Hittle, C.D., 1999, Delineation of saltwater intrusion in the surficial aquifer system in eastern Palm Beach, Martin, and St. Lucie Counties, Florida, 1997-98

INTRODUCTION

Urban development in Palm Beach, Martin, and St. Lucie Counties, Fla. (fig. 1), has expanded rapidly in recent decades, resulting in a need for additional freshwater withdrawals from the surficial aquifer system – the primary source of drinking water for this tri-county area. Potable-water demand for urban users is projected to increase 115 percent in Palm Beach County and 89 percent each in Martin and St. Lucie Counties from 1990 to 2010 (South Florida Water Management District, 1998). The increased demand on the coastal well fields, which draw water from the surficial aquifer system, may contribute to saltwater intrusion. There are limited data as to the location or movement of the saltwater interface in the tri-county area, with the exception of previously collected data in the immediate vicinity of the existing coastal well fields. It is possible that the combination of pumpage from the well fields and drainage caused by rivers and canals has a regional effect on the saltwater interface.

In October 1996, the U.S. Geological Survey (USGS) entered into a cooperative study with the South Florida Water Management District (SFWMD) to determine the present location of the interface between freshwater and oceanic saltwater in the surficial aquifer system along the coast of southeastern Florida. This map report documents the position of the saltwater interface in the surficial aquifer system in 1997-98 through the evaluation of chloride and geophysical data.

Hydrogeologic Setting

The surficial aquifer system underlies Palm Beach, Martin, and St. Lucie Counties and primarily consists of sand, clay, silt, shell, and limestone of Holocene, Pleistocene, and Pliocene age. Its thickness is variable (decreasing westward and northward) and is estimated to be as much as 400 ft (feet) in Palm Beach County (Miller, 1987; Shine and others, 1989), 210 ft in Martin County (Miller, 1980), and 180 ft in St. Lucie County (Miller, 1980). The surficial aquifer system is composed of several stratigraphic units (fig. 2). Listed from oldest to youngest, they are the Tamiami Formation (Pliocene); Caloosahatchee Formation (Pliocene/Pleistocene); Fort Thompson Formation, Anastasia Formation, Miami Limestone (limited areal extent), and Pamlico Sand (Pleistocene); and undifferentiated alluvium and terrace deposits (Holocene). Impermeable and semipermeable clays and marls (calcareous clays) of the Hawthorn Group of Miocene age and the Tamiami Formation of Pliocene age unconformably underlie the surficial aquifer system at its base. Units of the same relative age might interfinger with each other; thus, all units are not usually present in one location.

The main water-producing zones of the surficial aquifer system vary in depth and location throughout the study area, but are relatively shallow. About 85 percent of Palm Beach County's permitted ground-water withdrawal is pumped from depths of less than 150 ft; Martin and St. Lucie Counties pump more than 90 percent of their permitted ground-water withdrawal from depths of less than 150 ft (Alvarez and Bacon, 1988). Additionally, hydraulic conductivities in the main water-producing zones of the surficial aquifer system vary, but generally decrease to the north. The average hydraulic conductivities are estimated to be: 1,600 ft/d (feet per day) in southeastern Palm Beach County, 150 ft/d in northeastern Palm Beach County (Shine and others, 1989), between 32 and 126 ft/d in Martin County (Adams, 1992), and generally less than 150 ft/d in St. Lucie County (Butler and Padgett, 1995).

Hydrologic Features

A canal and levee system is the primary means of controlling water levels in the surficial aquifer system in southeastern Florida. Levees are used to impound water in the south-central part of Palm Beach County, which includes Water Conservation Areas 1 and 2A. The Loxahatchee River on the eastern boundary of Palm Beach and Martin Counties and the St. Lucie River on the eastern boundary of Martin and St. Lucie Counties (fig. 1) act as drains on ground water (Kane, 1992a; 1992b). Control structures on the canals maintain freshwater heads in the canals and control drainage. The structures along the coast prevent saltwater from migrating up the canals.

The primary canals and associated salinity-control structures (fig. 1) in Palm Beach County, from south to north, are the Hillsboro Canal and structure G-56, Hidden Valley Canal (C-15) and structure S-40, Boynton Canal (C-16) and structure S-41, West Palm Beach Canal (C-51) and structure S-155, C-17 Canal and structure S-44, and C-18 Canal and structure S-46. In Martin County, the primary canals and associated salinity-control structures, from south to north, are the St. Lucie Canal (C-44) and structure S-80 and the C-23 Canal and structure S-48; and in St. Lucie County, they are the C-24 Canal and structure S-49 and the C-25 Canal and structure S-50.

DELINEATION OF SALTWATER INTRUSION IN EASTERN PALM BEACH, MARTIN, AND ST. LUCIE COUNTIES

The inland subsurface movement of oceanic saltwater into the surficial aquifer system is a major concern in eastern Palm Beach, Martin, and St. Lucie Counties. In coastal aquifers where freshwater comes in contact with saltwater of the ocean, a condition of dynamic equilibrium exists. If freshwater levels are lowered substantially by drainage or pumpage, saltwater will migrate inland through the aquifer. As water levels are stabilized, the movement of saltwater is stabilized. Similarly, as freshwater levels are raised (perhaps by increased rainfall or reduced pumpage), saltwater will retreat seaward (Miller, 1978, p. 30). The effects of pumping and draining freshwater from the surficial aquifer system may take many years before a freshwater/saltwater equilibrium is reached. Seasonal movement (wet season/dry season) of the saltwater interface may occur on a local scale, but the regional migration of the saltwater interface either inland or seaward will be slow.

The boundary in the surficial aquifer system between freshwater and saltwater is not sharp; it is a transition zone that is controlled, in part, by the hydraulic conductivity of the aquifer. For the purposes of this report, this transition zone will be called the saltwater interface. Chloride concentrations greater than 100 mg/L (milligrams per liter) were considered to be evidence of saltwater mixing with freshwater in the surficial aquifer system and indicate the presence of the saltwater interface. The saltwater interface can have chloride concentrations ranging from 100 to 19,000 mg/L (average chloride concentration of seawater; Hem, 1992).

The approximate location of the farthest inland extent of the saltwater interface was defined through the evaluation of chloride and geophysical data and is shown in figure 1. Seaward of the saltwater interface line (fig. 1), the influence of saltwater intrusion exists above the base of the surficial aquifer system. Landward of the line, oceanic saltwater was not detected. Contour lines depicting the altitude of the base of the surficial aquifer system (Miller, 1980; Miller, 1987; Shine and others, 1989) also are shown in figure 1. The intersection of the saltwater interface line and the contour lines indicates the depth of the saltwater interface at its greatest inland extent (the equivalent of the saltwater front or toe) at the base of the surficial aquifer system; an exception to this occurs when pumping induces lateral migration above the base of the surficial aquifer system.

Chloride data were obtained from 72 wells in the USGS and SFWMD ground-water monitoring well networks (table 1). Borehole-induction logs were obtained from 16 polyvinyl chloride (PVC) cased wells to determine the depth to the saltwater interface (table 1). The borehole-induction probe can only be used in wells with no casing or non-conductive casing, such as PVC. Technical procedures for borehole-induction logging are described by McNeill and others (1990). Examples of induction logs for four wells (PB-1496, PB-1195, PB-1723, and M-1289) are shown in figures 3 to 6. Surface-geophysical measurements (time domain electromagnetic) were obtained at 131 sites by using techniques prescribed by McNeill (1980) to determine the approximate depth to the saltwater interface (table 2). Surface geophysics were used in areas where well data were lacking (fig.1).

Induction logs of freshwater-saturated rocks yield conductivities that typically are less than 25 mS/m (millisiemens per meter), whereas saltwater-saturated rocks yield conductivities that typically are greater than 67 mS/m. Surface-geophysical measurements of conductivities are usually less than 30 mS/m for freshwater-saturated materials and greater than about 100 mS/m for saltwater-saturated materials (Fitterman and Deszcz-Pan, 1998). These conductivity values were based on data from the surficial aquifer system (Biscayne aquifer) in southern Florida; however, the basic lithology (sand and limestone) is similar throughout the surficial aquifer system in southeastern Florida, and therefore, equivalent conductivities were used within the study area.

Surface-geophysical results were interpreted by using Temix software (Interpex Limited, 1996). The software runs a series of forward and inverse modeling programs, creating a layered earth, one-dimensional model (Interpex Limited, 1996). The approximate depth to the saltwater interface (table 2) was produced by examining a best fit model. The error band, presented in table 2, represents alternative models that fit the data nearly as well as the best fit model. Small differences between the error band depths and the approximate depth to the saltwater interface indicate a model whose parameters (depth and conductivity) were resolved with greater confidence than those models with larger differences.

Lithologic conductive zones (LCZ's) within the surficial aquifer system contain clay minerals, which respond as high conductivity values to geophysical measurements. The high conductivity response could be misinterpreted as saltwater if monitoring well or lithologic data are unavailable for comparison. Ten surface-geophysical sites were interpreted as potential LCZ's (fig. 1 and table 2), and were defined as fresh based on the site location and surrounding chloride and geophysical data.

Southeastern Palm Beach County

Rainfall, pumpage from the coastal well fields, and the canal system are major factors that influence ground-water levels and the movement of the saltwater interface in southeastern Palm Beach County. The Lake Worth Drainage District (LWDD) operates the largest canal system in southeastern Palm Beach County, covering an area of about 325 mi² (square miles). It lies within the area south of C-51, north of the Hillsboro Canal, west of Interstate 95 (I-95), and east of U.S. Highway 441 (fig. 1). Water is maintained in the LWDD canals at levels ranging from 15.5 ft above sea level to tide level by way of a system of pumps and control structures within four large equalizing canals (north-south) and more than 50 smaller lateral canals (east-west) (Shine and others, 1989). By maintaining water levels within the canals above sea level, the influence of saltwater intrusion can be reduced.

In much of this area, the base of the surficial aquifer system is 100 ft or more below the water-supply production zones. The Boca Raton well fields lie north of Hillsboro Canal, which separates eastern Palm Beach and Broward Counties. A coastal structure (G-56) is situated on the canal slightly west of I-95. The inland position of this control structure results in greater drainage to the east, lowering water levels (Kane, 1992a), and resulting in the inland movement of the saltwater interface. Boca Raton has eastern and western well fields (fig.1), with most of the pumping coming from the western well fields. Water is pumped from the production zone of the eastern well fields at a depth above 120 ft below land surface. Surface-geophysical data indicate that the saltwater interface underlies the well field between 119 and 130 ft below land surface. Two monitoring wells, PB-490 and PB-491, could not be located; however, historical chloride data show evidence of saltwater intrusion, with concentrations greater than 250 and 10,000 mg/L in wells PB-490 and PB-491, respectively.

In Highland Beach, the saltwater interface underlies the eastern part of the well field. Although insufficient data exist to clearly define the saltwater interface, figure 7 shows a general estimate of its location. The production zone for the well field is between 85 and 120 ft below land surface. Chloride concentrations in well PB-948 increased substantially from about 2,000 mg/L in 1977 to 7,800 mg/L in 1998 (table 1 and fig. 7). Borehole-geophysical data for well PB-948 (table 1) show the saltwater interface is about 165 ft below land surface. Nearby well PB-1496 had a chloride concentration of about 455 mg/L in 1998 (table 1 and fig. 7), and geophysical conductivities increased from 20 to 60 mS/m between depths of about 170 and 195 ft below land surface (fig. 3).

Delray Beach and Boynton Beach have western and eastern well fields with both eastern well fields located less than 0.5 mi (mile) west of the Intracoastal Waterway (fig. 1). In 1977, the saltwater interface was reported to be within 1,000 ft laterally of the eastern well fields (Scott and others, 1977). Water from the Delray Beach eastern and western well fields is pumped at a depth above 130 ft below land surface. Surface-geophysical data indicate the saltwater interface underlies the eastern well field between 154 and 164 ft below land surface at sites 5 and 12 (table 2). Chloride concentrations were determined to be about 190 mg/L at a depth of 222 ft in well PB-1710 and 11,500 mg/L at a depth of 161 ft in well PB-1707 (table 1).

In Boynton Beach, the saltwater interface underlies the eastern well field where water is pumped at a depth above 135 ft below land surface. Borehole-geophysical data for well PB-1195 indicate the saltwater interface is at about 105 ft below land surface east of the well field (fig. 4 and table 1), and a chloride concentration of 13,250 mg/L (well PB-1736) was detected at a depth of 186 ft (table 1). Surface-geophysical data for site 1 (table 2) indicate that the saltwater interface lies below the eastern well field at a depth of 190 ft below land surface.

Municipal water supply is limited to shallow aquifer pumping from a few production wells between Boynton Beach and Lake Worth. The Lake Worth well field lies less than 1 mi west of the saltwater interface. The steep slope of the saltwater interface (fig. 8) in the Lake Worth area was noted by Scott and others (1977). Water levels along the coast in Lake Worth are higher than in Delray Beach, Highland Beach, and Boca Raton (Kane, 1992a) and may affect the slope of the saltwater interface in this area. A segment of the Lake Worth monitoring well network consists of deep PVC-cased wells along an east-west transect between the well field and Intracoastal Waterway (fig. 8). Chloride and borehole-geophysical data indicate the saltwater interface is at the base of the surficial aquifer system near well PB-1723 (figs. 5 and 8). The combination of deep wells, PVC casing, and wells located along an east-west transect resulted in a well-defined saltwater interface in the Lake Worth area.

Surface water from the West Palm Beach Water Catchment area, west of and including Lake Mangonia and Clear Lake, is used by the City of West Palm Beach for municipal water supply (Shine and others, 1989). A lack of wells in this area made surface-geophysical surveys the sole source of data used to evaluate the saltwater interface throughout West Palm Beach (fig. 1).

Northeastern Palm Beach County

Fresh ground-water levels in northeastern Palm Beach County are primarily influenced by rainfall, pumping from the coastal well fields, the canal system, and the Loxahatchee River. The Riviera Beach well field has a production zone between 43 and 245 ft below land surface. Chloride concentrations in monitoring wells east of the water-supply well field, wells PB-1726 and PB-1727, indicate that freshwater lies at 200 ft below land surface. Surface-geophysical data for sites 73 and 141 (fig. 1) indicate the inland extent of the saltwater interface is about 1 mi west of wells PB-1726 and PB-1727. Chloride concentrations from the production wells do not indicate the presence of saltwater, and there are no deep monitoring wells within the well field to confirm the surface-geophysical results.

Between Riviera Beach and Jupiter, three well fields are operated by Seacoast Utilities (Richards Road, Lilac Street, and Hood Road well fields). These well fields are all located west of the saltwater interface as shown in figure 1. The Richards Road well field (fig. 1) is located farther east than the other two well fields and lies within 0.25 mi of the saltwater interface near structure S-44 (fig. 1). More monitoring well data are needed in this area to better define the inland extent of the saltwater interface.

The Jupiter well field is near the southwest fork of the Loxahatchee River. Monitoring well and surface-geophysical data indicate that the saltwater interface is east of the well field (fig. 1). A chloride concentration of about 480 mg/L was detected in well PB-1730 at a depth of between 273 and 294 ft below land surface (table 1). Chloride concentrations indicate that freshwater is present at a depth of 253 ft in monitoring well PB-1732; however, surface-geophysical survey 45 shows that the saltwater interface is present at a depth of about 181 ft, and chloride concentrations slightly greater than 100 mg/L have been reported in the production wells just west of surface-geophysical site 45. Surface-geophysics sites 102, 103, 151, and 153, which are west of the saltwater interface, indicate a LCZ from 100 to 150 ft below land surface (fig.1 and table 2). The LCZ was identified from lithologic logs of a nearby production well.

The Tequesta well field is located along the boundary of Palm Beach and Martin Counties and lies between the Intracoastal Waterway and the Loxahatchee River. The well field has a shallow production zone between 30 and 70 ft below land surface with the base of the surficial aquifer system at about 200 ft below sea level. Chloride concentrations were 4,200 mg/L in well PB-892 and 400 mg/L in well M-1319 at depths of 75 and 130 ft, respectively (table 1). Surface-geophysical data from site 115 suggest that the area is underlain by saltwater at a depth of 105 ft (fig. 1 and table 2), which is confirmed by an earlier study (Scott and others, 1977) that showed saltwater intruding into the existing well field. The inland position of the saltwater interface near Tequesta shows the effects of drainage (resulting in lower ground-water levels) from the Loxahatchee River.

Eastern Martin and St. Lucie Counties

Fresh ground-water levels in Martin and St. Lucie Counties are primarily influenced by rainfall, pumping from the coastal well fields, the Loxahatchee River, and the St. Lucie River. At the Hobe Sound well field in southeastern Martin County, water is pumped from a shallow zone composed of a sandy limestone between 48 and 110 ft below land surface (Technos, Inc., 1994). Chloride and borehole-geophysical data indicate that the saltwater interface is moving horizontally through the production zone east of the production wells as shown in figure 9. The production zone is separated from the base of the surficial aquifer system by a less permeable unit composed of sand, limestone, and clay. Borehole-geophysical data (well M-1289) were used to identify freshwater above and below a horizontal plug of saltwater in the aquifer (fig. 6). This interpretation is supported by chloride data for wells M-1288 (41 mg/L), M-1289 (26 mg/L), and M-1321 (2,850 mg/L). Technos, Inc. (1994) identified the same horizontal plug of saltwater by using multiple surface-geophysical soundings and borehole-geophysical logs. Hobe Sound was the only location in the study area in which freshwater in the surficial aquifer system was found below the farthest inland extent of the saltwater interface.

The position of the saltwater interface between Hobe Sound and Stuart lies slightly west of the Intracoastal Waterway and the St. Lucie River. Before flowing into the Intracoastal Waterway, the St. Lucie River flows between two major peninsulas, which are susceptible to saltwater intrusion. Lower water levels along the coast caused by drainage from the St. Lucie River (Kane, 1992b) allows the saltwater interface to move inland in this area. The Stuart well field lies on the south side of the river and is centered within the peninsula. A limited source of freshwater recharge to the water-supply wells was noted by Scott and others (1977), but the position of the saltwater interface appears to have changed little from the 1977 location. The saltwater interface appears to be limited to the land directly adjacent to the river, and monitoring well and surface-geophysical data indicate that the interior of the peninsula contains freshwater near the base of the shallow surficial aquifer system.

The Martin County North well field is located in Jensen Beach on the peninsula north of the St. Lucie River (fig. 1). Data from the monitoring well network indicate that the saltwater interface is near the western edge of the St. Lucie River. A chloride concentration of 7,200 mg/L was measured at about 189 ft below land surface in well M-1293 near the base of the shallow aquifer (table 1) about 0.75 mi to the south of the well field. Saltwater intrusion near Jensen Beach, as in Stuart, is the result of lowered freshwater levels in the aquifer caused by drainage from the St. Lucie River.

In St. Lucie County, the regional saltwater interface parallels the coastline and does not extend inland, except for the area near the St. Lucie River. The major production well fields in eastern St. Lucie County are in Port St. Lucie and Fort Pierce. Three monitoring wells east of the Port St. Lucie well field have chloride concentrations that exceed the 100-mg/L criteria used in this report: well STL-329 (200 mg/L), well STL-330 (122 mg/L), and well STL-331 (225 mg/L). The wells appear to be too far inland to be affected by the regional saltwater interface. The Fort Pierce well field also does not appear to be affected by the regional saltwater interface.

SUMMARY AND CONCLUSIONS

A study was conducted to determine the 1997-98 location of the saltwater interface in the surficial aquifer system along the coast in Palm Beach, Martin, and St. Lucie Counties. The saltwater interface was delineated through the evaluation of chloride data and surface- and borehole-geophysical data.

Southeastern Palm Beach County is the region most affected by saltwater intrusion due to the proximity of many well fields to the coast. The eastern well fields of Boca Raton, Highland Beach, Delray Beach, and Boynton Beach are underlain by the saltwater interface, although the inland extent of the saltwater interface at this time. More monitoring wells are required to confirm the surface-geophysical results near the eastern well fields.

The Lake Worth Utilities well field is west of the present position of the saltwater interface. The monitoring wells at this well field proved effective for locating the saltwater interface. Deep PVC-cased wells, located along an east-west transect, provided sufficient data to delineate the saltwater interface.

The saltwater interface in northeastern Palm Beach County was found to be underlying the well fields of Riviera Beach and Tequesta, but east of the well fields of Seacoast Utilities and Jupiter. Fresh ground-water levels along the coast between Riviera Beach and Tequesta are lowered by drainage from canals and the Loxahatchee River, which may affect the location of the saltwater interface in this area. More monitoring well data from deeper within the surficial aquifer system is required to confirm the surface-geophysical data near Riviera Beach. Although Seacoast Utilities and Jupiter have well fields that lie west of the saltwater interface, the proximity of the saltwater interface to some of the production wells is evident, and more information on the position of the interface would be useful.

Martin County, although not as demanding as Palm Beach County on potable water resources, has three locations where saltwater intrusion is of the greatest concern: the Hobe Sound, Stuart, and Martin County North well fields. Hobe Sound has a zone of saltwater intruding horizontally through a sandy limestone production zone. The horizontal movement of the saltwater interface within this production zone makes the farthest landward extent of the interface lie above the base of the surficial aquifer system. The production zone is separated from the base of the surficial aquifer system by a less permeable unit composed of sand, limestone, and clay. Monitoring well coverage in this area is sufficient to define the extent of saltwater intrusion. The area in the vicinity of the St. Lucie River is naturally susceptible to saltwater intrusion due to the lower freshwater levels in the aquifer caused by drainage, although no discernible movement in the saltwater interface has been identified since 1977. The saltwater interface was not detected within the surficial aquifer system in St. Lucie County, except for the north fork of the St. Lucie River.

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Table 1. Chloride concentrations and approximate depth to saltwater interface for selected monitoring wells in Palm Beach, Martin, and St. Lucie Counties, 1997-98

[Approximate depth to saltwater interface based on borehole-geophysical data. Fresh indicates no saltwater interface found in well (value indicates depth to saltwater interface). Data for wells PB-490 and PB-491 are based on 1993 historical record (wells not found). *, chloride data from South Florida Water Management District data base; >, greater than the value; ?, Unknown; --, no data]

Local well number	Latitude	Longitude	Open interval (feet below land surface)	Chloride concentration (milligrams per liter)	Approximate depth to saltwater interface (feet below land surface)
PB-490	262117	0800550	122 - 127	>250	--
PB-491	262114	0800540	202 - 207	>10,000	--
PB-892	265728	0800601	? - 75	4,200	--
PB-948	262434	0800431	170 - 175	7,800	165
PB-1063	261950	0800743	? - 134	60	--
PB-1195	263048	0800346	? - 325	--	105
PB-1496	262435	0800436	195 - 200	455	170
PB-1669	262212	0800447	108 - 131	24	--
PB-1686	262034	0800641	? - 131	40	--
PB-1707	262755	0800401	? - 161	11,500	--
PB-1710	262713	0800419	? - 222	190	--
PB-1711	262741	0800420	? - 115	26	--
PB-1713	262817	0800412	? - 141	22	Fresh
PB-1714	262803	0800411	? - 159	18	Fresh
PB-1715	262650	0800419	? - 140	32	Fresh
PB-1717	263453	0800315	135 - 145	960	--
PB-1720	263437	0800327	150 - 160	2,400	--
PB-1722	263632	0800304	160 - 165	268	165
PB-1723	263633	0800314	310 - 315	410	310
PB-1724	263635	0800338	307 - 312	36	Fresh
PB-1725	263638	0800356	282 - 287	39	Fresh
PB-1726	264643	0800334	? - 200	25*	--
PB-1727	264717	0800335	? - 200	16*	--
PB-1730	265603	0800736	273 - 294	480*	--
PB-1732	265550	0800707	232 - 253	55*	--
PB-1733	265611	0800802	189 - 210	220*	--
PB-1734	264858	0800448	84 - 110	40	--
PB-1735	264832	0800427	84 - 110	16	--
PB-1736	263053	0800344	? - 186	13,250*	--
PB-1737	263053	0800350	? - 162	9,950*	--
M-1010	271109	0801255	? - 126	33	--
M-1090	271127	0801447	123 - 128	26	--
M-1091	271123	0801351	118 - 123	23	--
M-1092	270313	0800721	155 - 160	3,050	--
M-1132	271010	0801223	103 - 104	680	--
M-1141	270952	0801352	? - 109	25	--
M-1147	270943	0801457	? - 150	215	145
M-1158	271156	0801412	125 - 128	22	--
M-1165	271017	0801235	103 - 106	47	--
M-1286	270313	0800721	49 - 59	425	--
M-1287	270305	0800730	102 - 113	4,250	--
M-1288	270303	0800737	60 - 70	41*	--
M-1289	270303	0800737	156 - 166	26*	90
M-1293	271302	0801532	? - 189	7,200	170
M-1294	271409	0801622	? - 137	34	--
M-1296	271512	0801435	? - 136	23	--
M-1298	271333	0801510	? - 141	25	Fresh
M-1301	271126	0801924	80 - 140	28	--
M-1304	271021	0801708	80 - 120	23	--
M-1305	271021	0801616	80 - 140	45	Fresh
M-1306	271102	0801624	80 - 140	40	Fresh
M-1307	271114	0801819	70 - 150	53	--
M-1309	270614	0800842	189 - 200	37	--
M-1316	270628	0800903	170 - 175	18	--
M-1318	270727	0800941	150 - 155	26	--
M-1319	265830	0800529	100 - 130	400*	--
M-1321	270303	0800737	115 - 120	2,850*	--
M-1323	270859	0801028	126 - 128	1,100*	--
STL-317	271429	0801718	? - 175	100	--
STL-318	272753	0802005	105 - 115	40*	--
STL-319	272743	0802000	105 - 115	39*	--
STL-320	272738	0802033	105 - 115	26*	--
STL-321	272531	0801956	105 - 115	15*	--
STL-322	272538	0802053	105 - 115	44*	--
STL-323	272936	0802129	105 - 115	44*	--
STL-324	272855	0802111	105 - 115	17*	--
STL-325	272907	0802130	105 - 115	47*	--
STL-326	272549	0802060	105 - 115	43*	--
STL-327	272710	0802128	105 - 115	43*	--
STL-328	272534	0802219	105 - 115	62*	--
STL-329	271942	0800215	105 - 115	200*	--
STL-330	272056	0802046	108 - 118	122*	--
STL-331	271924	0801954	104 - 107	225*	--

[1] Chloride sample from open interval with approximate depth to saltwater interface from borehole geophysics. See figure 9.

Table 2. Approximate depth to saltwater interface and error band of saltwater interface layer for surface-geophysics sites, 1997-98

[Fresh, freshwater at base of surficial aquifer system (saltwater interface not found at site); LCZ, lithologic conductive zone or clay layer; --, not applicable, freshwater to base of surficial aquifer system]

Site number	Latitude	Longitude	Approximate depth to saltwater interface (feet below land surface)	Error band of the saltwater interface layer (feet below land surface): Minimum	Error band: Maximum
1	263048	0800411	190	175	199
2	263016	0800331	54	50	57
3	262909	0800358	92	85	99
4	262809	0800438	Fresh/LCZ	--	--
5	262651	0800426	164	149	173
6	263314	0800341	208	193	223
7	263311	0800312	94	88	100
8	263241	0800404	196	183	210
9	265656	0800502	67	66	69
10	270325	0800757	Fresh	--	--
12	262700	0800416	154	152	160
13	263151	0800413	170	159	182
14	263451	0800316	174	157	185
15	263834	0800350	Fresh/LCZ	--	--
16	263903	0800308	218	202	232
18	271329	0801321	69	65	76
19	271121	0801425	Fresh	--	--
20	263549	0800333	216	213	222
21	263556	0800301	84	79	87
22	264021	0800326	Fresh	--	--
23	264020	0800313	175	167	182
24	264226	0800316	92	78	106
25	264229	0800341	181	158	202
26	271309	0801548	179	169	192
27	271141	0801444	Fresh	--	--
28	271025	0801508	154	139	167
29	270650	0801650	Fresh	--	--
32	264202	0800337	153	143	165
34	264356	0800349	Fresh	--	--
35	264244	0800338	270	256	280
36	264647	0800327	220	201	237
37	264742	0800360	194	178	207
38	264851	0800401	63	61	67
40	264959	0800418	53	49	56
42	265017	0800451	Fresh	--	--
43	265132	0800543	Fresh	--	--
45	265541	0800714	181	175	192
46	265707	0800527	108	107	111
50	262103	0800530	123	118	128
51	262104	0800546	130	123	146
53	262054	0800719	Fresh/LCZ	--	--
54	261937	0800609	170	167	181
56	262156	0800559	Fresh	--	--
58	273242	0802347	Fresh	--	--
59	272910	0802212	Fresh	--	--
60	272546	0802030	Fresh	--	--
61	272437	0801928	Fresh	--	--
62	271820	0801643	Fresh	--	--
63	271753	0801759	Fresh	--	--
64	271532	0801734	Fresh	--	--
65	270825	0801228	Fresh	--	--
66	270850	0801249	Fresh	--	--
67	270549	0800909	Fresh	--	--
69	262308	0800512	119	111	125
70	262300	0800556	Fresh	--	--
71	262625	0800440	Fresh	--	--
73	264651	0800408	259	258	264
74	273218	0802140	Fresh	--	--
75	273151	0802120	Fresh	--	--
76	272809	0802000	Fresh	--	--
77	272556	0801938	Fresh	--	--
78	272455	0801854	Fresh	--	--
79	272338	0801845	Fresh	--	--
80	271757	0801526	Fresh	--	--
81	271457	0801413	Fresh	--	--
82	271626	0801556	Fresh	--	--
83	271505	0801342	174	172	177
84	271134	0801318	Fresh	--	--
85	271111	0801340	Fresh	--	--
86	270953	0801136	37	35	39
91	263413	0800359	176	172	186
92	263421	0800321	207	207	213
93	263636	0800358	Fresh	--	--
94	263800	0800349	Fresh/LCZ	--	--
95	264602	0800421	144	129	189
96	264449	0800413	Fresh/LCZ	--	--
97	265113	0800359	158	148	173
98	265121	0800432	88	85	90
99	265404	0800426	113	112	115
100	265604	0800625	132	128	142
101	265608	0800759	121	113	152
102	265506	0800755	Fresh/LCZ	--	--
103	265638	0800849	Fresh/LCZ	--	--
104	265657	0800719	188	183	197
105	265913	0800820	108	99	117
106	271036	0801346	Fresh	--	--
107	271017	0801549	70	58	85
108	271046	0801624	149	138	161
109	271202	0801743	Fresh	--	--
110	271344	0801605	Fresh	--	--
111	265410	0800618	Fresh	--	--
112	265603	0800517	67	67	68
113	265630	0800622	101	100	107
114	265854	0800830	Fresh	--	--
115	265815	0800628	105	103	111
116	270002	0800608	172	168	176
117	270020	0800831	Fresh	--	--
118	265912	0800658	175	174	179
119	265851	0800630	190	190	193
120	265938	0800849	Fresh	--	--
121	270132	0800652	Fresh	--	--
122	270358	0800758	Fresh	--	--
123	270455	0800814	Fresh	--	--
124	270655	0800917	Fresh	--	--
125	271619	0801740	Fresh	--	--
126	271547	0802007	Fresh	--	--
127	271415	0802021	Fresh	--	--
128	271240	0801820	139	133	146
129	270850	0801213	Fresh	--	--
130	270859	0801212	Fresh	--	--
132	270942	0801612	Fresh	--	--
133	270701	0801609	Fresh	--	--
134	270816	0801513	146	133	158
135	263700	0800343	Fresh/LCZ	--	--
136	263754	0800413	Fresh	--	--
138	264141	0800410	Fresh	--	--
139	264931	0800555	Fresh	--	--
140	264754	0800616	Fresh	--	--
141	264655	0800503	Fresh	--	--
142	264504	0800445	Fresh	--	--
144	262603	0800501	Fresh	--	--
145	262505	0800442	151	122	171
146	262709	0800511	Fresh	--	--
149	262713	0800532	Fresh	--	--
150	263220	0800439	Fresh	--	--
151	265559	0800821	Fresh/LCZ	--	--
152	265440	0800649	Fresh	--	--
153	265528	0800844	Fresh/LCZ	--	--
155	263350	0800426	Fresh	--	--
156	263018	0800432	Fresh	--	--
158	263024	0800517	Fresh	--	--

Series	Stratigraphic and hydrologic units		Lithology
Holocene	Undifferentiated alluvium and terrace deposits	Surficial aquifer system, undifferentiated	Sand with local shell beds
Pleistocene	Pamlico Sand	Surficial aquifer system, undifferentiated	Fine- to medium-grained sand
Pleistocene	Miami Limestone	Surficial aquifer system, undifferentiated	Oolitic limestone
Pleistocene	Anastasia Formation	Surficial aquifer system, undifferentiated	Interbedded sand, shell, and limestone
Pleistocene	Fort Thompson Formation	Surficial aquifer system, undifferentiated	Sandy limestone and marl
Pleistocene	Caloosahatchee Formation	Surficial aquifer system, undifferentiated	Marl with minor sand and silt
Pliocene	Tamiami Formation	Surficial aquifer system, undifferentiated	Marl with beds of fossiliferous limestone
Miocene	Hawthorn Group: Peace River Formation	Intermediate confining unit	Phosphatic sand and clay
Miocene	Hawthorn Group: Arcadia Formation	Intermediate confining unit	Sand and limestone

Figure 2. Stratigraphic units included in the undifferentiated surficial aquifer system. Modified from Scott (1988). [Stratigraphic units of Pleistocene series are equivalent in part.]

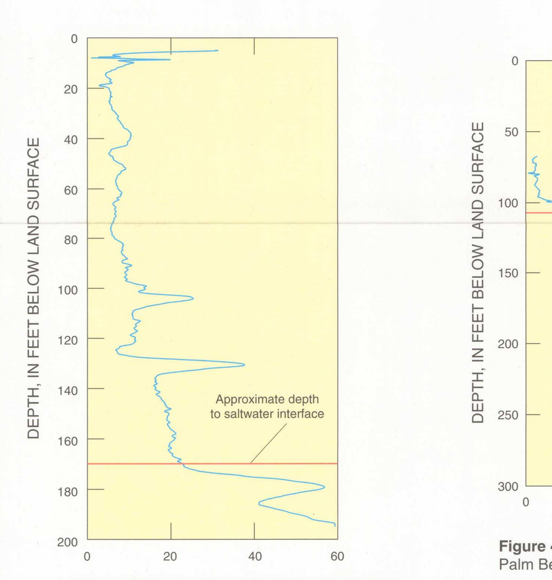

Figure 3. Borehole-geophysical log of well PB-1496 in Highland Beach, Palm Beach County.

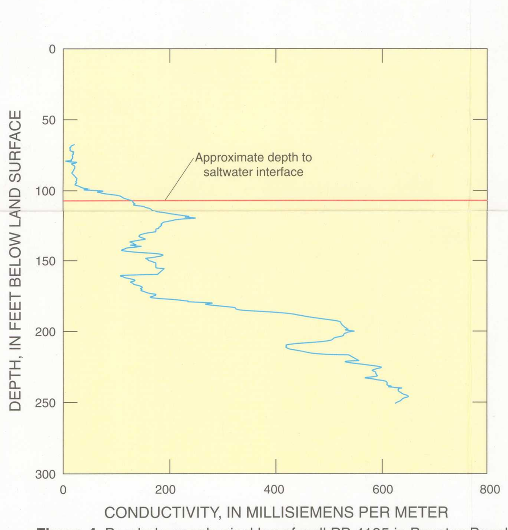

Figure 4. Borehole-geophysical log of well PB-1195 in Boynton Beach, Palm Beach County.

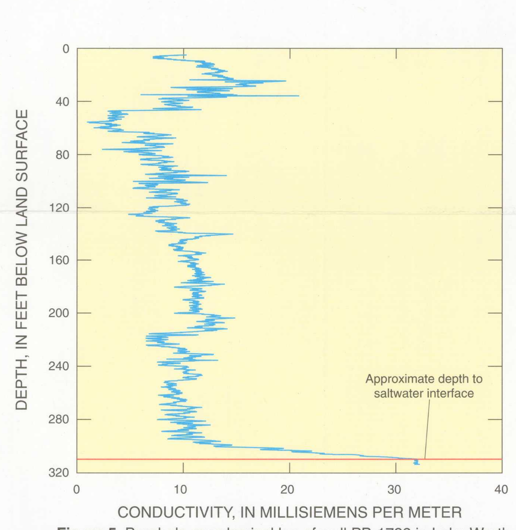

Figure 5. Borehole-geophysical log of well PB-1723 in Lake Worth, Palm Beach County.

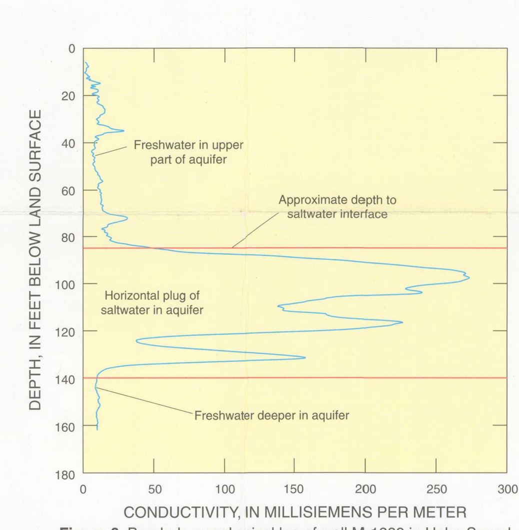

Figure 6. Borehole-geophysical log of well M-1289 in Hobe Sound, Martin County.

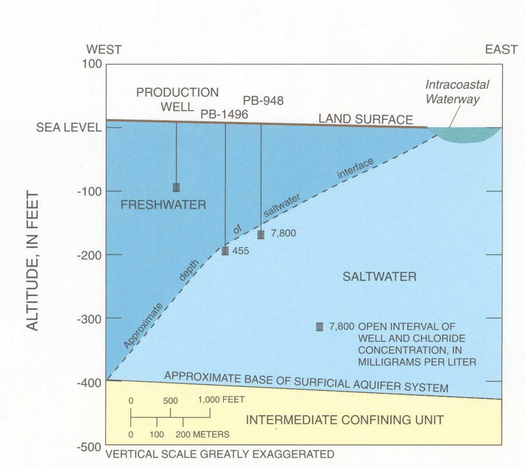

Figure 7. Generalized freshwater-saltwater profile across the surficial aquifer system in Highland Beach, Palm Beach County.

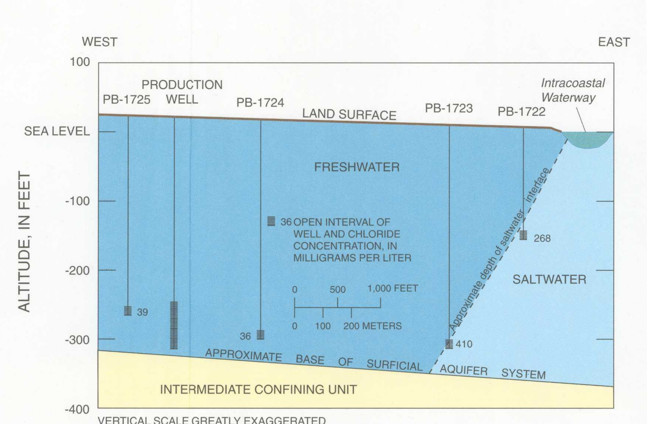

Figure 8. Generalized freshwater-saltwater profile across the surficial aquifer system in Lake Worth, Palm Beach County.

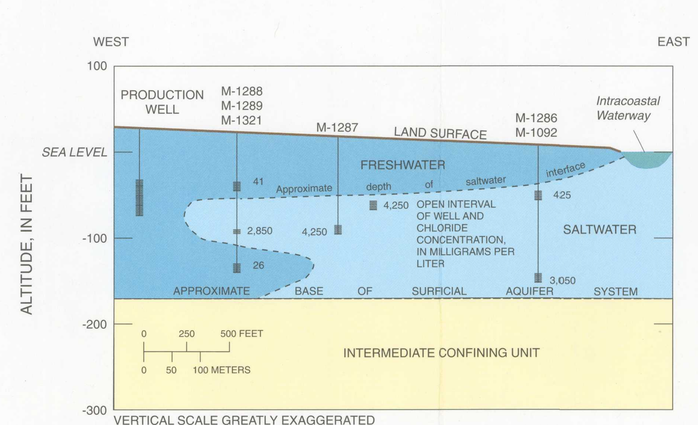

Figure 9. Generalized freshwater-saltwater profile across the surficial aquifer system in Hobe Sound, Martin County.

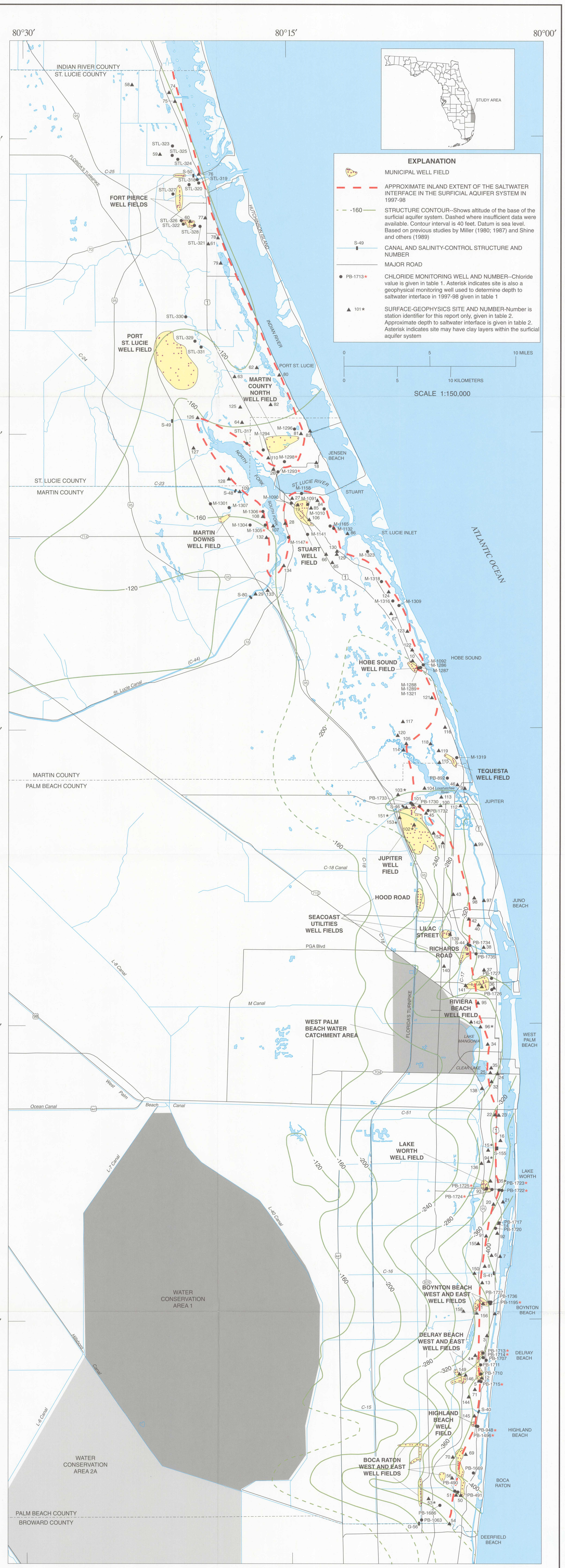

Figure 1. Location of the approximate inland extent of the saltwater interface in the surficial aquifer system in Palm Beach, Martin, and St. Lucie Counties, Florida, 1997-98. [Altitude of the base of the surficial aquifer system, data-collection sites, and municipal well fields are also depicted.]

DELINEATION OF SALTWATER INTRUSION IN THE SURFICIAL AQUIFER SYSTEM IN EASTERN PALM BEACH, MARTIN, AND ST. LUCIE COUNTIES, FLORIDA, 1997-98

By Clinton D. Hittle
1999