Hydrogeology, Aquifer Characteristics, and Ground-Water Flow of the Surficial Aquifer System Broward County, Florida

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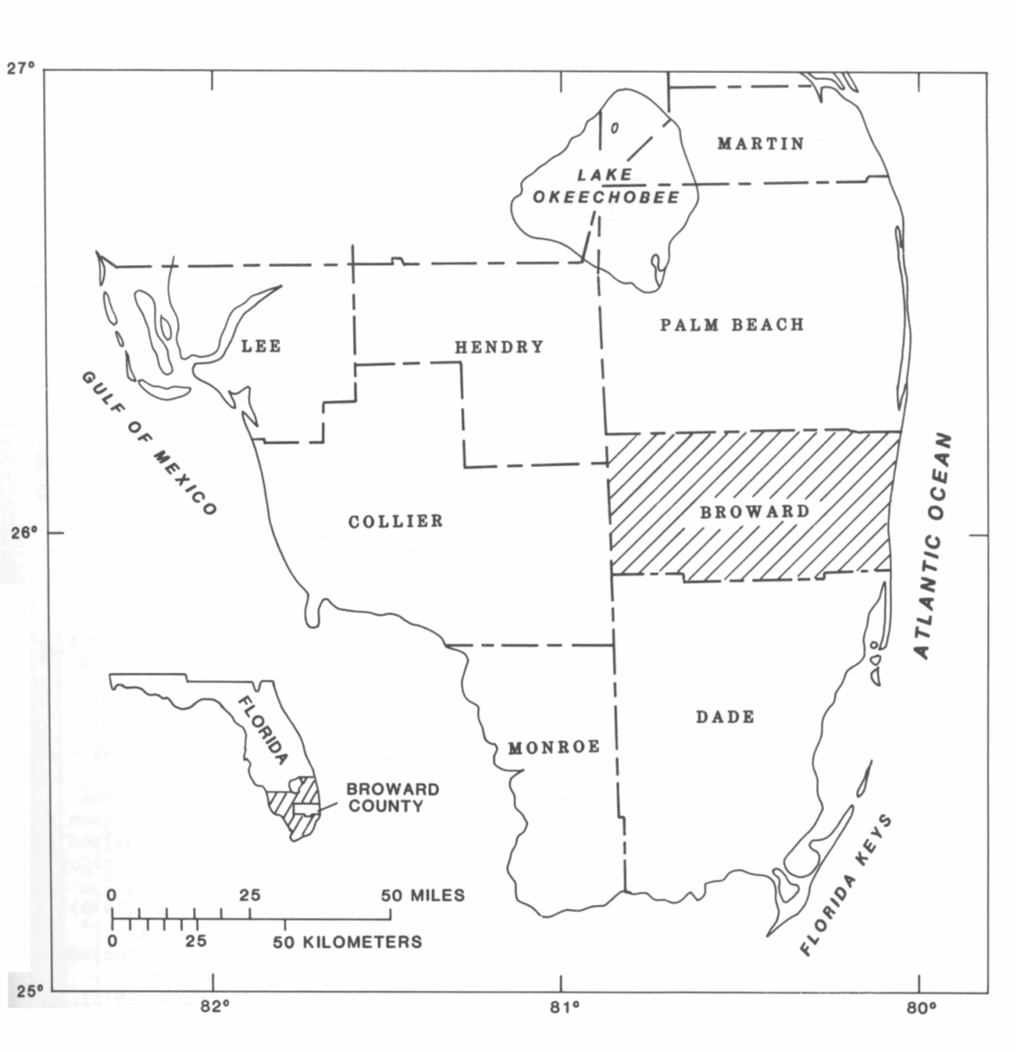
U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 87-4034

Prepared in cooperation with the
SOUTH FLORIDA WATER MANAGEMENT DISTRICT



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

CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who may prefer to use metric (International System) units, rather than the inch-pound unites used in this report, values may be converted by using the

following factors:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon per minute (gal/min)	0.00006309	cubic meter per second (m^3/s)
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]

Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms (mg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less then 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

<u>Sea Level</u>: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD 1929) --a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called “Mean Sea Level of 1929.”

Hydrogeology, Aquifer Characteristics, and Ground-water Flow of the Surficial Aquifer System, Broward County, Florida

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South Florida Water Management District

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Tallahassee, Florida
1988

U.S. DEPARTMENT OF THE INTERIOR
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ABSTRACT

An investigation of the surficial aquifer system in Broward County, begun in 1981, is part of a regional study of the aquifer system in southeast Florida. Test drilling for lithologic samples, flow measurements taken during drilling, aquifer testing, and analyses of previously available data permitted delineation of the permeability framework (on geologic sections), the aquifers in the system and the generalized transmissivity distribution, and interpretation of the ground-water flow system.

The surficial aquifer system, in which an unconfined ground-water flow system exists, comprises the sediments from land surface to the top of a regionally persistent zone of low permeability called the intermediate confining unit. The aquifer system materials vary from clays to cavernous limestone in composition. These sediments are grouped as the Biscayne aquifer at the top; an intervening semiconfining unit primarily of clayey sand; a gray limestone aquifer in the Tamiami Formation (west Broward County); and sand or clayey sand near the base of the surficial aquifer system. The depth of the base of the aquifer system ranges from about 160 feet below land surface in westernmost Broward County to more than 350 feet near the coast. These drilling and aquifer-test data indicate a complex permeability framework. Hydraulic conductivities of the very highly permeable zone of the Biscayne aquifer exceed 10,000 feet per day in places; in the gray limestone aquifer, they range from 590 to 930 feet per day, except in a less-permeable upper zone of the aquifer that occurs primarily in northwesternmost Broward County.

Transmissivities of the surficial aquifer system vary locally but have a definite areal trend. Estimated values are generally about 300,000 square feet per day or more in the southeast, south-central, and part of coastal northeast Broward County. Transmissivity is lower to the north and west, decreasing to less than 75,000 square feet per day over a large area in northwest and north-central Broward County. High transmissivity generally is associated with the Biscayne aquifer. The gray limestone aquifer has transmissivities that range from about 20,000 to 88,000 square feet per day in west Broward County. The transition from high transmissivity to relatively low transmissivity is often only a few miles wide and coincides with the decrease of cavernous porosity and associated permeability in the Fort Thompson Formation or the Anastasia formation.

Ground-water circulation in Broward County must be considered in either predevelopment or development conditions because of changes in hydrologic factors that control flow. Effective canal drainage and large-scale pumping from municipal well fields have greatly altered the predevelopment flow system in east Broward County by: (1) eliminating a coastal ground-water ridge; (2) reducing deep circulation and reducing or eliminating seasonal westward movement of ground

water; and (3) causing accelerated stormwater runoff and short ground-water flow paths, generally lowering the water table, and inducing saltwater intrusion. In west Broward County, hydrologic and permeability framework evidence suggests that water entered the gray limestone aquifer by lateral movement from Hendry, Collier, and Palm Beach Counties, and by downward seepage from the Everglades and the Biscayne aquifer during predevelopment times, and moved southward into Dade County to coastal discharge areas. Depth profiles of specific conductance and chloride support the interpreted movement in west Broward County. Circulation in the Biscayne aquifer inland was also primarily to the south. Little change in the predevelopment ground-water flow system has occurred in west Broward County compared to east Broward County.

INTRODUCTION

Southeast Florida (fig. 1) is underlain by materials of varying permeability from land surface to depths of 150 to 400 feet that provide most of the water used in the area. This body of materials is herein called the surficial aquifer system. In parts of Dade, Broward and Palm Beach Counties, a highly permeable part of that aquifer system has been named the Biscayne aquifer (Parker, 1951; Parker and others, 1955). Adjacent to or underlying the Biscayne aquifer are less permeable, relatively unknown, by potentially important water-bearing materials which also are part of the surficial aquifer system.

Most previous work in southeast Florida had been concentrated in the populated coastal area. Drilling and monitoring activities were commonly restricted to zones used for water supply or to overlying zones. Hence, information concerning the characteristics of the western or deeper parts of the Biscayne aquifer and of sediments below the Biscayne aquifer in the surficial aquifer system were insufficient for present needs. Because of persistent increases in were demand from the surficial aquifer system in the highly populated and growing coastal area of southeast Florida and because of attendant concerns for the protection and management of the water supply, the U.S. Geological Survey, in cooperation with the South Florida Water Management District, began and investigation to define the extent of the surficial aquifer system and its characteristics on a regional scale.

The overall objectives of the regional study are to determine the hydrogeologic framework, the extent and thickness of the surficial aquifer system an the aquifers within it, the areal and vertical water-quality distribution and factors that affect the water quality, the hydraulic characteristics of the components of the surficial aquifer system, and to describe ground-water flow in the aquifer system. Results of the investigation are planned for publication in a series of reports that provide information for each county or area as it becomes available. Broward County (fig. 1) is the first to be investigated in this regional study. Three reports were planned for Broward County, including a geologic framework report prepared by Causarás (1985), a water-quality report, and a hydrogeology ground-water report.

Purpose and Scope

This report describes the hydrogeology of the surficial aquifer system and ground-water flow in the aquifer system in Broward County, Fla. The purpose is to provide fundamental background information that is basic for qualitative or quantitative evaluations of the ground-water resource and the hydraulic response of the system to natural or artificial stresses. Specifically, the objectives

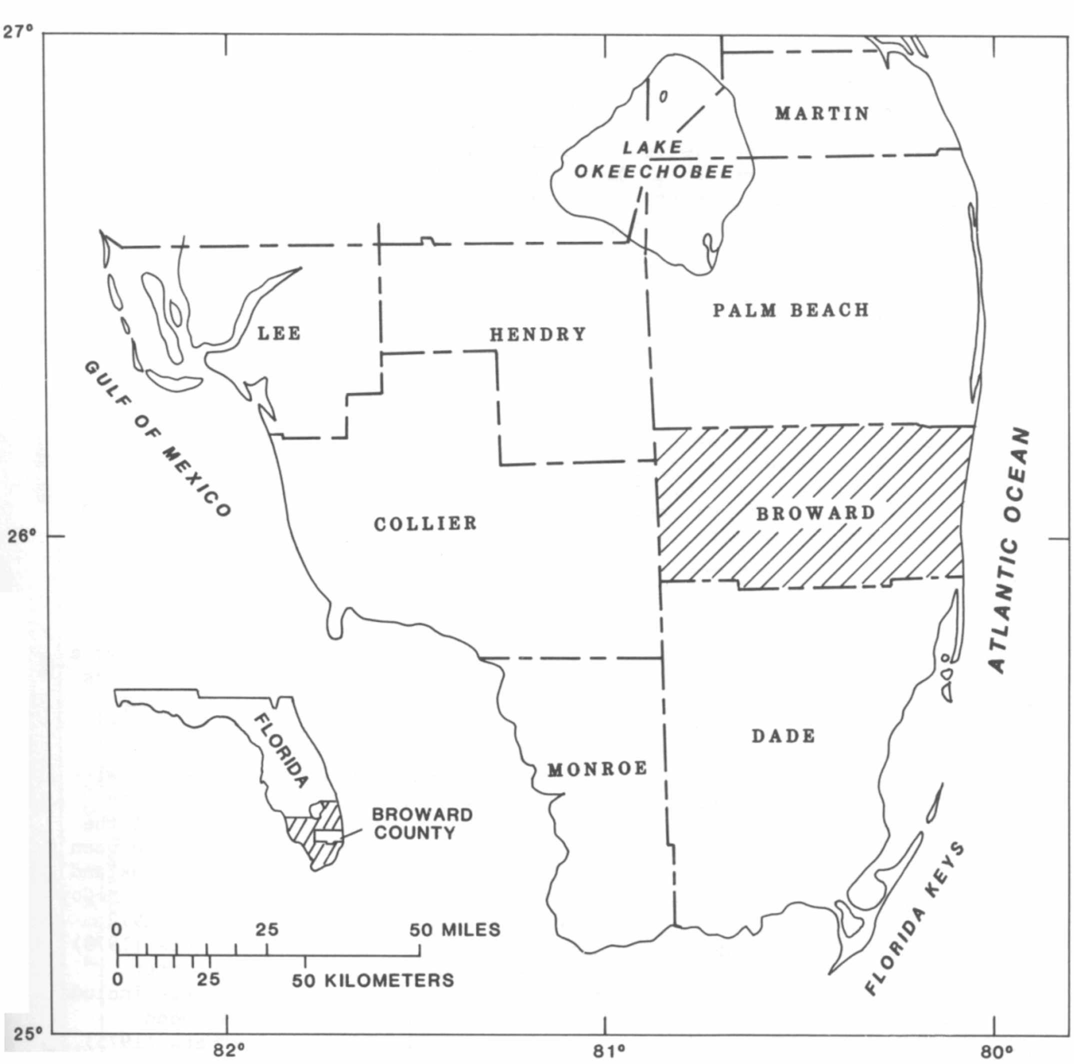

Figure 1. Location of Broward County, Florida.

are to: (1) define the surficial aquifer system and aquifers within it; (2) characterize hydraulic properties of the surficial aquifer system; and (3) interpret ground-water flow in the surficial aquifer system.

The study is intended to provide a broad countywide characterization of the surficial aquifer system rather than detailed site-specific or local information. An extensive field program of hydrogeologic test drilling, water-quality sampling, and aquifer testing was conducted during 1981-84. Most test holes in west and central Broward County were drilled to a depth of about 200 to 230 feet, but those closer to the coast were drilled much deeper, reaching 476 feet at two sites. At most sites, drilling fully penetrated the surficial aquifer system, reaching into the upper part of the underlying confining unit. Other data selected from existing geologic logs, historic water-level records, and aquifer or production well tests were used to supplement the field data.

Previous Investigations

Although a comprehensive water-resources investigation has not been made heretofore for all of Broward County, many investigations of selected topics or areas—almost exclusively in the eastern part of the county—have been reported. Parker and others (1955) gave information on the geology of the county; the occurrence, movement, and quality of ground water and surface water; and saltwater intrusion. Schroeder and others (1958) improved knowledge of the Biscayne aquifer with many shallow test holes and geologic sections in west Broward and Dade Counties and a contour map of the base of the aquifer. Studies of ground-water resources of local areas (fig. 2) have been reported by Vorhis (1948) for Fort Lauderdale, by Sherwood (1959) for Oakland and Hardee (1970) for the lower Hillsboro Canal area, and by Bearden (1972; 1974) for Hallandale and Hollywood, respectively. Sherwood and others (1973) synthesized the available data and much new information to form a better understanding areally of east Broward County. Other pertinent reports include a discussion of the chemical quality of waters by Grantham and Sherwood (1968), “Water and the south Florida environment” by Klein and others (1975), and the most recent description of the Biscayne aquifer and its hydrologic characteristics by Klein and Hull (1978).

Methods

Hydrogeologic test drilling was conducted at sites arranged to form intersecting lines across the county (fig. 3, table 1). A reverse-air dual tube drilling method, which circulates air (no drilling mud was used) downward in the annulus between the tubes and back to the surface in the inner tube with entrained cuttings and water, was used. The method alleviated problems of collecting representative geologic samples that mud-rotary methods often encounter in this area. The problems include lost circulation in cavities with loss of samples and “running water sands” that cause collapse of test holes. Pieces of rock layers and clean (free of drilling mud) samples of clastic materials were obtained from which inferences of hydraulic properties were made. Some of the rock samples were used for laboratory tests for porosity and hydraulic conductivity. Additionally, the samples were assigned a relatively accurate depth, and hydrologic observations were made of flow variations during drilling and at 10-foot intervals after completing each drill pipe length.

After drilling each 10-foot length of drill pipe, air was circulated to obtain water from the aquifer. Circulation was continued, for several minutes if necessary, to obtain water as free from sediment as possible. Yields varied between 0 and 300 gal/min. Water samples were collected for analyses of specific conductance in the field and chloride concentration in the laboratory. Experience has shown that specific conductance and chloride concentration of water collected from circulation during drilling is similar, in most circumstances, to results from complete analyses of water collected by normal pumping and filtering techniques inside the drill rod and of water collected from finished wells at the test sites. The water produced by air circulation at a given depth is generally representative of the formation water at that depth. Profiles of specific conductance or chloride concentration with depth can then be constructed. These profiles have proven useful in revealing gross water-quality characteristics and making hydrologic or hydraulic inferences.

Previously available aquifer tests and specific capacities of production wells were compiled for estimating transmissivity and hydraulic conductivity in east Broward Count. On the basis of the geologic sections prepared by Causarás (1985), inspection of geologic samples, and hydrologic observations made during drilling, a hydraulic testing program was designed to provide estimates of transmissivity or hydraulic conductivity of selected zones or materials at selected sites primarily

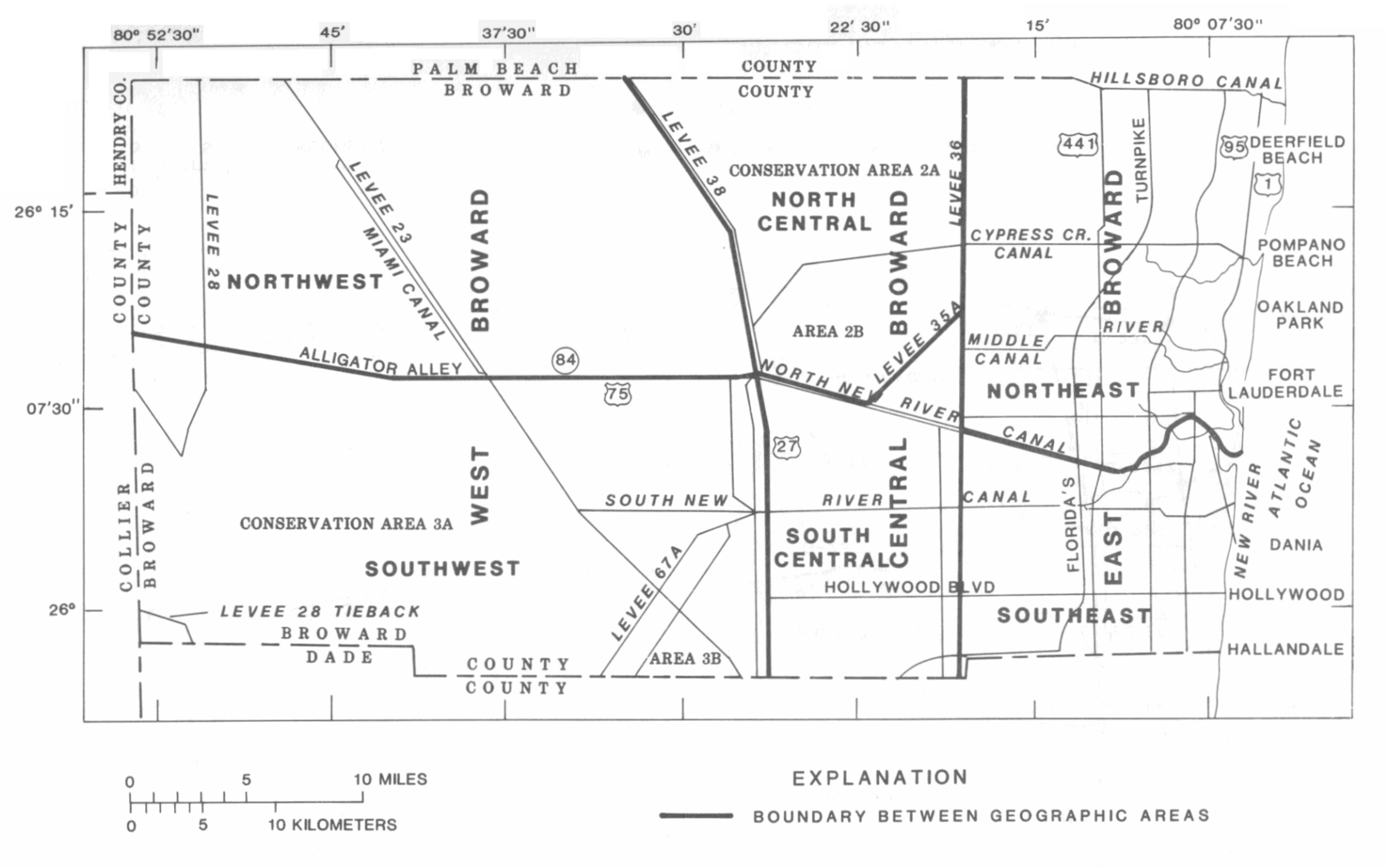

Figure 2. Geographic areas of Broward County

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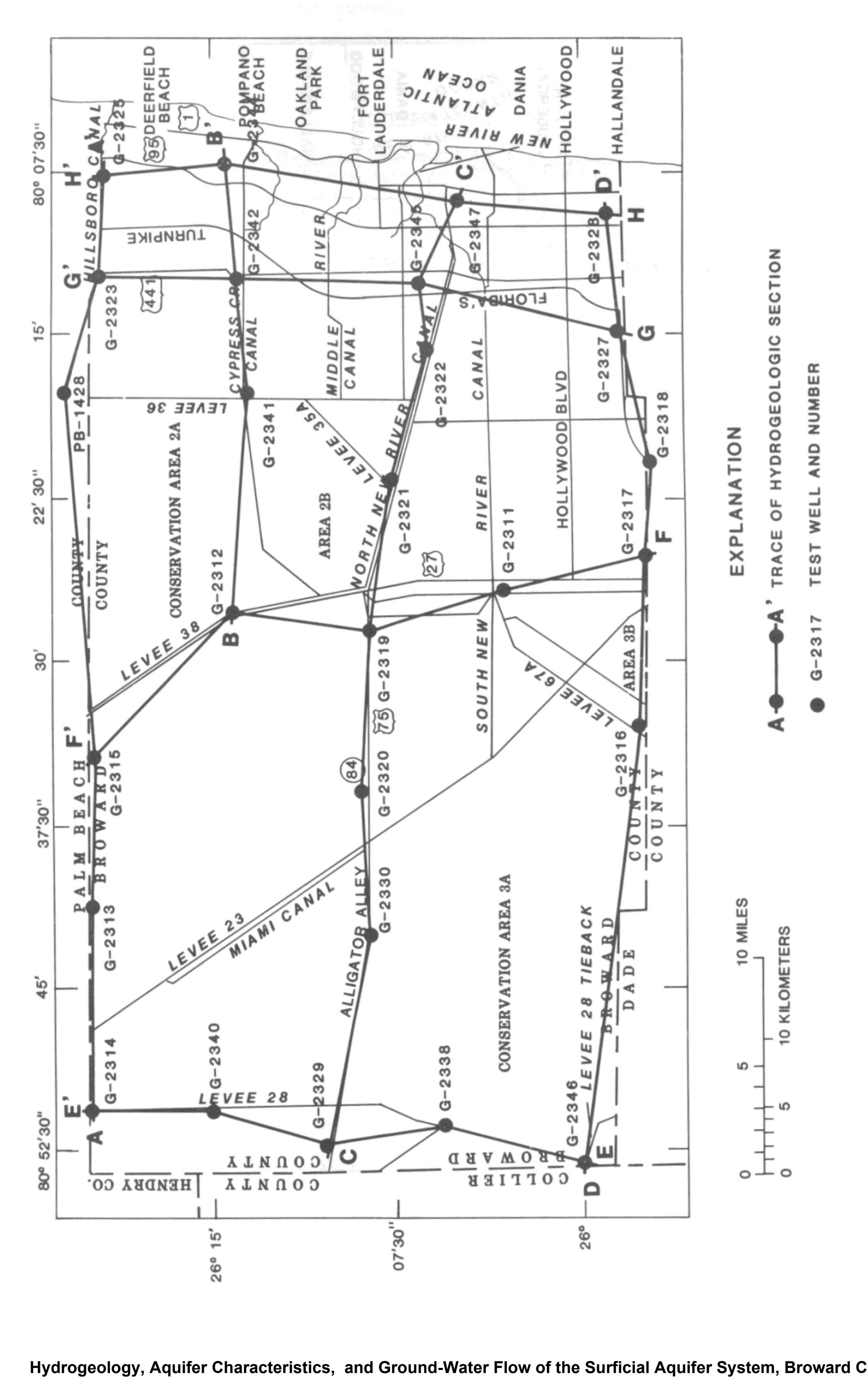

Figure 3. Location of test drilling sites and hydrogeologic sections (from Causaras, 1985). Well numbers and site names are listed in table 1

Table 1. U.S Geological Survey well numbers and informal site names for test sites

[see figure 3 for location of sites]

USGS well number	USGS site identification number			Informal site name (this report only)
	Latitude	Longitude	Sequence number	
G-2311	260335	0802637	01	S-9 pump station
G-2312	261347	0802737	01	Twenty-Six Mile Bend
G-2313	261958	0804106	01	North Everglades central
G-2314	261952	0805002	01	North Everglades west
G-2315	261958	0803421	01	North Everglades east
G-2316	255732	0803256	01	South Everglades east
G-2317	255722	0802455	01	Snake Creek Canal west
G-2318	255724	0802036	01	Snake Creek Canal east
G-2319	260843	0802839	01	Alligator Alley east
G-2320	260846	0803542	01	Alligator Alley central
G-2321	260742	0802200	01	Markham Park
G-2322	260617	0801612	01	Plantation
PB-1428	262109	0801751	01	Hillsboro Canal west
G-2323	261938	0801215	01	Hillsboro Canal east
G-2325	261938	0800752	01	Hillsboro Locks
G-2327	255829	0801448	01	Miramar east
G-2328	255918	0800918	02	Hallandale well field
G-2329	261014	0805122	01	Alligator Alley Snake Road
G-2330	260844	0804159	01	Alligator Alley west
G-2338	260532	0805036	01	Southwest Everglades
G-2340	261458	0804947	01	Northwest Everglades
G-2341	261343	0801758	01	Cypress Creek Canal west
G-2342	261348	0801220	01	Cypress Creek Canal east
G-2344	261423	0800715	01	Pompano Beach well field
G-2345	260461	0801235	01	North Dixie well field
G-2346	255958	0805222	01	South Everglades west
G-2347	260507	0800856	01	Snyder Park

in central and west Broward County. In some instances, multiple-well tests were made to determine storage coefficients.

Historic records of ground-water and surface-water levels were compiled from U.S. Geological Survey and South Florida Water Management District files to prepare water-level maps useful for interpreting ground-water flow.

Acknowledgments

The author greatly appreciates the interest and support of the South Florida Water Management District in this cooperative program. Permission and access were given to locate most of the test sites on their right-of-way. In addition, they provided stage data for the water-conservation areas and for some of the canals and construction data for selected municipal supply wells. Also, Broward County, the cities of Fort Lauderdale, Hallandale, and Pompano Beach, and the Florida Department of Transportation gave site permission and access rights. Roy Reynolds of the Broward County Water Resources Management Division assisted in location of control structures and areas of controlled drainage in Broward County. Special thanks is given to the many municipal well-field operators for providing information on well construction and specific-capacity tests of production wells.

DESCRIPTION OF STUDY AREA

Geographic Features

Broward County, located near the southern tip of peninsular Florida, encompasses and area of about 1,220 mi^2 (fig. 1). The county is bounded by the Atlantic Ocean on the east, Dade County on the south, Palm beach county on the north, and Collier County and Hendry County on the west. The eastern third of Broward County is primarily urban and agricultural; the western two-thirds is water-conservation areas. Early urbanization was along the coast because of good drainage and access to the ocean. Urbanization is now almost fully developed for several miles inland, and land farther west originally drained for agriculture is rapidly being converted into new urban areas. The population of Broward County in 1980 was 1,018,257 (James O’Rourke, Broward County Office of Planning, oral commun., 1985). Geographic areas and place names of Broward County, referred to in this report, are shown in figure 2.

Physiographic Features and Natural Drainage

Physiographic features (fig. 4) have significantly controlled the environment, drainage, and ultimately the land use of Broward County. The Atlantic Coastal Ridge, 5 miles or less in width, forms the highest ground in the county from 10 feet above sea level in the south to 22 feet in the north. It is a natural barrier to drainage of the interior, except where it is breached by shallow sloughs or rivers. The Sandy Flatlands, west of the Atlantic Coastal Ridge, is lower and prior to development was poorly drained. The Everglades, which covers most of Broward County, is slightly lower than the Sandy Flatlands, and when natural conditions prevailed, is was seasonally inundated. Drainage was slow and general to the south channeled behind the higher coastal area.

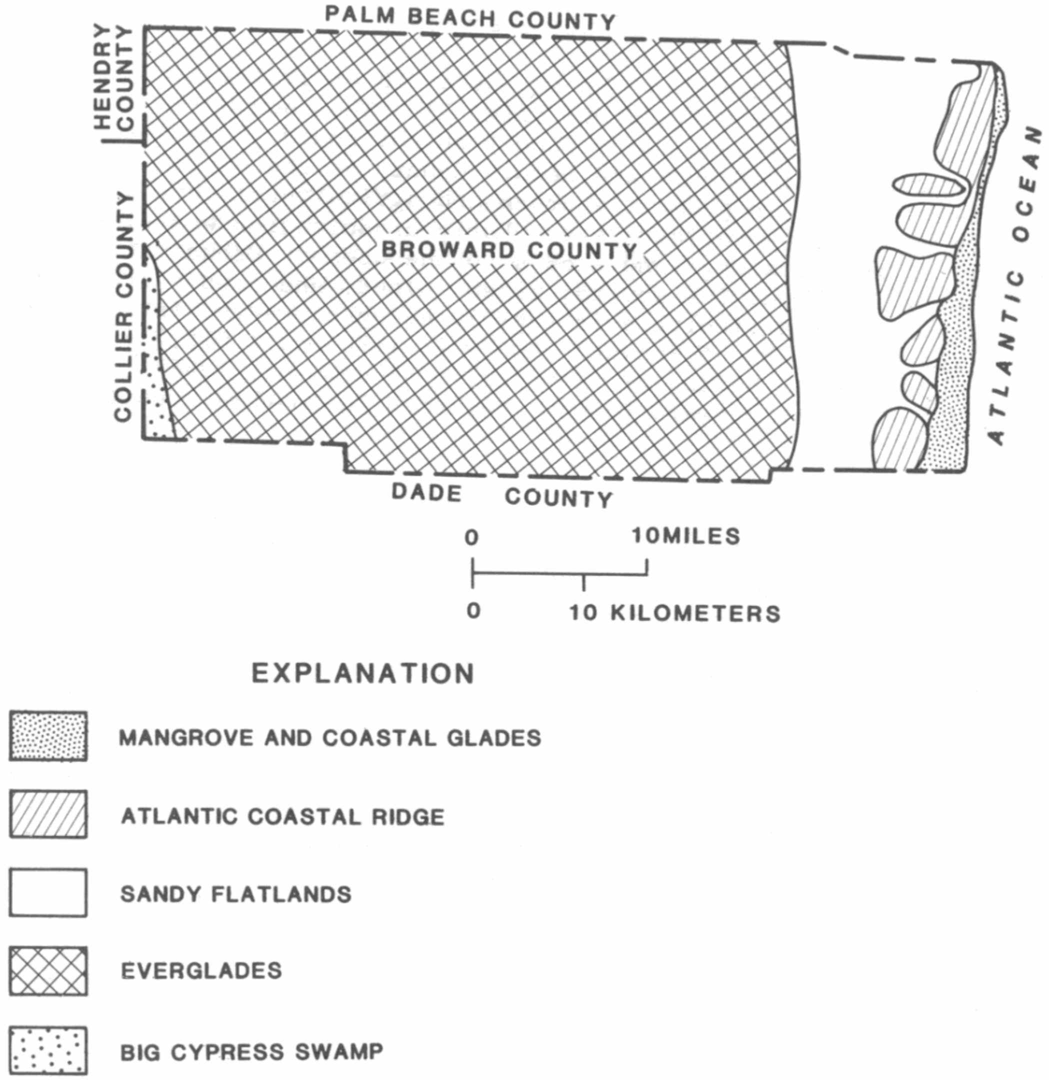

Figure 4. Physiographic features of Broward County prior to development (from Parker and others, 1955, plate 12.

The Everglades is highest, about 13 feet above sea level, along the Palm Beach County line and lowest, about 5 feet above sea level, in south-central Broward County along the Dade County line.

The predominant soils of the area and their drainage characteristics are shown in. The best drainage by way of infiltration occurs on sands of the Atlantic Coastal Ridge and the Sandy Flatlands. Soils having poor drainage cover most of the county. Their low permeability causes ponding. Ponds, particularly in the Everglades, may contain up to several feet of peat and muck.

Water-Management Facilities

A complex water-management system, part of the South Florida Water Management System, has been developed to adapt the natural environment to man's needs (fig. 6). Water-conservation

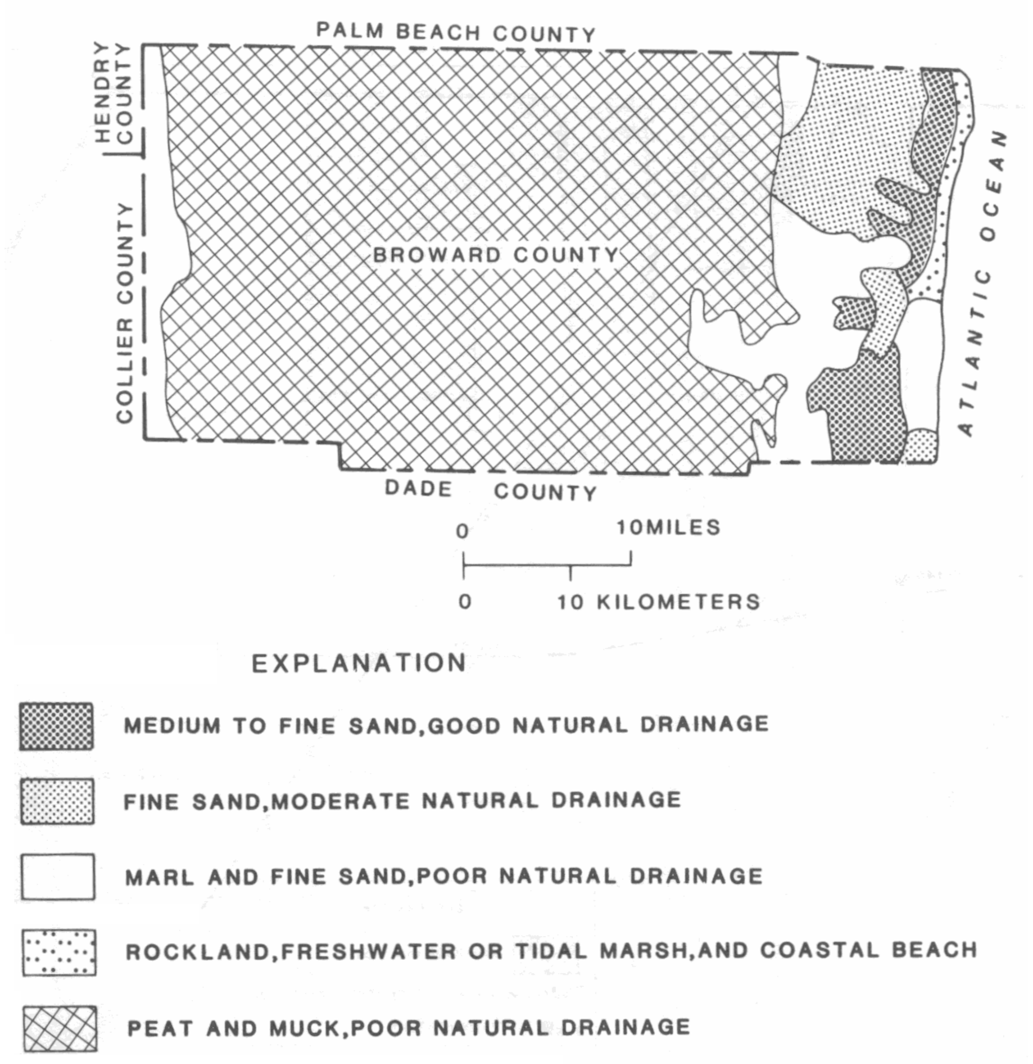

Figure 5. Distribution of soil types in Broward County and their drainage characteristics (modified from General Soil Map of Florida, Soil Conservation Service, 1962, by Klein and others, 1975, p. 11).

areas, bounded by levees and canals, cover most of the area that was previously the Everglades in Broward County. These conservation areas store rainfall and excess wet-season water which is pumped from drainage districts in Broward County and the agricultural area of southwest Palm Beach County, or collected by gravity drainage from east Hendry County. Four large stations, S-7, S-8, S-9, and S-140, pump water from canals into the conservation areas. The stored water is used during periods of low water levels to maintain flow to Everglades National Park to the south, to provide recharge for municipal well fields, and to maintain ground-water levels near the coast for preventing or retarding saltwater intrusion.

A system of nine major canals has been built for long-distance transport of water eastward from the water-conservation areas or from Lake Okeechobee for flow augmentation as described above, or for discharge of excess water either by gravity drainage to the ocean or by pumping to water-conservation areas. These major canals, in conjunction with secondary canals and ditches, are used for rapid removal of excess water. Gates or locks on canals regulate elevations, and retard saltwater intrusion. There are 22 districts in east and central Broward County where water levels are controlled (Roy Reynolds, Broward County Water Resources Management Division, written commun., 1984). The principal functions of most of these districts are drainage of seasonally or intermittently flooded areas and general lowering of ground-water levels to increase the thickness of the unsaturated zone. Unlike the other large pump stations mentioned above, S-13 transfers drainage water toward the ocean rather than pumping water into storage. An important function of some districts is to maintain ground-water levels in the dry season by outseepage or to provide water for flood irrigation. More information about the surface-water system in Broward County is contained in Sherwood and others (1973).

GENERAL AQUIFER FRAMEWORK AND DEFINITIONS

Overview

Historically, two major aquifer systems have been identified in Broward County (fig. 7a). The lower aquifer system is commonly known as the Floridan aquifer (Parker and others, 1955) but has recently been renamed to Floridan aquifer system (Miller, 1986) because it is composed of two or more distinct aquifers. This system is areally extensive, occurring in all of Florida and parts of adjacent states. In Broward County, the top of the Floridan aquifer system is about 950 to 1,000 feet below sea level. The upper part of the system contains confined water with 30 to 60 feet of head above sea level (F.W. Meyer, U.S. Geological Survey, oral commun., 1984).

Overlying the Floridan aquifer system in Broward County is a 550- to 800-foot thick sequence, consisting of green clay, silt, limestone, and fine sand, referred to as the intermediate confining unit (previously called the Floridan aquiclude, Parker and others, 1955, p. 189). A few zones within this sequence may be minor aquifers, but in general, the sediments are relatively impermeable. These sediments mostly belong to the Hawthorn Formation (Miocene age), but the uppermost sediments locally may belong to the Tamiami Formation (Pliocene age). Overlying the intermediate confining unit is the surficial aquifer system, the source of freshwater supplies for Broward County and for most of southeast Florida and the subject of this report.

Surficial Aquifer System

The surficial aquifer system comprises all materials from the water table to the top of the intermediate confining unit. These materials are primarily cavity-riddled limestone and sandstone, sand, shell, and clayey sand with minor clay or silt and range in age from Pliocene to Holocene (see Causarás, 1985). Practically speaking, the top of the system ay be considered to be the land surface because virtually all of Broward County formerly was seasonally or perennially flooded, although drainage by canals in recent years has reduced the occurrence of flooding in east and south-central Broward County. The base of the system is defined hydraulically by a significant contrast in average permeability. It is the surface, mappable over a multicounty area, that separates the thick section of generally permeable sediments (surficial aquifer system) from a thick section of sediments having generally low permeability (intermediate confining unit). The upper part of the intermediate

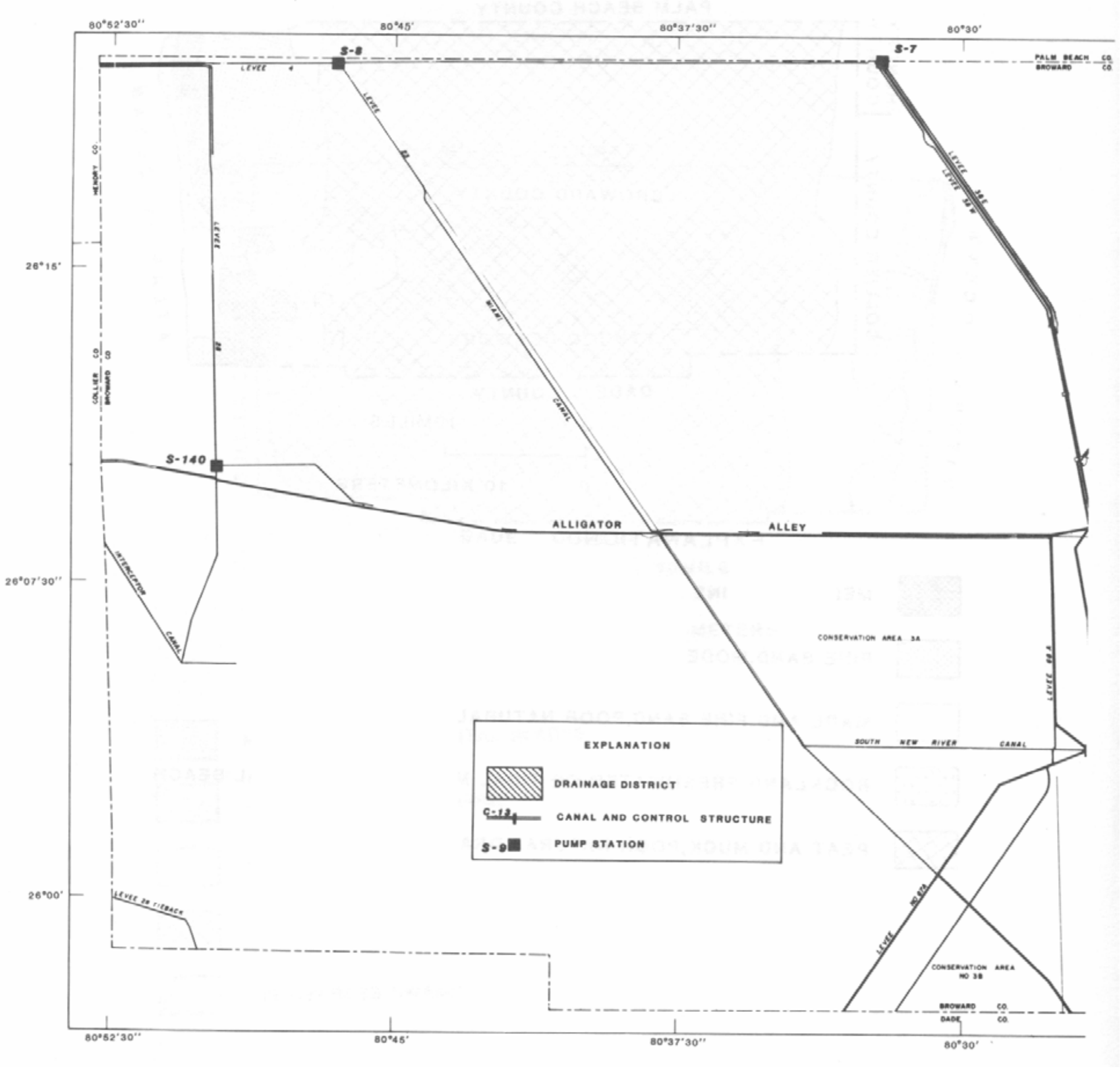

Figure 6. Features of the water-management system in Broward County.

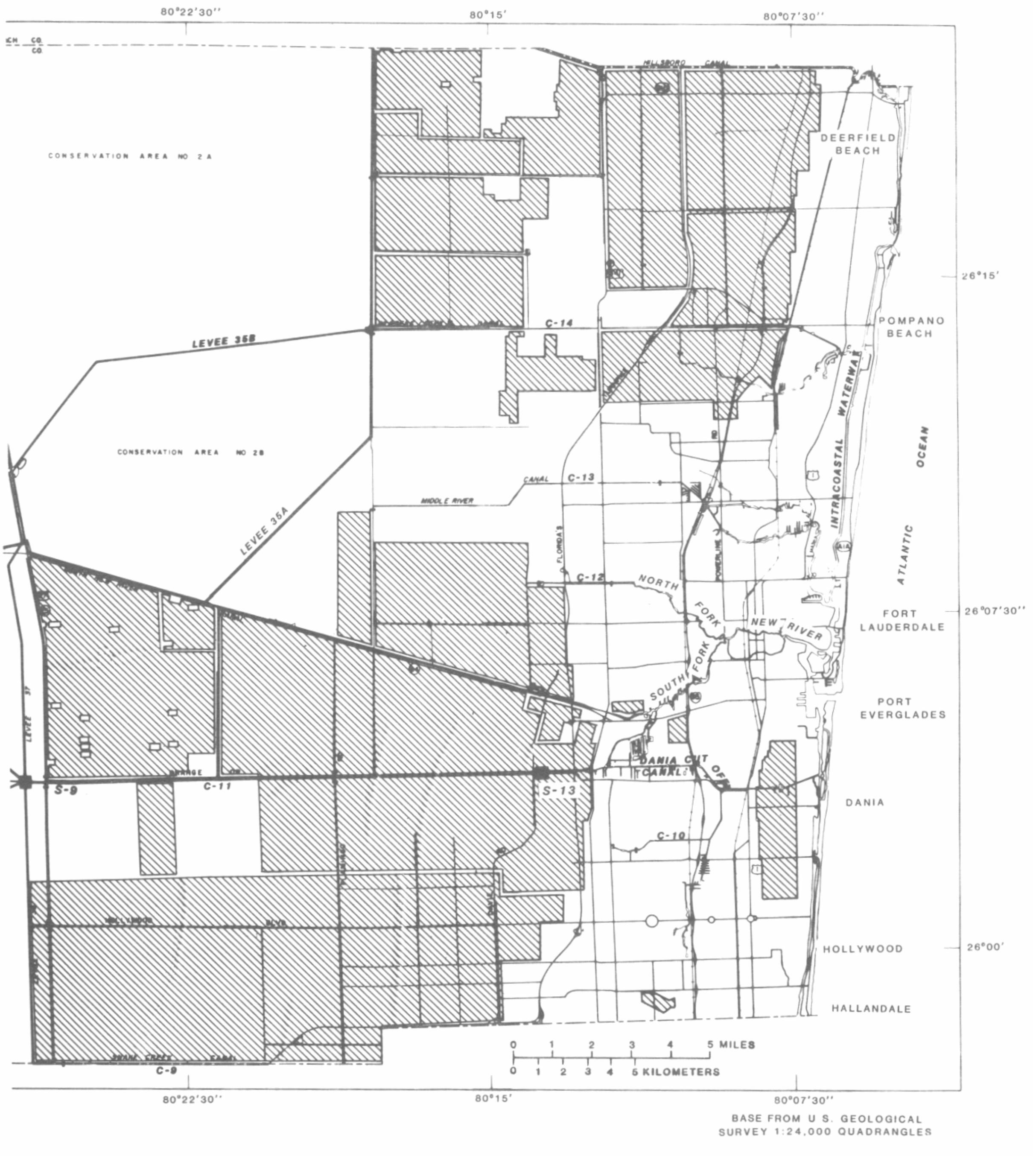

Figure 6. Features of the water-management system in Broward County -- (Continued).

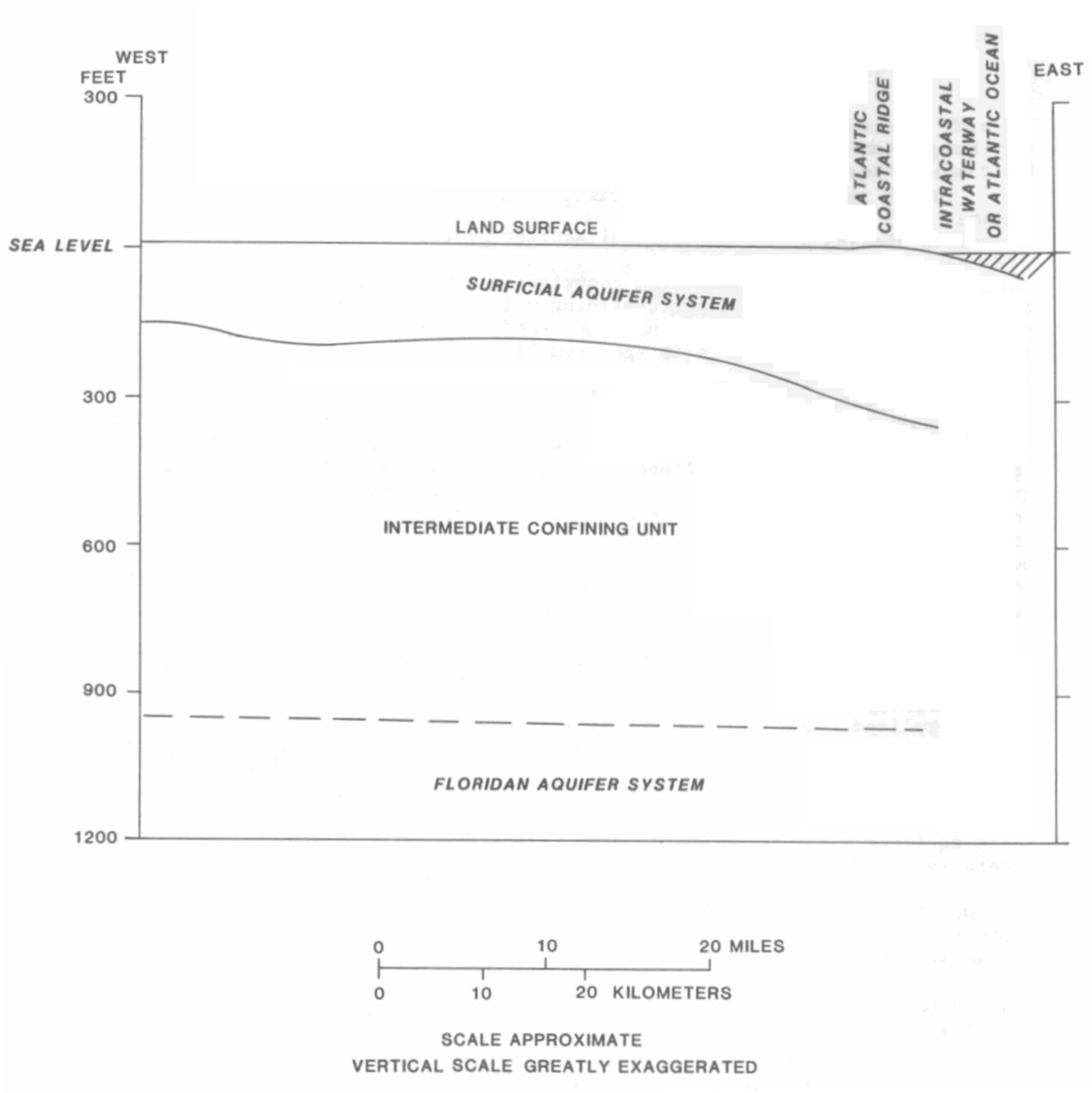

Figure 7a. Generalized hydrogeologic framework of Broward County.

confining unit is usually green clay or silt, locally sandy, except near the coast where it is composed of green, fine-grained calcarenite.

Sediments of the surficial aquifer system have a wide range of permeability, and locally may be divided into one for more aquifers separated by less permeable or semiconfining units. A hydrogeologic section that illustrates the generalized framework of the system in Broward County from west to east is shown in figure 7B. The Biscayne aquifer is the best known and contains the most permeable materials of the surficial aquifer system (fig. 8). Another permeable unit, informally

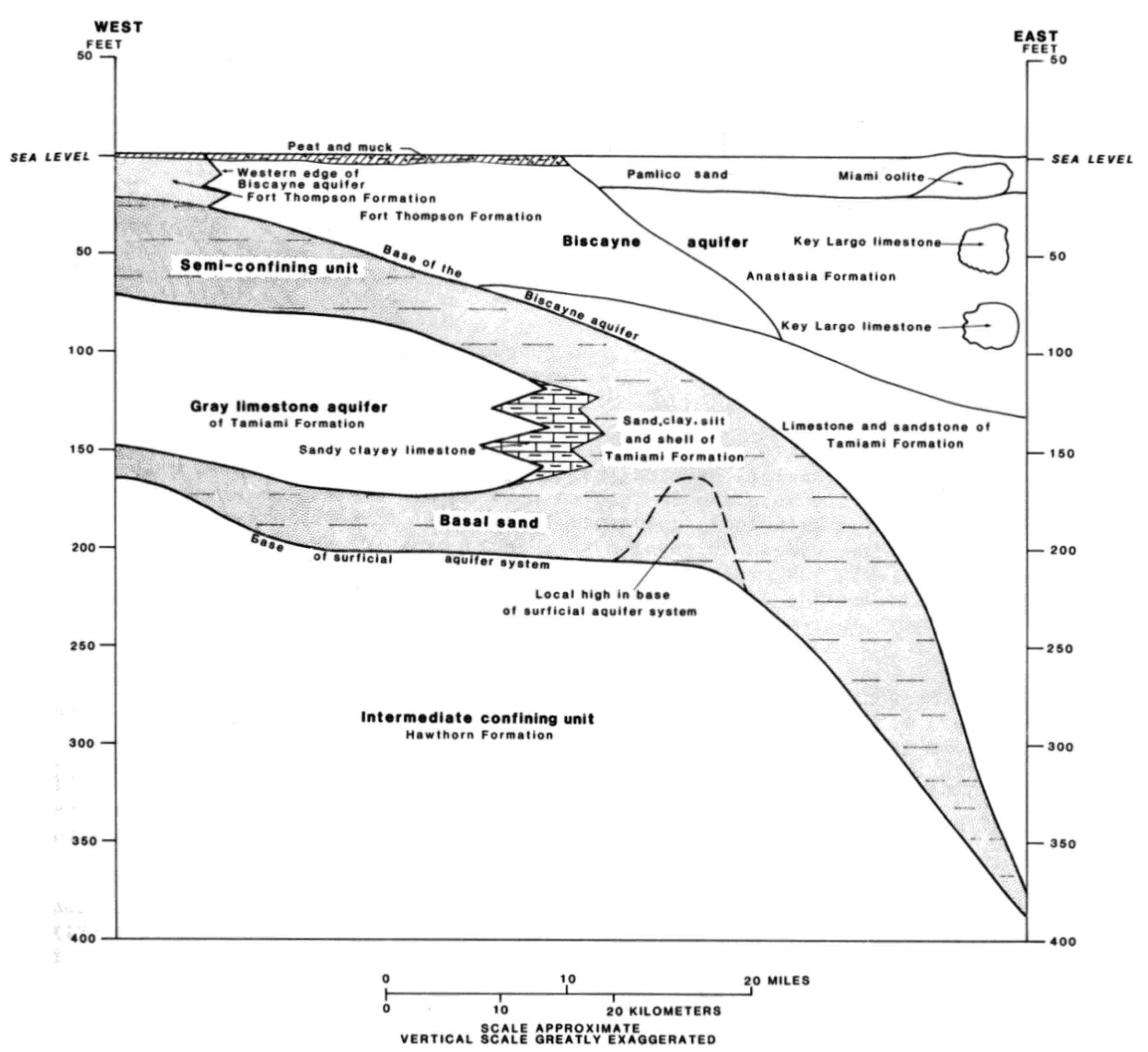

Figure 7b. Schematic relations of geologic formations, aquifers, and confining unit of the surficial aquifer system across Broward county.

termed the gray limestone aquifer in this report, was not previously known in Broward County. Separating or underlying these aquifers are less-permeable sand, limestone, silt, and clay, which generally act as leaky units.

Due to large permeability contrasts with adjacent materials, permeable unity (aquifers or smaller sections within aquifers) may exhibit semiconfined characteristics when stressed. However, the head distribution throughout the surficial aquifer system is closely related to the water table, generally less that 10 feet above sea level, which contrasts sharply with the head in the confined Florida aquifer system.

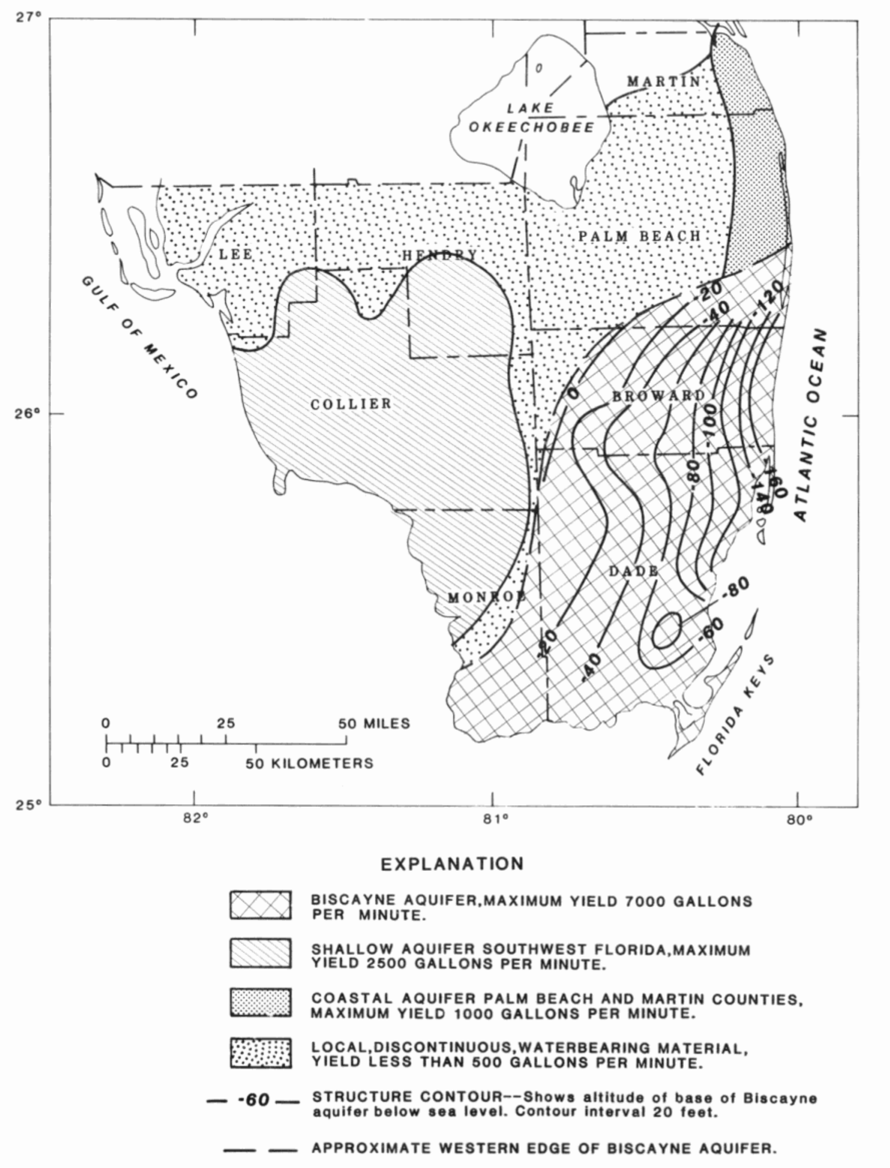

Figure 8. Areal extent and yield to wells of Biscayne aquifer and other aquifers of the surficial aquifer system in south Florida (from Klein and others, 1975. p. 31).

Biscayne Aquifer

The Biscayne aquifer is the only formally named aquifer in the surficial aquifer system in Broward County. Because it is the principal aquifer in Broward County (it has been declared a sole-source aquifer; Federal Register Notice, 1979) and because some refinement of the definition of the aquifer will be given herein, a brief summary of previous definitions, maps delineating the aquifer, and some problems are included below.

The Biscayne aquifer was named and defined by Parker (1951, p. 820) as follows:

> “The name Biscayne aquifer is proposed for the hydrologic unit of water-bearing rocks that carries unconfined ground water in southeastern Florida.“

In a later comprehensive treatment of water resources in southeast Florida, Parker and others (1955, p. 160, 162) give the following information:

> “The Biscayne aquifer, named after Biscayne Bay, is the source of the most important water supplies developed in southeastern Florida. It is the most productive of the shallow nonartesian aquifers in the area and is one of the most permeable in the world. The aquifer extends along the eastern coast form southern Dade County into coastal Palm Beach County as a wedge-shaped underground reservoir having the thin edge to the west. It underlies the Everglades as far as northern Broward County, though in that area it is comparatively thin, and the permeability is not as high as it is farther east and south.”
>
> “The Biscayne aquifer is a hydrologic unit of water-bearing rocks ranging in age from upper Miocene through Pleistocene. The aquifer is comprised, from bottom to top, of parts or all of the following formations: (1) Tamiami Formation (including only the uppermost part of the formation—a thin layer of highly permeable Tamiami Limestone of Mansfield); (2) Caloosahatchee Marl (relatively insignificant erosion remnants and isolated reefs); (3) Fort Thompson Formation (the southern part); (4) Anastasia Formation; (5) Key Largo Limestone; and (6) Pamlico Sand.”

Shallow core borings by the U.S. Army corps of engineers on west Dade and Broward Counties, in conjunction with other well data, provided a basis for an additional description of the Biscayne aquifer and a contour map of the base over most of Dade and south Broward Counties (Schroeder and others, 1958). The contour map was later modified by Klein and others (1975, p. 31) and is shown in figure 8. A more recent summary description of the Biscayne aquifer is given by Klein and Hull (1978).

Despite the definitions and accumulated knowledge about the Biscayne aquifer, some ambiguities and practical problems remain. Schroeder and others (1958, p. 5) indicate that although the base of the Biscayne aquifer is readily determined as the top of low permeability sand or “marl” of the Tamiami Formation in the Miami area, it is more difficult to define the lateral and basal limits of the Biscayne aquifer in Broward and Palm Beach Counties where clastic materials predominate and interfingering or gradations of sands and calcareous materials are common. Also, some geologic formations that make up the Biscayne aquifer extend beyond the area generally ascribed to the aquifer. Thus, to delineate the boundaries, changes of hydraulic properties within the geologic formations must be determined. The key criterion for defining the Biscayne aquifer apparently is the presence of highly permeable limestone or calcareous sandstone in the Fort Thompson Formation, Anastasia Formation, or Key Largo Limestone.

The hydraulic behavior of the Biscayne aquifer may also cause confusion. In his 1951 definition, Parker stated that the Biscayne aquifer carries unconfined ground water. Throughout the area (except near well fields or margins of water-conservation areas), water levels at depth are almost identical to the local water table. Water in the Biscayne aquifer is unconfined in that the potential distribution (as indicate by water levels in tightly cased wells) is closely related to the water table or to surface-water bodies. Because of considerable stratification and local permeability variations of the aquifer, aquifer tests of highly permeable zones overlain by much less permeable sand or muddy sand may exhibit semiconfined behavior, particularly during early stages of pumping.

The Biscayne aquifer is redefined herein as that part of the surficial aquifer system in southeast Florida comprised (from land surface downward) of the Pamlico Sand, Miami Oolite, Anastasia Formation, Key Largo Limestone, and Fort Thomson Formation all of Pleistocene age, and contiguous highly permeable beds of the Tamiami Formation of Pliocene age where at least 10 feet of the section is very highly permeable (a horizontal hydraulic conductivity of about 10,000 ft/d or more). Solution-riddled limestone or sandstone of Broward and Dade Counties has hydraulic conductivities often exceeding 10,000 ft/d. The permeability requirement of this definition provides a means of estimating the aquifer boundary where the Fort Thompson Formation, Anastasia Formation, or Key Largo Limestone grade laterally into less-permeable facies. If there are contiguous highly permeable (having hydraulic conductivities of about 100 ft/d or more) limestone or calcareous sandstone beds of the Tamiami Formation, the lower boundary is the transition from these beds to subjacent sands or clayey sands. Where the contiguous beds of the Tamiami Formation do not have sufficiently high permeability, the base of highly permeable limestone or sandstone in the Fort Thompson Formation, Anastasia Formation, or Key Largo Limestone is the base of the Biscayne aquifer.

Gray Limestone Aquifer

In addition to the Biscayne aquifer, a previously undefined aquifer, composed of gray (in places, greenish-gray or tan) limestone of the lower part and locally the middle part of the Tamiami Formation, was found at depth in west Broward County (fig. 7b). The gray limestone usually is shelly with abundant shell fragments or carbonate sand and minor quartz sand, and it is lightly to moderately cemented. Laterally, the gray limestone grades eastward to less-permeable, sandy, clayey limestone and eventually sand and sandstone, except at one locality where coarse shell sand and quartz occur. Although it is less permeable than the Biscayne aquifer, the gray limestone is nevertheless a significant aquifer and a potential source of water. The aquifer is informally and locally named here as the gray limestone aquifer. It is defined as that part of the limestone beds (usually gray) and contiguous coarse clastic beds of the lower to middle part of the Tamiami Formation that are highly permeable (having a hydraulic conductivity of about 100 ft/d or more) and at least 10 feet thick. Above and below the gray limestone aquifer in west Broward County and separating it from the Biscayne aquifer and the base of the surficial aquifer system are sediments having relatively low permeability, such as mixtures of sand, clay, silt, shell, and lime mud, and some sediments of moderate to low permeability, such as limestone, sandstone, and claystone (fig. 7b).

Subsequent drilling has traced the gray limestone aquifer into southwest Palm Beach County where the water contains high dissolved solids (W.L. Miller, U.S. Geological Survey, oral commun., 1984) and into northwest Dade County where the water generally has low dissolved solids. The aquifer probably extend westward into Collier County, and it likely is the source of water for irrigation and drinking on the Seminole Indian Reservation and sugar cane fields of southeast Hendry County.

ESTIMATES OF TRANSMISSIVITY, HYDRAULIC CONDUCTIVITY, AND STORAGE COEFFICIENT

The principal hydraulic characteristics determined for this investigation are horizontal hydraulic conductivity and transmissivity. The hydraulic conductivity K of material comprising an aquifer is a measure of the material’s capacity to transmit water. The transmissivity T is the rate at which water is transmitted through a unit width of the saturated thickness of the aquifer under a unit hydraulic gradient. For a given uniform material, hydraulic conductivity and transmissivity are related by the expression:

$$T = Kb \tag{1}$$

where

T is transmissivity, in square feet per day,
K is hydraulic conductivity, in feet per day, and
b is thickness of the uniform material, in feet.

Three methods were used to obtain estimates of transmissivity or hydraulic conductivity; (1) calculation from specific capacities of municipal supply wells; (2) aquifer test results from published U.S. Geological Survey reports, from a report by the U.S. Army Corps of Engineers, or from reports prepared by consulting firms; and (3) tests conducted in this study. The estimates provided the primary basis of the hydraulic conductivity framework portrayed in the next section.

Where several layers of differing materials occur ("n" layers), the aggregate or total transmissivity of the aquifer is the sum of the transmissivities of the individual layers, expressed by:

$$T = \sum_{i=1}^{n} T_i = \sum_{i=1}^{n} K_i b_i \tag{2}$$

where

T is total transmissivity,
T_i is transmissivity of the ith layer of the n layers,
$K_{\bar{i}}$ is hydraulic conductivity of the ith later of the n layers, and
b_i is thickness of the ith layer of the n layers.

The average hydraulic conductivity K, of a sequence of layers is then:

$$\bar{K} = \frac{T}{\sum_{i=1}^{n} b_i} \tag{3}$$

Hydraulic conductivities for individual layers or for aggregate sections are calculated from the above relation (eq. 3) after transmissivity estimates have been obtained. At some sites, the storage coefficient S, defined as the volume of water and aquifer releases form or takes into storage per unit surface area per unit change in head, is also determined. Values of S are usually about 0.2 for water-table aquifers and 10^{-5} and 10^{-3} for confined aquifers (Lohman, 1979).

Specific Capacity of Production Wells and Estimated Transmissivity

Theis and others (1954) suggested procedures for estimating transmissivity from specific capacity (Q/s) data by means of the Thies nonequilibrium equation expressed as:

$$T = \frac{Q}{4\pi s} W(u) = \frac{W(u)}{4\pi} \frac{Q}{s} \tag{4}$$

where

$W(u)$ is well function of u and $u = r^2S/4Tt$,
t is time, in days,
r is distance from pumping well to point of observation or effective radius of pumped well in single well tests,
Q is pumping rate (length^3/time),
s is drawdown (length), and
S is storage coefficient (unitless).

By substituting into the expression for u, the extreme values of the variable for an aquifer (T, S), effective well radius, and pumping time for a given area, the range of values of the term $W(u)/4\pi$ may be evaluated for that area (McClymonds and Franke, 1972, described this procedure in a regional study of Long Island, New York). For Broward County, the range was found to be from 170 to 370, and averaged about 270, for T in square feet per day when the specific capacity (Q/s) is expressed in gallons per minute per foot of drawdown. Thus, an approximate value of transmissivity may be obtained from:

$$T = 270\frac{Q}{s} \tag{5}$$

In addition to the potential errors in the original data and in using an average value of 270, any deviations from the Theis assumptions are limitations on the accuracy of the estimated transmissivity. The effects of leakage on drawdown are small near the production well; hence, deviations from true confinement are minimized at the production well (Neuman and Witherspoon, 1972). In Broward County, the effective radius of a production well may be substantially larger than the nominal radius because most of the wells are open to cavity-riddled zones. This would result in a higher specific and estimated transmissivity. However, turbulent flow may occur in cavities near wells, causing greater drawdown, and therefore, a smaller specific capacity and a smaller estimated transmissivity. Finally, the development of the equation above assumes a 100-percent efficient well. However, friction losses at the well screen or rock face and in the well also cause greater drawdown, and therefore, a small specific capacity and a smaller estimate of transmissivity. Thus, the limitations described are partly offset.

Construction details and production test data for selected supply wells in east and central Broward County are given in table 2 (shown at the end of report); site locations are shown in figure 9. The data were compiled from information provided by the well owners or from files of the South Florida Water Management District. Well diameters, ranging from 4 to 24 inches, and type of finish are given because pumping capacity varies with those factors. Although open-hole finish predominates, screened wells are common. The production intervals identify highly permeable zones at each site and were helpful in preparation of the permeability framework. The discharges and drawdowns are those reported on well completion test forms rather than the rated capacity of the pump and well. Although, in many cases, the pumping period is not known, examination of detailed test data from several wells shows that virtually all the drawdown occurs within a few minutes. Specific capacities were calculated, and the maximum and minimum values of specific capacity for each site are shown in figure 9.

Histograms of the specific capacity for supply wells in four areas in east and south-central Broward County are shown in figure 10. Most specific capacities range from 100 to 2,000 (gal/min)/ft. In the north (areas 2 and 4), specific capacities tend to be lower, on the average, than in the south (areas 1 and 3). In area 4, most are less than 100 (gal/min)/ft. The highest values are in south-

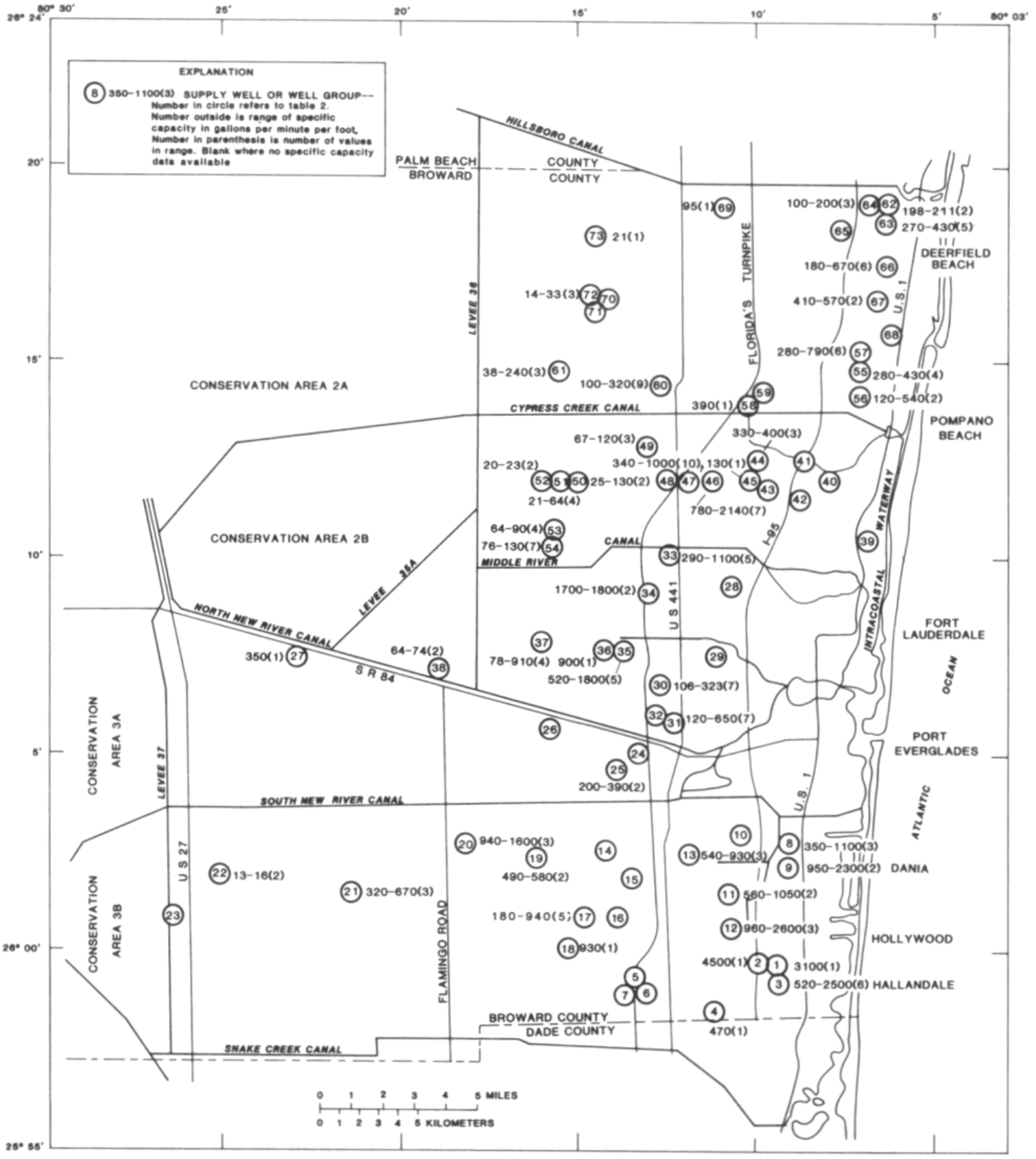

Figure 9. Location and range of specific capacity for supply wells in east and south-central Broward County.

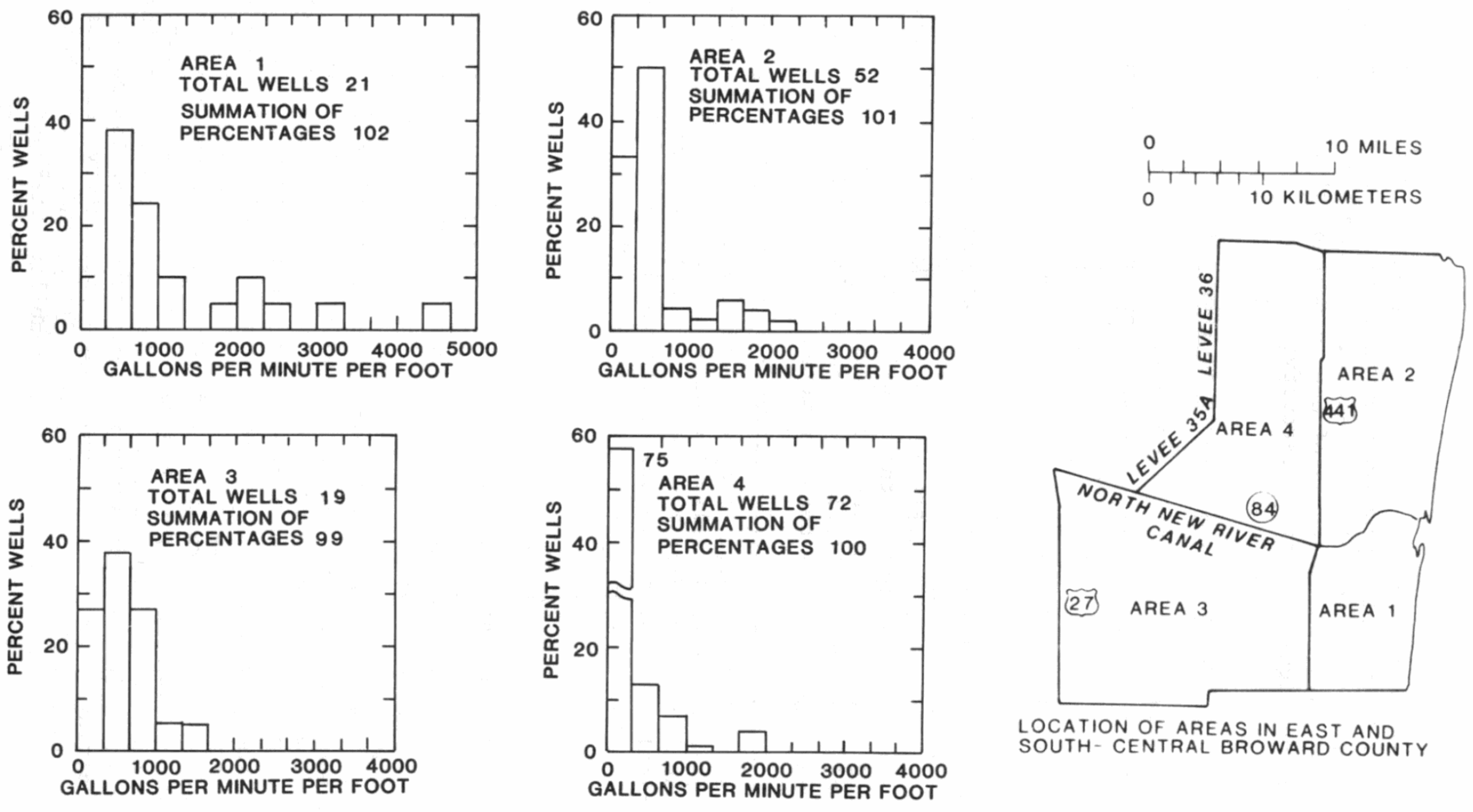

Figure 10. Specific capacity for supply wells in four areas in east and south-central Broward County

east Broward County (area 1), as high as 4,500 (gal/min)/ft at a Hallandale municipal supply well. Figure 10 also shows, in general, that specific capacities are higher, on the average, in the coastal areas (1 and 2) than in the inland areas (3 and 4) directly west.

At most well fields, there is a considerable range in specific capacity. For example, values range from 520 to 4,500 (gal/min)/ft at Hallandale and from 100 to 320 (gal/min)/ft at Margate Utilities. Factors causing variations include (1) differing well efficiency and well diameter, (2) differing thickness of production interval, (3) differing depth intervals tapped by the wells, and (4) local variations in transmissivity. A significant amount of the variation is normally caused by differences in well efficiency and well construction.

Estimates of transmissivity from specific capacities provide many values that maybe used to characterize transmissivity in local areas and may reveal areal trends or patterns. Transmissivities calculated from the relation $T = 270\ Q/s$ are shown in table 2 (at the end of report). Virtually all the supply wells are open to only part, often less than 25 percent, of the highly to very highly permeable materials in the Biscayne aquifer. Therefore, the transmissivity of the aquifer should be greater than the estimated value. Two methods commonly used to correct for partial penetration—one used by McClymonds and Franke (1972) on Long Island, N.Y., and also Bredehoeft and others (1983) for the Dakota aquifer; and the other proposed by Turcan (1963) and advocated by Walton (1970)—were applied to three sites. However, the results were many times greater than values estimated directly from the specific capacity by equation 5 and are considered unreasonably high. (One "corrected" value was 17,000,000 ft^2/d.) Correction methods are often hard to apply in Broward County because of the difficulty in determining the thickness of the highly permeable zone of the aquifer; the production intervals of the wells are commonly very short, sometimes 5 feet or less (therefore, water is probably drawn from much more of the aquifer than the production interval); and the methods assume homogeneous aquifer materials, whereas in detail the very highly permeable zone is heterogeneous, having layers ranging from sand to limestone with large cavities. A representative transmissivity at a given site is considered to be in the range of one to perhaps three times the value calculated from the highest specific capacity.

Previously Available Aquifer Tests

Conducting carefully controlled and successful aquifer tests in southeast Florida is difficult because: (1) large wells and pumps are needed to adequately stress the very transmissive aquifer; (2) the aquifer has a highly layered and nonuniform permeability distribution, thus, partial penetration and approximate nature of hydraulic models are common problems; (3) a long time is needed to determine the storage coefficient if a delayed yield type of response occurs; (4) boundary effects occur as drawdown propagates outward very rapidly and encounters surface-water recharge sources (canals, lakes, or quarries); (5) small and rapid drawdown, which may also introduce inertial effects, makes early time data difficult to collect; and (6) the pumped water must be removed a long distance so that local water levels in the test area may often be obtained from as little as 5 feet of highly permeable rock, aquifer tests have not commonly been conducted.

Selected aquifer test results from published U.S. Geological Survey reports are listed in table 3. Also included is a notation characterizing the method of analysis. Despite the above practical problems and the use of various analytical methods, the values listed provide an indication of aquifer transmissivity at those sites. Locations of the sites are shown in figure 11.

Tests Conducted in this Study

Most of the field tests for this study were conducted in central or west Broward County where there was little previous data (fig. 11). For various pumping tests, 23 wells were installed: 22 were 6-inch wells (with 6-inch open interval) and 1 was a 5-inch well (with 8-inch open interval). At many sites, separate wells were placed in the upper and lower parts of the Biscayne aquifer. At six western sites, wells were also installed in the gray limestone or in a shell sand of the Tamiami Formation. One pumping test was performed in a deep zone in east Broward County where the only data available in deep zones (below 150 feet) were two specific capacity tests of production wells. All of the production wells have open-hole construction, except for two, which are screened, located at the Twenty-Six Mile Bend site (fig. 11, G-2312). Because the wells were installed using an air-circulation method (no drilling mud), clogging of pore spaces or cavities in the aquifer was minimized. Several small-diameter (1 1⁄2- or 2-inch) wells were also installed for monitoring water levels, primarily in zones other than the pumped zone and for slug testing. Most of these wells gave oscillatory responses to slug tests, which indicate moderate to high permeability; therefore, those results are used only as a general guide for the permeability framework.

The field tests may be divided into three types: single-well pumping tests using only the pumped wells for observations of response in the production zone, multiple-well pumping tests where a separate observation well in the pumped zone was also motored, and slug tests. The single-well pumping tests included step-drawdown tests, drawdown-recovery tests, and specific capacity tests. By use of a 4-inch suction pump, discharges up to 530 gal/min were obtained. Transmissivities and hydraulic conductivities obtained from the pumping tests and well construction data are listed in table 4.

Step-drawdown tests were run at sites with moderate to high transmissivities. Pumping rates typically were about 160, 260, 370, and 500 gal/min, but for comparatively low transmissivity zones, the pumping rates were reduced as needed. For the lowest transmissivity zones, only specific capacity tests were run at low pumping rates to minimize well losses. The step-drawdown tests were usually run as independent cycles, each cycle consisting of 30 minutes of pumping followed by a recovery period. Whenever recovery was sufficiently slow, the highest discharge step was run for 60 to 100 minutes followed by recovery measurements. The Biscayne aquifer recovered far too quickly, within 1 or 2 minutes, to make satisfactory measurements, but recovery tests were sometimes possible in the gray limestone aquifer, and transmissivity values calculated from recovery data were similar to the step-drawdown test results.

Jacob (1947) expressed drawdown in a pumped well by the relation:

$$s_w = BQ + CQ^2 \qquad (6)$$

where

s_w is drawdown in pumped well,
BQ is aquifer loss term,
CQ^2 is well loss term,
B is constant,
C is constant, and
Q is discharge.

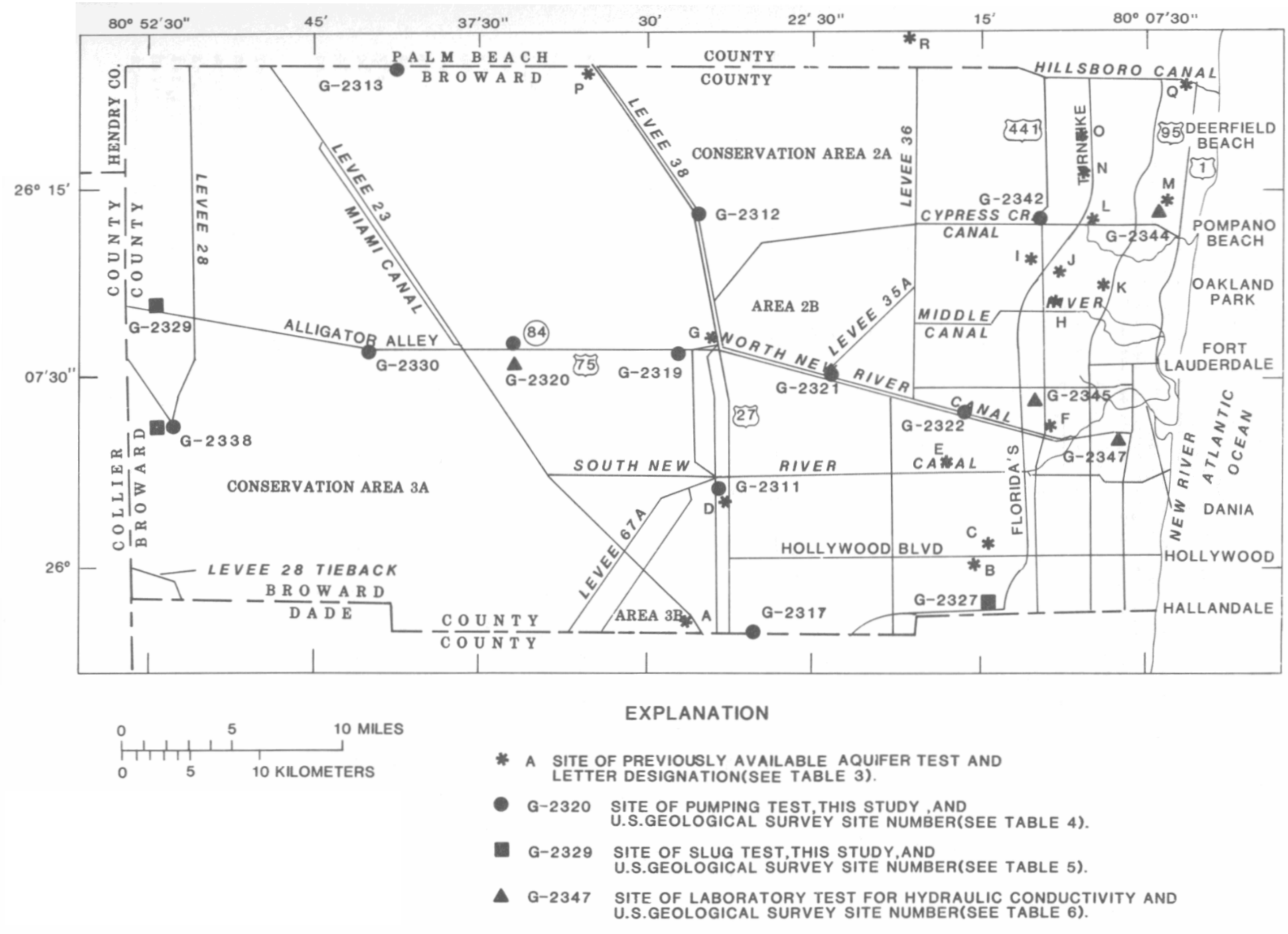

Figure 11. Location of previously available aquifer tests and various hydraulic tests conducted in this study.

Table 3. Aquifer hydraulic properties determined in previously available tests

[See figure 1 for location of sites. Location or owner: AA, Alligator Alley; FL-D, Fort Lauderdale-Dixie well field; P, Prospect well field; PB-P, Pompano Beach-Palmaire well field; SFSH, South Florida State Hospital; SR-7, State Road 7. Latitude and longitude for sites represented by map letter C, F, J, L, M, and Q are accurate to ±1 second; latitude and longitude for the remaining sites are accurate to ±30 seconds. Method of test analysis: DY, delayed yield (Boulton, 1963; Neuman, 1972); E, equilibrium (U.S. Army Corps of Engineers, 1953); L, leaky (Hantush and Jacob, 1955); NL, nonleaky (Theis, 1935), CH_2M is CH_2M Hill, Inc.; M&DM is James M. Montgomery, Consulting Engineers, Inc., and Dames and Moore.

Inch-pound units: Transmissivity, in square feet per day; Storage coefficient or specific yield, is unitless; --, data not available.]

Map letter	Location of owner	Latitude	Longitude	Date of test	Method of test analysis	Transmissivity	Storage coefficient or specific yield	Source of information	Remarks
A	Miami Canal	255730	0802730	1952	E	640,000	--	ACE (1953)	
B	SFSB	260000	0801500	1985	DY	180,000+	--	M&DM (1985)	Tested only deep zone; less transmissive than usual production zone.
C	Pembroke Pines	260050	0801450	1985	DY	510,000	--	M&DM(1985)	
D	Near S-9 pump station	260330	0802600	1951	E	920,000	--	ACE (1953)	
E	Tree Tops Park	260400	0801630	1985	DY	900,000	--	M&DM (1985)	
F	FL-D well field	260609	0801205	1947	NL	160,000	--	CDM (1980a)	Partially penetrating production and observation wells.
G	Near U.S. Highway 27 and AA	260845	0802630	1951	E	110,000	--	ACE (1953)	
H	Canal C-13 and SR-7	261020	0801210	1980	DY	97,000	0.093	CDM (1980a)	Corrected for partial penetration.
I	North Lauderdale	261300	0801315	1985	DY	140,000	--	M&DM (1985)	
J	P (Fiveash)	261143	0801121	1979	DY	260,000	.25	CDM (1980b)	Corrected for partial penetration. Production well 36.
K	P (Executive Airport)	261130	0801000	1956-57	L, NL	330,000	.015	Sherwood (1959)	
L	PB-P	261355	0801030	1979	NL	90,000	--	CH_2M (1979)	
M	Pompano Beach	261520	0800705	1961	NL	200,000	.30	Tarver (1964)	
N	Trade winds Park	261600	0801030	1985	DY	360,000	--	M&DM (1985)	
O	Winston Park	261730	0801030	1985	DY	120,000	--	M&DM (1985)	
P	North New River Canal	262000	0803230	1951	E	8,700	--	ACE (1953)	
Q	Deerfield Beach	261901	0800643	1961	L	53,000	.004	Tarver (1964)	See footnote 1.
R	Hillsboro Canal	262115	0801750	1951	E	0.86+	--	ACE (1953)	Test conducted in 4.6 feet of near-surface limestone; does not include deeper limestones.

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[1] Sherwood and others (1973) report transmissivity at site is much higher than that shown because more permeable zone occurs below tested interval.

Table 4. Aquifer hydraulic properties determined from pumping test in this study

[See figure 11 for location of sites and table 1 for informal site name. USGS, U.S. Geological Survey; SN, sequence, number. Well finish: OH, open hole; S, screen. Geologic formation: Qa, Anastasia Formation; Qf, Fort Thompson Formation; Tt, Tamiami Formation. Type of test: 1, step-drawdown test (Jacob, 1947; Bierschenk, 1963); 2, multiple well aquifer test (Theis, 1935; Cooper and Jacob, 1946; Hantush and Jacob, 1955; Cooper, 1963); 3, specific capacity test (Theis and others, 1954; McClymonds and Franke, 1972); 4, single well (production well) recovery test (Theis, 1935). Inch-pound units: diameter of open interval, in inches; open interval, in feet below land surface; approximate aquifer interval affected by test, in feet below land surface; transmissivity, in square feet per day; approximate average hydraulic conductivity, in feet per day. Remarks: S/C, storage coefficient; S/S, specific storage; GL, gray limestone aquifer.]

USGS well number	Site identification number			Well finish	Diameter of open interval	Open interval	Approximate aquifer interval affected by test	Geologic formation	Type of test	Transmissivity	Approximate average hydraulic conductivity	Remarks
	Latitude	Longitude	SN									
G-2311A	260335	0802637	03	OH	6	22.5-30	21-32	Qf	1	240,000	22,000	Estimate may be high because of leakage from nearby canal.
G-2311B	260335	0802637	02	OH	6	40-65	36-65	Qf	1	670,000	23,000	
G-2312J	261347	0802737	03	S	6	110-140	106-140	Tt	2,3	22,000	650	S/C S=6x10^{-5}
G-2312K	261347	0802737	04	S	6	40-50	40-62	Tt	3	9,000	300	Partially penetrating well
G-2313A	261958	0804106	02	OH	6	12-22	12-22	Qf	3	18,000	1,800	Most flow is from interval 17-22 feet
G-2313B	261958	0804106	03	OH	6	46-81	46-82	Tt	3	9,000	280	GL, upper part
G-2313C	261958	0804106	04	OH	6	106-146	106-146	Tt	1	26,000	650	See footnote 1
G-2313J	255722	0802455	02	OH	6	40-61	40-61	Qf	1	710,000	34,000	
G-2317K	255722	0802455	03	OH	6	20-30	20-33	Qf	1	66,000	5,000	Same as for G-2311A
G-2319D	260843	0802839	06	OH	6	31-49	31-50	Qf	1	430,000	23,000	
G-2319X	260843	0802839	02	OH	6	118-140	113-156	Tt	4	22,000	590	Thickness of GL is 37 feet; 43-foot aquifer interval includes 6 feet of sand
G-2320J	260846	0803542	02	OH	6	93-167	83-167	Tt	1	67,000	910	Transmissivity of whole aquifer is about 76,000 square feet per day; GL.
G-2320X	260846	0803542	08	OH	6	30-55	30-59	Qf	1	66,000	2,600	See footnote 2
G-2321J	260742	0802200	02	OH	6	60-88	51-87	Qf, Tt	1	870,000	24,000	Very high permeability from 65-75 feet, especially in cavities at 70-73 feet.
G-2321K	260742	0802200	03	OH	6	15-24	16-24	Qf	1	260,000	32,000	Same as for G-2311A
G-2322F	260617	0801612	07	OH	6	69-117	69-117	Qa, Tt	1	600,000	13,000	
G-2330X	260844	0804159	04	OH	6	20-33	21-33	Qf	1	67,000	5,600	
G-2330Y	260844	0804159	03	OH	6	38-48	38-49	Qf	1	860,000	78,000	
G-2330Z	260844	0804159	02	OH	6	81-167	72-167	Tt	1, 2, 4	88,000	930	S/C S=7x10^{-5} and S/S S_s= 8x10^{-7} foot^{-1}; GL.
G-2338B	260532	0805036	03	OH	6	10-33	10-35	Qf, Tt	3	17,000	680	
G-2338C	260532	0805036	04	OH	6	102.5-156	101-157	Tt	2	50,000	890	See footnote 3.
G-2342B	261348	0801220	03	OH	8	170-190	170-190	Tt	3	1,500	75	

[1] Overlying semiconfining layer is very leaky; 0.7 foot of drawdown occurred in G-2313B and 0.1 foot of drawdown in G-2313A (both wells 15 feet away); GL, lower part.

[2] Pumping another 6-inch diameter well open from 35 to 55 feet indicates even lower transmissivity for Biscayne aquifer at this site.

[3] Nearly ideal for Theis assumptions; recovery analysis of pumped well and both straight-line drawdown and recovery analyses of observation wells at radial distances of 29.7 and 100 feet agree very closely on transmissivity; S/C S≅1x10^{-5} and S/S S_s≅3x10^{-7}; open and affected intervals are from top of levee about 6 feet above land surface; GL.

The step drawdown test is a method of evaluating the aquifer loss, *B*, and well loss, *C*, constant and assigning relative amount of drawdown (head loss) to the aquifer and to the well. Bierschenk (1963) used a plot of s_w/Q versus Q to determine *B* (the *Y*-intercept) and *C* (the slope of the line). Once *B* is determined, the specific capacity of an ideal well (one that measures only aquifer losses can be calculated from $Q/S = 1/B$, and a transmissivity can be estimated from this specific capacity. The average constant 270 was used, as before, for the Biscayne aquifer, The multiplier of 300 was used for the gray limestone aquifer, which is semiconfined and has a much narrower range of hydraulic characteristics (small storage coefficient and limited ranges of transmissivity, on the basis of results shown in table 4 and other tests recently completed in Dade County).

A Bierschenk type of plot for selected wells used in this study is shown in figure 12. This figure illustrates the method, and the six wells selected are representative of the three groups that the data formed. The Biscayne aquifer data are divided into two distinct groups—an upper, less-transmissive zone and a deeper, highly transmissive zone. The data from the gray limestone forms a third group having a different slope than the upper Biscayne zone but having roughly similar B value and transmissivity. Both zones of the Biscayne aquifer occur in central and west Broward County.

The relation between specific capacity and pumping rate for selected wells is shown in figure 13. As in figure 12, the wells may be divided into three groups. In the upper group are wells that tap high transmissivity zones of the Biscayne aquifer at depths generally ranging from 40 to 80 feet. Specific capacities for this group increase rapidly with decreasing pumping rate, and the curvature indicates that well losses are greater than aquifer losses in the drawdown relation (eq. 6) over most of the range of pumping rate. Drawdown at the lowest pumping rates (about 160 gal/min) ranged from 0.16 to 0.30 foot.

A second group of three wells are open to most or all of the gray limestone aquifer at the respective sites. Results from these wells from straight or slightly curved lines at much lower specific capacities. For these wells, aquifer and well losses are more nearly equal for the range of pumping rate shown.

Three shallow wells open to less cavernous limestone and muddy sand in the upper part of the Biscayne aquifer plot in the range similar to wells finished in the gray limestone. The plots for these wells are slightly more curved than those of the gray limestone aquifer. This variation could be caused by different hydraulic effects of flow in cavities, variable effective radius as a function of pumping rate, or by some influence of nearby canals.

Aquifer tests or recovery tests were performed at four sites, of which three had one or more observation wells in the production zone. The observation wells were placed near the pumped wells to minimize the effects of leakage and to obtain measurable drawdowns. A transducer and high-speed chart recorder were used on one of the tests (well G-2312J) to obtain accurate early time water-level measurements during pumping and recovery periods. Data from the aquifer tests were analyzed by a nonleaky semilog drawdown method described by Cooper and Jacob (1946) and the recovery method (Theis, 1935; Todd, 1980, p. 131-135), or by leaky aquifer methods described by Cooper (1963) and Hantush and Jacob (1955). The results, listed in table 4, include storage coefficients that are accurate within about one-half order of magnitude. Examples of recovery tests are shown in figure 14.

An estimate of average horizontal hydraulic conductivity may be calculated from the transmissivities obtained from the tests (table 4) using equation 3. For specific capacity or step-drawdown test, the length of open hole or screen is a reasonable estimate of the thickness of the aquifer that contributes most of the flow to the well, if the aquifer has significantly greater horizontal hydraulic conductivity than vertical hydraulic conductivity (as shown by layering) and if the open interval is relatively long (McClymonds and Franke, 1972, p. E11). For wells having short open intervals (less than about 20 to 25 feet) in the Biscayne aquifer, an estimate of the principal aquifer intervals supplying water to the wells, on the basis of drilling observations, lithologies, and wells in other intervals, was used to calculate the hydraulic conductivity. For the multiwell aquifer tests and the single-well recovery tests, the aquifer thickness (excluding sand beds in permeable limestone) rather than the open interval was used in the calculations.

Slug tests were performed on five small-diameter wells open to sand or semiconfining materials to obtain hydraulic conductivities for some of the less-permeable materials in the surficial

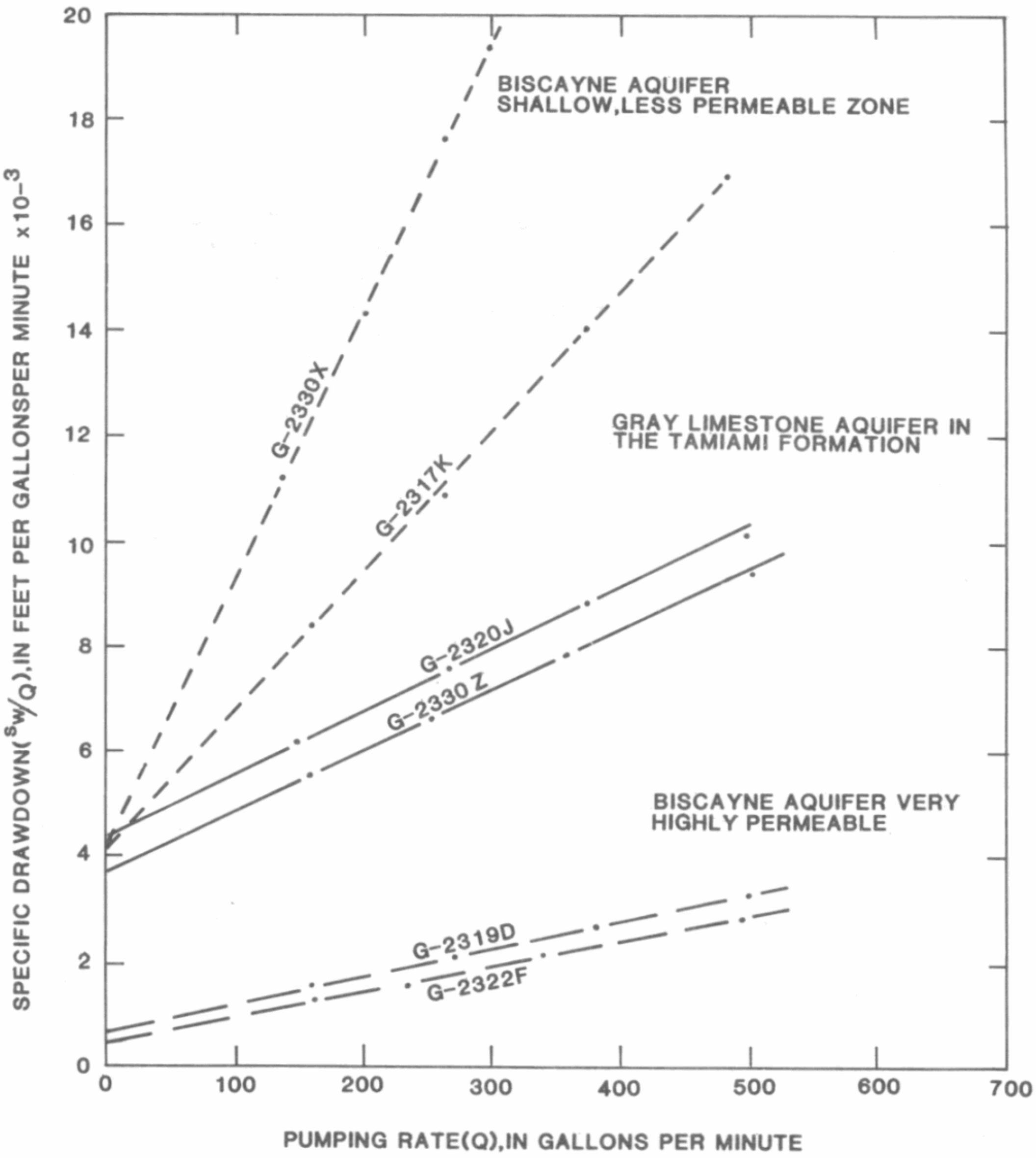


Figure 12. Relation between specific drawdown (s_w/Q) and pumping rate (Q) for selected test wells.

aquifer system. For three tests, air pressure was used to displace the water level, and a transducer and high-speed chart recorder were used to monitor water-level recovery (method described by Prosser, 1981). For two tests where water-level responses were slow, a bailer and chalked tape were used. Data from these tests were analyzed by the Hvorslev method (Hvorslev, 1951), which is suitable for water-table conditions (E.P. Weeks, U.S. Geological Survey, oral commun., 1984). Results of these teste are shown in table 5.

Laboratory tests for hydraulic conductivity and porosity were performed on nine rock samples obtained from various zones during normal drilling operations by the dual-tube reverse-air method. (Coring and testing were performed by Core Laboratories, Inc., Dallas Texas.) Horizontal and vertical directions were determined for the samples from bedding features and shape. Horizontally oriented cores of 1-inch diameter were cut to obtain horizontal hydraulic conductivities, K_h,

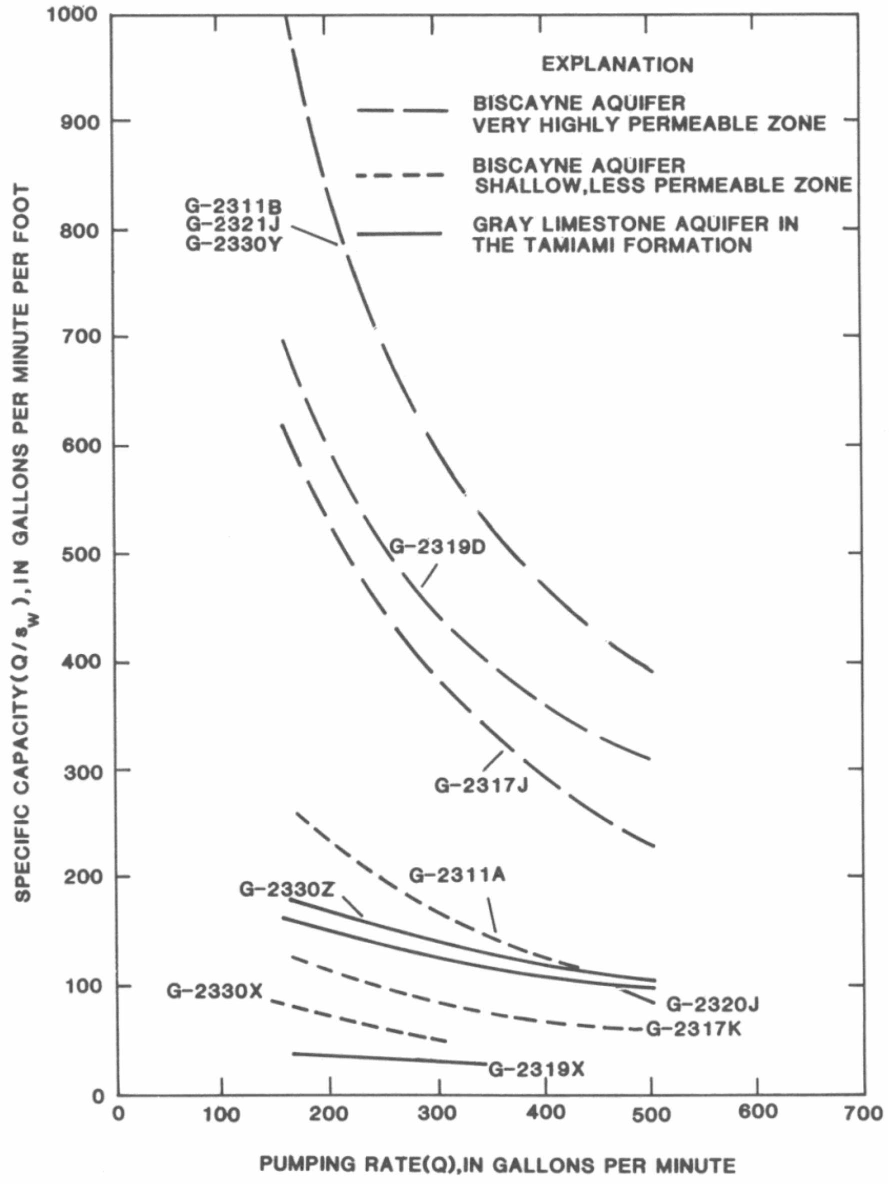


Figure 13. Relation between specific capacity (Q/s_w) and pumping rate (Q) for selected test wells.

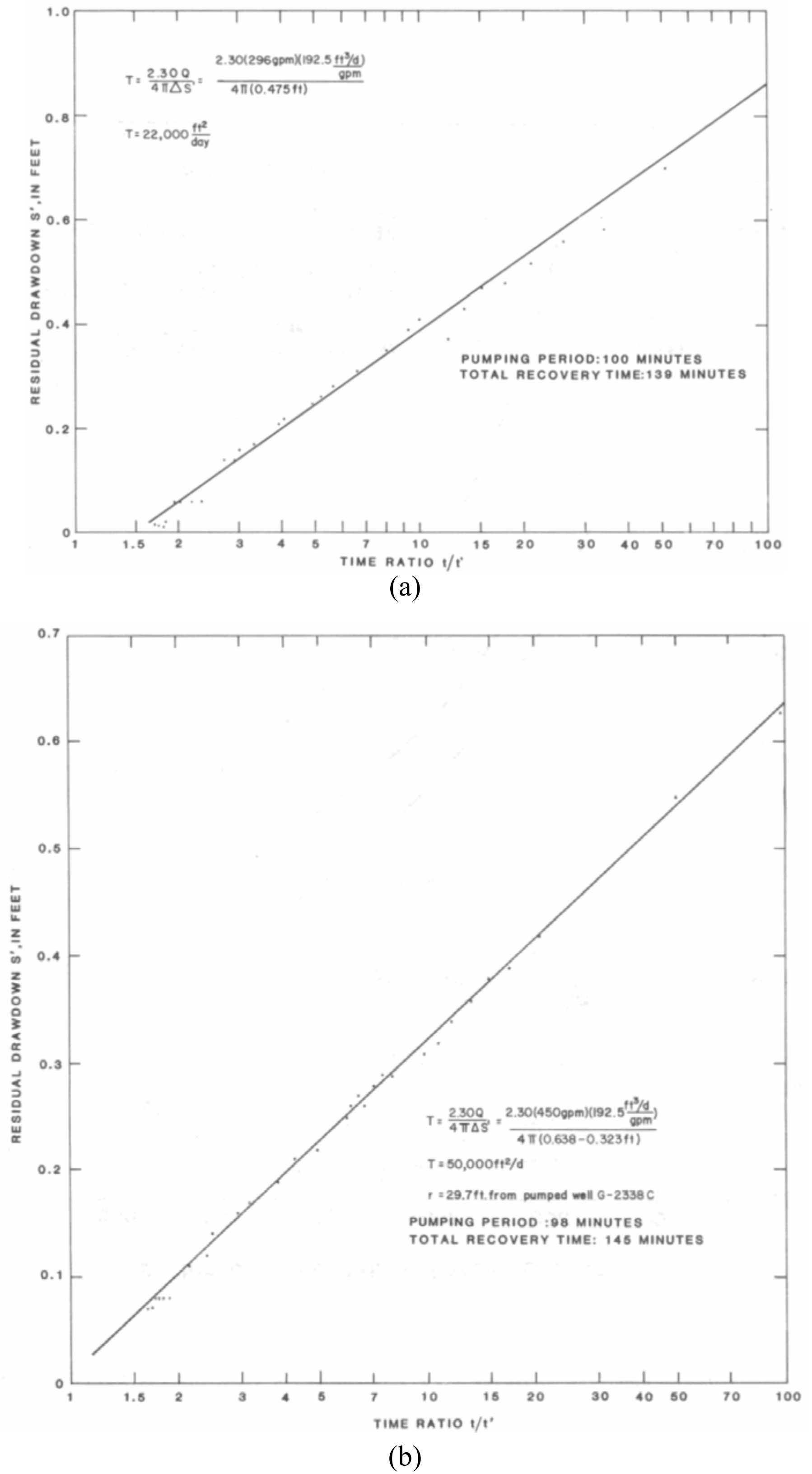


Figure 14. Recovery test plots and analyses for (a) pumped well G-2319X at site G-2319 and (b) observation well G-2338D at site G-2338. “T” is total time elapsed since pumping began and “T” is time since recovery began (end of pumping).

except for one sample which probably was oriented so as to yield a vertical hydraulic conductivity, K_v. Water similar in composition to native ground water was uses for the tests. Porosity was determined using a helium—Boyle's law technique to measure pore volume and then crushing the sample to grain size to measure grain volume. Results of these tests are shown in table 6.

HYDROGEOLOGY

Hydraulic Conductivity Framework and Hydraulic Conductivity of the Sediments

The hydraulic conductivity framework (permeability distribution) of the surficial aquifer system is portrayed by superimposing ranges of hydraulic conductivities on the eight geologic sections prepared by Causarás (1985). The framework is shown in figures 15 to 22 (location of well and sections are shown in fig. 3). Some aspects of areal variations in the lithology of geologic formations are included here as part of the discussion of the hydraulic conductivity framework because of relations between lithology and hydraulic conductivity. Detailed lithologic logs for each well and a description of the geology of the aquifer system are contained in the report by Causarás (1985). In addition to the hydraulic data and municipal well data reported in the previous section, other information used to construct the hydraulic conductivity framework included:

- Flow rates obtained while drilling the test holes by the dual-tube reverse-air method;
- Hydrologic inferences from inspection of all the geologic samples;
- Published values of hydraulic conductivity in relation to grain size and sorting for clastic sediments and sandstone; and
- Grain-size and sorting descriptions by Causarás (1985) and sieve analysis of selected samples.

The range of hydraulic conductivities of the materials that make up the surficial aquifer system is about seven orders of magnitude—from more than 10,000 ft/d for the more permeable cavernous zones to about 0.001 ft/d or less for dense green clay. For the hydraulic conductivity sections, this range is divided into five categories, and general lithologies are shown in table 7. Virtually all materials having hydraulic conductivities more than 1,000 ft/d occur only in the Biscayne aquifer—the possible exception being local areas of the gray limestone aquifer. Large supply wells are usually finished in materials that have high to very high permeabilities. Materials that have moderate permeability are considered the lower limit useful in this area as an aquifer for water supply, primarily for domestic purposes. Materials of low permeability (from 0.1 to 10 ft/d) are not generally used for supply but permit seepage or leakage of water to more permeable beds. Materials of very low permeability to practically impermeable (less than 0.1 ft/d) will retard ground-water circulation considerably where present in thicknesses of a few feet or more.

The sections (figs. 15-22) provide an indication of the horizontal hydraulic conductivity of the rocks or sediments. Because of the scale of the sections, rapid vertical changes in lithology and permeability could not be shown. Where it appears that a few or several thin zones of high permeability occur, separated by less-permeable materials (for example, dense limestone), the higher range is shown. In such instances, the sections give a more accurate portrayal of the capability of the formation to permit lateral movement of water than to permit vertical movement.

Table 5. Hydraulic conductivities determined from slug tests in this study

[See figure 11 for location of sites and table 1 for informal site name. USGS, U.S. Geological Survey; SN, sequence number. Well finish, is screen. Method of analysis, is Hvorslev (1951). Inch-pound units: approximate interval tested, in feet below land surface; hydraulic conductivity, in feet per day. Geologic formation: Qf, Fort Thompson Formation; QP, Pamlico Sand; Tt, Tamiami Formation.]

USGS well number	Latitude	Longitude	SN	Approximate interval tested	Geologic formation	Lithology	Hydraulic conductivity
G-2327A	255820	0801448	01	23.5-26.5	Qp	Fine sand, minor lime mud, moderately sorted.	44
G-2327B	255820	0801448	02	39.5-42.2	Qp	Fine sand, minor lime mud, moderately sorted.	27
G-2329A	261014	0805122	02	17-20	Qf	Fine sand with lime mud.	16
G-2329B	261014	0805122	03	36-40	Tt	Mixed lime mud, shell fragments, quartz sand.	.16
G-2338H	260532	0805036	09	68.2-70	Tt	Very fine sand, silt and clay.	.061

Table 6. Hydraulic conductivities and porosities of samples determined by laboratory tests

[Tests performed by Core Laboratory, Inc., Dallas, Texas. See figure 11 for location of sites and table 1 for informal site name. Inch-pound units: sample depth interval, in feet below land surface; porosity, in percent; hydraulic conductivity, in feet per day. Geologic formation: Th, Hawthorn Formation; Tt, Tamiami Formation. Direction of test: Kh, horizontal hydraulic conductivity; Kv, vertical hydraulic conductivity].

USGS well number	Latitude	Longitude	SN	Sample depth interval	Geologic formation	Lithology	Porosity	Hydraulic conductivity	Direction of test
G-2320	260846	0803542	01	79-83	Tt	Quartz sandstone	37	12	Kh
G-2344	261423	0800715	01	466-469	Th	Sandy calcarenite, friable	41	.40	Kv
G-2345	260641	0801235	01	176-179	Tt	Limestone	40	5.1	Kh
				179-183	Tt	Do.	39	3.3	Kh
				189-193	Tt	Do.	38	4.4	Kh
G-2347	260507	0800856	01	359-363	Th	Sandy calcarenite, friable	38	3.4	Kh
				399-403	Th	Do.	45	.61	Kh
				419-423	Th	Do.	47	1.3	Kh
				463-466	Th	Do.	48	8.9	Kh

West Broward County

A generalized west Broward County hydrogeologic section begins at land surface with a few feet of peat, muck, and lime mud of freshwater limestone. (At the drill sites, some of these materials have been replaced with road or levee fill.) Below, to depths of 30 to 40 feet (figs. 15, 17, 18, and 20) are interbedded materials of the upper part of the Fort Thompson Formation consisting of hard, dense, cream, gray, or brown limestone, particularly in the upper part (fig. 23); sand or sand and shell with lime mud matrix; and some limestone with poorly to moderately developed solution-cavity zones. These upper beds generally retard vertical movement of water, but thin zones with cavities may be very highly permeable.

Below the upper part of the Fort Thompson Formation is the very highly permeable zone of the Fort Thompson Formation (fig. 24) in the Biscayne aquifer. Along Alligator Alley (fig. 3), this zone extends from about 30 to 50 feet below land surface (fig. 17). At the Alligator Alley west site (G-2330, fig. 17), an extremely productive cavernous zone was found at 39 to 40 feet in four wells. In contrast, 6 miles east (G-2320, fig. 17), the 30- to 50-foot interval contains abundant sand, shell, and lime mud that is interbedded with, or fills cavities in, the limestone, greatly reducing the hydraulic conductivity. This suggests that there may be considerable variability of hydraulic conductivity and transmissivity in the Biscayne aquifer in west Broward County (see table 4 for test results).

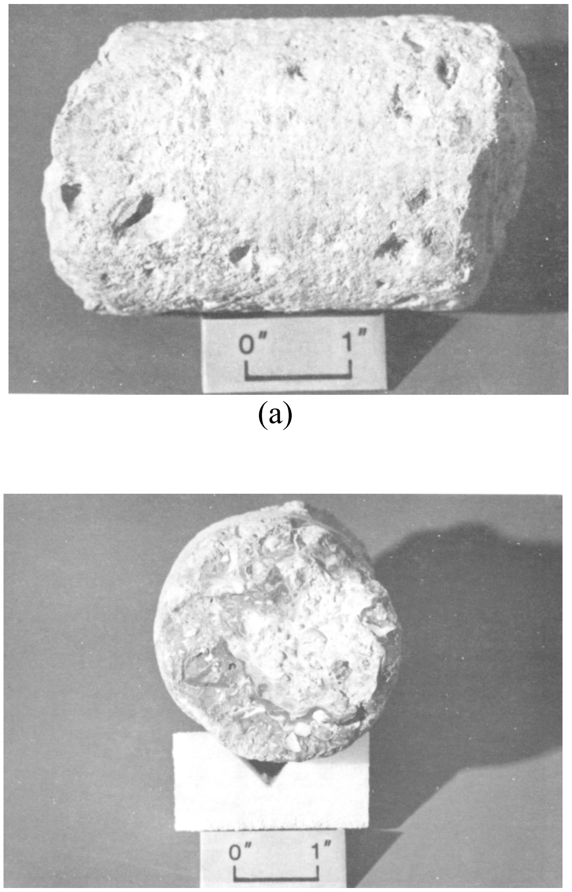
Along the eastern edge of Broward County and southward from Alligator Alley, the very highly permeable zone thickens and the base deepens to about 70 feet (G-2311 and G-2317, fig. 20). Locally, highly permeable limestone beds of the Tamiami Formation that immediately underlie the Fort Thompson Formation are included in the Biscayne aquifer. Near the western edge of the county (for example, G-2329 and G-2340, figs. 17 and 19), the permeable limestone is commonly replaced by 40 to 70 feet of mixed lime mud, sand, and shell, or slightly indurated limestone having low permeability, except at the southwest Everglades site (fig. 19, G-2338) where about 35 feet of highly permeable shelly limestone occurs (G-2338B, table 4). A slug test in the lime-mud-shell-sand mixture at the Alligator Alley Snake Road site (G-2329B, table 5) indicated a hydraulic conductivity of 0.16 ft/d. North of Alligator Alley the Fort Thomson Formation thins, and at the North Everglades west, central, and east sites (fig. 15, G-2314, G-2313, and G-2315, respectively), only minor very permeable zones occur in beds that are primarily dense limestone or muddy sand. Thus, the Biscayne aquifer does not extend to those sites.

From 20 to 60 feet of green, clayey sand and shell and limestone of the upper part of the Tamiami Formation, mostly of low to moderate permeability (G-2329, G-2330, G2320, and G-2319, fig. 17) occur below the Fort Thompson Formation in west Broward County. Green clay or green claystone, sandstone, and lime mud also occur, usually in minor quantities. These materials of the upper part of the Tamiami Formation and the lime mud-sand-shell beds of the Fort Thompson Formation previously described (along the western edge of Broward County) form a semiconfining unit that overlies the gray limestone aquifer and separates it from the Biscayne aquifer wherever the latter occurs in west Broward County (fig 7b). The degree of confinement varies areally. Pumping a 6-inch well in either unit (Biscayne aquifer or gray limestone aquifer) at the Alligator Alley central site (G-2320, fig. 17) quickly causes water-level drawdown on the unpumped unit equal to 15 to 20 percent of that in the pumped unit. This semiconfining unit is also leaky at the north Everglades central site (G-2313, fig. 15). Pumping well G-2313C (see table 4), open to the gray limestone between 106 and 146 feet, at about 400 gal/min for 25 to 30 minutes resulted in measured drawdowns of 7.21 feet (includes calculated well loss of 2.54 feet) in the pumped well, 0.73 foot in well

Table 7. Approximate ranges of hydraulic conductivity of materials that compose the surficial aquifer system, Broward County.

[Range, in feet per day; >, greater than; <, less than. Geologic formation: Qa, Anastasia Formation; Qf, Fort Thompson Formation; Qk, Key Largo Limestone; Qm, Miami Oolite; Qp, Pamlico Sand; Th, Hawthorn Formation; Tt, Tamiami Formation; Tth, undifferentiated Tamiami Formation or Hawthorn Formation; Ttl, Tamiami Formation, lower part; Ttu, Tamiami Formation, upper part.]

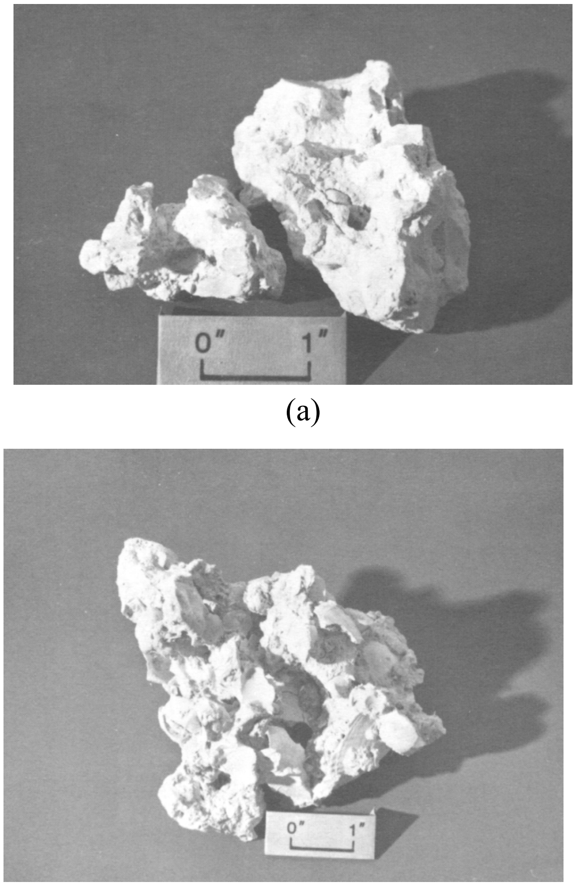
Horizontal hydraulic conductivity		Materials - lithology and porosity	Geologic formations
Qualitative permeability	Range		
Very high	≥1,000	Solution-riddled limestone, commonly shelly or sandy.	Qf, Qa
		Calcareous sandstone, may be shelly or have shell fragments; solution holes or rib-like channels.	Qa,Tt
		Coralline limestone, reefal, very porous.	Qk
High	100-1,000	Gray, shelly limestone, locally sandy, relatively soft.	Tt
		Limestone or calcareous sandstone interbedded with sand, or with sand partially filling cavities.	Qa, Tt, Qf
		Coarse shell sand and quartz sand.	Tt
		Dense, charcoal gray to tan limestone with some solution channels, usually shelly or sandy.	Ttu
Moderate	10-100	Very fine to medium, relatively clean quartz sand.	Qp, Qa, Tt
		Fine to medium quartz and carbonate sand.	Tt
		Cream-colored limestone with minor channels.	Qf, Qa
		Tan, cream, or greenish limestone, locally containing shell sand.	Tt
		Calcareous sandstone and sand.	Tt, Qa
		Slightly clayey or sandy, gray limestone	Tt
		Oolitic limestone.	Qm
Low	0.1-10	Very fine to medium sand with some clay, silt, or lime mud, locally shelly.	Tt, Qf, Qa
		Soft gray or buff limestone with silt and fine sand.	Tt
		Dense, calcareous sandstone.	Tt
		Light-green, fine-grained foraminiferal limestone with very fine quartz sand.	Tt
		Dense, hard limestone with very small cavities orchannels; approximately equal mixtures of sand, shell fragments, and lime mud.	Qf
Very low to practically impermeable.	≤.01	Green clay or silt; locally with very fine sand.	Th, Tth, Ttl, Ttu,
		Sandy, shelly lime mud.	Tt
		Very dense, hard limestone with no apparent solution cavities or fractures.	Qf



(a)

(b)

Figure 23. Hard, dense limestone of low permeability of the Fort Thompson Formation that occurs at shallow depths in west Broward County. (a) very tight caprock at site G-2315; and (b) representative sample of low-permeability limestone at site G-2330 (0 to 30 feet deep).



(a)

(b)

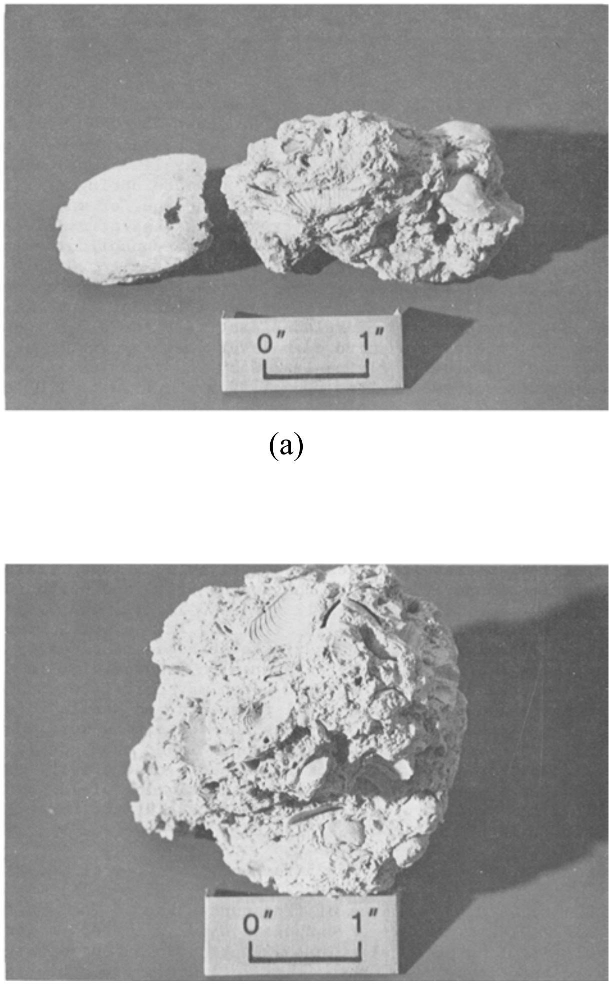
Figure 24. Very highly permeable limestone of the Fort Thompson Formation in south-central and west broward County. (a) porous limestone with chalky cavity linings at 58 to 60 feet deep at site G-2317; and (b) porous, sandy, shelly limestone bolown out of well open at 40 to 65 feet deep at site G-2311.

G-2313B (open 46 to 81 feet), and 0.12 foot in well G-2313A (open to the water-table aquifer between 12 and 22 feet). Both observation wells are 15 feet from the pumped well. However, confinement is much greater in westernmost Broward County where the semiconfining unit is primarily green clay, silt, or a lime mud-sand-shell mixture (G-2338, between 50 and 101 feet; G-2346, between 28 and 60 feet; fig. 19) of low to very low permeability. At the southwest Everglades site (G-2338), leakage was not apparent during a 100-minute pumping test of well G-2338C open to the gray limestone. A bailer test of well G-2338H, open to a mixture of soft sand, silt, and clay in the upper part of the semiconfining unit, indicated a hydraulic conductivity of 0.061 ft/d (table 5). The unit becomes increasingly more clayey and stiff with depth at that site, and consequently, is less permeable than the tested interval. At site G-2338, the unit has the lowest permeability of any of the test sites in west Broward County.

Gray, shelly, relatively soft limestone (fig. 25) of the Tamiami formation in west Broward County forms a water-bearing unit, referred to as the gray limestone aquifer in this report. The top of this aquifer is usually found at a depth of about 70 to 100 feet below land surface (figs. 17-19, except in the northwest corner where it occurs at about 35 to 40 feet below land surface (figs. 17-19), except in the northwest corner where it occurs at about 35 to 40 feet below land surface (G-2313 and G-2314, figs. 15 and 19). Minor quartz sand or tan limestone lenses (probably less permeable than the gray limestone) occur near the base of the aquifer at some sites. Observations made during drilling and examination of the lithologic samples suggest that the aquifer may be divided into two layers in many places—an upper layer that is less permeable and commonly thinner than the lower mor permeable and more consolidated layer. Thu upper layer is much thicker and nearer the surface at sites G-2314 and G-2313 (figs. 15 and 19) where there is a poorly consolidated and cemented facies of the lime mud-shell-sand mixture that occurs farther south (G-2340 and G-2329, fig. 19). At the North Everglades east site (G-2315 between 170 and 185 feet, fig. 15) there is a third deep layer that appears to be in a local basin, separated from the overlying layers by sand and less-permeable limestone. The thickness of the aquifer ranges from about 30 to 110 feet in west Broward County.

Aquifer test (G-2320J, G-2330Z and G-2338C, table 4 indicate the hydraulic conductivity of the gray limestone aquifer is about 900 ft/d in the central and southwestern part of west Broward County. Apparently, there is a decrease in hydraulic conductivity and transmissivity near the eastern edge of west Broward County, on the basis of a hydraulic conductivity of 590 ft/d at the Alligator Alley east sites (G-2319X, table 4; G-2319, fig. 17) and the presence of less-permeable or less-productive (much lower yields during drilling) facies found at sites to the south, east, and north (G-2311 and G-2312, fig. 20; G-2321, fig. 17; G-2312 and G-2341, fig. 16). The test value of 650 ft/d (G-2313C, table 4; G-2313, fig. 15) at the north Everglades central site and the lithologies and lower yields at adjacent sites to the east and west suggest a general decrease in hydraulic conductivity in that area. The apparent decreases to the east and north may correlate with changes from a limestone having abundant coarse shell fragments and shells to a more fine-grained limestone with smaller pore spaces and containing more quartz sand, silt, and clay. The poorly consolidated upper layer that occurs in northwest Broward County probably has a lower hydraulic conductivity than the main part of the aquifer, as indicated by relatively low yields obtained during test drilling and a value of 280 ft/d from a test at the north Everglades central site (G-2313B, table 4; G-2313, fig. 15).

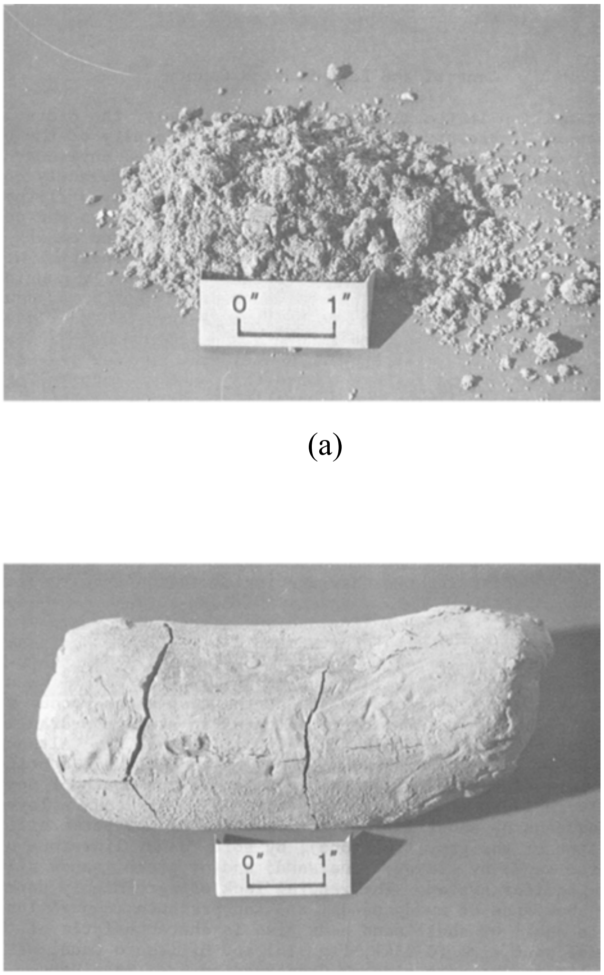
Below the gray limestone, from 0 to 25 feet of limestone of moderate to low permeability (for example, G-2315 and G-2316, figs. 15 and 18) may occur locally above a 20- to 40-foot sequence of fine quartz sand. The quartz sand locally may contain moderate amounts of carbonate sand in the upper part. The sand has relatively little clay or silt in the upper part but becomes greenish and more phosphatic and clayey with depth (fig. 26a) until green clay or silt is found (fig. 26b). At some places, the green clay is very stiff, and at others, it is softer and less compact or cohesive. The transition from muddy sand to clay or silt, with the consequent permeability contrast, marks the base of the surficial aquifer system in west Broward County. The base occurs at a relatively uniform depth of about 160 to 200 feet in that area.



(a)

(b)

Figure 25. Gray, shelly, highly permeable limestone of the Tamiami Formation in west Broward County. (a) 119 to 123 feet deep, site G-2320; and (b) 130 to 140 feet deep, site G-2319.



(a)

(b)

Figure 26. Silty, very fine sand with phosphorite and stiff, green, silty clay of the Tamiami Formation in west Broward County. (a) 239 to 243 feet deep, site G-2315; and (b) 209 to 212 feet deep, site G-2313.

Central and East Broward County

A major transition on the geology, and consequently, the hydraulic conductivity framework of Broward County occurs in the vicinity of the boundary between west and central Broward County. The depositional environments of the sediments in east and central Broward County were sufficiently complex and variable in space and time that there is less similarity of lithology between the test holes there than in west Broward County where the continuity of lithology is greater. Logs given in reports by Parker and others (1955), Sherwood and other (1973, and drilling experiences (Joe Voegtle, U.S. Geological Survey, oral commun., 1983) indicate that even locally considerable variation in lithology may occur. The sediments of the surficial aquifer system in central Broward County tend to be fine grained and poorly sorted—mostly clayey, fine-grained sands and fine-grained limestone. From about the boundary between central and east Broward County, the aquifer system and the principal geologic formations thicken toward the coast. Accompanying this trend, the sediments gradually become generally cleaner and coarser. Locally, near the coast, some coralline limestones are interpreted to have been reefs (Causarás, 1985). Although there are prominent changes in characteristics of the geologic formations from west to east (a coast parallel depositional pattern), there is also an important trend from south to north of decreasing limestone content (especially cavernous limestone) and increasing sand and mud content.

In north-central Broward County, at the Twenty-Six Mile Bend site (G-2312, fig. 20), a very different hydrogeologic section than the generalized west Broward County section occurs. Underlying near-surface peat deposits and extending to a depth of 106 feet below land surface are muddy sands either interbedded with limestone or within cavities in limestone; thus, the interval has lower permeability than sites in south-central Broward County (G-2321, G-2311, G-2317, and G-2318; figs. 17, 18, and 20). Coarse shell sand, quartz sand, and shell-the thickest found at any of the test sites—occur from 106 to 140 feet (fig. 27). An aquifer test indicates and average hydraulic conductivity of 650 ft/d for this zone (G 2312J, table 4). Although the extent of this shell sand is not known, it may be in hydraulic continuity laterally with part of the gray limestone aquifer to the south or north and presently included in that aquifer (fig. 20). The coarse layer is underlain in sequence by about 15 feet of limestone if low permeability (a lateral equivalent of the gray limestone); by soft, sandy limestone or carbonate and quartz sand; by clayey, fine sand; and by green, sandy silt at the base of the aquifer system. The general lack of very highly permeable limestone, the abundance of muddy sands, and the presence (though less) of highly permeable shell or shell sand beds also is characteristic of the Cypress Creek Canal west site (G-2341, fig. 16) and Hillsboro Canal west site (PB-1428, fig. 15) on the east side of Conservation Area 2A. Hence, these lithologies and permeabilities appear to be characteristic of the northern half of the north-central Broward County area.

Along the western edge of south-central Broward County (G-2317, G-2311, and G-2319; fig. 20), the upper 35 to 40 feet of the Fort Thompson Formation contains low or moderately permeable sand with lime mud and shell, and dense limestone interbedded with some very highly permeable limestone beds that have thin horizons with cavities. The cavities may be partially filled with muddy sand. A lower zone of the Fort Thompson Formation, extending to depths of about 60 to 70 feet, is solution-riddled limestone that is relatively free from sand or lime mud (fig. 24a, b). Hydraulic conductivities of this zone may often exceed 10,000 ft/d (G-2311B, G-2317J, table 4). The Fort Thompson Formation is very highly permeable, especially in a cavernous zone at 71 feet (G-2321J, table 4). Subjacent beds of the Tamiami Formation are locally of high permeability and are included in the Biscayne aquifer.

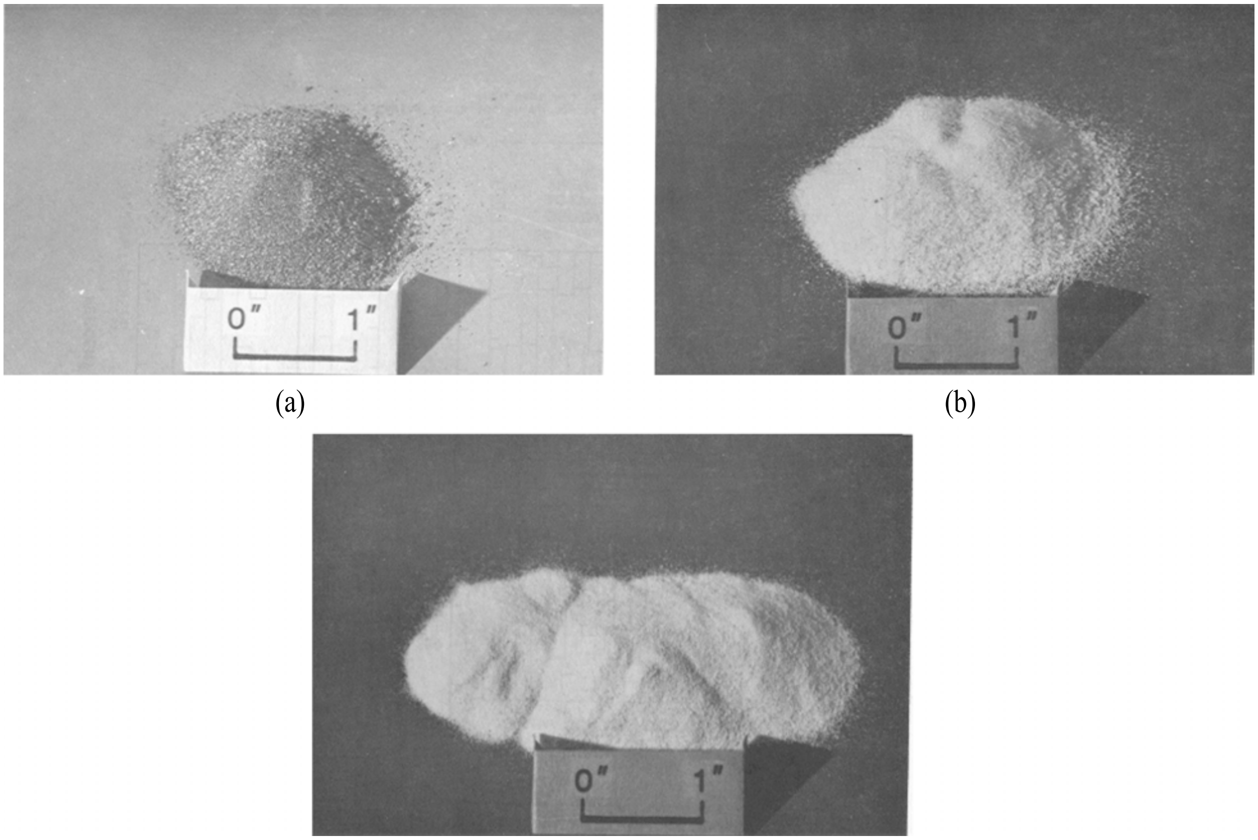
Figure 27. Coarse, shell sand and quartz sand of the Tamiami Formation in west Broward County. Occurs from 126 to 129 feet deep, site G-2312.

Except for shell sand zones in north-central Broward County or local highly permeable limestone included in the Biscayne aquifer, most of the Tamiami Formation in central Broward County consists of unconsolidated sediments of low or moderate permeability. The gray, shelly limestone of the Tamiami Formation in west Broward County, which composes most of the gray limestone aquifer, generally thins and grades eastward in central Broward County into less-permeable, sandy, silty, or clayey limestone or clayey, carbonate and quartz sands (figs. 7b, 17, and 18). In most places, the other Tamiami Formation sediments are thick sequences of clayey or silty fine sand, sandy silt, or sandy lime mud (see G-2341, fig. 16; G-2321, fig. 17; and G-2311 and G-2317, fig. 20). A notable exception to the characteristic low permeability of Tamiami Formation sediments in this area occurs at the Hillsboro Canal west site (PB-1428, fig. 15). There, 20 feet of gray limestone suggests that the aquifer is continuous across the northern edge of central Broward County.

In east Broward County, the uppermost materials are mostly fine to medium quartz sand (figs. 15-18 and 21) of the Pamlico sand and the Anastasia Formation. The sands are usually clean and moderately permeable, but locally the Anastasia sands may have some lime mud in the matrix (fig. 28) or thin limestone interbeds of low or moderate permeability. Two slug tests at the Miramar east site (G-2327, figs. 18 and 21) in fine sand with minor lime mud indicated hydraulic conductivities of 44 and 27 ft/d (G-2327A and G2327B, respectively, table 5). At sites located 6 to 7 miles inland, this sand body is thick, reaching depths of 80 feet in the northeast and 50 feet in the southeast (fig. 21). The sand thins westward toward central Broward County and eastward toward the coast where it overlies or interfingers with limestone of the Anastasia Formation and Key Largo Limestone. Interfingering with discontinuous beds of the Miami Oolite may occur at shallow depths over much of east Broward County.

The highly to very highly permeable zone of the Biscayne aquifer in east Broward County underlies the sand body and the Miami Oolite. It is composed of part of the Anastasia Formation, the Key Largo Limestone, the Fort Thompson Formation, and part of the Tamiami Formation (figs. 16 and 17). The municipal supply wells listed on table 2 (at the end of report) are open to this zone and were used as and aid in mapping highly permeable materials. To allow comparisons among four areas in east and south-central Broward County, histograms of the depth to the top of production intervals (fig. 29 and thickness of production intervals (fig. 30) were prepared. These show that few wells are less than 50 feet deep, that most are cased to depths 50 and 120 feet below land surface (depending on the area), and that the production intervals (open hole or screen lengths) are usually between 5 and 20 feet thick. The very highly permeable zone is usually thicker than indicated by the histograms of production interval thickness because large quantities of water can often be obtained from thin cavernous zones and because the zone commonly has interbeds of sand. In a given area, production wells are often finished at a variety of depths. In some instances, deeper highly permeable zones may occur but are not used, such as reported by Bearden (1974, p. 25) for the Hollywood area.

A wide variety of lithologies with differing degrees of cavity-related permeability development occurs in the very highly permeable zone, including coarse-grained limestone (fig. 31a), micritic limestone often containing large cavities, sandy micritic limestone, limestone composed of calcite-cemented mixtures of carbonate and quartz sand (fig. 31b.), and calcareous sandstone or sandy limestones commonly occur as round or tubular concretionary structures (fig. 31c), usually lying loose in sand and of moderate permeability, or small cavities that probably are highly permeable (fig. 31d). These sandstones occur in both the Anastasia Formation and Tamiami Formation. Sand is commonly found interbedded with permeable rock layers or found in partially filled cavities. Several of these lithologies usually occur at any given site. However, highly permeable coral-



(a)

(b)

(c)

Figure 28. Near-surface sands in east Broward County. (a) fine, brownish quartz sand (6 to 9 feet deep, site G-2345); (b) clean, white, fine quartz sand (29 to 33 feet deep, site G-2327); and (c) fine to very fine quartz sand with 5 to 10 percent lime mud matrix (43 to 46 feet deep, site G-2327).

line limestone (fig. 32), assigned by Causarás (1985) to the Key Largo Limestone, was found only in wells near the coast (fig. 22).

Several miles inland from the coast, the base of the highly to very highly permeable zone of the Biscayne aquifer is about 150 to 200 feet below land surface (fig. 21). Bearden (1974, p. 25) reported that in the Hollywood area, highly permeable limestones of the Tamiami Formation extend to a depth of about 200 feet (about midway between wells G-2327 and G-2345, fig. 21). Also, at the Dixie well field (near site G-2345, figs. 17 and 21), municipal production well open at 181 to 189 feet (see table 2 at the end of report) and geologic logs reporting large cavities (Parker and others, 1955) indicate highly permeable limestones exist there from about 190 to 200 feet. However, the geologic logs indicate that lithologies probably range from very high to low permeability in this zone. Laboratory tests on tree samples of limestone from 176 to 193 feet deep at the north Dixie well field site indicated hydraulic conductivities of only about 4.3 ft/d, but porosity averaged 39 percent (table 6). The limestone from about 140 to 193 feet in this well (G-2345) shows little or no development or small interconnected cavity networks; hence, as suggested by Parker's logs, cavities may be few but several inches to greater than 1 foot wide. As shown in figure 21, along the northernmost and southernmost parts of the section, Tamiami limestone or sandstone deeper than about 150 to 160 feet is less permeable than at Hollywood and the Dixie well field and is not included in the Biscayne aquifer. At the Cypress Creek Canal east site (G-2342, figs. 16 and

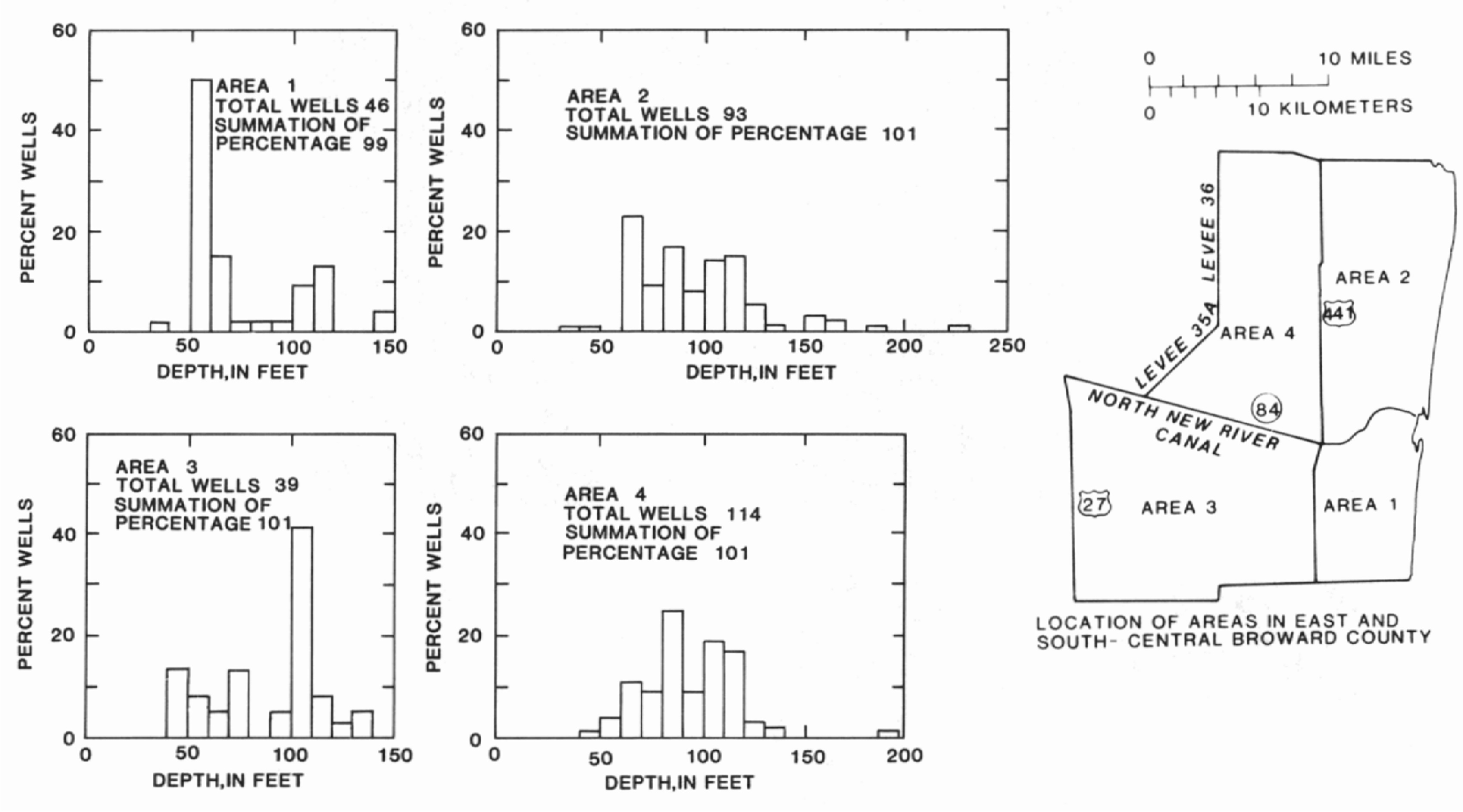


Figure 29. Casing depth (depth to top of production interval) of production wells in four areas in east and south-central Broward County.

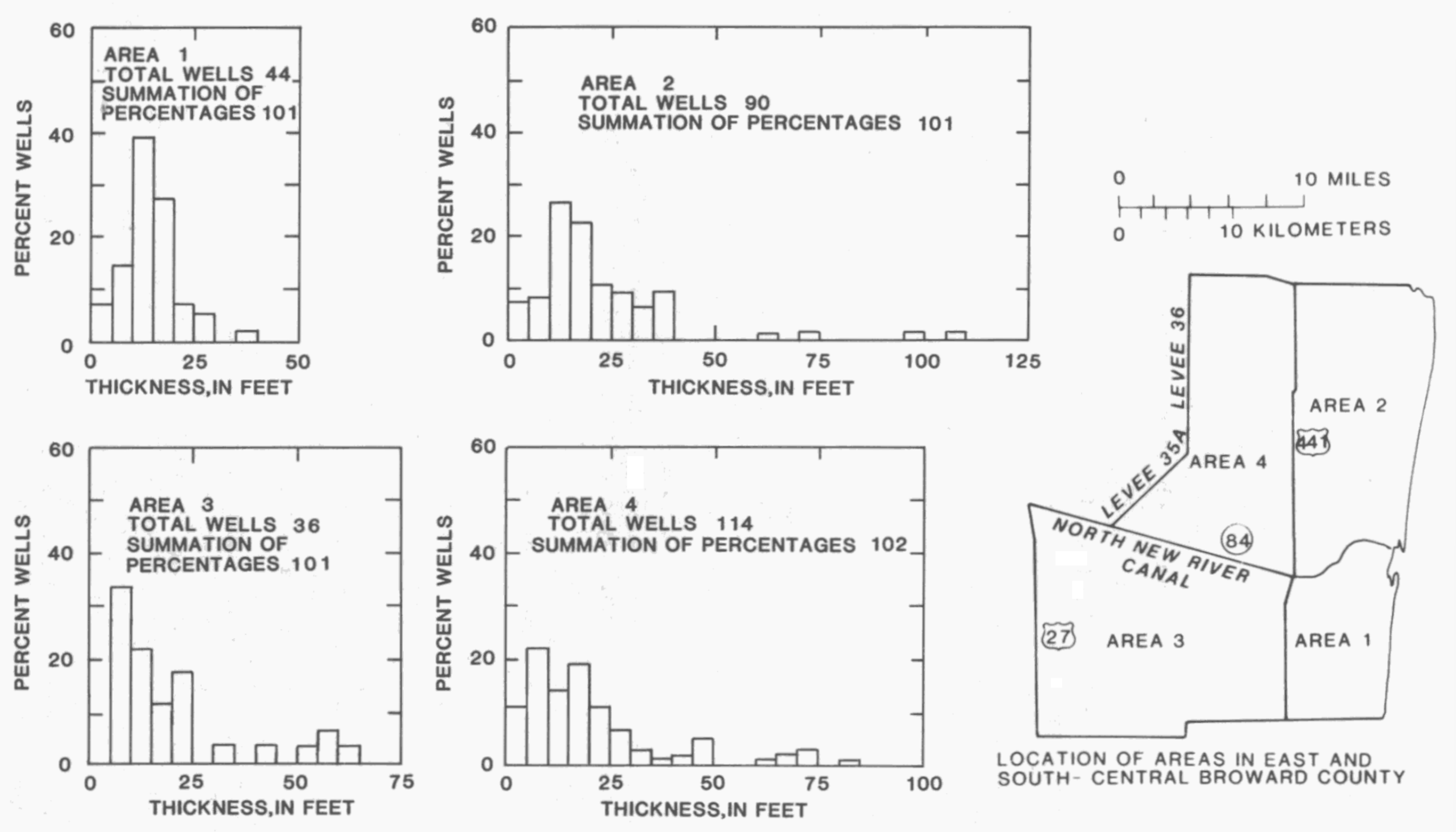
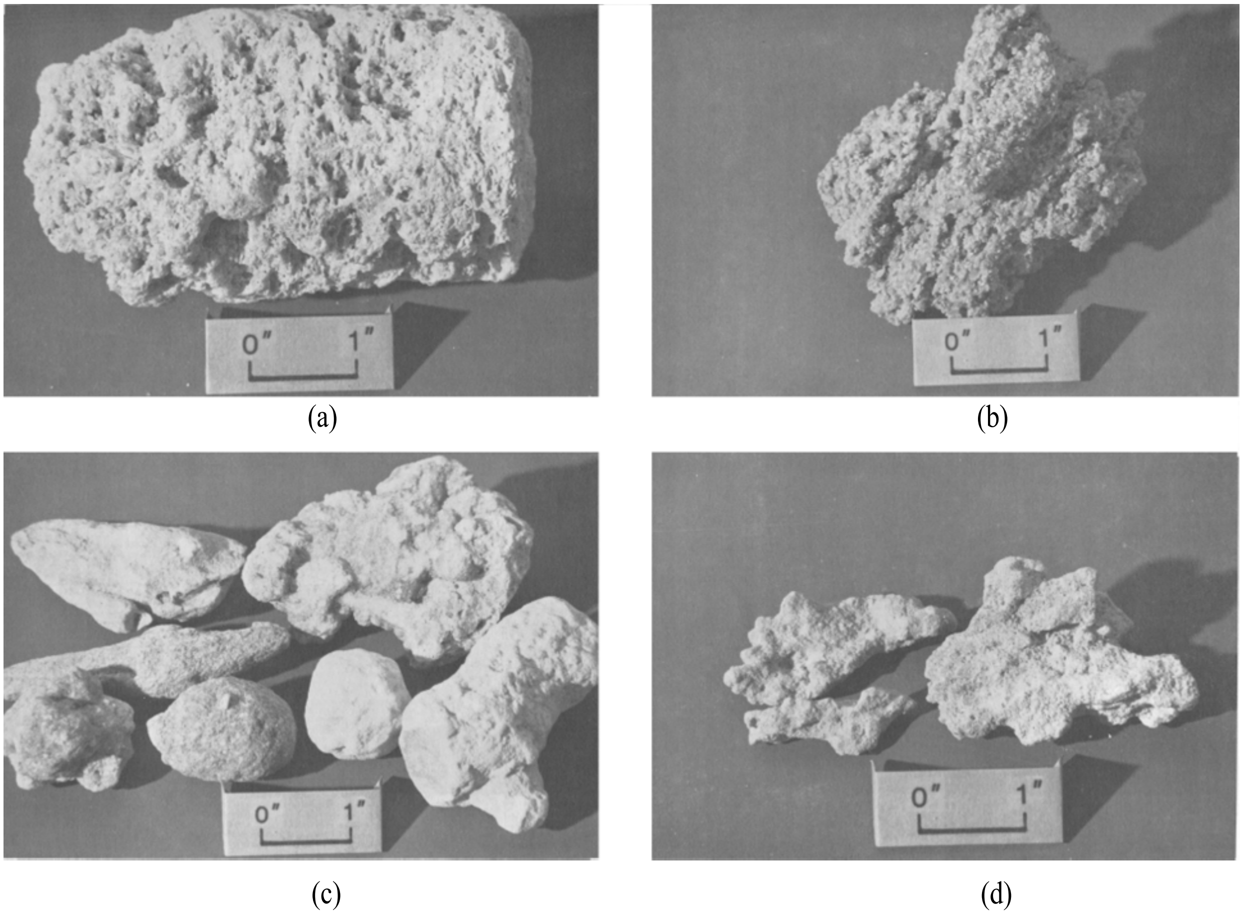


Figure 30. Thickness of production zone (open hole or screened iinterval) of production wells in four areas in east and south-central Broward County.



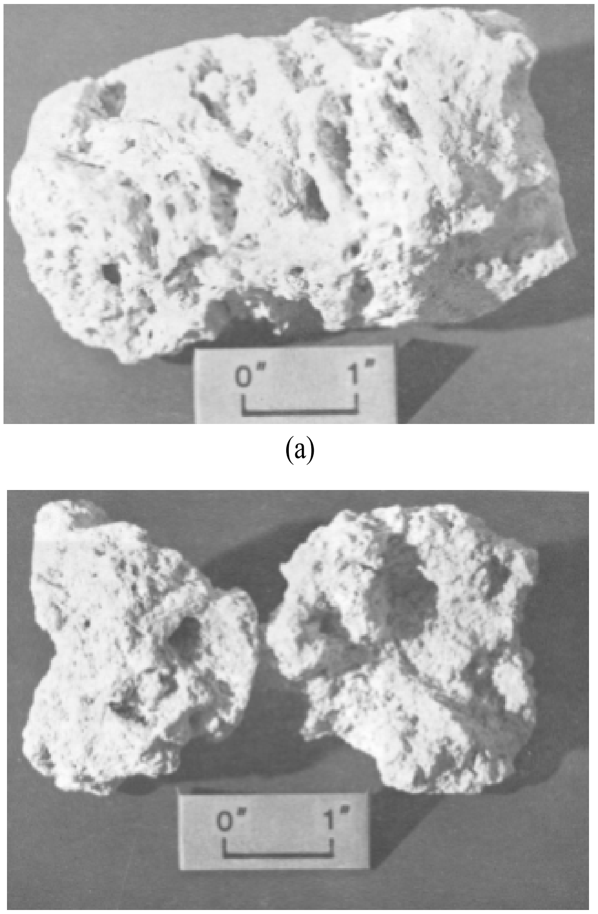
(a) (b)

(c) (d)

Figure 31. Some common lithologies in the Biscayne aquifer in east Broward County. (a) carbonate grainstone with abundant quartz. Anastasia Formation near the coast (70 to 74 feet deep, site G-2347); (b) carbonate grinstone showing linear structure and tubular porosity, Anastasia Formation (80 to 95 feet deep, site G-2322); (c) various calcite-cemented "concretionary" structures, Anastasia and Tamiami Formations near the coast (0 to 300 feet, site G-2347); and (d) calcareous sandstone (296 to 299 feet deep, site G-2347).

21), a specific capacity test of greenish, lightly to moderately cemented quartz and carbonate sand and sandy, shelly limestone between depths of 170 and 190 feet gave a hydraulic conductivity of 75 ft/d, comparable to a medium sand (G-2342B, table 4).

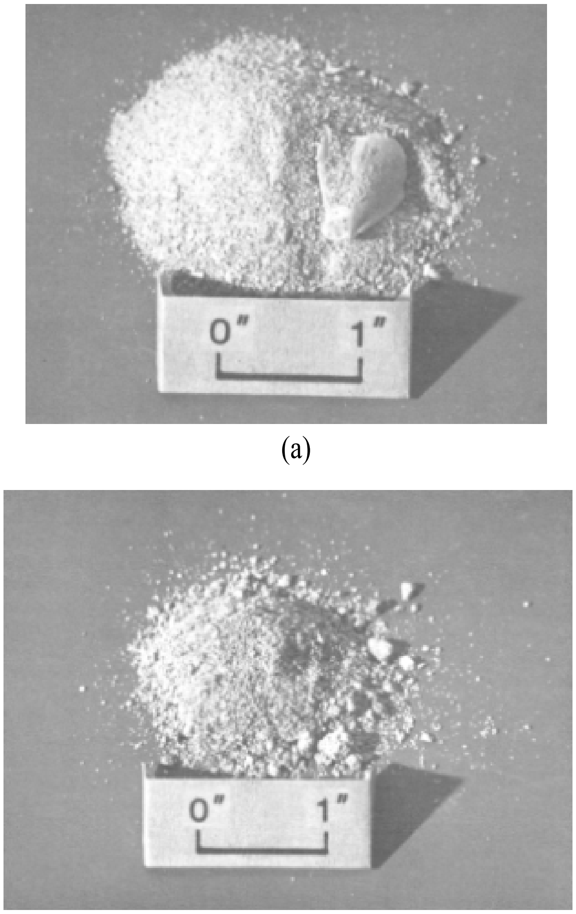
In east Broward County inland from the coast, the Tamiami Formation sediments that underlie the very highly permeable zone of the Biscayne aquifer form a thick section of quartz and carbonate sand (fig. 33a) of moderate permeability. Locally, there may be an admixture of minor silt or minor beds of light-greenish or grayish, soft limestone that locally may be sandy (fig. 33b). At the north Dixie well-field site (G-2345, fig. 17), for example, these sediments extend from 193 to 310 feet below land surface. The average vertical hydraulic conductivity of this sand zone is less than the horizontal hydraulic conductivity, especially at the north Dixie well field where there are many thin layers of silt, siltstone, and greenish limestone of low permeability. The lowest part of this section, immediately overlying the base of the surficial aquifer system, is clayey or silty quartz and phorphorite sand similar to west Broward County.



(a)

(b)

Figure 32. Coralline, very highly permeable Key Largo Limestone. (a) 97 to 100 feet deep, site G-2347; and (b) 87 toi 90 feet deep, site G-2347.



(a)

(b)

Figure 33. Quartz and carbonate sand or soft, sandy limestone of the Tamiami formation in east Broward County. (a) 266 to 269 feet, site G-2345; and (b) 203 to 206 feet deep, site G-2342.

Nearer the coast at the Snyder Park site and the Pompano Beach well-field site (G-2347 and G-2344, figs. 16, 17, and 22), the quartz and carbonate sands of the Tamiami formation are generally coarser and better sorted. Differential cementation and solution processes acting on these sediments have produced more permeable zones (than farther inland) composed of calcareous sandstones or sandy limestones (fig. 31d). Although no aquifer test and little production data are available for this deep zone, the hydraulic conductivities probably range from 100 to more than 1,000 ft/d, depending on the development of solution cavities. Thus, the Biscayne aquifer extends to depths of about 330 feet in this area. A few hard sandstone layers apparently lack solution features and probably have hydraulic conductivities of about 10ft/d.

The uppermost part of the intermediate confining unit underlying the surficial aquifer system in east Broward County is predominantly silt rather than the clay found in west Broward County. However, near the coast, no clay or silt was found. Instead, various types of limestone of low permeability occur. At the Snyder Park site (G-2347, figs. 17 and 22) and the Pompano Beach well-field site (G-2344, figs. 16 and 22), at least 100 feet of soft, fine-grained, greenish calcarenite (fig. 34) with up to 25 percent very fine quartz sand was found. Laboratory permeability tests on four

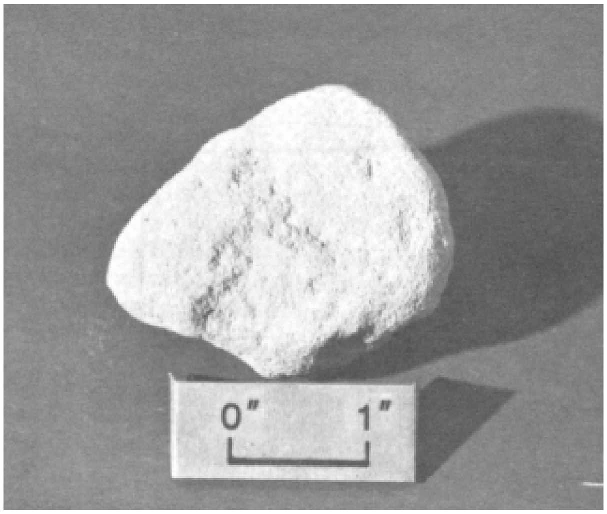


Figure 34. Greenish, sandy calcarienite in east Broward County. Occurs from 419 to 423 feet, site G-2347.

samples from the Snyder Park site indicated horizontal hydraulic conductivities ranging from 0.61 to 8.9 ft/d and averaging 3.6 ft/d (table 6). Although this limestone is much more permeable than clay, it is much less permeable than the overlying materials, which are predominantly highly permeable limestone or sandstone, and it is a lateral equivalent of the clay and silt to the west. Therefore, the top of this thick sequence is taken as the base of the surficial aquifer system along the coast.

Delineation of the Surficial Aquifer System and Aquifers within the System

Contour maps were prepared that delineate the surficial aquifer system and the aquifers within the system. These maps are based on the aquifer definitions previously given, aquifer test results, and the hydrogeologic sections (figs. 15-22).

A contour map showing the altitude of the base of the surficial aquifer system below sea level is given in figure 35. In addition to the test holes drilled in this study, eight others from Parker and others (1955) or from U.S. Geological Survey files were used to select the base. The base of the surficial aquifer system is at a relatively uniform altitude of 150 to 200 feet below sea level (about 160 to 210 feet below land surface) over the western two-thirds of the county. The base slopes gradually downward to the east and also into a small depression at the North Everglades east site (G-2315, figs. 3 and 15). The base rises to a high area shown as a north-south ridge through the Cypress Creek Canal west site (g-22341, figs. 3 and 16) where more than 60 feet of sandy silt was found below the base of the aquifer system. This trend could continue southward, passing near the Markham Park site (g-2321), to the Snake Creek Canal west site (G-2317) at the Dade County line. However, the latter test hole was not drilled sufficiently deep to be certain that the base had been reached. A continuation of the ridge-like high area of the base has been recently found to the north on Palm Beach County (W.L. Miller, U.S. Geological Survey, oral commun., 1984). Eastward from this trend, the base slopes downward at 10 to 20 ft/mi to altitudes of 300 to 400 feet below sea level along coastal Broward County.

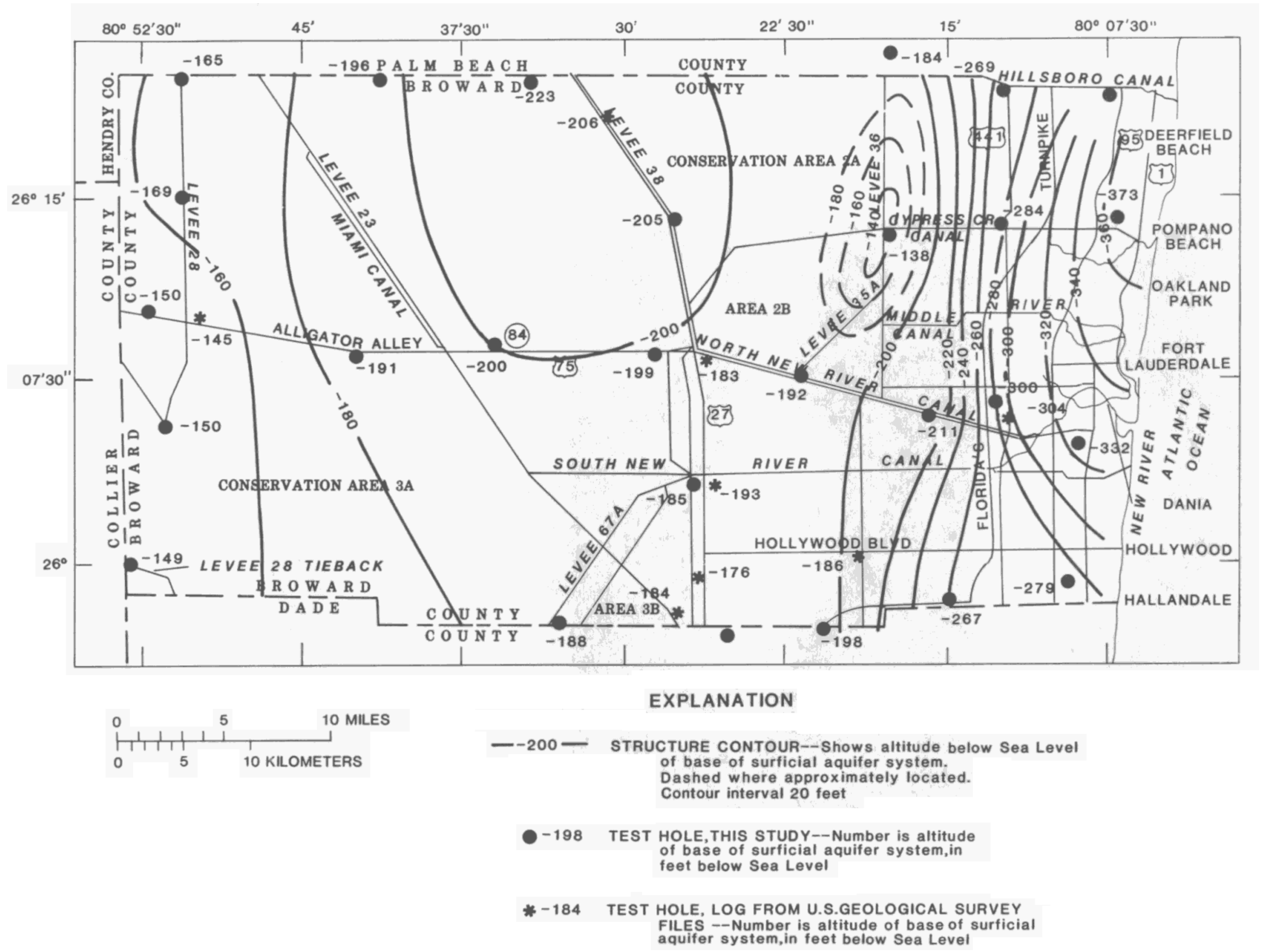


Figure 35. Generalized configuration of the base of the surficial aquifer system in Broward County.

Contours on the base and the top of the highly permeable gray limestone aquifer in the Tamiami Formation are shown in figure 36. The aquifer, as mapped, includes all intervals of the gray limestone that are at least 10 feet thick and have an estimated hydraulic conductivity of at least 100 ft/d. Also included is the coarse shell sand at the Twenty-Six Mile Bend site, although it is not known for certain that it connects with highly permeable gray limestone beds. The configuration of the top is complex. It generally slopes downward to the east from 20 to 85 feet below sea level along the Collier County line to about 110 feet below sea level near the eastern edge of west Broward County. In contrast, the base is more uniform in altitude. Its configuration is slightly basin shaped, the deepest point being 173 feet below sea level along Alligator Alley is about 90 feet thick. The north Everglades west site (G-2314, figs. 15 and 19) has the greatest thickness, about 110 feet, but the average permeability at the site is much lower than along Alligator Alley.

The eastern edge of the gray limestone aquifer is near the boundary between west and central Broward County, except near the Palm Beach county line. The eastern edge is mapped at the rapid transition from highly permeable limestone or contiguous shell sand (hydraulic conductivity of at least 100 ft/d) to much less permeable facies, except near the Hillsboro Canal west site (PB-1428, fig. 15). East of the site, the gray limestone may change to low permeability fine-grained facies of the Tamiami Formation, as in most of central Broward County, or it may connect directly with the Biscayne aquifer. Recent test drilling has shown that the aquifer continues into southwest Palm Beach County (W.L. Miller, U.S. Geological Survey, oral commun., 1984) and into northwest Dade County. Figure 36 indicates that it also extends into Collier County and Hendry County.

The base and approximate western and northern limit of the Biscayne aquifer are shown in figure 37. The limit is drawn where the thickness of very highly permeable limestone or calcareous sandstone is estimated to decrease to less than 10 feet. It follows relatively close to the boundary given in figure 8 by Klein and others (1975), except that the northern half of north-central Broward County was excluded because test drilling conducted in this investigation did not indicate sufficient thickness of very highly permeable limestone in the area. The sediments in the excluded area are predominantly muddy sands and shell or limestone that are generally not highly permeable. The base os drawn on the bottom of highly permeable limestone or sandstone in the Tamiami Formation that is virtually contiguous with overlying rocks of very high permeability in the Fort Thompson Formation, Anastasia Formation, or Tamiami Formation. In General, the Biscayne aquifer is shallow, and the base deepens gradually in west and central Broward County. However, the aquifer thickens, and the base deepens very rapidly in the coastal area to more than 300 feet below sea level.

A significant difference between figure 37 and previous maps is that the very thick, highly permeable, calcareous sandstone and limestone beds at depth in the coastal area are included in the Biscayne aquifer. In agreement with this interpretation, Tarver (1964, p. 8) suggested that the base of the Biscayne aquifer is about 400 feet below sea level near the coast in northeast Broward County. Previous test data near the coast were sparse because salt water intrusion is a problem. Other contour maps (such as shown in figure 8) or reports typically indicate a depth of about 160 feet based on wells drilled primarily to zones used for municipal supplies.

Transmissivity Distribution of the Surficial Aquifer System and Relation to Aquifers on the System

The generalized distribution of transmissivity on the surficial aquifer system of Broward County is shown in figure 38. The lines represent approximate boundaries that separate areas of

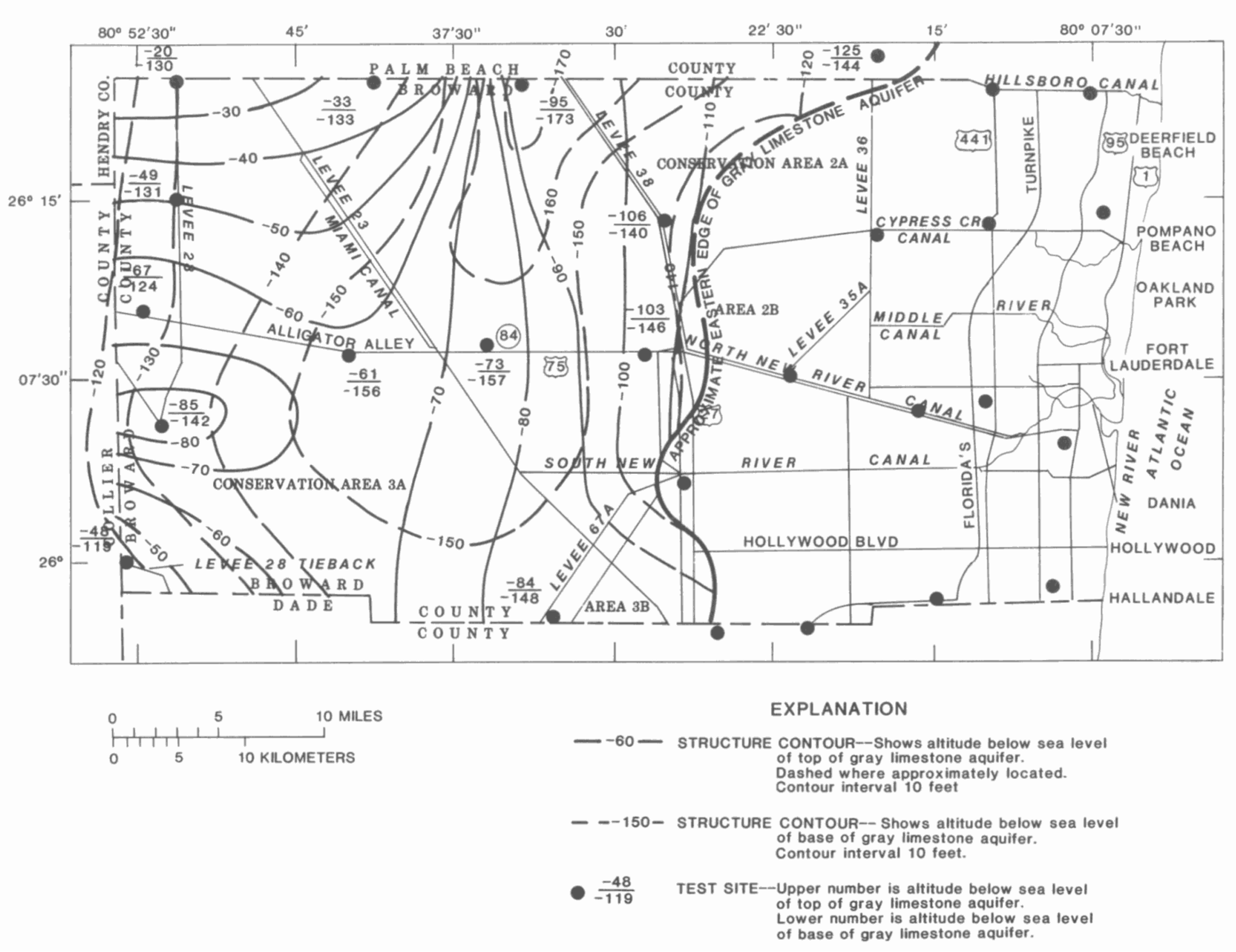


Figure 36. Generalized configuration of the top, base and approximate eastern limit of the grey limestone aquifer in Broward County.

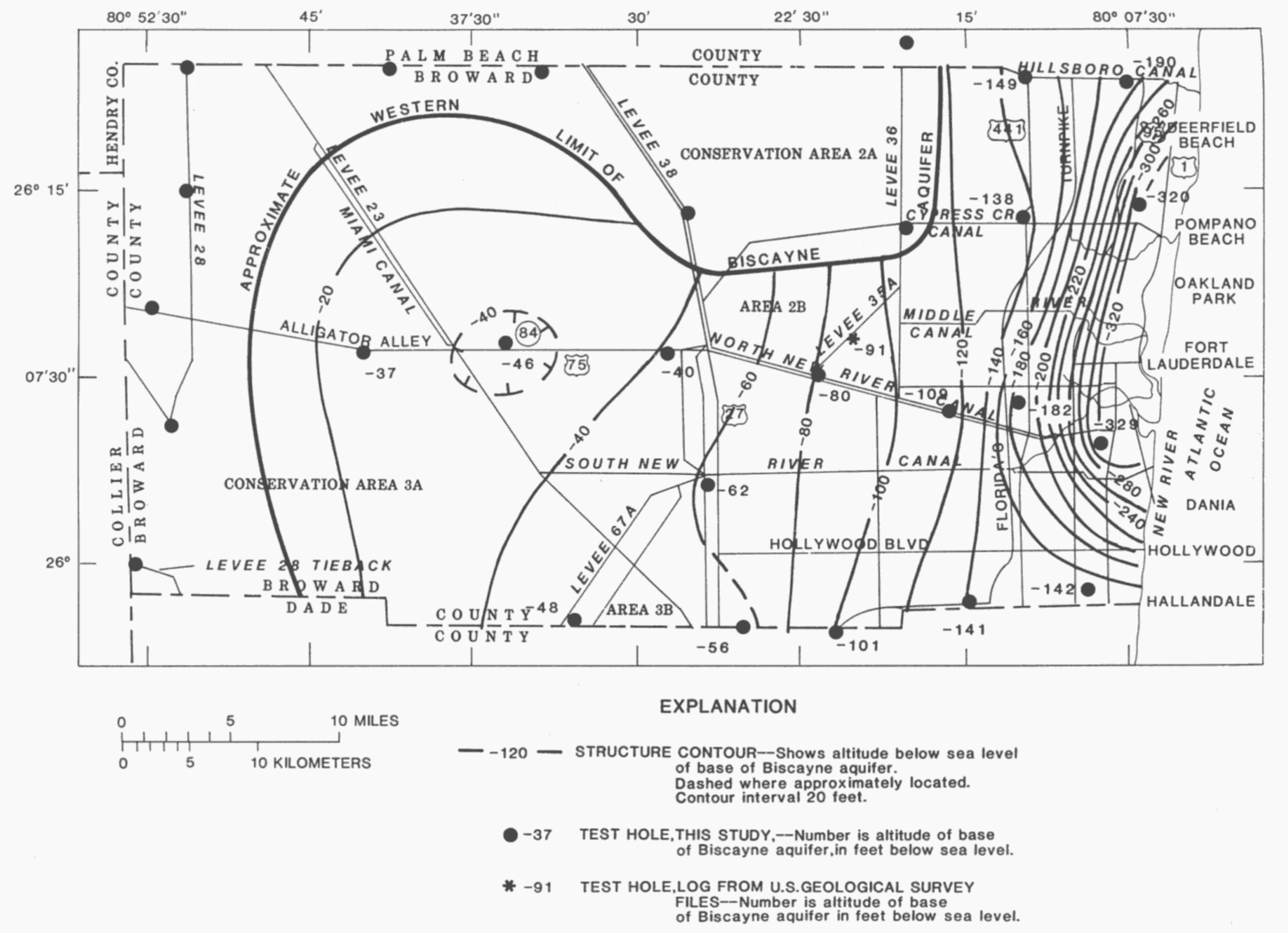


Figure 37. Generalized configuration of the base and approximete western and northern limit of the Biscayne aquifer in Broward County.

general ranges of transmissivity. Transmissivity may vary by an order of magnitude within a mapped area and locally may be either less or greater than the range indicated. Therefore, site-specific investigations of transmissivity and the hydrogeology may often be necessary for various potential local uses of the water resource. Values taken into consideration for mapping, selected from those listed in tables 2 to 4 are shown and are subject to the limitations previously discussed. The mapping emphasized the higher transmissivity values because they are believed to be close to the true transmissivity in that all values may be lower than natural due to well construction or partial penetration. Other information used as mapping guides include the hydrogeologic test drilling results particularly in west and north Broward County, drawdown around well fields, and an attempted aquifer test of the Hallandale well field. Hydraulic data within about 2 miles of the coast are lacking because supply wells are not drilled in the area threatened by saltwater intrusion.

In general, the surficial aquifer system increases in transmissivity from less than 75,000 ft^2/d in north and west Broward County to probably greater than 1,000,000 ft^2/d in coastal southeast Broward County. The transition from relatively low to high transmissivity occurs across a narrow east-west trending zone in central Broward County and is more gradual elsewhere. The transmissivity in coastal areas usually exceeds transmissivity in those areas several miles directly inland. In much of east and south-central Broward County, the transmissivity of the surficial aquifer system is about 300,000 ft^2/d or more. Most of the transmissivity in that area occurs within the very highly permeable zone of the Biscayne aquifer. In west Broward County, the gray limestone, like the Biscayne aquifer, has significant transmissivity and accounts for most of the transmissivity of the surficial aquifer system along the westernmost and northernmost part of that area.

In southeast Broward County, the high specific capacities from partially penetrating wells at the Hallandale well field (fig. 9), as much as 4,500 (gal/min)/ft, suggest that the transmissivity there may exceed 1,000,000 ft^2/d. This is supported by observation of drawdowns of only a few hundredths of a foot in nearby wells for a pumping rate of 2,400 gal/min during an aquifer test (Bearden, 1972, p. 15) that was unsuccessful because of the nominal drawdown, and by the very shallow cone of depression for the well field. High specific capacities and low hydraulic gradients (Bearden, 1974, figs. 11-13) at the Hollywood and Dania well fields suggest that transmissivity in these areas may also exceed 1,000,000 ft^2 d. Also, the Hollywood area has at least two highly permeable zones (Bearden, 1974, fig. 7 and p. 10, 30, and 31), and the supply wells are partially penetrating. This area of very high transmissivity may extend as far north as the Snyder Park test drilling site (G-2347, figs. 17 and 22) where thick, extremely porous, and permeable Key Largo Limestone and other permeable lithologies were found.

In northeast Broward County, the transmissivity is less than that in the southeast because the surficial aquifer system contains more sand and less limestone having large cavities. The lowest transmissivities in east or south-central Broward County occur in the northwestern part of east Broward County, west of the Cypress Creek Canal east site and Hillsboro Canal east site (G-2342 and G-2323, respectively). Most of the sediments in that area are sand and shell, commonly with clay or lime mud (figs. 15 and 16).

Available data indicate that transmissivity of the surficial aquifer system may be extremely variable in west Broward County, primarily because of variations within the Biscayne aquifer. Because few tests are available on the Biscayne aquifer in west Broward County (three test sites lie outside the Biscayne aquifer), the mapped pattern (fig. 38) should be used with caution in that area. Very high transmissivity occurs where the Biscayne aquifer has significant open solution-cavity zones. Otherwise, transmissivity on the gray limestone aquifer in the Tamiami Formation may equal or exceed that of the Biscayne aquifer. The Alligator Alley central site (G-2320, fig. 17), cav-

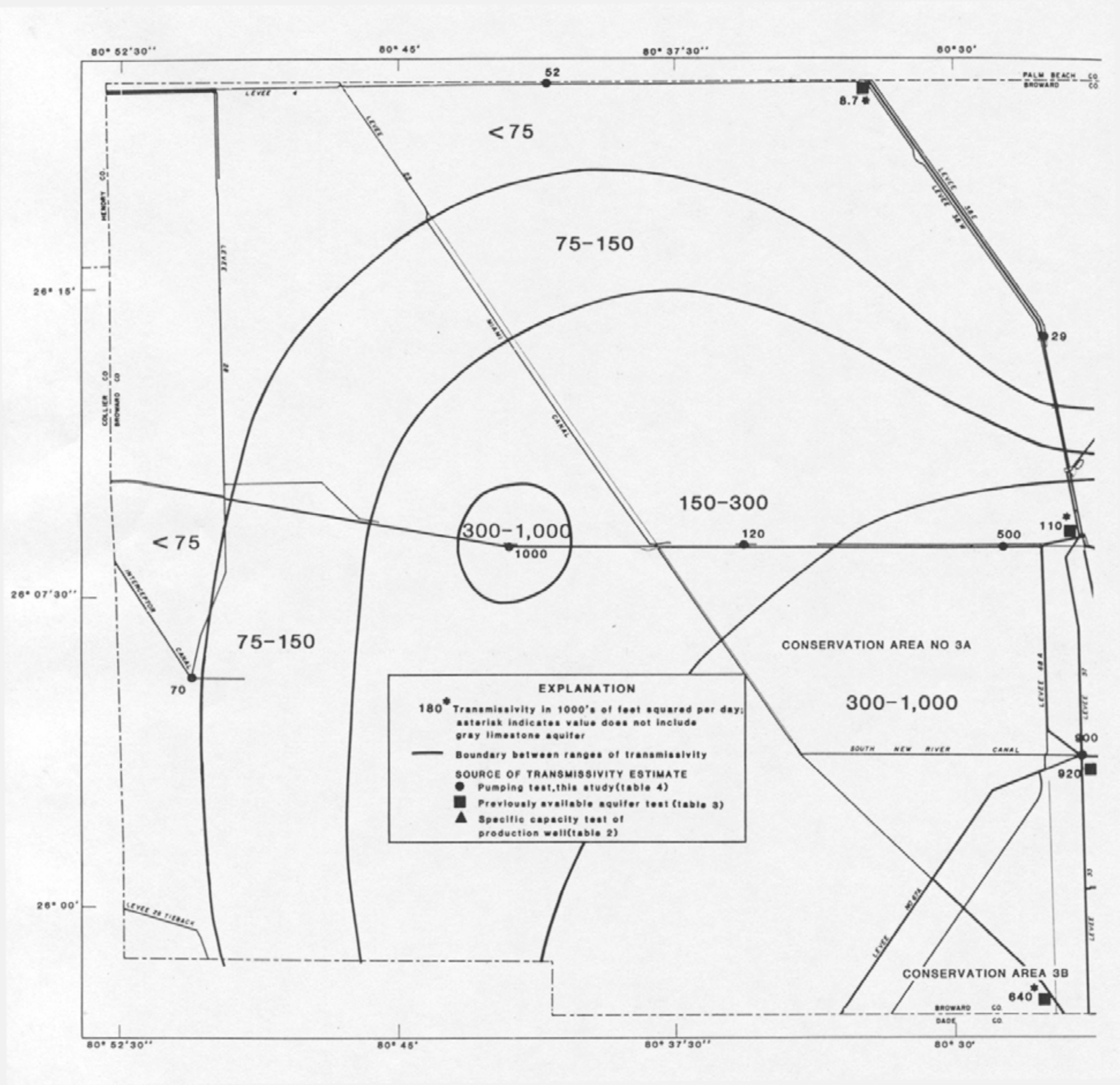
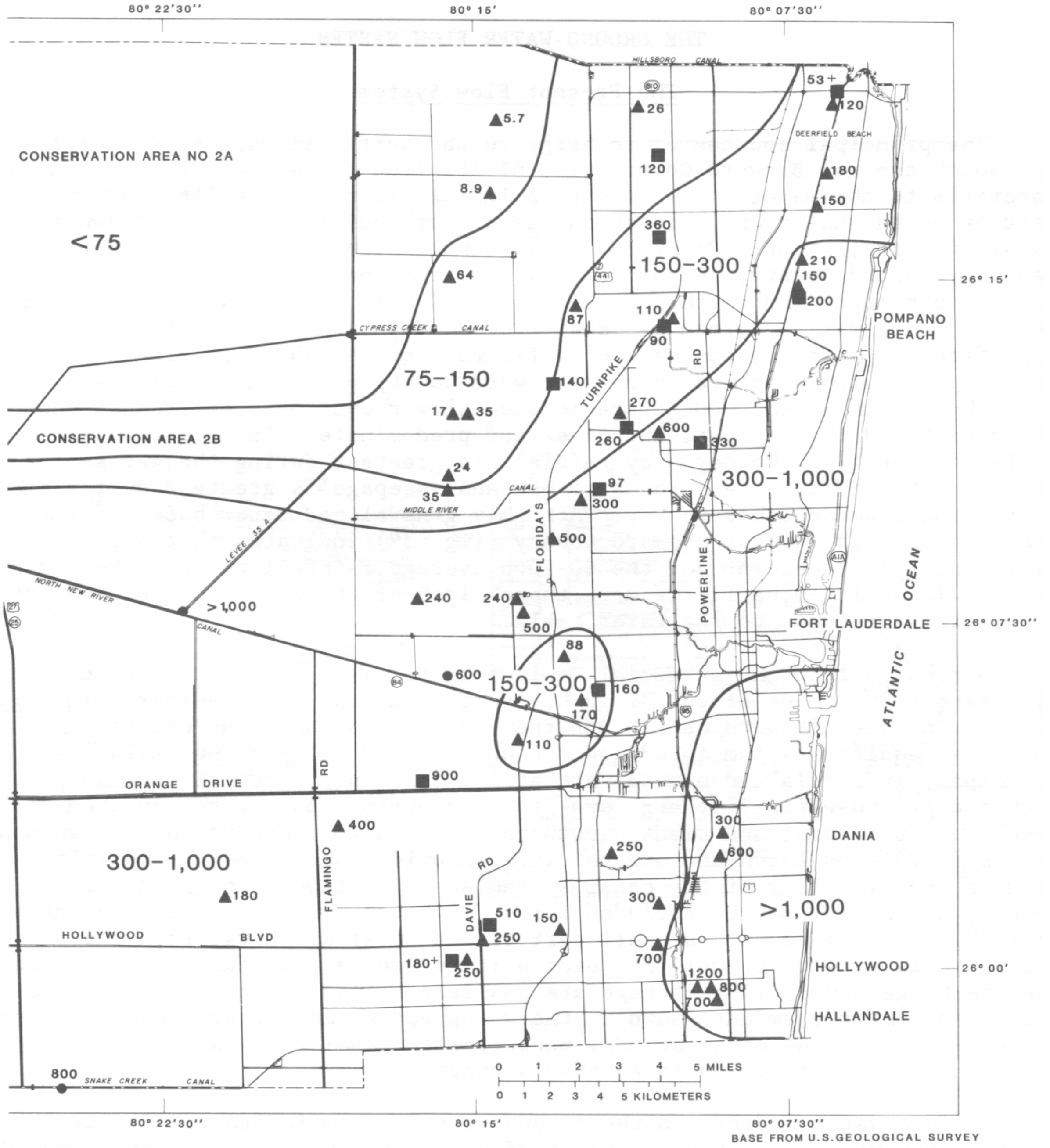


Figure 38. Generalized distribution of transmissivity of the surficial aquifer system in Broward County.



BASE FROM U.S.GEOLOGICAL SURVEY
1:24,000 QUADRANGLES

Figure 38. Generalized distribution of transmissivity of the surficial aquifer system in Broward County (continued).

ity zones are either poorly developed or mostly filled with sand, shell, and lime mud. At site G (fig. 11, table 3), a test by the U.S. Army Corps of engineers in the Biscayne aquifer indicated a comparatively low transmissivity of 110,000 ft^2/day. At the Twenty-Six Mile Bend site (G-2312, fig. 20), very little rock with open solution holes exists, and the site is not included in the Biscayne aquifer. The boundary between the area of less than 75,000 ft2/d and that of 75,000 to 150,000 ft2/d should be regarded as a general trend. It closely approximates the western limit of the Biscayne aquifer shown in figure 36. North and west of that boundary, the limestones of the Fort Thompson Formation are thinner and denser with fewer cavities; therefore, the gray limestone aquifer is likely to have greater transmissivity than the Fort Thompson Formation in that area. The transmissivity of the gray limestone aquifer throughout most of west Broward County probably ranges from 20,000 to 88,000 ft2/d. It is less where the aquifer thins or is absent along the eastern edge of west Broward County.

THE GROUND-WATER FLOW SYSTEM

The Present Flow System

The principal sources of recharge to the surficial aquifer system in east and south-central Broward County are infiltration of rainfall through surface materials to the water table, and to a lesser extent, water imported from the west or north that seeps through canals to the aquifer or is withdrawn from canals from irrigation. Under the water-conservation areas of west north-central Broward County, recharge is by infiltration of direct rainfall, of water backpumped from south-central Broward County or from west Palm Beach County, or of water drained by canal from Hendry County. Soil types have significant control on the ease of infiltration. As shown in figure 5, the most rapid drainage occurs in east Broward County on medium to fine sand or on rocky coastal areas. Drainage is much slower over most of Broward County where peat and muck or marl and fine sand predominate. Infiltration also varies seasonally. Recharge by rainfall is greatest during the wet season from June to November, and recharge by canal seepage is greatest during the dry season from December to May. A highly generalized water budget for the Biscayne aquifer in east Broward County (fig. 39) indicates that about 37 inches, or 62 percent, of the 60-inch average rainfall reaches the water table. In addition, a little more than 1 inch of the 2.5 inches pumped by supply wells returns to the water table.

Discharge from the surficial aquifer system is by: (1) evapotranspiration (about 20 inches of the 37 inches that infiltrate the aquifer, fig. 39); surficial aquifer system in adjacent counties; and (3) pumping wells for municipal, industrial, domestic, and agricultural supplies. Evapotranspiration and ground-water discharge are greatest during the wet season when water levels, temperature, and plant growth rates are high. Reports by Sherwood and others (1973) and Leach and others (1972) provide much quantitative information on the hydrology of the canal system and its effects on ground-water levels, temperature, and plant growth rates are high. Reports by Sherwood and others (1973) and Leach and others (1972) provide much quantitative information on the hydrology of the canal system and its effects on ground-water levels, which will not be included here. Although pumpage (about 2.5 inches in 1973, fig. 39) is only a small part of the total discharge from the aquifer, its effect is amplified because it is greatest during the dry season when recharge and aquifer storage are smallest. Also, because pumpage has increased over the amount shown in the water budget and because many pumping centers are near the coast or near uncontrolled canal reaches inland from the coast, saltwater intrusion is a serious concern.

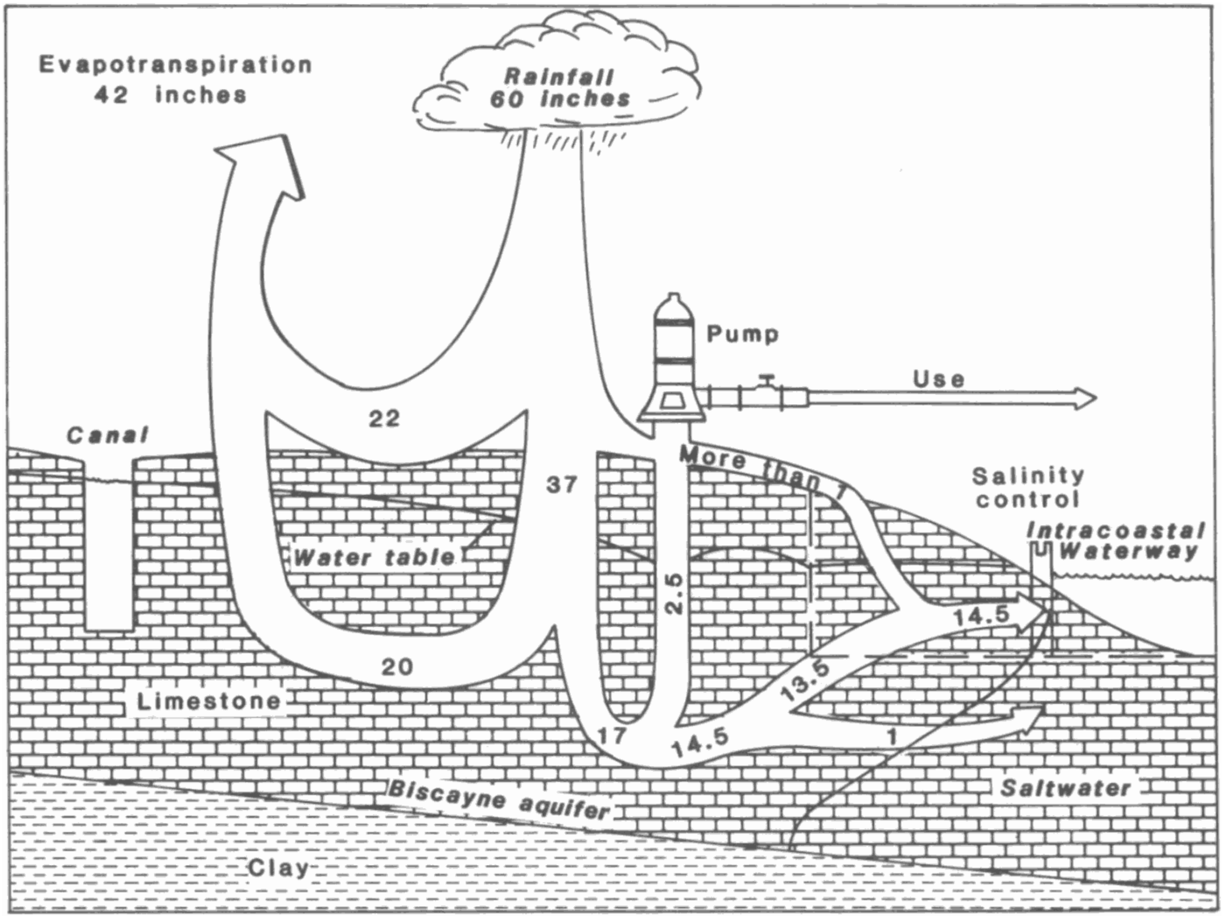


Figure 39. Generalized water budget for the Biscayne aquifer in east Broward County (from Sherwood and others, 1973).

Surface-water bodies and the ground-water system in Broward County are sufficiently well connected so that surface-water levels and adjacent ground-water levels are comparable under most circumstances. Surface water and ground water are considered the visible and hidden components of a continuous water body. Therefore, the hydraulic head at the upper limit of the ground-water body may be mapped both from water-table wells and from surface-water staff gages or recorders.

Ground-water level maps for the surficial aquifer system at the end of wet seasons and dry seasons are shown in figures 40 and 41, respectively. The maps represent 9-year monthly water levels for September (wet season) or for April (dry season). The maps portray average hydraulic head in the surficial aquifer system and the sustained hydraulic gradients available for moving ground water during the extreme seasonal conditions. Also, some areas of recharge and discharge and generalized directions of flow may be interpreted from the maps, as shown by arrows in figure 40.

The highest water levels in Broward County are maintained in the water conservation areas, particularly in north-central Broward County where the September average is 13.5 to 14 feet above sea level, and in the northeast were water pumped from Hillsboro Canal infiltrates from several canals to from a ground-water mound at 12.5 to 14 feet above sea level (Roy Reynolds, Broward

County Water Resources Management Division, oral commun., 1984). These are originating areas of flow systems, wherein ground water moves from recharge zones where levels are high to discharge zones where levels are low. Water levels of less than 4 feet occur in most of south-central, southeast and coastal northeast Broward County. In these low-water areas, especially in sandy areas, infiltration of rainfall is the principal source of recharge, although ground-water mounds do not appear at the scale of mapping and contour interval in figure 40. The lowest water levels are within the cones of depression formed around the major municipal well fields. The largest drawdown cones are those of the Fort Lauderdale Prospect well field and the Pompano Beach well field (fig. 40). Water levels in April (near the end of the dry season) range from 0 to 2 feet lower than those in September (end of the wet season) over most of the area, but declines greater than 2 feet occurred in the Fort Lauderdale Prospect well field and the Pompano Beach well field.

Ground-water movement in the Biscayne aquifer has been usually considered in terms of generalized areal flow directions as shown in figure 40. However, the three-dimensional nature of ground-water circulation and the effects of canals on water levels and circulation patterns should be considered.

Prior to canal construction, most ground water in east or south-central Broward County probably move downward from the water table through sand (and perhaps some less-permeable beds) to cavernous limestones and sandstones at depths of 40 to 100 feet below land surface and 30 feet to more than 100 feet thick (figs. 16-18). Infiltrating water that reached this very highly permeable zone of the Biscayne aquifer, which is 100 to 1,000 times more permeable than overlying sands, could move long distances horizontally, perhaps as much as 20 miles, with relatively small head loss. Water would then move upward through sand or other materials to areas of discharge in the ocean, the Intracoastal Waterway, sloughs, or low swamp areas. This circulation pattern would likely be more efficient hydraulically than flow paths through the shallow materials of moderate to low permeability.

Since canal construction, canals have had a major effect on ground-water levels and movement. Their prime function is drainage of ground water, although some canals, especially near well fields (for example, the Dixie and Prospect well fields, fig. 40), have become sources of infiltrating to the aquifer system. In most water-control districts (fig. 6), canals lessen peak water levels by providing lower ground-water levels prior to storms and by providing efficient surface-water and ground-water drainage. The multiplicity of canals effectively “short circuits” much of the natural ground-water flow by allowing shorter flow paths, local discharge, and rapid movement away by canal rather than slower movement through the ground to more distant discharge zones. The water budget (fig. 39) shows that for an estimated 14.5 inches of water involved in ground-water flow, about 13.5 inches returned to canals for discharge to the ocean, but only 1 inch is discharged directly from the ground to the ocean.

As an aid to understanding the effects of canals on the aquifer, interpreting ground-water movement, and planning site investigations, canal-aquifer relations in Broward County may be conceptually divided into the following possible classes:

- Losing—Canals or reaches of canals that lose (recharge) water to the surficial aquifer system.
    - Partially penetrating—Recharge is added to ground-water flow that passes underneath the canal.
    - Fully penetrating—The canal is a line source for ground-water movement away from the canal in both directions; there is no regional underflow.

- Gaining—Canals that collect water discharge from the surficial aquifer system and carry the water away.
    - Partially penetrating— Canals that intercept only part of the ground-water flow; some ground water passes underneath the canal to more distant discharge areas.
    - Fully penetrating—The canal is a line sing to ground-water flow. Although canals usually penetrate a small part of the surficial aquifer system, there is no underflow, and all flow is captured.
- Cross flow—Canal or ditches usually blocked or controlled, which have a negligible effect upon the surficial aquifer system; ground water passes across or under the canals.

However, except where the aquifer is highly stressed either by well fields in northeast Broward County or by ponding (water-conservation areas), water-level gradients are often so low and water levels of deep zones unavailable that classification of individual canal sites is difficult without further investigation. The peripheral canals of the water-conservation areas, which collect large amounts of seepage, are examples of sites where it is important to determine the ground-water flow pattern in more detail. Some underflow in the very highly permeable zone of the Biscayne aquifer is inferred in figure 40.

The Predevelopment Flow System

Circulation in the predevelopment ground-water flow system would have been controlled by differences in water level, by distance and direction from recharge areas to discharge areas, and by the permeability distribution of the surficial aquifer system. Topography would have played a significant role in generating water-level differences and sites of recharge and discharge. General interpretation of circulation in the predevelopment system may be based on the above factors. Concepts of the circulation may be either refined or supported by the three-dimensional water-quality characteristics of ground water in the surficial aquifer system.

The two primary controls of natural water quality on the surficial aquifer system are geochemical reactions and the degree to which freshwater circulation has flushed out old saltwater. This salty water is relict from former high sea-level stands, when the sea inundated Broward County (Parker and others, 1955) and saltwater invaded the surficial aquifer system. A plot of dissolved solids versus chloride concentration for water-quality data collected in this study is shown in figure 42. Also shown is the relation obtained by diluting seawater with pure water, using chloride as an index of the percentage of seawater. The plot suggests that most of the seawater has been flushed out, and the mixed water is naturally similar to diluted seawater. Typically, the ground water has 350 to 550 mg/L (milligrams per liter) more dissolved solids than diluted seawater having the same chloride concentration. The additional dissolved solids are derived from geochemical reactions, primarily the solution of calcite. Only in waters with dissolved solids less than about 900 mg/L (about two-thirds of the samples, excluding the modern saltwater intrusion samples) do products of geochemical reactions dominate the chemistry of Broward County ground water (fig. 42). Hence, profiles of chloride concentrations or of specific conductance in Broward County ground water can be used to indicate the degree of flushing and relative activity of circulation at various depths in the surficial aquifer system. As with the relation between dissolved solids and chloride, there is also a close linear relation between specific conductance and chloride. Unflushed saltwater dominates the chemistry of the water above a specific conductance of a bout 1,250 µs/cm (microsiemens per centimeter) and a chloride concentration of about 200 mg/L.

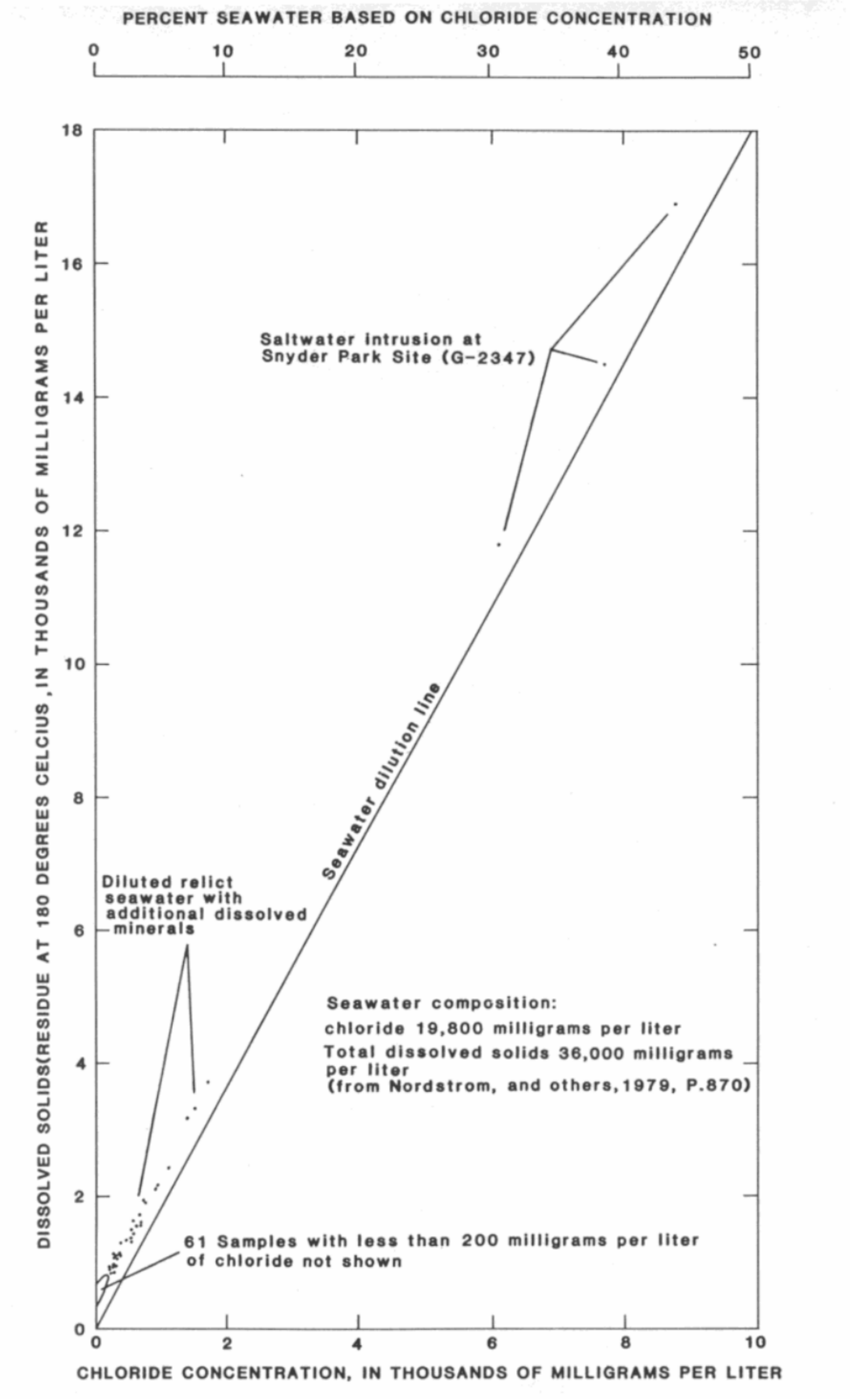


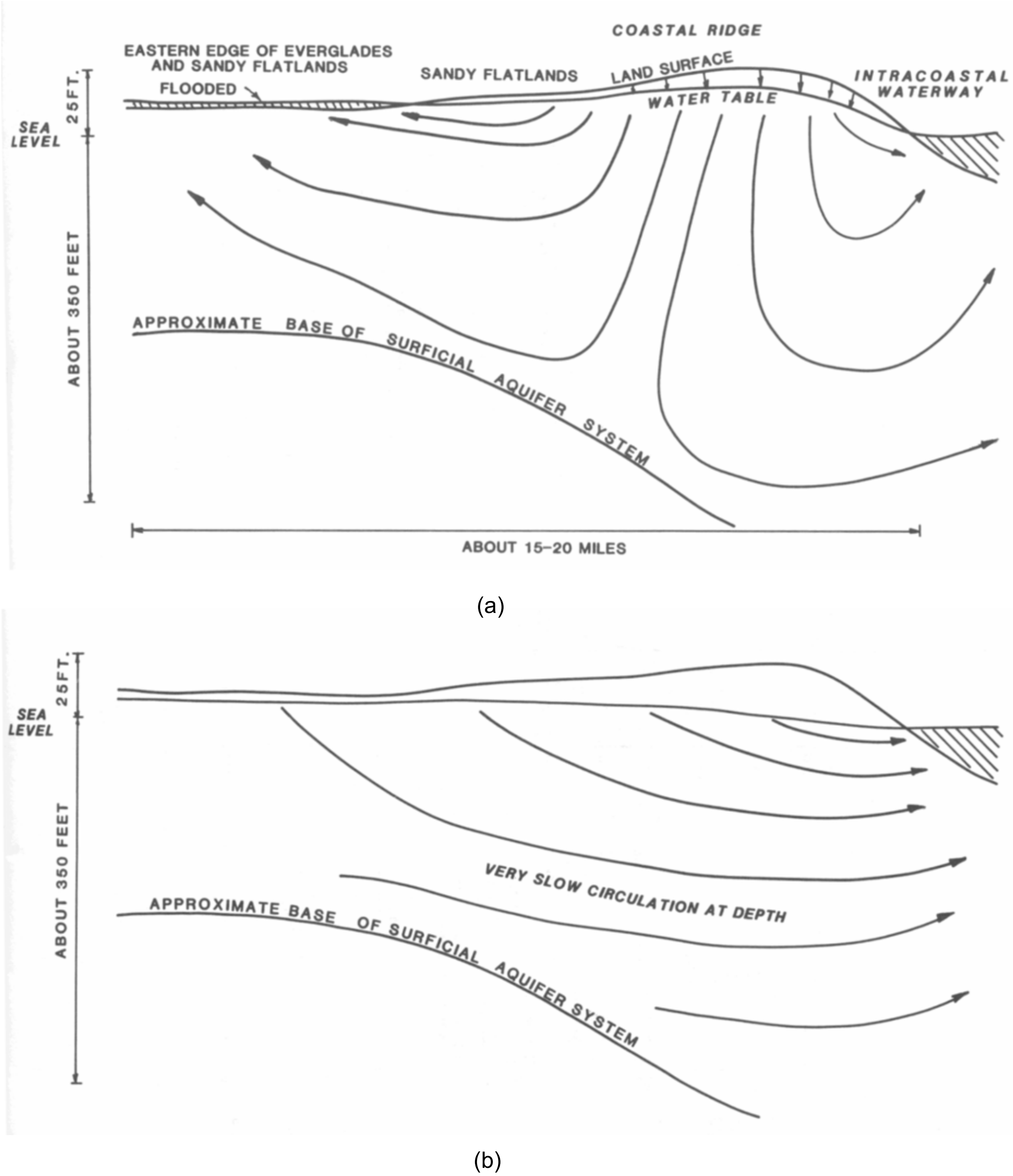
Figure 42. Relation between dissolved solids and chloride concentrations in ground-water samples from Broward County and apparent relation of the chemistry to dilute seawater.

Before the development of Broward County, the water levels of the natural hydrologic system were different than at present. The water levels in the region, now occupied by the Everglades Water-Conservation Areas, were somewhat lower. In fact, the Everglades frequently dried up seasonally. However, in most of east Broward County, before urbanization and the installation of the drainage canal system, water levels were higher than shown in figures 40 and 41, except for the recharge mound adjacent to the Hillsboro Canal in the northeast. The greatest differences between now and then likely occurred along the Atlantic Coastal Ridge (fig. 4), particularly in northeast Broward County. Recharge from summer rainfall would build up a ground-water ridge beneath the coastal ridge in Dade County was reported by Parker and others (1955, p. 211, 212, and 227). Also, some evidence for ground-water mounding beneath the high ground in southeast Palm Beach County may be seen on a water-level may for November 1984, by Miller (1985), although the mounding probably is subdued compared to predevelopment conditions and shifted a few miles west due to effects of canals. In north Palm Beach County, the same map shows a broad northwest-southeast trending ground-water high that also follows the topography. The coastal ground-water high probably existed for a longer time seasonally in Broward County than in Dade County because transmissivity is lower in northeast Broward County than in Dade County, and the top of the very highly permeable zone is deeper in Broward County.

The presence of a coastal ground-water ridge would have a significant effect on flow in the predevelopment system. A conceptual ground-water flow pattern for such a system is shown in figure 43a. Coincidentally, the highest land and highest ground-water levels occurred where the aquifer is thickest and of generally high permeability with little clay or lime mud. This would allow deep circulation that would gradually flush old saltwater (see hydrogeologic sections, figs. 15-18). Another important consequence of the seasonal ground-water ridge. In west Broward County, ground water probably moved to the southeast or south, generally similar to surface flow in the Everglades, rather than to the east (the shortest distance to a coastal discharge zone).

Prior to urbanization and during normal dry seasons, the coastal groundwater ridge would gradually decay. Coastal water levels would decline mort rapidly than inland water levels due to proximity to discharge areas and generally higher transmissivity in the coastal area than inland. If the water table beneath the coastal ridge declined to a lower level than the water table inland. Water that had been moving westward would temporarily stagnate and then reverse direction so that all flow was either toward the coast or toward sloughs (fig. 43b). Such seasonally varying water-level and circulation patterns dominated by a coastal ground-water ridge would partly explain the occurrence of freshwater with low chloride concentrations and low specific conductance deep under the coastal ridge (fig. 44a,b), and the occurrence of poorer quality water often found deep under inland areas located 5 to 15 miles from the coast, where residence times would have been longer and where flushing is less complete (fig. 44d,e).

The permeability distribution has also affected circulation and flushing in east Broward County, as may be seen by comparing specific conductance profiles at various test sites with the permeability framework. The lower section of the surficial aquifer system is much less permeable than the middle section, particularly 5 to 15 miles inland (see figs. 17, 21, and 22). Gradients of increasing specific conductance with depth in some of the deep quartz and carbonate sand sequences, such as at the north Dixie well field and Plantation sites (fig. 44d,e; G-2345 and G-2322, fig. 17), indicate less circulation has occurred there than in the very highly permeable zones above. At the north Dixie well-field site, layers of silt or clay a few inches or less thick are present and retard vertical circulation and flushing. However, the steep gradient in specific conductance begins in limestone at a depth of about 150 feet. This may indicate that some limestone beds have



(a)

(b)

Figure 43. Hypothesized patterns of ground-water movement in east Broward County prior to development. Controlled by: (a) coastal ground-water ridge during wet season; and (b) seaward gradient after dissipation of ground-water ridge in dry season.

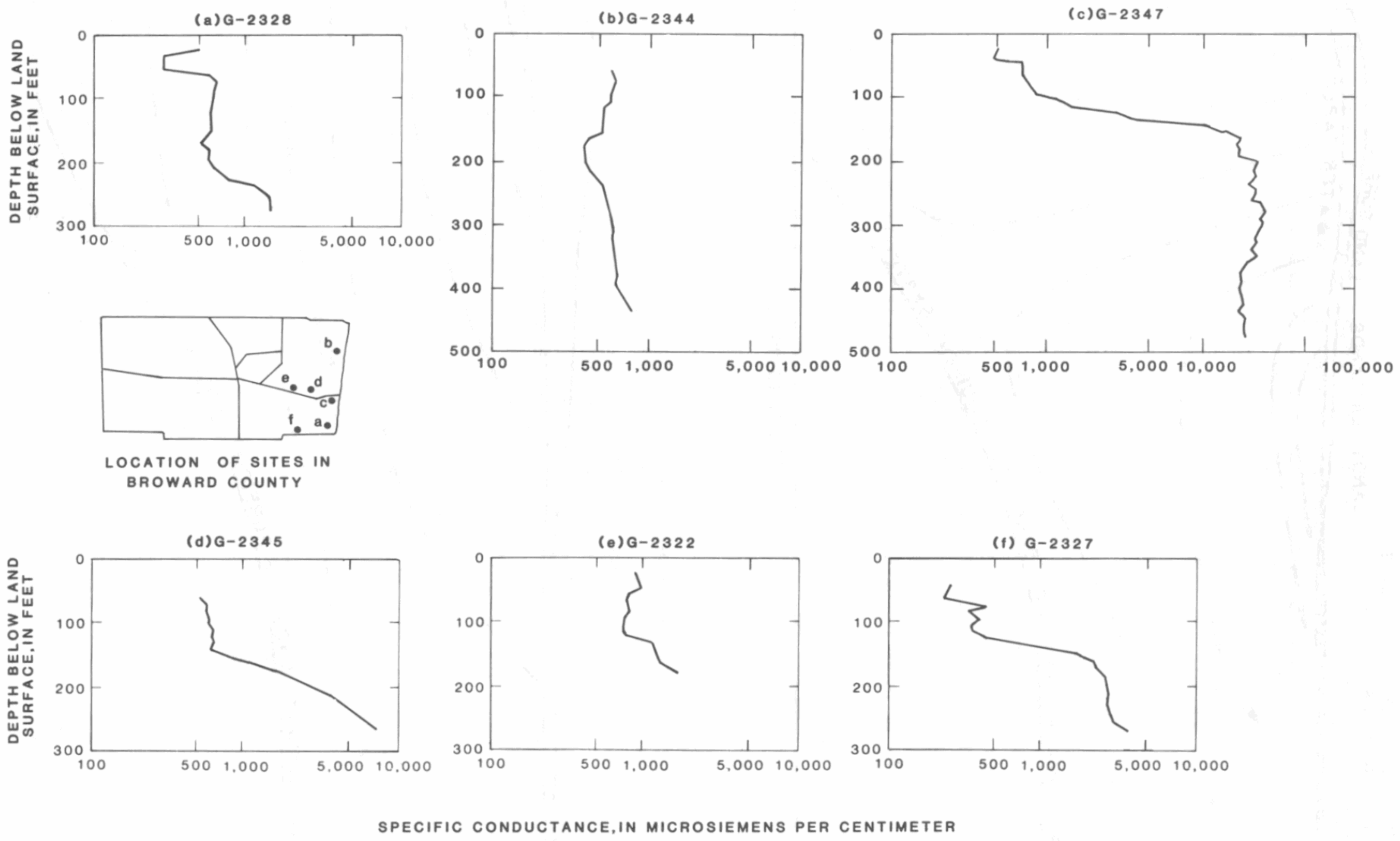


Figure 44. Depth profiles of specific conductance of ground water at selected sites in east Broward County.

low permeability or that upconing of poorer quality water is occurring. At some sites, a specific layer of low permeability has restricted flow to deeper, more permeable materials. For example, at the Miramar east site, a 20-foot thick layer of limestone from 120 to 140 feet below land surface has low permeability, which retards circulation and flushing in the underlying materials (fig 44f).

At the coastal discharge part of the ground-water flow system, there is a freshwater-saltwater interface. However, the relatively low-water levels, shown if figures 40 and 41, suggest much saltier water might be expected in the deeper parts of the aquifer system beneath the coastal ridge than indicated by the specific conductance profiles at the Hallandale and Pompano Beach well-field sites (figs. 44a, b). Salty water does occur at the Snyder Park site (fig. 44c) where specific conductance reaches 25,000 µs/cm, about half that of seawater. Aside from the dynamic rather than static characteristics of the flow system (Kohout, 1960; Kohout and Klein, 1967), three other possible explanations for the relatively deep occurrences of freshwater should be considered. A fourth explanation, that of downward flow of freshwater in the borehole while pumping to collect the water samples, can be eliminated because samples from finished wells have verified the data collected during drilling, except fro one lithology not present in the coastal area.

The first explanation attempts to relate the salinity profile to the present hydrology. It assumes that the saltfront is in an equilibrium position with the possible exception of coastal areas that are stressed by well-field pumpage. The explanation requires that there be beds having sufficiently low permeability at the Hallandale and Pompano Beach areas to confine flow at depth and to sustain higher hydraulic heads there than at the water to be derived from nearby upgradient areas. This concept might explain the Pompano Beach specific conductance profile because water moves toward the site from high ground-water levels to the west (figs. 40 and 41). However, it is because no areas of significantly higher water levels presently exist near that site. Also, test drilling indicates only minor beds having low permeability in the surficial aquifer system at either site.

A second explanation considers the deep freshwater in some areas near the coast to be relict from the last major glacial period, the Wisconsin. During that glacial period, sea level was commonly lower than at present in south Florida (Parker and others, 1955, p. 124). According to this concept, freshwater circulation would have displace seawater, at least in the coastal areas, and the freshwater-saltwater interface would be near a different shoreline, some distance (perhaps a few miles) east of the present shoreline. However, a prolonged period of flushing due to a lower sea level during the Wisconsin should have removed all the seawater from inland areas of east and south-central Broward County, but specific conductance profiles (fig. 44d-f) indicate that flushing is incomplete. Furthermore, vertical circulation near the coast should be very good because of the overall high permeability (as discussed in the “Hydrogeology” section) and the very few beds having relatively low permeability. Thus, for the present sea level and water-table conditions, saltwater should displace freshwater in a relatively short time compared to the length of time since the end of the last glaciation. Saltwater intrusion at the Snyder Park site (fig. 44c), where water levels are relatively low but have not been so affected by the development of Broward County as have been the Hallandale and Pompano Beach sites, may be an example of such a displacement. Therefore, it seems unlikely that the freshwater found beneath the coastal ridge is relict from glacial times.

A third explanation for freshwater at unusual depths beneath the coastal ridge relates the freshwater profile to hydrologic conditions after sea level had risen to about its present position before development of Broward County. It also considers the effect of changing ground-water levels on the location and shape of the freshwater-saltwater interface. Before the development of the canal drainage system, ground-water levels along the coastal ridge were probably considerably higher than at present. This difference may have been several feet near Hallandale nad possibly greater than 10 feet in northeast Broward County and where the coastal ridge exceeds and altitude of 15 feet (more than 20 feet in places) and the aquifer is less permeable than to the south. In correspondence with the higher water levels, the saltfront would have been farther seaward than with present water levels, and freshwater may have reached a depth of 600 feet or more beneath the coastal ridge. The salty water at the Snyder Park site (fig. 42, highest points; fig. 44c) occurs in a broad low area, having an altitude between 5 and 10 feet. The site is about 0.75 mile west of the coastal ridge, which is very narrow (only about 1,000 feet wide), and has an altitude of about 15 feet in that area. Because the coastal ridge is much narrower near Snyder Park than it is to the north and south, it may not have had as much influence on predevelopment circulation patterns in the vicinity of Snyder Park.

The occurrence of deep freshwater with a low-water table suggests that the saltfront may not be in a stable position, and that it may still be moving inland in response to decreases in head. During transient conditions, the cross-sectional shape of the freshwater-saltwater interface could be complex wherein most rapid advancement may occur in the very highly permeable zone (which is also tapped for water supply), and slower advancement may occur in the less-permeable materials below that zone. At the Snyder Park site (fig. 44c) where the saltwater intrusion apparently is in progress, the transitions from freshwater to saltwater occurs primarily between 100 and 160 feet. Specific conductance reaches a maximum of about 25,000 μS/cm (about 50-percent seawater) between 260 and 310 feet and then decreases to about 18,000 μS/cm between 380 and 476 feet, the bottom of the test hole. The implication of the third explanation is that the freshwater beneath the coastal ridge in the deeper parts of the aquifer may be predevelopment in age, and that under present water-management practices, it may eventually be replaced by seawater. This interpretation appears to be supported by recent large increases in chloride concentration in observation wells east of the Hallandale and the Pompano Beach well fields (R.S. Sonenshein, U.S. Geological Survey, oral commun., 1986) and by intrusion at Snyder Park. Additional investigation is needed to evaluate whether this concept adequately explains the occurrence of anomalous freshwater beneath the coastal ridge.

The gray limestone aquifer of the Tamiami Formation in west Broward County is underlain and overlain by materials of lower permeability, although the overlying materials permit leakage from or to the Biscayne aquifer. The gray limestone aquifer extends to the north, west, and south into adjacent counties but grades eastward from the eastern edge of west Broward County into clayey limestone, clayey sand, and silt. These latter materials form a lithologic barrier (because of low permeability), with the possible exception of the northernmost Broward County area, which retards eastward movement of water from the gray limestone aquifer or westward movement from the middle part of the Tamiami Formation in east Broward County (fig. 45). Water levels in the aquifer at three sites along Alligator Alley appear to be about the same as those in the overlying Biscayne aquifer and the ponded water in the conservation areas, although measurements have not yet been made.

Interpreted flow directions in the gray limestone aquifer (fig. 45) are believed to represent predevelopment ground-water movement, although present-day movement is probably similar. Water entered west Broward County by lateral movement from recharge areas at higher altitudes in Hendry County, northeast and north-central Collier County, and to a lesser degree, west Palm Beach County. This laterally moving water is part of a regional ground-water flow system, wherein water moves from those higher altitude areas to coastal discharge zones. Movement of water in west Broward County was generally southward into Dade County and its southern coast, rather than eastward, because of the coastal ground-water ridge in Dade and Broward counties. Water also very likely entered the gray limestone over a large area. Leakage would have occurred during the wet season and at least the early part of the dry season. The amount of leakage would vary areally according to local confining properties of overlying beds and according to local vertical hydraulic gradients.

Water-quality data (Barbara Howie, U.S. Geological Survey, written commun., 1986) show greater dissolved solids or higher specific conductance in water in the gray limestone than in the Biscayne aquifer or other overlying materials that yielded water, and greater freshening of water (flushing out of old seawater) in the gray limestone to the south and west than to the north and east. These general water-quality characteristics may be observed in the selected specific conductance profiles (fig. 46a-f) for the surficial aquifer system and in the chloride concentrations at the top and bottom of the gray limestone aquifer (fig. 45). The degree of flushing may be most easily seen by comparing chloride concentrations at the bottom of the gray limestone. Along most of the Broward-Palm Beach County line, chloride exceeds 1,000 mg/L at the bottom of the gray limestone, indicating more than 5--percent relict seawater and approaches 10 percent at the Hillsboro Canal west site (PB-1428). The trend of increasing specific conductance and chloride (poorer quality water) to the north continues into southwest Palm Beach County (Parker and others, 1955, p. 811-813; Scott, 1977; and W.L. Miller, U.S. Geological Survey, oral commun. 1984). This supports the interpretation that circulation decreases to the north because southwest Palm Beach County lies between tow areas having high ground water, the Atlantic Coastal Ridge and Hendry County, and because the distance to discharge areas is maximum. Low specific conductance and chloride in the southernmost and westernmost parts of west Broward County support the interpretation of more active circulation there. Water samples collected during recent test drilling revealed that the trend of low specific conductance water continues southward in northwest Dade County. In general, the presence of diluted relict seawater at depth in west Broward County is evidence that circulation is slow, and that the water is predominantly much older than the beginning of development in the area. An estimated rate of lateral movement of water in the gray limestone, ranging from about 30 to 60 ft/yr, further indicates the antiquity of the water.

The slope of the specific conductance profiles (fig. 46) or the change in chloride concentration from top to bottom in the gray limestone aquifer (fig. 45), in some instances, indicates the source(s) of the water. In westernmost Broward County, the specific conductance is nearly uniform (vertical slope) from top to bottom, which implies virtually all lateral movement from Hendry County or Collier County and no leakage from above. This conclusion, on the basis of water quality, agrees with the interpretation, on the basis of the hydraulic framework, in that leakage there should be the least of any tested area because of thick confining clays and lime mud. The decrease in slope from west to east, as shown by the sites along Alligator Alley (fig. 46b-e), and from south to north, the Broward-Palm Beach County line (fig. 45 and 46f), indicates an increasing percentage of the flow comes from local leakage downward from overlying fresher water. This also agrees with the interpretation on the basis of the hydraulic framework and water levels.

SUMMARY

In 1981, the U.S. Geological Survey, in cooperation with the South Florida Water Management District, began an investigation of the surficial aquifer system in Broward County, as part of a regional study of the system in southeast Florida. The purpose of this report is to characterize the ground-water hydrology, including defining and delineating the surficial aquifer system and aquifers within it, to portray the permeability (hydraulic conductivity) framework of the surficial aqui-

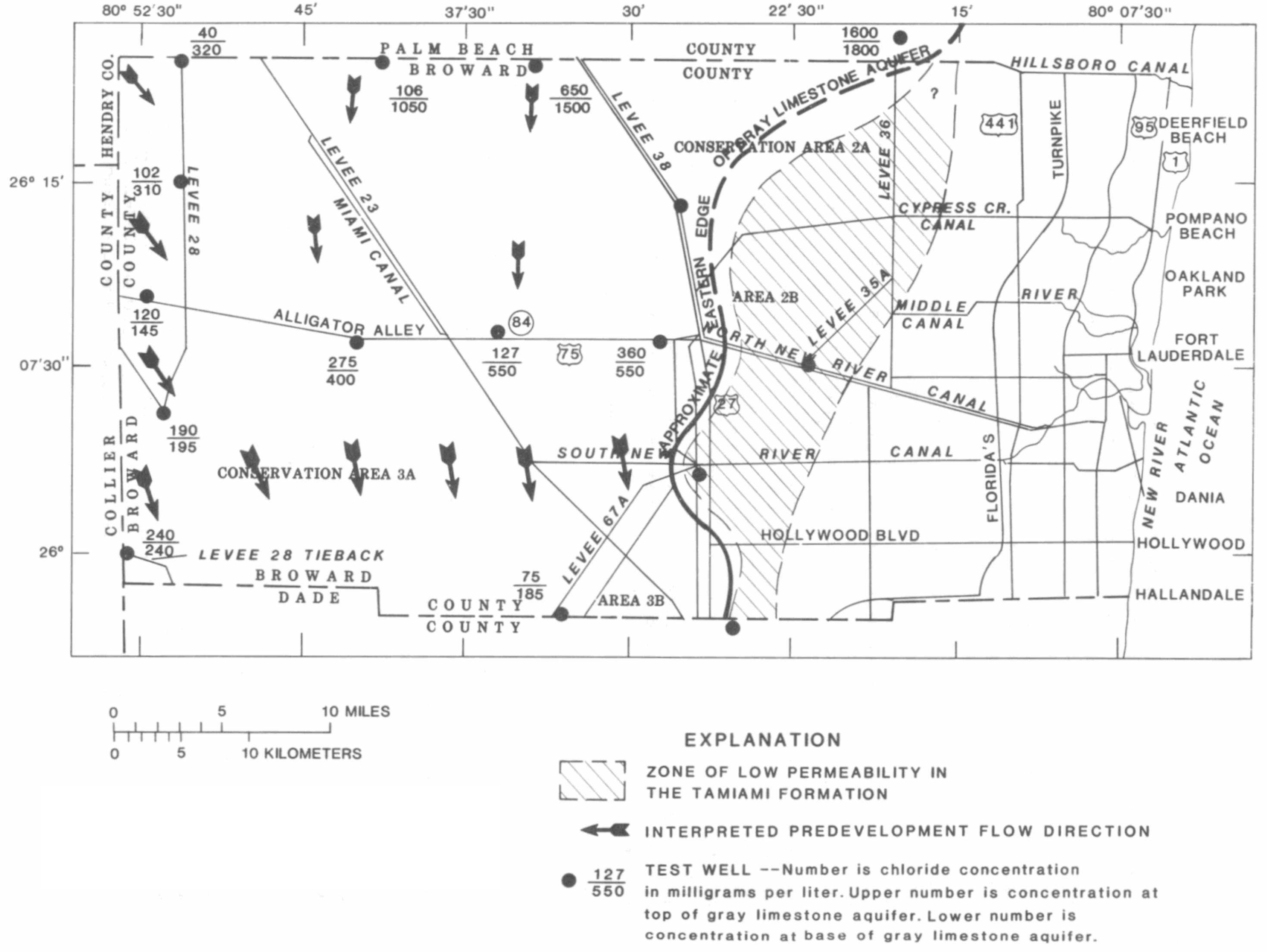


Figure 45. Chloride concentrations and predevelopment flow directions in the gray limestone aquifer of the Tamiami Formation, and a zone of low permeability east of the gray limestone aquifer in Broward County.

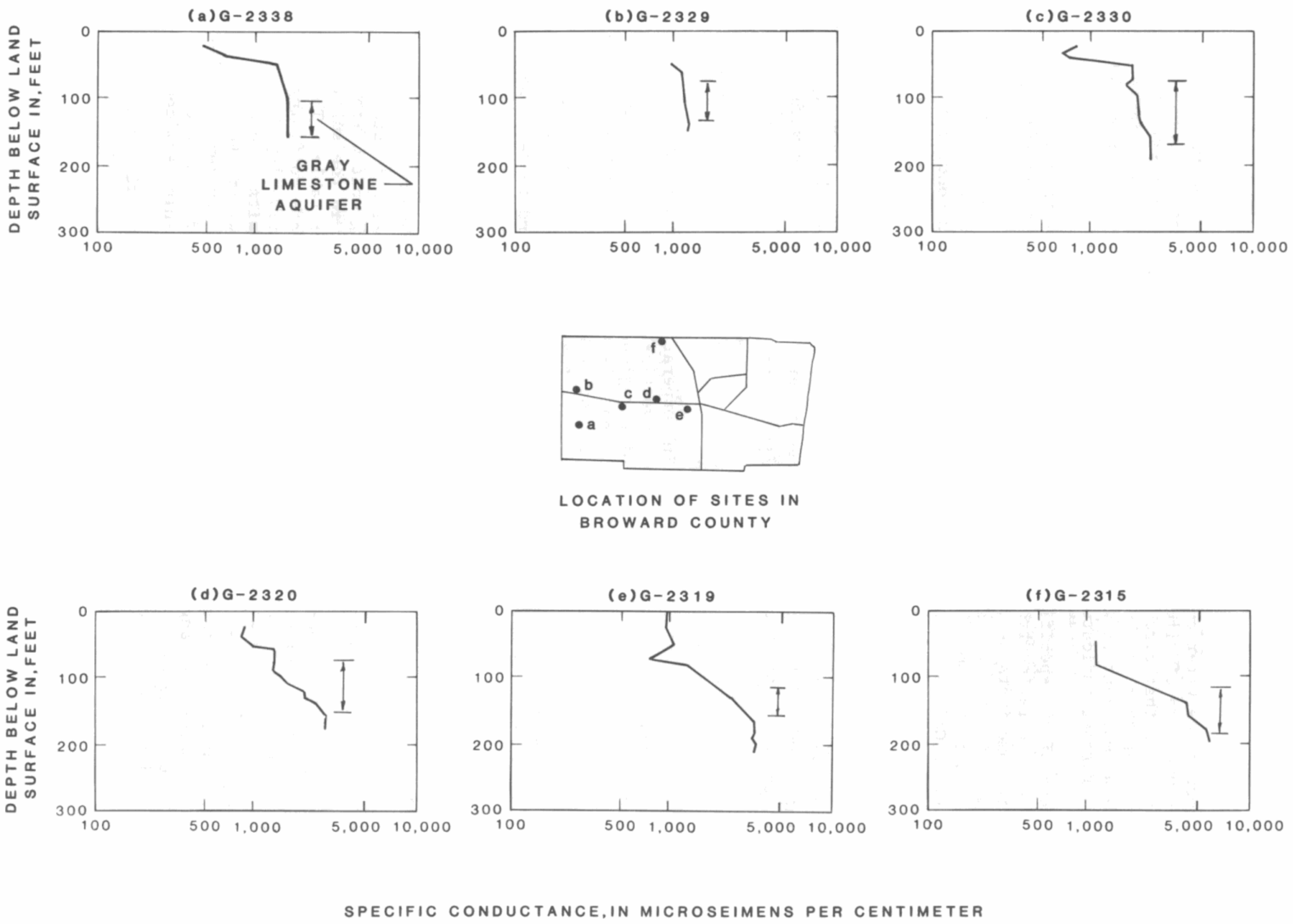


Figure 46. Depth profiles of specific conductance of ground water at selected sites in west Broward County. Also shown is the top and base of the gray limestone aquifer of the Tamiami Formation.

fer system by hydrogeologic sections, to map the generalized transmissivity distribution, and to describe the general pattern of ground-water flow. The methods used were: (1) hydrogeologic test drilling; (2) aquifer testing of wells open to selected zones or lithologies; and (3) analyses of previously available geologic logs, long-term water-level records, aquifer tests, and specific capacity tests of large supply wells.

The surficial aquifer system in Broward County is defined as all materials from land surface to the top of the intermediate confining unit which confines the Floridan aquifer system. Groundwater circulation in the surficial aquifer system is driven by or closely related to the water table. The base of the surficial aquifer system (also top of the intermediate confining unit) in most places is the permeability contrast between slightly clayey sands in the lower part of the Tamiami Formation and thick deposits of clay, silt, or sandy clay or silt, either in the upper part of the Hawthorn Formation or lowermost part of the Tamiami Formation. The surficial aquifer system, having materials ranging more than about seven orders of magnitude of hydraulic conductivity, contains two aquifers with an intervening semiconfining bed, which is mostly clayey sand.

The definition of the Biscayne aquifer is refined to include permeability and thickness criteria. The Biscayne aquifer is that part of the surficial aquifer system composed of Pamlico Sand, Miami Oolite, Anastasia Formation, Key Largo Limestone, Fort Thompson Formation, and contiguous subjacent highly permeable limestone or sandstone of the Tamiami Formation where at least 10 feet of the section is very highly permeable (horizontal hydraulic conductivity of about 1,000 ft/d or more). The delineation of the Biscayne aquifer differs from previous work in that less of northwest and north-central Broward County are included within the area of the aquifer, and the aquifer is substantially thicker near the coast. The upper part of the Biscayne aquifer is composed primarily of quartz sand in the east and dense limestone, peat, and lime mud in sand in the west; the lower part is a highly to very highly permeable zone of limestone and calcareous sandstone that have abundant solution cavities and some interbedded sand. Hydraulic conductivities of the highly permeable zone of the Biscayne aquifer may exceed 10,000 ft/d.

The gray limestone aquifer is defined as that part of the limestone beds in the lower and locally the middle part of the Tamiami formation that are highly permeable (hydraulic conductivity of about 100 ft/d or more) and at least 10 feet thick. Lateral changes of this limestone to less-permeable clayey, sandy limestone or carbonate sand are excluded from the aquifer, but depths between 20 and 100 feet below sea level in west Broward County, and it extend to between 102 and 170 feet below sea level. Calculated hydraulic conductivities in the gray limestone aquifer range from 590 to 930 ft/d for most of the aquifer, but the poorly consolidated upper part in northwest Broward County is less permeable.

Materials ranging from moderate to very low permeability occur within semiconfining beds separating or underlying the aquifers of the surficial aquifer system and as less permeable layers within the aquifers, especially the Biscayne aquifer. On the basis of two permeability tests and values reported in the literature, most of the relatively clean sands found in Broward County would be moderately permeable, having hydraulic conductivities of about 30 to 100 ft/d. Clayey or silty sands, which are common in the interval that separates the Biscayne aquifer from the gray limestone aquifer and as the basal unit of the surficial aquifer system throughout the area, are less permeable. Silt, clay, and mixtures of lime mud, shell, and sand form even less-permeable layers in the system, especially in the semiconfining unit that overlies the gray limestone aquifer in west Broward County, and have hydraulic conductivities that generally range from about 0.001 to 1.000 ft/d. Many types of limestone in the area also have relatively low permeability.

Analysis of test drilling, specific capacities, and pumping tests indicates that transmissivity of the surficial aquifer system is locally variable but has a definite areal pattern. Transmissivity in south-central, southeast, and part of northeast Broward County generally exceeds 300,000 ft^2/d and may exceed 1,000,000 ft^2/d in the southeastern coastal area of Hallandale and Hollywood. Transmissivity rapidly decreases to less than 75,000 ft^2/d over a large area in northwest and north-central Broward County. In areas with high transmissivity, most of the transmissivity occurs in the cavernous zone of the Biscayne aquifer. Transmissivity of the gray limestone aquifer in west Broward County ranges from about 20,000 to 88,000 ft^2/d. In northwest Broward County, the gray limestone aquifer may have higher transmissivity than overlying limestone beds of the Fort Thompson Formation and upper part of the Tamiami Formation.

Circulation in the ground-water flow system is likely to be different in some respects after development of the ara because water levels, distance to discharge areas, and patterns of recharge have changed. Features of the water-management system that affect circulation include canals, drainage districts, irrigation or artificial recharge areas, water-conservation areas, pumping stations, control structures on canals, and well fields. Canals quickly remove much ground water during storms, greatly shortening ground-water flow paths compared to predevelopment conditions. However, it is frequently unclear whether canals act as fully penetrating boundaries, thereby dividing the system into many independent flow cells, or as partially penetrating boundaries of flow systems. Coastal water levels have been lowered, the threat of saltwater intrusion into coastal well fields a serious concern. The anomalous occurrence of freshwater to depths of several hundred feet below the coastal ridge, where water levels are generally less than 2 feet above sea level, suggests that the saltfront in not at an equilibrium position and that the surficial aquifer system. Under the present conditions of development, south and generally similar to the interpreted predevelopment pattern. Locally, differences may occur due to the drainage by the major canals (such as the Miami Canal), differences in water level between water-conservation areas, and underflow along the eastern edge of the water-conservation areas.

Prior to alterations of the hydrologic system by man, the likely development of a wet-season ground-water ridge under the topographic coastal ridge in east Broward County may have caused seasonal, deep, downward, and westward movement of ground water; flooding of the Everglades and of swamps in the Sandy Flatlands; and southward movement of ground water in west Broward County. The natural water-quality characteristics of Broward County are primarily related to the flushing of old seawater from the aquifer by circulation of fresh ground water prior to development and to solution of calcite. Circulation in the predevelopment ground-water flow system was controlled by water levels (such as the coastal ground-water ridge), distance to discharge areas, pattern of recharge, and by the permeability framework of the surficial aquifer system. On the basis of these controls during predevelopment conditions, water apparently entered the gray limestone aquifer in Broward County by lateral movement from upgradient areas in Hendry, Collier, and Palm Beach Counties and by downward leakage from overlying sediments and the Everglades. Ground-water movement was to the south into Dade County and to coastal discharge areas. The hydrologic interpretations are supported by the natural water-quality pattern areally and vertically in the surficial aquifer system.

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Table 2. Owners, construction details, and hydraulic data for large supply wells in Broward County

[See figure 9 for location of sites; Site name: BCCE, Broadway Country Club Estates; BCCI, Broward County Correction Institute; BCU, Broward County Utility; CCTP, Cypress Creek Trailer Park; DATP, Driftwood Acres Trailer Park; FL-F, Fort Lauderdale-Fiveash; PB-P, Pompano Beach-Palmaire; SCU, South Canal Utility, Inc. Finish: OH, open hole; S, screen. Inch-pound units: diameter, in inches; production interval, in feet below land surface; discharge, in gallons per minute; drawdown, in feet; pumping period, in hours; specific capacity, in gallons per minute per foot; estimated transmissivity, in feet squared per day (270 x specific capacity). USGS, U.S. Geological Survey]

Site name	Map num -ber	Own-er's well num -ber	USGS supply well number	Lati-tude	Long-itude	Dia-me-ter	Fin-ish	Pro-duc-tion inter-val	Dis-charge	Draw-down	Pum-ping per-iod	Spe-cific capa-city	Estim-ated trans-missi-vity
Hallandale	1	7	S-1537	2559	8009	18	S	72-87	2,500	0.8		3,100	840,000
do.	2	8	S-2157	2559	8009	20	S	101-107	3,600	.8		4,500	1,200,000
do.	3	1	S-1531A	2559	8009	10	S	59-83	1,000	.5		2,000	540,000
		2	S-1534A	2559	8009	10	S	60-82	1,000	.4		2,500	680,000
		3	S-1535	2559	8009	10	S	62-82	1,529	2	8	770	210,000
		4	S-1536	2559	8009	12	S	51-68	1,045	2		520	140,000
		5	S-1532A	2559	8009	12	S	51-70	1,060	2		530	140,000
		6	S-1533A	2559	8009	12	S	51-70	1,060	2		530	140,000
BCU District 3B	4	1	S-2141	2558	8011	6		-- -100					
		2	S-1493	2558	8011	8		-- -100					
		3	S-2142	2558	8011	12		-- -130					
		4	S-2143	2558	8010	8		102-140	2,100	4.5		470	130,000
BCU District 3C	5	1	S-2144	2559	8013	4		-- -80					
		2	S-2145	2559	8013	6		50-57					
		3	S-2146	2559	8013	10		73-80					
Miramar	6	1	S-1494	2558	8013	6	S	100-110					
		6	S-2222	2559	8013	12		100-109					
		7	S-2223	2559	8013	12		100-109					
		8	S-2224	2559	8013	8		100-109					
		9	S-2225	2559	8013	8		100-109					
do.	7	2	S-2218	2558	8013	6		100-110					
		3	S-2219	2558	8013	8		100-110					
		4	S-2220	2558	8013	8		100-110					
		5	S-2221	2558	8013	10		110-120					
Dania	8	A	S-1366	2602	8009	12		[1]93-93	2,000	1.9	6	1,100	280,000
		B	S-1367	2602	8009	12		-- -93					
		C	S-1523	2602	8009	12		100-110	700	2.0	5	350	95,000
		D	S-1524	2602	8009	12		110-120	700	2.0	5	350	95,000
do.	9	E	S-2153	2602	8009	12		[1]88-88	1,140	1.2	6	950	260,000
		F	S-2154	2602	8009	12		100-112	1,140	.5	6	2,300	620,000
do.	10	G	S-2155	2602	8010	18		65- --					
		H	S-2156	2602	8010	18		69- --					
Hollywood	11	16	S-2168	2600	8010	14		118-123		.15	36		
		17	S-2169	2600	8010	14		58-70					

Table 2. Owners, construction details, and hydraulic data for large supply wells in Broward County -- Continued

Site name	Map number	Owner's well number	USGS supply well number	Latitude	Longitude	Diameter	Finish	Production interval	Discharge	Drawdown	Pumping period	Specific capacity	Estimated transmissivity
Hollywood (cont'd)	11	18	S-2170	2600	8010	14		58-70					
		19	S-2171	2600	8010	14	OH	65-69					
		20	S-2172	2601	8010	24	OH	60-75	2,800	5	4	560	150,000
		21	S-2173	2601	8010	24	OH	59-75	4,200	4	5	1,050	280,000
do.	12	1	S-332	2600	8010	12	S	55-67					
		2	S-333	2600	8010	12	S	53-65					
		3	S-334	2600	8010	12	S	53-65					
		4	S-335	2600	8010	12	S	53-70					
		5	S-2158	2600	8010	12		53-70					
		6	S-2159	2600	8010	12		52-65					
		7	S-2160	2600	8010	12		55-68					
		8	S-2161	2600	8010	12		110-125					
		9	S-2162	2600	8010	12		54-67					
		10	S-1496	2600	8010	12		52-65					
		[2]11	S-2163	2600	8010	12	OH	53-65					
						10	OH	115-130					
		[2]12	S-2164	2600	8010	12	OH	53-65					
						10	OH	140-149					
		[2]13	S-2165	2600	8010	12	OH	53-65					
						10	OH	115-130					
		[2]14	S-2166	2600	8010	12	OH	38-65					
						10	OH	143-152					
		[2]15	S-2167	2600	8010	12	OH	53-65					
						10	OH	111-120					
		22		2600	8011	20	OH	59-75	2,400	2.5		960	260,000
		24		2600	8010	20	OH	59-75	2,400	2.5		960	260,000
		26		2600	8010	20	OH	53-80	3,600	1.4	1.1	2,600	690,000
BCU District 3A	13	1	S-1488	2603	8011	12		-- -60				540	150,000
		2	S-1489	2603	8011	10		-- -60	700	.8		880	240,000
		3	S-2139	2603	8011	12	OH	60-65				930	250,000
Modern Pollution	14	1	S-2229	2602	8014	12	OH	100-115	-				
		2	S-2230	2602	8014	12	OH	131-150					
	15	1	S-1497	2601	8013	10		-- -200					
Pembroke Pines Plant 1	16	1	S-2102	2600	8013	8	S	90-110					
		2	S-2103	2600	8013	10	S	70-111					
		3	S-2104	2600	8013	10		105-111					
Pembroke Pines Plant 2	17	1	S-2105	2600	8014	12	OH	106-113	1,500	2.5	1.5	600	160,000

Table 2. Owners, construction details, and hydraulic data for large supply wells in Broward County -- Continued

Site name	Map num -ber	Own-er's well num -ber	USGS supply well number	Lati-tude	Long-itude	Dia-me-ter	Fin-ish	Pro-duc-tion inter-val	Dis-charge	Draw-down	Pum-ping per-iod	Spe-cific capa-city	Estim-ated trans-missi-vity
Pembroke Pines Plant 2 (cont'd)		2	S-1455	2600	8014	12	OH	105-112	500	.9	2	560	150,000
		3	S-2106	2600	8014	12	OH	106-111	1,500	1.6	12	940	250,000
		4	S-2107	2600	8014	16	OH	114-144	2,100	11.5		180	49,000
		5		2600	8014	16	OH	103-115	3,000	4.4		680	180,000
South Florida State Hospital	18	1	S-1495	2600	8015	10		57-121					
		2	S-2231	2600	8015	10		70-120					
		3	S-2232	2600	8015	10		111-118	745	.8	12	930	250,000
Cooper City East	19	1	S-1498	2603	8016	10		-- -114					
		2	S-2108	2603	8016	10	OH	-- -82	700	1.2		580	160,000
		3	S-2109	2603	8016	12	OH	-- -86	825	1.6		490	130,000
Cooper City\ West	20	1	S-2110	2603	8018	12	OH	67-76	2,300	1.9	12	1,200	320,000
		2	S-2111	2603	8018	12	OH	92-108	820	.5		1,600	440,000
		3		2603	8018				1,225	1.3		940	250,000
South Broward Utility Company	21	1		2602	8021	12	OH	40-60	400	.6	.5	670	180,000
		2		2602	8021	12	OH	42-60	1,000	3.1	.5	320	86,000
		3		2602	8021	12	OH	40-60	400	.9	.75	440	120,000
BCCI	22	1	S-2088	2601	8025	6	S	60-80	120	9.1	8	13	3,500
		2	S-2089	2601	8025	6	S	56-76	125	7.6	8	16	4,500
Holly Lake Utility	23	1		2600	8026	8		42-100					
		2		2600	8026	8		42-100					
Ferncrest Utilities	24	1	S-2201	2605	8013	6	OH	-- -89					
		2	S-2202	2604	8013	4	OH	-- -87					
		3	S-2203	2605	8013	8	OH	-- -89					
		4		2605	8013	8	OH	-- -90					
Davie	25	1	S-1499	2604	8013	10		100-110					
		2	S-2204	2604	8013	10		100-110					
		3	S-2205	2604	8013	12		133-150	1,075	5.4		200	54,000
		4	S-2206	2604	8013			125-140	900	2.3		390	110,000
Sunrise System 2	26	1	S-1501	2605	8015	10	S	-- -60					
		2	S-2090	2605	8015	12	S	-- -102					
		3	S-2091	2605	8015	12	S	-- -102					
		4	S-2092	2605	8015	12	S	-- -102					
		5	S-2093	2605	8015	12	S	-- -102					
		6	S-2094	2605	8015	12	S	-- -102					
		7	S-2095	2605	8015	12	S	-- -102					

Table 2. Owners, construction details, and hydraulic data for large supply wells in Broward County -- Continued

Site name	Map num-ber	Own-er's well num-ber	USGS supply well number	Lati-tude	Long-itude	Dia-me-ter	Fin-ish	Pro-duc-tion inter-val	Dis-charge	Draw-down	Pum-ping per-iod	Spe-cific capa-city	Estim-ated trans-missi-vity
Bonaventure	27	1	S-2096	2607	8022	8		70- --					
		2	S-2087	2607	8022	8		70-68	450	1.3	.25	350	95,000
Flamingo	28	1	S-1507	2609	8010	8	S	63-74					
BCU	29	1	S-1504	2607	8011			-- -100					
Fort Lauderdale Dixie	30	2	S-363	2606	8012	12	OH	110-125	400	2.0	18.0	200	54,000
		3	S-364	2606	8012	12	OH	110-125	567	3.72		152	41,000
		4	S-365	2606	8012	12	OH	110-125					
		5	S-2039	2606	8012	12	OH	87-99					
		6	S-2040	2606	8012	12	OH	181-189	530	1.97		269	73,000
		7	S-368	2606	8012	12	S	110-125	818	7.74		106	29,000
		8	S-2041	2606	8012	12	OH	89-104	644	4.25		152	41,000
		9	S-919	2607	8012	12	S	110-125	688	2.13		323	89,000
		10	S-920	2607	8012	12	S	82-148					
		24	S-2011	2606	8012	10	OH	89-115					
		25	S-2012	2606	8012	10	OH	89-115	455	2.45		186	50,000
		26	S-2013	2606	8012	10	OH	89-114					
do.	31	11	S-2116	2606	8012	12	OH	85-130	750	6.1	24	120	32,000
		12	S-1502	2606	8011	12	OH	110-126					
		13	S-951	2606	8012	12	S	110-125					
		14	S-952	2606	8012	12	S	110-125					
		15	S-953	2606	8012	12	S	110-125	580	.89		650	170,000
		16	S-954	2605	8012	12	S	110-125	555	1.36		408	110,000
		17	S-955	2605	8012	12	S	110-125					
		18	S-956	2605	8012	12	S	110-125					
		19	S-957	2605	8012	12	S	110-125	360	.83		430	120,000
		20	S-2007	2606	8012	10	OH	89-115	839	2.74		306	83,000
		21	S-2008	2606	8012	10	OH	87-114	350	2.25		156	42,000
		22	S-2009	2606	8012	10	OH	89-115					
		23	S-2010	2605	8012	10	OH	87-114	424	3.29		129	
Broadview Park Water Company	32	1	S-2136	2605	8013	10	S	60-90					
		2	S-2137	2605	8013	12	S	70-100					
		3	S-2138	2605	8013	12	S	107-110					
	33	1	S-2112	2610	8012	12		72-100	1,550	3.8		410	110,000
		2	S-1508	2610	8012	12		70-100					
		3	S-2113	2610	8012	12	OH	89-100	1,250	1.1		1,100	310,000
		4	S-2114	2610	8012	12		76-100					
		5	S-2115	2610	8012	20	S	84-100	2,100	7.3	8	290	78,000
		6		2610	8012	20	S	49-69	2,100	5.5		380	110,000
		7		2610	8012	20	S	55-75	2,100	5.5		380	110,000
Lauderhill	34	1	S-2120	2609	8013	8	S	-- -117					

Table 2. Owners, construction details, and hydraulic data for large supply wells in Broward County -- Continued

Site name	Map num -ber	Own- er's well num -ber	USGS supply well number	Lati- tude	Long- itude	Dia- me- ter	Fin- ish	Pro- duc- tion inter- val	Dis- charge	Draw- down	Pum- ping per- iod	Spe- cific capa- city	Estim- ated trans- missi- vity
Lauderhill (cont'd)		2	S-2121	2609	8013	12	S	-- -124					
		3	S-2122	2609	8013	12	S	-- -154					
		4	S-2123	2609	8013	12	S	-- -90					
		5	S-2124	2609	8013	24	S	-- -115	2,000	1.1		1,800	470,000
		6	S-2125	2609	8013	24	S	-- -121	1,000	.6		1,700	460,000
		7	S-2126	2609	8013	24	S	127-142					
Plantation	35	8	S-2133	2607	8013	12	OH	70-74					
		[2]9	S-2134	2607	8013	12	OH	65-80	1,360	1.4	4	970	260,000
						18	OH	83-86	1,300	2.5		520	140,000
		[2]10	S-2135	2607	8013	12	OH	65-80	1,300	2.2		590	160,000
						18	OH	84-90	1,360	1.4		970	260,000
		11		2607	8013	20	OH	74-118	2,100	1.2		1,800	470,000
do.	36	1	S-2127	2607	8014	8	OH	75-85					
		2	S-2128	2607	8014	8	OH	100-110					
		[2]3	S-2129	2607	8014	8	OH	50-58					
						8	OH	55-65					
		4	S-1505	2607	8014	8	OH	80-90					
		5	S-2130	2607	8014	12	OH	68-74	1,625	1.8		900	240,000
		6	S-2131	2607	8014	8	OH	86-95					
		7	S-2132	2607	8014	8	OH	75-85					
Gulf Stream Utilities	37	1	S-2082	2607	8016	12	OH	94-99	700	9.0		78	21,000
		2	S-2083	2607	8016	12	OH	101-117	700	1.8		390	110,000
		3	S-2084	2607	8016	16	OH	95-100	2,340	3.3	6	710	190,000
		4	S-2085	2607	8016	16	OH	93-96	3,100	3.4	6	910	250,000
Sunrise system	38	1	S-1457	2607	8019	8		68-75	1,000	15.6	12	64	17,000
		2	S-1503	2607	8019	8		67-75	1,000	13.6	12	74	20,000
		3	S-2097	2607	8019	10		58-62					
		4	S-2098	2607	8018	10		70-75					
		5	S-2099	2607	8018	10		64-69					
		6	S-2100	2607	8018	10		66-70					
		7	S-2101	2607	8018	10		64-66					
Coral Ridge Country Club	39	1	S-1325	2610	8007	12		85- --					
		2		2610	8007	12		85					
		3		2610	8007	12		78-88					
	40	1	S-1405	2612	8008	6		68-68					
		2	S-1405A	2612	8008	4		-- -203					
BCU District 1B	41	1	S-1414A	2612	8008	6	OH	103-110					
		2	S-1414	2612	8008	6	OH	103-110					
		3	S-2117	2612	8008	8		102-115					

Table 2. Owners, construction details, and hydraulic data for large supply wells in Broward County -- Continued

Site name	Map num -ber	Own-er's well num -ber	USGS supply well number	Lati-tude	Long-itude	Dia-me-ter	Fin-ish	Pro-duc-tion inter-val	Dis-charge	Draw-down	Pum-ping per-iod	Spe-cific capa-city	Estim-ated trans-missi-vity
BCU District 1B (cont'd)		4	S-2118	2612	8008	8		102-115					
		5	S-2119	2612	8008	8		103-110					
BCU District 1C	42	1	S-1443	2611	8008	8	OH	104-108					
		2	S-1370	2611	8009	10		-- -108					
FL-F Executive Airport	43	2	S-1289	2611	8009	10	S	120-132	500	1.5		330	89,000
		3	S-1290	2611	8010	10	S	113-125					
		4	S-1291	2611	8010	10		100-112					
		5	S-1292	2611	8009	10	S	110-125					
			S-1293	2611	8009	10	S	104-116					
			S-1294	2611	8009	10	S	118-130					
			S-1295	2611	8009	10	S	116-128	600	1.5		400	110,000
			S-1296	2611	8009	10	S	113-125					
			S-1297	2611	8009	10	S	113-125	600	1.5		400	110,000
			S-2014	2611	8009	12	OH	133-152					
do.	44	12	S-2015	2611	8009	12	OH	100-115					
		13	S-2016	2612	8009	12	OH	79-94					
		14	S-2017	2612	8009	12	OH	85-100					
		15	S-2018	2612	8009	12	OH	116-131					
		16	S-2019	2612	8010	12	OH	75-90					
		23	S-2025	2612	8010	12	OH	68-80					
do.	45	17	S-2020	2611	8010	12	OH	110-125					
		18	S-1509	2611	8010	12	OH	64-79					
		19	S-2021	2612	8010	12	OH	61-76					
		20	S-2022	2611	8011	12	OH	61-76					
		21	S-2023	2611	8010	12	OH	60-75					
		22	S-2024	2611	8010	12	OH	110-125					
		24	S-2026	2612	8010	12	OH	68-80					
		35	S-2037	2611	8011	17	OH	70-96	2,220	17.7	48	130	35,000
FL-F new well field	46	36		2611	8011	17	OH	81-99	750	.35	1.0	2,140	600,000
		37		2611	8011	17	OH	82-98	850	.52	1.0	1,630	440,000
		38		2611	8011	17	OH	82-102	1,450	1.0	1.0	1,450	390,000
		39	S-2038	2611	8011	17	OH	85-98	2,100	1.52	3.5	1,380	370,000
		40		2611	8011	17	OH	62-90	760	.4	1.0	1,900	510,000
		41		2611	8011	17	OH	82-95	700	.4	1.0	1,800	490,000
		42		2611	8011	17	OH	82-91	780	1.0	1.0	780	210,000
FL-F Prospect Lake	47	25	S-2027	2611	8011	17	OH	112-150	2,040	5.8	48	350	95,000
		26	S-2028	2611	8011	17	OH	105-144	2,178	6.5	48	340	92,000
		27	S-2029	2611	8011	17	OH	100-120	2,175	5.4	48	400	110,000

Table 2. Owners, construction details, and hydraulic data for large supply wells in Broward County -- Continued

Site name	Map num -ber	Own-er's well num -ber	USGS supply well number	Lati-tude	Long-itude	Dia-me-ter	Fin-ish	Pro-duc-tion inter-val	Dis-charge	Draw-down	Pum-ping per-iod	Spe-cific capa-city	Estim-ated trans-missi-vity
FL-F Prospect Lake (cont'd)		28	S-2030	2612	8011	17	OH	81-103	2,190	4.5	48	490	130,000
		29	S-2031	2612	8011	17	OH	86-116	2,140	4.5	48	480	130,000
		30	S-2032	2612	8011	17	OH	90-109	2,130	5.0	48	430	120,000
		31	S-2033	2612	8012	17	OH	80-100	2,200	2.2	48	1,000	270,000
		32	S-2034	2612	8012	17	OH	82-103	2,200	4.2	48	520	140,000
		33	S-2035	2611	8012	17	OH	80-101	2,225	3.38	48	658	180,000
		34	S-2036	2611	8012	17	OH	75-90	2,200	3.7	48	600	160,000
BCCE and Broadview Utility	48	CC-1	S-1510	2612	8012	12							
		U-1	S-2228	2612	8012	12		98-112					
		2	S-2226	2612	8012	12							
		3	S-2227	2612	8012	12		105-115					
North Lauderdale	49	1	S-2233	2613	8013	24	OH	106-129	2,500	21	2	120	32,000
		2	S-2234	2612	8013	24	OH	105-128	1,000	10	3	100	27,000
		3	S-2235	2612	8013	24	OH	103-126	1,000	15	2	67	18,000
Tamarac	50	1	S-2062	2611	8015	12	OH	112-126	840	6.6		,130	35,000
		3	S-2001	2611	8015	12	OH	109-115	560	22.8		25	6,800
		7	S-2002	2611	8015	12	OH	111-125	730	6.1		120	32,000
do.	51	2	S-2063	2611	8015	12	OH	101-112	790	12.3		64	18,000
		4	S-2064	2612	8015	12	OH	101-110	610	28.8		21	5,700
		8	S-2067	2611	8015	12	OH	105-123	590	16.8		35	9,500
		9	S-2068	2612	8015	12	OH	108-115	710	19.6		36	9,700
Tamarac	52	5	S-2065	2612	8015	12	OH	102-117	640	32.9		20	5,400
		6	S-2066	2612	8015	12	OH	102-109	690	30.6	23	6,200	
Sunrise System 1	53	2	S-2069	2610	8015	18	OH	110-115	1,140	12.7	12	90	24,000
		3	S-2070	2610	8015	18	OH	70-106	1,000	15.6	12	64	17,000
		4	S-2071	2610	8015	18	OH	91-104	1,000	12.7		79	21,000
		5	S-2072	2610	8015	18	OH	93-ll2	1,000	12.6		79	21,000
do.	54	10	S-2077	2610	8015	18	OH	80-84	1,000	7.7	12	130	35,000
		11	S-2078	2610	8015	18	OH	84-91	1,000	12.4	12	81	22,000
		12	S-2004	2610	8015	18		80-86	1,000	9.1	12	ll0	30,000
		13	S-2079	2610	8015	18	OH	80-84	1,000	13.2	12	76	21,000
		14	S-2003	2610	8015	18		84-90	1,000	12.6	12	79	21,000
		15	S-2080	2610	8015	18	OH	83-87	1,000	12.5	12	80	22,000
		16	S-2081	2610	8015	18	OH	84-88	1,000	10.3	12	97	26,000
Pompano Beach	55	2	S-2043	2614	8007	16	OH	-- -136		5.8			
		3	S-998	2614	8007	16	OH	-- -107	1,300	3.3		390	110,000
		4	S-1514	2614	8007	16	OH	-- -140		2.1			
		5	S-2044	2614	8007	16	OH	97-108		4.7			

Table 2. Owners, construction details, and hydraulic data for large supply wells in Broward County -- Continued

Site name	Map num -ber	Own-er's well num -ber	USGS supply well number	Lati-tude	Long-itude	Dia-me-ter	Fin-ish	Pro-duc-tion inter-val	Dis-charge	Draw-down	Pum-ping per-iod	Spe-cific capa-city	Estim-ated trans-missi-vity
Pompano Beach (cont'd)		9	S-2048	2614	8007	16	OH	97-131	1,500	5.3	24	280	76,000
		10	S-2049	2614	8007	16	OH	93-113	1,500	3.8	24	400	110,000
		11	S-2050	2614	8007	16	OH	88-127	1,500	3.5		430	120,000
do.	56	1	S-340	2613	8007	12	OH	180-193	800	6.9		120	32000
		8	S-2047	2614	8007	16	OH	90-99	1,500	28		540	150,000
do.	57	[2]6	S-2045	2615	8007	16	OH	-- -115					
						14	OH	160-165	2,150	7.6	12	280	76,000
		7	S-2046	2615	8007	16	OH	90-90		7.7			
		12	S-2051	2615	8007	16	OH	90-123	1,500	1.9	12	790	210,000
		13	S-2052	2615	8007	16	OH	115-115	1,500	4.3	24	350	95000
		14	S-2053	2615	8007	16	OH	114-114	1,500	4.3	24	350	95,000
		15	S-2054	2615	8007	18	OH	115-140	2,000	5.2	24	390	110,000
		16	S-2055	2615	8007	18	OH	114-130	2,000	5.2	24	390	110,000
PB-P	58	1		2613	8010	15	OH	76-150	2,140	5.5	72	390	110,000
Collier City	59	1	S-1512	2614	8010	6	S	165-168					
Margate Utilities	60	1	S-2207	2614	8012	8		-- -120					
		2	S-2208	2614	8012	12		-- -100	950	5.1		190	51,000
		3	S-1513	2614	8012	12		111-117	916	3.3		280	76,000
		4	S-2209	2614	8012	12	OH	100-105					
		5	S-2210	2614	8012	12	OH	100-105	800	3.8		210	57,000
		6	S-2211	2614	8012	12	OH	100-105	690	6.8		100	27,000
		7	S-2212	2614	8012	18	OH	95-105	1,000	4.8		210	57,000
		8	S-2213	2614	8012	18	OH	95-105	900	6.5		140	38,000
		9	S-2214	2614	8012	18	OH	88-108	2,220	6.8	48	320	87,000
		10	S-2215	2614	8012	18	OH	87.5-108					
		11	S-2216	2614	8012	18	OH	101-103	2,300	9.2	8	250	68,000
		12	S-2217	2614	8012				2,175	8.3		260	70,000
Coral Springs Improvement District	61	1	S-2059	2614	8015	8	S	60-105	1,520	6.6	24	240	64,000
		2	S-2060	2614	8015	8	S	60-105					
		3	S-2061	2614	8015	8	S	60-105					
		4		2614	8015	8	S	[3]55-75				38	10,000
								[3]100-120					
		5		2614	8015	8	S	[3]89-110				53	14,000
								[3]119-140					
Deerfield Beach	62	1	S-2174	2619	8006	8	OH	-- -92					
		2	S-1518	2619	8006	12	OH	-- -96					
		3	S-2175	2619	8006	12	OH	-- -110					
		9	S-2181	2619	8006	12	OH	-- -100					

Table 2. Owners, construction details, and hydraulic data for large supply wells in Broward County -- Continued

Site name	Map num -ber	Own-er's well num -ber	USGS supply well number	Lati-tude	Long-itude	Dia-me-ter	Fin-ish	Pro-duc-tion inter-val	Dis-charge	Draw-down	Pum-ping per-iod	Spe-cific capa-city	Estim-ated trans-missi-vity
Deerfield Beach (cont'd)		10	S-2182	2619	8006	14	OH	60-90	536	2.54	.01	2ll	57,000
		11	S-2183	2618	8006	14	OH	60-85	1,024	5.17	8	198	53,000
do.	63	12	S-2184	2618	8006	14	OH	60-83	1,024	3.8	8	270	73,000
		13	S-2185	2618	8006	14	OH	60-85	1,024	3.3	8	310	84,000
		14	S-2186	2618	8006	14	OH	60-96	1,024	3.6	8	280	76,000
		15	S-2187	2618	8006	14	OH	60-96	1,024	2.4	8	430	120,000
		16	S-2188	2618	8006	14	OH	60-96	1,024	3.0	8	340	92,000
do.	64	4	S-2176	2618	8006	12	OH	-- -112					
		5	S-2177	2618	8006	12	OH	-- -100					
		6	S-2178	2619	8006	12	OH	66-87	1,000	7.7	5	130	35,000
		7	S-2179	2618	8006	12	OH	67-100	1,000	10	5	100	27,000
		8	S-2180	2619	8006	12	OH	64-100	1,000	5	9	200	54,000
do.	65	17	S-2189	2618	8007	14	S	155-180	:			[4]	[4]150,000
		18	S-2190	2618	8007	14	S	155-180				[4]	
		19		2618	8007	14	S	-- -180				[4]	
		20		2618	8007	14	S	-- -180				[4]	
BCU District 2A	66	1	S-1517	2617	8006	8		-- -178					
		2	S-2147	2617	8006	12		154-180					
		3	S-2148	2617	8006	10		-- -143					
		4	S-2149	2617	8006	18		107-122	2,100	7.5		280	76,000
		5	S-2150	2617	8006	12	OH	125-139	1,780	9.7		180	49,000
		6	S-2151	2617	8006	18		125-160	2,100	7.3		290	78,000
		7	S-2152	2617	8006	20		128-140	2,100	3.3		640	170,000
		8		2617	8006	24		35-143	3,200	4.8		670	180,000
		9		2617	8006	24		45-143	2,600	8.5		310	84,000
Hillsboro Beach	67	1	S-2236	2616	8006	8	S	61-71	369	.9		410	
		2	S-2237	2616	8006	8	S	64-73	400	.7		570	
		3	S-2238	2616	8006	12	S	90-104	1,550				
		4	S-2239	2616	8006	12	S	128-138	1,500				
BCU	68	1	S-1515	2615	8006			80-140					
New Mark Glen	69	1	S-2096	2618	8010	16		-- -200					
		2		2618	8010	12		103-120	600	6.3	2	95	26,000
Coral Springs	70	1	S-2191	2616	8014	8	S	93-138					
		2	S-2006	2616	8014	8	S	89-134					
		3	S-2192	2616	8014	8	S	100-165					
		4	S-2005	2616	8014	8	S	110-174					
		5	S-2193	2616	8014	8	S	102-175					
		6	S-2194	2616	8024	8	S	105-175					
		7	S-2195	2616	8014	8	S	95-175					

Table 2. Owners, construction details, and hydraulic data for large supply wells in Broward County -- Continued

Site name	Map num -ber	Own-er's well num -ber	USGS supply well number	Lati-tude	Long-itude	Dia-me-ter	Fin-ish	Pro-duc-tion inter-val	Dis-charge	Draw-down	Pum-ping per-iod	Spe-cific capa-city	Estim-ated trans-missi-vity
Coral Springs (cont'd)		8	S-2196	2616	8014	8	S	85-155					
do.	71	12	S-2200	2616	8014	8	S	125-165					
University Utility	72	E-l	S-2056	2616	8014	8	OH	127-140	450	32.7	8	14	3,800
		E-2	S-2057	2616	8014	12	OH	132-138	450	15.4	8	29	7,800
		E-3	S-2058	2616	8014	12	OH	132-138	575	17.3	8	33	8,900
SCU	73	1		2618	8014	12	S	-- -121	180	8.5	24	21	5,700

[1] Single-Cased well; water is apparently drawn from bottom.

[2] Well deepened; first listing is shallow well data and second listing is for deepened wells.

[3] Finish is multiple screen with blank casing in between; interval that specific capacity relates to is unknown.

[4] Range of specific capacity of these four wells, as given in text of a consultant's report, is 231 to 538 gal/min/ft; transmissivity listed is for the site, but it is uncertain which well it pertains to.