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PREPARED IN COOPERATION WITH
PALM BEACH AND MARTIN COUNTIES, SOUTH FLORIDA WATER MANAGEMENT DISTRICT,
LAKE WORTH DRAINAGE DISTRICT,
AND
THE CITIES OF BOCA RATON, JUNO BEACH, RIVIERA BEACH, AND TEQUESTA

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OPEN-FILE REPORT

SALTWATER INTRUSION IN THE SHALLOW AQUIFER IN MARTIN AND PALM BEACH COUNTIES, FLORIDA

By
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INTRODUCTION

Urban growth has been rapid in recent years in Palm Beach and Martin Counties in an elongated area paralleling the coast and extending inland 2 to 3 mi, primarily because of the proximity of the ocean and the fact that the area is relatively free from floods. The increased population has placed greater demands on water supplies obtained from wells tapping the shallow aquifer adjacent to the coast. While the population of eight coastal communities increased by an estimated 25 percent between 1970 and 1973, the municipal-water demand increased about 45 percent in approximately the same time span.

The withdrawal of large quantities of fresh ground water in the vicinity of the coast has reduced or locally reversed the natural seaward hydraulic gradient and, in places, allowed saltwater to advance landward in the aquifer, displacing freshwater. This landward advance is termed saltwater intrusion. The purpose of this report is to show the position of the saltwater front in eight urban areas adjacent to the coast. The saltwater front, as shown on the profiles, is based on a chloride concentration of 250 mg/L which is recommended as a limit for water that is considered potable (NAS and NAE, 1973). The chloride concentration of native freshwater almost always is less than 50 mg/L in the coastal aquifer.

HYDROLOGIC SETTING

The shallow aquifer underlies all of Martin and Palm Beach Counties, an aggregate area of 2,537 mi^2, and is the principal source of fresh ground water for public water supply along the coast. The aquifer includes the Pliocene Tamiami Formation, the Pleistocene Anastasia Formation and Pamlico Sand in Martin County (Lichtler, 1960, p. 21). It is named the Biscayne aquifer in the Boca Raton and Delray Beach areas of Palm Beach County (Parker and others, 1955, p. 160) and is designated the shallow aquifer in other areas (Land and others, 1973, p. 20). The aquifer consists of beds and lenses of sand, shells, sandstone, and limestone extending from land surface to a maximum depth of about 250 ft in northeast Martin County. In the coastal area of the two counties it contains a major water-bearing zone 40 to 150 ft thick which yields as much as 1,500 gal/min to large supply wells.

The principal source of recharge to the shallow aquifer is local rainfall, chiefly during the wet season, May–October, when 70 percent of the annual rainfall occurs. The aquifer is also replenished, but to a lesser extent, by seepage from the lower controlled reaches of the major canals and connecting lakes, chiefly during the dry season, November–April.

The principal loss of water from the shallow aquifer is by evapotranspiration. Some ground water is discharged by underflow to the ocean or to the Intracoastal Waterway. Additional ground water is also lost by seepage to major canals during the wet season when coastal control structures in canals are opened to lower ground-water levels in areas of potential flooding. For example, when the South Florida Water Management District and the Lake Worth Drainage District release water through major canals to prevent flooding, ground-water levels in southeast Palm Beach County, east of Conservation Area 1 (located on fig. 1) are lowered.

The main source of saltwater intruding the shallow aquifer is the Intracoastal Waterway. On the coastal islands between the Intracoastal Waterway and the ocean the shallow aquifer is subject to intrusion from two directions and receives no fresh ground-water flow from the mainland.

Prior to urban development along the coast in Martin and Palm Beach Counties, the ground-water levels were high and saltwater in the shallow aquifer extended inland only a few hundred feet. A considerable quantity of fresh ground water flowed naturally into the ocean, and it was this underflow under a relatively high hydraulic gradient that kept saltwater out of the aquifer. As the population grew, well fields were established near the coast and canals were dredged to provide flood protection and to make more land available for development.

CHARACTERISTICS OF SALTWATER INTRUSION

Kohout (1960) and Cooper and others (1964) have hypothesized from data collected near Miami that saltwater perpetually flows inland in the lower part of an aquifer which is in hydraulic contact with the ocean, and after becoming progressively diluted with freshwater in the zone of diffusion, becomes less dense than ocean water and rises and moves seaward along the base of the upper, freshwater part of the aquifer. Data indicate that the zone of diffusion ranges in thickness from 15 ft to as much as 50 ft. The cyclic flow is operative only if there is a seaward hydraulic gradient in the freshwater segment of the aquifer (fig. 2). If the seaward gradient were greatly reduced or reversed, the zone of diffusion and the body of saltwater in the aquifer would move farther inland.

The extent to which saltwater will intrude into a coastal aquifer is highly variable. For a given change in freshwater hydraulic gradient, it will move more readily in zones of high permeability than it will in zones of low permeability. Along the coast in Martin and Palm Beach Counties, for example, the saltwater front may penetrate farther inland in the major water-bearing zone than in those parts of the aquifer above and below this zone.

FACTORS AFFECTING SALTWATER INTRUSION

Several factors have contributed to bringing saltwater farther into the aquifer. One is the increase in municipal pumping which locally has reduced or reversed the natural seaward gradient within the aquifer. This reduction or reversal of the seaward hydraulic gradient near the coast is the prime reason for saltwater intrusion problems in Palm Beach and Martin Counties. Another is the digging of short, dead-end canals along the coast to create canal-front property with access to the ocean by boats. These canals, generally uncontrolled because of the absence of a salinity control structure, merely become inland extensions of saltwater, and thus aggravate the saltwater intrusion problem. Urbanization, resulting in the covering of recharge areas with buildings and pavement, reduces the potential recharge area and also accelerates runoff through drainageways or storm sewers that generally discharge directly to the ocean. The effect is less recharge to the aquifer.

Drainage canals, on the other hand, are not a major cause of saltwater intrusion along the coast in either Martin or Palm Beach Counties because their flows are regulated, and high water levels are maintained even during dry seasons in most areas.

EXTENT OF SALTWATER INTRUSION

Saltwater intrusion into the shallow aquifer along the coast is likely to be greatest during the dry season when water levels are low and pumping rates high. The extent of saltwater in the aquifer at the end of the 1975 dry season along the coast of Martin and Palm Beach Counties is illustrated by a series of profiles through eight selected well-field areas. The scales of the profiles and inset maps are identical for comparison purposes. Data on ground-water salinity used in the preparation of the profiles were obtained from salinity monitor wells and test holes drilled between the well fields and the salty surface-water bodies, and from production wells. The profiles were shaped by first plotting the aquifer boundaries and salinity data on a graph with equal horizontal and vertical scales and then drawing profiles comparable to those obtained from analyses of physical models made by Bear and Dagan (1964, p. 206, experiment 2). The well fields are those of the cities of Stuart, Tequesta, Juno Beach, Riviera Beach, Lake Worth, Boynton Beach, Delray Beach, and Boca Raton.

Martin County

The city of Stuart constitutes the largest municipal ground-water demand in Martin County. The profile A-A′-A″ indicates that saltwater at the bottom elevation at the wells in the major water-bearing zone is about 2,700 ft north of the nearest supply well, and an estimated 3,000 ft west of the supply wells. Since the Stuart well field is bounded on three sides by saltwater bodies, and fresh ground water can flow into the vicinity only from the south, the recharge potential to the well field is severely restricted.

Palm Beach County

The greatest extent of saltwater intrusion in the vicinity of coastal well fields is in northeast Palm Beach County. The proximity of saltwater to well fields in Tequesta and Juno Beach is shown in profiles B-B′ and C-C′. The profiles show a bend outward in the interface in the vicinity of the municipal wells, caused by large withdrawals from wells above and near the freshwater-saltwater interface. The movement of saltwater has been lateral and vertical. Saltwater has already contaminated some supply wells in Tequesta. Both municipal well fields are located between two surface saltwater bodies. In Juno Beach a freshwater lake between the well field and the ocean serves as a local source of recharge to the aquifer and aids some in retarding saltwater intrusion. Even with this recharge, recent increases in pumpage have caused the freshwater-saltwater interface to advance farther inland.

In most cities along the coast, salty ground water has not shown substantial advancement inland towards municipal well fields. The steep slope of the interface at Lake Worth and Riviera Beach reflects the relatively high water levels between the municipal wells and the coast. Well fields in southeast Palm Beach County receive infiltration from E-4 Canal whose level is maintained nearly constant through water-management practices. This infiltration tends to stabilize and minimize water-level drawdowns caused by pumping and to retard saltwater intrusion.

A potential threat exists in Delray Beach and Boynton Beach where salty ground water at 150 to 200 feet below sea level is within 1,000 ft laterally from the nearest municipal wells. Municipal wells in these fields have a maximum depth of about 100 ft below sea level.

The bulk of the pumping in Boca Raton has been shifted to the area north of that shown in profile H-H′, and to a new area inland from the El Rio Canal.

Other public water supplies being monitored regularly for saltwater intrusion are at Palm Beach International Airport and Lantana. As withdrawals increase in all municipal areas, salinity and water-level monitoring will become increasingly important.

SUMMARY

The major concentration of population and industry in Palm Beach and Martin Counties is along the coastal ridge. In recent years ground-water levels in parts of the area have been lowered as a result of large ground-water withdrawals and drainage, causing some inland advances of saltwater in the shallow aquifer. This growing problem of saltwater intrusion is generally the limiting factor on well-field development along the coastal ridge.

Saltwater flows in a cycle inland to the zone of diffusion where it is dispersed and diffused, and then carried back to the sea by the seaward flow of freshwater. When withdrawal of fresh ground water near the coast reduces or reverses the seaward gradient, or the gradient is lowered by a reduction in recharge or precipitation, the zone of diffusion will migrate landward.

The extent of saltwater intrusion is highly variable and dependent on local geologic and hydrologic conditions. In Stuart, Martin County, the proximity of surface saltwater bodies on three sides of the municipal well field poses a threat to existing facilities and a greater threat if withdrawals are increased. In Palm Beach County the greatest extent of saltwater intrusion into coastal well fields is in Tequesta and Juno Beach. Saltwater has advanced into the Tequesta well field and is near the Juno Beach well field.

The most effective ways of reducing the threat of saltwater intrusion are to drill public-supply wells farther inland, to stabilize the withdrawal of water from coastal wells, to control the dredging of additional tidal canals, and to reduce the discharge of freshwater to the ocean.

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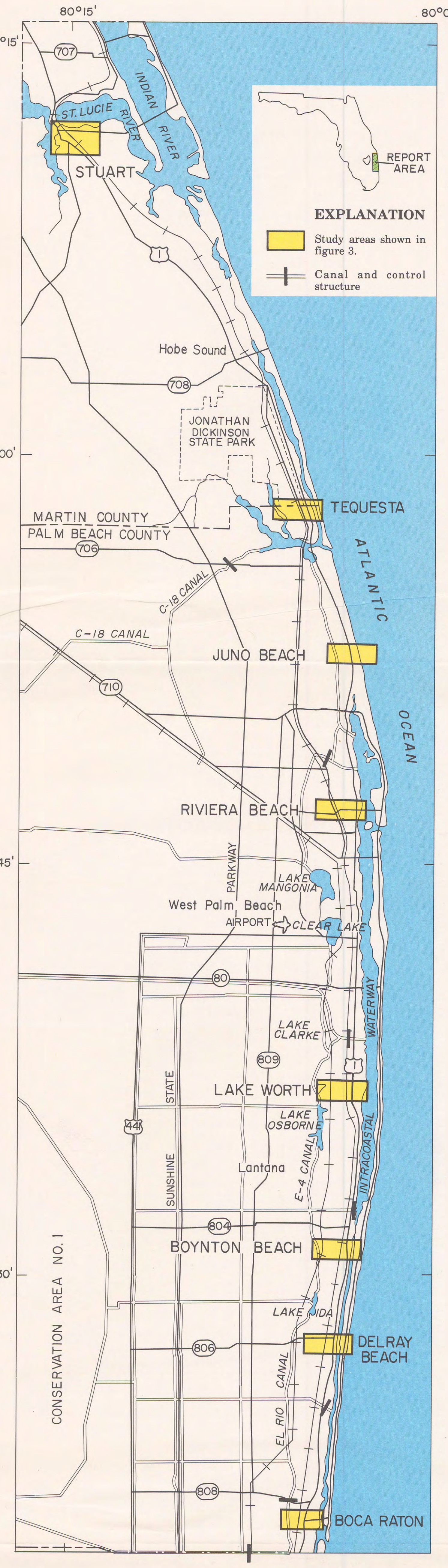


Figure 1. — Eastern Palm Beach and Martin Counties showing selected well field areas.

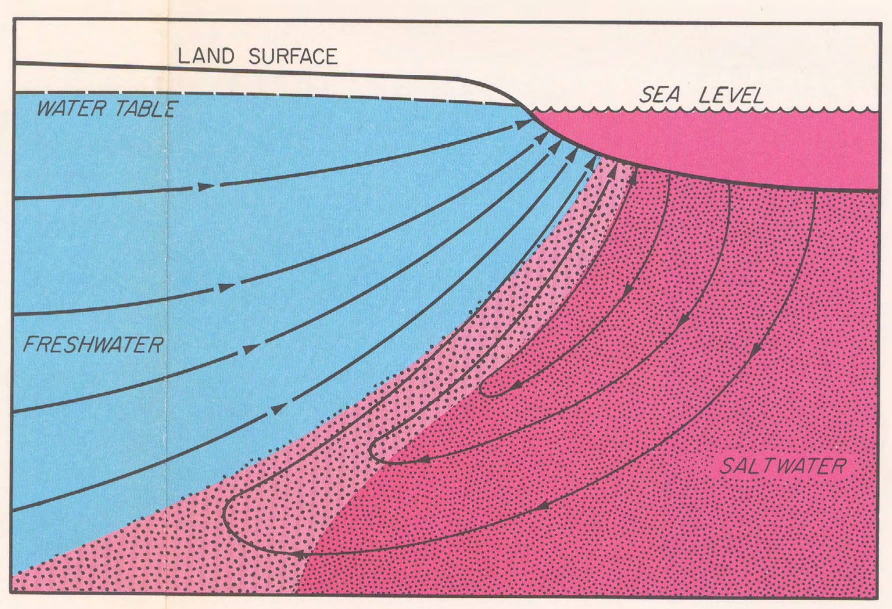
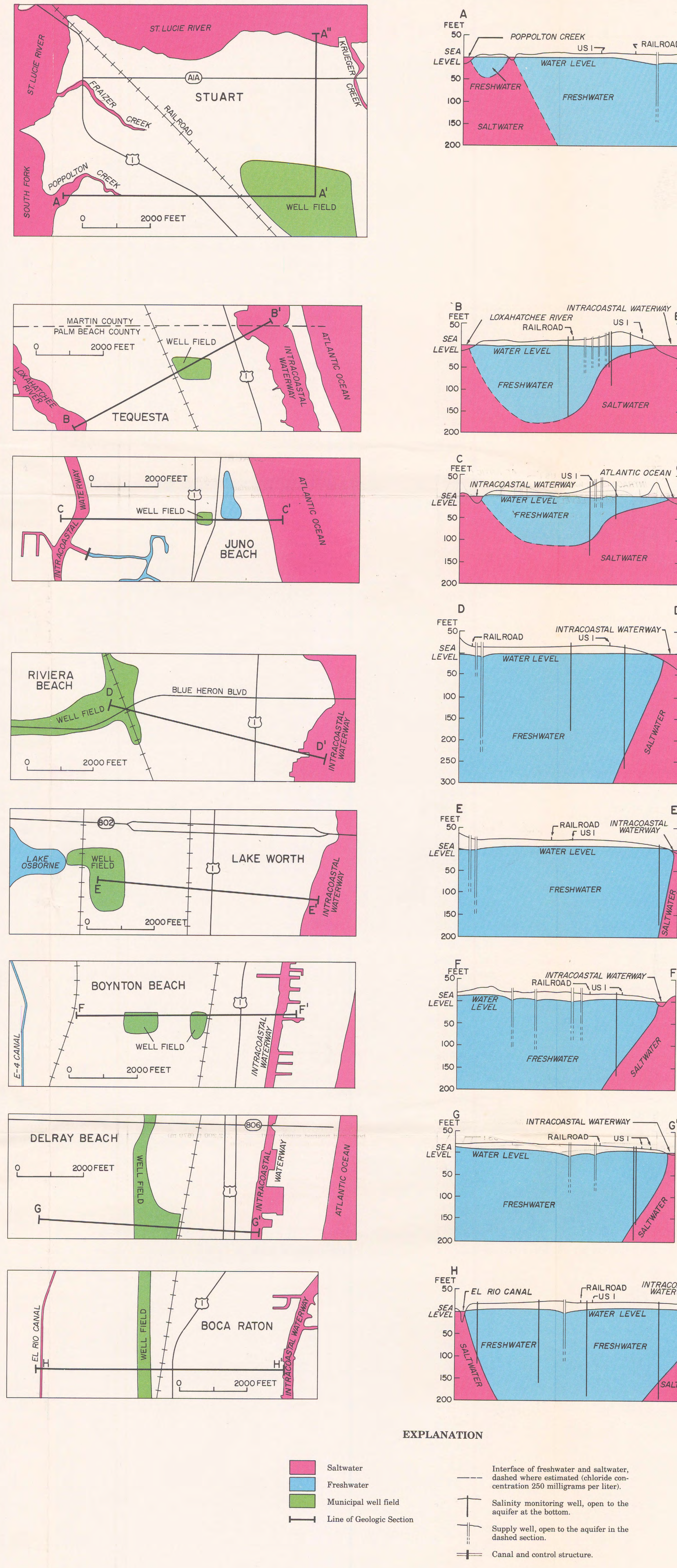


Figure 2. — Ground-water movement along the coast and cyclic flow pattern in the zone of diffusion which separates freshwater and saltwater.



STUART

Distance between saline-surface-water body and nearest supply well .... 3,700 ft (1100 m)
Horizontal distance between interface of freshwater and saltwater and bottom of nearest supply well (estimated) .... 2,700 ft (820 m)
Average depth of supply wells, below mean sea level .... 140 ft (43 m)
Average daily municipal pumpage, in million gallons per day ....1970... not known
1974... 2.3
Population of municipality:
[Apr. 1, 1970 census] 4,820
[July 1, 1973 estimate] 5,960

TEQUESTA

Distance between saline surface-water body and nearest supply well .... 1,400 ft (430 m)
Horizontal distance between interface of freshwater and saltwater and bottom of nearest supply well (estimated) .... 0 ft (0 m)
Average depth of supply wells, below mean sea level .... 40 ft (12 m)
Average daily municipal pumpage, in million gallons per day ....1970... 1.3
1974... 1.9
Population of municipality:
[Apr. 1, 1970 census] 2,642
[July 1, 1973 estimate] 3,798

JUNO BEACH

Distance between saline surface-water body and nearest supply well .... 1,900 ft (580 m)
Horizontal distance between interface of freshwater and saltwater and bottom of nearest supply well (estimated) .... 1,000 ft (305 m)
Average depth of supply wells, below mean sea level .... 35 ft (10 m)
Average daily municipal pumpage, in million gallons per day ....1970... 0.06 (Estimate)
1974... 0.27 (Estimate)
Population of municipality:
[Apr. 1, 1970 census] 747
[July 1, 1973 estimate] 883

RIVIERA BEACH

Distance between saline surface-water body and nearest supply well .... 5,100 ft (1550 m)
Horizontal distance between interface of freshwater and saltwater and bottom of nearest supply well (estimated) .... 4,200 ft (1300 m)
Average depth of supply wells, below mean sea level .... 230 ft (70 m)
Average daily municipal pumpage, in million gallons per day ....1970... 3.7
1974... 5.2
Population of municipality:
[Apr. 1, 1970 census] 21,401
[July 1, 1973 estimate] 25,164

LAKE WORTH

Distance between saline surface-water body and nearest supply well .... 5,800 ft (1800 m)
Horizontal distance between interface of freshwater and saltwater and bottom of nearest supply well (estimated) .... 5,500 ft (1700 m)
Average depth of supply wells, below mean sea level .... 130 ft (40 m)
Average daily municipal pumpage, in million gallons per day ....1970... 4.3
1974... 4.8
Population of municipality:
[Apr. 1, 1970 census] 23,714
[July 1, 1973 estimate] 25,934

BOYNTON BEACH

Distance between saline surface-water body and nearest supply well .... 2,200 ft (670 m)
Horizontal distance between interface of freshwater and saltwater and bottom of nearest supply well (estimated) .... 1,600 ft (490 m)
Average depth of supply wells, below mean sea level .... 90 ft (30 m)
Average daily municipal pumpage, in million gallons per day ....1970... 3.6
1974... 6.6
Population of municipality:
[Apr. 1, 1970 census] 18,115
[July 1, 1973 estimate] 25,507

DELRAY BEACH

Distance between saline surface-water body and nearest supply well .... 2,200 ft (670 m)
Horizontal distance between interface of freshwater and saltwater and bottom of nearest supply well (estimated) .... 1,600 ft (490 m)
Average depth of supply wells, below mean sea level .... 75 ft (23 m)
Average daily municipal pumpage, in million gallons per day ....1970... 5.4
1974... 8.4
Population of municipality:
[Apr. 1, 1970 census] 19,915
[July 1, 1973 estimate] 25,046

BOCA RATON

Distance between saline surface-water body and nearest supply well .... 3,000 ft (900 m)
Horizontal distance between interface of freshwater and saltwater and bottom of nearest supply well (estimated) .... 2,500 ft (760 m)
Average depth of supply wells, below mean sea level .... 100 ft (30 m)
Average daily municipal pumpage, in million gallons per day ....1970... 10.8
1974... 15.6
Population of municipality:
[Apr. 1, 1970 census] 29,538
[July 1, 1973 estimate] 38,874

Figure 3. — Location map and hydrologic sections through selected well fields.

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