DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
SOUTH FLORIDA WATER MANAGEMENT DISTRICT

WATER-RESOURCES INVESTIGATIONS
REPORT 86-4330 (SHEET 1 OF 2)

INTRODUCTION

Broward County is a rapidly developing area of 1,219 mi² along the southeast coast of Florida. The county is underlain by a surficial aquifer system which includes the Biscayne aquifer, a sole-source aquifer for much of southeast Florida. Because the surficial aquifer system is a highly permeable unconfined aquifer system with water levels generally less than 10 feet below land surface, ground water in Broward County is susceptible to chemical contamination from the surface environment. Ground water in Broward County flows eastwardly toward the Atlantic Coastal Ridge where water is withdrawn for municipal supply.

Previous investigations of the surficial aquifer system were localized and focused on the aquifers beneath the coastal ridge. The U.S. Geological Survey, in cooperation with the South Florida Water Management District, has undertaken a study to define the regional geologic, hydrologic, and hydrochemical characteristics of the surficial aquifer system. The investigation of the surficial aquifer system in Broward County, discussed in this report, is the first phase of the regional study.

The purpose of this report is to describe the chemical characteristics of water in the surficial aquifer system in Broward County. This report presents water-quality data collected in the summer of 1981 during the drilling of geologic test holes at 27 sites throughout the county. Supplementary data, mostly specific conductance and dissolved chloride, collected from several of the finished wells in 1981 and early 1982 are also included. These data provide baseline information that can be used for water-resources management purposes and for comparison in future ground-water monitoring.

PHYSICAL AND HYDROLOGIC FEATURES

The physiographic provinces of Broward County, as defined by Davis (1943, p. 40) and modified by Klein and others (1975, p. 8), are shown in figure 1. The Atlantic Coastal Ridge, which covers the easternmost part of the county, generally is 3 to 5 miles wide and has an altitude of 5 to 25 feet above sea level. It is interrupted in places by extensions of the Everglades known as transverse glades. The coastal ridge is naturally well drained, primarily due to rapid infiltration, and for this reason it is highly developed and densely populated in Broward County. The Sandy Flatlands is west of the coastal ridge and covers an area about 4 to 11 miles wide. The area has an altitude that ranges from 5 to 16 feet above sea level. Although the Sandy Flatlands is poorly drained under natural conditions, the construction of drainage canals (fig. 1) has facilitated development. Except for a small area of Big Cypress Swamp in the southwestern part of Broward County, the rest of the county is in the Everglades and has an altitude that ranges from 4 to 13 feet above sea level. The Everglades is poorly drained and, except for the sparsely populated Seminole and Miccosukee Indian reservations, is uninhabited.

South Florida's normal rainfall cycle consists of a wet season from June to October, during which 75 percent of the 52 to 60 inches of average annual rainfall occurs (Sherwood and others, 1973, p. 8), and a dry season from November to May. This pattern is frequently interrupted by years of drought (when the "wet season" is dry) or excessive rainfall (when the "dry season" is wet). The problems associated with these variations of the normal rainfall cycle have been addressed in Broward County in two ways. Most of the western two-thirds of the county is partitioned into four conservation areas (2A, 2B, 3A, and 3B) by levees (fig. 1). These areas, which occupy most of the Everglades province, are used for water catchment and impoundment during periods of excess rainfall. During droughts, water can be moved from the conservation areas to the eastern part of Broward County through an extensive canal system to recharge the surficial aquifer system and maintain freshwater heads. Both the conservation areas and the canal system are maintained by the South Florida Water Management District.

The surficial aquifer system underlying Broward County varies in thickness from 400 feet in the eastern part of the county to 160 feet in the western part (J.E. Fish, U.S. Geological Survey, oral commun., 1982). It consists of limestone, sandstone, sand, shell, lime mud, silt, and clay of late Miocene to Pleistocene age (Causaras, 1985). To determine the depth of test holes during the drilling program, the base of the surficial aquifer system was defined as a thick, relatively impermeable layer of green clay or silt, which generally marks the upper limit of the Hawthorn Formation as used by Causaras (1985). Interpretation of lithologic samples taken during drilling has substantiated this definition of the base of the surficial aquifer system for Broward County, except for coastal areas (Causaras, 1985). In Broward County, a large part of the surficial aquifer system is designated the Biscayne aquifer (fig. 1). The Biscayne aquifer is highly productive with transmissivities as high as 4 (Mgal/d)/ft, or 5.4 x 10^5 ft²/d, in Broward County (Sherwood and others, 1973, p. 66).

METHODS AND PROCEDURES

Test well sites were chosen along three east-west transects and three north-south transects with two additional sites (wells G-2341 to G-2343) in the northeast (fig. 2). The well locations were chosen approximately equidistant from each other, except where surface features made drilling infeasible. At three sites (wells G-2323, G-2338, and G-2342), it was not possible to collect adequate water samples during drilling at shallow depths; therefore, an additional shallow well was drilled at these sites. Thus, the drilling program for Broward County was comprised of 30 wells at 27 sites.

Wells were hammered to the base of the surficial aquifer system by a reverse-air, dual-wall, drill-pipe method. At well G-2317 on the Dade-Broward County line (fig. 2), a relatively impermeable silt layer was found at a depth of 109 to 140 feet and drilling was halted; however, this probably was not the base of the surficial aquifer system. The base of the surficial aquifer system also was not reached at well G-2325, the first site drilled on the Atlantic Coastal Ridge, because the aquifer was thicker than previously thought, and the driller did not have enough drill pipe to reach the base. All wells were cased to the deepest producing zone with polyvinyl chloride (PVC) casing and finished with 10 feet of PVC screen.

Reverse-air, dual-wall drilling does not require drilling fluids or mud; thus, it was possible to stop drilling and collect unaffected, point-source samples throughout the water column. Within the pumping zone (20 to 200 feet beneath land.surface), water samples for extensive laboratory analysis (pH, alkalinity, specific conductance, major ions, selected nutrients and dissolved iron, aluminum, and manganese) generally were collected at the first producing zone and thereafter at about 40-foot intervals. Water samples below 200 feet were collected at 50- to 60-foot intervals. Frequently, the sampling intervals were adjusted where sloughing sands or impermeable strata made sampling impossible or where a change in lithology suggested a change in water quality. In addition to these samples for extensive water-quality analysis, grab samples of the flow produced by air circulation were collected at 10-foot intervals for specific conductance measurement and dissolved chloride analysis. If a significant change in specific conductance occurred between successive grab samples, drilling was halted and a sample was collected for extensive laboratory analysis. At well sites along the middle east-west transect and at other selected well sites, samples were also collected for dissolved trace-element analysis.

At some sites, there were intervals of the surficial aquifer system where a submersible pump could not be used. At these intervals, samples for extensive analysis were collected from a vacuum pump or occasionally from the drill-pipe discharge. Selected nutrients, metals, and pH analyses for these samples were considered qualitatively and were not included in interpretations of data.

Several aspects of the water-quality sampling procedure were developed specifically for the Broward County drilling program. Therefore, at the completion of the drilling program and again in the winter of 1982, all wells were resampled for specific conductance and dissolved chloride as a quality-control check of the procedure.

Based on these data, new wells were installed at the sites of wells G-2315 and G-2345. Data from these new wells, and from the resampling of the original wells, indicated that during drilling some mixing of ground water probably occurred in the clayey sands just above the base of the surficial aquifer system; thus, samples collected during drilling represented an interval of the water column rather than a point source. These analyses are not included in this report.

Specific conductance, pH, and alkalinity were determined onsite at the time of sampling. Dissolved chloride concentration for the 10-foot grab samples were determined in the Miami laboratory. Concentrations of major ions, selected metals, and trace elements were determined by the U.S. Geological Survey National Water Quality Laboratory--Atlanta in Doraville, Ga.; concentrations of nutrients were determined by the U.S. Geological Survey Field Service Unit in Ocala, Fla. Water samples were preserved in the field using the method prescribed in Beetem and others (1981). The analytical techniques used for the determinations are described by Goerlitz and Brown (1972), Fishman and Brown (1976), and Skougstad and others (1979).

DATA AVAILABILITY

Data collected for this study are available upon request. These data are stored in the WATSTORE water-quality files and are directly available to users that have computer access to WATSTORE. The south Florida data files of WATSTORE are maintained at Geological Survey computer facilities in Reston, Va., and Miami, Fla. Information as to the availability of specific types of data, the acquisition of data or products, and user charges are available from the U.S. Geological Survey, Suite 107, 9100 N.W. 36th Street, Miami, Fla.

CHEMICAL CHARACTERISTICS OF GROUND WATER

There are three major factors controlling the chemical characteristics of ground water in the study area that should be considered when interpreting chemical data:

1. Diluted seawater is found in western Broward County because the area's low rates of both infiltration and ground-water circulation have not been sufficient to flush seawater remaining from the periodic inundations by Pleistocene seas (Parker and others, 1955, p. 821).
2. In the east, seawater mixes with freshwater in the aquifer along the coast and along reaches of canals and rivers that are downgradient of salinity-control structures. This is particularly apparent in the vicinity of New River (fig. 1) where ground-water quality has deteriorated because of seawater intrusion.
3. Man's activities have affected the chemistry of the surficial ground water of Broward County, at least locally, by the construction of the conservation areas and levees and by providing sources of potential contamination such as landfills, chemical spills, and highly fertilized agricultural areas.

Chemical data collected during this study indicate that Broward County has three major water-quality regimes: The coastal ridge, the conservation areas, and the area between these two regions (fig. 2). In the following discussion, well G-2325 is considered a coastal ridge site because, although it is not evident from figure 2, this well is on a part of the coastal ridge that runs along the Palm Beach-Broward County line (see Klein and others, 1975, p. 8), and ground water at this location is chemically similar to ground water beneath the coastal ridge.

Vertical Profiles of Specific Conductance and Dissolved Chloride

Specific conductance is an indicator of the total mineralization of ground water. In this report, the terms "specific conductance" and "mineralization" are used interchangeably. In southeast Florida, specific conductance of ground water is closely related to dissolved chloride concentration. Most of the dissolved chloride derives from residual seawater that remains from prior inundations or from more recent seawater intrusion. Figure 3, based upon samples taken at 10-foot intervals during the drilling of well G-2327, shows how specific conductance reflects dissolved chloride concentration. The relation is clear, although not strictly linear because of changing composition as ground water progresses from fresh to brackish water with increasing depth. Figure 4 shows the specific conductance data collected at 10-foot intervals during the drilling program and the estimated depths at which 250-mg/L (milligrams per liter) dissolved chloride concentration was found. A chloride concentration of 250 mg/L is emphasized because it is a secondary drinking water standard (Florida Department of Environmental Regulation, 1982), and the depth at which this concentration occurs is frequently the lower limit of freshwater. In Broward County, concentrations of 250-mg/L dissolved chloride can be expected for specific conductances between 1,280 and 1,820 µS/cm (microsiemens per centimeter at 25 °C). Figure 5 shows areal variations in specific conductance at several different depths.

West of the salt front, ground water under the coastal ridge where vertical and horizontal drainage are excellent is the least mineralized (fig. 4). To the north (wells G-2325 and G-2344), ground water is fresh to the base of the surficial aquifer system. To the south (well G-2328), ground water is slightly more mineralized but meets the 250-mg/L chloride standard to a depth of about 250 feet. The effects of seawater intrusion from New River are apparent in well G-2347. Excluding those areas strongly affected by seawater intrusion, specific conductance of ground water from the coastal ridge ranges from 270 to 1,370 µS/cm, and dissolved chloride ranges from 14 to 260 mg/L.

Between the coastal ridge and the conservation areas, specific conductance of ground water increases to the west and to the north. Dissolved chloride concentrations are less than 250 mg/L to depths of 200 feet or more, except for an anomalous area in the south which encompasses wells G-2322, G-2327, and G-2345 (located in the Dixie well field). Unlike the rest of the region, ground water in the vicinity of these wells shows a sharp increase in mineralization beginning at a depth of 120 to 140 feet. Areas of low permeability in the aquifer may explain this more highly mineralized water. In particular, a low permeability silt layer was found from 120 to 140 feet below land surface during the drilling of well G-2327. Another explanation for the increased mineralization at well G-2345 might be the upconing of saltwater caused by heavy pumping at the Dixie well field. Except for the anomalous area in the south, specific conductance in this part of the county ranges from 495 to 1,780 µS/cm, and dissolved chloride ranges from 33 to 320 mg/L.

Ground water beneath the conservation areas is more mineralized than east of the levees. Vertical and horizontal drainage are poor, and residual seawater has not been diluted or flushed as well as along the coastal ridge. Except for areas of seawater intrusion, the most mineralized ground water in Broward County is found in the north-central part (wells G-2313, G-2315, and PB-1428) where specific conductance at 190 feet is 5,800 to 6,600 µS/cm and dissolved chloride is 1,500 to 1,700 mg/L. These ranges are about the equivalent of 10 percent seawater.

Beneath the conservation areas, specific conductance generally decreases from north to south and is lower along the western edge of the county. However, there is much areal variation in specific conductance at any particular depth (fig. 4). From 0 to 110 feet, there are areas of high mineralization in the southwestern corner of the county (wells G-2330, G-2338, and G-2346) and to the north in the vicinity of well PB-1428; there is an area of low mineralization in the northwestern corner of the county (well G-2314). In the vicinity of well G-2311, low permeability materials were initially found at about 75 feet below land surface, and ground water is more highly mineralized than that at similar depths in nearby areas.

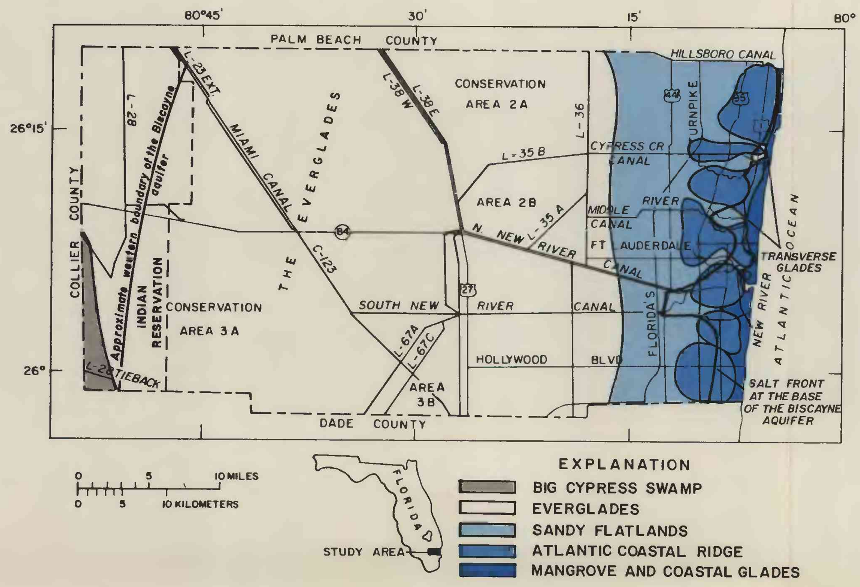

Figure 1.--Physiographic and hydrologic features of Broward County. [Physiographic provinces from Klein and others (1975, p. 8) and modified from Davis (1943, p. 40); boundary of Biscayne aquifer from J.E. Fish (U.S. Geological Survey, written commun., 1984); and salt front from Franks, ed. (1982, sheet 3)].

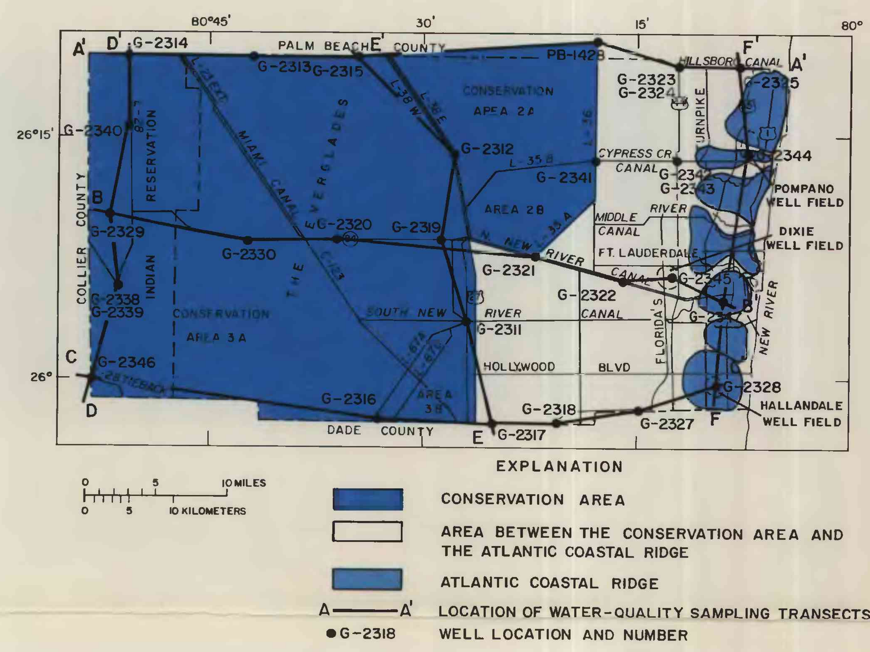

Figure 2.--Location of wells and water-quality sampling transects in Broward County.

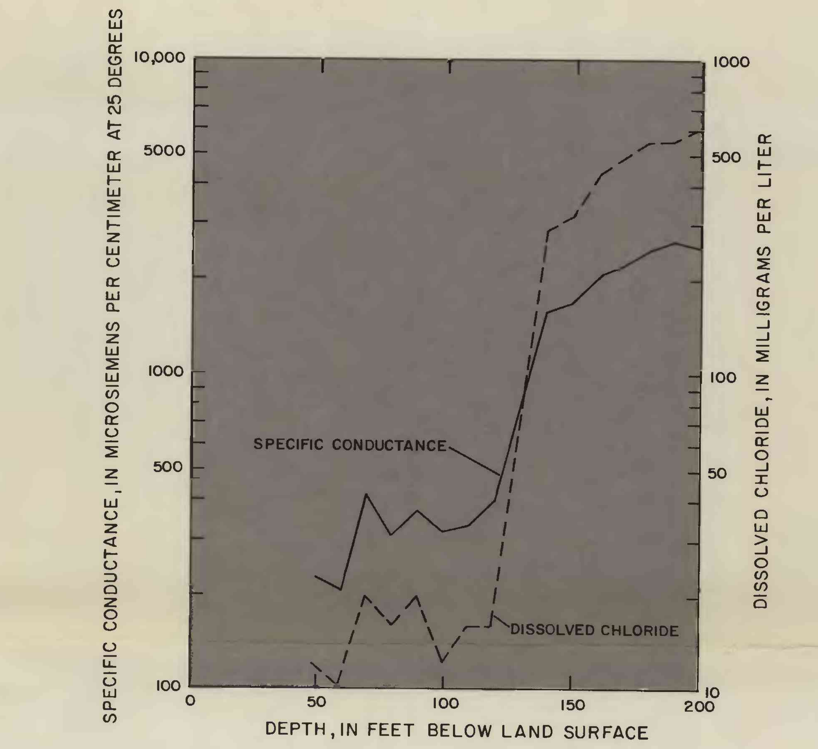

Figure 3.--Depth-specific conductance and dissolved chloride concentration for well G-2327.

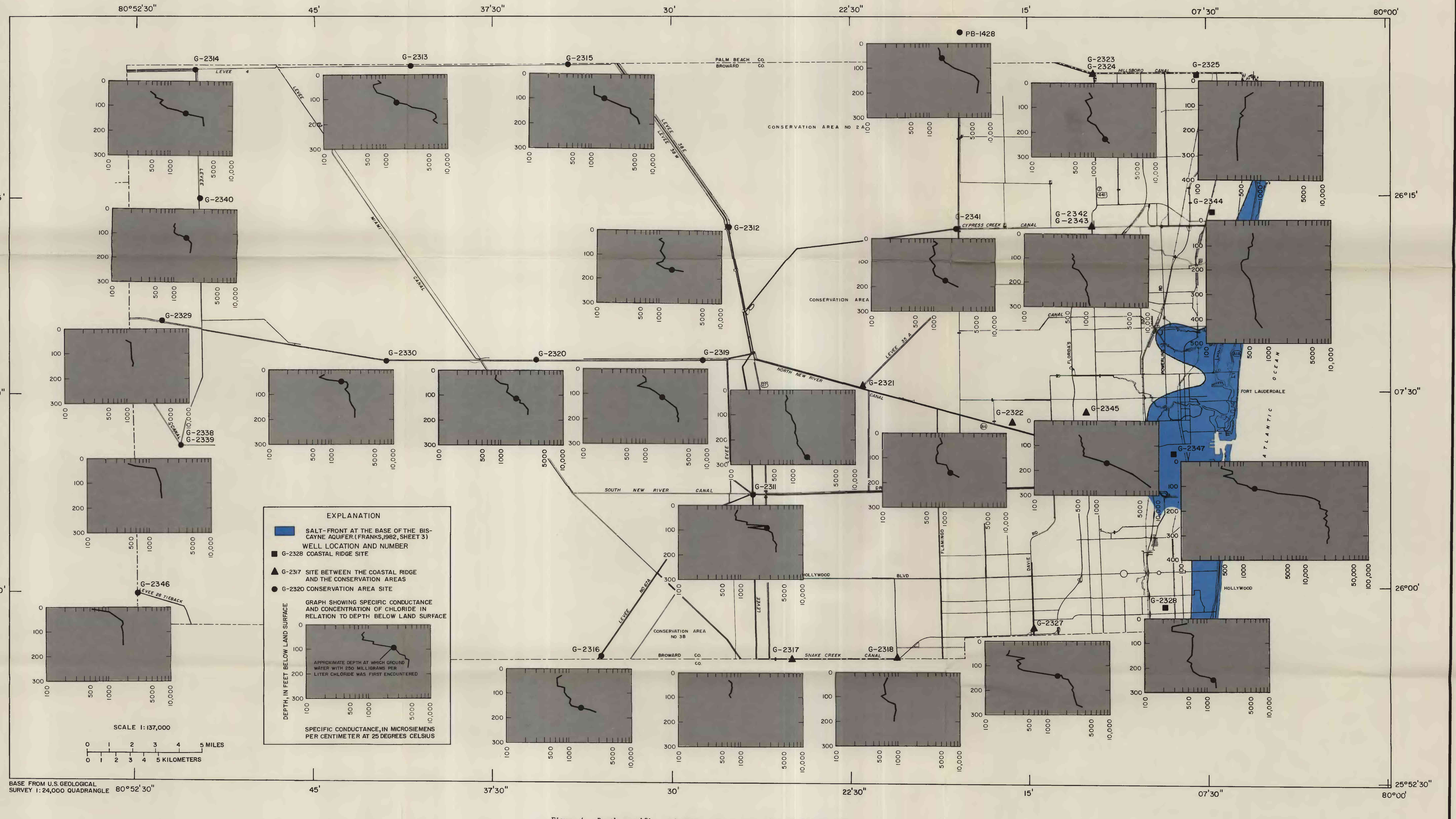

Figure 4.--Depth-specific conductance and concentration of chloride (250 milligrams per liter) for water in the surficial aquifer system.

CHEMICAL CHARACTERISTICS OF WATER IN THE SURFICIAL AQUIFER SYSTEM, BROWARD COUNTY, FLORIDA

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