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GEOHYDROLOGIC RECONNAISSANCE OF DRAINAGE WELLS IN FLORIDA--AN INTERIM REPORT

By Joel O. Kimrey and Larry D. Fayard

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS AND ABBREVIATIONS

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

Multiply	By	To obtain
inch (in)	25.4	millimeter (mm)
yard (ft)	0.9144	meters (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
foot (ft)	0.3048	meter (m)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
gallon per day (gal/d)	3.785	liter per day (L/d)
	0.003785	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.00378	cubic meter per minute (m^3/min)
million gallons per day (Mgal/d)	0.04381	cubic meters per second (m^3/s)

* * * * * * * * *

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

GEOHYDROLOGIC RECONNAISSANCE OF DRAINAGE WELLS IN FLORIDA--AN INTERIM REPORT

By Joel O. Kimrey and Larry D. Fayard

ABSTRACT

Drainage wells include all wells that are used to inject surface water directly into an aquifer, or shallow ground water directly into a deeper aquifer, primarily by gravity. By this definition, drainage wells in Florida may be grouped into two broad types: (1) Surface-water injection wells, and (2) interaquifer connector wells. Drainage wells of the first type are further categorized as either Floridan aquifer drainage wells or Biscayne aquifer drainage wells. Effective use of drainage wells requires a source of injection water (a losing aquifer or surface water); prevailing natural downward gradient from the source to the receiving aquifer; and transmission and storage characteristics of the receiving zone that will allow emplacement of the volumes of injection water without head buildup sufficient to decrease severely the downward gradient. This interim report presents the results of a reconnaissance investigation of the geohydrologic aspects of Floridan aquifer drainage wells and interaquifer connector wells.

The most common use of Floridan aquifer drainage wells is to supplement surface drainage for urban areas in the karst terranes of topographically higher areas of central and north Florida. Drainage wells are the primary means of urban drainage for the Ocala (35 wells), Live Oak (46 wells), and Orlando (392 wells) areas. Records are available for a total of 607 Floridan aquifer drainage wells.

Data are available for 6 wells in the Ocala area, 9 in the Live Oak area, and 10 in the Orlando area that allow comparison of the quality of water samples from Floridan aquifer drainage wells with the standards of the National Interim Primary Drinking Water Regulations and the National Secondary Drinking Water Regulations. Comparison indicates that maximum contaminant levels for turbidity, color, and iron, manganese, and lead concentrations are equaled or exceeded in some drainage-well samples, and that relatively high counts for coliform bacteria are present in samples from most of the wells. Floridan aquifer drainage wells are estimated to recharge an average of 50 million gallons per day in the Orlando area.

At present (1981) the predominant use of interaquifer connector wells in Florida is concentrated in the phosphate mining areas of Polk and Hillsborough Counties. These wells serve the dual purposes of facilitating mining operations (by providing drainage) and supplying artificial recharge to the Floridan aquifer. Records are available for 167 interaquifer connector wells in the mining areas of Polk, Hillsborough, and Manatee Counties.

Water-quality analytical data are available that allow comparison between samples from 13 connector wells with standards of the National Primary and Secondary Drinking Water Regulations. Samples from most of these wells exceeded standards values for iron concentration and turbidity. Samples from 7 of the 13 wells exceeded standards values for gross alpha concentrations.

Those data available indicate that injection rates for most single connector wells range from about 40 to 275 gallons per minute. A summary of data for March 1980 indicates a total injection rate of about 26 million gallons per day for 142 connector wells throughout the phosphate mining areas.

INTRODUCTION

The UIC (Underground Injection Control) parts of the SDWA (Safe Drinking Water Act - Public Law 93-523, as amended by Public Law 95-190) require the U.S. Environmental Protection Agency to develop and publish regulations on minimum requirements to prevent underground injections through wells that may endanger underground sources of drinking water. Responsibility for development of the UIC regulations is further delegated to those States that have assumed primary enforcement responsibility, or primacy. The Florida Department of Environmental Regulation is in the process of assuming responsibilities as the lead agency to administer primacy for the State of Florida. As part of the preparation for administering a UIC program, the Department of Environmental Regulation, in cooperation with the U.S. Geological Survey, is conducting a geohydrologic investigation of "drainage wells" throughout the State.

For purposes of this investigation drainage wells are considered to include all wells that are used to inject surface water directly into an aquifer, or shallow ground water directly into a deeper aquifer, primarily by gravity. Typically, all such wells in Florida are finished open-end into limestones or dolomites of the receiving aquifer zone; those that drain ground water from shallow to deeper zones are screened in unconsolidated materials of the upper zones. For convenience, all wells considered as drainage wells under the above definition may be grouped into two broad types: (1) surface-water injection wells, and (2) interaquifer connector wells. In this report, drainage wells of the first type are further categorized as either Floridan aquifer drainage wells or Biscayne aquifer drainage wells.

The general purpose and scope of this investigation is to conduct a statewide geohydrologic appraisal of drainage wells, on a reconnaissance basis, to:

1. Determine areal distribution of drainage wells;

2. Investigate the general character of water that they emplace in the various aquifers;

3. Investigate the geohydrologic conditions for areas of drainage-well usage; and

4. Estimate the probable magnitude of present and potential groundwater pollution problems.

This interim report presents results of investigation, from October 1978 to April 1981, for Floridan aquifer drainage wells and interaquifer connector wells. Biscayne aquifer drainage wells are discussed only briefly in the section on distribution, use, and history of drainage wells.

METHODS OF INVESTIGATION

Initial investigative activities were to compile a computerized working data base, or well inventory, from all available sources of information on existing drainage wells. A major source was the permitting records of various State agencies. Beginning in 1937, permits by the Florida State Board of Health, or delegated local health agencies, were required for construction of drainage wells. In more recent years, most of this authority has been assumed by the Florida Department of Environmental Regulation. For information on nonpermitted wells, a literature search of both published and unpublished reports was made and written inquiries were addressed to the local health or pollution control departments for each county in the State and to other agencies that might have knowledge of or information on drainage wells, such as the district offices of the Florida Water Management Districts, the Florida Department of Transportation, and the U.S. Soil Conservation Service.

Objectives in compiling the working data base were to obtain as complete data on drainage wells as practical, to include as a minimum: accurate location by longitude-latitude coordinates; well specifications (diameter and length of cased and open-hole sections); and the date drilled and use of well. In general, these data were available from the various permitting records, though precise locations and present use were verified in the field for selected wells. Locations for permitted Floridan aquifer drainage wells in Pinellas and Hillsborough Counties and Biscayne aquifer drainage wells in Dade County were furnished by the Florida Department of Environmental Regulation and converted to longitude-latitude coordinates. A selective field inventory verified and updated the existing data on location and use of wells;

provided current information on accessibility of wells for geophysical logging and water-quality sampling; and added data on nonpermitted wells. Emphasis was given in this selective field inventory to large-diameter (12-inch or greater) wells in those areas of the State where drainage-well concentrations are greatest.

Information in the working data base showed a lack of ground-water quality data for most of the areas affected by drainage wells. Accordingly, large-diameter wells in the various areas were sampled and analyzed for a list of parameters agreed on by the Geological Survey and the Department of Environmental Regulation. The parameters analyzed include the major ions and most of those in the standards established by the National Interim Primary Drinking Water Regulations and the National Secondary Drinking Water Regulations (U.S. Environmental Protection Agency, 1975; 1977). Because of the association of connector wells with phosphate deposits and mining, selected radiochemical parameters also were included for samples from interaquifer connector wells. Various bore-hole geophysical logs and specific capacity data were obtained for each sampled well. Caliper (borehole diameter) logs were particularly useful because they tend to show individual caverns, or cavernous zones, into which injection occurs. Concurrent with above field activities, observations were made relative to general hydrologic conditions in the areas drained by drainage wells; the general types of wastewaters currently being injected; and estimates of the probable total volumes.

GENERAL GEOHYDROLOGY

Ground water is one of the most valuable natural resources in Florida. Water use data for 1975 (Leach, 1978) indicate that ground water comprised about 48 percent (3,320 Mgal/d) of the total freshwater withdrawn for use in the State (6,918 Mgal/d). By freshwater use categories, ground water supplied about 86 percent (986 Mgal/d) of the total 1,146 Mgal/d withdrawn for public supply; 83 percent (779 Mgal/d) of the total 940 Mgal/d withdrawn for industrial self-supplied use; 43 percent (1,239 Mgal/d) of the total 2,868 Mgal/d withdrawn for irrigation; 95 percent (252 Mgal/d) of the 266 Mgal/d for rural domestic and livestock use; and 4 percent (63 Mgal/d) of the 1,698 Mgal/d of freshwater used for cooling water in the generation of thermoelectric power. Additionally an average of about 95 Mgal/d of saline ground water was withdrawn for use during 1975.

The use of ground water for potable purposes is generally the use that is most apt to be adversely affected by subsurface injection of wastewater, whether by drainage wells or other means. Consideration that about 86 percent of total water use for public supply and 99 percent of total water use for rural domestic use was obtained from ground-water sources (during 1975) tends to accentuate the need for better understanding of the effects of drainage wells on the geohydrologic regimen of the areas in which they are used. A brief summary of characteristics and extent of the principal aquifers in Florida is given below as background for more detailed geohydrologic discussion of the various areas.

Previous investigators (Hyde, 1965; Pascale, 1975) have discussed the potable ground-water resources of Florida as occurring in four major aquifers, or aquifer systems; the Floridan, Biscayne, and sand-and-gravel aquifers, and a largely undifferentiated complex denoted as the shallow aquifers. That treatment of aquifer identification and terminology is used in the present report, with exception that the term "other aquifers" is used in lieu of "shallow aquifers." Figure 1 shows the general geographic areas of the State in which each of these aquifers, or aquifer systems, is the principal source of potable ground water.

Floridan Aquifer

The Floridan is part of a regional aquifer system that underlies all of Florida and parts of Alabama, Georgia, and South Carolina. As defined by Parker and others (1955, p. 189) the Floridan aquifer includes "* * * parts or all of the middle Eocene (Avon Park and Lake City Limestones), upper Eocene (Ocala Limestone), Oligocene (Suwannee Limestone), and Miocene (Tampa Limestone), and permeable parts of the Hawthorn Formation that are in hydrologic contact with the rest of the aquifer." The Floridan is composed of limestone, dolomitic limestone, and dolomite and ranges in thickness from about 1,500 feet in north-central Florida (Gilchrist and Levy Counties) to about 3,000 feet in south Florida (Dade County). The top of the aquifer is at or near land surface in the western part of north-central Florida; it plunges to a depth in excess of 1,500 feet in west Florida (Escambia County) and in excess of 1,100 feet in south Florida (Miller, 1981a; 1981b).

The transmissivity of the Floridan is generally high and has been enhanced by solution in most areas. Its average yield to properly constructed 12-inch wells exceeds 500 gal/min over the majority of the areas of the State in which the aquifer contains freshwater (Pascale, 1975). There are also large areas in which average Floridan well yields exceed 1,000 gal/min, and a number of areas (particularly in central and southeast Florida) where well yields of 5,000 gal/min, or more, are not uncommon. A natural unpumped flow of 12,000 gal/min has been reported for a well in Putnam County, and one of 9,000 gal/min has been measured for a well in Lake County. Thus the Floridan is one of the most productive aquifers in the world, and it is used wherever it contains freshwater (fig. 1) to the virtual exclusion of other sources for public water supply.

The Floridan is overlain by varying thicknesses of clastic materials over most of its areal extent; these include sand, clay, shell, and various intermixed lithologies. The overlying materials function both to partially confine the aquifer, and as the media through which the aquifer is naturally recharged and discharged. In general, the aquifer is

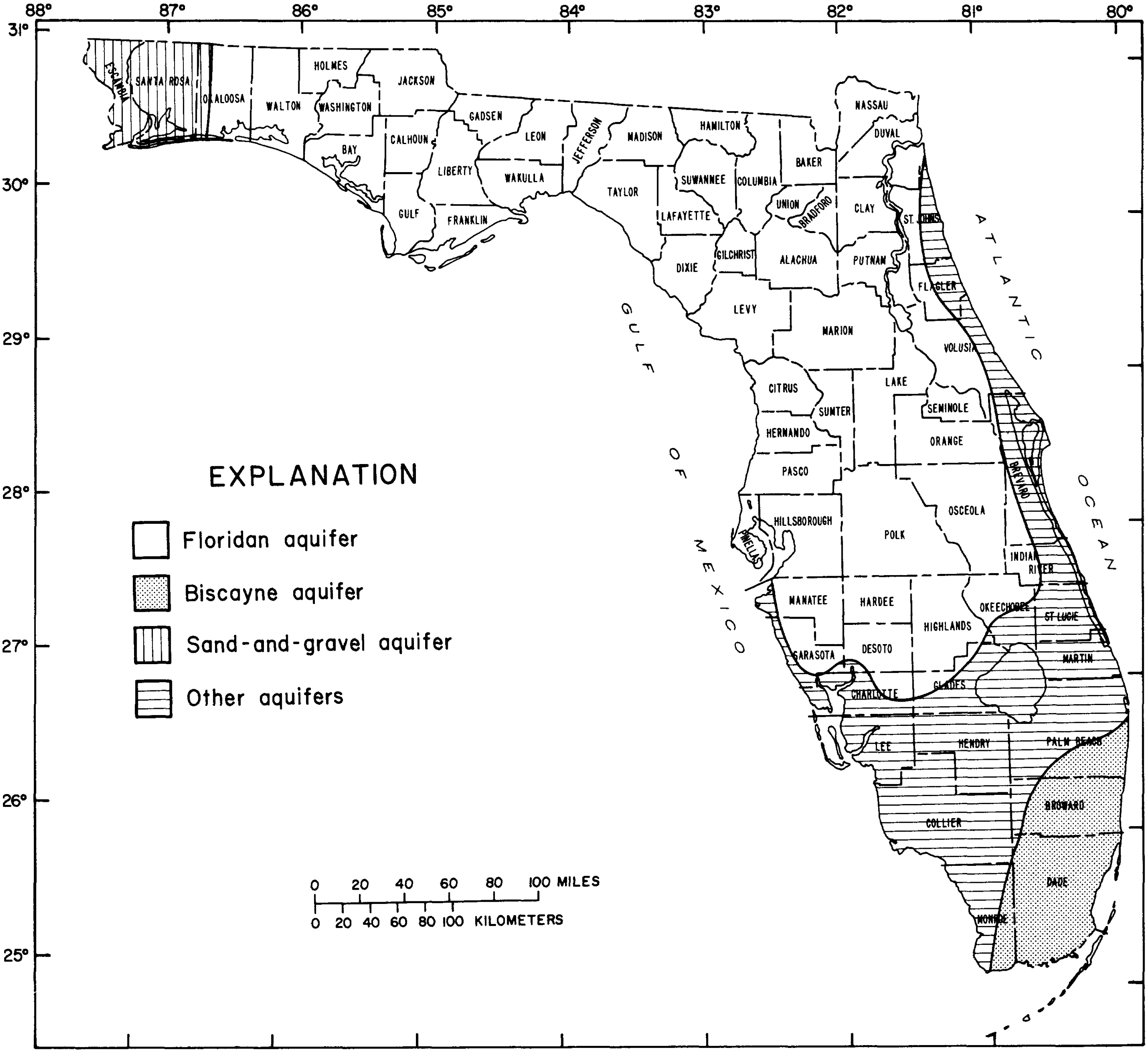


Figure 1.--Sources of potable ground water in Florida.

recharged in the topographically higher interior parts of central and west Florida (Stewart, 1980) and discharged (by wells, springs, and diffuse upward leakage) over a large area of south Florida, along the entire Atlantic coast and much of the Gulf coast, and in the major stream valleys throughout the remainder of the State. The generalized map of areas of artesian flow for May 1974 (fig. 2; adapted from Healy, 1975) is pertinent in that it delineates some large areas of the State where gravity injection to the Floridan is not feasible. In general, the Floridan also contains the freshest, or least mineralized, water in or adjacent to those interior areas where recharge occurs, and more mineralized water toward the discharge areas.

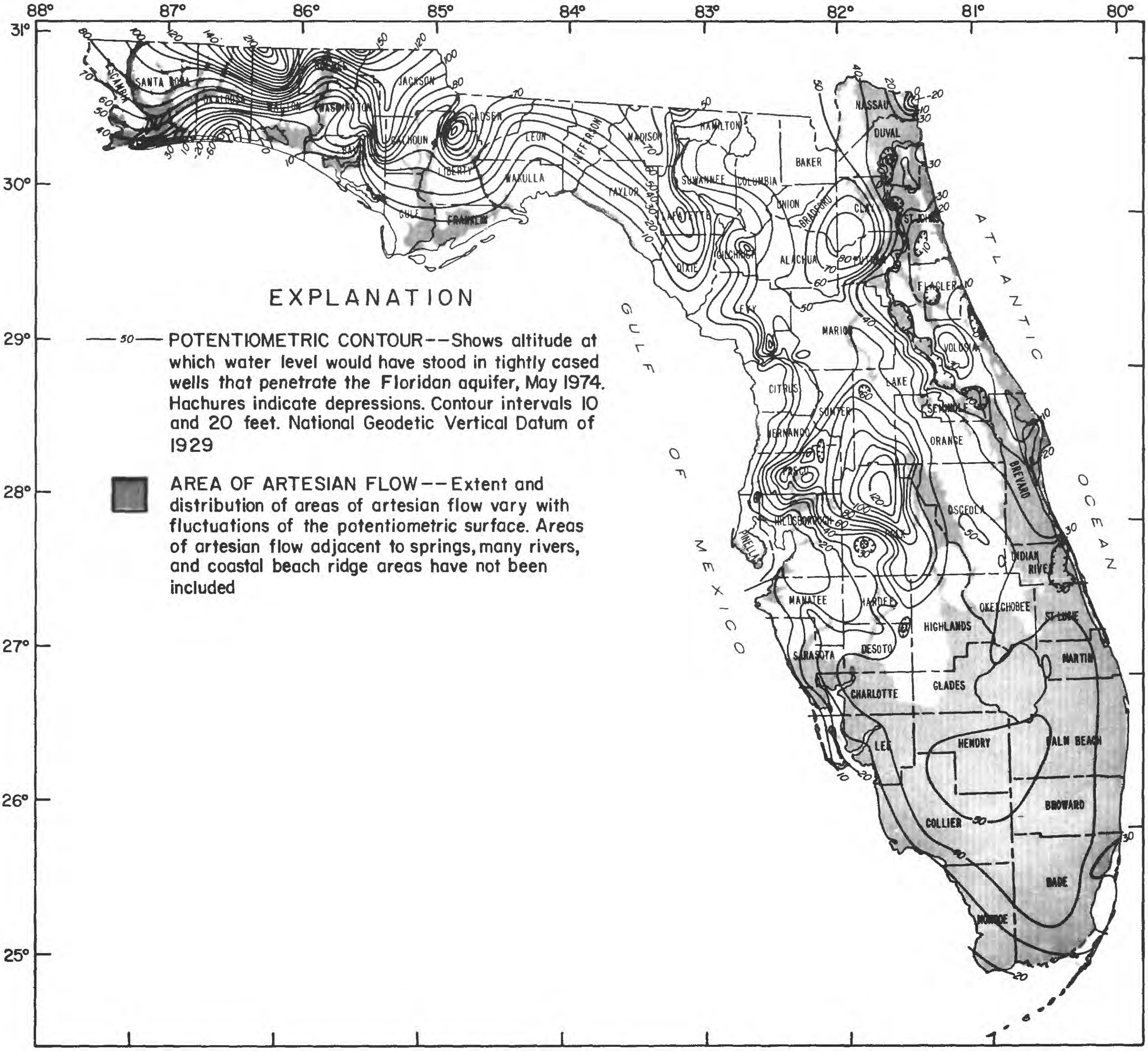
Biscayne Aquifer

This aquifer is the principal source of potable water in southeast Florida (fig. 1); it supplies all municipal water systems in the area from south Palm Beach County southward, including the system that furnishes the Florida Keys by pipeline from the mainland (Klein and Hull, 1978, p. 3). The Biscayne aquifer consists of geologic formations that range in age from Pliocene through Pleistocene; these are, from oldest to youngest, the Tamiami Formation of Pliocene age; the Caloosahatchee Marl of Pliocene and Pleistocene age; and the Fort Thompson Formation, Key Largo Limestone, Anastasia Formation, Miami Oolite, and Pamlico Sand of partly equivalent and of Pleistocene age (Hyde, 1965).

The aquifer is composed of limestone, sandstone, and sand. In south and west Dade County the limestone and sandstones are predominant. In north Dade, Broward, and Palm Beach Counties the aquifer is primarily sand; generally the sand content increases to the east and north. The various limestone zones in the aquifer contain numerous solution cavities and caverns that tend to result in generally high vertical and horizontal permeabilities. The aquifer is more than 200 feet thick in coastal Broward County and thins to an edge 35 to 40 miles inland in the Everglades (Klein and Hull, 1978).

The Biscayne aquifer contains ground water under unconfined conditions. Its generally high vertical permeability allows rapid recharge by infiltration of rainfall. Natural discharge is to the Atlantic Ocean, to numerous canals, and to direct evapotranspiration from the shallow water table. Klein and Hull (1978, p. 15) conclude the following in regard to recharge and discharge of this aquifer:

> "Parker and others (1955) and Meyer (1971) estimated that 20 in. of the approximately 60 in. of annual rainfall in Dade County is lost directly by evaporation, about 20 in. is lost by evapotranspiration after infiltration, 16 to 18 in. is discharged by canals and by coastal seepage, and the remainder is utilized by man. Sherwood and others (1973, p. 49) indicated comparable values for Broward County. Thus, nearly 50 percent of the rainfall that infiltrates the Biscayne aquifer is discharged to the ocean, a reflection of the high degree of connection between the aquifer and the canal system."



EXPLANATION

—50— POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells that penetrate the Floridan aquifer, May 1974. Hachures indicate depressions. Contour intervals 10 and 20 feet. National Geodetic Vertical Datum of 1929

▨ AREA OF ARTESIAN FLOW--Extent and distribution of areas of artesian flow vary with fluctuations of the potentiometric surface. Areas of artesian flow adjacent to springs, many rivers, and coastal beach ridge areas have not been included

Figure 2.--Potentiometric surface and areas of artesian flow of the Floridan aquifer, May 1974.

The Biscayne aquifer generally contains a hard, calcium carbonate type water. Saltwater intrusion along the coast results in occurrence of chloride concentrations of 1,000 mg/L, or greater, at the base of the aquifer (Klein and Hull, 1978, fig. 17). Ground-water quality is also affected by pollutants that can enter the aquifer by direct infiltration from land surface or controlled canals, septic-tank and other drainfields, solid-waste dumps, and drainage wells (Klein and Hull, 1978). Parker and others (1955, p. 160) indicate that the Biscayne "* * * is the most productive of the shallow nonartesian aquifers in the area and is one of the most permeable in the world." Yields of properly constructed large-diameter wells in this aquifer exceed 2,000 gal/min over much of its area of occurrence (Pascale, 1975).

Sand-and-Gravel Aquifer

This aquifer underlies the four westernmost counties in Florida and is the principal source of potable ground water in Santa Rosa and Escambia Counties (fig. 1). The Floridan aquifer occurs at progressively greater depths to the west in this area (Vernon, 1973), and contains highly mineralized water in parts of the area.

The sand-and-gravel aquifer is composed of sediments ranging in age from Miocene to Pleistocene. The sediments are predominantly very fine to very coarse quartz sand, mixed in places with quartz gravel and chert pebbles. Lenses of gravel and clay occur throughout the aquifer (Hyde, 1965). Its thickness, in Florida, ranges from a thin edge along the Walton-Washington County line to about 400 feet in northeast Santa Rosa County and about 700 feet in south-central Escambia County; its thickness along the Gulf coast is generally less than 250 feet (Musgrove and others, 1961, fig. 4, p. 14). The top of the aquifer is at or near land surface over its area of occurrence in Florida, and is recharged by direct rainfall that infiltrates to the water table. The aquifer is naturally discharged along the Gulf coast, to lakes and incised stream channels, and by evapotranspiration in some areas. Ground water usually occurs under unconfined conditions in the sand-and-gravel aquifer, but is locally confined under artesian pressure in deeper parts of the aquifer that are overlain by clay beds (Musgrove and others, 1961, p. 17).

Quality of ground water in most areas is generally slightly acidic and low in dissolved solids, hardness, chloride, and iron concentrations. Large-diameter screened wells that tap the sand-and-gravel aquifer generally yield 250 gal/min or more, except along the coast where the aquifer is usually less than 250 feet thick and contains clay beds that reduce the transmissivity (Pascale, 1975).

Other Aquifers

Other surficial or near surface water-bearing zones are present over most of the State; for example, most of the overburden sediments on the Floridan aquifer contain some unconfined to partially confined permeable sand or shelly zones that will yield small to moderate quantities of water to either driven well points or drilled and screened wells. Locally, also, confined zones of sand and shell are present within the overburden sediments on the Floridan (Lichtler, 1971). However, because of their generally low yield, these other aquifers are little used in those areas of the State where the three major aquifers that are described above are present and contain freshwater. They are used, by necessity, for public supplies in an elongated area that extends from the southwest Gulf coast, easterly to the Atlantic coast and thence northerly to southeast Duval County (fig. 1).

Their lithologies, thicknesses, and hydrologic characteristics vary widely in the areas in which they constitute the principal sources of potable ground water. In south Florida they range in age from Miocene to Holocene and are comprised of limestones in the upper part of the Hawthorn Formation; beds of shell and limestone in the Tamiami Formation; shell beds in the Caloosahatchee Marl; sand and shell zones in the Anastasia Formation; and sands of the various terrace deposits (Hyde, 1965). They range in thickness from about 30 feet in Hendry County to about 300 feet in western and central Palm Beach County. Along the Atlantic coast they are composed primarily of Pleistocene and Holocene sand and shell deposits, but extend downward to include Miocene or Pliocene age deposits in some areas. North of Palm Beach, their thickness ranges from about 20 to 150 feet.

The tops of the various water-bearing zones are generally near land surface and they, thus, contain water under largely unconfined conditions. Recharge occurs directly from local rainfall and natural discharge occurs to nearby bodies of surface water, including the numerous canals in some areas, and by direct evapotranspiration from the shallow water table. Water quality in the freshwater parts of these aquifers is generally low in chloride concentrations; soft to very hard; and commonly high in color and iron (Hyde, 1965). Wells that tap these aquifers along the Atlantic coast generally yield less than 250 gal/min because these aquifers consist of sediments of relatively low permeability, such as fine sand, clay, shell, and occasional thin layers of dense limestone (Pascale, 1975). However, in northern Collier and southern Hendry Counties the aquifer is composed of highly permeable limestone (Klein and others, 1964, p. 44) and large-diameter wells generally yield at least 2,000 gal/min (Pascale, 1975).

GENERAL DISTRIBUTION, USE, AND HISTORY OF DRAINAGE WELLS

The types of gravity drainage wells considered by this investigation may be conveniently typed as (1) surface-water injection wells, and (2) interaquifer connector wells. Surface-water injection wells are further categorized by the aquifer into which they inject--that is, as either Floridan aquifer drainage wells or Biscayne aquifer drainage wells. The general distribution of Floridan aquifer drainage and interaquifer connector wells, by county, is shown by figure 3. The locations of virtually all wells that are included in the totals of figure 3 were verified by field inventory during the present, or related, investigations. Each type is discussed separately below in terms of distribution, use, and history.

Surface-Water Injection Wells

Floridan Aquifer Drainage Wells

The most common use of these wells is to supplement surface drainage in the closed-basin karst terranes of the generally topographically higher areas of central, north-central, and northwest Florida. Their effective use requires a natural downward gradient from the water table or body of surface water to the confined or partially confined Floridan (receiving) aquifer; sufficiently high transmissivity in the receiving aquifer; and, of course, a surplus of surface water for disposal into the receiving aquifer. Their construction is relatively simple (diagram of fig. 4-Ia): The overburden sediments are cased off and the casing is usually seated in the first competent zone to be penetrated in the top of the Floridan aquifer; open hole is then drilled into the Floridan until enough permeable zones (usually cavities) have been penetrated to accept the quantitites of surface water to be disposed to the well. The common means of conveying the excess surface waters to these drainage wells is to construct the well's gravity intake in a lake, storm sewer, storm-sewer outfall, or collection basin. In most of their areas of use the natural downward head difference, coupled with high Floridan aquifer transmissivity, allow such drainage wells to receive relatively large volumes of water.

The earliest documentable construction and use of Floridan aquifer drainage wells began in Orlando, in Orange County, in 1904. Unklesbay (1944, p. 20-21) gives the following account:

> "According to Sellards (1908, p. 62-63 and 1910, p. 71) and Stringfield (1933, p. 21), the first drainage well in Orange County was drilled about 1904. In April of that year, a sinkhole (probably Lake Greenwood), which had previously carried away surplus surface water through its connections with underground drainage channels, became clogged, and a considerable area in southeastern Orlando was flooded by heavy rains. After several unsuccessful attempts to reopen the sink, a drainage well was drilled as an experiment. In August, a two-inch test well was drilled, and it proved successful enough to warrant the construction of larger wells. The next year two more wells, one 8-inch and one 12-inch, were completed and these drained a large part of the flooded area. These wells, however, were not sufficient to drain the area

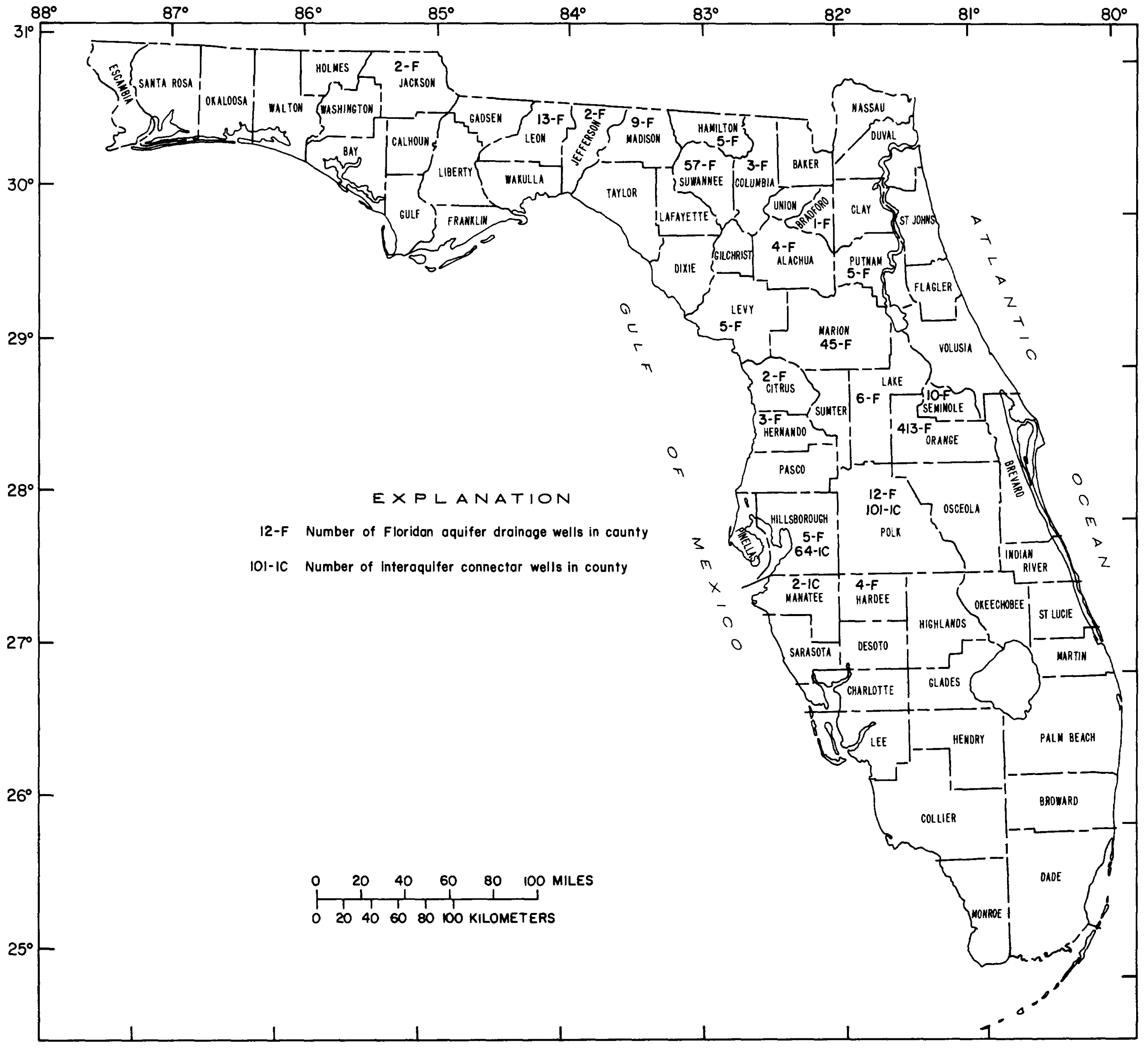


Figure 3.--General distribution of Floridan aquifer drainage wells and interaquifer connector wells.

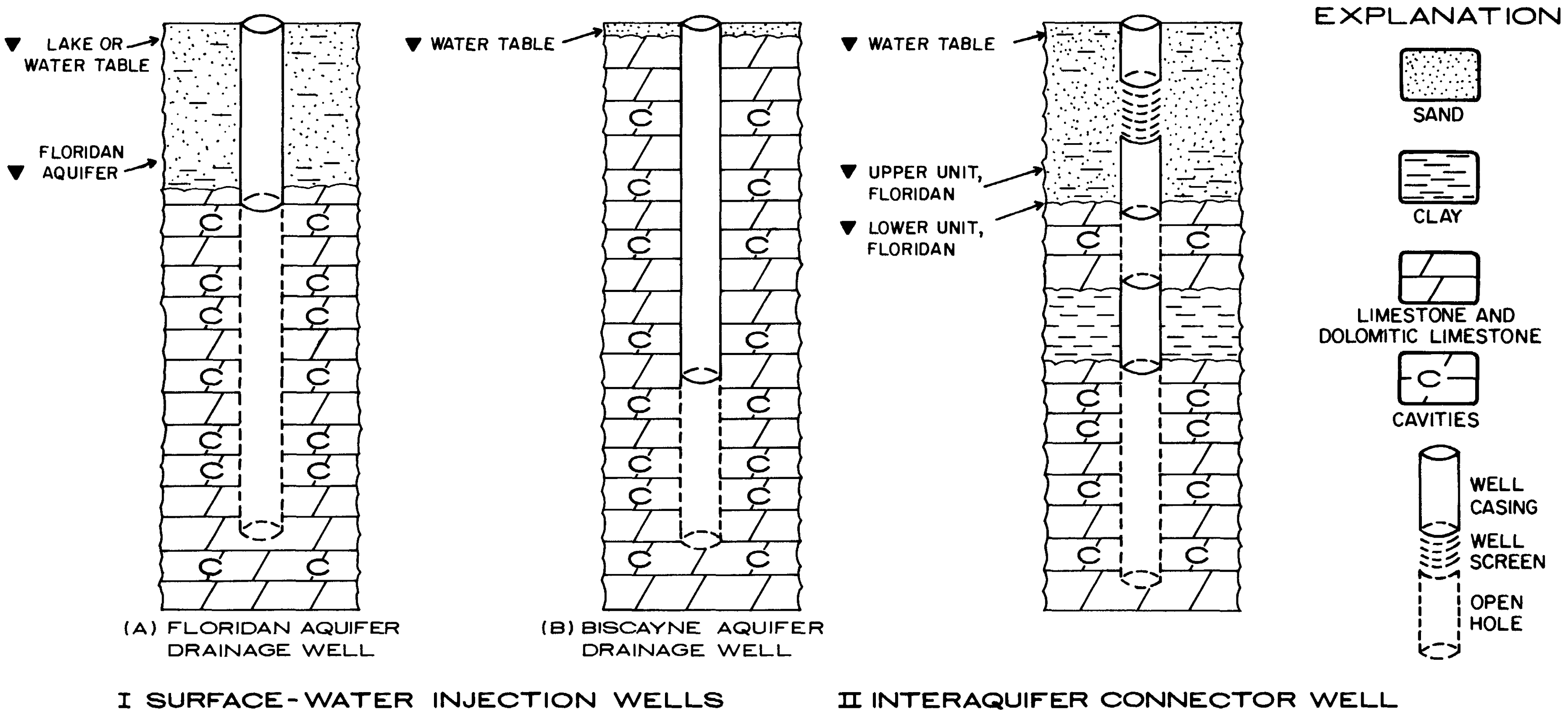


Figure 4.--The three general types of drainage wells.

> completely, so in the winter of 1906 two more 12-inch wells were constructed, and by February 1907, a fourth 12-inch well had been completed. By the end of March 1907, the water was almost back to its normal level."

Those wells in southeast Orlando are the earliest known drainage wells in Florida to have been specifically constructed for disposal of excess surface water. However, similar wells had previously been constructed and utilized for disposal of untreated (raw) domestic sewage in certain, though unspecified, areas of central Florida. In this regard, Sellards (1908, p. 64-65) indicates:

> "The disposal of sewage through bored wells has been practiced to a limited extent at a few localities of inland Florida for many years. The wells in use receive usually the drainage from private dwellings, or the combined drainage from two or three dwellings. Occasionally public buildings, as the court house, city hall, hospital, and hotels, are connected up with these wells. With the rapid growth of the inland towns during the past few years, the number of these private wells in the towns in which this method is used, have been very greatly increased.
>
> "The principles and conditions which permit of disposal of sewage through bored wells are precisely those already explained in connection with drainage wells and natural sink-holes. The sewage is conducted by means of the well either to a cavity or to a porous stratum and is carried away by the underground water circulation.
>
> "The depth of the wells intended for sewage is exceedingly variable, in this respect resembling the water wells of the same locality. Practically without exception they reach and enter the artesian water supply. Extreme range in depth is from 35 to 500 feet. In size the wells may vary from two to twelve inches. A cemented cesspool is usually provided, which in the more carefully constructed wells is divided into two divisions. The first division receives the solids; the second is for liquids only, and is separated from the first by a screen. The drainage well leads from the second division, the opening being guarded by a screen."

The densest concentration of Floridan aquifer drainage wells is in the Orlando area, where some 400 drainage wells are known in an area of about 400 square miles. Their history of development and use is also best documented in this area, as summarized by Kimrey, 1978 (p. 9-10):

"Following the successful drainage of Lake Greenwood by drainage wells, they became the commonly accepted solution to drainage problems in the Orlando area over the next four decades. Their use became applied to almost all aspects of land drainage and wastewater disposal, that is, to lower and control lake levels; to drain wetlands and highways; to dispose of stormwater and other surplus effluents such as industrial wastes; and to drain effluent away from septic tanks. The largest number of drainage wells during this period (1904-44) was for relief of flooding problems caused by excessively heavy rains in 1926 and 1928."

"Drainage-well construction was accelerated again during the wetter-than-average years of 1948 and 1954. Then the anomalously wet years of 1959 and 1960 probably resulted in the highest rate ever of drainage-well construction. According to Lichtler, and others, (1968, p. 128), the single most active year for drilling of drainage wells was 1960 when about 35 wells were constructed. The extreme climatic conditions of 1959 and 1960 resulted in record high surface and ground-water levels in the Orlando area during the fall of 1960. And this, in turn, resulted in an unusual situation related to drainage-well use in that, at the time they were most pressingly needed, their capacity to emplace surface waters in the Floridan was reduced by the high aquifer pressures. Such conditions had previously occurred during the summer of 1930 (Stringfield, 1933, p. 22), but not on so large a scale as in 1960. In fact, some drainage wells actually flowed at land surface during the fall of 1960, and had to be equipped with pressure injection pumps to allow their use as disposal wells until the potentiometric surface of the Floridan again declined to below land surface."

"Again, 1964 was an excessively wet year and the available records indicate that drainage-well construction was intensified as a result. Following this, few have been constructed to present (1977), at least as a matter of public record."

"The present (1977) use of drainage wells is predominantly that of regulation of lake stages and disposal of storm sewage. The increasingly stringent environmental regulations of recent years have resulted in cessation or great reduction of disposal of the more noxious effluents such as sanitary sewage and industrial wastes, that were previously emplaced in the Floridan aquifer by drainage wells. However, the continued disposal of storm runoff and lake waters, through a general improvement in quality over past years, continued to pose quandaries and potential problems: the volumes and general quality of such disposed waters are not well known, and this method of wastewater disposal is by far the most economic means of surface drainage for the area."

The above chronology of drainage-well use for the Orlando area is believed also to be generally typical of their history in other areas where large use is made of Floridan aquifer drainage wells. That is, their original uses may have been for disposal of domestic sewage in certain local areas; then, as urbanization of the karst terranes increased, they began to be used for disposal of storm runoff, to regulate lake stages, to drain agricultural lands and highways, and to dispose of industrial wastewater. But, with the advent of modern sewage-treatment methods and increasingly stringent environmental regulations, their present (1981) use is predominantly that of regulation of lake stages and disposal of stormwater. Beyond this speculation, however, it is difficult to specify more precisely their chronology for other areas; it was not necessary to obtain a permit of any kind to install drainage wells prior to 1937, and few records of their construction and use prior to that time are thus available.

Two other urban areas that are drained almost entirely by drainage wells are the cities of Ocala and Live Oak (fig. 3). Records are available for 35 drainage wells, in or adjacent to the city of Ocala, which receive most of the surface drainage from the area. The Floridan aquifer crops out in part of the area, so some runoff disposal is also directly to natural (in some cases, improved) sinkholes that are open to the top of the aquifer.

For Live Oak, records of 46 wells are available that provide disposal of storm runoff for the urban area. The best available historical documentation of disposal of sanitary sewage to Floridan drainage wells is for the city of Live Oak area. According to Telfair, 1948 (p. 1):

> "On June 8, 1948, samples from the 400-foot well examined in the central laboratory of the State Board of Health were found to contain large numbers of the coliform group of bacteria which are always found in the bowels of men and higher animals. An emergency increase of chlorination was required, and the investigation by the Bureau of Engineering which ensued is described hereinafter."

The "400-foot well" was one of two public-supply wells in use, at that time, by the city of Live Oak. Sanitary sewage from the area was disposed of, as follows (Telfair, 1948, p. 2):

> "In one sinkhole basin, at Brown and Fifth Streets, the sanitary sewers of Live Oak converge to an old septic tank which has completely degenerated from consistent neglect. Its effluent is discharged to four drainage wells, thereby dumping the combined excreta of the city into the same limestone formations from which the common water supply is derived. The daily flow varies from about 1/4 million gallons to a probable wet weather maximum of about 4 million gallons. There are at least 3 private sewage disposal wells known to exist."

In the subsequent investigation sodium chloride was used as a ground-water tracer and Telfair (1948, p. 10) concluded, "First, that the drinking water supply of Live Oak is persistently and heavily polluted with bacteria and protozoa originating in the bowels of warm-blooded animals; second, that there is a direct connection between drainage well 9 and the public water well and that there is reason to suspect such a cross-connection may occur with sewage well 30 at times of heavy sewage flow; * * *." Available records indicate that wells 9 and 30 and the supply well were all open to the upper 200 to 300 feet of the Floridan aquifer. Well 9 appears to have been about 600 feet from, and well 30 about 2,400 feet from the supply well. Telfair's report of investigation indicates that there were about 9 "sewage wells" and 24 "drainage wells" in use during this period (1948). The disposal of sanitary sewage to Floridan aquifer drainage wells has, of course, since been discontinued; at present, the 46 known drainage wells in Live Oak are used only for disposal of storm runoff.

Records are presently available for a total of 607 Floridan aquifer drainage wells that are distributed throughout central and north-central Florida. Their distribution, by county, is shown in figure 3.

Biscayne Aquifer Drainage Wells

These wells are used to dispose of storm runoff and other wastewaters in southeast Florida; the heaviest concentrations are in Dade and Broward Counties. There the Floridan aquifer is deeply buried, and cannot be used practically for gravity injection because its potentiometric surface is above the land surface (fig. 2). The Biscayne aquifer crops out, or is near land surface, in most of this area. This unconfined and highly transmissive aquifer is thus utilized for gravity disposal of excess surface waters in southeast Florida. Typical drainage-well construction in the Biscayne aquifer is shown in the diagram of figure 4-Ib.

The use of Biscayne aquifer drainage wells probably began in the 1920's or early 1930's. They were apparently a commonly used method of drainage by the time that State Board of Health permitting of drainage wells began in 1937, and their use increased along with urbanization of the coastal areas of southeast Florida. Records are presently available for more than 4,000 Biscayne aquifer drainage wells, most of which are in Dade and Broward Counties. The wells are generally cased to inject into aquifer zones where residual chloride concentrations are greater than 1,500 mg/L, a practice intended to minimize any effects that injection of wastewater might have on potable zones of the aquifer.

Biscayne aquifer drainage wells are not further discussed in this interim report.

Interaquifer Connector Wells

These wells differ from Floridan aquifer drainage wells in that they convey waters from overlying aquifers, rather than surface waters, to deeper aquifers, usually the Floridan. Their construction (fig. 4-II) thus usually requires emplacement of a well screen in the clastic materials of the overlying (losing) aquifer zone in addition to seating of the casing bottom in competent rock and drilling to penetrate a zone of sufficient receiving transmissivity in the deeper (receiving) aquifer. Their effective use requires a source of recharge to the screened zone and sufficient transmissivity in this losing zone, as well as a prevailing natural downward gradient and sufficient transmissivity in the receiving zone. The areas of Florida that lend best to successful use of interaquifer connector wells tend generally to coincide with similar areas where Floridan aquifer drainage wells function best; that is, areas of prevailing downward gradient to the Floridan where the top of this aquifer, and its receiving zones, are within a few hundred feet of land surface.

The most common geohydrologic factor in areas where connector wells are used is the presence of a relatively impermeable zone between the surficial and Floridan aquifers. In fact, "A connector well is so named because it connects two aquifers that, under natural conditions, are hydraulically separated by a confining bed." (Hutchinson and Wilson, 1974, p. 3). From the standpoint of water quality, connector wells differ from the other types of gravity drainage wells described herein in that the water recharged by connector wells has been moved through the natural filter of the clastic materials that comprise the losing aquifers.

The concept of connector-well use is not new, though their use in Florida is of relatively recent origin. The concept likely originated from the long-accepted observation that zonal interchange of ground water occurs in an open well bore that penetrates (and thus connects) two water-bearing zones at different heads. The interchange is, of course, from the zone of higher head to the zone of lower head, or, for most interaquifer connector wells in Florida, from the various surficial aquifers to the Floridan.

Hydraulic problems that may relate to interaquifer connector wells are those of clogging, or decrease in transmissivity of the losing and receiving zones. The losing zone is almost always screened and the inside of the screen is usually aerated during connector-well operation; these are conditions that tend to favor clogging of the well screens by precipitation or by growth of iron bacteria. Despite this potential however, few problems have been reported of screen clogging other than by growth of iron bacteria; and apparently, growth of iron bacteria is significantly reduced by use of plastic, rather than metal, well screen. Problems of clogging or reduction of transmissivity in the receiving aquifer have been minimal with wells that inject into the Floridan aquifer.

The first planned and documented use of interaquifer connector wells in Florida was probably as experimental wells to artificially recharge the Floridan aquifer. For example, Watkins (1977) reports on a series of controlled field experiments that began in 1970 with a connector well in western Orange County; and Hutchinson and Wilson (1974) report on a theoretical evaluation of a similar installation in northeastern De Soto County. At about the same period (late 1960's to early 1970's) attention began to be directed toward potential for use of such wells to also capture some water from surface runoff and evaporation, thus achieving a land surface drainage objective in addition to the beneficial effects of artificially recharging the Floridan aquifer. In this regard Knochenmus (1975) reported on a theoretical investigation, and Bush (1978) on a controlled field experiment, in eastern Orange County.

Then according to Hutchinson (1977, p. 10):

> "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."

At present (1981), the predominant use of connector wells is concentrated in the phosphate mining areas of the Peace and eastern Alafia River basins in southwest Polk and southeast Hillsborough Counties. Their use is for the dual purposes of facilitating the mining operations and artificially recharging the Floridan aquifer. A summary of the geohydrologic units in the area and their water-bearing properties is shown in table 1. The phosphate ore, or "matrix," occurs in the Bone Valley Formation and is mined by open-pit dragline methods. The natural hydraulic gradient is downward from the unconfined surficial aquifer, to the partially confined upper unit of the Floridan aquifer, to the confined lower unit of the Floridan. Mining operations, dependent on location and depth, may be subject to excessive inflow of ground water from both the surficial aquifer and the upper unit of the Floridan. Interaquifer connector wells are used to rid the mining operations of this excess water by emplacing it in deeper aquifer zones. Several schemes of interaquifer connection have been used in the area; that is, draining of a screened part of the surficial aquifer into an open-hole part of the upper Floridan, or into an open-hole part of the lower Floridan; draining of an open-hole part of the upper Floridan into the lower Floridan; or draining of both the surficial and upper Floridan units into the lower Floridan. The latter type construction is the most efficient in that it concurrently relieves the pressure in both upper water-bearing zones and maximizes the vertical extent of drainage for individual connector wells.

Another technique that has been developed and used to increase effectiveness of interaquifer connector wells is the siphon conveyance of water from networks of shallow well points to a central injection well. This technique may greatly increase the lateral extent of drainage and maximize the recharge achieved by an individual connector well.

Use of interaquifer connector wells has now (1981) become an accepted and commonly used technique throughout the central Florida phosphate mining area. From a mining standpoint there are numerous comments on their beneficial use. These comments are typified by Paugh (1979, p. 4) in discussion of their use at one mining area:

> "In summary, the application of subsurface and surface dewatering is essential to open pit mine drainage control in the deep sinkhole areas at Watson Mine. Gravity connector wells have dewatered the surficial aquifer in the overburden and reduced the artesian head in the pit bottom limestone. The effect has been improved matrix yardage recovery, productivity, and dragline safety."

Records are currently available for a total of 167 interaquifer connector wells in the phosphate mining area. Of these wells, 101 are in Polk County, 64 are in Hillsborough County, and 2 are in Manatee County. Their distribution, by county, is shown in figure 3.

Table 1.--Summary of geohydrologic units, upper Peace and eastern Alafia River basins, Florida

[From Hutchinson, 1977]

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 semiconfining beds	0	0-225	Fine to 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

GEOHYDROLOGIC ASPECTS, FLORIDAN AQUIFER DRAINAGE WELLS

The densest concentrations of Floridan aquifer drainage wells are in the Ocala, Live Oak, and Orlando areas where they constitute the major means of urban drainage. The geohydrologic aspects of these three urban areas are discussed separately below, followed by a discussion of Floridan drainage wells in other areas.

Some water-quality analytical data are available for samples from drainage wells in the three urban areas that are discussed separately below. These data were collected during the present investigation for Ocala and Live Oak, and during a concurrent investigation for Orlando. Some analytical data on quality of storm runoff are available from previous investigations for the Live Oak and Orlando areas. In addition, water-quality analytical data for selected public-supply wells are available, and included, for each of the three areas.

The water samples from Floridan aquifer drainage wells were analyzed for the major ions and for most of those parameters in the standards established by the National Interim Primary Drinking Water Regulations and National Secondary Drinking Water Regulations. The samples from Floridan drainage wells were collected by installing a submersible pump to a depth of 20 to 30 feet below the static water level, and pumping it at a rate of about 400 gal/min until both specific conductance and drawdown had equilibrated (usually a period of 1 to 3 hours) prior to collection of samples. Water samples were collected and analyzed by the methods described in Brown and others (1970), Goerlitz and Brown (1972), and Fishman and Brown (1976).

Estimates of natural recharge to the Floridan aquifer may be derived from (1) consideration of potentially available recharge, and (2) from observations of recharge rates for closed-basin karst terranes in central Florida. Most of the areas of high drainage well density (fig. 3) are in the well-drained upland areas that have been mapped (Stewart, 1980) as areas of high recharge to the Floridan aquifer. Average rainfall is about 52 in/yr over most of these areas (Hughes and others, 1971), and there is little or no surface drainage from interior parts of the closed-basin karst terranes. Thus the total average rainfall for the terrane may be apportioned to evapotranspiration and recharge to the Floridan aquifer; and the potentially available recharge may be approximated by considering the probable average evapotranspiration from the terrane. In this regard, other investigators (Knochenmus and Hughes, 1976; Tibbals, 1978) have tended to attribute a minimum of 30 to 35 inches of the average annual precipitation to evapotranspiration, thus leaving an average of 17 to 22 in/yr as potential ground-water recharge. These amounts of natural recharge might be considered as a maximum for a closed-basin terrane under the climatic conditions of central Florida.

The second method of estimating natural recharge is by use of the observed rates for closed-basin karst terranes in central Florida. The best examples are the adjoining ground-water basins of Silver and Rainbow Springs, which are largely in Marion County and total some 1,375 square miles. The combined long-term discharge of these two springs averages about 940 Mgal/d, or about 15 in/yr over the basins' area. Similar average annual recharge rates have been derived by other investigators for like terranes in central Florida (Lichtler, 1971; Tibbals, 1975, Knochenmus and Hughes, 1976). Thus,15 inches may be considered an average value for natural recharge in the more effective recharge areas of central Florida. These observed recharge rates are the average for ground-water basins of several hundred square miles or larger in area. It is thus logical that parts of the basins are contributing less recharge than the average, and that other parts are contributing more than this average.

The use of drainage wells to augment surface drainage of an urbanized, closed-basin karst terrane tends to increase the amount of recharge to the Floridan aquifer that would have occurred under natural conditions. Drainage wells, in effect, short circuit the confining beds, thus emplacing larger volume rates of recharge. This, in turn, is reflected in lower water table and lake stages, and thus a reduction in the evapotranspiration component of the water budget. In addition, drainage wells are used primarily where paving has reduced ground-water recharge and made more water available as storm runoff which, if rapidly conveyed to drainage wells, will tend to reduce evapotranspiration further from the area. Total recharge in an urban basin drained by drainage wells is thus a combination of some component of the natural recharge and the component that is directly injected to the aquifer. The total recharge for such a basin cannot be directly determined from available data.

Ocala Area

Ocala is a city of about 37,170 population (University of Florida, 1981, p. 32) in central Marion County (fig. 3). The Ocala Limestone is at or near land surface over most of the area where land surface altitudes are at 100 feet or lower. The Hawthorn Formation overlies the Ocala Limestone with the contact being at an altitude of about 100 feet (Faulkner, 1973). Practically all drainage from the area is internal, by means of the unconfined and highly transmissive Ocala Limestone of the Floridan aquifer.

Most of the city of Ocala area is immediately upgradient from Silver Springs, which discharges an average of 530 Mgal/d from the Floridan aquifer a few miles east of Ocala. According to Faulkner (1973; 1976) this area comprises the most permeable flow zone to Silver Springs, and most ground-water flow to the springs probably occurs in the upper 100 to 200 feet of the aquifer. Faulkner's (1976) analysis considered the vertical distribution of sulfates in the upper 1,000 feet of the Floridan for the Ocala-Silver Springs area, as follows: The average sulfate concentration for 18 wells (40 to 200 feet deep) is 22 mg/L, and ranged from 0.0 to 92 mg/L. Sulfate concentrations are about 150 mg/L for Ocala public-supply wells open to intervals of about 120 to 350 feet; and the sulfate concentration is about 260 mg/L for a well open to the 850 to 1,083 feet interval. Sulfate concentration in Silver Springs discharge water averages about 40 mg/L, so calculations indicate that from about 86 to 92 percent of this discharge is from the upper 200 feet of the aquifer.

Locations for 35 drainage wells that are in, or adjacent to, the city area are shown in figure 5. All of these wells were verified to be still existent and functional during the present investigation. Most of these are in the bottoms of sinks, or closed depressions, that naturally received surface runoff or in excavated drainage-retention ponds. The available records indicate total depths for most of the Ocala area drainage wells to be less than 200 feet. Thus, the majority of storm runoff from the area is introduced directly to the top of the Floridan aquifer in the highly transmissive flow zone upgradient from Silver Springs. Caliper (borehole diameter) logs for two drainage wells in the Ocala area are shown in figure 6.

Until about 1970, public water supply for the city of Ocala was obtained from wells within the urban area of greatest drainage-well density. Those supply wells were open to intervals of about 120 to 350 feet and yielded water with average sulfate concentrations of about 150 mg/L (Faulkner, 1976). Since about 1970, public supply for the city has been obtained from a well field east of town and downgradient from the densest area of drainage-well injection. These five supply wells range in depth from 187 to 265 feet and yield water with sulfate concentrations of about 90 to 100 mg/L. Their location is to the north of State Road 40 and about 1 mile east of the eastern border of the area shown in figure 5. The water-quality analysis for one of the wells is included in table 2.

Six drainage wells were test pumped and sampled for water-quality analyses during July 1980; one sample of urban storm runoff also was collected for analysis. Two of the wells (21 and 24) were receiving injection water at time of sampling; the sample of storm runoff was colcollected in the immediate vicinity of these two wells. The other four drainage wells were not receiving injection water at time of sampling, but had probably received water within the preceding few days. Analytical data for the six drainage well samples, one sample of storm runoff, and for one public-supply well are shown in table 2. Locations of the six drainage wells that were sampled are noted in figure 5.

Comparison of analytical data for the six drainage wells with the maximum contaminant levels established by the National Interim Primary and Secondary Drinking Water Regulations standards indicates the following:

Turbidity values for two wells and color values for three wells equal or exceed the standards values. This might be expected in pumpage from drainage wells, particularly if the wells were receiving, or had recently received, injection water at time of pumpage. Stormwater runoff is usually conveyed to drainage wells under conditions of turbulent flow, and it often carries relatively large amounts of debris and

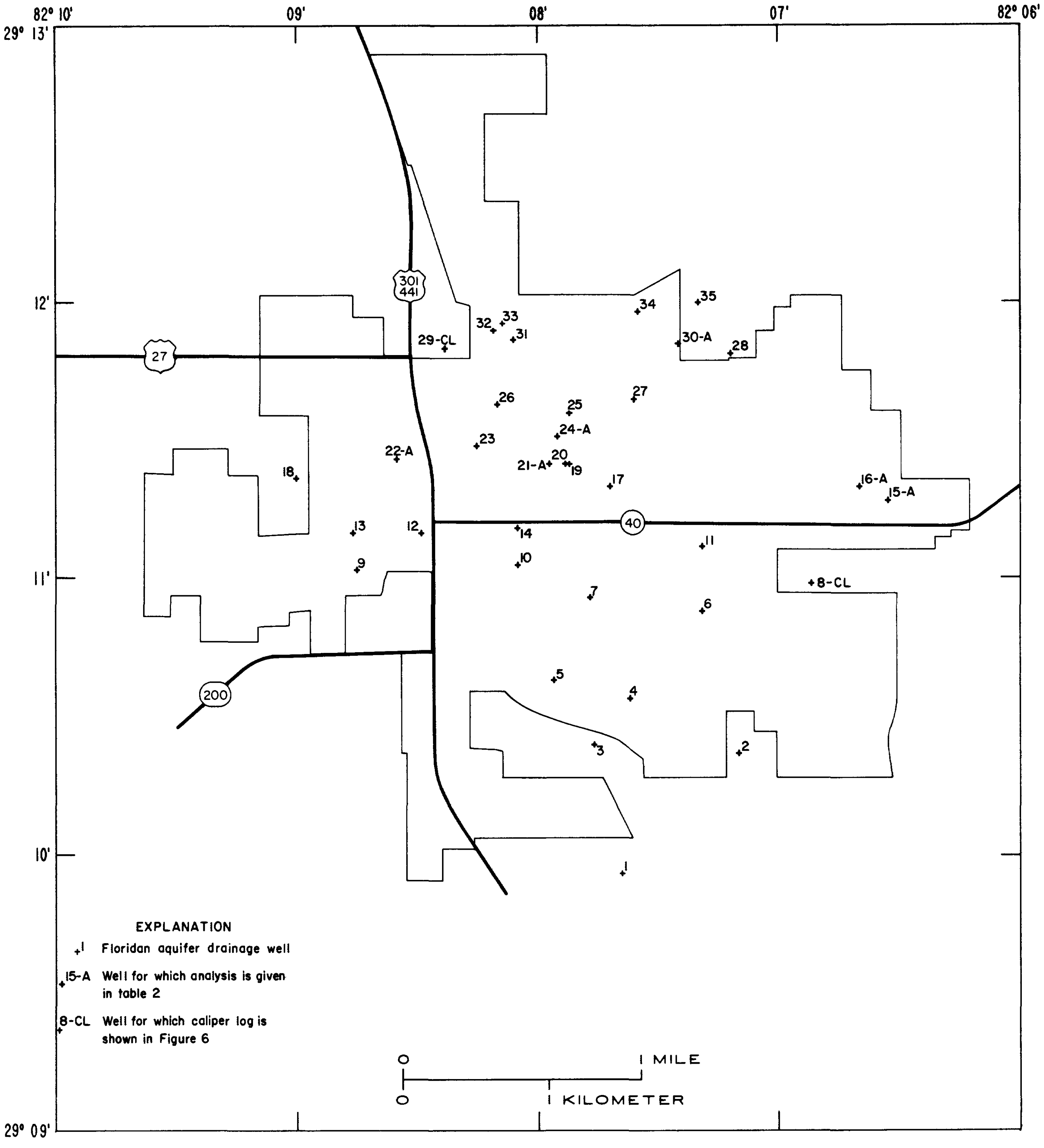


Figure 5.--Locations of Floridan aquifer drainage wells, Ocala area.

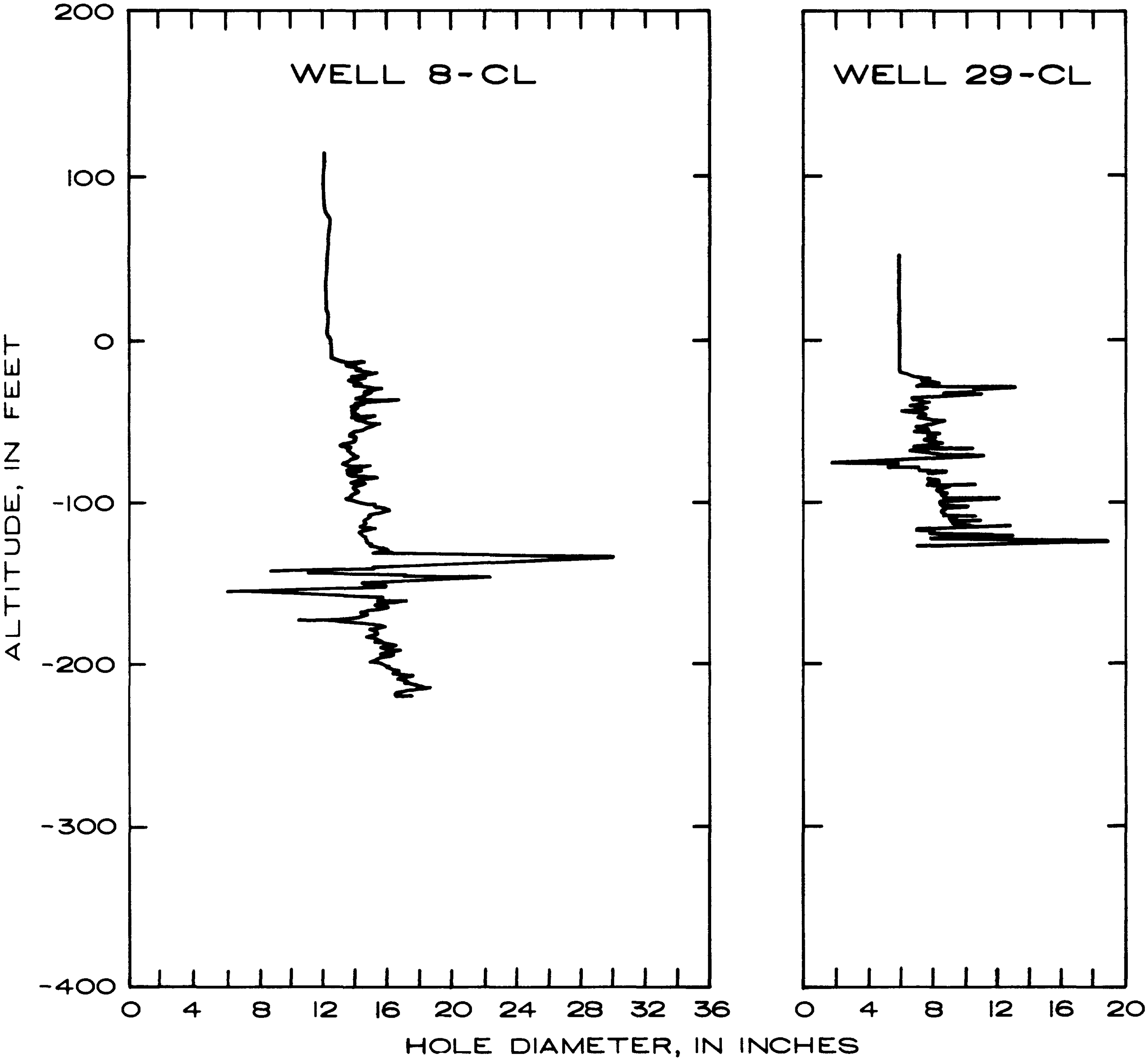


Figure 6.--Caliper logs, Ocala area.

TABLE 2.--ANALYSES OF WATER FROM FLORIDAN AQUIFER DRAINAGE AND PUBLIC-SUPPLY WELLS,OCALA AREA

STATION NUMBER	STATION NAME	SITE NUMBER, FIGURE 5	DATE OF SAMPLE	TIME	TEMPERATURE (DEG C)	SPECIFIC CONDUCTANCE (UMHOS)	TURBIDITY (NTU)
	DRAINAGE WELLS						
291117082063301	DRAINAGE WELL NO 23 OCALA FL	15	80-07-24	1120	27.5	203	4.0
291120082064001	DRAINAGE WELL NO 27 OCALA FL	16	80-07-28	1155	25.5	330	3.0
291125082075701	DRAINAGE WELL NO 31 OCALA FL	21	80-07-25	1120	27.5	299	17
291126082083501	DRAINAGE WELL NO 3 OCALA FLA	22	80-07-28	1640	28.5	194	6.0
291131082075501	DRAINAGE WELL NO 32 OCALA FL	24	80-07-29	1600	28.5	330	11
291151082072501	DRAINAGE WELL NO 16 OCALA FL	30	80-07-23	1800	23.5	452	3.0
291125082075702	STORM RUNOFF INTO POND AT OCALA DW #31		80-07-24	1350	--	318	170
	PUBLIC-SUPPLY WELL						
291215082052701	912205 CITY OF OCALA NF-03		76-08-26	0853	25.5	345	.00

DATE OF SAMPLE	PH (UNITS)	CARBON DIOXIDE DISSOLVED (MG/L AS CO2)	ALKALINITY FIELD (MG/L AS CACO3)	BICARBONATE FET-FLD (MG/L AS HCO3)	CARBONATE FET-FLD (MG/L AS CO3)	NITROGEN, ORGANIC TOTAL (MG/L AS N)	NITROGEN, AMMONIA TOTAL (MG/L AS N)	NITROGEN, NITRITE TOTAL (MG/L AS N)	NITROGEN, NITRATE TOTAL (MG/L AS N)	NITROGEN,AMMONIA + ORGANIC TOTAL (MG/L AS N)	NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	NITROGEN, TOTAL (MG/L AS N)
80-07-24	7.0	18	90	110	0	.52	.260	.010	.01	.78	.02	.80
80-07-28	7.6	7.4	151	184	0	.14	.030	.000	.22	.17	.22	.39
80-07-25	7.0	14	71	86	0	1.8	3.10	.580	2.5	4.90	3.1	8.0
80-07-28	7.5	4.7	75	92	0	.48	.190	.010	.02	.67	.03	.70
80-07-29	7.2	13	105	128	0	1.1	3.20	.010	.00	4.30	.01	4.3
80-07-23	6.9	41	168	205	0	.25	.600	.000	.01	.85	.01	.86
80-07-24	7.4	--	--	--	--	9.9	3.50	.280	.72	13.4	1.0	14
76-08-26	--	--	120	146	0	--	--	<.010	.01	--	.01	--

DATE OF SAMPLE	PHOSPHORUS, ORTHO, TOTAL (MG/L AS P)	PHOSPHORUS, TOTAL (MG/L AS P)	CARBON, ORGANIC TOTAL (MG/L AS C)	COLIFORM, TOTAL, IMMED. (COLS. PER 100 ML)	HARDNESS (MG/L AS CACO3)	HARDNESS, NONCARBONATE (MG/L CACO3)	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L)	SOLIDS, SUM OF CONSTITUENTS, DISSOLVED (MG/L)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	SODIUM, DISSOLVED (MG/L AS NA)	SODIUM ADSORPTION RATIO
80-07-24	.240	.320	9.1	5600	98	8	105	114	37	1.3	3.1	.1
80-07-28	.090	.110	5.7	410	160	9	185	201	57	4.0	3.3	.1
80-07-25	.780	1.00	26	E5600	94	24	161	168	31	4.0	12	.5
80-07-28	.280	.380	9.0	2700	85	10	97	108	30	2.4	4.5	.2
80-07-29	1.30	2.90	13	21000	100	0	154	166	35	4.0	12	.5
80-07-23	.580	.590	4.9	2900	200	35	259	251	68	8.0	6.9	.2
80-07-24	2.20	9.80	--	--	65	--	153	--	22	2.5	5.4	.3
76-08-26	--	--	--	--	220	100	344	280	70	11	10	.3

TABLE 2.--ANALYSES OF WATER FROM FLORIDAN AQUIFER DRAINAGE AND PUBLIC-SUPPLY WELLS, OCALA AREA--CONTINUED

DATE OF SAMPLE	PERCENT SODIUM	POTASSIUM, DISSOLVED (MG/L AS K)	CHLORIDE, DISSOLVED (MG/L AS CL)	SULFATE DISSOLVED (MG/L AS SO4)	FLUORIDE, DISSOLVED (MG/L AS F)	SILICA, DISSOLVED (MG/L AS SIO2)	ARSENIC TOTAL (UG/L AS AS)	BARIUM, TOTAL RECOVERABLE (UG/L AS BA)	BERYLLIUM, TOTAL RECOVERABLE (UG/L AS BE)	CADMIUM TOTAL RECOVERABLE (UG/L AS CD)	CHROMIUM, TOTAL RECOVERABLE (UG/L AS CR)	COPPER, TOTAL RECOVERABLE (UG/L AS CU)
80-07-24	6	1.4	6.2	8.1	.3	1.9	4	100	--	0	20	0
80-07-28	4	1.3	3.6	36	.3	4.7	--	--	--	0	--	--
80-07-25	20	9.4	39	24	.4	5.4	5	100	--	0	20	20
80-07-28	10	1.5	4.4	15	.5	4.4	2	--	0	0	20	--
80-07-29	18	9.6	23	13	.4	5.8	--	--	--	0	--	--
80-07-23	7	1.8	9.0	46	.7	8.5	--	--	--	--	--	--
80-07-24	10	36	23	30	.7	1.8	12	<50	--	0	140	300
76-08-26	9	.9	16	90	.3	9.3	1	<100	--	<2	40	--

DATE OF SAMPLE	IRON, TOTAL RECOVERABLE (UG/L AS FE)	LEAD, TOTAL RECOVERABLE (UG/L AS PB)	MANGANESE, TOTAL RECOVERABLE (UG/L AS MN)	NICKEL, TOTAL RECOVERABLE (UG/L AS NI)	SILVER, TOTAL RECOVERABLE (UG/L AS AG)	STRONTIUM, DISSOLVED (UG/L AS SR)	ZINC, TOTAL RECOVERABLE (UG/L AS ZN)	SELENIUM, TOTAL (UG/L AS SE)	MERCURY TOTAL RECOVERABLE (UG/L AS HG)	2,4-D, TOTAL (UG/L)	2,4,5-T TOTAL (UG/L)	SILVEX, TOTAL (UG/L)
80-07-24	840	0	170	--	0	80	30	0	<.1	.00	.00	.00
80-07-28	--	2	--	--	--	450	10	--	--	--	--	--
80-07-25	280	0	100	--	0	270	50	0	.1	.00	.00	.00
80-07-28	--	0	--	0	--	150	30	0	<.1	.00	.00	.00
80-07-29	--	1	--	--	--	250	10	--	--	--	--	--
80-07-23	--	--	--	--	--	790	--	--	--	--	--	--
80-07-24	820	200	1400	--	0	100	1900	0	.1	.07	.00	.00
76-08-26	--	5	--	--	ND	950	--	<1	<.5	.00	.00	.00

fine sedimentary material. These materials tend to deposit in any cavities that are penetrated by the drainage-well bore; they may again become suspended in the turbulent flow that results from pumping the well for sampling purposes and may result in the yield of turbid, colored water over relatively long periods of pumpage.

The standards values also are exceeded by total iron concentrations for one drainage well, and total manganese concentrations in samples from two wells. Concentrations of coliform bacteria range from 410 to 21,000 colonies/100 mL of sample. In general, storm runoff is less mineralized than ground water from the Floridan aquifer, but runoff usually contains much higher concentrations of bacteria, most nutrients, and trace metals than occur in uncontaminated ground water. The analysis of the sample of storm runoff (table 2) indicates that it equaled or exceeded the standards values for turbidity, color, and total recoverable chromium, iron, lead, and manganese. Concentration of coliform bacteria in the storm runoff sample was estimated as 5,000 colonies/100 mL of sample.

The cumulative basin areas that appear to be drained by the 35 drainage wells shown in figure 5 total about 4 square miles.

Live Oak Area

Live Oak, in Suwannee County (fig. 3), is a city of about 6,732 population (University of Florida, 1981, p. 23). The area is largely an internally drained karst terrane with land surface altitudes that vary from about 100 to 125 feet. The Suwannee Limestone, at an altitude of about 70 feet, comprises the top of the Floridan aquifer. The Suwannee is from 25 to 35 feet thick in the area (J. A. Miller, oral commun., 1981) and is utilized as a source for some private wells; however, its transmissivity is much lower than that of the underlying Ocala, Avon Park, and Lake City Limestones. These lower units, particularly the Ocala and Avon Park, are the principal source for high-capacity wells in the area. The potentiometric surface of the Floridan aquifer generally slopes to the west and southwest towards discharge areas along the Suwannee River.

The locations of 46 drainage wells that are in, or adjacent to, the city area are shown in figure 7. All of these well locations were verified by field inventory during the present investigation. Most are in the bottoms of natural sinks or other low-lying areas, and are used to augment the generally poor surface drainage system. Reported depths for most drainage wells are from about 100 to 400 feet. A few wells are reported as being shallower than 100 feet, and a few are deeper than 400 feet. The maximum depth reported is for well 25, with a total depth of 1,145 feet and cased to 726 feet. Caliper logs for two typical wells are shown in figure 8.

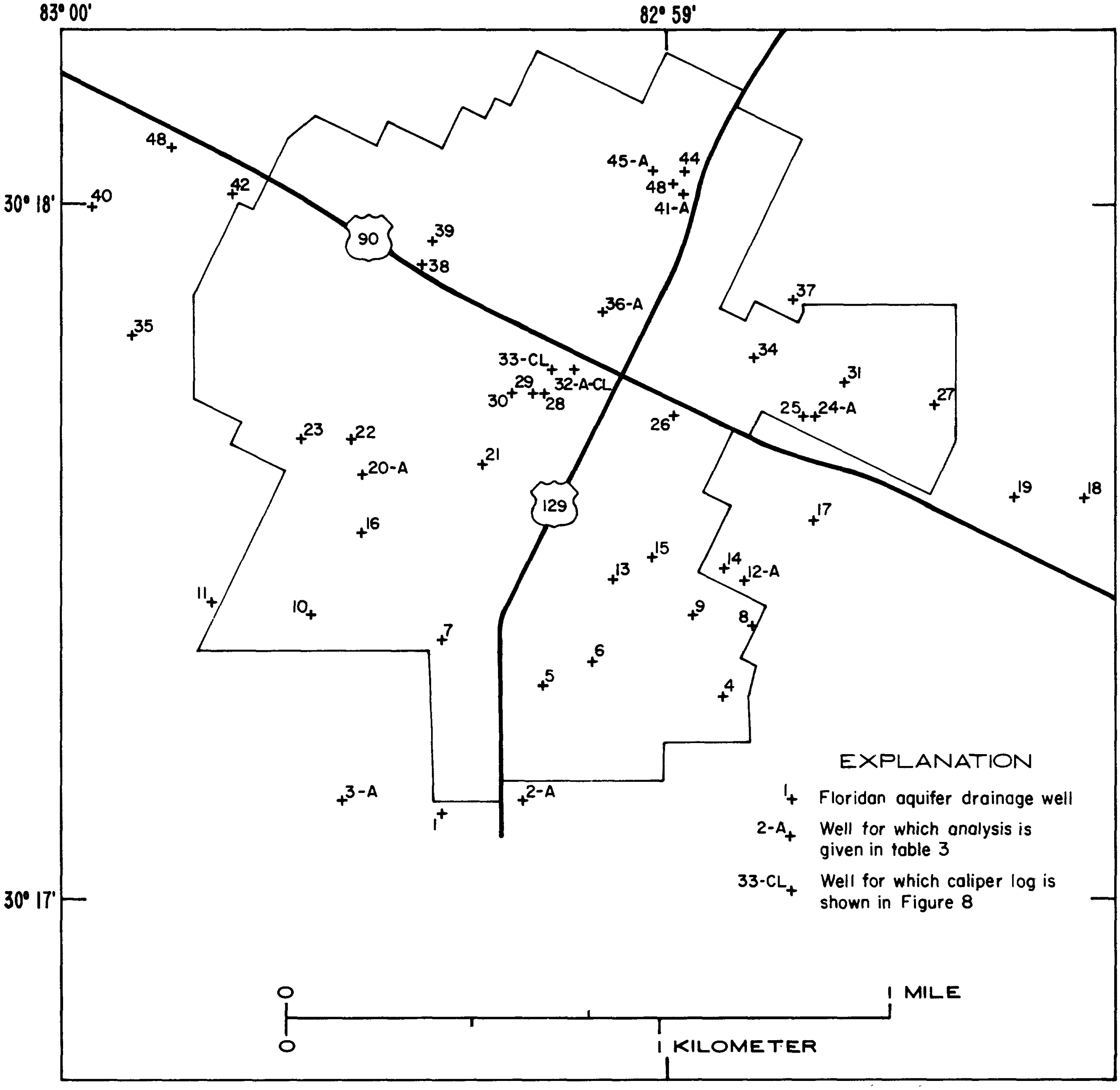


Figure 7.--Locations of Floridan aquifer drainage wells, Live Oak area.

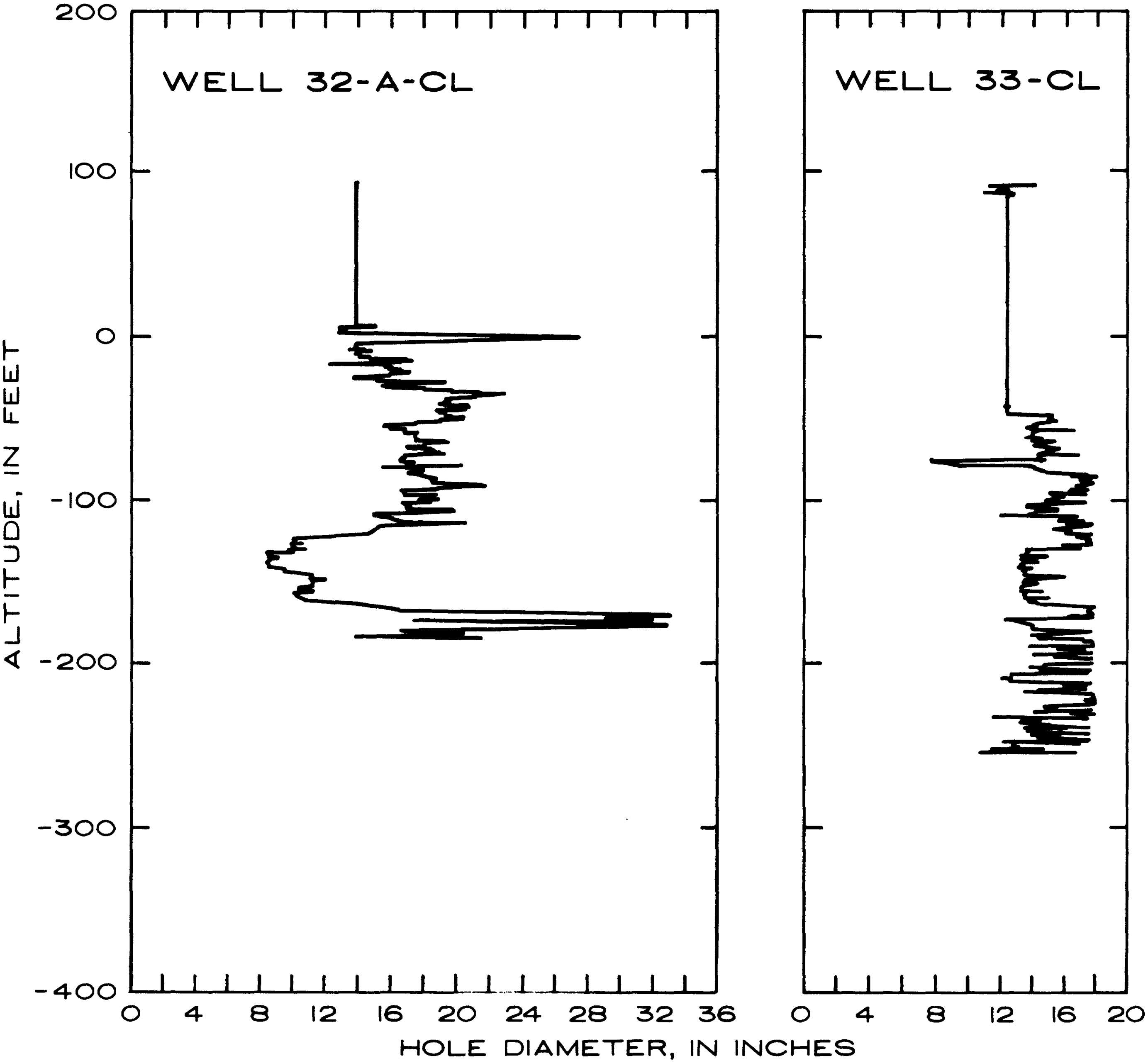


Figure 8.--Caliper logs, Live Oak area.

Public water supply for Live Oak was originally obtained from wells that were located in the urban area of densest drainage-well concentration (fig. 7). These sources became polluted by disposal of both storm and sanitary sewage to drainage wells, as described by Telfair (1948) and summarized in an earlier part of this report. As a result, the public-supply wells have been located to the east of town, in upgradient direction, and there have been no further reported problems of this nature.

Nine drainage wells were sampled for water-quality analyses during July 1980. None of the sampled wells were receiving injection water at time of sampling, but most had probably received water within several days immediately prior to the time of sampling. Analytical data for the drainage-well samples and for a public-supply well are shown in table 3. The analytical data for the nine drainage wells indicate that the National Interim Primary and Secondary Drinking Water Regulation standards values were equaled or exceeded by (1) turbidity for two samples; (2) color for three samples; and (3) lead for three samples. Concentrations of total coliform bacteria ranged from 1,060 to 77,000 colonies/100 mL of samples.

Data for quality of storm runoff to drainage wells in Live Oak are available from a previous investigation in which water samples were collected for two sites in commercial and two sites in industrial areas (Hull and Yurewicz, 1979). A total of 33 samples were collected for these four sites during a storm event of April 4, 1979, and analyzed for most of the parameters in the National Interim Primary and Secondary Drinking Water Regulations standards. In summary, these data indicate that (1) all samples equaled or exceeded the standards values for color and coliform bacteria, and (2) that one or more samples equaled or exceeded the standards values for lead, turbidity, iron, manganese and pH.

A cumulative total area of about 1.5 square miles appears to be drained by drainage wells in the Live Oak area.

Orlando Area

The Orlando Standard Metropolitan Statistical Area has a population (1980) of about 700,700 (University of Florida, 1981, p. 30). The term "Orlando area," as used herein, refers to an area of about 400 square miles (most in Orange County) where a high density of drainage wells is present (fig. 9).

Land surface altitudes in this approximately 400-square-mile area range from about 75 to 125 feet. Much of the interior part of the area is a karst terrane with topography characterized by numerous closed-basin sinkhole depressions and the absence of natural streams. The Floridan aquifer contains two highly transmissive zones: (1) a cavernous zone at average depths of about 150 to 600 feet in the Avon Park Limestone that is referred to as the upper producing zone (Lichtler and others, 1968) or the drainage-well zone (Kimrey, 1978), and (2) a cavernous zone

TABLE 3.--ANALYSES OF WATER FROM FLORIDAN AQUIFER DRAINAGE AND PUBLIC-SUPPLY WELLS, LIVE OAK AREA

STATION NUMBER	STATION NAME	SITE NUMBER, FIGURE 7	DATE OF SAMPLE	TEMPER-ATURE (DEG C)	TUR-BID-ITY (NTU)	COLOR (PLAT-INUM-CDBALT UNITS)	SPE-CIFIC CDN-DUCT-ANCE (UMHOS)
	DRAINAGE WELLS						
301709082591401	01725904CITY LIVE OAK DRAINAGE WELL #16	2	80-07-10	25.0	--	30	285
301709082593201	01725920CITY LIVE OAK DRAINAGE WELL #37	3	80-07-08	22.5	800	0	315
301724082585101	01725808CITY LIVE OAK DRAINAGE WELL #12	12	80-07-10	23.0	--	20	240
301735082582501	01725811CITY LIVE OAK DRAINAGE WELL #35	20	80-07-08	23.0	4.0	0	270
301746082590901	01725922CITY LIVE OAK DRAINAGE WELL #40	32	80-07-09	23.0	--	30	300
301747082585102	01725803CITY LIVE OAK DRAINAGE WELL #6	24	80-07-10	23.5	--	0	395
301751082590601	01725919CITY LIVE OAK DRAINAGE WELL #36	36	80-07-09	23.0	210	0	380
301801082585807	01825802CITY LIVE OAK DRAINAGE WELL #3	41	80-07-09	23.0	--	5	310
301803082590101	01825901CITY LIVE OAK DRAINAGE WELL #1	45	80-07-07	23.0	2.0	0	268
	PUBLIC-SUPPLY WELL						
301742082582901	LIVE OAK NO 5 BRYSON ST		76-09-01	23.0	--	10	355

DATE OF SAMPLE	PH (UNITS)	CARBON DIOXIDE DIS-SOLVED (MG/L AS CO2)	ALKA-LINITY FIELD (MG/L AS CACO3)	BICAR-BONATE FET-FLD (MG/L AS HCO3)	CAR-BONATE FET-FLD (MG/L AS CO3)	NITRO-GEN, ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, AMMONIA TOTAL (MG/L AS N)	NITRO-GEN, NITRITE TOTAL (MG/L AS N)	NITRD-GEN, NITRATE TOTAL (MG/L AS N)	NITRO-GEN,AM-MONIA + ORGANIC TOTAL (MG/L AS N)	NITRD-GEN, NO2+ND3 TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS N)
80-07-10	6.8	42	135	164	0	.50	1.30	.020	.05	1.80	.07	1.9
80-07-08	7.3	16	164	200	0	.14	.100	.010	.20	.24	.21	.45
80-07-10	7.3	10	107	130	0	.38	.840	.010	.02	1.20	.03	1.2
80-07-08	7.3	13	135	164	0	.04	.080	.020	.49	.12	.51	.63
80-07-09	6.8	41	131	160	0	1.3	.280	.060	.46	1.60	.52	2.1
80-07-10	6.8	56	180	220	0	1.5	.690	.000	.02	2.20	.02	2.2
80-07-09	7.1	29	189	230	0	1.2	.480	.050	.65	1.70	.70	2.4
80-07-09	7.3	16	164	200	0	.80	6.00	.000	.04	6.80	.04	6.8
80-07-07	7.4	13	164	200	0	.08	1.40	.000	.01	1.48	.01	1.5
76-09-01	7.2	19	151	184	0	--	--	<.010	.00	--	<.10	--

DATE OF SAMPLE	NITRO-GEN, TOTAL (MG/L AS NO3)	PHOS-PHORUS, ORTHO, TOTAL (MG/L AS P)	PHOS-PHORUS, TOTAL (MG/L AS P)	CARBON, ORGANIC TOTAL (MG/L AS C)	COLI-FORM, TOTAL, IMMED. (COLS. PER 100 ML)	HARD-NESS (MG/L AS CACO3)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)
80-07-10	8.3	.880	1.00	26	4400	130	0	179	155	49	1.4	6.0
80-07-08	2.0	.030	.740	13	--	160	0	178	175	58	2.7	2.7
80-07-10	5.4	.170	.350	6.7	1060	110	5	135	124	42	1.6	2.6
80-07-08	2.8	.090	.150	3.7	--	160	28	153	159	63	1.2	2.8
80-07-09	9.4	.240	.880	24	3000	140	5	183	165	51	2.1	6.7
80-07-10	9.8	.060	.180	3.6	3960	190	5	228	222	68	3.7	8.6
80-07-09	11	.160	.690	7.7	77000	200	14	220	227	78	2.0	4.2
80-07-09	30	.720	1.00	27	34000	170	2	209	188	61	3.4	6.5
80-07-07	6.6	.410	.420	2.1	68000	170	7	208	188	62	3.9	4.6
76-09-01	--	--	--	--	--	150	3	203	189	40	13	8.6

TABLE 3.--ANALYSES OF WATER FROM FLORIDAN AQUIFER DRAINAGE AND PUBLIC-SUPPLY WELLS, LIVE OAK AREA--CONTINUED

DATE OF SAMPLE	SODIUM AD-SORP-TION RATIO	PERCENT SODIUM	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SILICA, DIS-SOLVED (MG/L AS SIO2)	ARSENIC TOTAL (UG/L AS AS)	CADMIUM TOTAL RECOV-ERABLE (UG/L AS CD)	CHRO-MIUM, TOTAL RECOV-ERABLE (UG/L AS CR)	LEAD, TOTAL RECOV-ERABLE (UG/L AS PB)	NICKEL, TOTAL RECOV-ERABLE (UG/L AS NI)
80-07-10	.2	9	3.2	5.4	3.1	.4	5.7	--	2	--	28	--
80-07-08	.1	4	.9	1.3	5.8	.0	4.6	--	2	--	30	--
80-07-10	.1	5	2.4	2.4	4.7	.0	4.7	--	2	--	30	--
80-07-08	.1	4	1.8	2.0	3.8	.0	3.2	--	0	--	17	--
80-07-09	.3	10	1.0	8.1	13	.0	4.5	--	7	--	250	--
80-07-10	.3	9	1.3	15	9.2	.4	7.5	--	2	--	50	--
80-07-09	.1	4	3.0	5.1	16	.2	5.0	3	0	10	100	0
80-07-09	.2	8	4.0	5.4	2.2	.2	7.0	--	0	--	41	--
80-07-07	.2	5	1.7	4.7	5.1	.1	7.1	1	0	10	0	0
76-09-01	.3	11	1.1	12	5.8	.4	17	1	ND	20	10	--

DATE OF SAMPLE	STRON-TIUM, DIS-SOLVED (UG/L AS SR)	ZINC, TOTAL RECOV-ERABLE (UG/L AS ZN)	SELE-NIUM, TOTAL (UG/L AS SE)	MERCURY TOTAL RECOV-ERABLE (UG/L AS HG)	PER-THANE TOTAL (UG/L)	NAPH-THA-LENES, POLY-CHLOR. TOTAL (UG/L)	ALDRIN, TOTAL (UG/L)	LINDANE TOTAL (UG/L)	CHLOR-DANE, TOTAL (UG/L)	DDD, TOTAL (UG/L)	DDE, TOTAL (UG/L)	DDT, TOTAL (UG/L)
80-07-10	0	50	--	--	--	--	--	--	--	--	--	--
80-07-08	30	40	--	--	--	--	--	--	--	--	--	--
80-07-10	0	60	--	--	--	--	--	--	--	--	--	--
80-07-08	70	10	--	--	--	--	--	--	--	--	--	--
80-07-09	60	180	--	--	--	--	--	--	--	--	--	--
80-07-10	0	80	--	--	--	--	--	--	--	--	--	--
80-07-09	30	140	0	.1	.00	.00	.00	.00	.50	.00	.00	.00
80-07-09	0	60	--	--	--	--	--	--	--	--	--	--
80-07-07	0	10	0	.1	--	--	--	--	--	--	--	--
76-09-01	100	--	<1	<.5	--	.00	.00	.00	.00	.00	.00	.00

DATE OF SAMPLE	DI-ELDRIN TOTAL (UG/L)	ENDO-SULFAN, TOTAL (UG/L)	ENDRIN, TOTAL (UG/L)	TOX-APHENE, TOTAL (UG/L)	HEPTA-CHLOR, TOTAL (UG/L)	HEPTA-CHLOR EPOXIDE TOTAL (UG/L)	METH-OXY-CHLOR, TOTAL (UG/L)	PCB, TOTAL (UG/L)	2,4-D, TOTAL (UG/L)	2,4,5-T TOTAL (UG/L)	MIREX, TOTAL (UG/L)	SILVEX, TOTAL (UG/L)
80-07-10	--	--	--	--	--	--	--	--	--	--	--	--
80-07-08	--	--	--	--	--	--	--	--	--	--	--	--
80-07-10	--	--	--	--	--	--	--	--	--	--	--	--
80-07-08	--	--	--	--	--	--	--	--	--	--	--	--
80-07-09	--	--	--	--	--	--	--	--	--	--	--	--
80-07-10	--	--	--	--	--	--	--	--	--	--	--	--
80-07-09	.00	.00	.00	0	.00	.00	.00	.30	.00	.00	.00	.00
80-07-09	--	--	--	--	--	--	--	--	--	--	--	--
80-07-07	--	--	--	--	--	--	--	--	.01	.00	--	.00
76-09-01	.00	--	.00	0	.00	.00	.00	.00	.00	.00	--	.00

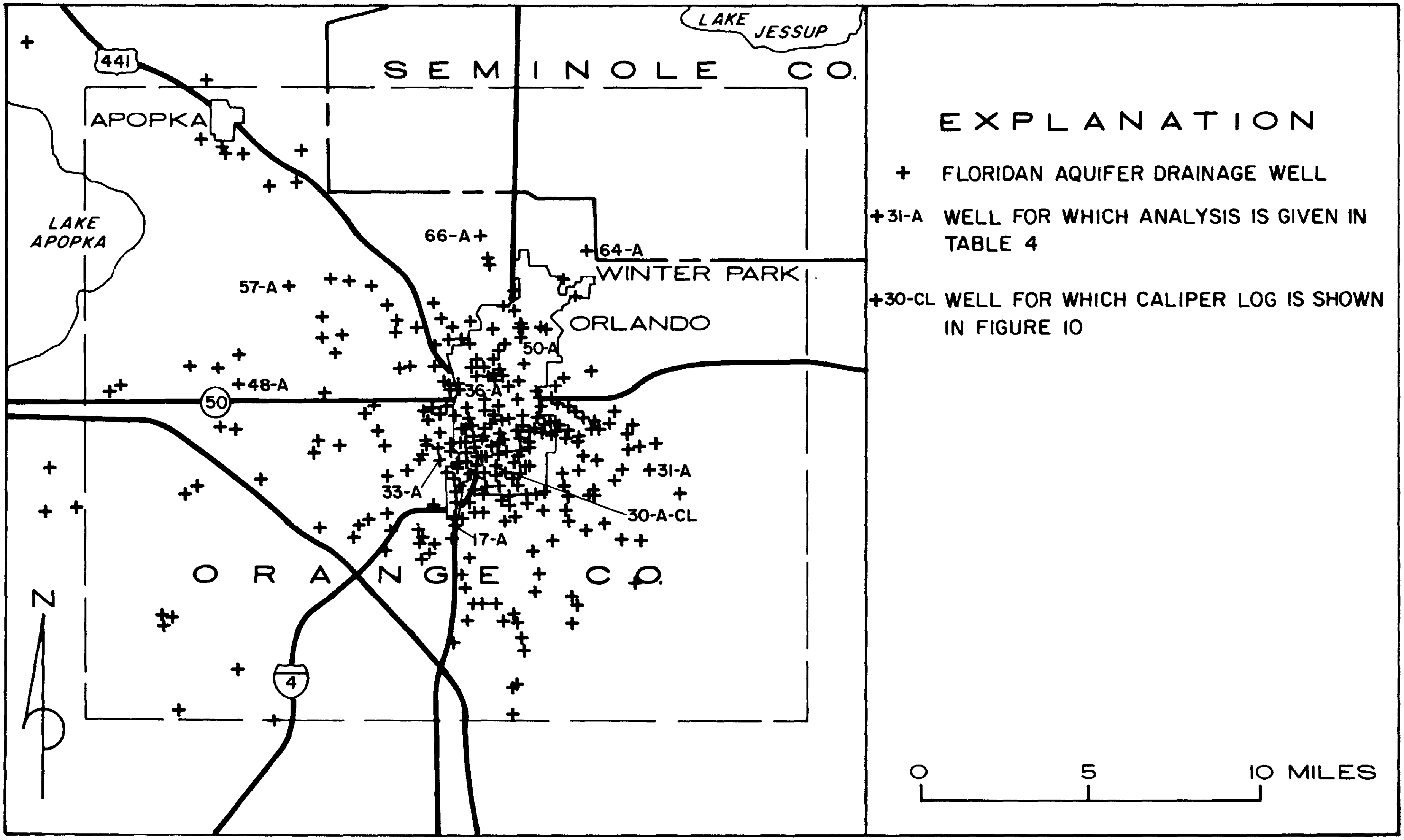


Figure 9.--Locations of Floridan aquifer drainage wells, Orlando area.

at average depths of 1,100 to 1,500 feet in the Lake City Limestone that is referred to as the lower producing zone. The two highly transmissive zones both contain freshwater in the Orlando area and are separated by several hundred feet of less permeable limestone and dolomitic limestone. Denser carbonate rocks prevail below the bottom of the lower producing zone and the freshwater-saltwater interface is considered to occur at an average depth of about 2,200 feet (C. H. Tibbals, oral commun., 1981).

Locations for 392 drainage wells in, or immediately adjacent to, the Orlando area are shown in figure 9. All well locations shown were verified by field inventory as part of the present investigations in the area. Depths of these wells range from about 120 to 1,050 feet; median depth is about 400 feet. With possible exception of the deeper well just mentioned, no drainage wells are known to penetrate to the depth of the lower producing zone (1,100-1,500 feet). These drainage wells are used to dispose of most stormwater and to regulate the stages of many lakes for the area. The capacities, or acceptance rates, of individual drainage wells are observed to range from a few hundred to several thousand gallons per minute, and Stringfield (1933, p. 22) reported a well in west Orlando to have an acceptance rate of 9,500 gal/min (Kimrey, 1978). Caliper logs for two wells in the Orlando area are shown in figure 10, and their locations are in figures 9 and 11. One well, about 675 feet deep, is used as a drainage well, and it probably penetrates the entire thickness of the upper producing, or drainage-well zone. The other well, about 1,000 feet deep, is used for public supply, and it probably penetrates to near the top of the lower producing zone.

Both the upper and lower producing zones are used for public water supply in the Orlando area. At present (1981), average public-supply withdrawals in the area are estimated at about 85 Mgal/d, with about 65 percent of this total being withdrawn from the lower producing zone; the remaining 35 percent is withdrawn from the upper producing, or drainage-well zone. Distribution of public-supply wells for both producing zones is shown in figure 11. Natural ground-water head relations in the area are such that the water table, or lake levels, are higher than the potentiometric surface of the upper producing zone, which in turn is higher than the potentiometric surface of the lower producing zone. The natural head differences between the upper and lower producing zones tend to be increased by use of the zones, as follows: The upper zone, though source for about 35 percent of public-supply withdrawals, is also the receiving zone for virtually all drainage wells in the area. Drainage-well injection results in an artificially high potentiometric surface in the upper zone on at least a seasonal basis (Unklesbay and Cooper, 1946; Lichtler and others, 1968; Kimrey, 1978). The potentiometric surface for the lower producing zone is depressed, to some degree, as a result of continuous withdrawals; so the prevailing average downward gradient between the two producing zones is increased by uses of the zones. There is hydraulic connection between the two producing zones as pointed out by Lichtler and others (1968), and Kimrey (1978). However, the degree of hydraulic connection is not known.

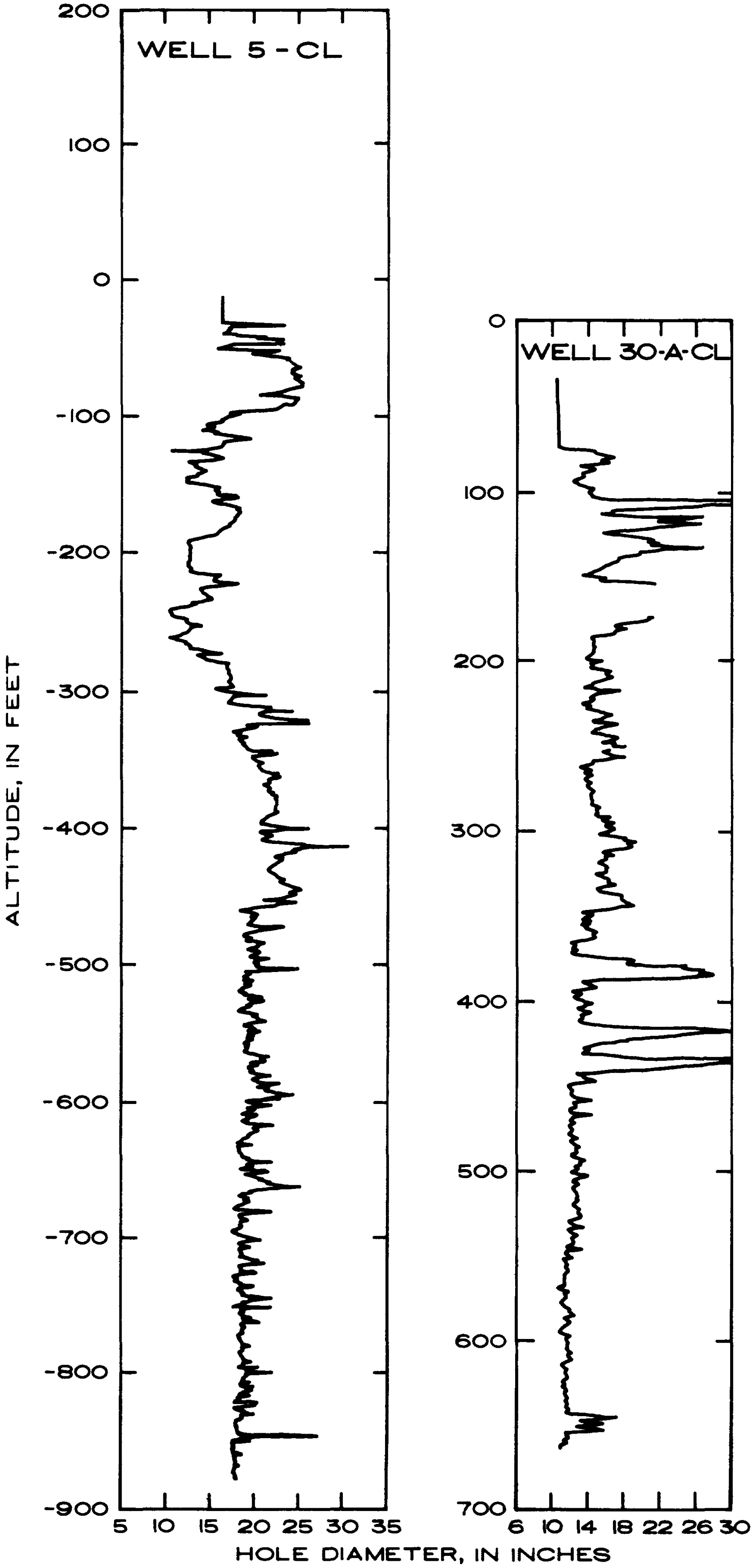


Figure 10.--Caliper logs, Orlando area.

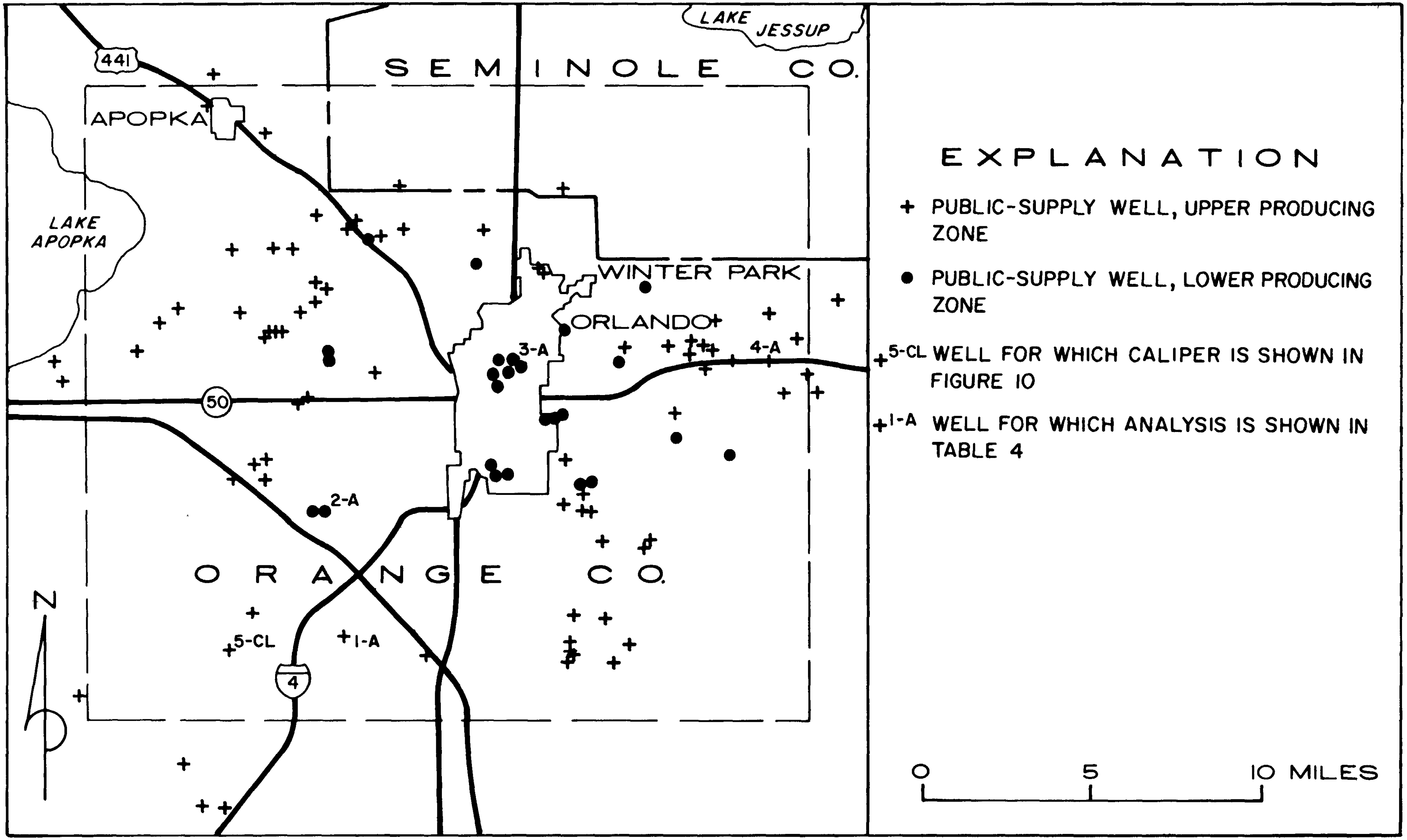


Figure 11.--Locations of public-supply wells, Orlando area.

Table 4 contains water-quality analytical data for 10 drainage wells, 2 public-supply wells open to the upper producing zone, and 2 public-supply wells open only to the lower producing zone. The 10 drainage wells for which data are shown were sampled in April 1978, or near the end of the annual dry season. Thus most, or possibly all, had received little or no injection water over the immediately preceding several months since the end of the 1977 rainy season; and some of these 10 wells had probably not received injection water over the several preceding years. Analytical data for water samples from these wells should thus be more representative of residual quality in the drainage-well zone than, for example, the data for samples from the Ocala and Live Oak areas that were collected during the rainy season.

Data on quality of stormwater runoff to lakes or drainage wells were not collected during the present study for the Orlando area. Such data, however, are available from other investigations. These data show that storm runoff generally contains higher concentrations of most nutrients and metals than water from drainage wells (E. R. German, oral commun., 1981).

Comparison of the analytical data for the 10 drainage wells (table 4) with the National Interim Primary and Secondary Drinking Water standards indicates the following:

1. Standards for color were exceeded in the sample from one drainage well;

2. Lead and manganese concentrations for the sample from one drainage well exceeded the standards values;

3. The standards value for iron was exceeded by iron concentrations in 8 of the 10 drainage wells;

4. Coliform bacteria ranged from 0 to 5,600 colonies/mL of sample; fecal coliform bacteria ranged from 0 to 940 colonies/mL of sample.

Analytical data for four public-supply wells in the Orlando area are also shown in table 4. Two of these wells (2 and 3) withdraw water from the lower producing zone; and the other two wells (1 and 4) withdraw water from the upper producing, or drainage-well zone. Of the two upper zone supply wells, one (well 1) is on the west side of the Orlando area, thus generally upgradient from most drainage wells, and the other (well 4) is on the east side of the area and thus generally downgradient from the area of densest concentration of drainage wells. Locations of these four public-supply wells are noted in figure 11.

Inspection of analytical data for the four public-supply wells indicates quite similar water quality. But water samples from the two lower zone supply wells and the downgradient upper zone supply well are slightly more mineralized than water from the upgradient public-supply well.

TABLE 4.--ANALYSES OF WATER FROM FLORIDAN AQUIFER DRAINAGE AND PUBLIC-SUPPLY WELLS, ORLANDO AREA

STATION NUMBER	STATION NAME	SITE NUMBER	DATE OF SAMPLE	SPE-CIFIC CON-DUCT-ANCE (UMHOS)	PH (UNITS)	COLOR (PLAT-INUM-COBALT UNITS)	TUR-BID-ITY (NTU)
	DRAINAGE WELLS (FIGURE 9)						
283002081234701	83012307 HOWARD JOHNSONS DRAIN WELL	17	78-04-19	242	7.5	5	5.0
283154081220701	83112204 LAKE DAVIS DRAIN WELL	30	78-04-17	321	6.8	10	2.0
283157081180401	83111802 ENGLEWOOD S/O DRAIN WELL	31	78-04-18	241	7.0	10	2.0
283211081241001	83212402 ORLANDO CITY YARD DRAIN WELL	33	78-04-27	328	7.0	20	1.0
283321081231801	83312311 LAKE CONCORD DRAIN WELL	36	78-04-10	313	7.7	10	5.0
283416081295901	83412901 LAKE FLORENCE DRAIN WELL	48	78-04-13	311	7.3	5	5.0
283530081214301	83S12107 LAKE MIDGET DRAIN WELL W-7627	50	78-04-26	290	7.0	10	3.0
283655081283401	83612801 LONG LAKE DRAIN WELL	57	78-04-12	266	7.5	10	16
283717081194202	83711904 LAKEMONT AVE DRAIN WELL	64	78-04-25	345	7.4	5	1.0
283735081224001	83712201 LAKE SYBELIA DRAIN WELL W-156	66	78-04-20	258	7.1	10	1.0
	PUBLIC-SUPPLY WELLS (FIGURE 11)						
282654081265701	ORLANDO UTIL. NO.11,SAND LK RD AT ORL,FL	1	77-09-06	230	7.7	0	--
283350081154301	EAST DALE ACRES P S, ORANGE CO,FL	4	77-09-03	278	7.2	0	--
283006081273701	ORLANDO UTILITIES,KIRKMAN RD AT ORL,FL	2	77-09-02	260	7.8	0	--
283353081222401	ORLANDO UTILITIES NO.2 LK IVANHOE AT ORL,FL	3	77-09-02	258	7.7	0	--

DATE OF SAMPLE	OXYGEN DEMAND, CHEM-ICAL (HIGH LEVEL) (MG/L)	OXYGEN DEMAND, BIO-CHEM-ICAL, 5 DAY (MG/L)	COLI-FORM, TOTAL, IMMED. (COLS. PER 100 ML)	COLI-FORM, FECAL, 0.7 UM-MF (COLS./ 100 ML)	HARD-NESS (MG/L AS CACO3)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)
78-04-19	22	6.8	5600	940	78	20	23	5.0	15	3.7	19	22
78-04-17	6	1.2	1	0	140	1	47	5.0	8.8	1.6	14	5.9
78-04-18	10	.7	410	210	110	18	33	6.1	7.5	1.1	15	12
78-04-27	14	1.8	330	34	150	4	45	9.1	9.5	1.6	13	9.0
78-04-10	8	.7	190	4	140	14	42	7.7	8.9	2.0	15	12
78-04-13	34	8.0	0	0	140	61	34	13	5.8	2.2	15	39
78-04-26	26	--	2200	650	140	0	47	4.4	4.0	1.8	4.9	13
78-04-12	8	.3	16	0	120	18	35	8.0	5.6	1.3	10	20
78-04-25	1	2.4	14	10	160	9	50	8.2	8.7	.9	15	8.7
78-04-20	0	.0	39	8	110	18	34	5.7	8.0	1.6	15	13
77-09-06	5	1.3	0	0	120	18	37	5.7	5.7	1.1	9.0	9.4
77-09-03	2	1.2	0	0	130	0	41	6.9	7.0	.9	9.3	5.3
77-09-02	30	2.4	0	0	120	25	35	8.5	5.2	1.9	7.9	17
77-09-02	3	1.2	0	0	120	13	34	8.3	6.7	1.0	9.9	4.7

DATE OF SAMPLE	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	ALKA-LINITY FIELD (MG/L AS CACO3)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SILICA, DIS-SOLVED (MG/L AS SIO2)	NITRO-GEN, NITRATE TOTAL (MG/L AS N)	NITRO-GEN, NITRITE TOTAL (MG/L AS N)	NITRO-GEN, AMMONIA TOTAL (MG/L AS N)	NITRO-GEN, ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS N)	PHOS-PHORUS, TOTAL (MG/L AS P)	ALUM-INUM, TOTAL RECOV-ERABLE (UG/L AS AL)
78-04-19	146	124	58	.1	1.3	.41	.020	.300	1.5	2.2	.150	290
78-04-17	162	176	139	.1	5.5	.00	<.010	2.00	.19	2.2	.300	80
78-04-18	109	135	92	.1	4.7	.09	<.010	.030	.25	.37	.040	190
78-04-27	190	188	146	.2	11	.00	<.010	.400	.27	.67	.360	40
78-04-10	170	169	120	.2	4.5	.01	<.010	.560	.15	.72	.120	60
78-04-13	221	163	78	.1	6.7	2.4	.140	.050	.10	2.7	.100	90
78-04-26	164	168	141	.1	3.5	.00	<.010	.900	.25	1.2	.660	40
78-04-12	141	154	102	.1	7.4	.85	.010	.050	.24	1.2	.270	500
78-04-25	198	191	151	.1	8.7	.00	<.010	.370	.14	.51	.420	80
78-04-20	130	139	92	.1	4.6	.07	.010	.370	.14	.59	.120	80
77-09-06	123	136	98	.1	9.1	.00	<.010	.280	.00	.28	.110	<100
77-09-03	160	163	130	.2	13	.00	<.010	.280	.01	.29	.050	20
77-09-02	157	147	98	.1	11	.00	<.010	.200	.01	.21	.050	20
77-09-02	175	140	110	.1	11	.00	<.010	.350	.00	.35	.050	10

TABLE 4.--ANALYSES OF WATER FROM FLORIDAN AQUIFER DRAINAGE AND PUBLIC-SUPPLY WELLS, ORLANDO AREA--CONTINUED

DATE OF SAMPLE	ALUMINUM, DIS-SOLVED (UG/L AS AL)	ARSENIC TOTAL (UG/L AS AS)	ARSENIC DIS-SOLVED (UG/L AS AS)	BARIUM, TOTAL RECOV-ERABLE (UG/L AS BA)	BARIUM, DIS-SOLVED (UG/L AS BA)	CADMIUM TOTAL RECOV-ERABLE (UG/L AS CD)	CADMIUM DIS-SOLVED (UG/L AS CD)	CHROMIUM, TOTAL RECOV-ERABLE (UG/L AS CR)	CHROMIUM, DIS-SOLVED (UG/L AS CR)	COBALT, TOTAL RECOV-ERABLE (UG/L AS CO)	COBALT, DIS-SOLVED (UG/L AS CO)	COPPER, TOTAL RECOV-ERABLE (UG/L AS CU)
78-04-19	<100	7	6	<100	<100	ND	<2	<20	<2	ND	2	6
78-04-17	40	1	1	<100	<100	<2	ND	<20	ND	ND	ND	<2
78-04-18	50	1	1	<100	<100	ND	<2	<20	ND	<2	2	5
78-04-27	20	2	1	<100	<100	ND	ND	<20	<2	ND	ND	3
78-04-10	40	3	3	<100	<100	3	4	<20	<2	ND	3	--
78-04-13	20	3	2	<100	<100	ND	<2	20	ND	2	ND	3
78-04-26	20	2	2	<100	<100	2	ND	<20	<2	2	2	3
78-04-12	40	2	1	<100	<100	ND	2	<20	ND	2	ND	7
78-04-25	20	2	1	<100	<100	<2	ND	<20	ND	3	ND	3
78-04-20	20	2	2	<100	<100	ND	ND	<20	ND	ND	ND	ND
77-09-06	<100	1	<1	<100	<100	ND	ND	<20	3	ND	ND	4
77-09-03	<100	<1	<1	<100	<100	ND	ND	<20	ND	ND	ND	3
77-09-02	20	<1	<1	<100	<100	ND	ND	<20	ND	ND	ND	ND
77-09-02	10	<1	<1	<100	<100	2	ND	<20	ND	ND	ND	2

DATE OF SAMPLE	COPPER, DIS-SOLVED (UG/L AS CU)	IRON, TOTAL RECOV-ERABLE (UG/L AS FE)	IRON, DIS-SOLVED (UG/L AS FE)	LEAD, TOTAL RECOV-ERABLE (UG/L AS PB)	LEAD, DIS-SOLVED (UG/L AS PB)	MANGANESE, TOTAL RECOV-ERABLE (UG/L AS MN)	MANGANESE, DIS-SOLVED (UG/L AS MN)	MERCURY TOTAL RECOV-ERABLE (UG/L AS HG)	MERCURY DIS-SOLVED (UG/L AS HG)	NICKEL, TOTAL RECOV-ERABLE (UG/L AS NI)	SELENIUM, TOTAL (UG/L AS SE)	SELENIUM, DIS-SOLVED (UG/L AS SE)
78-04-19	9	170	20	29	<2	<10	<10	<.5	<.5	4	<1	<1
78-04-17	ND	510	300	ND	ND	<10	<10	<.5	<.5	4	<1	<1
78-04-18	2	340	50	2	2	20	<10	<.5	<.5	ND	<1	<1
78-04-27	3	630	550	3	3	30	30	<.5	<.5	2	<1	<1
78-04-10	39	1400	1400	--	70	--	90	<.5	<.5	4	<1	<1
78-04-13	ND	1000	<10	ND	ND	<10	<10	<.5	<.5	13	3	3
78-04-26	ND	1200	1100	8	2	30	30	<.5	<.5	3	<1	<1
78-04-12	2	2300	1300	3	2	20	<10	<.5	<.5	2	1	<1
78-04-25	3	260	100	3	3	<10	<10	<.5	<.5	<2	<1	<1
78-04-20	ND	320	200	<2	ND	<10	<10	<.5	<.5	2	<1	<1
77-09-06	4	20	<10	ND	ND	<10	<10	<.5	<.5	ND	<1	<1
77-09-03	ND	70	30	2	ND	<10	<10	<.5	<.5	2	<1	<1
77-09-02	ND	120	20	9	5	<10	<10	<.5	<.5	5	<1	<1
77-09-02	ND	30	<10	26	3	<10	<10	<.5	<.5	20	<1	<1

DATE OF SAMPLE	STRONTIUM, DIS-SOLVED (UG/L AS SR)	ZINC, TOTAL RECOV-ERABLE (UG/L AS ZN)	ZINC, DIS-SOLVED (UG/L AS ZN)	CARBON, ORGANIC TOTAL (MG/L AS C)	METHYLENE BLUE ACTIVE SUB-STANCE (MG/L)	OIL AND GREASE (MG/L)	PCB, TOTAL (UG/L)	NAPHTHALENES, POLY-CHLOR. TOTAL (UG/L)	ALDRIN, TOTAL (UG/L)	CHLORDANE, TOTAL (UG/L)	DDD, TOTAL (UG/L)	ODE, TOTAL (UG/L)
78-04-19	80	<20	<20	6.0	.10	1	.00	.00	.00	.00	.00	.00
78-04-17	80	<20	ND	6.0	.00	--	.00	.00	.00	.00	.00	.00
78-04-18	80	<20	<20	7.0	.10	0	.00	.00	.00	.00	.00	.00
78-04-27	100	<20	<20	5.0	.10	0	.10	.00	.00	.00	.00	.00
78-04-10	100	20	20	6.0	.10	0	.00	.00	.00	.00	.00	.00
78-04-13	80	<20	<20	4.0	.00	--	.00	.00	.00	.00	.00	.00
78-04-26	90	<20	ND	6.0	.10	0	.20	.00	.00	.00	.00	.00
78-04-12	80	<20	<20	8.0	.00	--	.00	.00	.00	.00	.00	.00
78-04-25	90	<20	ND	4.0	--	0	.10	.00	.00	.00	.00	.00
78-04-20	90	<20	ND	.0	.10	--	.00	.00	.00	.00	.00	.00
77-09-06	90	<20	<20	5.0	.00	--	.00	.00	.00	.00	.00	.00
77-09-03	270	<20	<20	5.0	.00	--	.00	.00	.00	.00	.00	.00
77-09-02	730	ND	ND	.0	.00	6	.00	.00	.00	.00	.00	.00
77-09-02	240	<20	ND	1.0	.10	7	.00	.00	.00	.00	.00	.00

TABLE 4.--ANALYSES OF WATER FROM FLORIDAN AQUIFER DRAINAGE AND PUBLIC-SUPPLY WELLS, ORLANDO AREA--CONTINUED

DATE OF SAMPLE	DDT, TOTAL (UG/L)	DI- ELDRIN TOTAL (UG/L)	ENDO- SULFAN, TOTAL (UG/L)	ENDRIN, TOTAL (UG/L)	HEPTA- CHLOR, TOTAL (UG/L)	HEPTA- CHLOR EPOXIDE TOTAL (UG/L)	LINDANE TOTAL (UG/L)	PER- THANE TOTAL (UG/L)	TOX- APHENE, TOTAL (UG/L)	2,4-D, TOTAL (UG/L)	2,4,5-T TOTAL (UG/L)	SILVEX, TOTAL (UG/L)
78-04-19	.00	.00	--	.00	.00	.00	.00	--	0	.02	.00	.02
78-04-17	.00	.00	--	.00	.00	.00	.00	--	0	.00	.00	.00
78-04-18	.00	.00	--	.00	.00	.00	.00	--	0	.00	.00	.00
78-04-27	.00	.00	--	.00	.00	.00	.00	--	0	.02	.00	.00
78-04-10	.00	.00	--	.00	.00	.00	.00	--	0	.00	.00	.00
78-04-13	.00	.00	--	.00	.00	.00	.00	--	0	.01	.00	.00
78-04-26	.00	.01	--	.00	.00	.00	.00	--	0	.00	7.1	.00
78-04-12	.00	.00	--	.00	.00	.00	.00	--	0	.01	.00	.00
78-04-25	.00	.00	--	.00	.00	.00	.00	--	0	.00	.00	.00
78-04-20	.00	.00	--	.00	.00	.00	.00	--	0	.00	.00	.00
77-09-06	.00	.00	.00	.00	.00	.00	.00	.00	0	.00	.00	.00
77-09-03	.00	.00	.00	.00	.00	.00	.00	.00	0	.00	.00	.00
77-09-02	.00	.00	.00	.00	.00	.00	.00	.00	0	.00	.00	.00
77-09-02	.00	.00	.00	.00	.00	.00	.00	.00	0	.00	.00	.00

Comparison of analytical data for the 4 public-supply wells with the data for the 10 drainage wells also indicates a general similarity in concentrations of most major ions. However, concentrations of nutrients, metals, and bacteria are higher in the drainage-well samples. This appears logical in that quality of water from drainage wells is likely to be more directly affected by injection of stormwater runoff than is that for public-supply wells.

Estimates for average volumes of recharge by drainage wells in the Orlando area have previously been published by Lichtler (1972, p. 44) and Kimrey (1978, p. 15). These estimates reflect the observation that the Floridan aquifer was in dynamic equilibrium (that is, there was no appreciable cone of depression) until such time as total pumpage in the area exceeded about 50 Mgal/d, and thus suggested this volume as the average rate of recharge. There are about 35 to 40 square miles of the Orlando area that are almost totally drained by drainage wells. Beyond this, there are several tens of square miles that are partially drained by drainage wells.

Other Areas

A total of 473 Floridan aquifer drainage wells are included in the areas previously discussed as the Ocala, Live Oak, and Orlando areas. Additional records are available and locations have been verified for 134 wells in other areas throughout central and north-central Florida. Distribution of this total of 607 wells is shown, by county, in figure 3.

The use of these 134 Floridan aquifer drainage wells in "other areas" is similar to that of the 473 wells that are concentrated in the Ocala, Live Oak, and Orlando areas--that is, to provide, or supplement surface drainage and control lake levels in urban or suburban areas. However, these "other area" wells tend to be widely dispersed, or to be concentrated in smaller numbers than are the wells in the three major areas of drainage-well use.

Water samples were obtained from eight drainage wells in these other areas during the present investigation. Of these wells, two are in Hamilton County, three are in Leon County, one is in Madison County, and two are in Putnam County. Comparison of the analytical data from these eight drainage wells (table 5) with standards of the National Primary and Secondary Drinking Water Regulations indicate:

1. Maximum contaminant levels for turbidity are exceeded in samples from three wells (wells 302911083003601 and 302929082593601 in Hamilton County and well 303813084082101 in Leon County);

2. The levels for color are exceeded in the sample from well 302929082593601 in Hamilton County;

3. Levels for iron and manganese concentrations are exceeded in the sample from well 303813084082101 in Leon County.

TABLE 5.--ANALYSES OF WATER FROM FLORIDAN AQUIFER DRAINAGE WELLS IN HAMILTON, LEON, MADISON, AND PUTNAM COUNTIES

STATION NUMBER	STATION NAME	COUNTY	DATE OF SAMPLE	TEMPERATURE (DEG C)	TURBIDITY (NTU)	COLOR (PLATINUM-COBALT UNITS)
302911083003601	I-10 DRAIN WELL NR JASPER,FL	HAMILTON	80-08-14	20.0	390	15
302929082593601	SR-249 DRAIN WELL NR JASPER,FL	HAMILTON	80-08-14	20.5	6.0	20
303722084094501	DAWKINS POND DRAIN WELL, CHEROKEE PLANTATION	LEON	80-08-12	21.0	3.0	10
303813084082101	CARNES POND DRAIN WELL,CHEROKEE PLANTATION	LEON	80-08-12	20.0	25	10
303923084054401	THOMSON POND DRAIN WELL, LOVE RIDGE PLANTATION	LEON	80-08-13	21.0	5.0	0
302806083262501	MADISON COUNTRY CLUB DRAIN WELL	MADISON	80-08-13	23.0	1.0	10
293633081594601	COWPEN LAKE DRAIN WELL	PUTNAM	80-07-31	23.5	3.0	5
294308082002201	SWAN LAKE DRAIN WELL NR MELROSE,FL	PUTNAM	80-07-31	23.0	1.0	5

DATE OF SAMPLE	SPECIFIC CONDUCTANCE (UMHOS)	PH (UNITS)	CARBON DIOXIDE DISSOLVED (MG/L AS CO2)	ALKALINITY FIELD (MG/L AS CACO3)	BICARBONATE FET-FLD (MG/L AS HCO3)	CARBONATE FET-FLD (MG/L AS CO3)	NITROGEN, ORGANIC TOTAL (MG/L AS N)	NITROGEN, AMMONIA TOTAL (MG/L AS N)	NITROGEN, NITRITE TOTAL (MG/L AS N)	NITROGEN, NITRATE TOTAL (MG/L AS N)	NITROGEN,AMMONIA + ORGANIC TOTAL (MG/L AS N)	NITROGEN, NO2+NO3 TOTAL (MG/L AS N)
80-08-14	250	7.1	22	143	174	0	.34	.380	.010	.02	.72	.03
80-08-14	340	6.8	48	154	188	0	.18	.020	.050	.25	.20	.30
80-08-12	230	7.0	20	102	124	0	.01	.150	.000	.01	.16	.01
80-08-12	305	7.3	14	141	172	0	.01	.160	.000	.03	.17	.03
80-08-13	260	7.6	5.9	121	148	0	.01	.010	.000	.20	.02	.20
80-08-13	250	7.2	14	115	140	0	.00	.080	.010	.08	.08	.09
80-07-31	172	7.8	2.5	82	100	0	.18	.300	.000	.00	.48	.00
80-07-31	168	7.8	2.3	75	92	0	.19	.050	.000	.00	.24	.00

DATE OF SAMPLE	NITROGEN, TOTAL (MG/L AS N)	NITROGEN, TOTAL (MG/L AS NO3)	PHOSPHORUS, ORTHO, TOTAL (MG/L AS P)	PHOSPHORUS, TOTAL (MG/L AS P)	CARBON, ORGANIC TOTAL (MG/L AS C)	COLIFORM, TOTAL, IMMED. (COLS. PER 100 ML)	HARDNESS (MG/L AS CACO3)	HARDNESS, NONCARBONATE (MG/L CACO3)	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L)	SOLIDS, SUM OF CONSTITUENTS, DISSOLVED (MG/L)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)
80-08-14	.75	3.3	.350	4.00	14	2100	130	0	149	153	51	1.5
80-08-14	.50	2.2	.130	.130	12	700	190	35	205	201	70	3.4
80-08-12	.17	.80	.060	.090	10	600	100	1	121	111	35	3.7
80-08-12	.20	.90	.050	.340	12	--	150	6	162	159	45	8.4
80-08-13	.22	1.0	.030	.060	5.9	900	140	19	148	150	38	11
80-08-13	.17	.80	.110	.120	6.7	3100	130	11	140	132	42	5.2
80-07-31	.48	2.1	.050	.070	19	K0	86	4	111	97	29	3.2
80-07-31	.24	1.1	.040	.040	11	K5	80	5	109	96	23	5.6

DATE OF SAMPLE	SODIUM, DISSOLVED (MG/L AS NA)	SODIUM ADSORPTION RATIO	PERCENT SODIUM	POTASSIUM, DISSOLVED (MG/L AS K)	CHLORIDE, DISSOLVED (MG/L AS CL)	SULFATE DISSOLVED (MG/L AS SO4)	FLUORIDE, DISSOLVED (MG/L AS F)	SILICA, DISSOLVED (MG/L AS SIO2)	ARSENIC TOTAL (UG/L AS AS)	BARIUM, TOTAL RECOVERABLE (UG/L AS BA)	CADMIUM TOTAL RECOVERABLE (UG/L AS CD)	CHROMIUM, TOTAL RECOVERABLE (UG/L AS CR)
80-08-14	1.4	.1	2	1.6	3.0	3.5	.2	4.6	--	--	1	--
80-08-14	3.7	.1	4	.6	6.4	14	.2	9.8	--	--	0	--
80-08-12	1.8	.1	4	.7	2.8	.2	.1	5.0	--	--	0	--
80-08-12	2.2	.1	3	1.2	3.6	3.0	.1	11	27	<50	0	10
80-08-13	2.2	.1	3	.4	3.2	10	.1	12	--	--	0	--
80-08-13	2.9	.1	3	.8	2.8	4.8	.1	5.4	--	--	0	--
80-07-31	3.3	.2	8	.3	5.2	.5	.1	5.0	--	--	0	--
80-07-31	4.5	.2	11	.5	6.4	3.9	.2	7.0	--	--	0	--

DATE OF SAMPLE	IRON, TOTAL RECOVERABLE (UG/L AS FE)	LEAD, TOTAL RECOVERABLE (UG/L AS PB)	MANGANESE, TOTAL RECOVERABLE (UG/L AS MN)	SILVER, TOTAL RECOVERABLE (UG/L AS AG)	STRONTIUM, DISSOLVED (UG/L AS SR)	ZINC, TOTAL RECOVERABLE (UG/L AS ZN)	SELENIUM, TOTAL (UG/L AS SE)	MERCURY TOTAL RECOVERABLE (UG/L AS HG)	2,4-D, TOTAL (UG/L)	2,4,5-T TOTAL (UG/L)	SILVEX, TOTAL (UG/L)
80-08-14	--	24	--	--	70	60	--	--	--	--	--
80-08-14	--	3	--	--	110	70	--	--	--	--	--
80-08-12	--	7	--	--	60	30	--	--	--	--	--
80-08-12	2900	0	80	0	30	20	0	.3	.00	.00	.00
80-08-13	--	0	--	--	70	20	--	--	--	--	--
80-08-13	--	2	--	--	30	20	--	--	--	--	--
80-07-31	--	0	--	--	40	10	--	--	--	--	--
80-07-31	--	0	--	--	0	10	--	--	--	--	--

4. Coliform bacteria counts in samples from five of the wells range from 600 to 3,100 colonies/100 mL of sample.

In general, the quality of water samples from these eight drainage wells is similar to that of samples from drainage wells in the Ocala, Live Oak, and Orlando areas.

Summary and Conclusions

The present (1981) use of Floridan aquifer drainage wells is almost entirely for disposal of storm runoff and regulation of lake stages in closed-basin karst terranes. They are the major means of urban drainage for the Ocala, Live Oak, and Orlando areas; they also are used to augment drainage in several other areas of central and north Florida. The Floridan aquifer is also the major source of potable water supply in all of these areas, and drainage and supply wells often utilize the same or adjacent zones of the aquifer.

Use of drainage wells, from a quantitative standpoint, is a highly efficient means of artificial recharge to the Floridan aquifer. In the Orlando area, for example, their use appears to have offset the aquifer depressuring effects of withdrawals of about 50 Mgal/d. In this regard their use results in maintaining generally higher potentiometric pressures, which may be considered as an additional safeguard against vertical salt-water encroachment. Beyond these advantageous hydrologic aspects, their use in disposal of storm runoff and regulation of lake levels is the most economic means of handling these problems.

The negative aspects of drainage-well use relate to their potential for introducing pollutants directly, or adjacent, to zones that are also utilized for potable water supply. However these dual, and apparently incompatible, uses of the Floridan aquifer have resulted in relatively few documented cases of severe aquifer pollution being detected in public water supplies. Possible explanations include the following:

1. There is a general absence of large volumes of highly concentrated, toxic wastes in the water disposed to drainage wells. The injection water is predominately storm runoff from urban areas. Those data available for such runoff in central Florida indicate that its quality generally meets drinking water standards with the exception of high color, turbidity, bacteria, and concentrations of some nutrients and trace metals.

2. Geochemical and microbial reactions, as well as dilution, may attenuate or mask the presence of pollutants in the aquifer. Pollutants such as most trace metals and phosphorous compounds have a tendency to remain in solution only for short periods of time in an aquifer environment. Bacteria are also generally considered to have a limited span of persistence when introduced

to ground water, though their persistence may be greater in a cavernous limestone than in clastic aquifers. The presence of more conservative pollutants (nitrates, for example) may in time simply be masked by processes of dilution and dispersion.

3. Some supply wells are upgradient from drainage-well injection sites and thus relatively free of any potential for pollution from drainage wells. Examples are those on the east side of the Live Oak area and those on the west side of the Orlando area. Other supply wells appear to have escaped pollution by virtue of physical separation, though downgradient, from injection sites. Examples are public-supply wells on the east sides of the Ocala and Orlando areas.

4. There is the possibility that, as yet, sufficient time may not have elapsed for travel of pollutants between some injection and withdrawal areas. This factor might apply to lateral downgradient movement of injection water in any area; it also might apply to the vertical downgradient movement of water between the upper and lower producing zones in the Orlando area.

5. Available analytical data may not be indicative of all pollutant levels that may prevail in parts of the aquifer. The most complete sets of analytical data available for drainage- and public-supply well samples include most of the parameters of the National Interim Primary and Secondary Drinking Water Regulations standards and the major ions. Additional, or possible, pollutants have more recently been specified as, for example, those 129 compounds that comprise the list of priority pollutants or parameters. There are few, if any, complete suites of analytical data available for these parameters in ground water from areas where drainage wells are used. It is thus possible that Floridan aquifer drainage wells may be introducing some of these pollutants to zones that are utilized for public water supply.

GEOHYDROLOGIC ASPECTS, INTERAQUIFER CONNECTOR WELLS

Most interaquifer connector wells in Florida are in the phosphate mining areas of Polk and Hillsborough Counties. Their use allows more efficient mining by reducing water pressures in the ore body and immediately underlying zones, a practice which also serves as a method of recharge to the Floridan aquifer.

The geohydrologic units in the phosphate mining area have been discussed by several investigators including Hutchinson (1977) whose summary is included herein as table 1. Typically, there are the surficial aquifer and semiconfining beds; these contain the phosphate ore and the zones in which connector wells are screened. Then there is the upper unit, Floridan aquifer, which is comprised of the basal part of the Hawthorn Formation and the upper part of the Tampa Limestone, and the underlying semiconfining bed (the lower clay unit of the Tampa Limestone).

The confining bed is underlain by the lower unit, Floridan aquifer (The Suwannee, Ocala, Avon Park, and Lake City Limestones) which is the major source of public, industrial, and irrigation water supply for the area.

A factor in the widespread use of interaquifer connector wells in the phosphate mining area may be the relatively high transmissivity of the clastic materials that comprise the surficial aquifer. Hutchinson (1977), for example, reports an average transmissivity of 1,900 ft^2/d. This order of transmissivity, while low in comparison to most zones of the Floridan, is sufficient to allow relatively high gravity yield rates to individual wells. Connector-well experiments in other areas of central Florida have not been as successful because of lower transmissivities in the surficial aquifer, or losing zone. As examples, Bush (1978) reports a transmissivity of about 600 ft^2/d from a connector-well experiment in east Orange County, and Watkins (1977) reports a transmissivity of about 300 ft^2/d from experiments in west Orange County.

Figure 12 shows the location of 140 interaquifer connector wells in the phosphate mining areas of Polk and Hillsborough Counties. These well locations were verified during field work in the area from June to September 1980. All the wells convey shallow ground water to the upper or lower units of the Floridan aquifer; however, most injection is to the lower unit. The total number of interaquifer connector wells in the phosphate mining area varies from time to time because new wells may be constructed ahead of mining operations concurrent with the destruction, by mining, of existing wells.

Caliper logs for four interaquifer connector wells are shown in figure 13. These logs illustrate the different schemes of interaquifer connection that are used in the phosphate mining area. The shallowest well (14) is constructed to inject only into the upper unit of the Floridan aquifer. The two deeper wells (15 and 16) are constructed to inject into both the upper and lower units of the Floridan aquifer; the intervening confining unit is cased off. The well of intermediate depth (well 12) is apparently constructed to inject only into the lower unit of the Floridan.

Many domestic and low-yield (up to 200 gal/min) irrigation wells utilize the upper unit of the Floridan which contains moderately hard calcium bicarbonate freshwater throughout the area. The larger supplies (public, industrial, and irrigation) utilize the more highly transmissive lower unit of the Floridan. This unit contains freshwater to estimated minimum depths of 1,000 feet over most of the area. The larger supply wells are dispersed at points of use throughout the area; the total of industrial and irrigation withdrawals are believed to be considerably in excess of those for public supply.

Thirteen connector wells were test pumped for collection of water samples for chemical analysis during August and September 1980. Borehole geophysical logs--including caliper, natural gamma, fluid conductivity, and spinner survey logs--were obtained for these wells prior to sampling. The borehole geophysical logs indicate different patterns of

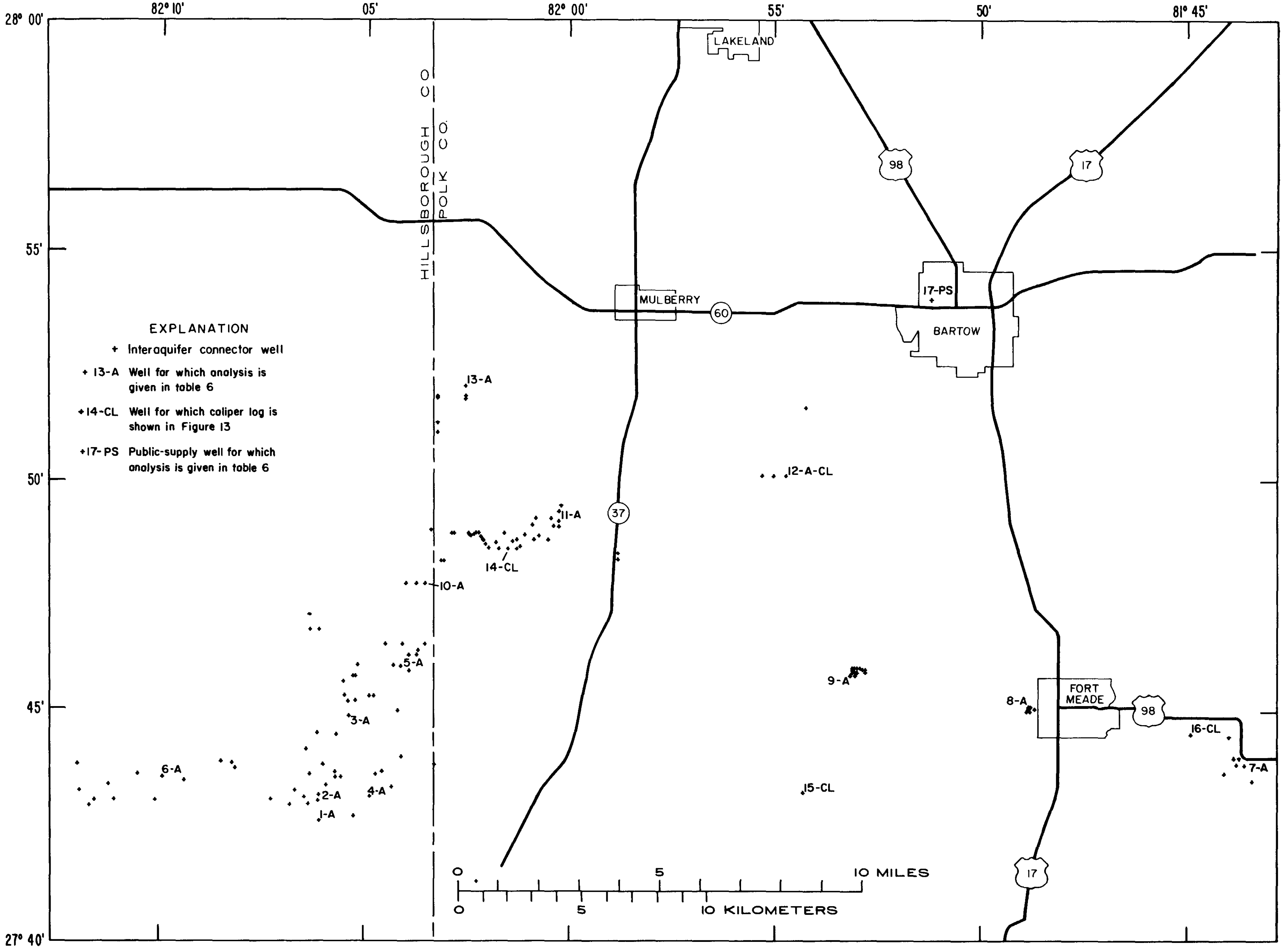


Figure 12.--Locations of interaquifer connector wells, phosphate mining area, Polk and Hillsborough Counties.

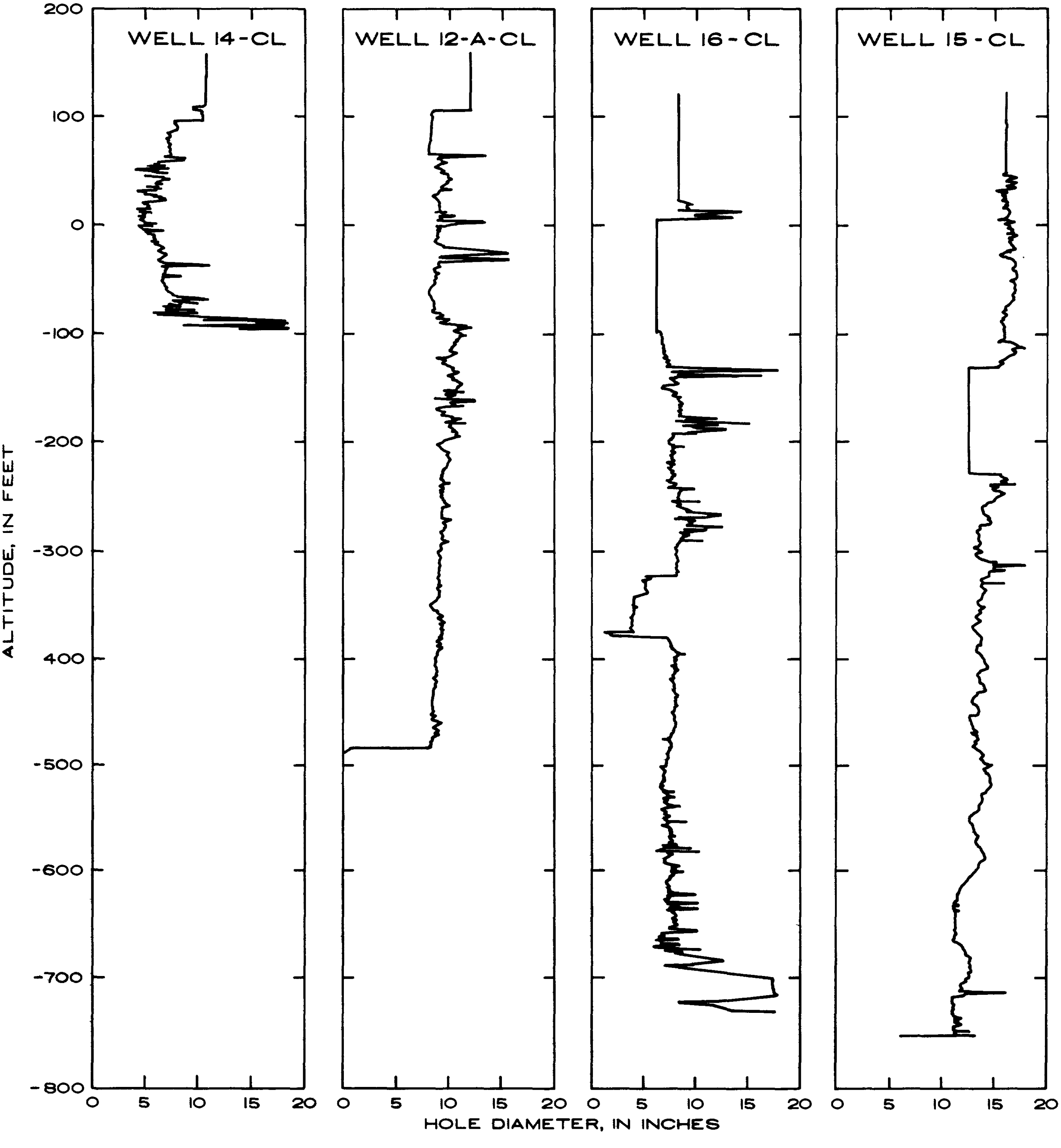


Figure 13.--Caliper logs, phosphate mining area, Polk and Hillsborough Counties.

circulation in some well bores. Circulation, of course, is always downward in the upper part of the saturated borehole as water from the losing surficial aquifer moves by gravity to injection into the Floridan. In some well bores, the downward movement of recharge water may persist as injection occurs over a relatively long vertical section of the borehole; in others, all of the recharged water may be injected to a single, narrow zone.

Water samples from the 13 connector wells were obtained by installing a submersible pump to a depth of 20 to 30 feet below static water level. Two pumps were used: One could be installed in 8-inch wells and yielded about 250 gal/min; the other required 10-inch, or larger, wells and yielded about 450 gal/min. All wells were pumped at rates of either 250 or 450 gal/min for a continuous period of 2 to 3 hours; by this time, specific conductance and drawdown had equilibrated and water samples were collected for chemical analysis. All wells were receiving injection water during the pumping and sampling operation, as indeed they had since their original installation. An additional water sample was collected from 3 of the 13 connector wells that were sampled. These samples were collected by setting the submersible pump at depths of 10 or 20 feet higher in the well bore and reducing the pumping rate in an attempt to obtain a more representative sample of the water being drained from the losing aquifer.

Analytical data for water samples from the 13 interaquifer connector wells, and for 1 public-supply well in the phosphate mining area, are shown in table 6. The data for 1 of the 13 wells (well 12) indicate a much more highly mineralized water than that yielded by any of the other wells. The sample from well 12 is an acidic, very hard, calcium-sodium sulfate type water. It has a specific conductance of 4,850 micromhos; hardness of 3,580 mg/L; sulfate content of 2,600 mg/L; ammonia nitrogen content of 160 mg/L; total organic carbon content of 41 mg/L; and also exceeds the standards values for turbidity, total iron, total manganese, combined radium 226-radium 228, gross alpha and gross beta concentrations. This connector well apparently is draining a part of the surficial aquifer that contains concentrations of contaminants that are not detected in any of the other data. The source of contaminants to this well is not known. The analytical data for the other 12 connector wells are discussed below.

The quality of water samples from connector wells in this environment might be expected to be variable. The areas of influence of some wells may drain undisturbed aquifer materials; those of other wells may, in part, drain materials that have been disturbed and backfilled during mining operations. Pump settings and pumping rates, during sampling in relation to intraborehole circulation of ground water, also may result in additional differences in water quality, as discerned from the resultant analytical data.

TABLE 6.--ANALYSES OF WATER FROM INTERAQUIFER CONNECTOR AND PUBLIC-SUPPLY WELLS, PHOSPHATE MINING AREA, POLK AND HILLSBOROUGH COUNTIES

STATION NUMBER	STATION NAME	SITE NUMBER, FIGURE 12	DATE OF SAMPLE	SAMPLING DEPTH (FT)	TEMPERATURE (DEG C)	TURBIDITY (NTU)	SPECIFIC CONDUCTANCE (UMHOS)
	INTERAQUIFER CONNECTOR WELLS						
274236082060801	LONESOME MINE 10-M-1 NR FT. LONESOME,FLA	1	80-09-05	95.0	23.0	19	282
	LONESOME MINE 10-M-1 NR FT. LONESOME,FLA	1	80-09-05	85.0	24.0	4.0	90
274302082061001	LONESOME MINE 10-D-1 NR FT. LONESOME,FLA	2	80-09-04	95.0	22.5	15	185
	LONESOME MINE 10-D-1 NR FT. LONESOME,FLA	2	80-09-04	75.0	23.0	3.0	70
274428082054301	BIG FOUR MINE PRW-7	3	80-08-29	75.0	25.0	70	103
	BIG FOUR MINE PRW-7	3	80-08-29	95.0	24.0	30	420
274242082051701	BIG FOUR MINE PRW-17	4	80-08-29	--	23.0	20	310
274626082033401	BIG FOUR MINE PRW-3	5	80-08-28	--	23.0	2.0	350
274334082095701	LONESOME MINE 1-L-1 NR. FT. LONESOME,FLA	6	80-09-03	--	23.5	17	253
274401081434401	DRAINAGE WELL WATSON P-1	7	80-08-20	--	25.0	16	214
274506081485101	MOBIL CHEM (FT MEADE 1) AT FT MEADE MINE	8	80-08-19	--	23.0	13	490
274546081531201	DRAINAGE WELL SILVER CITY MINE E-1	9	80-08-20	--	24.5	20	421
274745082033401	IMC KINGSFORD 134	10	80-08-26	--	--	2.0	200
274920082001801	IMC-KINGSFORD 104	11	80-08-25	--	--	14	310
275203082023601	MOBIL CHEM (NR-25) AT NICHOLS MINE	13	80-08-19	--	23.0	3.0	222
275007081544601	DRAINAGE WELL PHOSPORIA PR-3 IMC	12	80-08-21	--	25.0	35	4850
	PUBLIC-SUPPLY WELL						
275353081503301	BARTOW CITY NO.1 AT BARTOW,FL	17	79-09-04	--	26.0	--	468
	BARTOW CITY NO.1 AT BARTOW,FL	17	80-02-22	--	26.0	--	755

DATE OF SAMPLE	PH (UNITS)	CARBON DIOXIDE DIS-SOLVED (MG/L AS CO2)	ALKALINITY FIELD (MG/L AS CACO3)	BICARBONATE FET-FLD (MG/L AS HCO3)	NITROGEN, ORGANIC TOTAL (MG/L AS N)	NITROGEN, AMMONIA TOTAL (MG/L AS N)	NITROGEN, NITRITE TOTAL (MG/L AS N)	NITROGEN, NITRATE TOTAL (MG/L AS N)	NITROGEN, AMMONIA + ORGANIC TOTAL (MG/L AS N)	NITROGEN, NO2+NO3 TOTAL (MG/L AS N)	NITROGEN, TOTAL (MG/L AS N)	CARBON, ORGANIC TOTAL (MG/L AS C)
80-09-05	6.5	65	106	129	.06	.060	.000	1.0	.12	1.0	1.1	1.8
80-09-05	5.5	137	22	27	.02	.050	.000	1.0	.07	1.0	1.1	10
80-09-04	6.3	59	61	74	.14	.040	.000	.00	.18	.00	.18	12
80-09-04	5.3	96	10	12	.03	.050	.000	.00	.08	.00	.08	32
80-08-29	5.7	26	7	8	.82	.080	1.00	.00	.90	1.0	1.9	22
80-08-29	6.9	30	121	147	.11	.140	.010	.00	.25	.01	.26	7.5
80-08-29	5.9	207	84	103	.15	.150	.000	.01	.30	.01	.31	14
80-08-28	6.2	99	80	98	.06	.050	.000	.03	.11	.03	.14	3.6
80-09-03	6.2	82	66	81	.17	.090	.010	1.4	.26	1.4	1.7	2.4
80-08-20	6.0	70	36	44	.11	.020	.000	9.2	.13	9.2	9.3	3.1
80-08-19	6.4	168	217	264	.02	.040	.000	.01	.06	.01	.07	9.2
80-08-20	6.8	51	166	202	.12	.020	.000	.32	.14	.32	.46	16
80-08-26	6.3	38	39	48	.16	.060	.040	1.1	.22	1.1	1.4	11
80-08-25	6.6	44	90	110	.09	.150	.000	.02	.24	.02	.26	13
80-08-19	7.1	16	100	122	.01	.020	.000	.43	.03	.43	.46	10
80-08-21	4.3	.0	0	0	1.0	160	.000	.08	161	.08	161	41
79-09-04	7.4	--	--	--	--	--	--	--	--	--	--	--
80-02-22	7.8	--	160	--	--	--	--	--	--	--	--	--

DATE OF SAMPLE	PHOSPHORUS, ORTHO, TOTAL (MG/L AS P)	PHOSPHORUS, TOTAL (MG/L AS P)	HARDNESS (MG/L AS CACO3)	HARDNESS, NONCARBONATE (MG/L CACO3)	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L)	SOLIDS, SUM OF CONSTITUENTS, DIS-SOLVED (MG/L)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNESIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTASSIUM, DIS-SOLVED (MG/L AS K)	CHLORIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)
80-09-05	.720	2.40	120	16	152	135	35	8.4	7.0	.3	12	.3
80-09-05	.930	1.10	28	6	52	46	6.3	2.9	6.3	.2	10	.2
80-09-04	.340	2.00	73	12	105	88	25	2.5	4.6	.2	8.0	7.2
80-09-04	.260	.540	20	10	59	37	5.0	1.9	4.5	.2	8.0	7.4
80-08-29	6.60	6.60	630	620	50	439	120	79	220	.2	4.4	5.4
80-08-29	1.10	1.50	130	8	187	145	45	4.0	3.2	3.0	5.0	5.0
80-08-29	.480	1.20	95	11	127	112	33	3.0	6.0	.3	8.0	4.1
80-08-28	.700	.720	100	20	133	122	36	2.8	6.9	.3	11	12
80-09-03	.140	1.60	86	20	142	107	24	6.4	5.8	3.9	16	7.8
80-08-20	.150	2.80	89	53	195	85	24	7.1	5.6	.2	18	3.1
80-08-19	.730	1.20	270	53	286	281	60	29	12	.4	16	18
80-08-20	.300	.610	220	54	277	246	51	23	7.4	.9	11	34
80-08-26	.090	.090	63	24	111	101	16	5.7	10	.6	14	26
80-08-25	.930	1.20	140	48	190	179	45	6.2	14	.4	13	38
80-08-19	.530	.540	120	20	140	128	40	3.7	4.1	.2	5.0	5.4
80-08-21	.270	.320	860	860	3580	3430	230	70	400	18	20	2600
79-09-04	--	--	--	--	--	--	--	--	--	--	--	--
80-02-22	--	--	380	220	523	504	110	25	9.2	1.1	12	230

TABLE 6.--ANALYSES OF WATER FROM INTERAQUIFER CONNECTOR AND PUBLIC-SUPPLY WELLS, PHOSPHATE MINING AREA, POLK AND HILLSBOROUGH COUNTIES--CONTINUED

DATE OF SAMPLE	ENDRIN, TOTAL (UG/L)	ETHION, TOTAL (UG/L)	TOX-APHENE, TOTAL (UG/L)	HEPTA-CHLOR, TOTAL (UG/L)	HEPTA-CHLOR EPOXIDE TOTAL (UG/L)	METH-OXY-CHLOR, TOTAL (UG/L)	PCB, TOTAL (UG/L)	MALA-THION, TOTAL (UG/L)	PARA-THION, TOTAL (UG/L)	DI-AZINON, TOTAL (UG/L)	METHYL PARA-THION, TOTAL (UG/L)	2,4-D, TOTAL (UG/L)
80-09-05	.00	.00	0	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-09-05	.00	.00	0	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-09-04	.00	.00	0	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-09-04	.00	.00	0	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-29	.00	.00	0	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-29	.00	.00	0	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-29	.00	.00	0	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-28	.00	.00	0	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-09-03	.00	.00	0	.00	.00	.00	.00	.00	.00	.00	.00	.18
80-08-20	.00	.00	0	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-19	.00	.00	0	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-20	.00	.00	0	.00	.00	.00	.00	.00	.00	.00	.00	--
80-08-26	.00	.00	0	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-25	.00	.00	0	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-19	.00	.00	0	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-21	.00	.00	0	.00	.00	.00	.00	.00	.00	.00	.00	.00
79-09-04	--	--	--	--	--	--	--	--	--	--	--	--
80-02-22	--	--	--	--	--	--	--	--	--	--	--	--

DATE OF SAMPLE	2,4,5-T TOTAL (UG/L)	MIREX, TOTAL (UG/L)	SILVEX, TOTAL (UG/L)	TOTAL TRI-THION (UG/L)	METHYL TRI-THION, TOTAL (UG/L)	CESIUM 137 DIS-SOLVED (PCI/L)	STRON-TIUM 90 DIS-SOLVED (PCI/L)	RADIUM 226, DIS-SOLVED, RADON METHOD (PCI/L)	GROSS ALPHA, DIS-SOLVED (UG/L AS U-NAT)	GROSS BETA, DIS-SOLVED (PCI/L AS CS-137)	GROSS BETA, DIS-SOLVED (PCI/L AS SR/YT-90)	URANIUM DIS-SOLVED, EXTRAC-TION (UG/L)
80-09-05	.00	.00	.00	.00	.00	<1.0	<.7	.44	<3.3	2.4	2.3	.50
80-09-05	.00	.00	.00	.00	.00	<1.0	<.4	.25	2.3	2.2	2.1	.07
80-09-04	.00	.00	.00	.00	.00	<1.0	<.4	.87	180	10	9.7	.25
80-09-04	.00	.00	.00	.00	.00	<1.0	<1.5	1.0	850	29	28	.06
80-08-29	.00	.00	.00	.00	.00	<1.0	<.4	.77	590	25	24	.09
80-08-29	.00	.00	.00	.00	.00	<1.0	<.4	.34	180	13	13	.30
80-08-29	.00	.00	.00	.00	.00	<1.0	<.4	1.2	48	7.5	7.2	.18
80-08-28	.00	.00	.00	.00	.00	<1.0	<.4	.82	5.3	4.4	4.2	.50
80-09-03	.00	.00	.00	.00	.00	<1.0	<.4	.85	24	7.4	7.2	1.2
80-08-20	.00	.00	.00	.00	.00	<1.0	<.4	4.8	12	6.9	6.7	5.1
80-08-19	.00	.00	.00	.00	.00	<1.0	<.4	.95	<5.8	2.3	2.1	1.3
80-08-20	--	.00	--	.00	.00	<1.0	<.4	1.1	<4.0	3.9	3.7	1.4
80-08-26	.00	.00	.05	.00	.00	<1.0	<.4	2.6	38	5.4	5.2	.50
80-08-25	.00	.00	.00	.00	.00	<1.0	<.7	2.1	10	4.8	4.6	.70
80-08-19	.00	.00	.00	.00	.00	<1.0	<.4	.93	6.1	4.2	4.0	11
80-08-21	.00	.00	.00	.00	.00	<1.0	<.4	8.9	99	110	110	1.6
79-09-04	--	--	--	--	--	--	--	2.1	21	5.6	5.7	.18
80-02-22	--	--	--	--	--	--	--	--	--	--	--	--

TABLE 6.--ANALYSES OF WATER FROM INTERAQUIFER CONNECTOR AND PUBLIC-SUPPLY WELLS, PHOSPHATE MINING AREA, POLK AND HILLSBOROUGH COUNTIES--CONTINUED

DATE OF SAMPLE	FLUORIDE, DIS-SOLVED (MG/L AS F)	SILICA, DIS-SOLVED (MG/L AS SIO2)	ARSENIC TOTAL (UG/L AS AS)	BARIUM, TOTAL RECOV-ERABLE (UG/L AS BA)	CADMIUM TOTAL RECOV-ERABLE (UG/L AS CD)	CHROMIUM, TOTAL RECOV-ERABLE (UG/L AS CR)	COPPER, TOTAL RECOV-ERABLE (UG/L AS CU)	IRON, TOTAL RECOV-ERABLE (UG/L AS FE)	LEAD, TOTAL RECOV-ERABLE (UG/L AS PB)	MANGANESE, TOTAL RECOV-ERABLE (UG/L AS MN)	SILVER, TOTAL RECOV-ERABLE (UG/L AS AG)	STRONTIUM, DIS-SOLVED (UG/L AS SR)
80-09-05	.5	7.8	1	100	0	10	80	1600	18	10	0	100
80-09-05	.5	5.8	1	100	0	10	210	700	36	10	0	0
80-09-04	.3	3.6	1	100	1	10	8	1400	10	10	0	0
80-09-04	.3	3.5	0	100	1	10	5	980	12	10	0	40
80-08-29	.6	5.6	1	<50	9	20	280	5600	20	10	0	20
80-08-29	.6	6.5	1	100	0	10	19	950	3	10	0	0
80-08-29	.4	6.4	2	100	0	20	10	1200	3	10	0	70
80-08-28	.7	4.2	1	100	0	10	5	780	2	10	0	70
80-09-03	.3	3.1	2	<50	2	20	26	2800	19	10	0	--
80-08-20	.2	4.6	2	100	2	10	9	1000	3	10	0	70
80-08-19	.7	15	2	100	0	10	7	1400	2	30	0	210
80-08-20	.9	18	20	<50	2	20	97	1200	10	40	0	130
80-08-26	1.0	4.0	1	<50	0	20	16	790	4	10	0	20
80-08-25	.7	7.6	1	<50	1	10	4	1600	6	20	0	90
80-08-19	.4	9.0	110	<50	0	20	11	110	1	10	0	130
80-08-21	1.6	88	2	<50	8	20	15	25000	8	710	0	--
79-09-04	--	--	--	--	--	--	--	--	--	--	--	--
80-02-22	.5	17	--	--	--	--	--	--	--	--	--	3300

DATE OF SAMPLE	SELENIUM, TOTAL (UG/L AS SE)	MERCURY TOTAL RECOV-ERABLE (UG/L AS HG)	PER-THANE TOTAL (UG/L)	NAPHTHALENES, POLY-CHLOR. TOTAL (UG/L)	ALDRIN, TOTAL (UG/L)	LINDANE TOTAL (UG/L)	CHLORDANE, TOTAL (UG/L)	DDD, TOTAL (UG/L)	DDE, TOTAL (UG/L)	DDT, TOTAL (UG/L)	DI-ELDRIN TOTAL (UG/L)	ENDO-SULFAN, TOTAL (UG/L)
80-09-05	0	<.1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-09-05	0	<.1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-09-04	0	.1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-09-04	0	<.1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-29	0	.1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-29	0	.1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-29	0	.1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-28	0	<.1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-09-03	1	.1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-20	0	.3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-19	0	<.1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-20	1	.7	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-26	1	.2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-25	0	.1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-19	0	<.1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
80-08-21	0	.2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
79-09-04	--	--	--	--	--	--	--	--	--	--	--	--
80-02-22	--	--	--	--	--	--	--	--	--	--	--	--

The analytical data for the 12 connector wells indicate that their degree and types of mineralization are generally in the range that might be expected for varying mixes of shallow and Floridan aquifer ground water in this environment. Specific conductance values of the 15 water samples from 12 connector wells range from 70 to 490 micromhos. The three lowest conductance values are for the samples considered most representative of the unmixed injection water from the surficial aquifer. Field pH values for these 15 samples ranged from 5.3 to 7.1; the three lower values are for those samples with lowest specific conductance.

Comparison of the analytical data for the 12 connector wells with the standards established by the National Interim Primary Drinking Water Regulations and National Secondary Drinking Water Regulations indicates the following:

1. The standards values for turbidity are exceeded in 10 of the samples. Two of these samples are from well 3. The source of turbidity may be a combination of some continued injection of fine materials through the connector-well screens and residual fine materials that accumulated in the borehole during its construction. These wells are seldom, if ever, heavily pumped; their screened sections and bores may not have been so rigorously developed as would be the case for supply wells.

2. Concentrations of total iron exceeded standards values for samples from 11 of the 12 connector wells.

3. Of the determined radiochemical parameters, samples from 6 of the 12 connector wells exceeded the gross alpha standards. It is also noted that radium-226 concentration alone for the sample from 9 is 4.8 picocuries per liter. The applicable standard is 5 picocuries per liter for combined radium-226 and radium-228.

Two analyses are included in table 6 for a city of Bartow supply well (well 17). Both are included in order to allow comparability of more parameters from the public-supply well with those from the connector wells.

Measurements of inflow, or injection rates, to connector wells are not within the scope of the present investigation. However, the various mining companies maintain records of periodic measurements of injection rates for individual wells, and have generously made these data available. Injection rates are primarily a function of the head and transmissivity of the losing surficial aquifer. Floridan transmissivities are sufficiently high so that head buildup in the receiving aquifer never appears to be a factor in variation of injection rates. Thus, variation in injection rates for a particular well tend to relate to seasonal variations in head in the losing aquifer or, possibly in some cases, to decrease in transmission characteristics of the connector-well screen. Those data available indicate injection rates for single connector wells to range from less than 10 to more than 600 gal/min; injection rates for most wells range from about 40 to 275 gal/min. Injection rates to connector wells that receive water from a battery of siphoning wells are reported as high as 770 gal/min. A summary of data for March 1980 indicates a total injection rate of about 26 Mgal/d for 142 connector wells. Heads in the surficial aquifer are nearing their annual low in March, so this total injection rate might be slightly lower than one derived from injection data for all seasons of the year.

The phosphate industry is, and historically has been, the largest user of ground water in the area. Withdrawals in the area south of Bartow resulted in declines of the Floridan potentiometric surface on the order of 55 to 80 feet between September 1949 and May 1975 (Stewart and others, 1971; Mills and Laughlin, 1976). Since that period, there has been a general recovery of the potentiometric surface because of a net decrease in ground-water use by the phosphate industry. Recharge by connector wells has been a factor in this decrease in net usage of ground water. Reference to the Floridan potentiometric surface map for May 1980 (Yobbi and others, 1980) indicates potentiometric levels to be from about 10 to 25 feet higher than for May 1975 in the area south of Bartow.

In summation, interaquifer connector wells are an effective means of artificial recharge to the Floridan aquifer in the phosphate mining area of Polk and Hillsborough Counties. They function to short circuit the confining beds, particularly the clayey sections of the Tampa Limestone, and augment recharge to the lower unit of the Floridan aquifer. They thus are considered a factor in net decrease in ground-water use for the area, which in turn is reflected in recovery of the Floridan potentiometric surface from the lower levels of previous years. However, as is the case with Floridan drainage wells, some caution is suggested in regard to the water-quality aspects of this artificial recharge practice. Water samples from 12 of the 13 connector wells exceeded standards values of the National Drinking Water Regulations for the parameters of turbidity and total iron concentration. And, likely of more importance, 1 of the 13 wells is injecting a highly mineralized water; and 7 of the 13 are recharging waters that exceed the standards for gross alpha concentrations.

Suggestions for future investigations of interaquifer connector wells include water-quality sampling of a larger number of wells throughout the area in order to put the degree of representativeness of the present data base for 13 wells in better perspective. More detailed emphasis might also be given to the hydraulics and geochemistry (particularly radiochemistry) of the various zones of the lower Floridan unit to which injection waters may be introduced.

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