GEOHYDROLOGIC RECONNAISSANCE OF DRAINAGE WELLS IN FLORIDA

By Joel O. Kimrey and Larry D. Fayard

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WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
Suite 3015
227 North Bronough Street
Tallahassee, Florida 32301

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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.

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. These wells are generally effective as a method of urban drainage and lake level control. In areas so served, they emplace more recharge in the Floridan aquifer than it would receive under natural conditions. Continuing caution, however, is suggested in regard to the water-quality aspects of these wells because they often inject to the same aquifer zones from which public water supplies are withdrawn.

Biscayne aquifer drainage wells are used locally to dispose of stormwater runoff and other surplus water in southeast Florida. More than 5,000 drainage wells have been permitted in Dade County, and there are an estimated 2,000 in Broward County. The majority of these wells are used to dispose of water from swimming pools or to dispose of heated water from air-conditioning units. The remainder are used for disposal of urban runoff or of wastewaters from business and industry in the area. The use of Biscayne aquifer drainage wells may have minimal effect on aquifer potability so long as injection of runoff and industrial wastes is restricted to zones where chloride concentrations exceed 1,500 milligrams per liter.

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. Their use should have less effect on ground-water quality than that of surface-water injection wells.

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 the lead agency in the administration of 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.

Note that wells used to inject, or reinject, cooling water from air conditioners do not strictly meet the above definition of drainage wells. These air-conditioning return wells are included, however, in discussion of Biscayne aquifer drainage wells because of the large numbers of such wells in southeast Florida.

The general purpose and scope of this investigation was 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 ground-water pollution problems.

This report presents results of investigation, from October 1978 to April 1982, for Floridan aquifer drainage wells, Biscayne aquifer drainage wells, and interaquifer connector 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 county health or pollution control departments and to other agencies such as 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 for Floridan wells; 4-inch or greater for Biscayne wells) 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 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 1980 (Leach, 1983) indicate that ground water comprised about 51 percent (3,758 Mgal/d) of the total freshwater withdrawn for use in the State (7,309 Mgal/d). By freshwater use categories, ground water supplied about 87 percent (1,184 Mgal/d) of the total 1,361 Mgal/d withdrawn for public supply; 82 percent (643 Mgal/d) of the total 781 Mgal/d withdrawn for industrial self-supplied use; 53 percent (1,574 Mgal/d) of the total 2,997 Mgal/d withdrawn for irrigation; 94 percent (290 Mgal/d) of the 310 Mgal/d for rural domestic and livestock use; and 4 percent (66 Mgal/d) of the 1,859 Mgal/d of freshwater used for cooling water in the generation of thermoelectric power. Additionally, an average of about 98 Mgal/d of saline ground water was withdrawn for use during 1980.

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 87 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 1980) 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 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 instead of "shallow aquifers." Figure 1 shows the areas 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 of 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 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 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; modified 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 freshest, or least mineralized, ground water is in or adjacent to those interior areas where recharge occurs, and more mineralized water is toward the discharge areas.

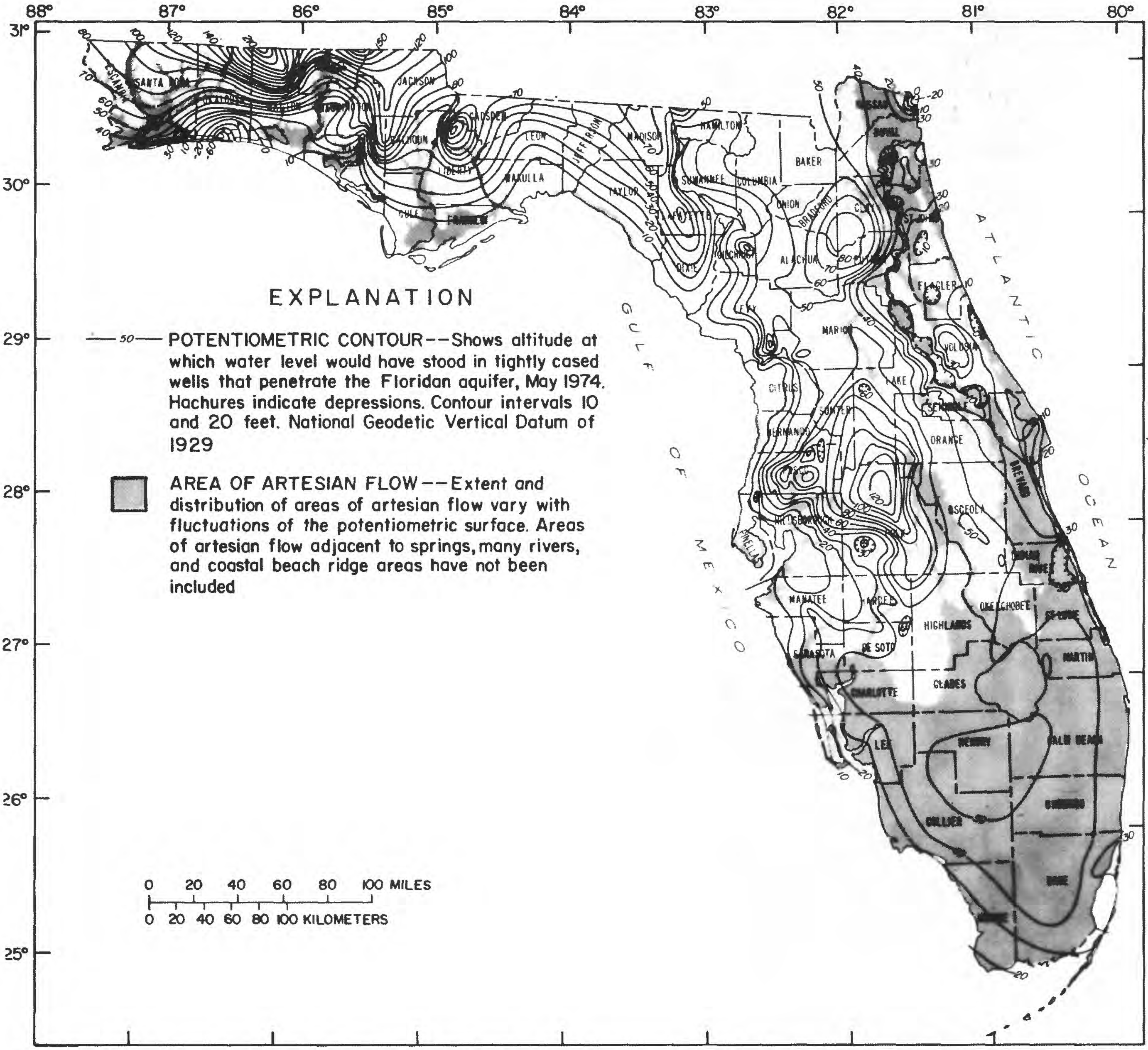

Figure 2.--Potentiometric surface and areas of artesian flow of the Floridan aquifer, May 1974. (Modified from Healy, 1975.)

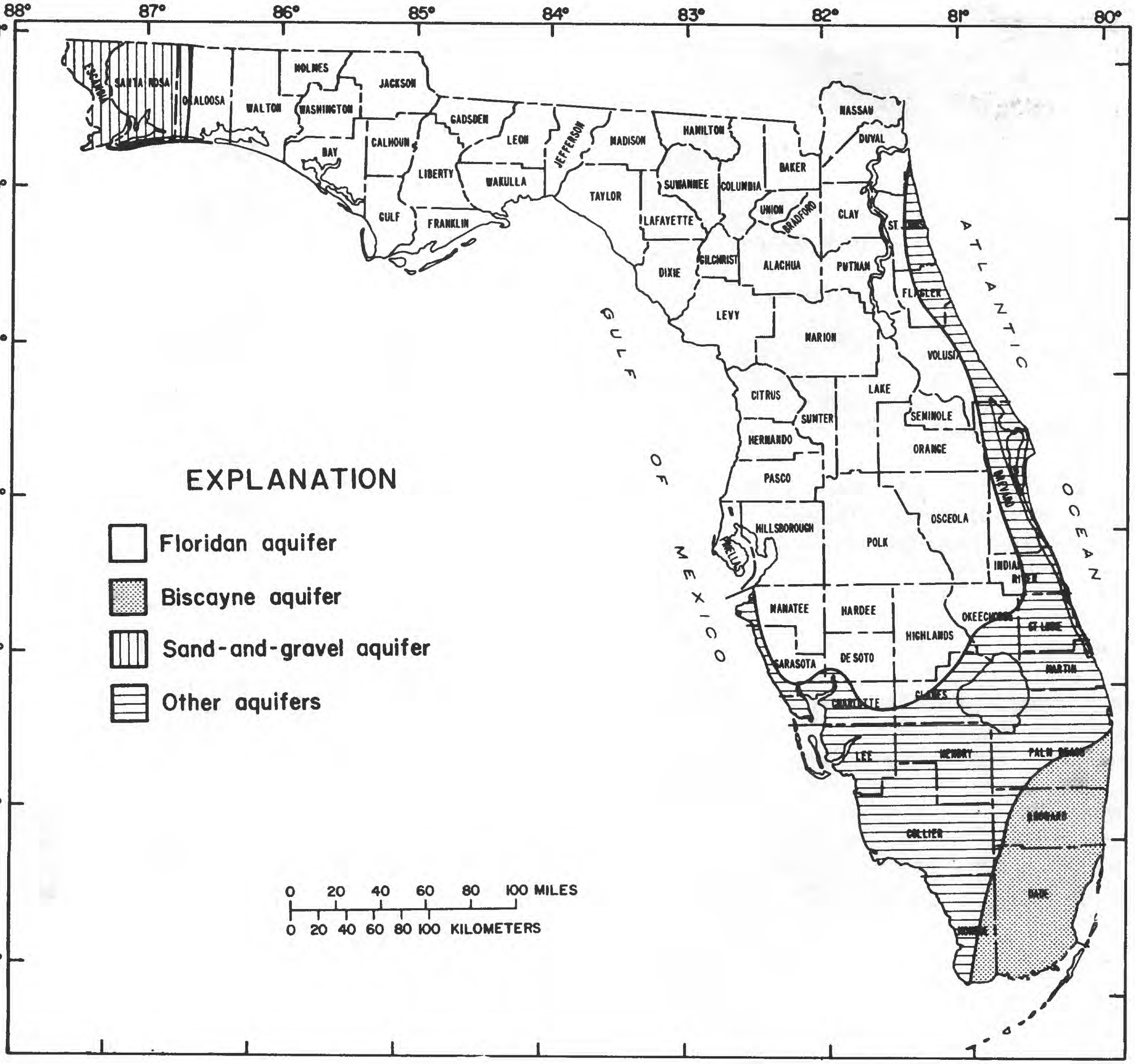

Figure 1.--Principal sources of potable ground water in Florida. (Modified from Hyde, 1965.)

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 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."

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). The aquifer is also vulnerable to contaminants that can enter 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). In Florida it ranges in thickness from an 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; along the Gulf Coast it is generally less than 250 feet thick (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 rainfall that infiltrates directly 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. The ground water 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 where the three major aquifers contain freshwater. They are used, by necessity, for public supplies in an elongate area that extends from the southwest Gulf Coast, easterly to the Atlantic Coast and thence northerly to southeast Duval County (fig. 1).

Their characteristics vary widely. 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, they range in thickness from about 20 to 150 feet.

The tops of the various water-bearing zones are generally near land surface and contain water under largely unconfined conditions. Recharge occurs directly from local rainfall and natural discharge is to nearby surface water, including the numerous canals in some areas, and by direct evapotranspiration. Water quality is generally low in chloride concentrations; soft to very hard; and commonly high in color and iron (Hyde, 1965). Yield of wells along the Atlantic Coast is generally less than 250 gal/min because these aquifers consist of fine sand, clay, shell, and occasional thin layers of dense limestone of relatively low permeability (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 are injected--that is, either Floridan aquifer drainage wells or Biscayne aquifer drainage wells. The general distribution of Biscayne and Floridan aquifer drainage wells and interaquifer connector wells, by county, is shown by figure 3. The locations of virtually all the Floridan aquifer drainage wells and interaquifer wells that are included in the totals in 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

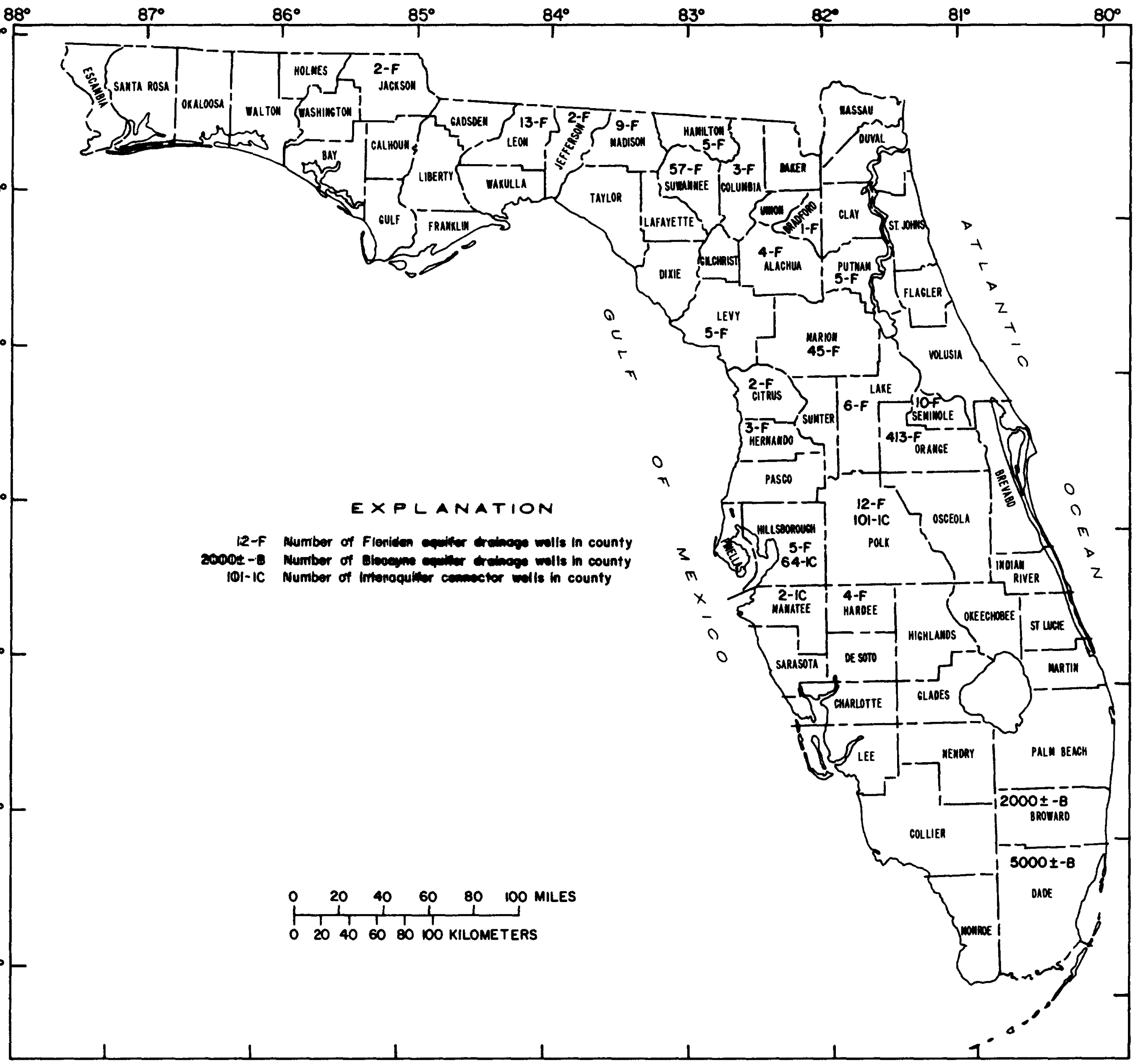

Figure 3.--General distribution of drainage wells and interaquifer connector wells.

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. Well construction is relatively simple (diagram of fig. 4-Ia): The overburden sediments are sealed off by casing which is usually seated in the first competent zone 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 quantities 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 areas 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 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

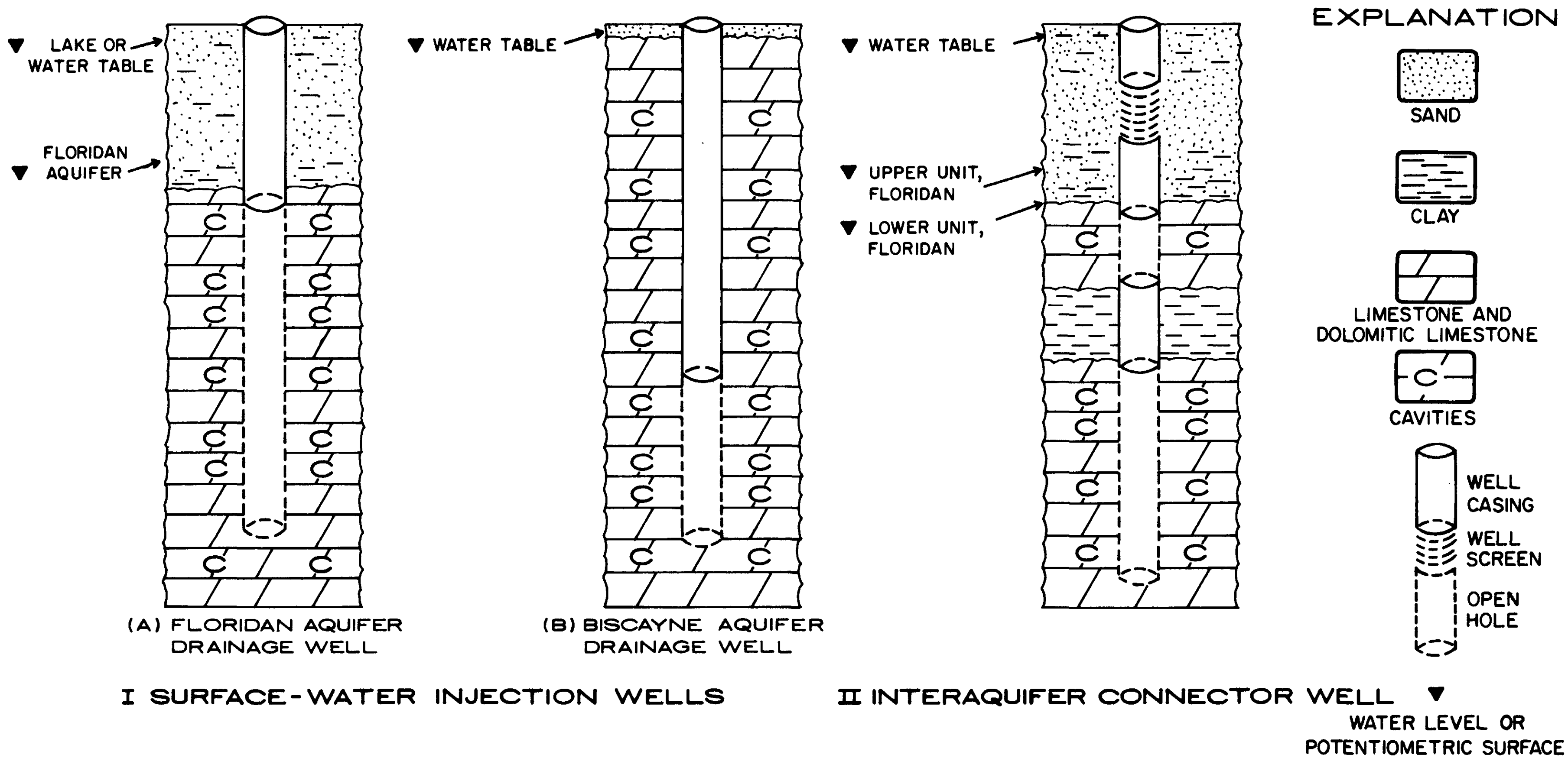

Figure 4.--The three general types of drainage wells.

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 highest 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 is believed to be generally typical of other areas where large use is made of Floridan aquifer drainage wells. That is, their original use 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 stormwater 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 Ocala and Live Oak (fig. 3). Records are available for 35 drainage wells, in or adjacent to 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 stormwater runoff for the urban area. The best available historical documentation of disposal of sanitary sewage to Floridan drainage wells is for the 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 groundwater 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 well 9, well 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 about 9 "sewage wells" and "drainage wells" were 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 for disposal of stormwater runoff only.

Records are presently available for 607 Floridan aquifer drainage wells throughout central and north-central Florida. Their distribution, by county, is shown in figure 3. Most permits for Floridan aquifer drainage wells were issued to the agency of local, county, or State government that has responsibilities for drainage in the particular area.

Biscayne Aquifer Drainage Wells

These wells are used locally to dispose of stormwater runoff and other wastewaters in southeast Florida; the heaviest concentrations are in coastal Dade and Broward Counties (fig. 3). There the Floridan aquifer is deeply buried, and is not used 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. Typical drainage-well construction in this unconfined and highly transmissive aquifer is shown in the diagram of figure 4-Ib, and is generally similar to that of Floridan aquifer drainage wells.

The use of wells for gravity disposal of surplus water to the Biscayne aquifer probably began in the 1920's or early 1930's. They were apparently a commonly used means of supplementary drainage and wastewater disposal by the time that State or local permitting of drainage wells began in 1937, and their use continued to increase along with the urbanization of coastal areas of southeast Florida. To date, a large, but undetermined number of drainage wells have been permitted in southeast Florida. Most permits for Biscayne aquifer drainage wells are held by individual property owners.

The most extensive records of permitting and construction of Biscayne aquifer drainage wells are available for Dade County. Here, for example, more than 5,000 permits were issued between 1937 and 1970; and, as best can be determined, the majority of the permitted wells were actually constructed. The vast majority of wells (more than 90 percent) in Dade County were permitted to dispose of water from swimming pools or of heated water from air-conditioning units. Most of these wells are less than 4 inches in diameter, and records indicate that they were permitted to inject to either freshwater or saline zones of the Biscayne. The remaining wells were permitted for injection of stormwater runoff or of wastewaters generated from business and industry in the area. These wells are usually 4 inches or larger in diameter, and records indicate that most were permitted to inject to zones where chloride concentrations of native aquifer water exceed 1,500 mg/L.

The Dade County permitting records indicate that drainage wells range in depth from less than 20 to more than 150 feet. The records also indicate that most wells are cased to within a few feet of their total depth, thus injection is into a relatively thin section of aquifer.

Permitting records, analagous to those for Dade County, are not available for Broward County. However, there may be as many as 2,000 Biscayne aquifer drainage wells in Broward County, based on a reconnaissance of the area during 1981.

Other than the permit records for Dade County, little or no preexisting data for Biscayne aquifer drainage wells were available during the present reconnaissance study. The generally referenced and comprehensive treatments of Biscayne aquifer hydrology make only casual mention of the existence and use of these wells (Parker and others, 1955, p. 277; Klein and Hull, 1978, p. 33, 47). A logical preliminary conclusion might thus be that the presence (or absence) of drainage wells does not significantly affect the areal regime of the Biscayne aquifer.

The estimated total numbers of Biscayne aquifer drainage wells for Dade and Broward Counties are shown in figure 3. Maps that show locations of individual wells are not included in this report because of the large total number of these drainage wells.

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 emplacing a well screen in the clastic materials of the overlying (losing) aquifer zone, seating 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 adequate yield from the screened zone, 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, Hutchinson and Wilson (1974, p. 3) state "A connector well is so named because it connects two aquifers that, under natural conditions, are hydraulically separated by a confining bed." 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 the potential to use 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."

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

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.

GEOHYDROLOGIC ASPECTS, FLORIDAN AQUIFER DRAINAGE WELLS

The largest 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 areas are discussed 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. 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 stormwater 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 included for the three areas.

The water samples from Floridan aquifer drainage wells were analyzed for the major ions and for most of those constituents 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 1 to 3 hours) prior to collection of samples. Water samples were collected and analyzed by the methods described in Goerlitz and Brown (1972), Fishman and Brown (1976), and Skougstad and others (1979).

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 designated by Stewart (1980) as areas of high recharge to the Floridan aquifer. Average rainfall is 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 attributed 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 groundwater 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 logical that parts of the basins are contributing less than the average recharge, and that other parts are contributing more than 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 evapotranspiration. In addition, drainage wells are used primarily where paving has reduced direct infiltration of rainfall and made more water available as stormwater runoff which, if rapidly conveyed to drainage wells, will tend further to reduce evapotranspiration 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 determined from available data.

Ocala Area

Ocala is a city of 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, the contact being at an altitude of about 100 feet (Faulkner, 1973). Virtually all drainage from the area is internal, by means of the unconfined and highly transmissive Ocala Limestone of the Floridan aquifer.

Most of the 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 sulfate 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 concentrations 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 interval 850 to 1,083 feet. Sulfate concentration in Silver Springs discharge water averages about 40 mg/L, so calculations indicate that most of this discharge is from the upper 200 feet of the aquifer.

Locations of 35 drainage wells in, or adjacent to, the city area are shown in figure 5. All of these well locations were verified by field inventory 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 records indicate that total depths for most of the wells are less than 200 feet. Thus, the bulk of stormwater runoff 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 supply for 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 city boundary of the area delineated 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 stormwater runoff also was collected for analysis. Two of the wells (21 and 24) were receiving injection water at time of sampling; the sample of stormwater runoff was collected 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 stormwater 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

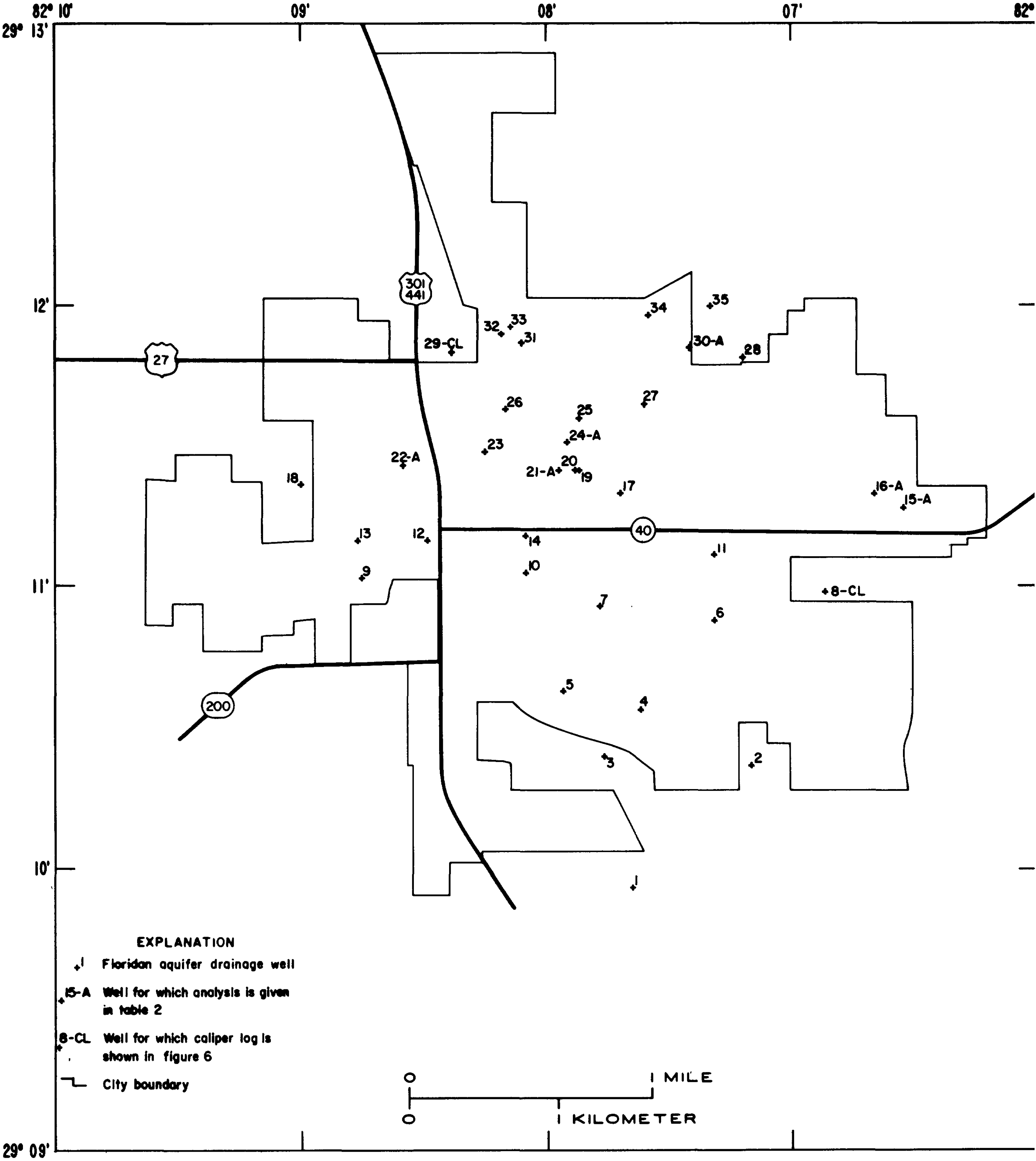

Figure 5.--Locations of Floridan aquifer drainage wells, Ocala area.

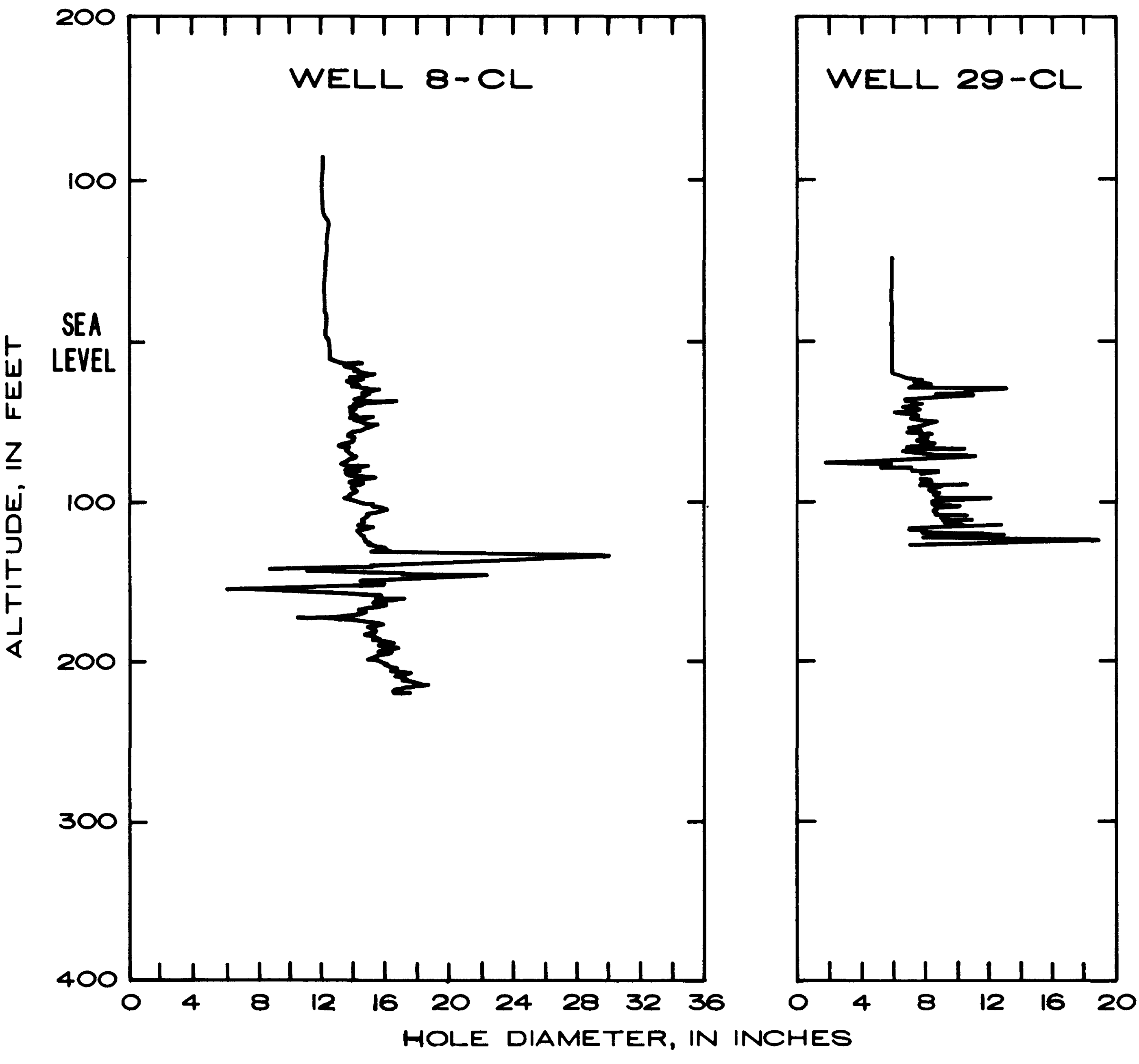

Figure 6.--Caliper logs, Ocala area.

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	TEMPER-ATURE (DEG C)	SPE-CIFIC CON-DUCT-ANCE (UMHOS)	TUR-BID-ITY (NTU)
	DRAINAGE WELLS						
291117082063301	DRAINAGE WELL NO 23 OCALA, FLA	15	80-07-24	1120	27.5	203	4.0
291120082064001	DRAINAGE WELL NO 27 OCALA, FLA	16	80-07-28	1155	25.5	330	3.0
291125082075701	DRAINAGE WELL NO 31 OCALA, FLA	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, FLA	24	80-07-29	1600	28.5	330	11
291151082072501	DRAINAGE WELL NO 16 OCALA, FLA	30	80-07-23	1800	23.5	452	3.0
291125082075702	STORM RUNOFF INTO POND AT OCALA DW NO 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 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)	NITRO-GEN, NITRATE TOTAL (MG/L AS N)	NITRO-GEN,AM-MONIA + ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, NO2+NO3 TOTAL (MG/L AS N)	NITRO-GEN, 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	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)	SODIUM AD-SORP-TION 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	8	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	36	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	

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

flow, and it often carries relatively large amounts of debris and fine sediment. 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 per 100 mL of sample. In general, stormwater 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 native ground water. The analysis of the sample of stormwater 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 stormwater runoff sample was estimated as 5,000 colonies per 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 25 to 35 feet thick in the area (J. A. Miller, U.S. Geological Survey, 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 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 west and southwest toward discharge areas along the Suwannee River.

The locations of 46 drainage wells that are in, or adjacent to, Live Oak are shown in figure 7. All of these well locations were verified by field inventory during the present investigation. Most wells 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 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.

Public water supply for Live Oak was originally obtained from wells in the urban area of highest drainage-well concentration (fig. 7). These sources became polluted by disposal of both stormwater and sanitary sewage

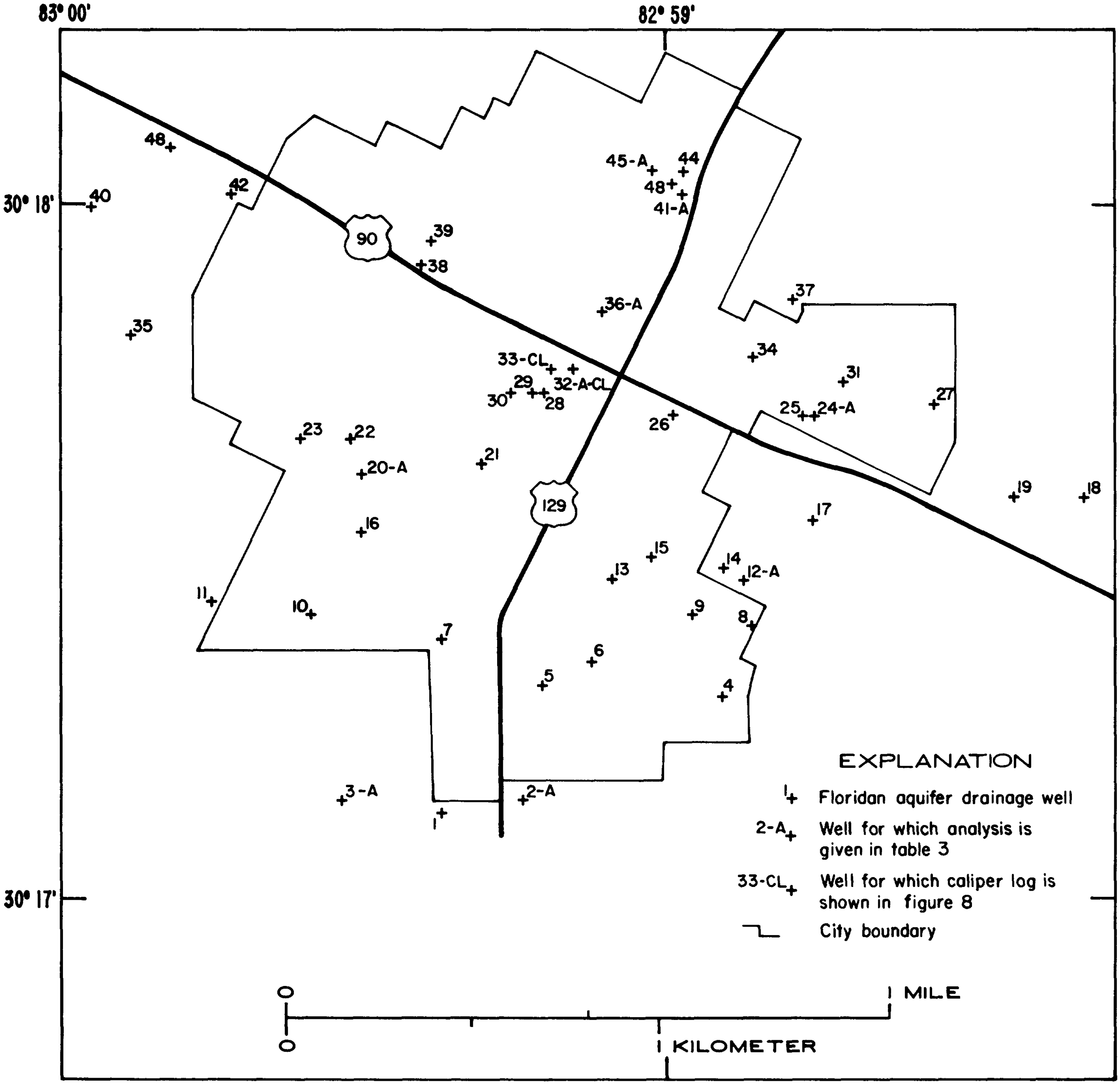

Figure 7.--Locations of Floridan aquifer drainage wells, Live Oak area.

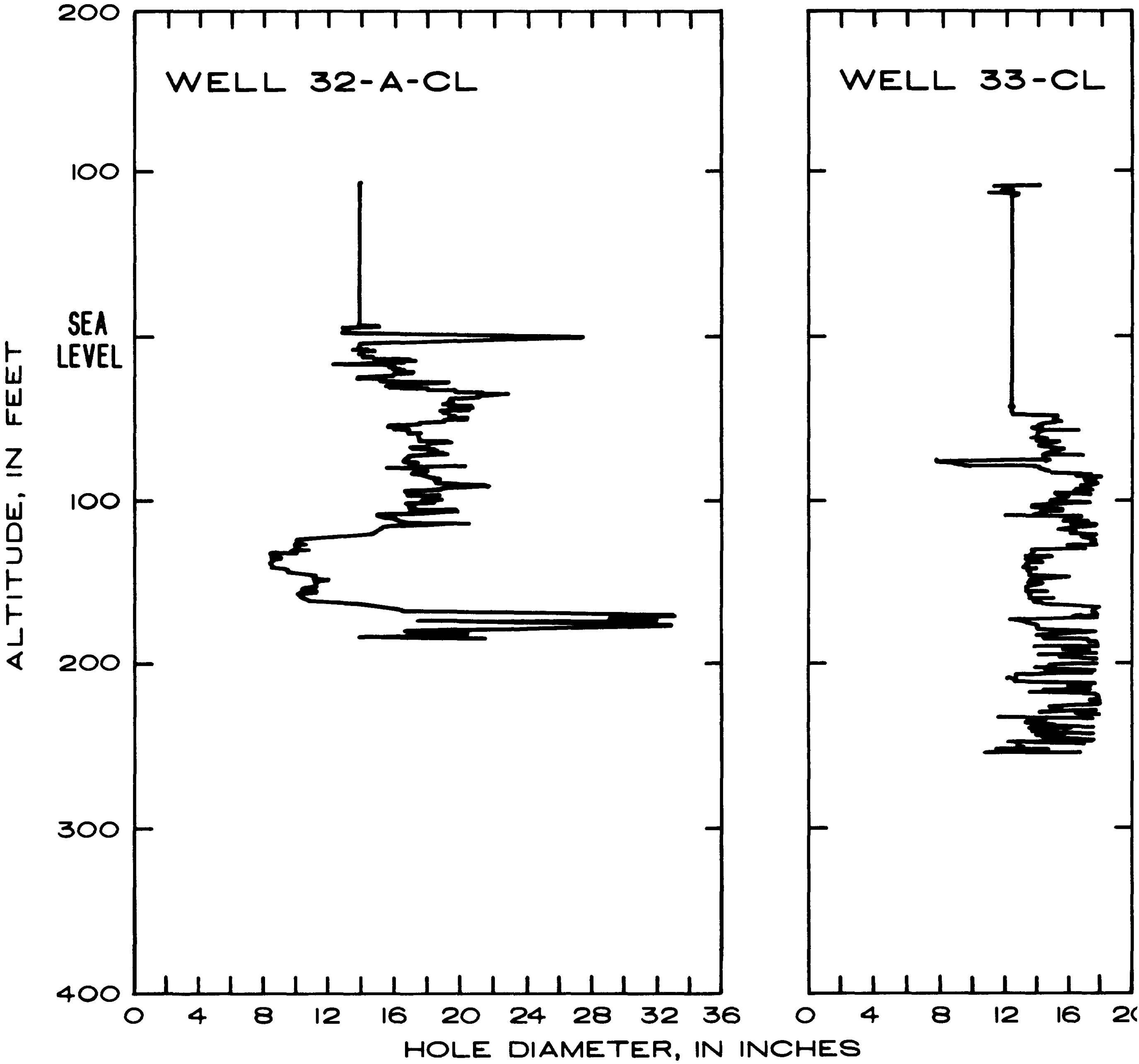

Figure 8.--Caliper logs, Live Oak area.

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 per 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 cited 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 Orlando area, as used herein, refers to an area of about 400 square miles (most in Orange County) that contains a high density of drainage wells (fig. 9).

Land surface altitudes in this area range from about 75 to 125 feet. Much of the interior part of the area is a karst terrane 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 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 contain freshwater in the Orlando area and are separated several hundred feet of less permeable limestone and dolomitic

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-COBALT UNITS)	SPE-CIFIC CON-DUCT-ANCE (UMHOS)
	DRAINAGE WELLS						
301709082591401	01725904 CITY LIVE OAK DRAINAGE WELL NO 16	2	80-07-10	25.0	--	30	285
301709082593201	01725920 CITY LIVE OAK DRAINAGE WELL NO 37	3	80-07-08	22.5	800	0	315
301724082585101	01725808 CITY LIVE OAK DRAINAGE WELL NO 12	12	80-07-10	23.0	--	20	240
301735082582501	01725811 CITY LIVE OAK DRAINAGE WELL NO 35	20	80-07-08	23.0	4.0	0	270
301746082590901	01725922 CITY LIVE OAK DRAINAGE WELL NO 40	32	80-07-09	23.0	--	30	300
301747082585102	01725803 CITY LIVE OAK DRAINAGE WELL NO 6	24	80-07-10	23.5	--	0	395
301751082590601	01725919 CITY LIVE OAK DRAINAGE WELL NO 36	36	80-07-09	23.0	210	0	380
301801082585807	01825802 CITY LIVE OAK DRAINAGE WELL NO 3	41	80-07-09	23.0	--	5	310
301803082590101	01825901 CITY LIVE OAK DRAINAGE WELL NO 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)	NITRO-GEN, NITRATE TOTAL (MG/L AS N)	NITRO-GEN,AM-MONIA + ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, NO2+NO3 TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS N)
80-07-10	6.6	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

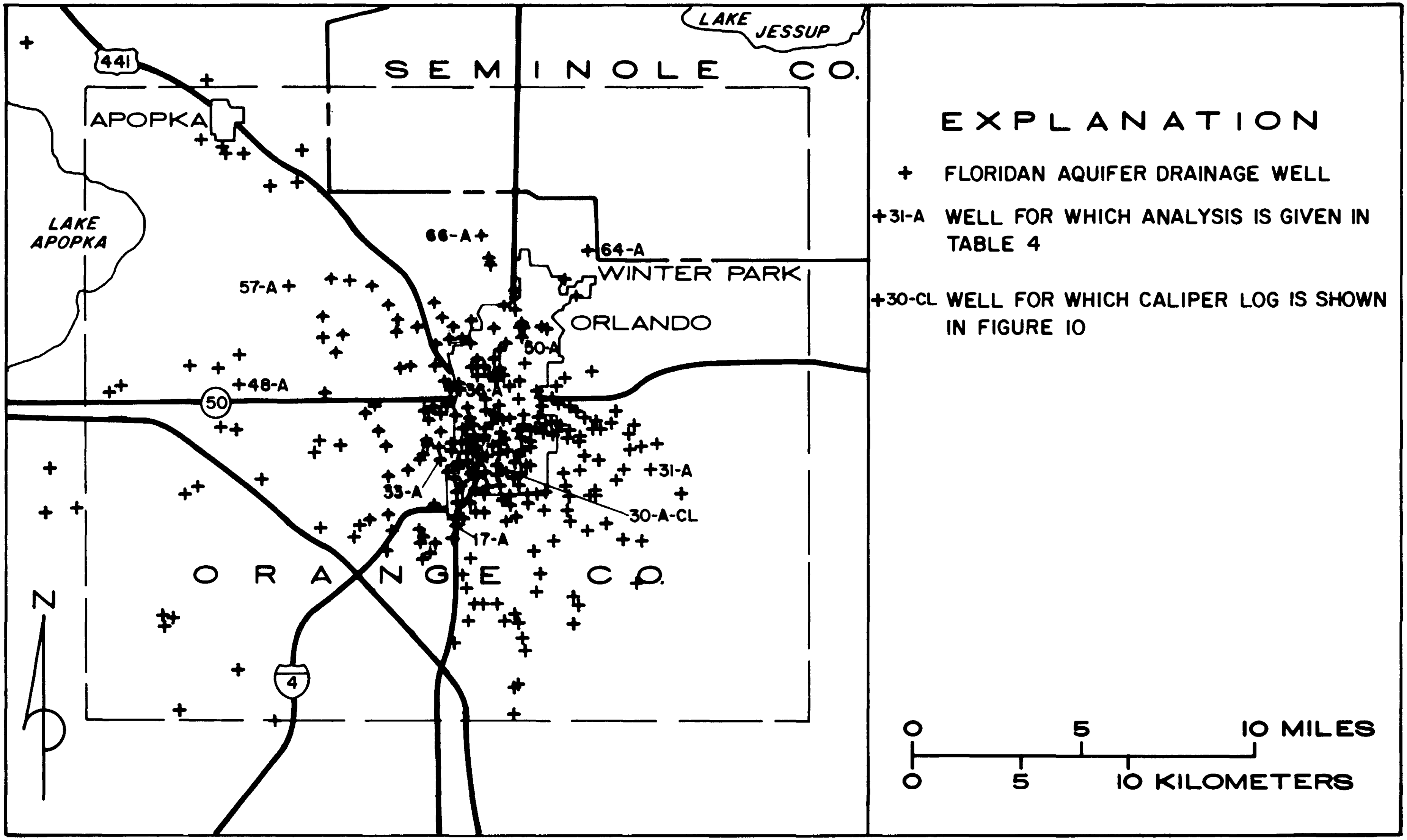

Figure 9.--Locations of Floridan aquifer drainage wells, Orlando, area.

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, U.S. Geological Survey, 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. Wells range in depth from about 120 to 1,050 feet; median depth is about 400 feet. With possible exception of the deepest 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 producing zones are used for public water supply in the Orlando area. Average withdrawals for 1980 in the area are estimated at 85 Mgal/d, about 65 percent of this total being withdrawn from the lower producing zone, and 35 percent from the upper producing, or drainage-well zone (Schiner and German, 1982). 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 the 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 public-supply 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.

Table 4 contains water-quality data for selected drainage wells, and for public-supply wells open to the upper and lower producing zones. The drainage wells were sampled in April 1978, near the end of the dry season and thus had received little or no injection water over the immediately

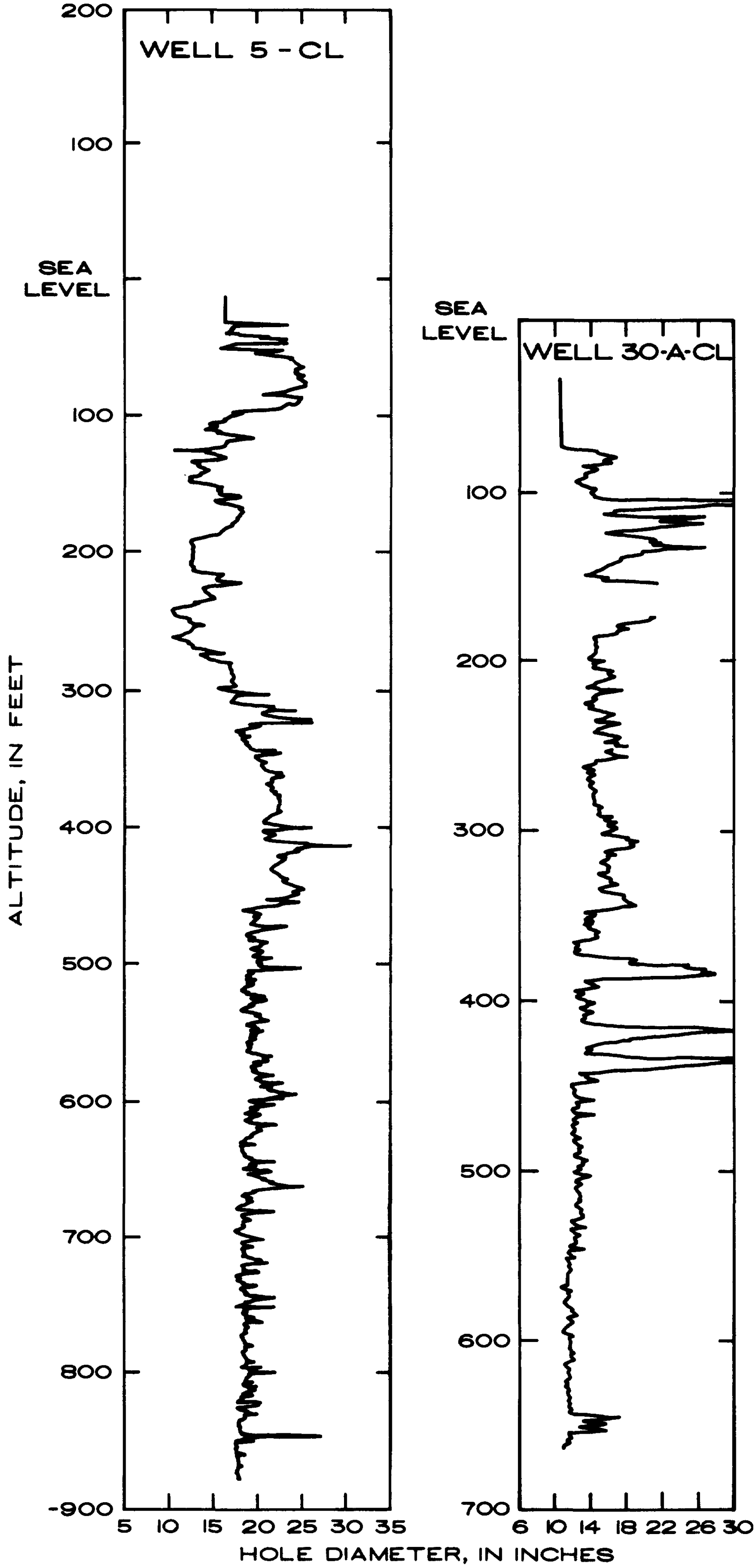

Figure 10.--Caliper logs, Orlando area.

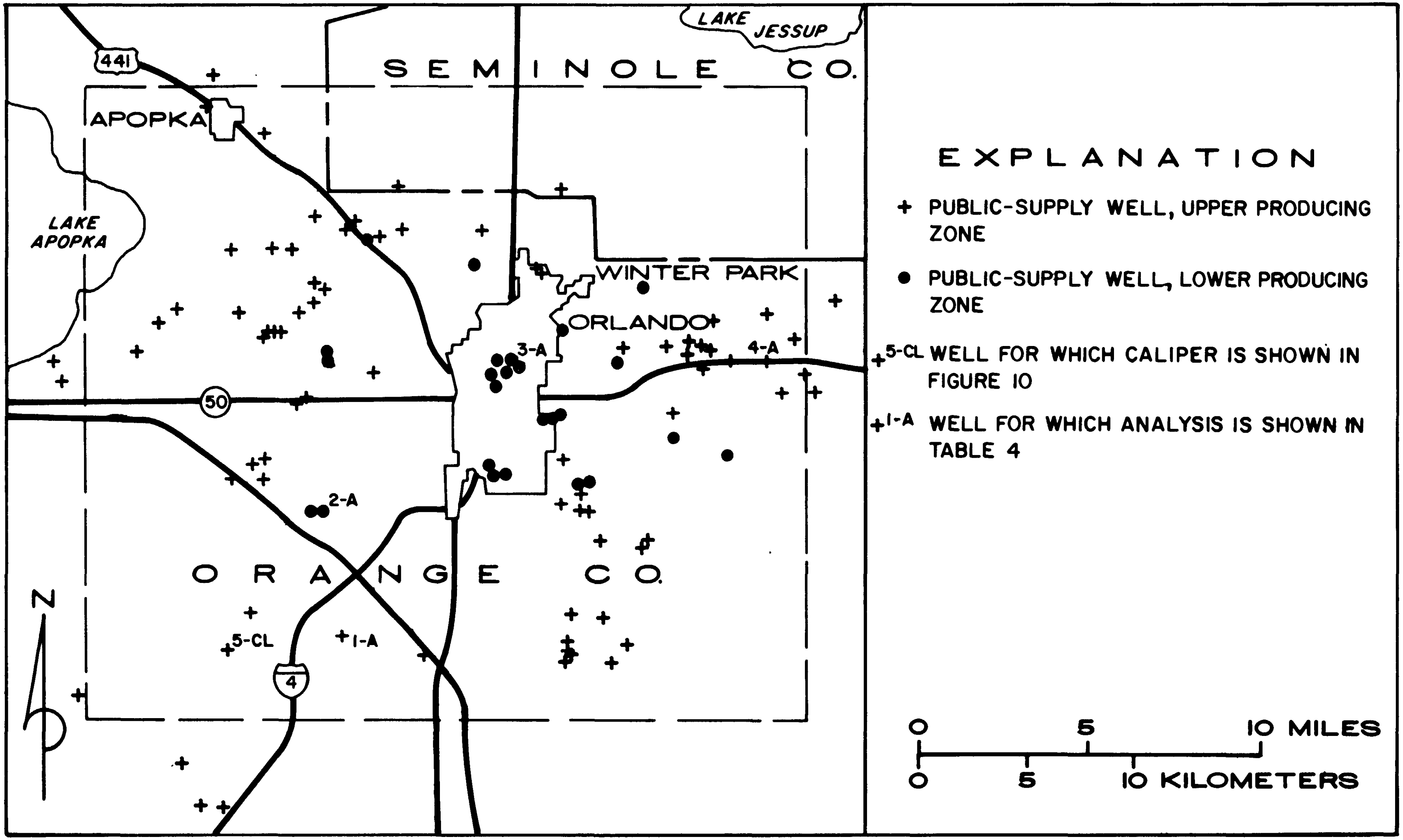

Figure 11.--Locations of public-supply wells, Orlando area.

Table 4.--Analyses of water from Floridan aquifer drainage and public-supply wells, Orlando area

STATION NUMBER	STATION NAME	SITE NUMBER	DATE OF SAMPLE	SPECIFIC CONDUCTANCE (UMHOS)	PH (UNITS)	COLOR (PLATINUM-COBALT UNITS)	TURBIDITY (NTU)
	DRAINAGE WELLS (FIGURE 9)						
283002081234701	83012307 HOWARD JOHNSONS DRAINAGE WELL	17	78-04-19	242	7.5	5	5.0
283154081220701	83112204 LAKE DAVIS DRAINAGE WELL	30	78-04-17	321	6.8	10	2.0
283157081180401	83111802 ENGLEWOOD S/D DRAINAGE WELL	31	78-04-18	241	7.0	10	2.0
283211081241001	83212402 ORLANDO CITY YARD DRAINAGE WELL	33	78-04-27	328	7.0	20	1.0
283321081231801	83312311 LAKE CONCORD DRAINAGE WELL	36	78-04-10	313	7.7	10	5.0
283416081295901	83412901 LAKE FLORENCE DRAINAGE WELL	48	78-04-13	311	7.3	5	5.0
283530081214301	83512107 LAKE MIDGET DRAINAGE WELL 2-7627	50	78-04-26	290	7.0	10	3.0
283655081283401	83612801 LONG LAKE DRAINAGE WELL	57	78-04-12	266	7.5	10	16
283717081194202	83711904 LAKEMONT AVE DRAINAGE WELL	64	78-04-25	345	7.4	5	1.0
283735081224001	83712201 LAKE SYBELIA DRAINAGE 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, FLA	1	77-09-06	230	7.7	0	--
283350081154301	EAST DALE ACRES P S, ORANGE CO, FLA	4	77-09-03	278	7.2	0	--
283006081273701	ORLANDO UTILITIES, KIRKMAN RD AT ORL, FLA	2	77-09-02	260	7.8	0	--
283353081222401	ORLANDO UTILITIES NO 2 LK IVANHOE AT ORL, FLA	3	77-09-02	258	7.7	0	--

DATE OF SAMPLE	OXYGEN DEMAND, CHEMICAL (HIGH LEVEL) (MG/L)	OXYGEN DEMAND, BIOCHEMICAL, 5 DAY (MG/L)	COLIFORM, TOTAL, IMMED. (COLS. PER 100 ML)	COLIFORM, FECAL, 0.7 UM-MF (COLS./ 100 ML)	HARDNESS (MG/L AS CACO3)	HARDNESS, NONCARBONATE (MG/L CACO3)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	SODIUM, DISSOLVED (MG/L AS NA)	POTASSIUM, DISSOLVED (MG/L AS K)	CHLORIDE, DISSOLVED (MG/L AS CL)	SULFATE DISSOLVED (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 DISSOLVED (MG/L)	SOLIDS, SUM OF CONSTITUENTS, DISSOLVED (MG/L)	ALKALINITY FIELD (MG/L AS CACO3)	FLUORIDE, DISSOLVED (MG/L AS F)	SILICA, DISSOLVED (MG/L AS SIO2)	NITROGEN, NITRATE TOTAL (MG/L AS N)	NITROGEN, NITRITE TOTAL (MG/L AS N)	NITROGEN, AMMONIA TOTAL (MG/L AS N)	NITROGEN, ORGANIC TOTAL (MG/L AS N)	NITROGEN, TOTAL (MG/L AS N)	PHOSPHORUS, TOTAL (MG/L AS P)	ALUMINUM, TOTAL RECOVERABLE (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, DISSOLVED (UG/L AS AL)	ARSENIC TOTAL (UG/L AS AS)	ARSENIC DISSOLVED (UG/L AS AS)	BARIUM, TOTAL RECOVERABLE (UG/L AS BA)	BARIUM, DISSOLVED (UG/L AS BA)	CADMIUM TOTAL RECOVERABLE (UG/L AS CD)	CADMIUM DISSOLVED (UG/L AS CD)	CHROMIUM, TOTAL RECOVERABLE (UG/L AS CR)	CHROMIUM, DISSOLVED (UG/L AS CR)	COBALT, TOTAL RECOVERABLE (UG/L AS CO)	COBALT, DISSOLVED (UG/L AS CO)	COPPER, TOTAL RECOVERABLE (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, DISSOLVED (UG/L AS CU)	IRON, TOTAL RECOVERABLE (UG/L AS FE)	IRON, DISSOLVED (UG/L AS FE)	LEAD, TOTAL RECOVERABLE (UG/L AS PB)	LEAD, DISSOLVED (UG/L AS PB)	MANGANESE, TOTAL RECOVERABLE (UG/L AS MN)	MANGANESE, DISSOLVED (UG/L AS MN)	MERCURY TOTAL RECOVERABLE (UG/L AS HG)	MERCURY DISSOLVED (UG/L AS HG)	NICKEL, TOTAL RECOVERABLE (UG/L AS NI)	SELENIUM, TOTAL (UG/L AS SE)	SELENIUM, DISSOLVED (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, DISSOLVED (UG/L AS SR)	ZINC, TOTAL RECOVERABLE (UG/L AS ZN)	ZINC, DISSOLVED (UG/L AS ZN)	CARBON, ORGANIC TOTAL (MG/L AS C)	METHYLENE BLUE ACTIVE SUBSTANCE (MG/L)	OIL AND GREASE (MG/L)	PCB, TOTAL (UG/L)	NAPHTHALENES, POLYCHLOR. TOTAL (UG/L)	ALDRIN, TOTAL (UG/L)	CHLORDANE, TOTAL (UG/L)	DDD, TOTAL (UG/L)	DDE, 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

preceding several months since the end of the 1977 rainy season; and some wells had probably not received injection water over the several preceding years. 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 (tables 2, 3).

Data on quality of stormwater runoff to lakes or drainage wells were not collected during the present study for the Orlando area. Such data, from German (1982) and Schiner and German (1982) show that stormwater runoff generally contains higher concentrations of most nutrients and metals than water from drainage wells (E. R. German, U.S. Geological Survey, oral commun., 1983).

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 in samples from the 10 wells ranged from 0 to 5,600 colonies per mL of sample; fecal coliform bacteria ranged from 0 to 940 colonies per mL of sample.

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

Analytical data for the four public-supply wells indicate similar water quality. But samples from the two lower zone supply wells and the downgradient upper zone supply well are slightly more mineralized than that from the upgradient public-supply well in the upper zone.

Samples from the 4 public-supply wells were similar to samples from the drainage wells 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 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 the rate of withdrawals in the area exceeded about 50 Mgal/d, suggesting that this was the average rate of recharge. A more recent statistical analysis (C. H. Tibbals, U.S. Geological Survey, written commun., 1983) suggests that drainage-well recharge is, on the average, about 30 to 35 Mgal/d in the Orlando area. About 35 to 40 square miles of the area are almost totally drained by drainage wells. The surrounding area is only 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, and additional records are available and locations have been verified for 134 wells in other areas throughout central and north-central Florida (see fig. 3). The use of these 134 Floridan aquifer drainage wells in other areas is similar to that of the wells in the Ocala, Live Oak, and Orlando areas--to provide, or supplement, surface drainage and control lake levels in urban or suburban areas. However, these other wells tend to be more widely dispersed than are the wells in the three major areas of drainage-well use.

Water samples were also obtained from two wells in Hamilton County, three in Leon County, one in Madison County, and two in Putnam County. Comparison of the analytical data from these 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.

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.

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	TEMPER-ATURE (DEG C)	TUR-BID-ITY (NTU)	COLOR (PLAT-INUM-COBALT UNITS)
302911083003601	I-10 DRAIN WELL NR JASPER, FLA	HAMILTON	80-08-14	20.0	390	15
302929082593601	SR-249 DRAIN WELL NR JASPER, FLA	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, FLA	PUTNAM	80-07-31	23.0	1.0	5

DATE OF SAMPLE	SPE-CIFIC CON-DUCT-ANCE (UMHOS)	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)	NITRO-GEN, NITRATE TOTAL (MG/L AS N)	NITRO-GEN,AM-MONIA + ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, 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	NITRO-GEN, TOTAL (MG/L AS N)	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)
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, DIS-SOLVED (MG/L AS NA)	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)	BARIUM, TOTAL RECOV-ERABLE (UG/L AS BA)	CADMIUM TOTAL RECOV-ERABLE (UG/L AS CD)	CHRO-MIUM, TOTAL RECOV-ERABLE (UG/L AS CR)
80-08-14	1.4	.1	2	1.6	3.0	3.6	.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	6.0	--	--	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	2.0	.1	3	.8	2.8	4.8	.1	5.4	--	--	0	--
80-07-31	3.3	.2	8	.3	5.2	.6	.1	6.0	--	--	0	--
80-07-31	4.5	.2	11	.5	6.4	3.9	.2	7.0	--	--	0	--

DATE OF SAMPLE	IRON, TOTAL RECOV-ERABLE (UG/L AS FE)	LEAD, TOTAL RECOV-ERABLE (UG/L AS PB)	MANGA-NESE, TOTAL RECOV-ERABLE (UG/L AS MN)	SILVER, TOTAL RECOV-ERABLE (UG/L AS AG)	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)	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	--	--	--	--	--

Conclusions

The present (1981) use of Floridan aquifer drainage wells is almost entirely for disposal of stormwater 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 is a highly efficient means of artificial recharge to the Floridan aquifer, from a quantitative standpoint. In the Orlando area, for example, their use appears to have offset the effects of withdrawals of 30 to 50 Mgal/d for public supply. Because they retard the lowering of water levels their use may be considered as an additional safeguard against vertical saltwater encroachment. Their use in disposal of stormwater runoff and regulation of lake levels is the most economic means of handling these problems.

The negative aspects of Floridan aquifer 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 predominantly stormwater 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 in the ground-water 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 are 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 constituents 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, BISCAYNE AQUIFER DRAINAGE WELLS

Biscayne aquifer drainage wells are concentrated in the urbanized coastal areas of Dade and Broward Counties. The primary drainage for these topographically low areas is by canals, but use of relatively shallow wells for local onsite disposal of surplus water is common as evidenced by their large numbers.

The initial fieldwork in southeast Florida for this investigation was a reconnaissance inventory in Dade County to verify and update existing data on location and use of drainage wells. This reconnaissance had to be selective because the source of existing data was permit records for some 5,000 wells. However, the reconnaissance appeared to validate that (1) most permitted wells were actually constructed, and (2) the majority are less than 4 inches in diameter and are used to dispose of water from swimming pools or heated water from air-conditioning units. Difficulty was noted, during inventory, in verifying the locations of many wells, particularly the older ones. Most permits for Biscayne aquifer drainage wells were issued to individual property owners. Land use has changed over time, and many drainage wells have been destroyed or simply lost.

The next phase of fieldwork in southeast Florida was a reconnaissance inventory in Broward County to collect new data on location and use of drainage wells. Geohydrologic and land-use conditions in Broward County appear to be quite similar to those for Dade County, but drainage-well permit records analogous to those for Dade were not available. New data collected for about 200 drainage wells in a reconnaissance of Broward County during mid-1981 indicate that the distribution and use of drainage wells there is similar to that for Dade County. Most are in the densely populated coastal areas, are relatively small in diameter, and used for drainage of swimming pools and return of cooling water. It is estimated that there may be as many as 2,000 or more Biscayne aquifer drainage wells in Broward County (fig. 3).

Thirteen of these Biscayne aquifer drainage wells in Broward County were then selected for geophysical logging and collection of water samples for chemical analyses. Locations are shown in figure 12. The main criterion in selecting these wells is that they all drain street runoff or other wastewaters generated in urban areas; they were also selected for geographic coverage over east Broward. All of these wells are 4 inches or greater in diameter and range in depth from about 45 to 205 feet. Caliper logs from two of the deeper wells are shown in figure 13. These logs indicate that most of the borehole is cased so that gravity injection is to a relatively thin section of aquifer at the bottom of the well. This feature of Biscayne aquifer drainage-well construction appears typical.

Water samples and geophysical data were collected from these 13 wells during November 1981. Caliper logs were made of the borehole prior to sampling. Then each well was sampled by use of a centrifugal pump, which discharged about 50 gal/min for 1-1½ hours. By this time specific conductance and drawdown had reached equilibrium, and the water samples were collected for chemical analyses.

A purpose for sampling these randomly selected wells that receive street drainage was to determine whether or not they injected to zones that contain brackish water. If not, the analytical data should give some indication of their use on potability of water in the Biscayne. Analytical data for water samples from the 13 wells are shown in table 6. These data indicate that all wells were injecting to nonpotable zones; that is, chloride concentrations range from about 1,400 to 16,000 mg/L and dissolved solids concentrations from about 2,900 to 29,000 mg/L. The effects of injection on formation water quality may be discernible in table 6 for some of the values for color, turbidity, coliform bacteria, nutrients, and trace metals.

Data on total quantities of water injected to Biscayne aquifer drainage wells are not available, and would be difficult to collect because of the large number of wells and the nature of their use. The large majority of Biscayne drainage wells are permitted to drain swimming pools and dispose of cooling water from air-conditioning units. Most water injected by these wells was previously withdrawn from the Biscayne, so its return to the aquifer aquifer does not represent a net change in quantity of ground water. Injection from these sources is freshwater and thus should have minimal potential to decrease the quality of water in the injection zone. The use of Biscayne drainage wells which appears more likely to affect the geohydrologic regime is that of injection of stormwater or wastewaters from urban areas. From a volume standpoint, practically all water injected to these wells is probably stormwater or street runoff.

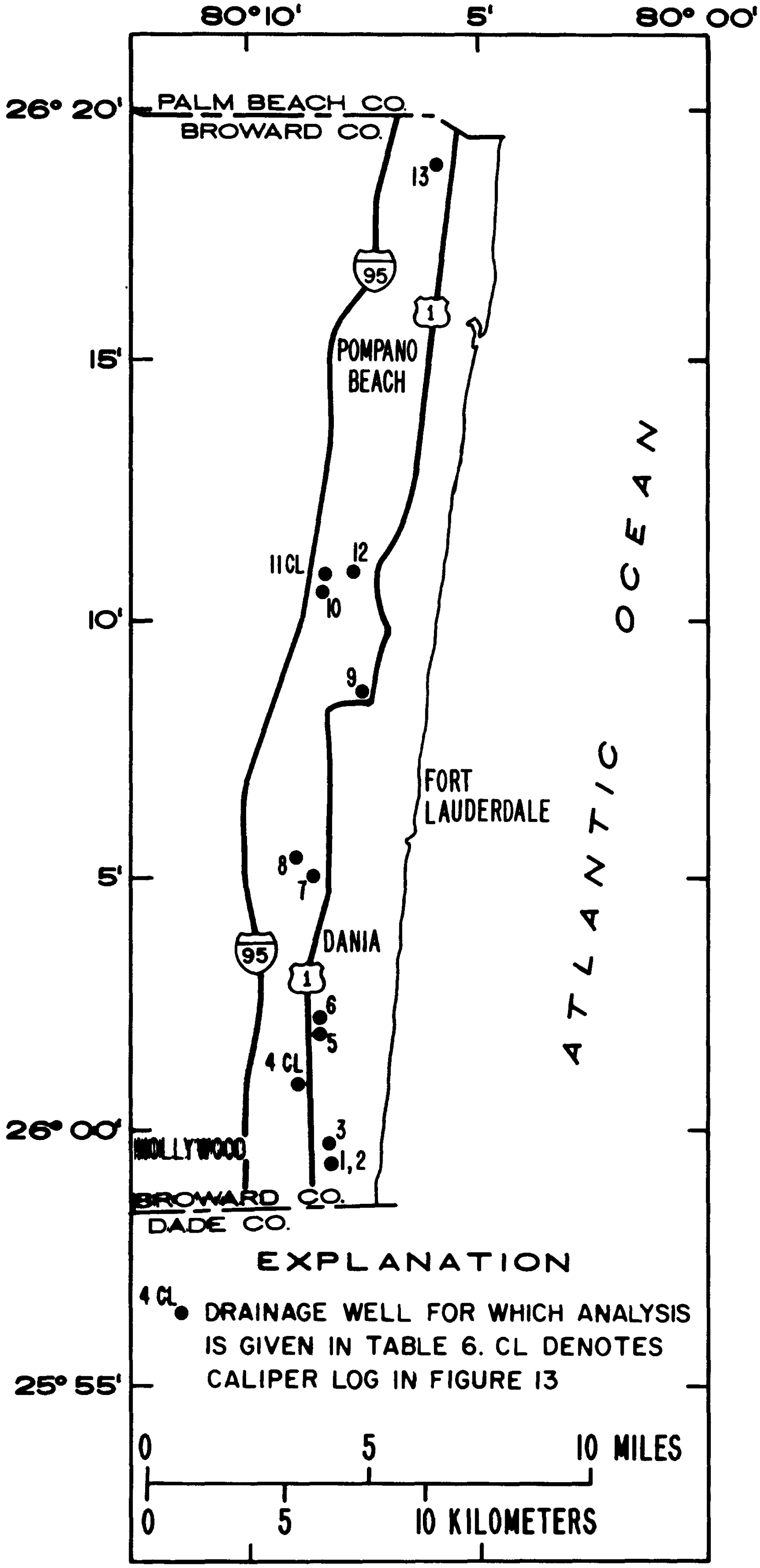

Figure 12.--Locations of ground-water sampling sites, Biscayne aquifer, Broward County.

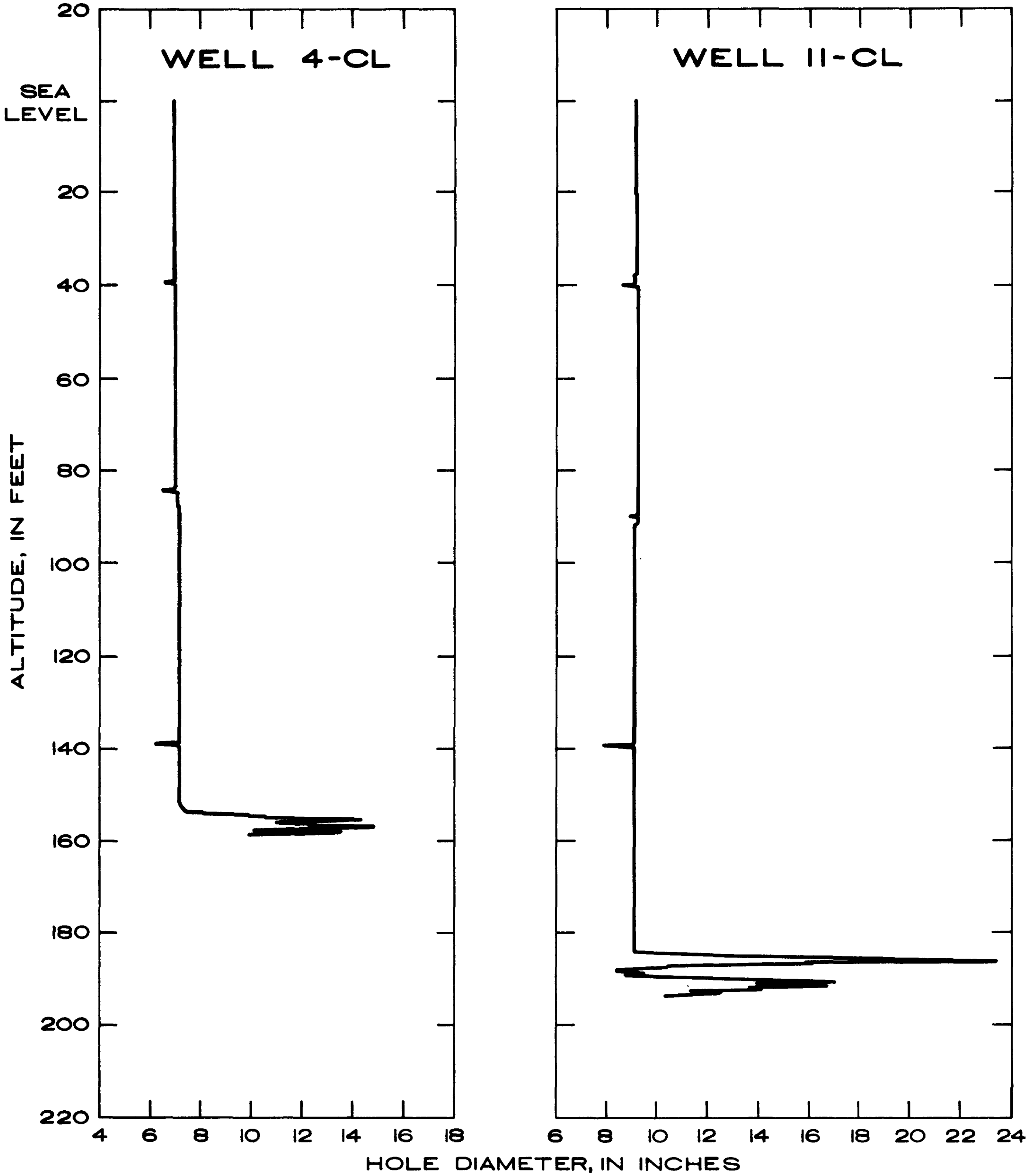

Figure 13.--Caliper logs, Broward County.

Table 6.--Analyses of water from Biscayne aquifer drainage wells, Broward County

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)
255908080081301	HALLANDALE-PUMPERNIKS S DRAINAGE WELL	1	81-11-16	6600	6.9	25	40
255909080081101	HALLANDALE PUMPERNIKS E DRAINAGE WELL	2	81-11-16	5900	6.8	35	--
255946080080801	HALLANDALE 1300 MOFFET AVE DRAINAGE WELL	3	81-11-15	40000	7.4	30	35
260048080084101	HOLLYWOOD POST OFFICE NORTH DRAINAGE WELL	4	81-11-12	24500	6.8	40	--
260226080081301	DANIA DRAINAGE WELL-SE 7 ST AND SE 4 AVE	5	81-11-15	31500	6.8	120	200
260239080081501	DANIA DRAINAGE WELL-SE 4 ST AND SE 5 AVE	6	81-11-15	32500	6.9	120	120
260500080082101	FT LAUDER-COOKIN GOOD DRAINAGE WELL	7	81-11-12	30200	7.0	50	--
260533080084801	FT LAUDER-AMOCO STA SR 84 DRAINAGE WELL	8	81-11-12	27800	6.9	30	--
260835080071401	FT LAUDER POWELL FORD DRAINAGE WELL	9	81-11-11	4250	7.6	20	--
261035080082501	OAKLAND PARK DRAINAGE WELL 6 AT OAKLAND PARK	10	81-11-13	26500	7.3	20	65
261041080081701	OAKLAND PARK DRAINWELL 1 AT OAKLAND PARK	11	81-11-15	10000	7.1	20	25
261046080075701	OAKLAND PARK DRAINWELL 4 NR OAKLAND PARK	12	81-11-13	12300	7.3	30	45
261350080061301	POMPANO BEACH AMOCO CAR WASH DRAINAGE	13	81-11-17	9500	7.8	30	30

DATE OF SAMPLE	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)	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)
81-11-16	K0	1400	1100	440	62	970	6.8	2200	210	5000	4020	248
81-11-16	K0	1100	870	330	77	920	13	1900	210	4200	3600	276
81-11-15	K100	5500	5300	380	1100	8800	340	16000	2100	30200	28800	221
81-11-12	K0	3900	3700	720	510	4700	50	9400	1200	17800	16780	240
81-11-15	K0	4700	4400	650	750	6700	160	12000	1600	23700	22000	292
81-11-15	K0	4600	4300	520	800	7100	230	13000	1600	24200	23500	333
81-11-12	K100	3800	3400	380	700	6000	200	11000	1300	20500	19800	443
81-11-12	K0	3500	3400	460	630	5400	98	10800	1200	19500	18000	323
81-11-11	K100	650	520	97	98	840	290	1400	240	2820	2900	130
81-11-13	K180	3400	3000	370	600	5000	160	9600	1200	18100	17100	450
81-11-15	K0	2500	2200	340	400	4900	150	8400	1000	16600	14900	320
81-11-13	K19100	1800	1500	210	300	2400	66	4300	540	8390	7600	223
81-11-17	K0	1400	1200	200	230	2000	6.2	3700	470	7000	6780	253

DATE OF SAMPLE	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)	PHOS-PHORUS, TOTAL (MG/L AS P)	ARSENIC TOTAL (UG/L AS AS)	BARIUM TOTAL RECOV-ERABLE (UG/L AS BA)	CADMIUM TOTAL RECOV-ERABLE (UG/L AS CD)	CHRO-MIUM TOTAL RECOV-ERABLE (UG/L AS CR)
81-11-16	.1	8.1	.00	.010	1.80	2.0	.250	--	--	3	--
81-11-16	.1	7.8	.00	.010	1.90	1.7	.180	--	--	<1	--
81-11-15	.5	6.3	.00	.010	.830	.99	.190	--	--	<1	--
81-11-12	.3	7.6	.00	.010	3.00	1.8	.070	1	700	<1	20
81-11-15	.3	8.1	.00	.020	2.50	1.4	.100	--	--	<1	--
81-11-15	.3	6.7	.00	.010	2.70	2.5	.410	--	--	<1	--
81-11-12	.6	7.0	.00	.040	16.4	.20	2.50	16	400	<1	20
81-11-12	.3	9.2	.00	.010	2.00	.30	.210	--	--	<1	--
81-11-11	.2	5.2	.00	.010	.060	1.2	1.20	--	--	<1	--
81-11-13	.5	9.9	.00	.010	2.00	1.3	.320	1	300	2	80
81-11-15	.3	9.0	.00	.010	2.50	.40	.290	--	--	<1	--
81-11-13	.3	5.6	.00	.010	1.60	.40	.740	--	--	2	--
81-11-17	.1	20	.01	.010	.970	1.2	1.50	1	100	<1	20

DATE OF SAMPLE	COPPER, TOTAL RECOV-ERABLE (UG/L AS CU)	IRON TOTAL RECOV-ERABLE (UG/L AS FE)	LEAD, TOTAL RECOV-ERABLE (UG/L AS PB)	MANGA-NESE TOTAL RECOV-ERABLE (UG/L AS MN)	MERCURY TOTAL RECOV-ERABLE (UG/L AS HG)	SELE-NIUM TOTAL (UG/L AS SE)	STRON-TIUM, DIS-SOLVED (UG/L AS SR)	ZINC TOTAL RECOV-ERABLE (UG/L AS ZN)
81-11-16	--	--	700	--	--	--	6300	230
81-11-16	--	--	800	--	--	--	4500	310
81-11-15	--	--	500	--	--	--	6900	140
81-11-12	19	5400	38	120	<.1	<1	8500	110
81-11-15	--	--	4	--	--	--	8500	60
81-11-15	--	--	6	--	--	--	6800	60
81-11-12	32	1900	8	110	.3	<1	7500	80
81-11-12	--	--	95	--	--	--	8000	90
81-11-11	--	--	56	--	--	--	1000	00
81-11-13	900	6100	500	80	.4	<1	6400	30
81-11-15	--	--	260	--	--	--	6000	120
81-11-13	--	--	72	--	--	--	3000	90
81-11-17	25	1500	200	40	<.2	4	3500	180

Data for quality of stormwater runoff were not collected during this investigation, but are available from other investigations in southeast Florida. For example, Mattraw and Miller (1981) and Miller and Mattraw (1982) present and analyze data for quality of runoff from three small drainage basins near Fort Lauderdale with different land uses (commercial, single family residential, and highway). General comparison of these data indicate "On a unit basis, the single family residential area yielded the largest loads of nitrogen, phosphorous, and dissolved solids. The commercial areas yielded the largest loads of lead, zinc, and chemical oxygen demand. Yields of carbon were about the same for the three areas." (Miller and Mattraw, 1982, p. 513.)

It is difficult, with available data, to identify the role of drainage wells in the regime of the Biscayne aquifer as clearly as may be done for drainage wells in the regime of the Floridan. Though there is a large number of Biscayne wells, most were not permitted for uses that result in any continuing injection of large quantities of water. Except for stormwater runoff, the water injected by most Biscayne aquifer drainage wells has been previously withdrawn from the aquifer, is probably not greatly different in quality from that of freshwater withdrawn from the aquifer, and is merely being returned. This reinjection, thus, amounts to a decrease in consumptive withdrawals from the aquifer rather than injection of a new component of recharge. So use of Biscayne aquifer drainage wells may have a relatively small effect on potability provided that the wells that emplace stormwater runoff and industrial wastewater are restricted to injection into zones where chloride concentrations exceed 1,500 mg/L.

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 operations by reducing water pressures in the zones being mined 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 that of 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 14 shows the location of 140 interaquifer connector wells in the phosphate mining areas of Polk and Hillsborough Counties. These well locations were verified during fieldwork 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 of changing activities in mining operations.

Caliper logs for four interaquifer connector wells, shown in figure 15, 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 the sampling. The geophysical logs indicate different patterns of 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 recharging water may be injected to a single, narrow zone.

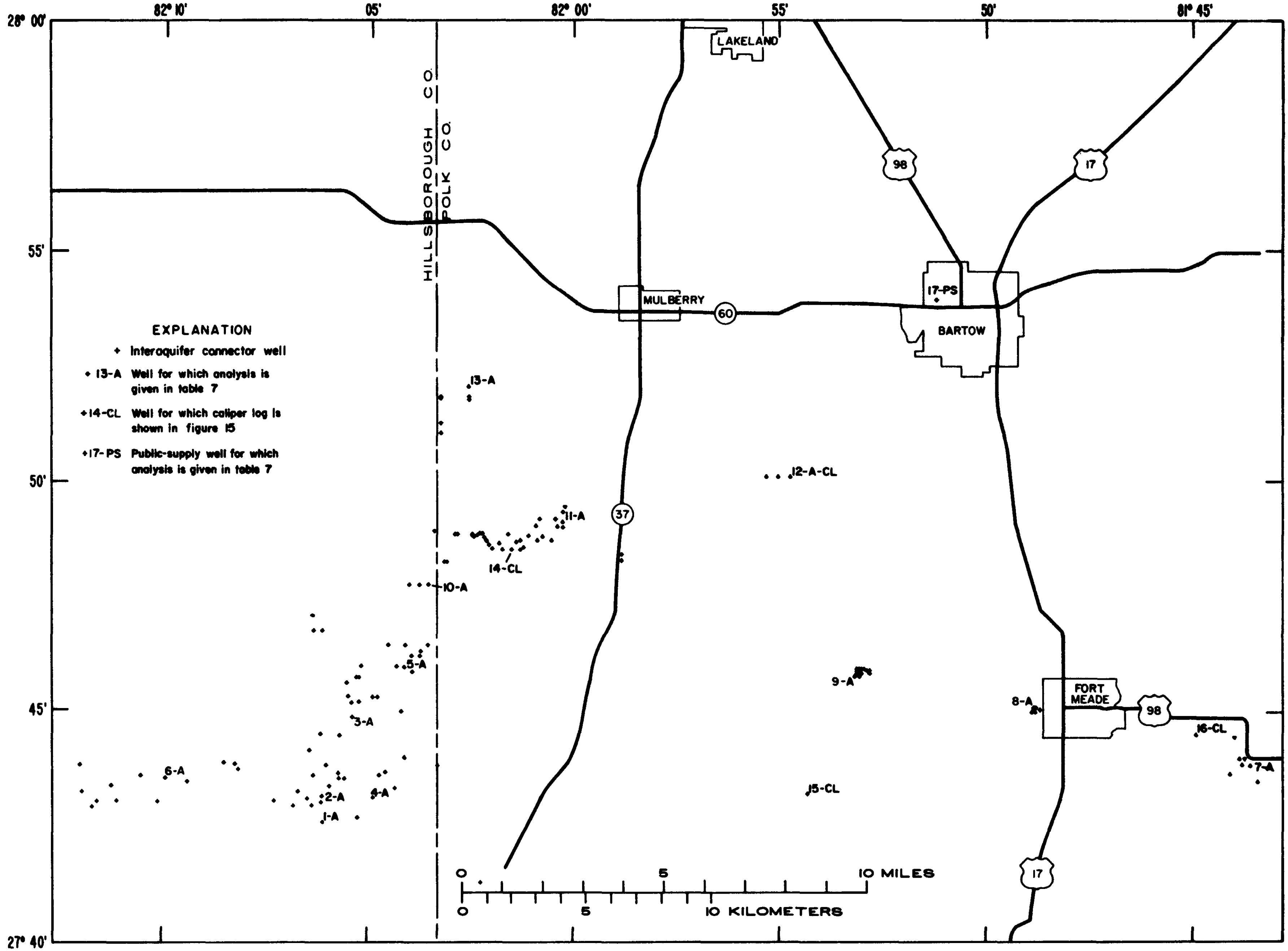

Figure 14.--Locations of interaquifer connector wells, phosphate mining area, Polk and Hillsborough Counties.

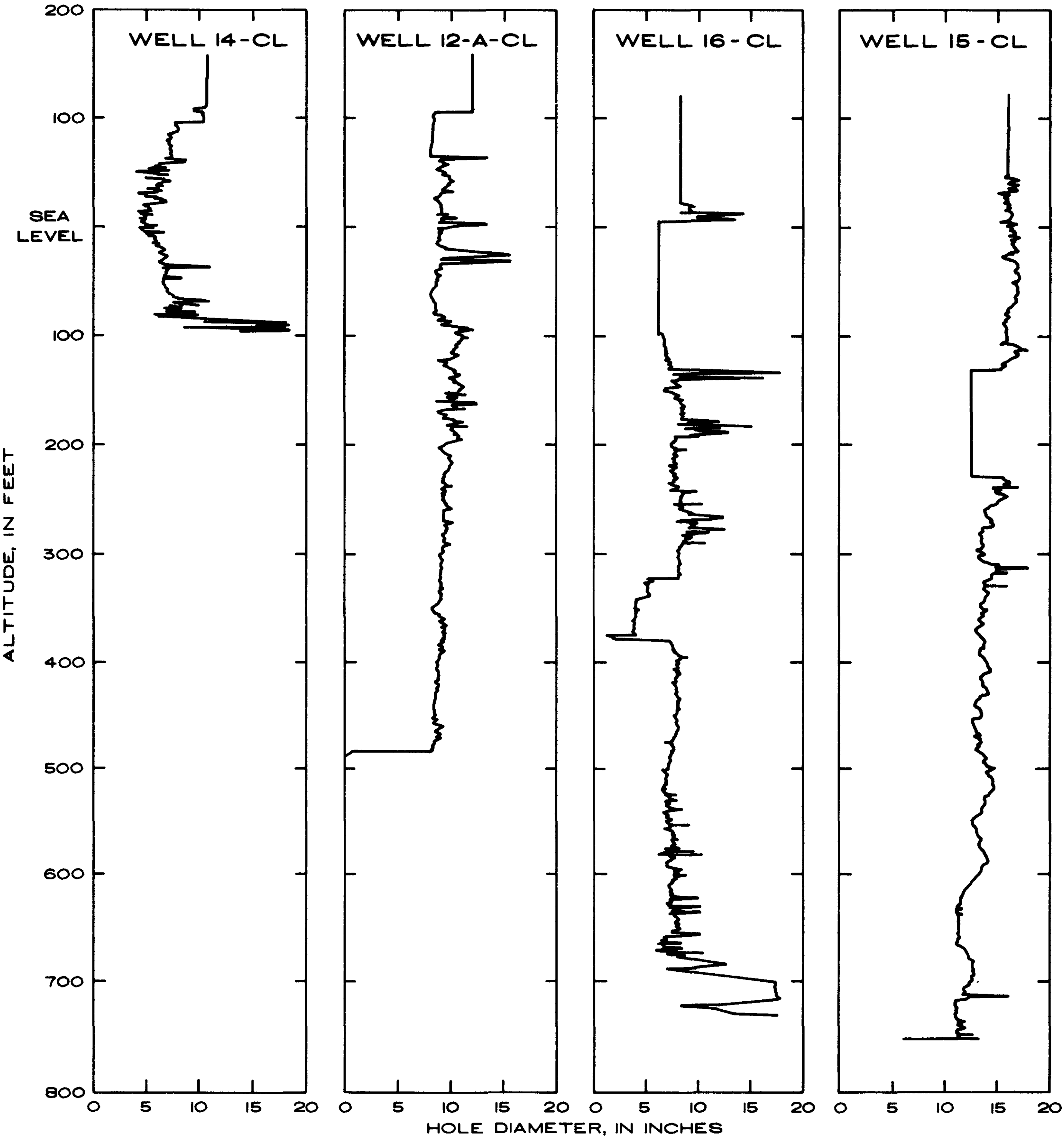

Figure 15.--Caliper logs, phosphate mining area, Polk and Hillsborough Counties.

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 continuously for 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 been 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 10 or 20 feet higher in the well bore and reducing the pumping rate in order to obtain a more representative sample from the losing aquifer.

Analytical data for water samples from the 13 interaquifer connector wells, and for one public-supply well in the phosphate mining area, are shown in table 7. The data indicate highly mineralized water from well 12; the water is an acidic, very hard, calcium-sodium sulfate type. It has a specific conductance of 4,850 micromhos; hardness of 3,580 mg/L; sulfate concentration of 2,600 mg/L; ammonia nitrogen, 160 mg/L; total organic carbon, 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 phosphate mining environment might be expected to be variable. Some wells may drain undisturbed aquifer materials; others may, in part, drain materials that have been disturbed and backfilled during mining operations. Depth of 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.

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 the 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:

Table 7.--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, FLA	17	79-09-04	--	26.0	--	468
	BARTOW CITY NO 1 AT BARTOW, FLA	17	80-02-22	--	26.0	--	755

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)	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 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)	POTASSIUM, DISSOLVED (MG/L AS K)	CHLORIDE, DISSOLVED (MG/L AS CL)	SULFATE DISSOLVED (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 7.--Analyses of water from interaquifer connector and public-supply wells, phosphate mining area, Polk and Hillsborough Counties--Continued

DATE OF SAMPLE	FLUO- RIDE, 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)	CHRO- MIUM, 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)	MANGA- NESE, TOTAL RECOV- ERABLE (UG/L AS MN)	SILVER, TOTAL RECOV- ERABLE (UG/L AS AG)	STRON- TIUM, 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	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)	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	--	--	--	--	--	--	--	--	--	--	--	--

Table 7.--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	--	--	--	--	--	--	--	--	--	--	--	--

1. The standards values for turbidity are exceeded in 10 of the samples; 2 of which 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.

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

3. 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 well 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 7 for a city of Bartow supply well (well 17) so that comparison can be made with the connector-well analyses.

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. Data indicate that injection rates for single connector wells 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 near their annual low in March, so this total injection rate might be slightly lower than one derived from injection data for an entire 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 low 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 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 radio-chemistry) of the various zones of the lower Floridan unit to which injection waters may be introduced.

SUMMARY AND CONCLUSIONS

Floridan aquifer drainage wells are used mainly for disposal of urban runoff in the topographically higher karst terranes 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 30 to 50 Mgal/d in the Orlando area.

Floridan aquifer drainage wells are generally effective as a means of urban drainage and lake level and flood control. They function as the most economic means of drainage in some urbanized closed-basin terranes. Their use results in more recharge to the Floridan aquifer than it would receive under natural conditions. This, in turn, results in generally higher hydraulic heads which may be considered as an additional safeguard against saltwater encroachment for areas that use drainage wells. Continuing caution, however, is suggested in regard to the water-quality aspects of these wells because a potential problem in their use is the fact that they often inject to the same aquifer zones that are used for potable supply.

Biscayne aquifer drainage wells are used in southeast Florida to dispose of stormwater runoff and other surplus waters. Most of these wells are in urbanized coastal areas of Dade and Broward Counties; permitting data are available for more than 5,000 drainage wells in Dade and 2,000 such wells are estimated for Broward. The majority of these wells are less than 4 inches in diameter and are used to dispose of cooling water from air-conditioning units and water from swimming pools. The remainder are used for disposal of stormwater runoff or wastewater from business and industry in the area.

Thirteen wells that drain runoff from urban areas in Broward County were selected and sampled for water-quality analyses. The analytical data indicate that all 13 of these wells were injecting to nonpotable zones in the Biscayne aquifer.

The large majority of Biscayne wells are used for draining swimming pools and air-conditioning units; in most cases they are merely returning freshwater to the aquifer from which it had been withdrawn. The use of Biscayne aquifer wells, despite their large numbers, may have minimal effect on the potable water regime of the Biscayne so long as injection of urban runoff and industrial wastewater is restricted to nonpotable zones.

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. All the wells convey shallow ground water to the upper or lower units of the Floridan aquifer; however, predominance of injection is to the lower unit.

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. One of the 13 wells yielded a highly mineralized water which exceeds maximum contaminant levels for a number of parameters including gross alpha and gross beta concentrations. Samples from 6 of the other 12 wells exceeded standards values for gross alpha concentrations. Additional investigation of occurrence and behavior of the radiochemical parameters is suggested for the areas where connector wells may be used.

Injection rates for single connector wells range from less than 10 to more than 600 gal/min; injection rates for most wells range from about 40 to 275 gal/min. A summary of data for March 1980 indicates a total injection rate of about 26 Mgal/d for 142 connector wells throughout the phosphate mining areas. Use of interaquifer connector wells should have less effect on ground-water quality in the receiving aquifer than use of surface-water injection wells. However, continued caution in regard to their use appears prudent because the losing zone is often unconfined and thus vulnerable to pollution.

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