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U.S. GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
MIAMI-DADE WATER AND SEWER DEPARTMENT
AND THE
METRO-DADE DEPARTMENT OF ENVIRONMENTAL RESOURCES MANAGEMENT

WATER-RESOURCES INVESTIGATIONS REPORT 96-4285

INTRODUCTION

Saltwater intrusion is a major threat to the freshwater resources of the coastal areas in southeastern Florida. There are three primary mechanisms by which saltwater contaminates the freshwater reservoir in the unconfined, surficial aquifers of the region: (1) subsurface movement of seawater (lateral large-scale intrusion), (2) seepage of seawater from tidal canals and streams, and (3) upward movement of connate saltwater (water remaining from the time of deposition) from lower formations due to well-field withdrawals. All three mechanisms are driven by the lowering of freshwater levels in the surficial aquifers. However, the effects of the last two mechanisms (seepage and upward movement) generally are limited to relatively small regions, whereas lateral intrusion affects a much larger region of the aquifers.

Urbanization of the coastal area, construction of drainage canals, and development of municipal well fields have led to a lowering of water levels in the Biscayne aquifer, a designated sole-source unconfined aquifer, in Dade County. Water samples collected from monitoring and supply wells from the early 1900's indicated the gradual inland movement of saltwater from the ocean into the freshwater part of the Biscayne aquifer in some areas along the eastern coast. Various methods to slow or reverse the inland movement of saltwater by raising water levels in the Biscayne aquifer have been implemented or are being considered. These methods include decreasing coastal withdrawals by the development of regional well fields farther inland, supplementing the water supply with water obtained from lower confined aquifers of highly mineralized water, increasing delivery of water to coastal canals from inland wetlands, and construction of additional surface-water control structures.

Water managers concerned with Dade County water supply need more information describing the inland extent and movement of saltwater in the Biscayne aquifer to determine which methods work best at controlling saltwater intrusion and the potential impacts of these methods on the ecosystem. Before 1994, the existing monitoring well network was not adequate to monitor the extent or movement of saltwater in the Biscayne aquifer. In some areas of Dade County, saltwater had reached or moved inland of the existing monitoring wells. There were no monitoring wells in other areas of Dade County. An improved network was needed to provide the information required by water-management officials to make decisions on changes in the operation of the well fields and surface-water controls in Dade County.

In October 1994, the U.S. Geological Survey, in cooperation with the Miami-Dade Water and Sewer Department and the Metro-Dade Department of Environmental Resources Management, began a 2-year study to: (1) determine the present location of the interface between freshwater and oceanic saltwater in the Biscayne aquifer along the eastern coast of Dade County, and (2) determine the historical and present rate of movement of the salt-water interface. This map report documents the position of the saltwater interface at selected locations in the Biscayne aquifer in 1995 through the evaluation of previously published maps, chloride data, and geophysical data. Movement of the interface is evaluated also.

Canal and Levee System

A canal and levee system (fig. 1) is the primary means of controlling water levels in the Biscayne aquifer. Due to high hydraulic conductivity of the bottom and side materials of most of the canals and the high water-table altitude, canal stages generally reflect water levels in the Biscayne aquifer. Levees are used to impound water in the remaining areas of the Everglades in the western part of Dade County, which include Water-Conservation Areas 3A and 3B and Everglades National Park. Surface water from the water-conservation areas is moved by pumping and operation of control structures through a network of canals toward the coast to augment ground-water supplies during periods of low water. Similarly, this system is used to release excess water to the ocean during periods of high water.

Hydrogeology of the Biscayne Aquifer

The Biscayne aquifer in Dade County consists of a wedge-shaped sequence of sedimentary deposits of the upper, most permeable zones of the surficial aquifer system (fig. 2). The Biscayne aquifer, as defined by Fish and Steward (1991, p. 11-12), is composed primarily of limestone and sand, with hydraulic conductivities commonly exceeding 10,000 ft/d (feet per day). The Biscayne aquifer is thickest along the eastern coast of Dade County. In southern and central Dade County, thicknesses along the coast range from 80 to 120 ft (feet). Near the coast in the north, the aquifer is between 160 and 200 ft thick (Fish and Steward, 1991, fig. 16). Water in the Biscayne aquifer is unconfined. Water levels respond rapidly to stresses on the ground-water system, including drainage and recharge from canals, recharge from rainfall, evapotranspiration, and pumpage from well fields.

HISTORY OF SALTWATER INTRUSION IN DADE COUNTY

The problem of saltwater intrusion in Dade County has been addressed by the U.S. Geological Survey since 1932 thru the collection and evaluation of water-level and salinity data. From 1904 to present time, the history of saltwater intrusion in central Dade County has been well researched and documented by Parker and others (1955) through 1950, Leach and others (1972) through 1969, and Klein and Waller (1985) through 1984.

In 1904 (prior to any human-induced drainage), the saltwater interface was estimated to be at or near the coast because of the very high water levels which occurred naturally in the Everglades. Freshwater was reported to seep from the Biscayne aquifer offshore into Biscayne Bay in sufficient quantities to be used as a supply of freshwater for ships. Beginning in 1909 with the extension of the Miami River and continuing through the 1930's, construction of drainage canals (with no control structures) and pumpage from coastal well fields resulted in the lowering of water levels in the Biscayne aquifer, thereby inducing the inland movement of saltwater into the aquifer. Additionally, seawater driven by tidal fluctuations in the drainage canals, resulting in the seepage of saltwater into the Biscayne aquifer from the canals. By 1946, salinity-control structures had been installed in all primary canals as far seaward as possible. These controls prevented saltwater driven by tidal changes from moving upstream in the canals beyond the controls. The controls also served to back up freshwater which maintained higher water levels in the Biscayne aquifer near the coastline. These water levels are higher than those that occurred during the period of uncontrolled drainage. The inland migration of saltwater in northern Dade County slowed or reversed in some areas as a result of the effects of these controls on water levels.

In the early 1960's, the existing canal system in southern Dade County was expanded to provide for flood control. The canals were equipped with flow-regulation structures both near the coast and inland, allowing water levels to be stepped down from structure to structure to prevent excessive drainage. However, the design and operation of this system lowered freshwater levels in the Biscayne aquifer, especially near the coast, allowing for the inland movement of saltwater during the drought years of 1970 and 1971. In 1976, additional water was routed to southern Dade County, raising water levels along the coast and slowing or reversing the inland movement of the saltwater interface (Klein and Waller, 1985).

Since 1984, additional events have occurred which have affected water levels in the Biscayne aquifer and, hence, the movement of the saltwater interface. Among these events are the initial operation of the Northwest Well Field and a consequent reduction in pumping from the Hialeah-Miami Springs Well Field, expansion of the Southwest Well Field, and changes in the delivery schedule of water to southern Dade County and Everglades National Park (fig. 1). Future changes in water levels might occur as a result of changes in the management of the ecosystem of south Florida. These changes will be based on the results of studies being conducted as part of the U.S. Geological Survey South Florida Ecosystem Program (McPherson and others, 1995) and other studies.

DELINEATION AND EXTENT OF SALTWATER INTRUSION IN THE BISCAYNE AQUIFER

The inland subsurface movement of oceanic seawater into the Biscayne aquifer is of primary concern in coastal Dade County. Saltwater, which is more dense than freshwater, moves inland below the freshwater, forming a wedge-shaped interface with freshwater in the Biscayne aquifer (fig. 3). This interface is dynamic, moving laterally in response to changes in water levels. Generally, there is a time lag in the movement of the interface in response to changes in water levels, with regional long-term changes having a greater effect than seasonal changes (Parker and others, 1955, p. 611).

The boundary between the freshwater and saltwater is not a sharp interface, but a transition zone with a width which is partially controlled by the hydraulic conductivity of the aquifer. In the Biscayne aquifer, this zone is generally thin. Chloride concentrations greater than 100 mg/L (milligrams per liter) are generally considered to be evidence of contamination with seawater, which has a chloride concentration of about 19,000 mg/L.

The approximate location of the saltwater interface was defined through the evaluation of a previously published 1984 map of the interface (Klein and Waller, 1985), chloride data (both current and historical), and geophysical data. Chloride data were obtained from 24 wells in the existing U.S. Geological Survey monitoring well network (table 1). The depths of the wells were considered in the evaluation because some of the wells were not screened at the base of the Biscayne aquifer. Vertical chloride profiles were obtained during the drilling of 16 new wells, with water samples collected about every 10 ft. The wells were drilled and screened below the saltwater interface, if present, or at the base of the Biscayne aquifer, if no saltwater was encountered (table 2).

Borehole induction logs (McNeill and others, 1990) were used for 1 existing well and for the 16 new wells to locate the depth to the saltwater interface (table 2). Induction logs were obtained from these wells at two different times in 1995 and 1996, 6 to 10 months apart, to detect any movement of the saltwater interface. No differences were noted in the induction logs for any of the monitoring wells over that time period. Examples of induction logs for two wells (G-3603 and G-3604) are shown in figure 4. The location of the saltwater interface is very distinct in the logs, when present (fig. 4, well G-3064). The small distance for the change from low to high conductivity, generally less than 10 feet, is an indication of the relatively thin transition zone between freshwater and saltwater. Surface-geophysical measurements were obtained at 11 sites using techniques prescribed by McNeill (1980) to determine the depth to the saltwater interface in areas where monitoring well data were not available (fig. 1).

Northeastern Dade County

The canal system is the major factor influencing ground-water levels and the movement of the saltwater interface north of Little River Canal in northeastern Dade County. Snake Creek, Biscayne, and Little River Canals (fig. 1) are used to drain the area, maintaining a very flat water table between the upper reaches of the Miami Canal and the coast (Sonenshein and Koszalka, 1996). Prior to the installation of coastal control structures in the 1940's on the Snake Creek, Biscayne, and Little River Canals, saltwater movement occurred inland in the canals as far as the Red Road Canal (fig. 1) during extreme dry periods (Parker and others, 1955, p. 632). Thus, there was seepage of saline water into the Biscayne aquifer throughout much of the area during this time period. Due to the installation of control structures, seepage is no longer a concern in this area. In addition, the location of the coastal saltwater interface is being monitored.

Chloride concentrations in water samples collected from existing monitoring wells in northeastern Dade County have indicated little, if any, inland movement of the saltwater interface since 1984. In fact, chloride concentrations decreased in the vicinity of the North Miami Eastside Well Field, after the well field was shut down between 1977 and 1982 (Sonenshein and Koszalka, 1996). Data collected from existing monitoring wells and three new monitoring wells (fig. 1 and table 2, wells G-3600, G-3601, and G-3602), and a map depicting the location of the saltwater interface in southeastern Broward County (Koszalka, 1995), were used to determine the location of the saltwater interface in northeastern Dade County. The saltwater interface in northeastern Dade County is shown in approximately the same location as in 1984 (Klein and Waller, 1985), with differences due to more information being available and not to any perceived movement of the saltwater interface.

North-Central Dade County

The canal system and pumpage from the Hialeah-Miami Springs and Northwest Well Fields are major factors influencing ground-water levels and movement of the saltwater interface in north-central Dade County, between the Miami and Little River Canals (fig. 1). Saltwater intrusion is considered a major threat to the Hialeah-Miami Springs Well Field, with evidence of contamination as early as 1939 (Klein and Ratzlaff, 1989). Two possible sources of saltwater to the well field are nearby tidal reaches of the Miami and Tamiami Canals and the coastal interface. Coastal control structures have been installed in these canals to prevent inland migration of tidal canal water. Pumpage from the Hialeah-Miami Springs Well Field was significantly reduced from 1984 to 1992 because of industrial contamination in the supply wells. Variations in chloride concentrations in water at monitoring wells near the Hialeah-Miami Springs Well Field indicate the possible effects of the installation of control structures and changing pumpage rates (Sonenshein and Koszalka, 1996).

The location of the saltwater interface is difficult to determine in north-central Dade County because of the lack of monitoring wells near the coastal saltwater interface and because of the presence of tidal canal water. Elevated chloride concentrations in the monitoring wells nearest to the Hialeah-Miami Springs Well Field could be due to seepage from tidal canals (Sonenshein and Koszalka, 1996). Surface-geophysical data at six locations and data from existing wells and from four new monitoring wells (fig. 1 and table 2, wells G-3602 to G-3605) were used to define the location of the saltwater interface in north-central Dade County. The inland bulge of the saltwater interface (fig. 1) is due to drainage of ground water by the tidal reaches of the Miami Canal. The saltwater interface in this area is shown farther seaward than in 1984 (Klein and Waller, 1985), partly because more information is now available and partly as a result of the possible seaward migration of the saltwater interface due to reduced pumpage from the Hialeah-Miami Springs Well Field. However, there is still uncertainty as to the exact location of the saltwater interface, as indicated by the dashed line in figure 1. Additional wells are needed in this area to better define the position of the saltwater interface and to monitor any possible movement toward the nearby Hialeah-Miami Springs Well Field.

South-Central Dade County

The canal system and pumpage from the four large well fields (Alexander Orr, Snapper Creek, Southwest, and West Well Fields) are major factors influencing ground-water levels and the movement of the saltwater interface in south-central Dade County (fig. 1). The Alexander Orr Well Field is the well field of primary concern in considering movement of the saltwater interface because this well field is located nearest to the coast. There was a decline in water levels in the center of the Alexander Orr Well Field, as a result of increased pumpage beginning in 1988 (Sonenshein and Koszalka, 1996).

The location of the saltwater interface is well defined in south-central Dade County, with data available from existing wells and six new monitoring wells (fig. 1 and table 2, wells G-3606 to G-3611). For comparison with the location of the saltwater interface in 1984 (Klein and Waller, 1985), the area is divided by the Snapper Creek Canal into two regions. North of the Snapper Creek Canal, the saltwater interface has moved inland (Sonenshein and Koszalka, 1996). This movement has been attributed to one of two possible causes, or a combination of the two: (1) a decline in water levels at the Alexander Orr Well Field, located north of the Snapper Creek Canal; and (2) a lowering of water levels in the Coral Gables Canal as a result of reconstruction of the tidal control structure (fig. 1). Additional research is required to determine the exact reason for the movement of the saltwater interface.

In the area south of the Snapper Creek Canal, the saltwater interface was farther inland on the 1984 map (Klein and Waller, 1985) than on the 1995 map (fig. 1). The difference is due to more information being available and not to any perceived movement of the saltwater interface. Elevated chloride concentrations in one monitoring well, G-1604, located just west of well G-1604A (fig. 1), were previously attributed to saltwater intrusion. However, based on data from the new monitoring wells, it is now believed that the elevated chloride concentrations are from another unknown source.

Southeastern Dade County

The canal system is the major factor influencing ground-water levels and the movement of the saltwater interface in southeastern Dade County (fig. 1). The initial canal system, completed in 1967, was designed not only to prevent flooding but also to prevent excessive drainage inland, allowing the saltwater interface to move inland. Subsequently, the primary changes to the system have been the addition of control structures and pump stations in response to changes in needs for water-level controls. There are numerous small municipal well fields in the area (fig. 1), but due to low pumpages and high hydraulic conductivities of the Biscayne aquifer, they appear to have little effect on regional water levels.

The location of the saltwater interface is difficult to determine in southeastern Dade County. Surface-geophysical data at four locations and data from existing wells and four new monitoring wells (fig. 1 and table 1, wells G-3612, G-3613, G-3615, and G-3616) were used to define the location of the saltwater interface in this area. Preliminary results from a saltwater intrusion study in Everglades National Park (Fitterman, 1996) were used to determine the location of the saltwater interface at the southern end of the study area. The saltwater interface is shown in the same general location as in 1984 (Klein and Waller, 1985), except for the central part of this area between the Black Creek and Mowry Canals (fig. 1). In this area, the 1995 interface is farther inland probably based on improved information and on movement of the saltwater interface, detected between 1984 and 1990 by Sonenshein and Koszalka (1996). In the southern part of southeastern Dade County, elevated chloride concentrations in water samples collected from some of the monitoring wells might be due to seepage from tidal saltwater. Additional data are needed between the Black Creek and Mowry Canals and in the southern part of southeastern Dade County to better define the position of the saltwater interface.

SUMMARY AND CONCLUSIONS

This map report depicts the approximate location of the saltwater interface in the Biscayne aquifer in 1995. The saltwater interface was defined through the evaluation of previously published maps of the interface, chloride data (both current and historical), and surface and borehole geophysical data. Sixteen wells were drilled to determine the location of the saltwater interface where additional data were needed. The location of the saltwater interface in 1995, compared to the location in 1984, was found to be approximately the same throughout much of Dade County, with most differences attributed to more information being available and not to any perceived movement of the saltwater interface. The canal system is the major factor influencing movement of the saltwater interface throughout the county. Pumpage from the large well fields in central Dade County also influences movement of the interface.

In northeastern Dade County, the saltwater interface has moved seaward near the North Miami Eastside Well Field, which was shut down between 1977 and 1982, with no evidence of any additional movement elsewhere in the area. In north-central Dade County (in the vicinity of the Hialeah-Miami Springs Well Field), the saltwater interface has also moved seaward, possibly in response to decreased pumpage at the well field from 1984 to 1992. In south-central Dade County, the saltwater interface moved inland north of the Snapper Creek Canal due to either increased pumping from the Alexander Orr Well Field or to a lowering of water levels in the Coral Gables Canal, or a combination of the two. South of the Snapper Creek Canal, the saltwater interface is not as far inland as was previously believed. In southeastern Dade County, the saltwater interface moved inland between the Black Creek and Mowry Canals from 1984 to 1990. Additional data are needed, especially in north-central and southern Dade County, to better determine the location of the saltwater interface.

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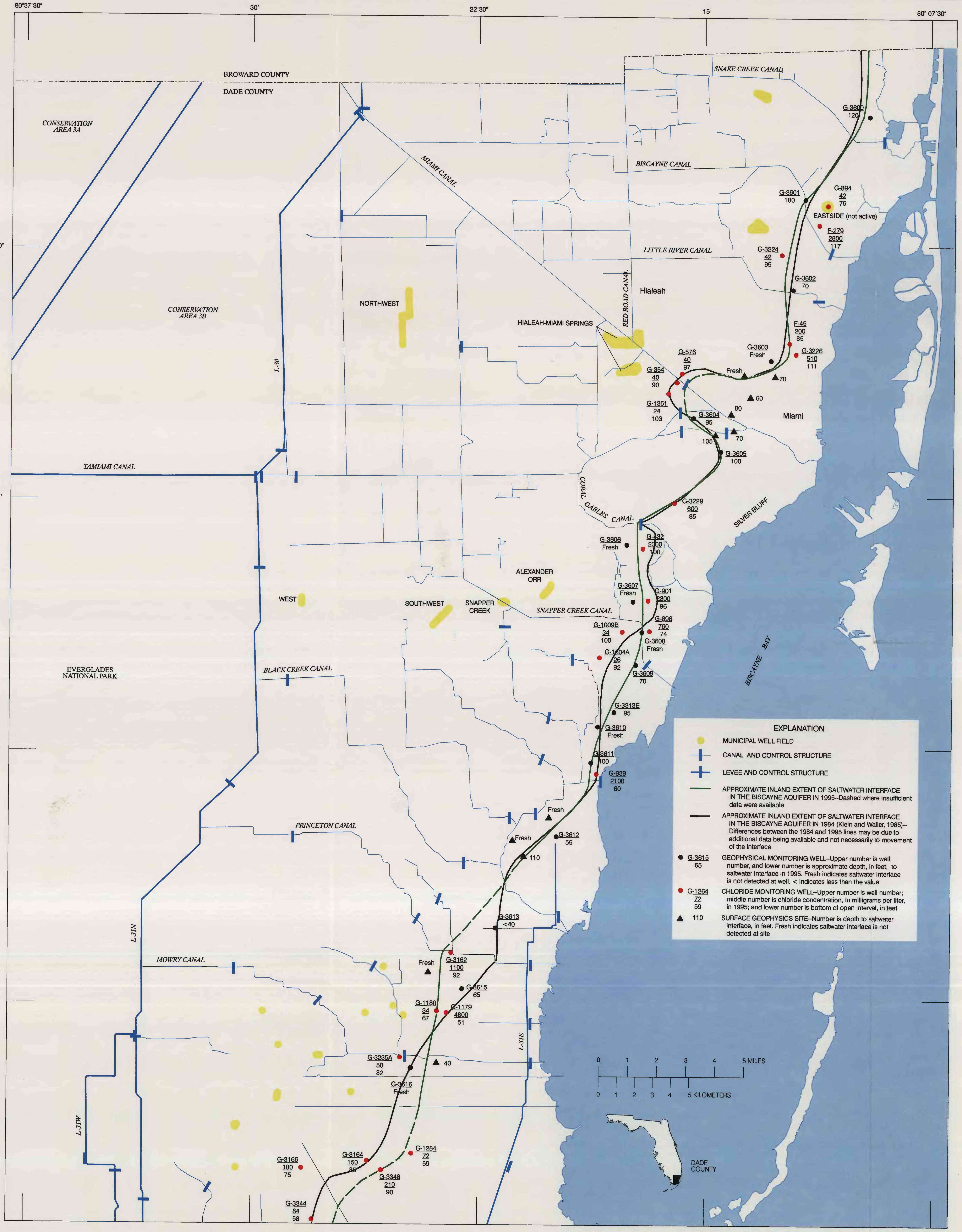

Figure 1. Location of the saltwater interface in the Biscayne aquifer in 1995 and location of monitoring wells, major canals, levees, well fields, and surface geophysics sites in Dade County.

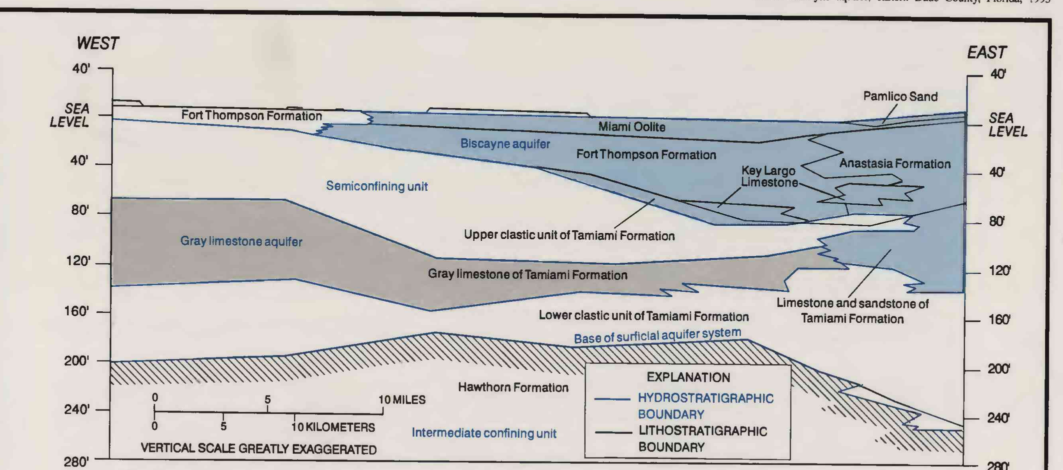

Figure 2. Geologic formations, aquifers, and confining units of the surficial aquifer system in central Dade County, (from Fish and Stewart, 1991).

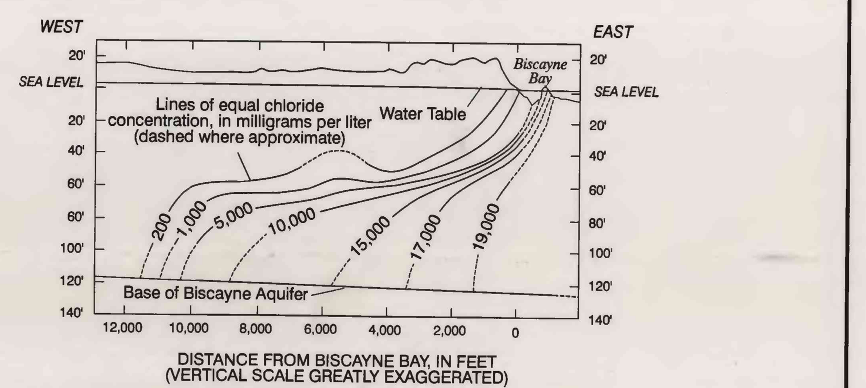

Figure 3. Cross section through the Silver Bluff area showing the zone of diffusion (from Kohout, 1960).

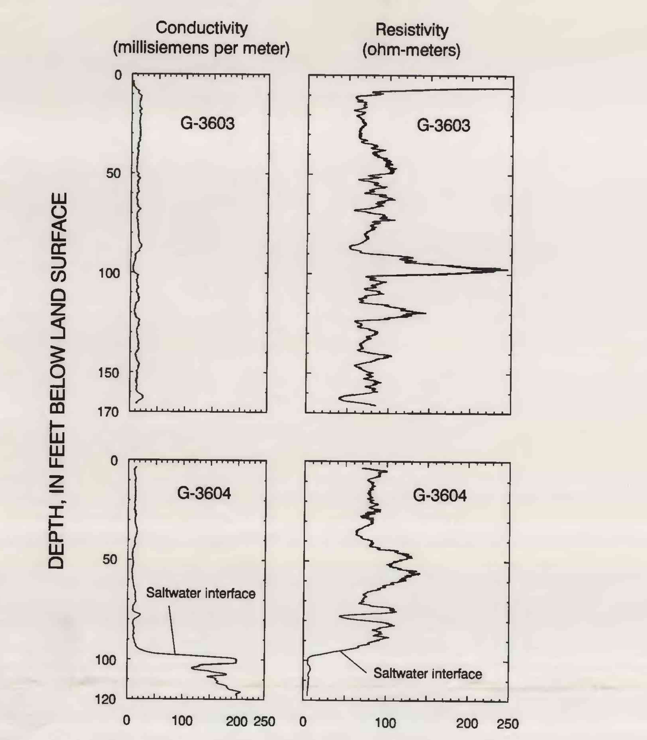

Figure 4. Borehole induction logs for wells G-3603 and G-3604.

Table 1. Inventory data and chloride concentrations in 1995 for existing monitoring wells

[USGS, U.S. Geological Survey; ? indicates top of open interval is unknown]

Local well number	USGS site identification number	Latitude	Longitude	Open interval (feet below land surface)	Chloride concentration (milligrams per liter)
F-45	254943080121501	254943	0801215	?-85	200
F-279	255315080111501	255315	0801115	?-117	2,800
G-354	254826080161501	254826	0801615	88-90	40
G-432	254335080170501	254335	0801705	98-100	2,300
G-576	254849080154802	254849	0801548	91-97	40
G-894	255350080105801	255350	0801058	74-76	42
G-896	254107080165201	254107	0801652	60-74	760
G-901	254201080173001	254201	0801730	95-96	2,300
G-939	253652080183701	253652	0801837	57-60	2,100
G-1009B	254106080174601	254106	0801746	99-100	34
G-1179	252944080233401	252944	0802334	0-51	4,800
G-1180	252947080235301	252947	0802353	0-67	34
G-1264	252532080244301	252532	0802443	6-59	72
G-1351	254813080161501	254813	0801615	100-103	24
G-1604A	254020080183101	254020	0801831	91-92	26
G-3162	253202080232601	253132	0802325	82-92	1,100
G-3164	252519080261101	252519	0802611	75-85	150
G-3166	252506080282201	252506	0802822	65-75	180
G-3224	255222080123001	255222	0801230	93-95	42
G-3226	254923080120201	254923	0801202	111-111	510
G-3229	254457080160301	254457	0801603	?-85	600
G-3235A	252824080250601	252824	0802506	72-82	50
G-3344	252334080260101	252334	0802601	55-58	84
G-3348	252502080254301	252502	0802543	59-90	210

Table 2. Inventory data and depth to saltwater interface in 1995 for monitoring wells having geophysical data

[USGS, U.S. Geological Survey; fresh indicates saltwater interface not found at well; < indicates less than the value]

Local well number	USGS site identification number	Latitude	Longitude	Open interval (feet below land surface)	Approximate depth to saltwater interface in 1995 (feet below land surface)
G-3313E	253831080180206	253831	0801802	32-114	95
G-3600	255626080093201	255626	0800932	195-200	120
G-3601	255358080114101	255358	0801141	185-190	180
G-3602	255116080120601	255116	0801206	155-160	70
G-3603	254908080125201	254908	0801252	155-160	Fresh
G-3604	254722080152201	254722	0801522	115-120	95
G-3605	254629080143101	254629	0801431	105-110	100
G-3606	254341080174001	254341	0801740	115-120	Fresh
G-3607	254156080172101	254156	0801721	115-120	Fresh
G-3608	254108080170601	254108	0801706	95-100	Fresh
G-3609	254005080171601	254005	0801716	80-85	70
G-3610	253819080183201	253819	0801832	105-110	Fresh
G-3611	253710080184701	253710	0801847	95-100	100
G-3612	253457080195501	253457	0801955	56-61	55
G-3613	253214080215401	253214	0802154	55-60	40
G-3615	253024080223101	253024	0802310	75-80	65
G-3616	252812080244301	252812	0802443	90-95	Fresh

DELINEATION AND EXTENT OF SALTWATER INTRUSION IN THE BISCAYNE AQUIFER, EASTERN DADE COUNTY, FLORIDA, 1995

By
Roy S. Sonenshein

1997