on a rural population of 67,000 and a per capita use of 100 gal/d, an estimated 6.7 Mgal/d or 7,400 acre-ft of water is pumped annually from the shallow aquifers.

During 1965 use of surface water for irrigation in all of Polk County averaged 30 Mgal/d (Pride, 1970). The current study area is smaller than the county, and surface-water use in the study area is estimated at 20 Mgal/d or 22,000 acre-ft annually. Use of surface water from lakes and streams is limited because of resulting infringement upon riparian rights of other property owners. The largest single withdrawal is for industrial use from Lithia Springs, on the Alafia River about 1 mi above the confluence with Fishawk Creek. About 5 Mgal/d is withdrawn from the springs for phosphate processing. In several areas, water is withdrawn from streams and lakes for citrus grove irrigation.

Artificial Recharge

Artificial recharge through connector wells became a common practice by the phosphate industry during the 1970's. This concept involved drilling wells open to both the overburden, which contains the matrix ore, and the underlying limestone aquifers, thereby providing a direct hydraulic connection between them (Hutchinson and Wilson, 1974). Because a head difference exists, water drains by gravity from the overburden into the limestone. Thus, for the phosphate industry, the purpose for installing such wells is twofold: (1) from an economic standpoint, connector wells provide an inexpensive means for partly dewatering an area and establishing good bank stability for drag lines prior to mining; and (2) from the standpoint of resource conservation, drawdown in the lower unit of the Floridan aquifer caused by pumping is reduced. In areas where the natural water table is at or near the land surface, water normally lost to evapotranspiration and runoff is captured.

In 1972 the recharge rate was measured through 17 connector wells at a mine site (R. W. Coble, written commun., 1974). The flow rates ranged from 60 to 275 gal/min and averaged slightly more than 125 gal/min. During 1975 recharge through 86 connector wells in the upper Peace and eastern Alafia River basins averaged 165 gal/min per well and totaled 23,000 acre-ft, or about 6 percent of the 370,000 acre-ft of water withdrawn from the lower unit of the Floridan aquifer in 1971.

PREVIOUS STUDIES

Geologic studies in the upper Peace and eastern Alafia River basins utilized in this report include those by Cathcart (1963a, 1963b, 1963c, 1964, and 1966) and Cathcart and McGreevy (1959), which deal with the economic geology and core drilling in the land-pebble phosphate district; stratigraphic studies by Bergendahl (1956), Ketner and McGreevy (1959), and Carr and Alverson (1959); and the many geologic logs of the Bureau of Geology, Florida Department of Natural Resources, prepared by C. W. Bishop, R. O. Vernon, E. R. Applin, and others.

Hydrologic investigations include ground-water resources appraisals and records of Hillsborough County (Menke, Meredith, and Wetterhall, 1961 and 1964) and of Polk County (H. G. Stewart, 1963 and 1966). These reports present technical information and data on well construction and chemical quality of water. Kaufman (1967) appraised the effects of ground-water pumpage during 1934-65. Robertson (1973) investigated hydrologic conditions of the Lakeland ridge and Robertson and Mills (1974) estimated ground-water use during 1970-71 in the upper Peace and eastern Alafia River basins. Wilson (1975) defined hydrogeologic units in Hardee and DeSoto Counties and his definitions are extended to the current study area.

HYDROLOGIC FRAMEWORK

The hydrogeologic units underlying the upper Peace and eastern Alafia River basins include the surficial aquifer, the upper and lower units of the Floridan aquifer, and intervening confining beds (table 1). The units discussed and evaluated in this report are the surficial aquifer and the upper unit of the Floridan aquifer.

Surficial Aquifer

Thickness, Lithology, Yield

The deposits of the surficial aquifer comprise an overburden blanket that covers the upper Peace and eastern Alafia River basins (fig. 3). The aquifer is as much as 225 ft thick in the ridge areas where it is composed of dune remnants, and it thins from the ridges to the river valleys and is absent in the lower reaches of many stream channels (fig. 4 and table 2). The deposits are predominantly fine-to-medium sand, and become increasingly clayey and phosphatic with depth. The base of the aquifer consists of clayey sands and sandy clays within the Bone Valley and Hawthorn Formations. Based on analysis of 190 geologic and driller's logs, these basal clayey deposits form a semiconfining bed that restricts vertical movement of water between the surficial aquifer and the upper unit of the Floridan aquifer.

Median grain size averaged 0.26 mm for 21 surficial aquifer bottom-hole core samples (table 3). The effective porosity, or specific yield, of 10 of the core samples averaged 29 percent. The aquifer is unconfined, although locally it consists of a multi-layered system of sand and clay units that display varying potentiometric heads. Because the surficial aquifer is not an homogeneous hydrogeologic unit, it is not everywhere a reliable source of supply. Well yields generally are less than 100 gal/min to domestic and irrigation wells, which are constructed with a casing finished at the bottom with a screen. Yields could probably be increased if greater care were used in well construction, particularly with respect to screen diameter, screen length, and installation of gravel packing.

Table 1. -- Hydrogeologic units

Hydrogeologic unit	Approximate range in depth below land surface (ft)	Approximate range in thickness (ft)	Physical character	Aquifer and yield characteristics	Formation	Geologic age
Surficial aquifer and semiconfining beds	0	0-225	Fine-coarse sand, interbedded with clayey sand, clay, and marl, phosphatic; poorly sorted.	Wells rarely yield more than 100 gal/min. Transmissivity averages 1,900 ft^2/d. Excellent water quality.	Undifferentiated clastics and Bone Valley Formation	Holocene to Pliocene
Upper unit, Floridan aquifer	0-225	0-280	Interbedded sandy limestone and calcareous clay; dolomitic; phosphatic; fossiliferous.	Wells commonly yield up to 200 gal/min. Transmissivity averages 2,200 ft^2/d. Good water quality.	Hawthorn Formation, Tampa Limestone	Miocene
Confining bed	25-300	0-100	Sandy clay, marl, and chert; dense phosphatic; bluish-to-greenish-gray.	Relatively impermeable, yields very little water to wells.	Tampa Limestone	
Lower unit, Floridan aquifer	40-400	500	Cavernous limestone, dolomite and evaporites	Yields as much as 5,000 gal/min. of mineralized water. Transmissivity commonly greater than 25,000 ft^2/d.	Suwannee Limestone	Oligocene
					Ocala Limestone, Avon Park Limestone, Lake City Limestone	Eocene

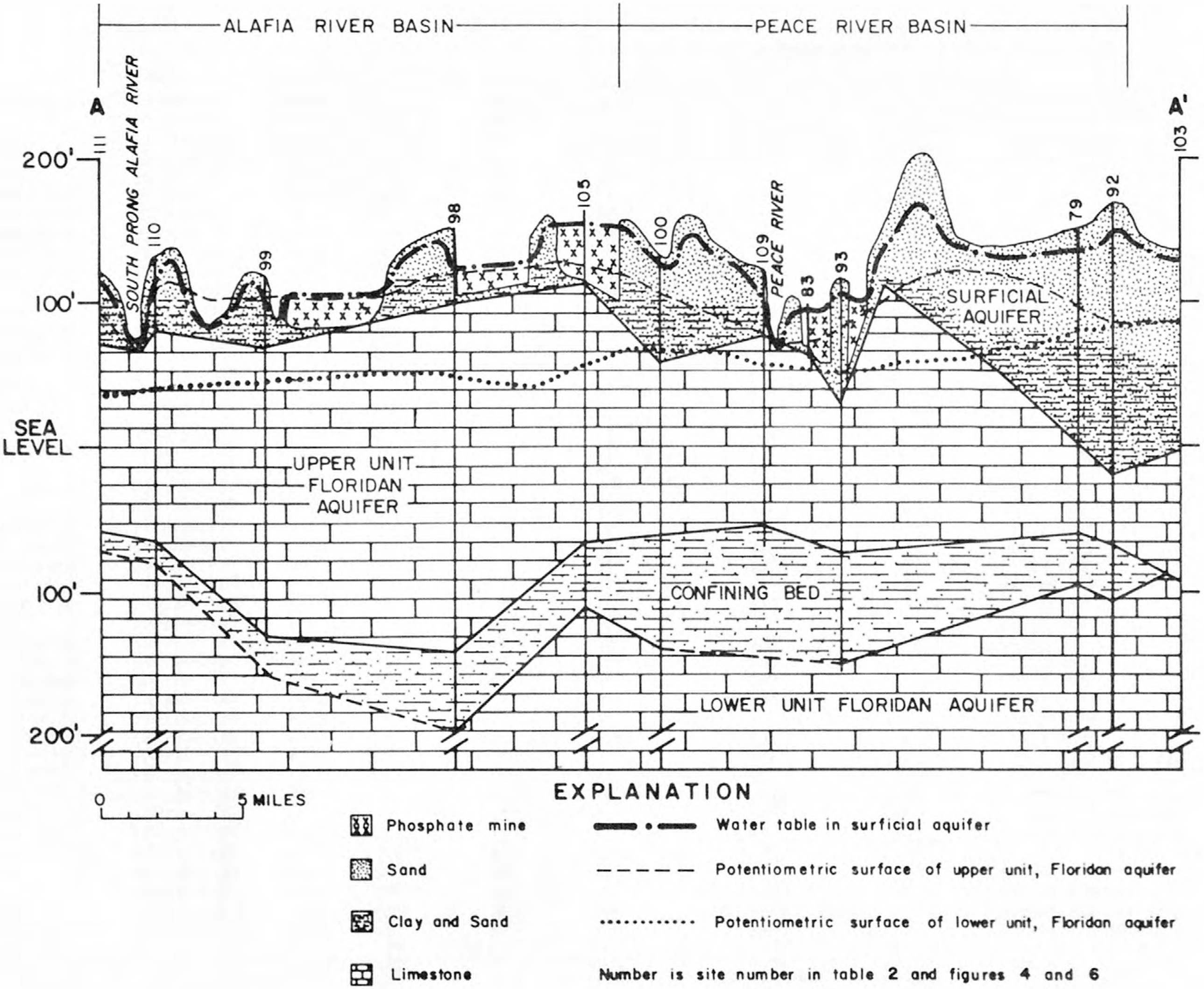

Figure 3 -- Hydrogeologic section A-A'

Table 2. -- Depths to tops of hydrogeologic units

Site number on fig. 4	Latitude/longitude	Section-township-range	FBG well number (W-)	Altitude of land surface (ft)	Depth of hole (ft)	Depth to top of hydrogeologic unit (ft)			Data source
						Upper unit, Floridan aquifer	Sand and clay unit, Tampa Limestone	Lower unit, Floridan aquifer	
1	---	33-33S-27E	---	85	78	77	---	---	Ketner & McGreevy (1959)
2	---	32-33S-27E	---	65	56	>56	---	---	Ketner & McGreevy (1959)
3	---	31-33S-27E	---	80	73	73	---	---	Ketner & McGreevy (1959)
4	---	35-33S-26E	---	125	52	52	---	---	Ketner & McGreevy (1959)
5	---	34-33S-26E	---	132	56	56	---	---	Ketner & McGreevy (1959)
6	---	31-33S-26E	---	107	52	47	---	---	Ketner & McGreevy (1959)
7	---	33-33S-25E	---	132	62	>62	---	---	Cathcart & McGreevy (1959)
8	---	33-33S-25E	449	125	660	70	345	410	Geologic log
9	---	20-33S-25E	---	109	315	49	260	280	Drill log
10	---	26-33S-23E	---	121	1702	43	324	467	Dames & Moore (1975)
11	---	29-33S-23E	---	115	132	87	>132	---	Drill log
12	---	21-33S-25E	---	75	35	32	---	---	Cathcart & McGreevy (1959)
13	---	19-33S-24E	---	120	905	64	340	379	Drill log
15	273520/813455	24-33S-27E	4333	100	1042	151	203	290	Drill log
16	273525/814728	23-33S-25E	4720	81	1070	75	228	340	Drill log
23	273548/814218	22-33S-26E	604	115	1176	80	200	230	Drill log
24	---	15-33S-24E	---	100e	60	50	---	---	Drill log
25	273641/813420	13-33S-27E	1832	100	1082	172	225	295	Drill log
26	---	08-33S-25E	---	70	30	25	---	---	Cathcart & McGreevy (1959)
28	273705/814345	08-33S-26E	7880	106	1070	91	195	253	Drill log
29	273735/815434	09-33S-24E	2494	120	932	34e	310	378	Drill log
30	273759/815259	11-33S-24E	965	115	210	79	>115	---	Drill log
31	---	05-33S-25E	---	101	390	50	290	350	Drill log
32	273823/814240	03-33S-24E	2732	116	1010	90	200	215	Geologic log
33	---	01-33S-22E	11570	137	462	52	300	386	Geologic log
35	273843/813734	04-33S-27E	1172	121	270	87	225	240	Drill log
37	---	34-32S-22E	---	135	916	55	270	293	Drill log
38	---	33-32S-24E	---	126	31	30	---	---	Cathcart (1966), plate 1
39	---	34-32S-24E	---	125	34	34	---	---	Cathcart (1966), log J
40	---	33-32S-25E	---	130	60	58	---	---	Cathcart & McGreevy (1959)
41	273847/813946	36-32S-26E	---	116	51	36	---	---	USGS test hole
42	273937/815159	36-32S-24E	---	126	42	40	---	---	USGS test hole
43	---	28-32S-23E	---	135	1020	44	255	305	Drill log
44	---	30-32S-22E	---	115	65	>65	---	---	Cathcart & McGreevy (1959)
45	---	30-32S-22E	---	115	65	>65	---	---	Cathcart & McGreevy (1959)
49	---	28-32S-24E	---	130	34	>34	---	---	Cathcart (1966), plate 1
50	274036/815606	20-32S-23E	---	134	29	28	---	---	Cathcart (1966), plate 1
51	---	20-32S-23E	---	150	50	>50	---	---	Cathcart & McGreevy (1959)
52	---	21-32S-25E	---	80	21	17	---	---	Cathcart & McGreevy (1959)
53	---	22-32S-24E	---	133	31	30	---	---	Cathcart (1966), plate 1
56	---	15-32S-25E	---	80	21	19	---	---	Cathcart & McGreevy (1959)
57	---	15-32S-24E	---	137	36	35	---	---	Cathcart (1966), plate 1
58	---	16-32S-22E	---	125	57	>57	---	---	Cathcart & McGreevy (1959)
59	---	17-32S-24E	---	145	33	32	---	---	Cathcart (1966), log G

e Estimated.
> Greater than.
< Less than.

Table 2. -- Depths to tops of hydrogeologic units - continued

Site number on fig. 4	Latitude/longitude	Section-township-range	FBG well number (W-)	Altitude of land surface (ft)	Depth of hole (ft)	Depth to top of hydrogeologic unit (ft): Upper unit, Floridan aquifer	Sand and clay unit, Tampa Limestone	Lower unit, Floridan aquifer	Data source
60	274130/815622	17-32S-23E	---	125	36	35	---	---	Cathcart (1966), plate 1
64	274145/815618	17-32S-23E	---	137	41	40	---	---	Cathcart (1966), plate 1
66	274155/815621	17-32S-23E	---	138	37	36	---	---	Cathcart (1966), plate 1
67	274208/815615	17-32S-23E	---	142	47	47	---	---	Cathcart (1966), plate 1
71	---	10-32S-24E	---	137	38	37	---	---	Cathcart (1966), plate 1
72	---	09-32S-24E	---	137	48	47	---	---	Cathcart (1966), log F
73	---	09-32S-26E	---	120e	52	30	---	---	Cathcart (1966), log A
75	274223/815618	08-32S-23E	---	143	39	38	---	---	Cathcart (1966), plate 1
76	274301/814144	10-32S-26E	411	192	926	<190	256	340	Geologic log
77	---	03-32S-23E	---	145	45	> 45	---	---	Cathcart & McGreevy (1959)
79	274345/813655	04-32S-27E	64	150e	735	150e	212e	350e	Geologic log
81	274352/820610	03-32S-22E	---	92	817	40	250	350	Drill log, questionable
83	---	36-31S-25E	---	100	33	32	---	---	Cathcart (1966), plate 1
84	---	35-31S-26E	---	145	45	40	---	---	Cathcart & McGreevy (1959)
85	---	34-31S-26E	---	190	100	>100	---	---	Cathcart & McGreevy (1959)
86	---	31-31S-27E	---	140	100	>100	---	---	Cathcart & McGreevy (1959)
87	---	33-31S-27E	---	140	75	70	---	---	Cathcart & McGreevy (1959)
88	---	36-31S-25E	---	95	367	35	150	225	Drill log
90	274400/820708	04-32S-22E	---	133	826	65	238	245	Drill log
92	274412/813605	34-31S-27E	967	167	963	185	235	275	Geologic log
93	274433/874456	31-31S-26E	---	115	265	84	190	265	Drill log
95	---	29-31S-24E	---	145	52	>52	---	---	Cathcart (1966), log B
96	---	28-31S-21E	---	145	95	>95	---	---	Cathcart & McGreevy (1959)
97	---	26-31S-21E	---	140	81	>81	---	---	Cathcart & McGreevy (1959)
98	274457/815752	25-31S-23E	3852	148	970	50	290	345	Geologic log
99	274457/820358	25-31S-22E	---	115	247	45	245	>247	LaMoreaux (1975c)
100	2745--/8151--	30-31S-25E	5	131	838	73	195	272	Geologic log
102	274505/814903	28-31S-25E	---	135	37	33	---	---	USGS test hole
103	274524/813409	25-31S-27E	5351	135	370	140	Absent	230	Geologic log
105	274509/815309	26-31S-24E	2304	163	911	50	230	275	Stewart (1963)
109	274651/814711	23-31S-25E	---	122	192	46	178	>192	SWFWMD log
110	274555/820715	20-31S-22E	2152	130	816	50	195	210	Geologic log
111	2746--/8209--	24-31S-21E	---	122	700	50	180	Unknown	Menke & others (1961)
117	274642/815432	18-31S-24E	---	122	839	40	255	310	LaMoreaux (1975a)
120	274724/814225	15-31S-26E	3779	165	255	90	220	>250	Geologic log
124	---	11-31S-23E	---	130e	300	50	230	>300	Drill log
125	---	12-31S-23E	---	130e	250	60	240	>250	Drill log
126	---	10-31S-23E	---	140e	496	81	281	369	Drill log
129	274754/814900	09-31S-25E	1008	131	802	50	190	210	Geologic log
130	2748--/8208--	07-31S-22E	1005	99	10,129	30	110	Unknown	Menke & others (1961)
131	274803/814820	10-31S-25E	639	115	800	30	150	200	Geologic log
132	274805/814821	10-31S-25E	995	110	748	25	130	175	Geologic log
135	274817/820115	09-31S-23E	---	155e	79	79	---	---	Cathcart (1963a), log H
137	---	03-31S-23E	---	145e	470	75	240	310	Drill log
138	---	05-31S-23E	---	160e	266	72	194	266	Drill log
144	---	35-30S-22E	---	141	43	43	---	---	Cathcart (1963a), log G
145	---	31-30S-23E	---	160e	750	60	260	270	Drill log
146	---	31-30S-23E	---	160e	320	60	245	300	Drill log
151	274957/814545	36-30S-25E	10	199	681	129	222	257	Geologic log

Table 2. -- Depths to tops of hydrogeologic units - continued

Site number on fig. 4	Latitude/longitude	Section-township range	FBG well number (W-)	Altitude of land surface (ft)	Depth of hole (ft)	Depth to top of hydrogeologic unit (ft)			Data source
						Upper unit, Floridan aquifer	Sand and clay unit, Tampa Limestone	Lower unit, Floridan aquifer	
155	---	26-30S-22E	---	115	74	74	---	---	Cathcart (1963a), log F
156	---	30-30S-24E	---	130e	432	43	160	207	Drill log
157	---	25-30S-25E	---	195e	309	90	200	215	Drill log
158	---	28-30S-27E	---	145	85	84	---	---	Cathcart & McGreevy (1959)
159	---	29-30S-27E	---	130	81	80	---	---	Cathcart & McGreevy (1959)
163	275038/814838	28-30S-25E	61	85	4540	20	125	140	Geologic log
167	---	21-30S-21E	---	71	41	41	---	---	Cathcart (1963a), log D
168	---	23-30S-25E	---	120e	132	20	130	>132	Drill log
169	---	20-30S-26E	---	150e	151	65	168	>151	Drill log
170	---	21-30S-26E	---	160e	500	80	177	210	Drill log
173	275123/814130	23-30S-26E	928	163	658	95	200	230	Geologic log
174	275137/814617	24-30S-25E	1006	171	717	60	180	260	Geologic log
176	275147/814852	16-30S-25E	2856	115	618	40	160	180	Geologic log
177	275150/815555	20-30S-24E	4185	173	832	60	190	245	Stewart (1966, p. 16)
178	---	18-30S-22E	119	66	776	49	90	190	Geologic log
179	---	16-30S-22E	---	55	18	18	---	---	Cathcart (1963a), log E
180	---	13-30S-22E	---	115	250	60	135	235e	Drill log
181	---	18-30S-27E	---	110	83	80	---	---	Cathcart & McGreevy (1959)
182	---	13-30S-26E	---	132	83	82	---	---	Cathcart & McGreevy (1959)
183	---	15-30S-26E	---	139	95	91	---	---	Cathcart & McGreevy (1959)
184	---	17-30S-26E	---	130	50	45	---	---	Cathcart & McGreevy (1959)
188	275224/820706	16-30S-22E	1448	57	820	25	75	95	Drill log
190	275228/815049	18-30S-25E	2431	133e	180	80	>180	---	Geologic log
191	---	11-30S-21E	---	50	12	12	---	---	Cathcart (1963a), log X
192	2753--/8142--	09-30S-26E	3747	141	720	100	170	200	Geologic log
194	275302/815154	12-30S-24E	---	120	1400	20	130	170	USGS test hole
195	275324/820154	08-30S-23E	410	115	190	<70	>190	---	Geologic log
196	275326/813412	12-30S-27E	500	242	1063	225	280	290	Geologic log
198	---	06-30S-22E	267	100	805	49	134	185	Geologic log
199	275350/815142	01-30S-24E	956	119	635	40	125	155	Geologic log
201	275405/815255	02-30S-24E	1801	147	1085	40	140	220	Geologic log
206	275423/815507	04-30S-24E	2765	218	721	120	250	300	Stewart (1966, p. 16)
208	---	32-29S-25E	---	105e	200	28	80	95	Drill log
209	---	36-29S-24E	---	140e	500	44	107	139	Drill log
211	275433/814650	35-29S-25E	---	110	141	70	---	---	Drill log
214	275441/813608	34-29S-27E	904	131	1155	120	156	164	Geologic log
216	275514/820732	32-29S-22E	---	90	36	31	---	---	USGS test hole
217	2755--/8207--	28-29S-22E	2165	135	112	49	95	>112	Geologic and drill log
220	---	26-29S-25E	---	110e	173	55	108	122	Drill log
224	---	20-29S-24E	---	250e	372	101	226	257	Drill log
229	275659/813432	24-29S-27E	341	222	732	210	272	305	Geologic log
230	275702/814702	23-29S-25E	672	128	601	105	Absent	---	Geologic log
231	---	13-29S-23E	---	160e	207	56	103	121	Drill log
235	275729/814047	13-29S-26E	952	150	663	125	Absent	---	Geologic log
238	---	27-29S-22E	2491	143	234	80	148	160	Geologic log
242	---	11-29S-23E	---	150e	280	60	140	160	Drill log
243	---	07-29S-21E	---	60	65	60	---	---	Cathcart & McGreevy (1959)
249	275659/813432	24-29S-27E	341	222	732	210	272	305	Geologic log
250	275851/814658	11-29S-25E	4634	140	290	60	Absent	---	Stewart (1966, p. 16)

Table 2. -- Depths to tops of hydrogeologic units - continued

Site number on fig. 4	Latitude/longitude	Section-township-range	FBG well number (W-)	Altitude of land surface (ft)	Depth of hole (ft)	Depth to top of hydrogeologic unit (ft)			Data source
						Upper unit, Floridan aquifer	Sand and clay unit, Tampa Limestone	Lower unit, Floridan aquifer	
253	---	05-29S-26E	2131	135	650	75	Absent	---	Geologic log
254	---	05-29S-24E	---	110e	22	18	---	---	Cathcart (1964), log U
257	275943/820140	05-29S-23E	633	132	671	25	90	145	Geologic log
258	275946/815338	03-29S-24E	4932	142	640	60	130	150	Stewart (1966, p. 16)
259	---	33-28S-24E	4775	140e	200	60	100	130	Stewart (1966, p. 16)
260	---	33-28S-22E	---	141	37	37	---	---	Cathcart (1963b), log D26
261	---	35-28S-21E	---	120	77	>77	---	---	Cathcart & McGreevy (1959)
262	275954/820101	33-28S-23E	632	135	683	50	110	145	Geologic log
264	---	25-28S-25E	---	140	85	81	---	---	Cathcart & McGreevy (1959)
265	---	26-28S-24E	---	120e	29	29	---	---	Cathcart (1964), log H
266	---	27-28S-22E	2491	143	234	80	148	160	Geologic log
267	---	28-28S-22E	---	135e	93	26	54	86	Cathcart (1963b), log D22
268	---	30-28S-22E	---	126e	39	28	>39	---	Cathcart (1963b), log D25
269	280043/815300	29-28S-24E	724	119	1037	40	100	115	Geologic log
270	280043/820732	29-28S-22E	4621	129	650	40	130	Unknown	Menke & others (1961)
271	280058/814352	29-28S-26E	864	165	240	110	170	200	Geologic log
274	---	21-28S-25E	---	135	50	48	---	---	Cathcart & McGreevy (1959)
275	---	20-28S-25E	---	132	40	39	---	---	Cathcart & McGreevy (1959)
276	---	22-28S-25E	---	131	78	74	---	---	Cathcart & McGreevy (1959)
277	---	20-28S-23E	---	134	1846	14	93	135	Stewart (1966, p. 20)
281	280204/814926	21-28S-25E	3633	130	955	75	115	158	Geologic log
282	280235/814451	18-28S-26E	518	141	550	Absent	90	120	Geologic log
283	280239/815724	24-28S-24E	3751	208	716	100	220	230	Geologic log
284	---	13-28S-25E	---	150	666	80	130	134	Drill log
285	---	15-28S-26E	---	146	100	98	---	---	Cathcart & McGreevy (1959)
286	---	14-28S-26E	---	155	120	110	---	---	Cathcart & McGreevy (1959)
287	---	15-28S-24E	---	120e	31	31	---	---	Cathcart (1964), log D
288	---	15-28S-24E	3425	124	191	60	96	107	Stewart (1963, p. 95)
289	---	18-28S-24E	3773	147	328	51	106	143	Stewart (1963, p. 95)
292	280304/815412	10-28S-24E	1800	141	570	60	90	100	Geologic log
295	---	07-28S-27E	458	103	600	90	110	160	Geologic log
296	280319/815124	07-28S-25E	3772	113	243	42	71	98	Drill log
298	280337/813711	09-28S-27E	1416	164	561	130	Absent	---	Geologic log
300	280348/814747	10-28S-25E	865	147	520	68	115	125	Geologic log
301	280352/814727	11-28S-25E	872	169	616	90	120	140	Geologic log
302	---	02-28S-24E	3770	110	59	38	>59	---	Stewart (1963, p. 97)
303	---	02-28S-24E	3767	121	59	37	>37	---	Stewart (1963, p. 97)
304	---	05-28S-24E	---	135e	27	26	---	---	Cathcart (1964), log G
305	---	05-28S-24E	---	135e	36	36	---	---	Cathcart (1964), log B
306	---	03-28S-23E	---	160e	190	60	120	141	Drill log
309	280446/814036	01-28S-26E	616	152	592	40	Absent	---	Geologic log
311	---	34-27S-24E	4018	133	1196	70	75	85	Geologic log
314	280522/214737	34-27S-25E	2647	159e	580	100	140	150	Geologic log
315	280535/815640	31-27S-24E	3769	136	82	37	59	74	Geologic log
317	---	38-27S-27E	3207	178	570	144	Absent	---	Geologic log
318	280559/815748	25-27S-23E	448	158	550	65	76	110	Geologic log
319	280617/814252	28-27S-26E	407	134	490	Absent	70	80	Geologic log
321	280634/813723	28-27S-27E	402	178	803	145	Absent	---	Geologic log

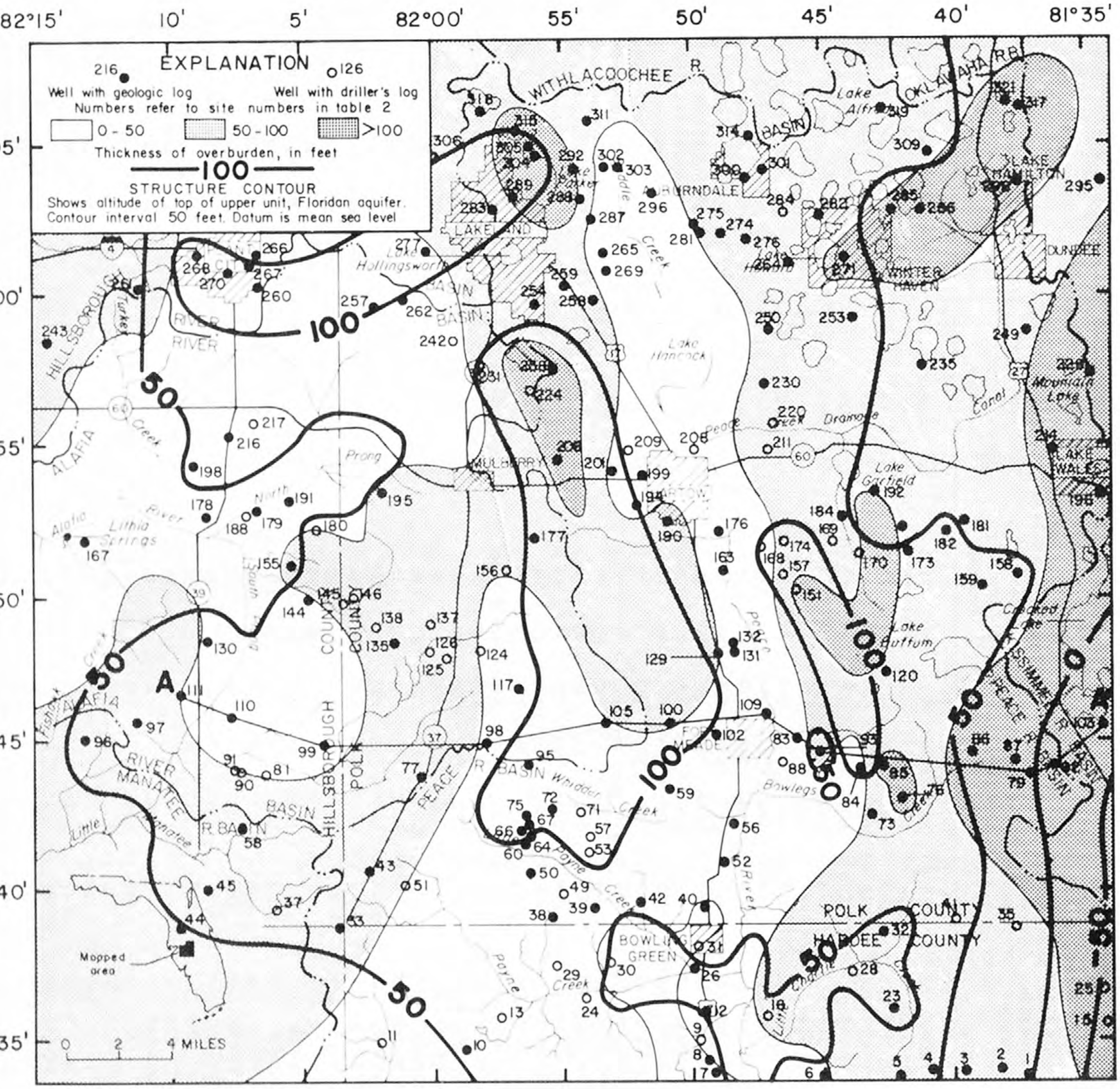

Figure 4 -- Altitude of the top of the upper unit, Floridan aquifer, and thickness of overburden deposits

Table 3. -- Physical characteristics of the surficial aquifer

[From core samples analyzed at U.S. Geological Laboratory, Denver, Colorado.]

Site number on fig. 10	Latitude/longitude	Section-township-range	Depth of sample (ft)	Median grain size (mm)	Clay content (percent)	Effective porosity (percent)
14	273516/814628	24-33S-25E	17	0.26	0	29.5
34	273835/814637	01-33S-25E	22	.37	5	19.3
48	274004/815330	27-32S-24E	22	.17	10	--
54	274043/813733	21-32S-27E	32	.25	10	--
68	274216/820847	07-32S-22E	22	.21	5	--
89	274400/813552	34-31S-27E	22	.31	0	--
94	274451/815316	35-31S-24E	27	.61	10	--
102	274505/814903	28-31S-25E	22	.21	5	35.8
104	274536/815938	27-31S-23E	17	.23	10	--
107	274544/821442	30-31S-21E	22	.35	0	--
108	274547/820725	20-31S-22E	32	.39	15	32.9
114	274622/814141	23-31S-26E	17	.25	10	25.3
122	274731/820323	13-31S-22E	22	.29	0	34.7
142	274912/814906	04-31S-25E	32	.21	15	21.6
143	274914/814607	01-31S-25E	32	.23	0	33
150	274942/815315	35-30S-24E	22	.14	20	--
152	275002/815850	35-30S-24E	17	.16	0	--
162	275032/814227	27-30S-26E	42	.24	0	27.9
165	275059/820904	30-30S-22E	18	.19	15	30.1
212	275433/814734	34-29S-25E	53	.23	10	--
256	275918/820719	04-29S-22E	22	.21	0	--

Transmissivity and Storage Coefficient

Hydraulic characteristics of the surficial aquifer were determined from pumping tests at two sites. Aquifer test results are summarized in table 4.

The transmissivities of the surficial aquifer and the upper unit of the Floridan aquifer varies considerably from place to place, as shown in figure 5. The transmissivity and storage coefficient of the surficial aquifer at site 91 in eastern Alafia River basin are 1,600 ft^2/d and 0.05, respectively. At site 42 in the upper Peace River basin, transmissivity and storage coefficient are 2,200 ft^2/d and 0.005, respectively. For analytical purposes, average transmissivity of the aquifer is estimated at 1,900 ft^2/d.

The low values of storage coefficient at sites 42 and 91 probably indicate incomplete dewatering of the sand in the cone of depression or anisotropy due to stratification of the surficial aquifer. Gravity drainage through an unconfined stratified aquifer progresses slowly, therefore, the storage coefficient appears to vary and to increase at a diminishing rate with the time of pumping (Walton, 1962, p. 6). A storage coefficient of 0.29, obtained from effective porosity data, is probably a more reliable estimate of this aquifer characteristic for long-term drawdown predictions.

Upper Unit, Floridan Aquifer

Lithology, Thickness, Yield

> "The upper unit of the Floridan aquifer consists of permeable limestone and dolomite beds of the Hawthorn Formation and Tampa Limestone (limestone unit)....The upper unit underlies all of DeSoto and Hardee Counties and in much of the area is hydraulically separated from the surficial aquifer by clay and marl, and from the lower unit of the Floridan aquifer by the sand and clay unit of the Tampa Limestone." (Wilson, 1975, p. 58.)

The aquifer defined by Wilson extends northward from Hardee County into Polk County where it is equivalent to the secondary artesian aquifer of Stewart (1966).

Topographically, the upper surface is an eroded karst plain with incised valleys that correspond to the present-day Peace and Alafia River basins (fig. 4). Because the upper part of the aquifer has been weathered, this zone probably is more permeable than deeper zones.

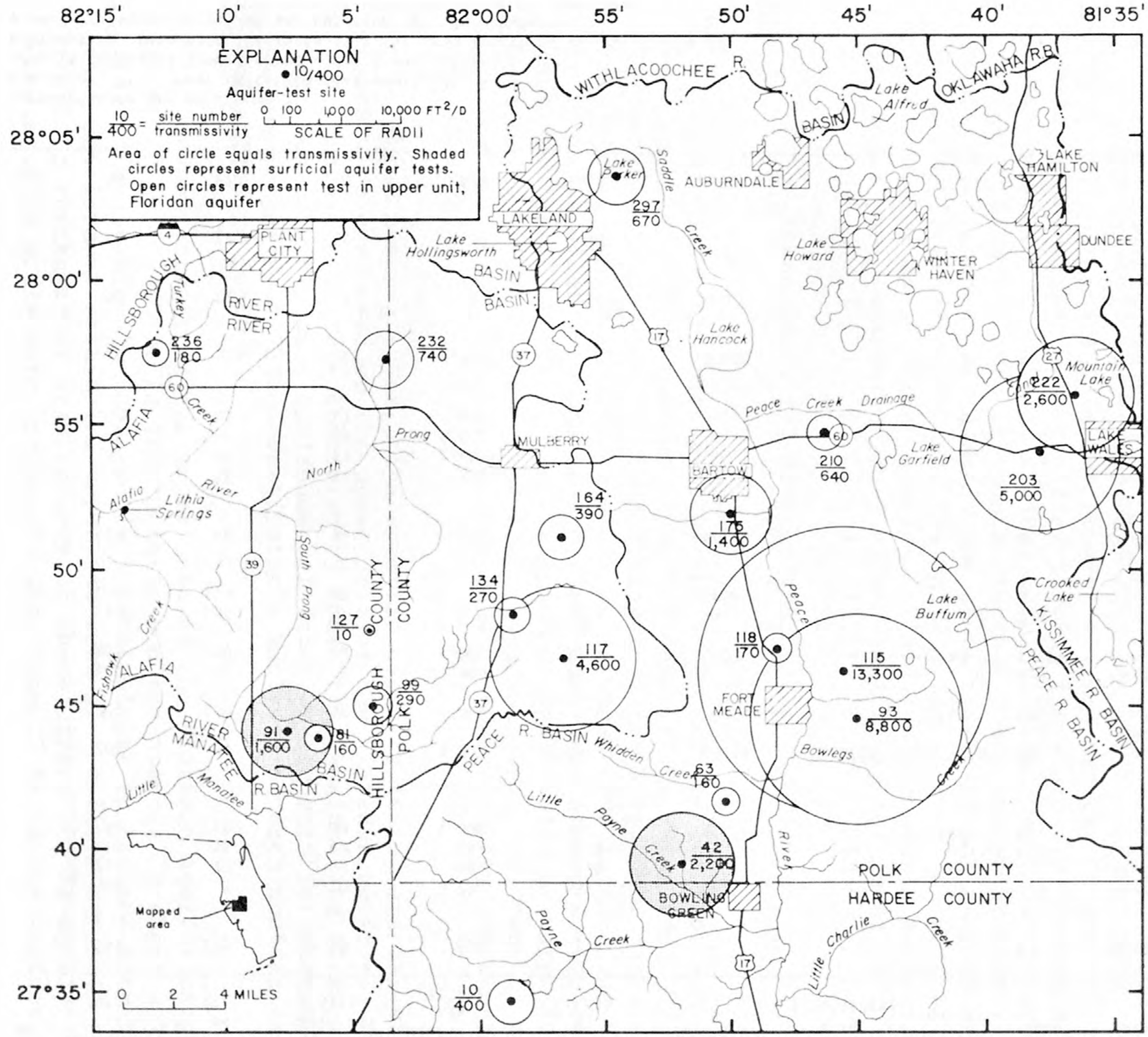

Figure 5 -- Transmissivity of the surficial aquifer and of the upper unit,
Floridan aquifer, at test sites

Table 4. -- Summary of aquifer tests

Site number[1]	Aquifer[2]	Aquifer thickness[3] ha (ft)	Amount of open hole hw (ft)	Amount of aquifer cased off[4] (ft)	Aquifer trans-missivity[5] Ta (ft^2/d)	Hydraulic conductivity K (ft/d)	Storage coefficient S	Leakage coefficient K'/B' [(ft/d)/ft]	Duration of test (hours)	Type of test[6]	Analytical technique	Source of data
10	UF	283	275	55	400	1.4	--	--	--	R	Jacob (1963)	Dames & Moore (1975)
42	SA	40	3	20	2,200	55	0.0051	--	72	P-3	Jacob (1963)	U.S.G.S.
63	UF	210	97	13	160	.8	--	--	--	R	Jacob (1963)	U.S.G.S.
81	UF	210	38	82	160	.8	--	--	1.7	P-0	Jacob (1963)	U.S.G.S.
91	SA	50	10	38	1,600	32	.05	--	144	P-4	Jacob (1963)	Water and Air Re-search (1975)
93	UF	106	38	0	8,800	83	.00018	0.00025	75.5	P-1	Hantush (1956)	U.S.G.S.
99	UF	202	150	52	290	1.4	.000042	--	24	P-1	Jacob (1963)	LaMoreaux (1975c)
115	UF	140	89	8	13,300	95	--	--	.7	P-0	Jacob (1963)	U.S.G.S.
117	UF	215	150	25	4,600	21	.00021	--	48	R, P-1	Jacob (1963)	Lamoreaux (1975a)
118	UF	165	135	17	170	1	--	--	1.7	P-0	Jacob (1963)	U.S.G.S.
127	UF	150	113	47	10	.1	.0001	--	0	S	Cooper and others (1967)	U.S.G.S.
134	UF	180	46	34	270	1.5	.0001	--	0	S	Cooper and others (1967)	U.S.G.S.
164	UF	120	75	32	390	3.3	--	--	1.7	P-0	Jacob (1963)	U.S.G.S.
175	UF	120	40	13	1,400	11.7	--	--	1.7	P-0	Jacob (1963)	U.S.G.S.
203	UF	90	101	0	5,000	55	--	--	1.7	P-0	Jacob (1963)	U.S.G.S.
210	UF	60	33	13	640	10.7	--	--	0	S	Cooper and others (1967)	U.S.G.S.
222	UF	70	32	8	2,600	37	.0001	--	0	S	Cooper and others (1967)	U.S.G.S.
232	UF	65	21	9	740	11.4	.001	--	0	S	Cooper and others (1967)	U.S.G.S.
236	UF	40	17	15	180	.5	--	--	0	S	Cooper and others (1967)	U.S.G.S.
297	UF	40	27	0	670	16.8	--	--	1.7	P-0	Jacob (1963)	U.S.G.S.

[1]Site numbers correspond to map of figure 5.
[2]SA = Surficial aquifer; UF = Upper unit, Floridan aquifer.
[3]Aquifer thickness is estimated from figures 4 and 6 and table 2.
[4]Estimated by subtracting overburden thickness (fig. 4) from length of casing (table 5).
[5]For slug tests well transmissivity (Tw) was adjusted by: Ta = Twha/hw.
[6]R = Recovery test; P-3 = Pump test, 3 distant observation wells; S= Slug test.

The underlying sand and clay unit of the Tampa Limestone, averaging 42 ft thick, forms a southward dipping depression beneath the Peace River. The aquifer thickness over this depression ranges from less than 30 ft along the northern basin boundaries to more than 250 ft, 10 mi southwest of Bowling Green (fig. 6 and table 2). The aquifer thins to the north. In the Lake Hamilton area and in the Kissimmee River basin, the aquifer appears to be in direct hydraulic connection with the lower unit of the Floridan aquifer as geologic logs indicate the absence of the intervening sand and clay unit of the Tampa Limestone.

Many domestic and low-yield irrigation wells tap the upper unit of the Floridan aquifer. Yields generally range between 10 and 200 gal/min. Wells are constructed by drilling through the weathered zone to hard rock, setting a metal or plastic casing, then drilling open-hole through the casing to a cavity zone or to a depth that meets the water-supply requirements of the owner. Frequently the upper unit will not meet an owner's water-supply requirements and the well is finished in the more productive lower unit of the Floridan aquifer. Yield could possibly be increased if the upper part (weathered zone) of the aquifer is not cased off.

Transmissivity, Storage and Leakage Coefficients

Hydraulic characteristics of the upper unit of the Floridan aquifer were determined from pumping, specific capacity, or slug tests of wells for which records were obtained during this investigation. Aquifer test results are summarized in table 4. Wells whose construction was known or could be determined from geophysical logs were deemed suitable for testing; consequently, many are abandoned supply wells or water-level monitoring wells. Because the history of such wells is unknown, derived aquifer characteristics of the sample do not necessarily represent average conditions.

Three pumping tests, nine specific capacity tests, and six slug tests were conducted on the upper unit of the Floridan aquifer. Two of the pumping tests were conducted by consulting engineering firms in conjunction with regional environmental impact statements for phosphate-mining companies. This investigator's analysis of each aquifer test is summarized in table 4.

Transmissivity of the upper unit of the Floridan aquifer ranges from 10 ft^2/d to 13,300 ft^2/d for 18 tests and the average is about 2,200 ft^2/d (fig. 5 and table 4). Apparently transmissivity is related more to solution development within the upper few feet of the limestone than to variations in thickness or stratigraphy of the aquifer. Of 12 aquifer tests conducted on wells which cased off more than 10 ft of the aquifer, transmissivity averaged 723 ft^2/d. Of six tests conducted on wells which cased off less than 10 ft, transmissivity averaged 5,185 ft^2/d.

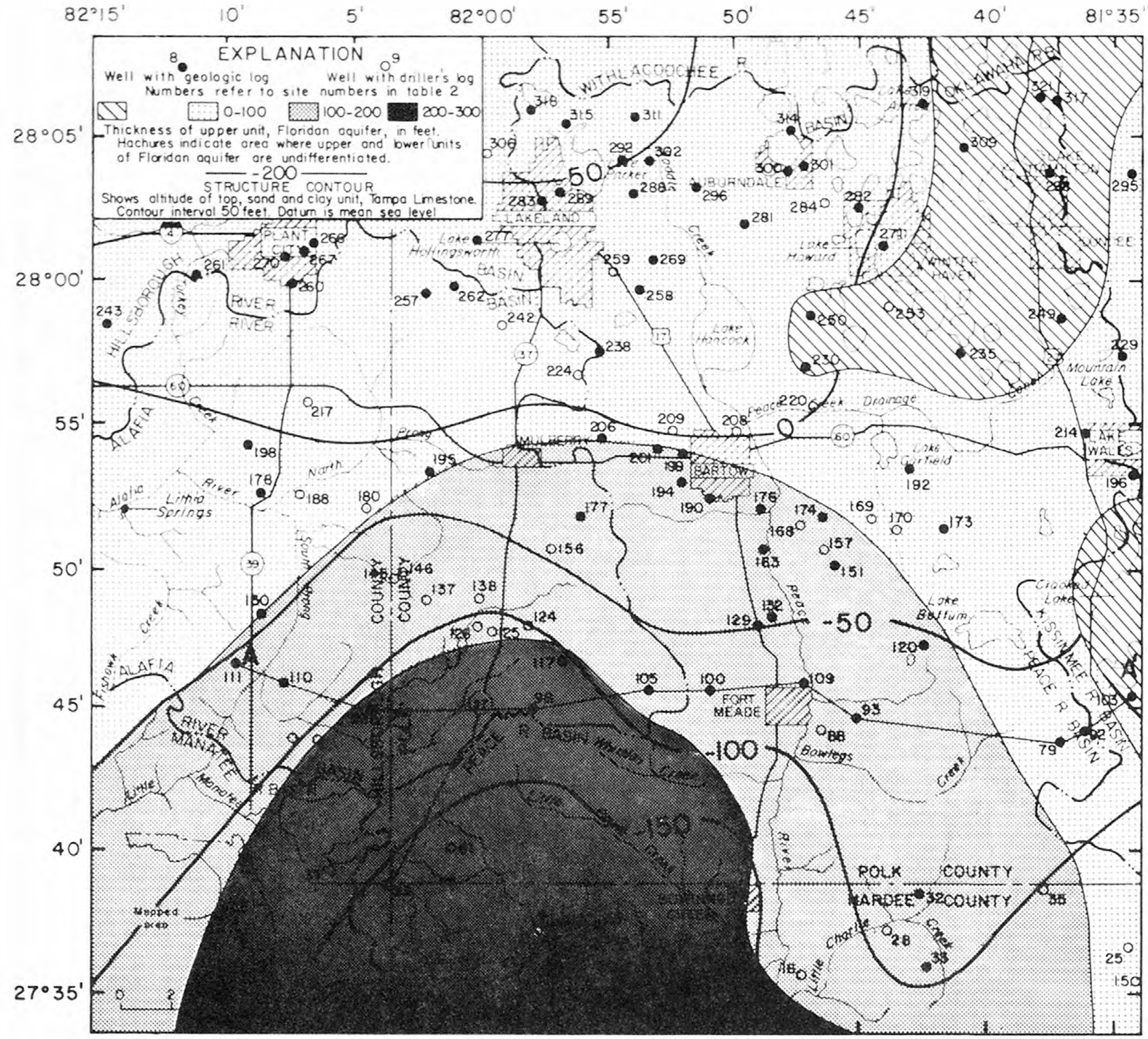

Figure 6 -- Altitude of the top of the sand and clay unit, Tampa Limestone, and thickness of the upper unit, Floridan aquifer

The wide range in transmissivity indicates formational heterogeneity that is substantiated by geophysical logs. A caliper log at site 127, where transmissivity is least, showed 113 ft of smooth-walled open hole, while at sites 93 and 115, where transmissivity was the greatest of the sites tested, cavities as large as 15 in in diameter were measured over open-hole intervals of less than 100 ft. Cavities occurred in the upper part of each hole, between 6 and 10 ft below the casing at site 93, and between 20 and 40 ft below the casing at site 115. Appreciable differences in transmissivity were also noted by Dames and Moore (1975, p. A-12) at site 10. Transmissivities at two sites less than 200 ft apart were 16 ft^2/d and 400 ft^2/d--as determined from tests of wells open to the same zone.

Storage coefficients ranged between 1.0×10^{-4} and 4.2×10^{-5} for 7 tests. These low values indicate that the upper unit of the Floridan aquifer is artesian.

The leakage coefficient determined at site 93 is 2.5×10^{-4} (ft/d)/ft. The computed leakage coefficient represents the net leakage of water to the aquifer through overlying and underlying semiconfining beds.

Water Quality

The sources of the chemical constituents in water vary with the environment in which the water is located. Rainwater becomes mineralized as it dissolves soluble minerals from the soil and rock through which it percolates. Ionic concentrations are relatively low in the surficial aquifer as shown in table 5 and figure 7. The quartz sand that constitutes the aquifer is relatively insoluble and clay particles tend to remove cations by adsorption. Median quality of water from the surficial aquifer is of a calcium bicarbonate type but with relatively high percentages of sodium and sulfate.

As water percolates through the upper unit of the Floridan aquifer, calcium and magnesium are dissolved from the limestone. The alkalinity is high, indicating that the bicarbonate ion concentration is high. The water becomes a distinct calcium bicarbonate type but with a high percentage of magnesium (fig 7). The concentrations of chloride, sodium, potassium, sulfate, and fluoride remain stable.

Median quality of water in the lower unit of the Floridan aquifer is similar to that of the upper unit of the Floridan aquifer (fig. 7). The water is primarily a calcium bicarbonate type in both units; however, in the lower unit the concentration of magnesium is about one half that of the upper unit.

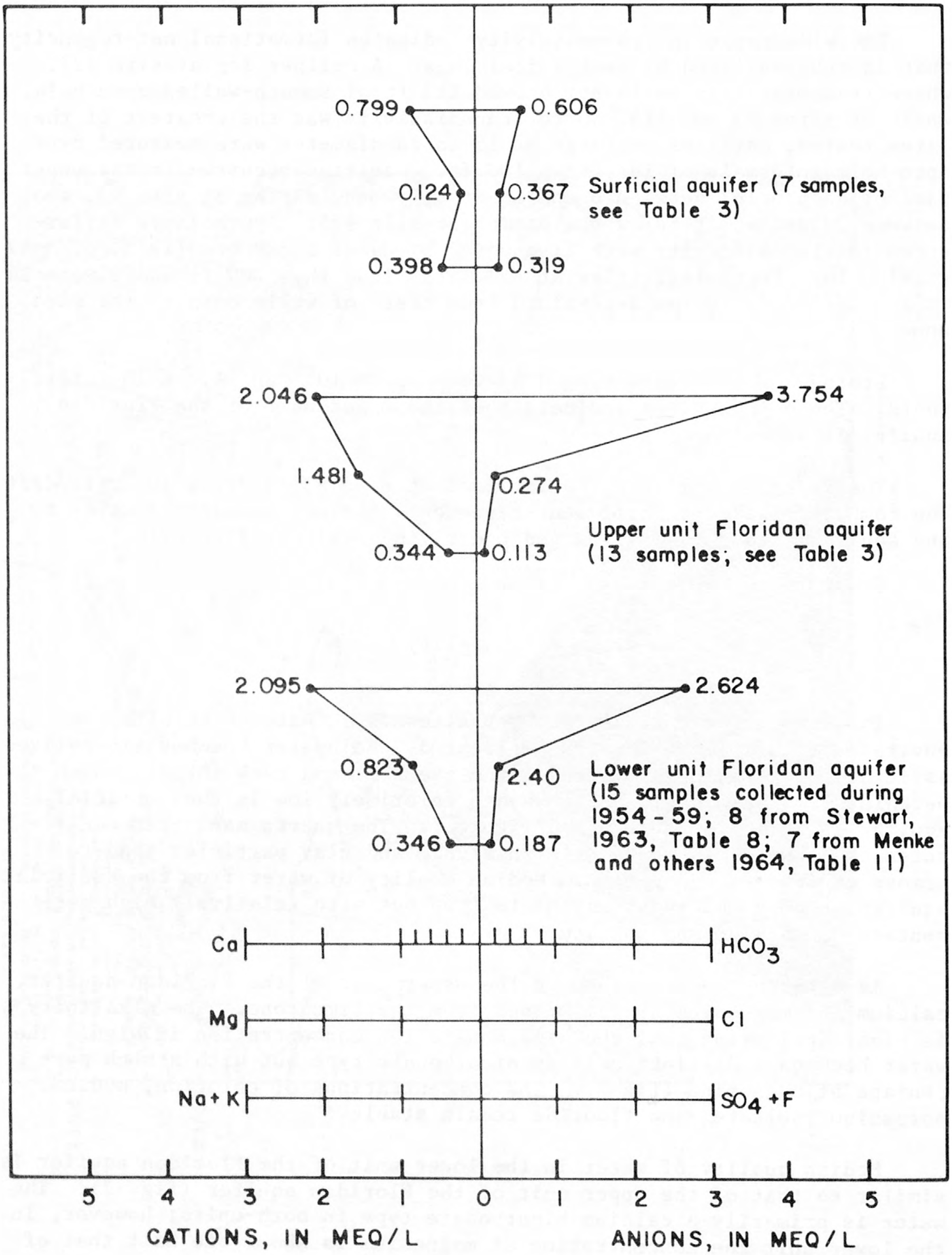

Figure 7 -- Median quality of water in the surficial aquifer and the upper and lower units of the Floridan aquifer

Table 5. -- Chemical analyses of ground and surface water

[UF, Upper unit, Floridan aquifer; SA, Surficial aquifer. Site locations are shown on figure 8. Chemical analyses are in milligrams per liter except where noted.]

Site number	Latitude/ longitude	Section-township-range	Hydrogeologic unit or name of site	Date of sample	Specific conductance (umho/cm at 25°C)	Silica (SiO_3)	Calcium (ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	pH (units)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)
10	---	26-33S-23E	UF	10-07-75	580	11	30	24	0.5	35	427	---	15	50	1.9
10	---	26-33S-23E	SA	10-07-75	325	19	33	12	14	12	208	---	32	38	.5
41	273847/813946	36-32S-26E	UF	03-12-75	394	19	41	20	16	.8	227	7.7	2	16	.4
42	273937/815159	36-32S-24E	SA	03-03-76	174	5.6	4.6	8	5.5	1.4	0	4.3	3	13	.2
63	274137/815003	17-32S-25E	UF	10-07-75	240	20	27	12	4.6	.9	133	7.7	2.7	5	.7
78	274336/820336	01-32S-22E	SA	03-11-75	64	2.5	6	1.5	3.5	.8	11	6.4	14	5.1	.1
90	274400/820708	04-32S-22E	UF	12-10-74	114	3.8	15	3.6	2.5	.2	69	7	2.1	3.3	.3
93	274438/814456	31-31S-26E	UF	12-10-75	180	11	20	8.2	3.8	.2	73	7.5	4.1	9.7	.4
101	274504/814656	26-31S-25E	Peace River	12-06-74	499	7.1	51	18	25	2.5	125	7.7	110	21	4.4
112	274612/815035	18-31S-25E	SA	12-05-74	478	9.4	41	20	18	2.1	40	6.6	77	18	.5
115	274623/814538	19-31S-25E	UF	07-31-75	544	24	56	33	12	1	333	7.4	13	9.3	.7
117	274642/815632	18-31S-24E	UF	09----74	430	46	38.4	14.6	--	1.6	249	7.7	11	8	---
123	---	08-31S-24E	SA	09----74	109	14	12	2.9	--	.7	37	5.8	12	0	---
141	274902/820057	04-31S-23E	SA	12-13-74	156	3.4	16	7.3	8.6	.3	19	6.1	45	8.7	.4
164	275059/815622	30-30S-24E	UF	08-22-75	214	32	24	8.5	6	1.1	120	7.7	4.2	4.8	.6
175	275141/814952	20-30S-25E	UF	07-24-75	543	24	64	27	13	.9	261	7.3	60	13	.2
185	275200/821350	13-30S-21E	Lithia Spring	12-06-74	407	14	59	7.6	12	.6	124	7.8	70	21	.4
188	275219/821241	16-30S-21E	Alafia River	12-06-74	622	20	66	15	48	2.2	67	7.4	160	51	5.6
203	275406/813745	04-30S-27E	UF	03-02-76	367	38	50	13	7.3	4	229	7.4	1.1	6.9	.3
216	275514/820732	32-29S-22E	SA	03-11-75	333	17	40	17	7.7	1	185	7.8	8.2	14	.9
221	275528/820724	29-29S-22E	UF	03-11-75	440	36	47	26	10	.5	266	7.8	.8	13	.5
232	275711/820329	13-29S-22E	UF	03-05-76	403	37	43	25	7.5	.6	250	7.6	2	8.3	.5
297	280334/815448	09-28S-24E	UF	03-04-76	318	29	32	18	7	.3	170	7.6	1.5	16	.8

Site number	Total hardness	Alakalinity as $CaCO_3$	Dissolved solids (sum)	Arsenic (As)	Hexavalent Chromium (Cr6)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Manganese (Mn)	Radium-226 (Ra_{226}) (pCi/L)	Strontium (Sr)	Zinc (Zn)	Remarks
10	---	---	425	---	---	---	1.4	---	---	---	0.2	---	Dames and Moore (1975, Table B-3)
10	---	---	290	---	---	---	.46	---	---	---	.03	---	Dames and Moore (1975, Table B-3)
41	180	186	227	---	---	---	---	---	---	0.2	.11	---	
42	44	0	41	0	0	0.001	.01	0	0.03	5.7	.04	0.01	High nitrate in sample
63	120	109	140	0.002	0	0	.92	0	.02	.98	.07	.08	
78	21	9	39	---	---	---	---	---	---	.2	.08	---	
90	52	---	65	---	---	---	---	---	---	.24	.08	---	
93	84	60	93	0	0	0	0	0.002	0	.26	.02	.01	
101	200	---	301	---	---	---	---	---	---	.12	.48	---	
112	180	---	206	---	---	---	---	---	---	5.3	.09	---	
115	280	273	313	0	0	0	.01	.001	.01	---	.18	.07	
117	156	204	301	---	---	---	.1	---	---	---	.1	---	LaMoreaux (1975a, Appendix D)
123	42	30	78	---	---	---	2.5	---	---	---	.1	---	LaMoreaux (1975a, Appendix D)
141	70	---	99	---	---	---	---	---	---	1.2	.1	---	Connector well
164	95	98	141	.002	0	.001	.01	0	0	---	.19	.01	
175	270	214	332	.001	0	.002	.01	0	.01	---	1.1	.03	
185	180	---	247	---	---	---	---	---	---	.68	1.1	---	
188	230	---	401	---	---	---	---	---	---	.06	.25	---	
203	180	188	235	0	0	0	.69	0	.02	7.3	.15	.34	
216	170	152	197	---	---	---	---	---	---	.2	.08	---	May interconnect with UF
221	220	218	265	---	---	---	---	---	---	---	.02	---	
232	210	205	247	.003	0	0	.1	0	.03	1.6	.1	0	
297	150	139	189	0	0	0	.17	0	.01	1.2	.06	0	

Figure 8 shows, by use of Stiff diagrams, the areal variation in concentrations of selected chemical constituents in 23 ground-water and surface-water samples. Complete chemical analyses are presented in table 5. Stiff diagrams for water samples collected from the wells at sites 42, 78, 112, 123, and 141 within the surficial aquifer correspond closely to the diagram of median water quality of the surficial aquifer (fig. 7). The diagrams at sites 10 and 216, also in the surficial aquifer, more closely resemble the diagram of median quality of water from the upper unit of the Floridan aquifer.

Stiff diagrams for sites 10, 41, 63, 93, 115, 164, 203, 221, 232, and 297 within the upper unit of the Floridan aquifer are similar to the median-quality diagram of the upper unit (fig. 7). The Stiff diagrams for sites 90, 117, and 175 are atypical. The sample from site 90 was less mineralized than the median water from the aquifer. The submersible pump used to withdraw the sample was not working properly, and the sample probably came from within the casing rather than fresh from the formation. The Stiff diagram for site 117 is similar to the median-quality diagram of the lower unit of the Floridan aquifer: in both waters the concentration of magnesium is low. Water from the well at site 175 is relatively high in sulfate which may indicate leakage from the overlying surficial aquifer.

Stiff diagrams for surface water sampled at sites 101 and 188, and the spring, site 185, indicate multiaquifer sources of water in these bodies (fig. 8). The streams are known to be fed by water from the Floridan aquifer (Menke and others, 1961, and Stewart, 1966) as well as by bank seepage from the surficial aquifer (fig. 7), suggesting a deep source for most of the 30 Mgal average daily flow from the spring. The Peace River (site 101) and Alafia River (site 188), on the other hand, probably receive water from the upper unit of the Floridan aquifer and the surficial aquifer. The high sodium and sulfate concentrations at these sites indicate an additional source, probably runoff.

The quality of the shallow ground water in the upper Peace and eastern Alafia River basins can be summarized as generally good. The water in the surficial aquifer is soft and in the upper unit of the Floridan aquifer it is generally hard. Water from both aquifers generally meets recommended drinking water standards of the Environmental Protection Agency (National Academy of Sciences and National Academy of Engineering, 1973) in total dissolved solids, common inorganic constituents, and trace metals. Dissolved iron is commonly above acceptable limits, which are based on aesthetic rather than health reasons. Of 77 sites sampled in a reconnaissance of dissolved radium-226 concentrations in ground water of central Florida, Irwin and Hutchinson (1976) determined that 14 percent of the samples from the surficial aquifer, 28 percent of the samples from the upper unit of the Floridan aquifer, and 9 percent of the samples from the lower unit of the Floridan aquifer exceeded the 3 picocuries-per-liter recommended limit. Radium-226 is a daughter of uranium which is associated

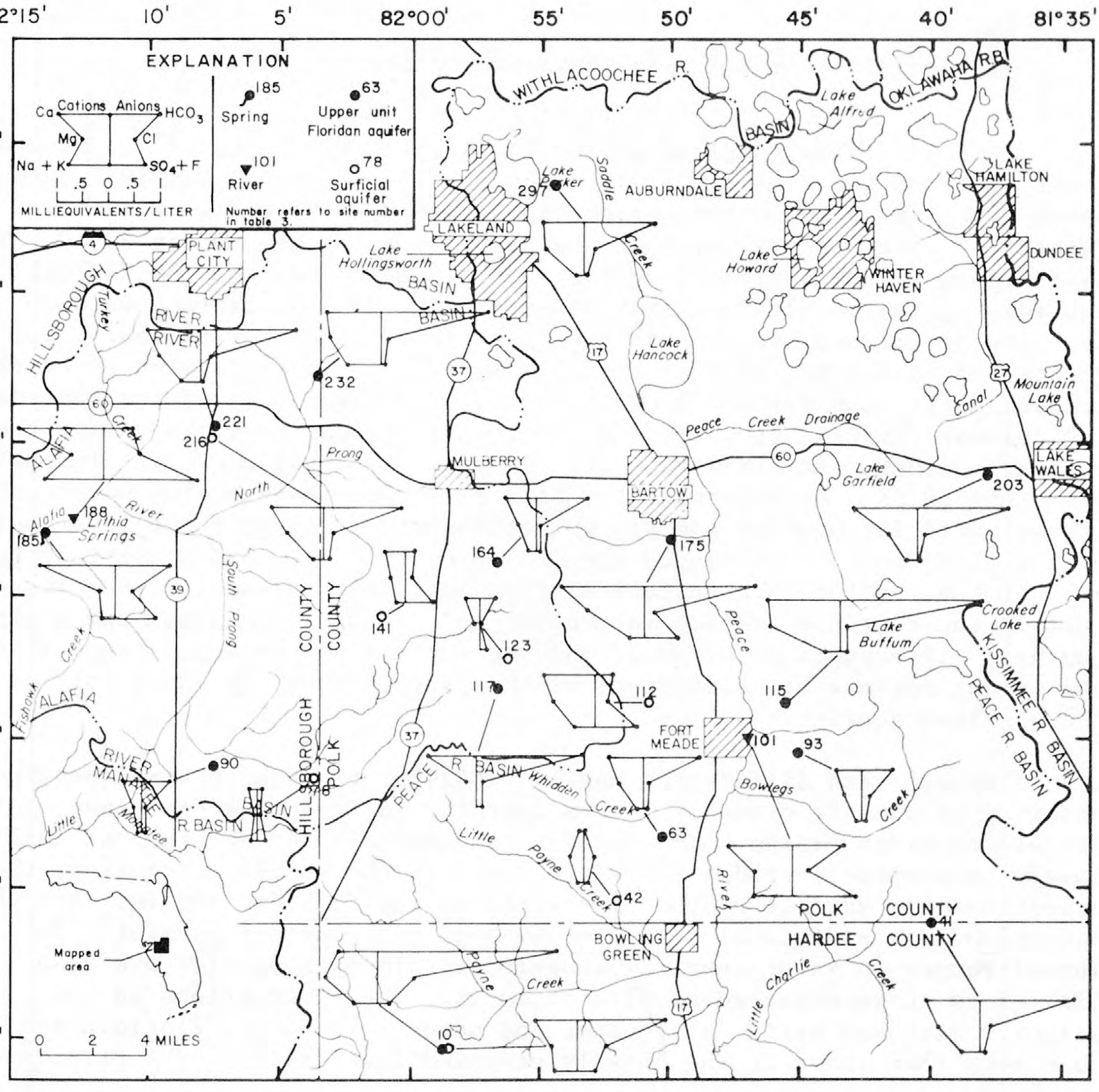

Figure 8 -- Quality of surface water and water from the surficial aquifer and upper unit of the Floridan aquifer

with phosphate deposits in the area. At two sites uranium is being recovered from byproducts of phosphate mining and plans are underway for the construction of several new recovery facilities (B. Boatwright, oral commun., 1976).

Ground-Water Levels, Movement, Recharge, and Discharge

Water-level fluctuations in the surficial aquifer and the upper and lower units of the Floridan aquifer for the 1-year period May 1975 through April 1976 are shown in hydrographs in figure 9. The wells are in a cluster at site 81 (fig. 4) near the South Prong of the Alafia River. The water table in the surficial aquifer and the upper unit of the Floridan aquifer fluctuated within a 5-ft range and the head difference between the levels remained constant at less than 10 ft. Neither the surficial aquifer nor the upper unit of the Floridan aquifer was stressed by nearby pumping during the period of measurement. The lower unit of the Floridan aquifer was stressed by pumpage from distant irrigation wells during the spring, however, and the water level in this hydrogeologic unit fluctuated more than 30 ft. At this site the head difference between the water table in the surficial aquifer and the potentiometric surface of the lower unit of the Floridan aquifer ranged from 38 to 66 ft. The head difference between the potentiometric surface of the upper unit and that of the lower unit of the Floridan aquifer ranged from 32 to 60 ft. Maximum and minimum head differences occurred during the dry and wet seasons, respectively, and during periods of maximum and minimum stress upon the lower unit of the Floridan aquifer.

Although head differences may be variable, the same general sequence observed at site 81 probably occurs over the entire upper Peace and eastern Alafia River basins. The sequence of ground-water levels from shallowest to deepest includes the water table in the surficial aquifer, the potentiometric surface of the upper unit of the Floridan aquifer, and the potentiometric surface of the lower unit of the Floridan aquifer. The annual ranges in water-level fluctuation within each aquifer are also similar to those observed at site 81 in that the fluctuations in the slightly stressed surficial aquifer and upper unit of the Floridan are much less than those in the heavily stressed lower unit of the Floridan.

Surficial Aquifer

Figure 10 shows the altitude of the water table in the surficial aquifer and the head difference between the water table and the potentiometric surface of the lower unit of the Floridan aquifer in September 1975. The map was prepared using measurements at 100 sites, including 42 wells constructed as part of this project, 18 existing wells, 40 surface-water stations and a map of the potentiometric surface of the lower

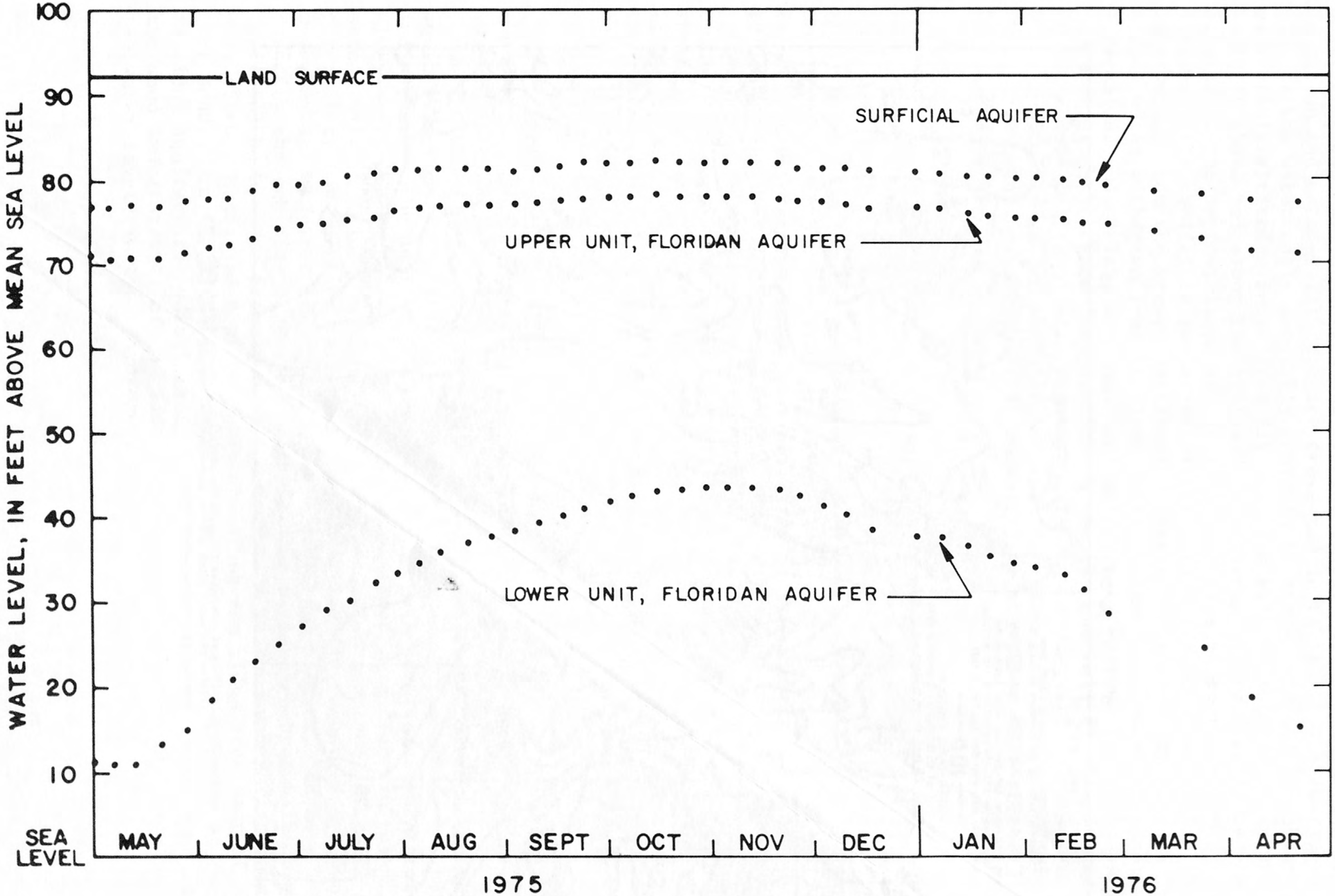

Figure 9 -- Surficial aquifer and upper and lower units of the Floridan aquifer at site 81, May 1975 through April 1976

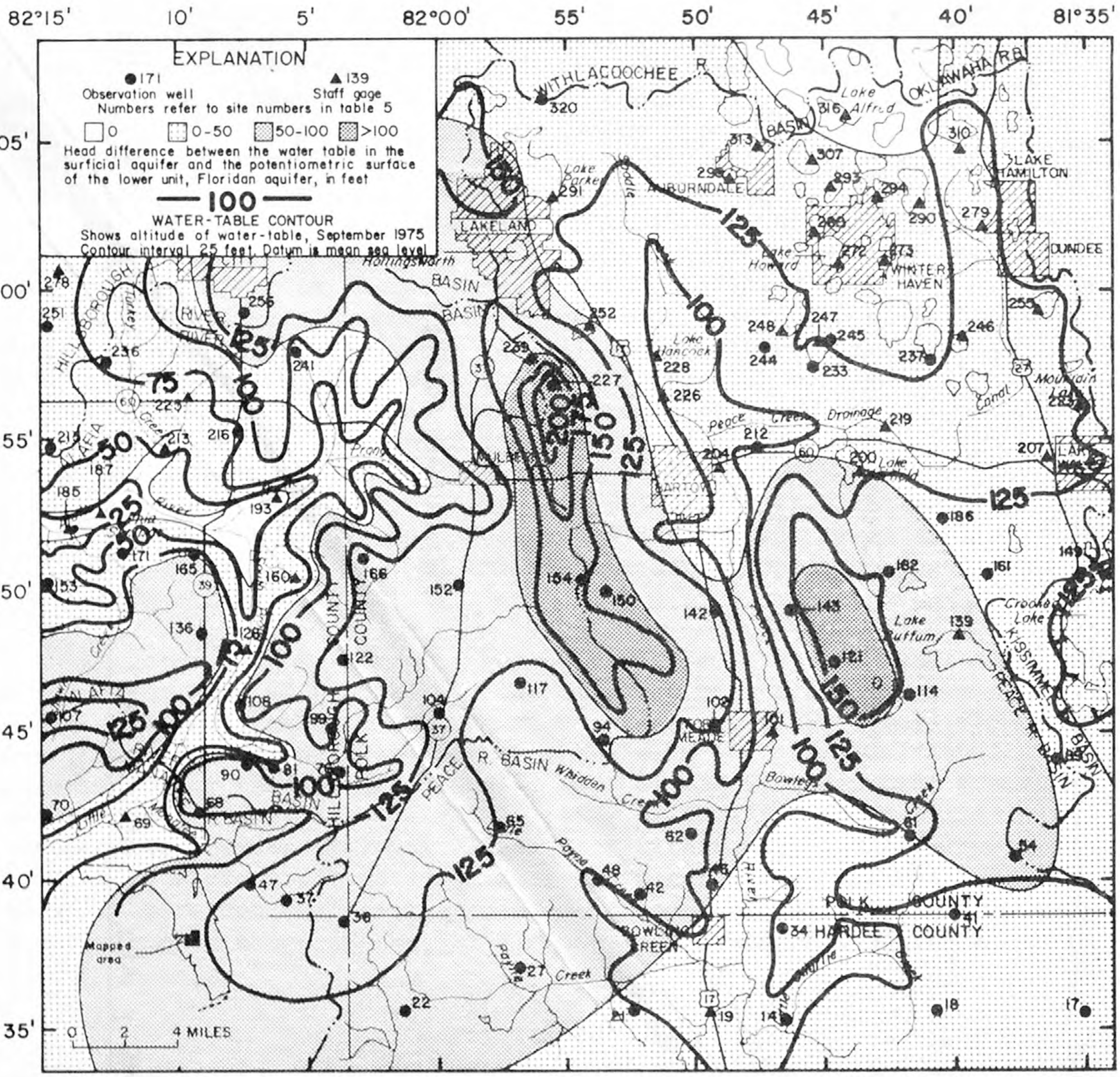

Figure 10 -- Altitude of the water table in the surficial aquifer and head difference between the water table and the potentiometric surface of the lower unit, Floridan aquifer, September 1975

unit, Floridan aquifer (Mills and others, 1976). Well-construction information and water-level data are presented in table 6. The configuration of the water table generally conforms to topography and the observed water-table altitudes range from 219 ft above msl on the Lakeland ridge to 10 ft above msl along the Alafia River. Ground-water flow is perpendicular to the contour lines and is from the ridge areas toward the streams. The aquifer is recharged directly by rainfall. Because no water is exported from the area, additional recharge is provided by seepage from ground water withdrawn from the lower unit of the Floridan aquifer for irrigation, industrial, and municipal purposes. Depressions in the water table along the streams indicate that these are the main discharge areas from the surficial aquifer. Discharge also moves downward through the basal semiconfining bed into the upper unit of the Floridan aquifer or, where this intervening aquifer is absent, into the lower unit of the Floridan aquifer.

Upper Unit, Floridan Aquifer

The altitude of the potentiometric surface of the upper unit of the Floridan aquifer and the head difference between the potentiometric surfaces of the upper and lower units of the Floridan aquifer in September 1975 are mapped in figure 11. The map was prepared using measurements of 1 spring and 44 wells for which data were obtained during this investigation. Well construction and water-level data are presented in table 7. The aquifer is artesian in most of the area. However, at sites 93, 115, 118, 164, 175, and 189, in the Peace River basin, water levels were below the top of the aquifer. The head difference between the potentiometric surfaces of the upper and lower units of the Floridan aquifer averages 40 ft.

The configuration of the potentiometric surface of the upper unit of the Floridan aquifer in Polk County has not changed appreciably since 1959-60 (Stewart, 1966, p. 88). The potentiometric surface generally conforms to the topography of the rock surface and movement of water in the aquifer is toward the streams. The depressions along the stream valleys indicate that the aquifer discharges water to both the Peace and Alafia Rivers. The increased gradient in the potentiometric surface in the stream valleys induces more rapid movement of water and thus increases possibility for solution development. The aquifer is recharged by downward leakage of water from the overlying surficial aquifer, and more directly through sinkholes and abandoned mine pits which breach the semiconfining beds. The primary recharge areas are in the swampy flatlands west of Fort Meade and Bowling Green and along the ridge area east of Fort Meade. In the Winter Haven area, the upper and lower units of the Floridan aquifer are hydraulically interconnected due to the absence of the sand and clay unit of the Tampa Limestone; therefore, in this area, the water levels in these hydrogeologic units coincide.

Table 6. -- Water levels in wells tapping the surficial aquifer and in surface-water bodies, May and September, 1975

[Locations of wells and surface-water sites are shown in figure 10. e, estimated.]

Well number	Latitude/ longitude	Section-township-range	Depth (ft)		Altitude of land surface (ft)	Altitude of water surface (ft)	
			Well	Casing		May 1975	September 1975
			WELLS				
14	273516/814628	24-33S-25E	17	14	93	81	86
17	273528/813448	23-33S-27E	17	12	103	96	101
18	273532/814024	24-33S-26E	31	26	109	100	107
21	273540/815216	24-33S-24E	17	12	113	102	108
22	273541/820203	20-33S-23E	18	13	121	114	120
27	273659/815639	07-33S-24E	23	18	117	110	114
34	273835/814637	01-33S-25E	15	10	121	113	119
36	273846/820320	01-33S-22E	18	8	135	130	135
37	---	34-32S-22E	32	22	135	125	132
41	273847/813946	36-32S-26E	27	22	116	110	115
42	273937/815159	36-32S-24E	23	20	126	113	116
46	273950/814922	28-32S-25E	22	17	95	85	89
47	273954/820714	28-32S-22E	14	--	130	119	125
48	274004/815330	27-32S-24E	23	18	102	96	100
54	274043/813733	21-32S-27E	32	27	149	143	147
61	274132/814143	14-32S-26E	22	17	132	117	124
62	274136/814955	17-32S-25E	--	--	134	119	124
65	274154/815729	13-32S-23E	27	22	135	122	125
68	274216/820847	07-32S-22E	22	17	122	109	115
70	274217/821442	18-32S-21E	22	17	101	84	90

Table 6. -- Water levels in wells tapping the surficial aquifer and in surface-water bodies, May and September, 1975 - continued

Well number	Latitude/ longitude	Section-township-range	Depth (ft)		Altitude of land surface (ft)	Altitude of water surface (ft)	
			Well	Casing		May 1975	September 1975
78	274336/820336	01-32S-22E	17	12	103	93	96
81	274352/820610	03-32S-22E	75	42	92	76	82
89	274400/813552	34-31S-27E	20	15	165	159	161
90	274400/820708	04-32S-22E	33	33	133	---	119
94	274451/815316	35-31S-24E	27	22	155	141	145
99	274457/820358	25-31S-22E	53	43	115	102	107
102	274505/814903	28-31S-25E	23	18	135	124	130
104	274536/815938	27-31S-23E	16	11	128	123	128
107	274544/821442	30-31S-21E	22	17	143	130	138
108	274547/820725	20-31S-22E	32	27	130	98	102
114	274622/814141	23-31S-26E	27	22	159	142	149
117	274642/815632	18-31S-24E	23	--	122	114	116
121	274729/814435	17-31S-26E	33	23	188	167	170
122	274731/820323	13-31S-22E	15	10	145	140	142
136	274822/820848	07-31S-22E	59	--	94	88	91
142	274912/814906	04-31S-25E	31	21	134	124	126
143	274914/814607	01-31S-25E	31	21	153	140	147
150	274942/815315	35-30S-24E	22	17	152	143	146
152	275002/815850	35-30S-23E	17	12	139	132	137
153	275006/821442	31-30S-21E	31	26	66	51	54

Table 6. -- Water levels in wells tapping the surficial aquifer and in surface-water bodies, May and September, 1975 - continued

Well number	Latitude/ longitude	Section-township-range	Depth (ft)		Altitude of land surface (ft)	Altitude of water surface (ft)	
			Well	Casing		May 1975	September 1975
154	275009/815408	34-30S-23E	58	58	163	---	162
161	275020/813830	29-30S-27E	21	16	137	127	132
162	275032/814227	27-30S-26E	44	39	174	141	141
165	275059/820904	30-30S-22E	17	12	101	93	98
166	275101/820255	30-30S-23E	17	12	144	136	142
171	275102/821159	22-30S-21E	16	--	76	69	74
186	275218/814015	13-30S-26E	35	20	140	126	131
212	275433/814734	34-29S-25E	52	42	110	70	74
215	275441/821440	31-29S-21E	27	22	96	68e	72
216	275514/820732	32-29S-22E	23	18	90	69	74
227	275644/815519	21-29S-24E	37	32	240	217	219
233	275723/814519	18-29S-26E	27	12	145	118	121
236	275731/821232	16-29S-21E	20	--	88	69	78e
237	275736/814049	14-29S-26E	22	17	146	129	130
241	275800/820518	14-29S-22E	31	--	104	94	100
244	275807/814704	11-29S-25E	27	25	136	---	121
245	275815/814442	07-29S-26E	26	24	139	123	126
251	275851/821412	07-29S-21E	22	17	75	65	72
256	275918/820719	04-29S-22E	22	17	146	137	144
320	280633/815540	29-27S-24E	20	19	143	---	Dry

Table 6. -- Water levels in wells tapping the surficial aquifer and in surface-water bodies, May and September, 1975 - continued

Site number	Name	Latitude/ longitude	Section-township-range	Altitude of water surface (ft)	
				May 1975	September 1975
	SURFACE-WATER BODIES				
19	Hog Branch	273532/814920	21-33S-25E	---	78
69	Little Manatee River	274216/821153	15-32S-21E	47	51
101	Peace River	274504/814656	26-31S-25E	71	72
128	S. Prong Alafia River	274747/820704	09-31S-22E	60	62
139	Lake Buffum	274830/814001	01-31S-26E	127	128
149	Crooked Lake	274939/813312	31-20S-28E	115	116
160	Mizelle Creek	275014/820517	27-30S-22E	70	72
185	Lithia Spring	275200/821350	13-30S-21E	8	10
187	Alafia River	275219/821241	16-30S-21E	---	13
193	N. Prong Alafia River	275259/820603	10-30S-22E	41	44
200	Lake Garfield	275402/814325	04-30S-26E	98	99
204	Peace River	275407/814903	04-30S-25E	94	96
205	Lake Wales	275413/813444	01-30S-27E	---	105
207	Lake Effie	275431/813611	03-30S-27E	114	115
213	Pleasant Grove Reservoir	275437/821003	36-29S-21E	59	60
219	Peace Creek Canal	275523/814228	34-29S-26E	101	103
223	Mountain Lake	275601/813459	26-29S-27E	111	111
225	Little Alafia River	275615/820923	24-29S-21E	59	61
226	Saddle Creek	275617/815105	19-29S-25E	96	98
228	Lake Hancock	275648/815129	18-29S-25E	96	98

Table 6. -- Water levels in wells tapping the surficial aquifer and in surface-water bodies, May and September, 1975 - continued

Site number	Name	Latitude/ longitude	Section-township-range	Altitude of water surface (ft)	
				May 1975	September 1975
239	Scott Lake	275744/815604	17-29S-24E	166e	166
246	Lake Ruby	275827/813930	07-29S-27E	118	118
247	Lake McLeod	275828/814510	07-29S-26E	117	117
248	Eagle Lake	275835/814632	12-29S-25E	119	120
252	Banana Lake	275852/815350	10-29S-24E	105	105
255	Lake Annie	275905/813640	03-29S-27E	109	110
272	Lake Howard	280058/814422	29-28S-26E	129	130
273	Lake Otis	280100/814252	28-28S-26E	120	121
278	Pemberton Creek	280134/821412	19-28S-21E	---	54
279	Lake Hamilton	280154/813842	19-28S-27E	118	119
280	Lake Cannon	280157/814521	19-28S-26E	---	131e
290	Lake Fannie	280250/814115	14-28S-26E	120	122e
291	Lake Parker	280259/815522	16-28S-24E	129	130
293	Lake Hartridge	280307/814459	18-28S-26E	129	130
294	Lake Smart	280308/814238	15-28S-26E	126	127
299	Lake Lena	280342/814822	10-28S-25E	133	133
307	Lake Mariana	280410/814520	06-28S-26E	135	136
310	Lake Henry	280450/813945	01-28S-26E	123	123
313	Ariana Lake	280513/814730	34-27S-25E	132	133
316	Lake Alfred	280548/814400	32-27S-26E	123	124

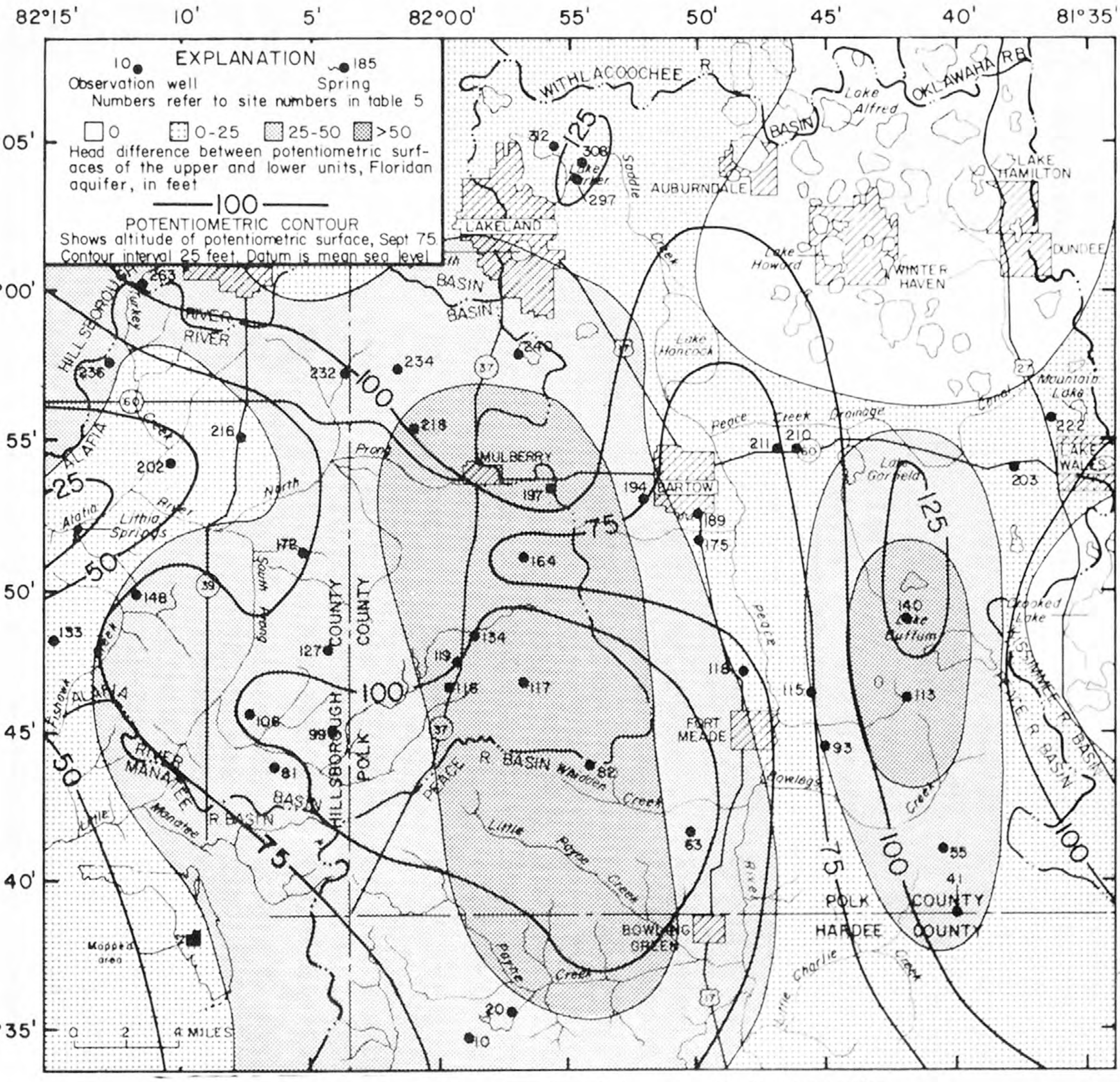

Figure 11 -- Altitude of the potentiometric surface of the upper unit, Floridan aquifer and head difference between the potentiometric surface of the upper unit and the potentiometric surface of the lower unit, Floridan aquifer, September 1975

Table 7. -- Water levels in wells tapping the upper unit, Floridan aquifer, May and September, 1975

[Site locations shown on figure 11. e, estimated.]

Site number	Latitude/ longitude	Section-township-range	Depth (ft)		Altitude of land surface (ft)	Altitude of water surface (ft)	
			Well	Casing		May 1975	September 1975
10	---	26-33S-23E	373	98	122	---	92
20	273539/815645	19-33S-24E	60	55	87	70.6	80e
37	---	34-32S-22E	270	65	135	45.1	66.3
41	273847/813946	36-32S-26E	51	46	116	90.1	103.1
55	274101/814021	24-32S-26E	76	66	145	110.7	115
63	274137/815003	17-32S-25E	160	63	134	---	118.7
74	274218/820357	12-32S-22E	191	---	134	112.4	119.7
81	274352/820610	03-32S-22E	160	122	92	70.4	77.3
82	274358/815404	03-32S-24E	201	110	140	124.9	123.5
93	274438/814456	31-31S-26E	122	84	108	---	81
99	274457/820358	25-31S-22E	247	97	115	99.0	104.3
106	274544/820711	28-31S-22E	250	---	130	104.8	107.7
113	274621/814148	22-31S-26E	92	---	157	82.7	101
115	274623/814538	19-31S-25E	152	63	121	45.6	64
116	274628/814919	23-31S-23E	120	80	125	95	104.8
117	274642/815632	18-31S-24E	215	65	122	---	52.9
118	274656/814812	15-31S-25E	197	62	137	85	87.8
119	274722/815900	14-31S-24E	---	---	130	40e	91.4
127	274745/820413	12-31S-22E	200	87	161	92	97.2
133	274806/821438	07-31S-21E	80	---	71	54.6	61.4
134	274812/815826	11-31S-23E	130	84	137	119	123.8
140	274847/814145	13-31S-26E	---	---	152	119.5	126.7

Table 7. -- Water levels in wells tapping the upper unit, Floridan aquifer, May and September, 1975 - continued

Site number	Latitude/ longitude	Section-township-range	Depth (ft)		Altitude of land surface (ft)	Altitude of water surface (ft)	
			Well	Casing		May 1975	September 1975
148	274935/821130	34-30S-21E	77	---	99	71.4	79.5
164	275059/815622	30-30S-24E	167	92	151	---	68.3
172	275103/820509	23-30S-22E	---	---	111	---	79.7
175	275141/814952	20-30S-25E	98	58	102	39.2	59.1
185	275200/821350	13-30S-21E	---	---	---	8	10
189	275225/814946	17-30S-25E	125	55	127	39.3	61.2
194	275302/815154	12-30S-24E	62	---	120	76.4	79.1
197	275334/815530	08-30S-23E	---	---	170	---	122.9
202	275405/821013	01-30S-21E	55	---	66	40.5	46.2
203	275406/813745	04-30S-27E	200	99	126	---	100.4
210	275433/814605	36-29S-25E	101	68	123	---	92.6
211	275433/814650	35-29S-25E	70	69	110	53.1	72
216	275514/820732	32-29S-22E	36	31	90	68.6	73.3
218	275518/820057	33-29S-23E	---	---	111	93.1	103.7
222	275545/813627	27-29S-27E	150	118	128	---	102.6
232	275711/820329	13-29S-22E	60	39	90	---	82
234	275727/820128	17-29S-23E	---	---	121	105.5	112.9
236	275731/821232	16-29S-21E	77	60	88	51.7	59
240	275754/815658	18-29S-24E	120	77	181	153	158
263	280012/821124	34-28S-21E	50	20	110	102.1	108.5
297	280334/815448	09-28S-24E	58	31	136	128	131.2
308	280412/815428	03-28S-24E	77	52	148	---	134.3
312	280503/815526	32-27S-24E	72	62	135	108	115.6

The hydrologic budget is a quantitative assessment of the inputs to and outputs from the zone of shallow ground water--that is, the surficial aquifer and the upper unit of the Floridan aquifer--in the upper Peace and eastern Alafia River basins. From year-to-year or season-to-season differences between inputs and outputs are balanced by changes in storage, as reflected in fluctuations of the water table and potentiometric surface, but, over the long term, inputs and outputs tend to balance.

The average annual hydrologic budget of the shallow ground-water zone is illustrated in figure 12 and may be expressed by the following terms:

INPUTS	MINUS	OUTPUTS	EQUALS	CHANGE IN STORAGE
$(P + I_{sw} + I_{gw})$	-	$(ET + R_a + R_p + O_{gw} + L)$	=	ΔS

where: P = Precipitation = 48.0 in, or 3.2 million acre-ft;

I_{sw} = Input from streams = 0.3 in, or 22,400 acre-ft;

I_{gw} = Input by return flow of ground-water pumpage = 5.6 in, or 376,000 acre-ft;

ET = Evapotranspiration = 41.2 in, or 2.75 million acre-ft;

R_a = Runoff of the Alafia River = 4.1 in, or 273,000 acre-ft;

R_p = Runoff of the Peace River = 5.9 in, or 393,000 acre-ft;

O_{gw} = Pumpage from the shallow ground-water zone = 0.1 in, or 7,400 acre-ft;

L = Leakage from the shallow ground-water zone to the lower unit of the Floridan aquifer = 2.6 in, or 173,000 acre-ft; and

ΔS = Change in storage of water in shallow ground-water zone = zero.

Inputs to and outputs from the shallow ground-water zone are balanced at 53.9 in, or 3.59 million acre-ft. The basis for the determination of each component in the hydrologic budget is as follows:

Average annual precipitation (P) is for 10 years of record (1966-75) at 5 stations in the study area (National Oceanic and Atmospheric Admin.).

Average annual input from streams (I_{sw}), estimated in this report on the basis of Pride (1970), represents irrigation pumpage from surface-water bodies rather than seepage through stream beds.

The Peace and Alafia River basin boundaries coincide with ground-water divides; consequently, ground-water inflow across the basin boundaries is negligible. Thus, the average annual input from ground-water

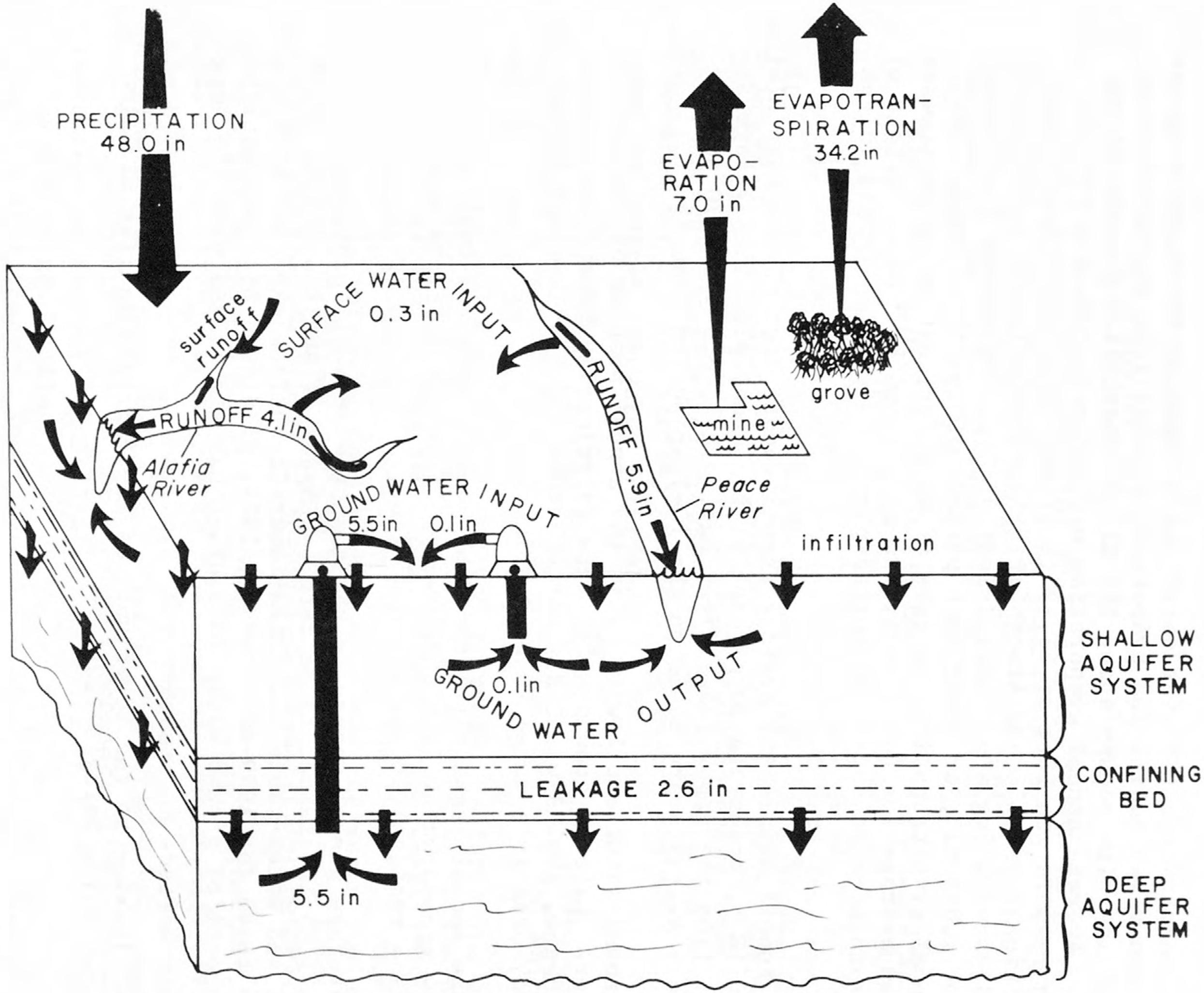

Figure 12 -- Annual hydrologic budget

sources (I_{gw}) represents return flow from irrigation, industrial, and municipal pumpage from the shallow aquifers and from the lower unit of the Floridan aquifer during 1971. This water is not exported to other basins and thus has the potential for seeping into the shallow ground-water zone.

Evapotranspiration (ET) was estimated by summing the total evaporation from open-water bodies and evapotranspiration from vegetated areas. Lakes and mining pits occupy about 180 mi^2 or about 14.4 percent of the total area. Average annual evaporation was determined from a 1966-75 average pan evaporation rate of 68.99 in at the Lake Alfred Experiment Station (National Oceanic and Atmospheric Administration). Evaporation rate was adjusted using a pan coefficient of 0.7. Vegetated land areas occupy about 1,070 mi^2, or about 85.6 percent of the total area. The average annual evapotranspiration rate of 40 in/yr, estimated by Stewart (1966) as an average for Polk County was multiplied by the percentage of vegetated land area to obtain evapotranspiration from land areas in the basin.

Total runoff equals the average annual runoff from the eastern Alafia River basin (R_a), occupying 30 percent of the area, plus the average annual runoff from the upper Peace River basin (R_p), occupying 70 percent of the area. Averages are based on the 10-year period 1966-75.

The ground-water outflow (O_{gw}) is the annual pumpage of shallow ground water. Lateral ground-water flow is primarily toward the stream channels, hence, ground-water discharge across the downgradient boundaries of the study area is assumed to be negligible.

Average annual leakage (L) through the confining bed that separates the shallow ground water from the lower unit of the Floridan aquifer is computed as a residual in the water budget.

The average annual change in the quantity of shallow ground water in storage (ΔS) is assumed to be zero. Pumpage of shallow ground water is minimal and water-table and potentiometric surface maps for 1975 are similar to those for 1959-60 (Stewart, 1966, p. 81 and 88), suggesting that the amount of ground water in storage has stabilized over the long term.

Annual leakage to the lower unit of the Floridan aquifer may also be calculated using Darcy's law:

$$Q = 365\ (K'/B')hA$$

where: Q = Annual leakage, in acre-ft;

K'/B' = Leakage coefficient of overlying confining beds, in (ft/d)/ft;

h = Average head difference between potentiometric surfaces of the upper and lower units of the Floridan aquifer, in ft;

A = Surface area of confining bed through which leakage occurs, in ac.

Average values used in the equation are:

$K'/B' = 1.2 \times 10^{-5}$ (ft/d)/ft (R. W. Wolansky, written commun., 1976);

h = 40 ft (fig. 11);

A = 800,000 ac.

Annual leakage through the confining bed in the upper Peace and eastern Alafia River basins is 140,000 acre-ft, or 2.1 in. Leakage (2.1 in) computed using Darcy's equation compares favorably with that derived as a residual of the hydrologic budget (2.6 in).

The residual of the hydrologic budget is a reasonable approximation of long-term average leakage of shallow ground water into the lower unit of the Floridan aquifer. Annual losses by pumping from the lower unit exceed gains from leakage by 2.9 in, or 193,000 acre-ft. Removal of water from storage within the lower unit partly compensates for this imbalance, and is reflected by progressive declines in the potentiometric surface of the lower unit, decreased natural discharge from the lower unit, increased horizontal ground-water movement into the cone of depression from outside the basins, and possible upward movement of the underlying saltwater-freshwater interface.

The total volume of shallow ground water stored in the upper Peace and eastern Alafia River basins is 46 million acre-ft, of which 14.4 million acre-ft is stored in the surficial aquifer and 31.6 million acre-ft is stored in the upper unit of the Floridan aquifer. The values were computed using specific yield data (estimated from effective porosity of the surficial aquifer in this report, and from the specific yield of limestone samples in Stewart, 1966, p. 113) and the thickness maps of figures 4 and 6. This volume is more than 6,000 times the annual volume of shallow ground water presently being pumped and more than 39 times the volume pumped from the lower unit of the Floridan aquifer during 1971.

Although the volume of stored water is large, only part of the available shallow ground water can be developed without significantly affecting the hydrologic budget of the area. Any increase in shallow ground-water outflow would be balanced by decreases in the other output components of the budget equation, or in the storage component. Consequences of removing excessive amounts of shallow ground water include the reduction in stream discharge, decline in lake levels, decline in ground-water levels, reduction in leakage to the lower unit of the Floridan aquifer, which in turn would increase the rate of decline of the potentiometric surface of the lower unit, or combinations of the above. Some benefit could be derived from a reduction of overland flow and evapotranspiration if development of the shallow ground-water resource lowered the water table substantially in an area where the water table was naturally at or near the land surface.

Management Alternatives

At least two management alternatives seem particularly suited for development of the shallow ground-water resources in the upper Peace and eastern Alafia River basins: (1) installation of a network of supply wells which would supplement pumpage from the lower unit of the Floridan aquifer; (2) installation of a network of gravity-flow connector wells--that is, wells that would connect the surficial aquifer and (or) the upper unit of the Floridan aquifer to the lower unit of the Floridan, and thereby recharge the lower unit by gravity flow. The two alternatives could be combined effectively.

The choice of alternatives would depend on the saturated thickness of the shallow aquifers and on the head differences between the shallow aquifers and the lower unit of the Floridan aquifer. Supply wells could be used in any area where the surficial aquifer and (or) the upper unit of the Floridan aquifer are of sufficient thickness to yield water to wells in the quantities desired. Connector wells would require sufficient head difference as well as ample aquifer thickness.

For illustrative purposes in this report, it is assumed that hydrologic conditions would be suitable for a network of supply wells in areas where the aquifer thickness is at least 50 ft. Similarly, it is assumed that conditions would be suitable for connector wells in areas where the aquifer thickness is at least 50 ft and the head difference between the shallow aquifers and the lower unit of the Floridan also is at least 50 ft.

Based on the criteria outlined above, areas having the potential for water development in the surficial aquifer and the upper unit of the Floridan aquifer in the upper Peace and eastern Alafia River basins were delineated as shown in figures 13 and 14, respectively. In the surficial aquifer, about 730 mi^2 are of sufficient thickness to permit development by supply wells (fig. 13). Of this, about 340 mi^2 has a water table high enough above the potentiometric surface of the lower unit of the Floridan aquifer to permit development by connector wells in conjunction with the supply wells. In the lower unit of the Floridan aquifer, about 990 mi^2 are suitable for development by supply wells, and of this about 250 mi^2 are suitable for development by connector wells in conjunction with the supply wells (fig. 14). Of the areas so delineated for development by supply wells, about 510 mi^2 are common to both the surficial aquifer and the upper unit of the Floridan aquifer.

The head differences on which areas were delineated as being suitable for successful operation of connector wells were based on water levels measured during September near the end of the rainy season. These head differences could represent the minimum for the year. During the dry season, head differences would increase because of increased pumping from the lower unit of the Floridan aquifer. Thus, the areas which at times would meet the head-difference criteria for connector wells could be appreciably greater than indicated in figures 13 and 14.

Well Network

In describing the function of connector wells, Knochenmus (1975, p. 21) noted that "As water from the nonartesian aquifer flows downward through the connector well, the water table declines. This decline reduces evapotranspiration and creates additional storage in the aquifer which allows for greater infiltration, thus capturing water which would have run off or evapotranspired." For this to occur, the water table under natural conditions must be at or near the land surface so that at least part of the evapotranspiration loss represents water withdrawn from the saturated zone, and also, so that at least part of the runoff represents water that could not infiltrate the ground because the surficial aquifer was full. If the water table is always several feet below land surface, the lowering of the water table by artificial means would not increase infiltration--and, hence, would not reduce overland runoff--and probably would cause little or no reduction in evapotranspiration. Under such conditions, capture would occur mostly or entirely in the form of a decrease in ground-water discharge into streams.

Although water levels were more than 10 ft below land surface in many of the wells tapping the surficial aquifer in the upper Peace and eastern Alafia River basins (table 6), water levels in September 1975 were at or less than 3 ft below the land surface in several wells, some of which were in interfluvial areas. The regional rainfall as represented by the average of rainfall at 5 stations--Lake Alfred, Lakeland, Bartow, Winter Haven, and Mountain View--was 1.4 in less than normal during May to September 1975, yet water levels in most of the surficial-aquifer wells rose 4 to 6 ft (table 6). Given the previously mentioned deficiency in the regional rainfall during 1966-75, the water table of the surficial aquifer seemingly could be at or near the land surface over a substantial part of the study area during years of normal or greater-than-normal rainfall. Thus, a wide-scale lowering of the water table by use of an extensive network of wells tapping the surficial aquifer--alone or in conjunction with the upper unit of the Floridan aquifer--offers some potential for capturing water from a reduction in evapotranspiration and overland runoff as well as from a decrease in ground-water discharge to streams.

A numerical analysis of the drawdown resulting from a well network operating under steady-state conditions has been developed by Papadopulos and Cooper (in Knochenmus, 1975, p. 24-28) and used by Knochenmus (1975) to demonstrate the potential for recharging a confined aquifer through a network of connector wells open to and fully penetrating the overlying surficial aquifer. The analysis derives the relation between drawdown

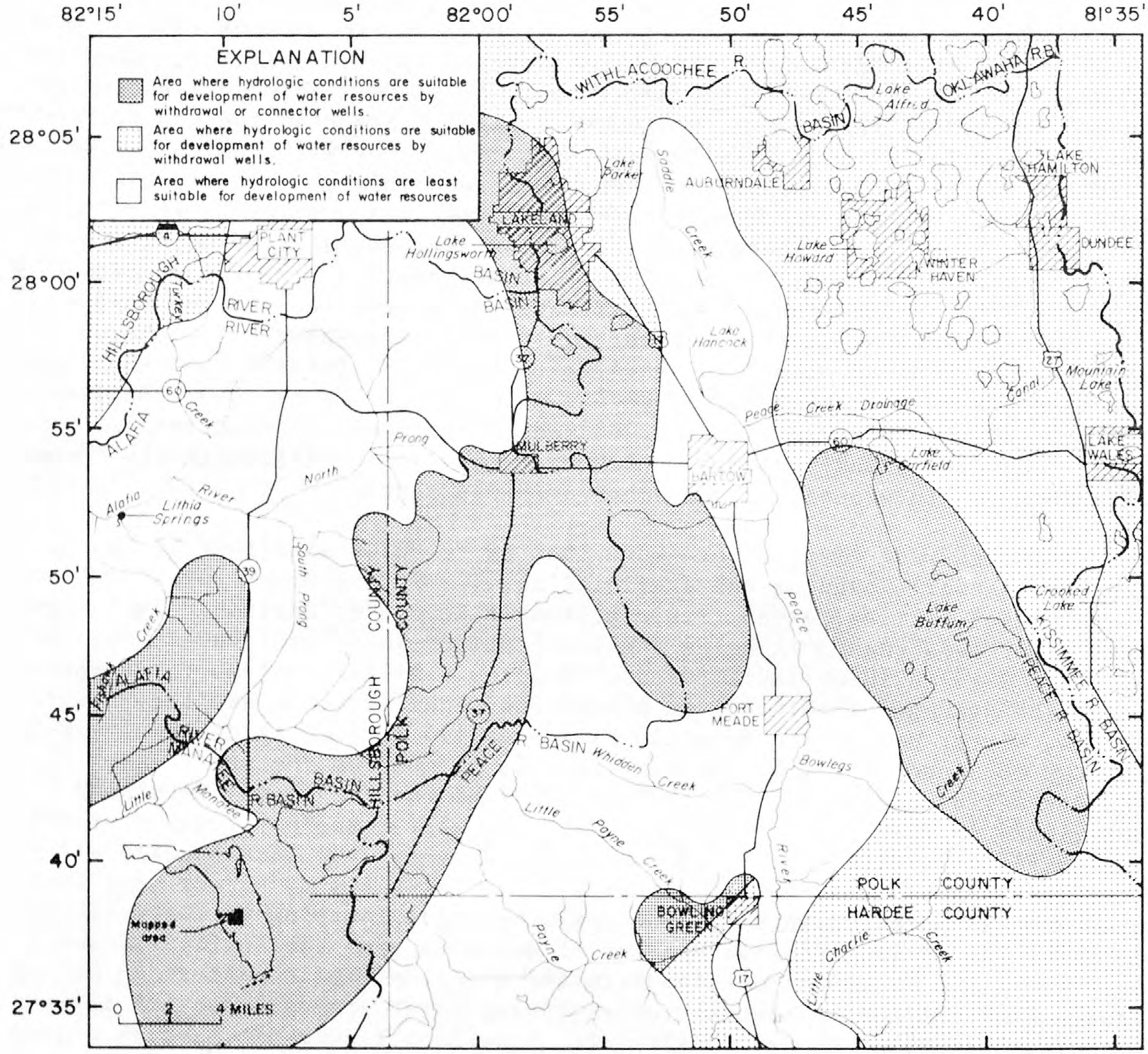

Figure 13 -- Relative potential for development of water resources in the surficial aquifer

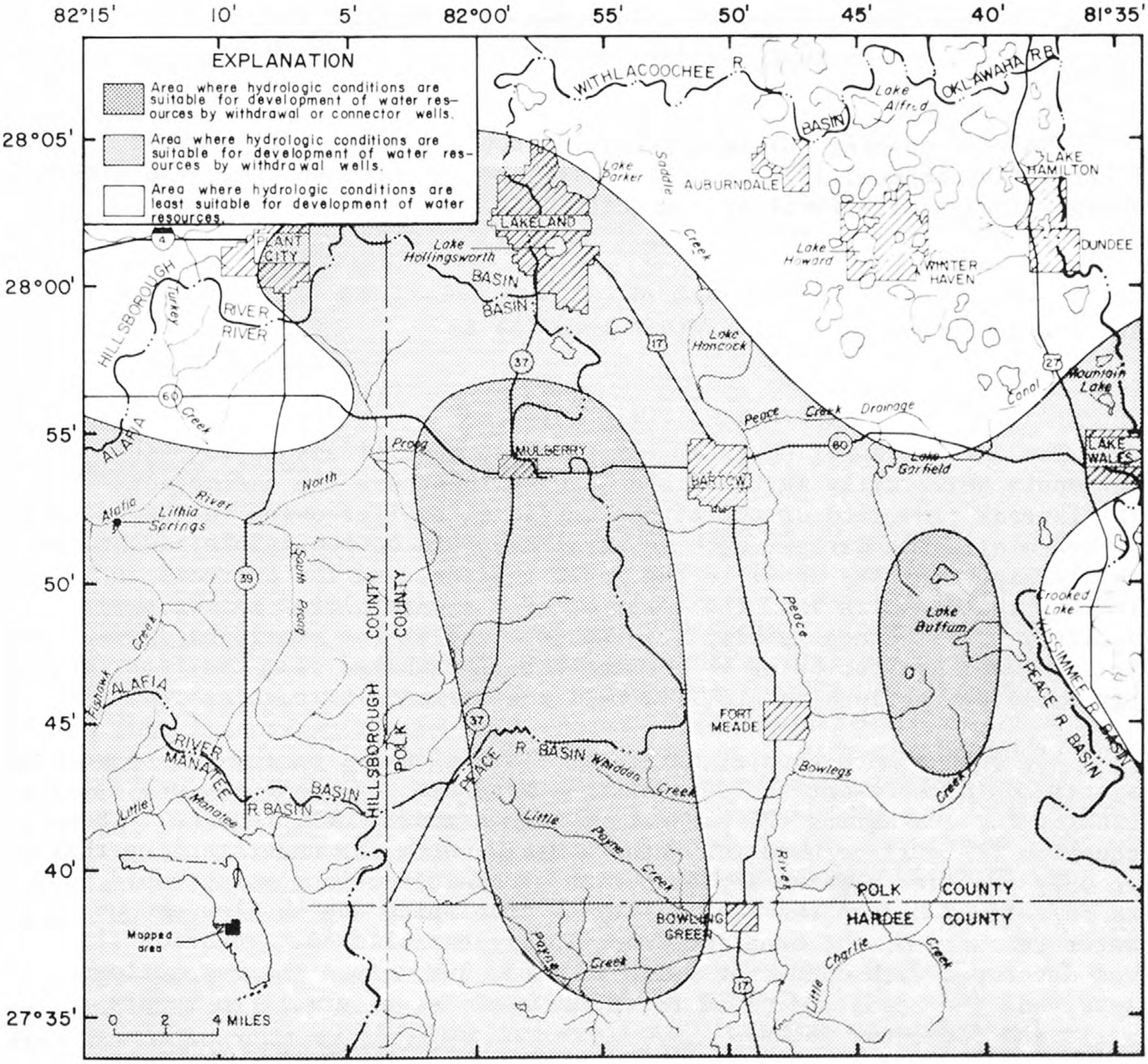

Figure 14 -- Relative potential for development of water resources in the upper unit, Floridan aquifer

in the wells (s_w), effective drawdown at the midpoint between wells (s_e), initial thickness (h_o) and transmissivity (T) of the surficial aquifer, capture rate (C_o), well radius (r_w), and well spacing (L), as expressed by the following equation:

$$\frac{\left[\left(s_w - \frac{s_w^2}{2h_o}\right) - \left(s_e - \frac{s_e^2}{2h_o}\right)\right] T}{C_o r_w^2} = f(L/r_w) \qquad (1)$$

The well spacing (L) is determined from a plot of L/r_w against $f(L/r_w)$ (Knochenmus, 1975, p. 28). With the computed spacing, the discharge of each withdrawal or connector well will be

$$Q = C_o L^2,$$

and the number of wells in a given area (A) is

$$N_w = A/L^2.$$

The derivation of equation (1) involves several assumptions that do not apply universally in the field. Among these are the assumptions that: (1) lateral flow into or out of the surficial aquifer owing to the effects of hydrologic boundaries--such as streams--would be negligible; (2) natural leakage from the upper to the lower aquifer, and the decrease in leakage that results from the lowering of the water level in the upper aquifer, would be negligible; (3) the increase in the static head of water in the lower aquifer owing to connector-well recharge from the upper aquifer would be negligible; and, (4) well losses would be negligible.

Although a more sophisticated mathematical model of the ground-water system could represent field conditions more exactly, data are presently lacking for evaluating the parameters such a model would require. Thus, equation (1) will be used for network design with the understanding that it only provides a gross approximation of specifications which would have to be refined before the feasibility of developing the shallow ground-water resource of the area could be finally established. Equation (1) was developed with connector wells in mind, but, given the assumptions involved, the results derived therefrom apply equally well to supply wells and connector wells.

Well spacing and discharge per well will be estimated for the 510-mi^2 area in which both the surficial aquifer and the upper unit of the Floridan aquifer are considered to be suitable for development following the assumption that all wells could tap both aquifers. The average transmissivities of the surficial aquifer and the upper unit of the Floridan aquifer were previously given as 1,900 and 2,200 ft^2/d (table 1), respectively; hence, the total transmissivity (T) of the two aquifers averages about 4,100 ft^2/d. The combined thickness of the two aquifers (h_o) would have a minimum value of 100 ft, and is assumed to average 150 ft or more over the entire area. The well radius (r_w) will be taken as 0.25 ft. Well drawdown (s_w) is assumed to be 50 ft, equal to the minimum head difference specified in the criteria for connector wells. Because of the uncertainty as to what would constitute reasonably representative values of the drawdown between wells (s_e) and the capture rate (C_o), computations were performed for a range of values for these parameters as indicated in table 8. In the following example, values used for s_e and C_o were taken as 10 ft and 0.5 ft, respectively:

$$f(L/r_w) = \frac{(50 - \frac{2,500}{300}) - (10 - \frac{100}{300})}{\frac{0.5}{365} \times 0.0625} \times 4,100 = 1.53 \times 10^9$$

From an extension of the graph presented by Knochenmus (1975, p. 28)

$$L/r_w = 3.2 \times 10^4.$$

Thus, the well spacing (L) = $3.2 \times 10^4 \times 0.25 = 8,000$ ft;

discharge per well (Q) = $(0.5/365) \times 8,000^2 \times (7.48/1,440)$
= 455 gal/min; and,

number of wells (N_w) = $(510 \times 5,280^2)/8,000^2 = 222$.

The computed well discharges (table 8) are considerably greater than the average combined yields of wells that presently tap the surficial aquifer and the upper unit of the Floridan aquifer (table 1), possibly because well losses were disregarded. Knochenmus (1975, p. 29 and 30) showed that the effect of the well radius is relatively small. For a given well drawdown (s_w), the effective drawdown (s_e) is the primary control on well discharge, and capture rate is the primary control on well spacing. Regardless of the assumed effective drawdown,the combined yield of all wells is theoretically the same and equal to the designated capture rate. Apparent discrepancies can result from small errors in the graphical determination of the L/r_w ratio.

For the given area of 510 mi^2, the volume of water represented by a capture rate of 6 in/yr would equal about 45 percent of the 1971 pumpage from the lower unit of the Floridan aquifer. Inasmuch as additional water could be obtained in other parts of the study area where either the surficial aquifer or the upper unit of the Floridan aquifer is suitable for development, it is apparent the development of the shallow groundwater resource could alleviate the pumping stress on the lower unit of the Floridan. Whether a capture rate as great as 6 in/yr could be achieved without severe impact on the surface-water hydrology of the area is not known.

Table 8. -- Network design for development of shallow ground-water resources for ranges of maximum capture rate and effective drawdown

[Results derived from solution of equation (1) with assumed parameter values as follows: s_w = 50 ft; h_o = 150 ft; r_w = 0.25 ft; and T = 4,100 ft^2/d.]

Capture (ft/yr)	Effective drawdown (ft)	Well spacing (ft)	Discharge per well (gal/min)	Number of wells in area
0.25	5	12,000	512	99
	10	11,250	450	112
	15	10,500	392	129
0.50	5	8,500	514	197
	10	8,000	455	222
	15	7,500	400	253
0.75	5	7,000	526	290
	10	6,500	451	337
	15	6,000	384	395

The total quantity of water available for capture within a given area consists of the surface and subsurface flow from the area plus water derived from any reduction in evapotranspiration that results from the lowering of ground-water levels. In the upper Peace and eastern Alafia River basins a substantial part of the surface flow is base flow derived from the surficial aquifer and the upper unit of the Floridan aquifer. The water-budget analysis of the study area showed that the surface flow from the area is large in relation to the subsurface flow from the area. During 1966-75 the surface flow from the area averaged 10 in/yr; however, the rate of flow varied appreciably from year to year and within each year. For example, during the 1975 water year (October 1974 to September 1975) the surface flow from the area was only 5.6 in, and about 60 percent of the annual flow occurred in a 4-month span, June through September. Inasmuch as the level of water in many of the wells tapping the surficial aquifer rose 4 to 6 ft from May to September 1975, the opportunity for reducing overland flow and evapotranspiration by lowering the water table seemingly was small during the early months of 1975. Thus, during this and other relatively dry periods a capture rate of 6 in/yr apparently could not be accomplished without an accompanying reduction in base flow that at times would be of drastic proportions. Of course, the effect of withdrawals of shallow ground water would be mitigated to some extent by the recycling of part of the water applied for use within the area because not all the applied water would be consumed.

Lowering the hydraulic head in the surficial aquifer also may have adverse effects on citrus growth, and could cause changes in the ecology in some areas. Moreover, lowering the head in the upper unit of the Floridan aquifer might cause nearby domestic wells that tap this aquifer to go dry; might accelerate development of solution channels in the limestone; might increase the probability of sinkhole collapse; and would reduce natural leakage to the lower unit of the Floridan aquifer.

A proposal of potential merit would be to develop the shallow ground water conjunctively with the deep, the objective being to maximize the use of shallow ground water during wet spells and to reserve the deep ground water for use during dry spells. The capacity for storing additional water in the lower unit of the Floridan aquifer would be increased by pumping during dry spells. The potential for withdrawing shallow ground water and for artificially recharging the lower unit of the Floridan aquifer without adverse effects would be greatest during wet spells. The potential for capturing appreciable quantities of water by reducing overland flow and evapotranspiration through wide scale lowering of shallow ground-water levels in the area of study probably could be realized only during wet spells. The capture of overland flow would not increase the total quantity of water available but it could make possible more beneficial use of part of the flood water that presently escapes to the ocean. The capture of water derived from a reduction of evapotranspiration would increase the quantity of water available for alternative uses. At some stage further lowering of the shallow ground-water levels would produce minimal increases in the quantity of water derived from the reduction of overland flow and evapotranspiration. Withdrawals of shallow ground water could be terminated either at this stage or at the stage where the projected adverse effects of additional withdrawals could not be tolerated, whichever might come first.

Assessment of the feasibility of such a proposal would require broad-scope investigations that would: (1) establish how overland runoff and evapotranspiration vary with depth to the water table in the area of consideration; (2) determine where and how long the water table is close enough to the land surface that a reduction in overland flow and evapotranspiration could be expected to result from a lowering of the water table; (3) define more accurately the natural leakage of shallow ground water into the lower unit of the Floridan aquifer, and the extent that natural leakage would be reduced by a decrease in the head difference between the shallow ground water and the water of the lower unit, and hence, establish whether artificially recharging the lower unit with shallow ground water could produce a net gain in recharge; (4) establish the stage at which the various adverse effects associated with the withdrawal of shallow ground water either would become intolerable or would more than offset the benefits derived therefrom.

SUMMARY AND CONCLUSIONS

The shallow aquifers underlying the 1,250 mi^2 upper Peace and eastern Alafia River basins range between 50 and 300 ft thick and occur as two distinct aquifers: (1) the surficial aquifer, which consists mainly of sand and is underlain by (2) the upper unit of the Floridan aquifer, composed mainly of limestone and dolomite. Transmissivities of the two aquifers vary but average about 1,900 ft^2/d for the surficial aquifer and about 2,200 ft^2/d for the upper unit of the Floridan. About 46 million acre-ft of water are stored in the two aquifers, the water quality generally meeting the drinking water standards recommended by the National Academy of Sciences and National Academy of Engineering for total dissolved solids, common inorganic constituents, and trace metals except iron.

Annual leakage of shallow ground water into the lower unit of the Floridan aquifer is estimated at 2.6 in, which is not enough to offset the 5.5 in of water pumped from the lower unit. Because water levels in wells tapping the more productive lower unit of the Floridan are declining over the long term, development of the shallow ground-water resource is now being weighed. Two water-management alternatives seem particularly suited: (1) installation of a network of supply wells which would supplement pumpage from the lower unit of the Floridan aquifer; (2) installation of a network of gravity-flow connector wells that would connect the surficial aquifer and (or) the upper unit of the Floridan aquifer to the lower unit of the Floridan, recharging the lower unit by gravity flow. A combination of supply wells and connector wells could be used effectively.

On the assumption that ample well yields would require an aquifer thickness of at least 50 ft, and that successful operation of connector wells would require a head difference of 50 ft or more, areas having potential for water development were delineated. For the surficial aquifer about 730 mi^2 are considered suitable for development by supply wells including 340 mi^2 which are also classed as being suitable for connector wells. For the upper unit of the Floridan aquifer, about 990 mi^2 are considered suitable for development by supply wells, including 250 mi^2 which are also considered suitable for connector wells. Of the areas so delineated for development by supply wells, about 510 mi^2 are common to both the surficial aquifer and the upper unit of the Floridan aquifer, and such wells could tap both aquifers.

Well-network computations indicated that a grid of a few hundred wells could produce enough shallow ground water to alleviate the hydrologic stress imposed by present pumping of the lower unit of the Floridan aquifer. However, during dry spells, virtually all of the captured water would come from a reduction of ground-water discharge. Thus, extensive dewatering of the shallow aquifers could drastically reduce streamflow in the area because most of the base flow of the streams comes from the surficial aquifer and from the lower unit of the Floridan aquifer.

The adverse effects of withdrawing shallow ground water from aquifers in the upper Peace and eastern Alafia River basins perhaps could best be minimized if the shallow ground water and the deep ground water were developed conjunctively. Use of the shallow ground water could be maximized during wet spells; use of deep ground water could be reserved for dry spells. Pumping of the lower unit of the Floridan aquifer during dry spells would increase the capacity for artificial recharge with shallow ground water during wet spells. The potential for capturing appreciable quantities of water from a reduction of overland flow and evapotranspiration is greatest during wet spells when the shallow ground-water levels are highest. Capture of overland flow would permit more beneficial use of flood water that now escapes to the ocean. Capture of water derived from a reduction of evapotranspiration would increase the quantity of water available for alternative uses. Further investigations would be required to establish whether appreciable net benefits could result from such a proposal and whether the associated adverse effects could be tolerated.

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*U.S. GOVERNMENT PRINTING OFFICE: 1978-746-326/757. Region 4.

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