HYDROGEOLOGY OF A ZONE OF SECONDARY PERMEABILITY IN THE SURFICIAL AQUIFER OF EASTERN PALM BEACH COUNTY, FLORIDA

By Leo J. Swayze and Wesley L. Miller

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CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square foot (ft^2)	929.0 0.09294	square centimeter (cm^2) square meter (m^2)
square foot per day (ft^2/d)	0.09290	square meter per day (m^2/d)
gallon (gal)	0.003785	cubic meter (m^3)
gallon per minute (gal/min)	$6.308x10^{-5}$	cubic meter per second (m^3/s)
gallon per minute per foot [(gal/min)/ft]	0.0002070	cubic meter per second per meter (m^3/s)/m

HYDROGEOLOGY OF A ZONE OF SECONDARY PERMEABILITY IN THE SURFICIAL AQUIFER OF EASTERN PALM BEACH COUNTY, FLORIDA

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ABSTRACT

The surficial aquifer is the primary source of freshwater for the heavily developed coastal area in eastern Palm Beach County. Well fields are generally located in a discontinuous zone of high secondary permeability in the surficial aquifer that extends from the Juno Beach area south to Broward County and varies in width from about 4 to 15 miles. This zone is the northernmost extension of the Biscayne aquifer. The zone, formed by varying dissolution of aquifer limestone materials during Pleistocene changes in sea level, ranges in depth from about sea level to 220 feet below sea level. Because of proximity to the Atlantic Ocean and saltwater estuaries on the east and diluted residual seawater to the west, the aquifer is susceptible to saltwater intrusion.

The ground water is predominantly a calcium bicarbonate type. Dissolved solids, calcium carbonate hardness, and chloride are greatest along the saltwater-intruded coastline and in the western part of the study area where diluted residual seawater exists. Total organic carbon increases inland because of infiltration of rainwater through thicker layers of organic soils.

Ground-water levels in the surficial aquifer in eastern Palm Beach County are strongly influenced by controlled levels in canals of the South Florida Water Management and the Lake Worth Drainage Districts. In March 1981 after 12 months of below-average rainfall, ground-water levels ranged from about 2 feet above sea level along the coast to nearly 21 feet above sea level, 15 miles inland in the northwest section of the study area.

1.0 INTRODUCTION

1.1 Objective and Existing Publications

STUDY OF A PRIME FRESHWATER SOURCE IN
EASTERN PALM BEACH COUNTY, FLORIDA

A zone of high secondary permeability in the surficial aquifer has been described and delineated. Heavy development in the area mandates better understanding of this reliable freshwater source.

This report, prepared in cooperation with Palm Beach County, describes the geology and hydrology of a zone in the surficial aquifer in eastern Palm Beach County. The areal and vertical extent of the zone, previously described as a "cavity-riddled section (which) offers excellent potential for development of future ground-water supplies" (Rodis and Land, 1976, p. 11) (hereafter referred to as a zone of secondary permeability), is discussed and delineated. This zone is the northern extension of the Biscayne aquifer.

Development of the densely populated coastal area of eastern Palm Beach County is expanding west into undeveloped or agricultural areas. Because of this development, withdrawal of water from the surficial aquifer, the county's main freshwater source, is also increasing. An increasing number of wells for municipal, industrial, and private use are drawing more water from the aquifer. Because of its proximity to the Atlantic Ocean and saltwater estuaries and to diluted residual seawater in the western parts of the county, the aquifer is susceptible to saltwater intrusion. This has mandated the need for a better understanding of the zone of secondary permeability in the surficial aquifer.

This zone has been characterized as a calcareous sandstone or limestone with numerous solution cavities (Scott, 1977, p. 7) and has frequently been identified in the vicinity of Florida's Turnpike. Near Riviera Beach, this zone, locally called the "Turnpike aquifer," was determined to have a transmissivity of 11,000 ft^2/d (Fischer, 1980, p. 26).

The selected bibliography on the facing page lists published reports pertaining to various aspects of the surficial aquifer and hydrologic system in Palm Beach County. The reports vary in areal coverage from local site specific to regional water-resources investigations.

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1.0 INTRODUCTION

1.1 Objective and Existing Publications

1.2.1 Geologic, Water-Quality, and Water-Level Data Collection

HYDROLOGIC AND GEOLOGIC DATA COLLECTED AT 95 WELLS IN EASTERN PALM BEACH COUNTY

Geologic, water-quality, and water-level data were used to describe the zone of secondary permeability.

Data were collected at 95 wells penetrating the surficial aquifer in eastern Palm Beach County during this investigation to delineate the zone of secondary permeability. Of this total, 56 were existing wells, and 39 were new wells drilled specifically to collect hydrologic and geologic data. The wells range in depth from 11 to 520 feet below land surface. The types of data collected at selected wells included geology, water quality, and water levels.

Geologic data collected at 68 wells included lithologic logs, driller's logs, and geophysical logs (spontaneous potential, resistivity, neutron, and gamma-ray) (Swayze and others, 1981). These data were interpreted and correlated to determine the aquifer geology and to estimate the areal and vertical extent of the zone of secondary permeability in the surficial aquifer.

Point ground-water samples were collected from 39 wells penetrating the aquifer to depths ranging from 40 to 252 feet below land surface. These samples were analyzed for selected parameters and used to evaluate the vertical and spatial distribution of water-quality types in the surficial aquifer.

Water levels were measured in 30 wells which range in depth from 11 to 279 feet below land surface. Continuous water-level recorders were installed in 13 wells.

Figure 1.2.1-1 shows the study area, locations of all wells used for data collection, and the local well numbers. A complete tabulation of water-quality, water-level, and well-construction data at these wells is available from the National Water Data Storage and Retrieval System (WATSTORE). For information about WATSTORE, see section 5.0 of this report.

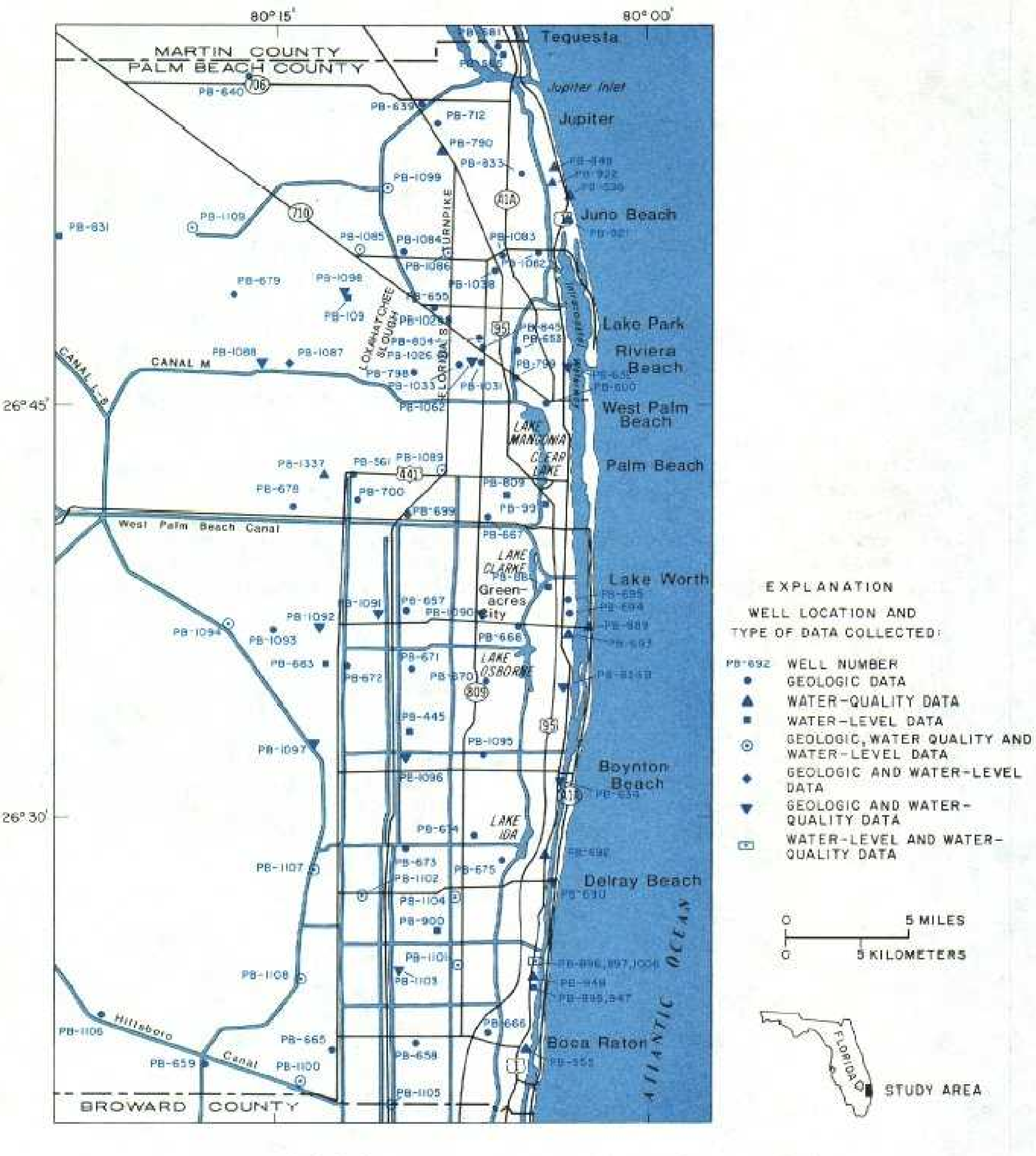

Figure 1.2.1-1.--Locations of wells and types of data collected in eastern Palm Beach County.

1.0 INTRODUCTION--Continued

1.2 Approach

1.2.1 Geologic, Water-Quality, and Water-Level Data Collection

1.0 INTRODUCTION--Continued

1.3 Land Use

1.3.1 Existing and Planned Land Use

LAND USE INFLUENCES FRESHWATER NEEDS IN PALM BEACH COUNTY, FLORIDA

Continued growth in Palm Beach County will result in the need for further development of freshwater resources. The surficial aquifer is the only fresh ground-water source being developed.

Land use and development in eastern Palm Beach County will greatly influence location and development of additional freshwater sources. The densely populated and developed section of Palm Beach County, originally limited to a narrow urbanized coastal band, is steadily expanding west into formerly undeveloped and agricultural areas. Development of the county's main freshwater source, the surficial aquifer, is also expanding to the west from the coastal area. Increasing numbers of municipal well fields, industries, and private wells are drawing water from the aquifer.

Figure 1.3.1-1 shows existing incorporated municipal areas, major well fields, and the generalized land-use areas designated for eastern Palm Beach County. Present land-use guidelines are part of the 1980 Comprehensive Plan for Palm Beach County.

Figure 1.3.1-2 shows generalized land use for the same area in 1970. A comparison of the two figures reveals the appreciable growth rate and the increase in municipal well-field pumpage required to supply this increased growth.

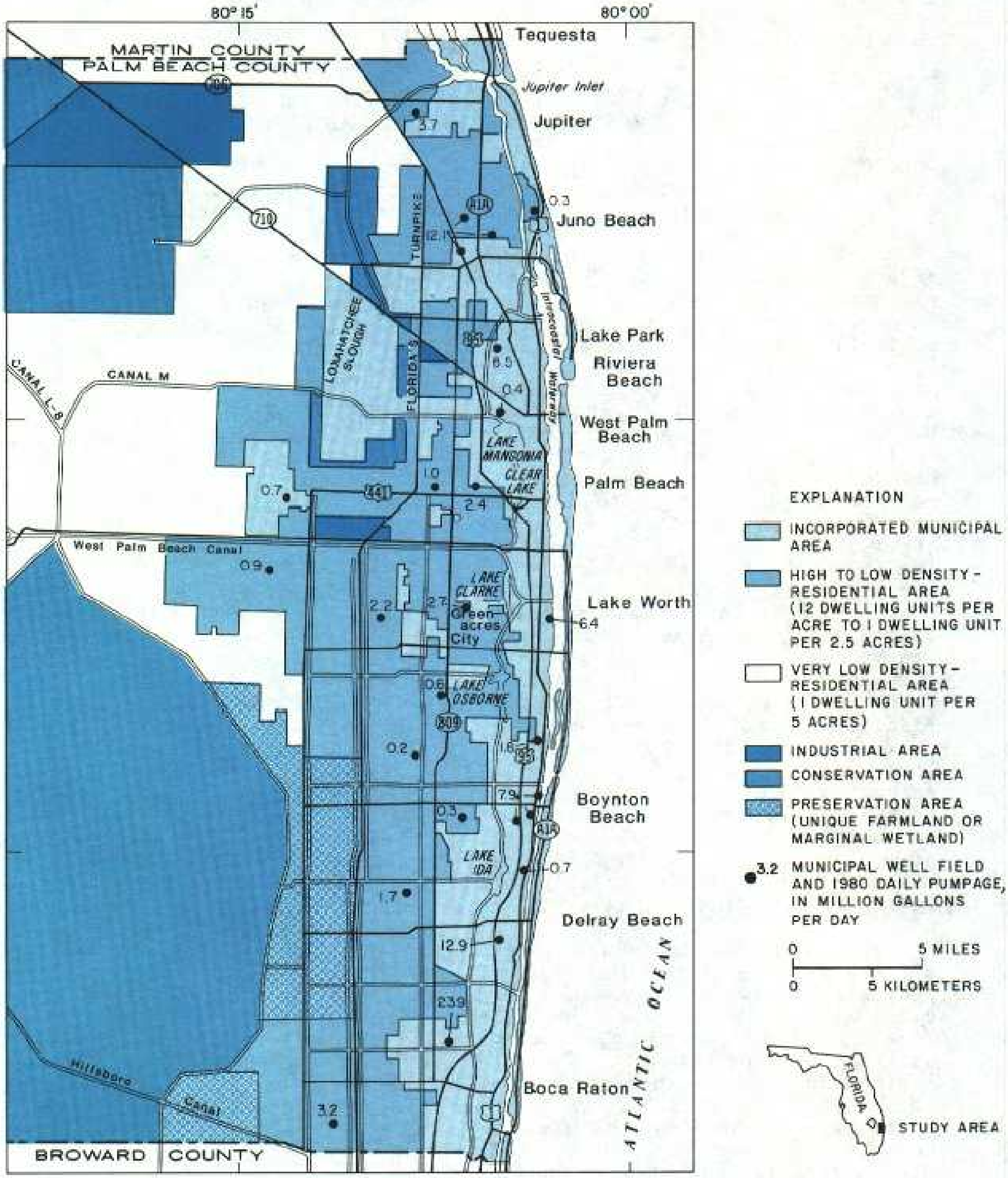

Figure 1.3.1-1.--Generalized land-use areas, municipal areas, and major well fields in eastern Palm Beach County, 1980.

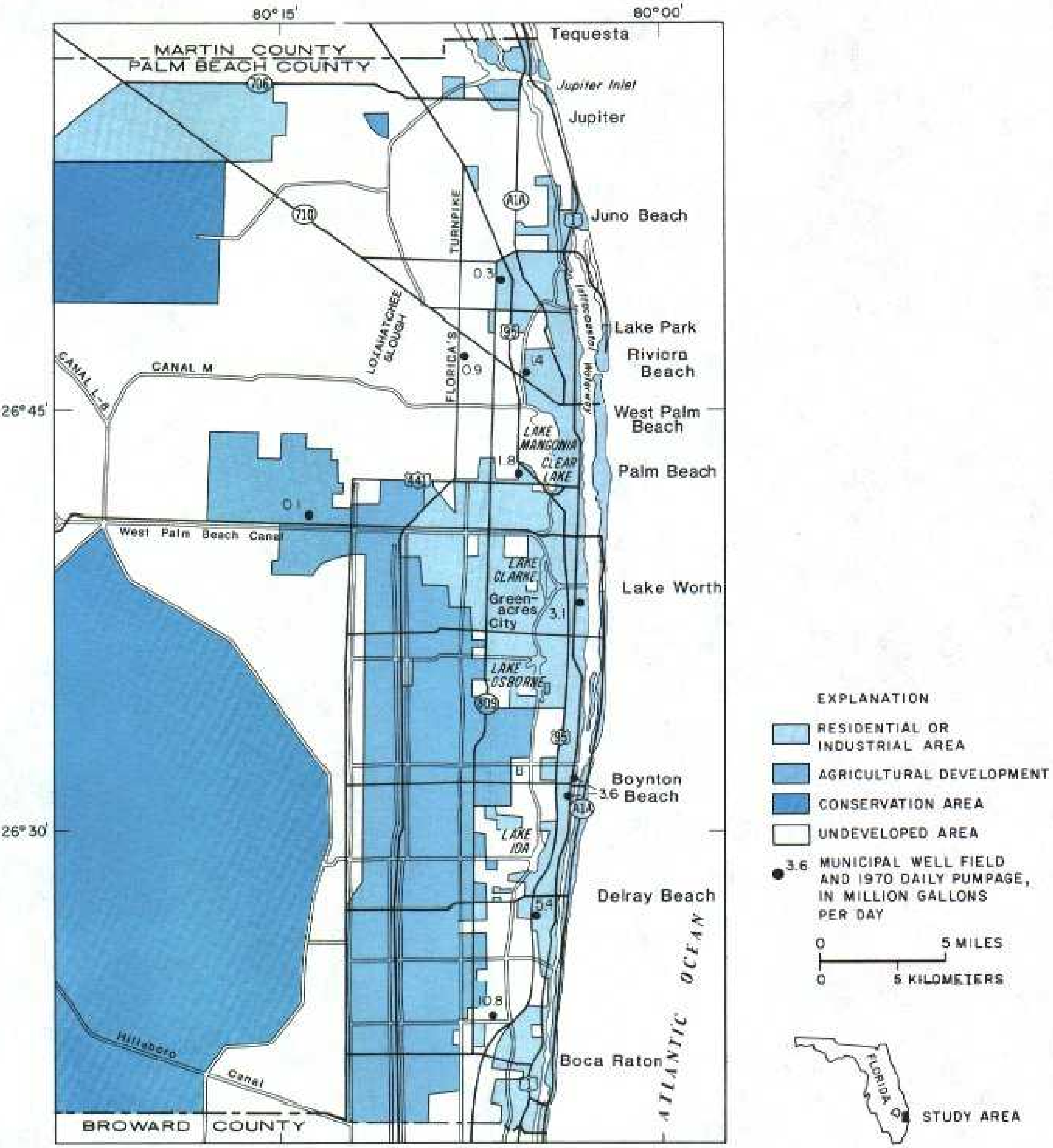

Figure 1.3.1-2.--Generalized land-use areas, municipal areas, and major well fields in eastern Palm Beach County, 1970.

2.0 GEOLOGY

2.1 Delineation of a Zone of Secondary Permeability

PRESENCE OF SOLUTION CAVITIES DELIMITS ZONE OF SECONDARY PERMEABILITY

A zone of secondary permeability in the surficial aquifer was produced by dissolution of cementing materials.

A discontinuous zone of secondary permeability, which is the northernmost extension of the Biscayne aquifer, exists in much of the surficial aquifer in eastern Palm Beach County. A geohydrologic description of the Biscayne aquifer can be found in Parker and others (1955). The increased permeability in this zone of the aquifer is due to post-depositional dissolution of calcareous materials in the Anastasia Formation of Pleistocene age (Parker and others, 1955, p. 100). The materials removed appear to have been calcitic cementing agents that bound together the calcareous quartz sandstones, coquinas, and sandy limestones (Fischer, 1980, p. 17). Dissolution of cementing materials produces the characteristic "cavity-riddled" lithology and secondary permeability. Many of the lithologic units extend beyond the areal extent of the zone, differing only in the absence of cavities (or lower secondary permeability). The amount of secondary permeability development in the zone varies greatly both vertically and horizontally.

The zone of secondary permeability was identified in 49 of 68 geologic test wells in eastern Palm Beach County. The presence of solution cavities was indicated during drilling by frequent loss of circulating fluid or 3- to 5-inch drops of the rotating drill bit. Drilling cuttings from the zone commonly contained subrounded particles, calcite crystals, and large amounts of loose, fine-grained, quartz sand that are further indications of partially filled cavities.

Figure 2.1-1 delineates the approximate areal extent of the zone of secondary permeability. Also shown are the locations and well numbers of the 68 selected geologic test wells (49 in the zone) and lithologic section lines used to delineate the zone.

The zone of secondary permeability lies below sea level, and the thickness is variable as indicated by the following top and bottom altitudes.

Well No.	Depth interval (in feet below sea level)	Well No.	Depth interval (in feet below sea level)
PB-1108	47-97	PB-1082	28-136
-1107	54-102	-1062	34-95*
-1105	65-185	-1038	79-97
-1104	35-220	-1033	37-112*
-1103	65-199	-1031	48-113*
-1102	74-197	-1029	27-111*
-1101	36-201	-1026	37-97
-1100	53-165	-834B	12-172*
-1099	17-116	-845	68-72*
-1098	20-140	-798	27-102
-1097	64-104	-699	75-105
-1096	65-172	-694	23-92
-1095	23-143	-690	10-119
-1094	1-122	-679	58-68
-1093	23-102	-675	86-176
-1092	37-100	-674	61-183
-1091	38-123	-673	71-156
-1090	56-132	-672	58-143*
-1089	25-165	-671	67-101
-1087	30-152	-670	70-205
-1086	29-118	-668	27-33
-1085	22-147	-658	66-201
-1084	28-138	-657	62-117
-1083	85-180	-655	26-132
		-654	32-134

*Well did not completely penetrate the zone of secondary permeability.

The degree of permeability is also variable within the zone. Solution cavities are most likely to be found 50 to 70 feet below sea level and are common between 45 and 110 feet below sea level (fig. 2.1-2).

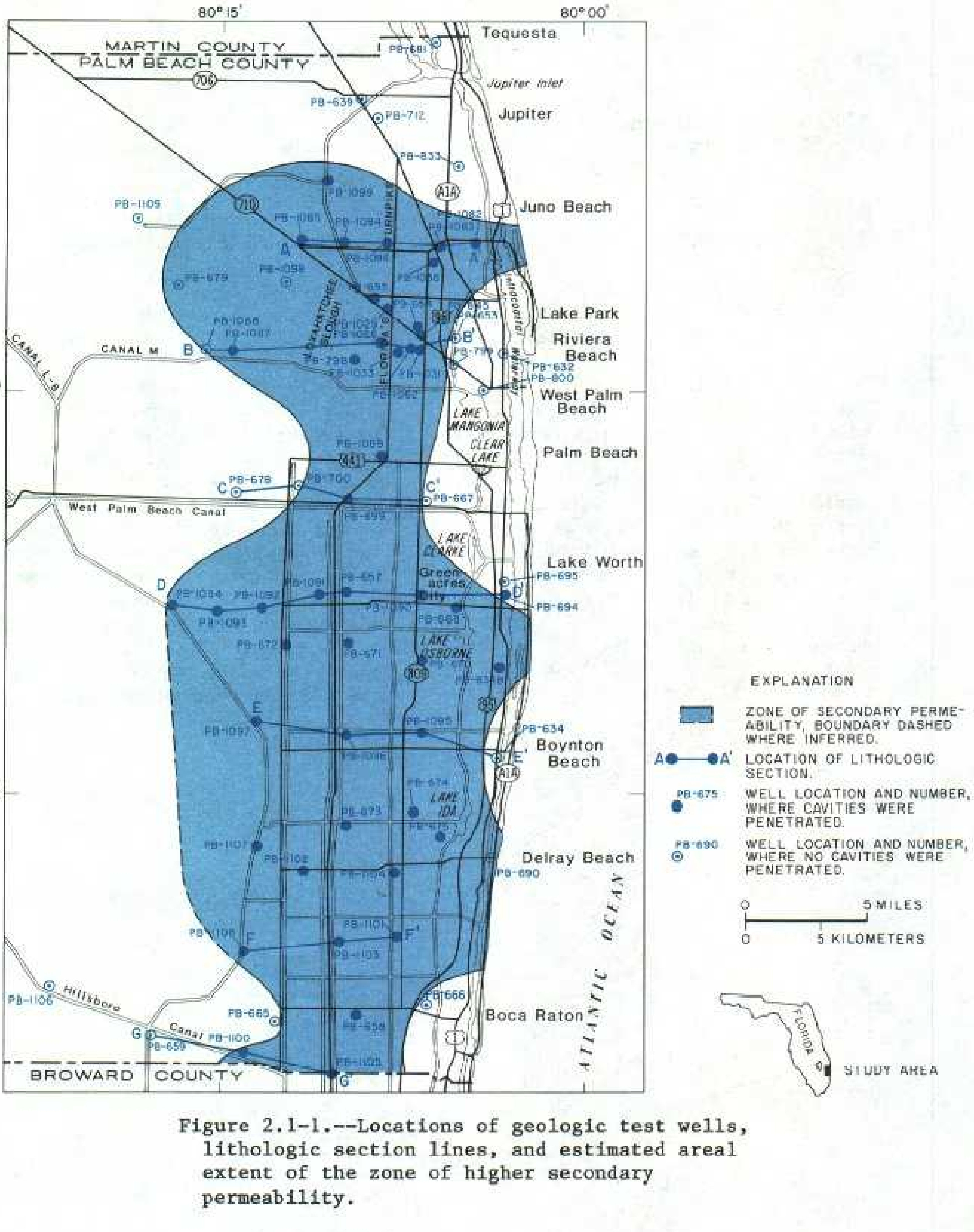

Figure 2.1-1.--Locations of geologic test wells, lithologic section lines, and estimated areal extent of the zone of higher secondary permeability.

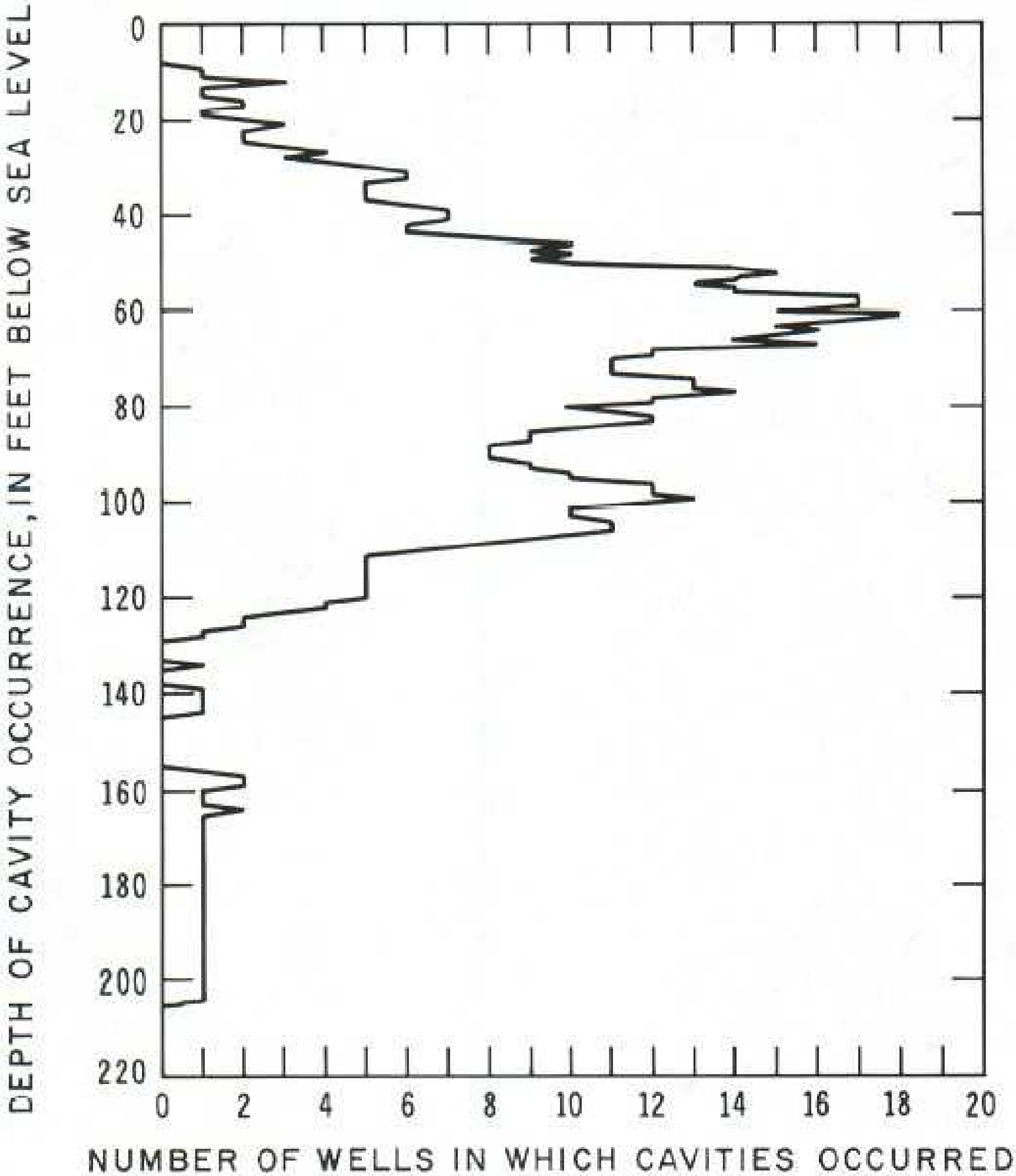

Figure 2.1-2.--Number of wells in which cavities occurred with respect to depth.

LITHOLOGIC SECTIONS THROUGH THE ZONE OF SECONDARY PERMEABILITY

The zone of secondary permeability in the surficial aquifer was formed as a result of sea-level variations during the Pleistocene Epoch.

The materials that form the surficial aquifer in eastern Palm Beach County were deposited in a variety of environments ranging from beach and lagoonal to shallow marine. The axes of the lithologic units generally trend north-south, paralleling the present shoreline. The stratigraphy and lithology represent depositional and erosional cycles due to sea-level changes during Pleistocene time.

Lithologic sections A-A' to G-G', shown in figures 2.1.1-1 to 2.1.1-7 (see figure 2.1-1 for section locations), indicate the extreme variability of the depth and thickness of the zone of secondary permeability. Changes in sea level and corresponding changes in ground-water levels, combined with variable susceptibility to dissolution of the aquifer materials, created the cavity-riddled characteristics which resulted in the secondary permeability.

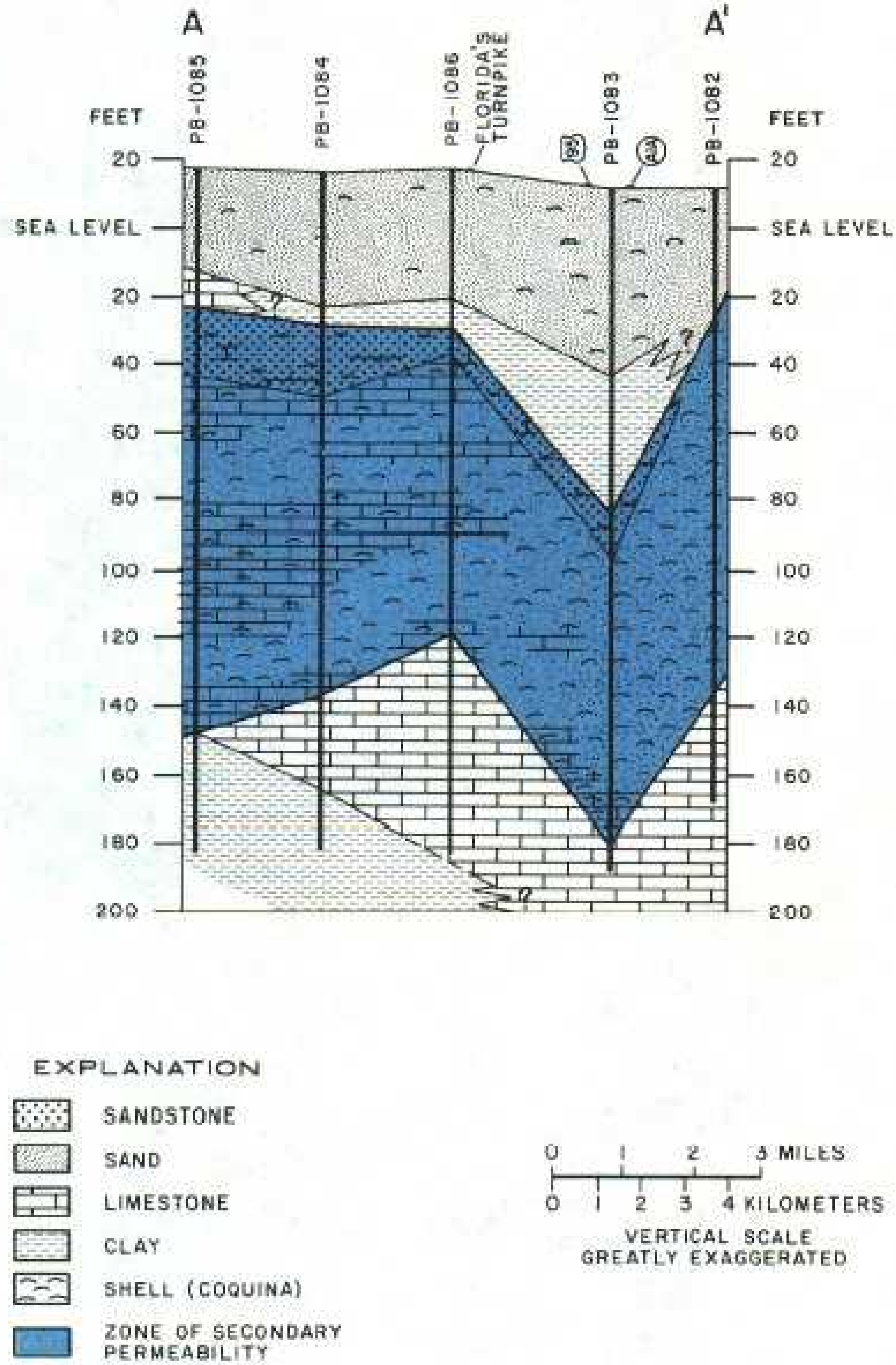

Figure 2.1.1-1.--Lithologic section A-A'.

2.0 GEOLOGY--Continued

2.1 Delineation of a Zone of Secondary Permeability--Continued

2.1.1 Lithology

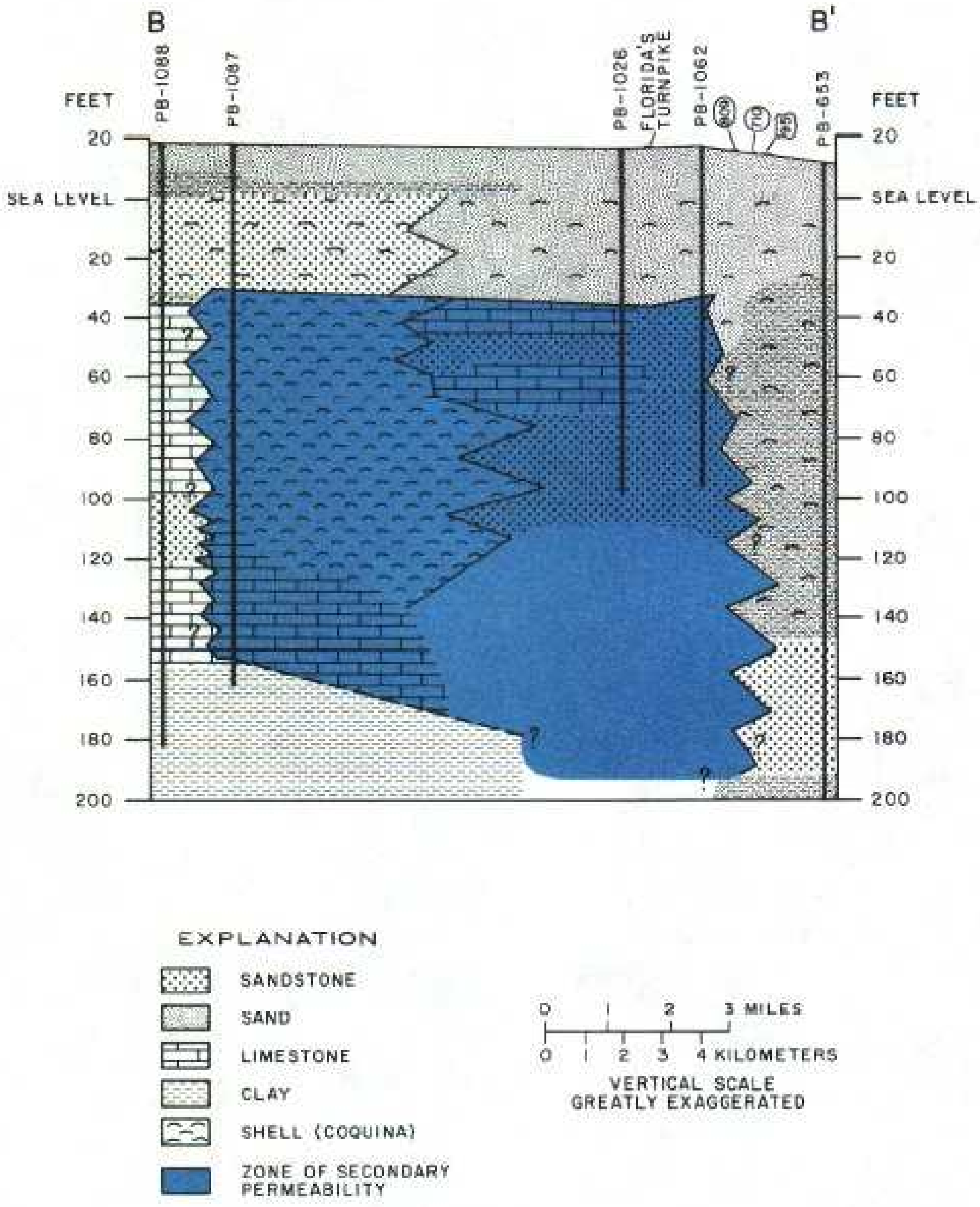

Figure 2.1.1-2.--Lithologic section B-B'.

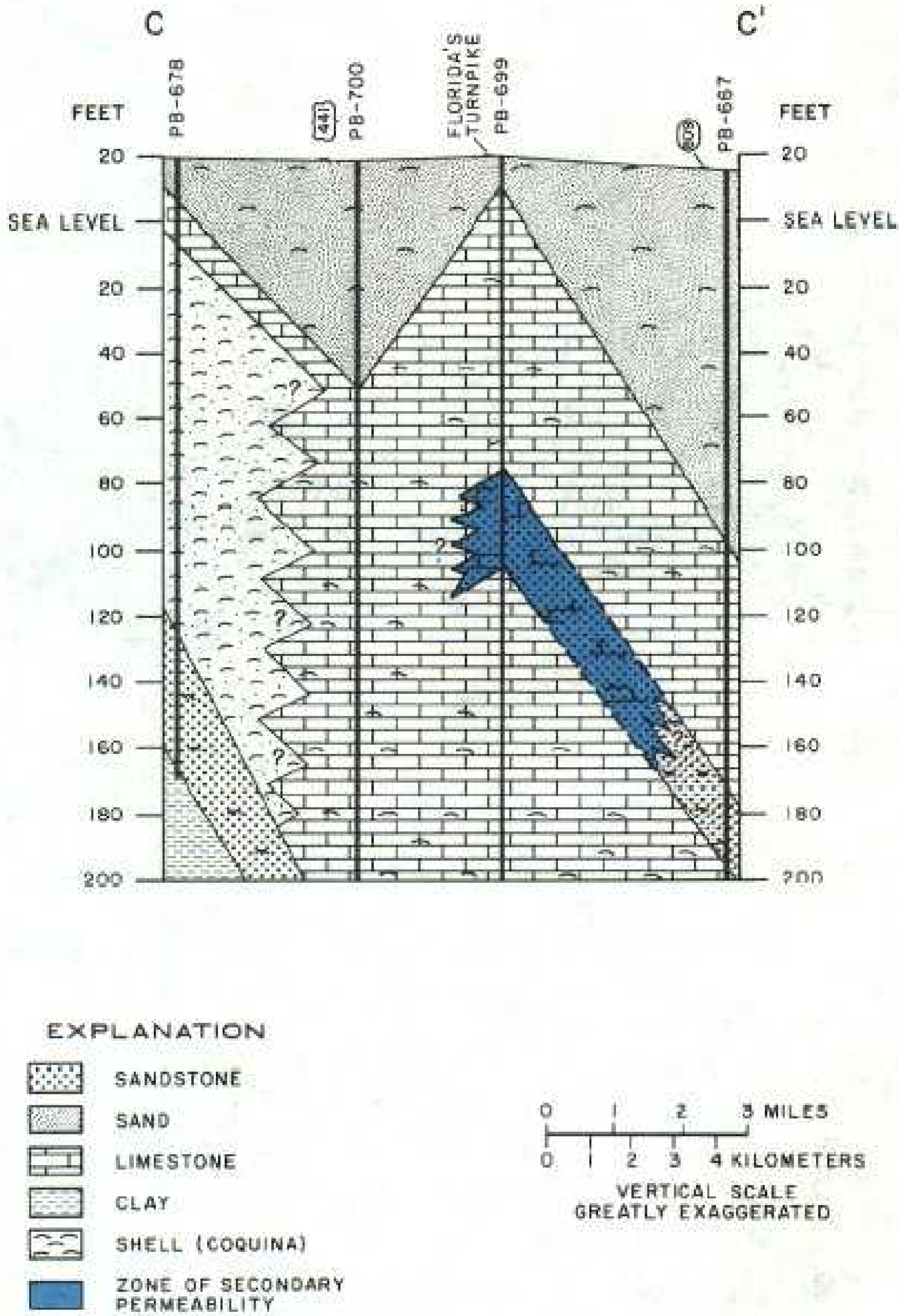

Figure 2.1.1-3.--Lithologic section C-C'.

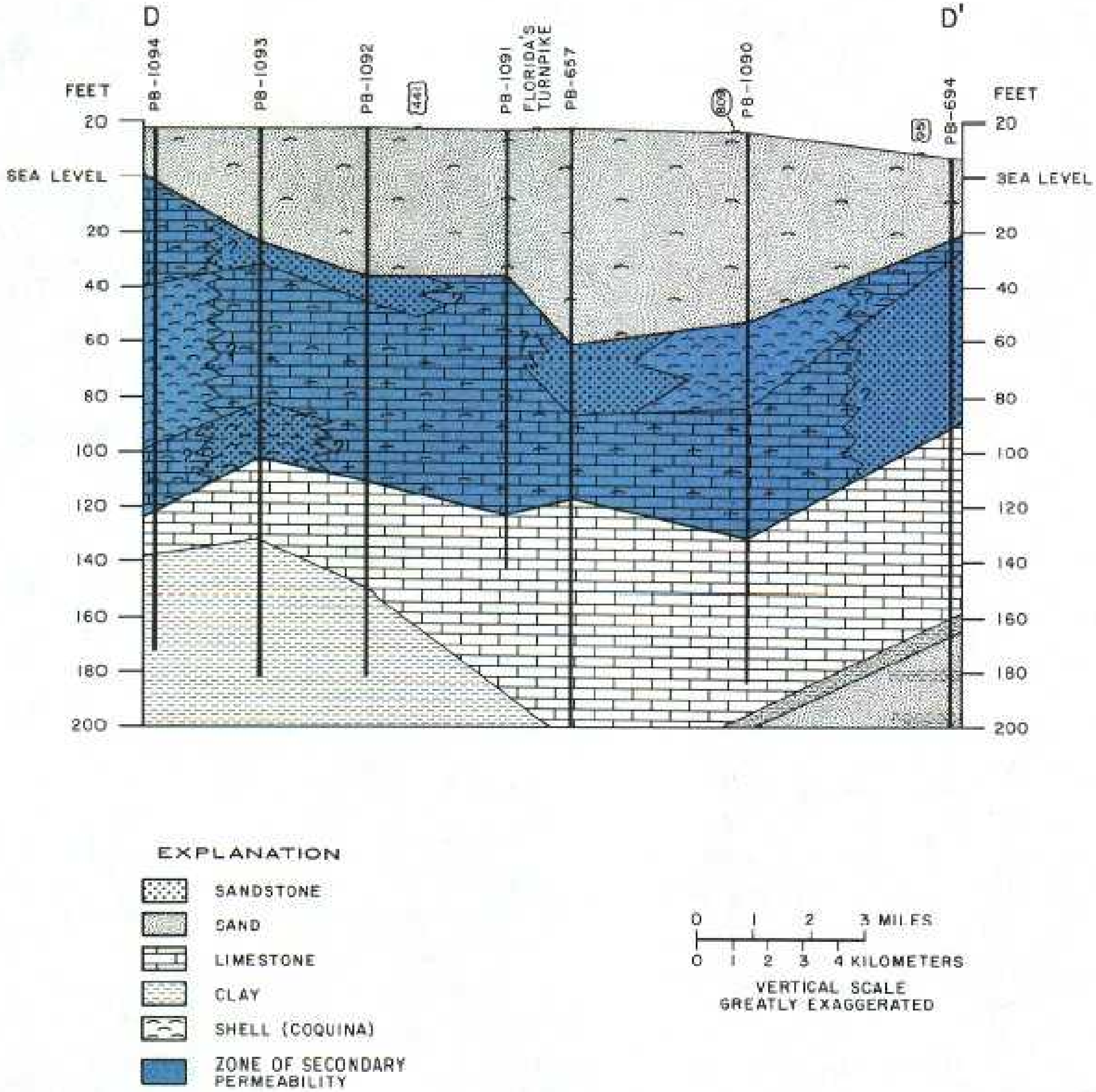

Figure 2.1.1-4.--Lithologic section D-D'.

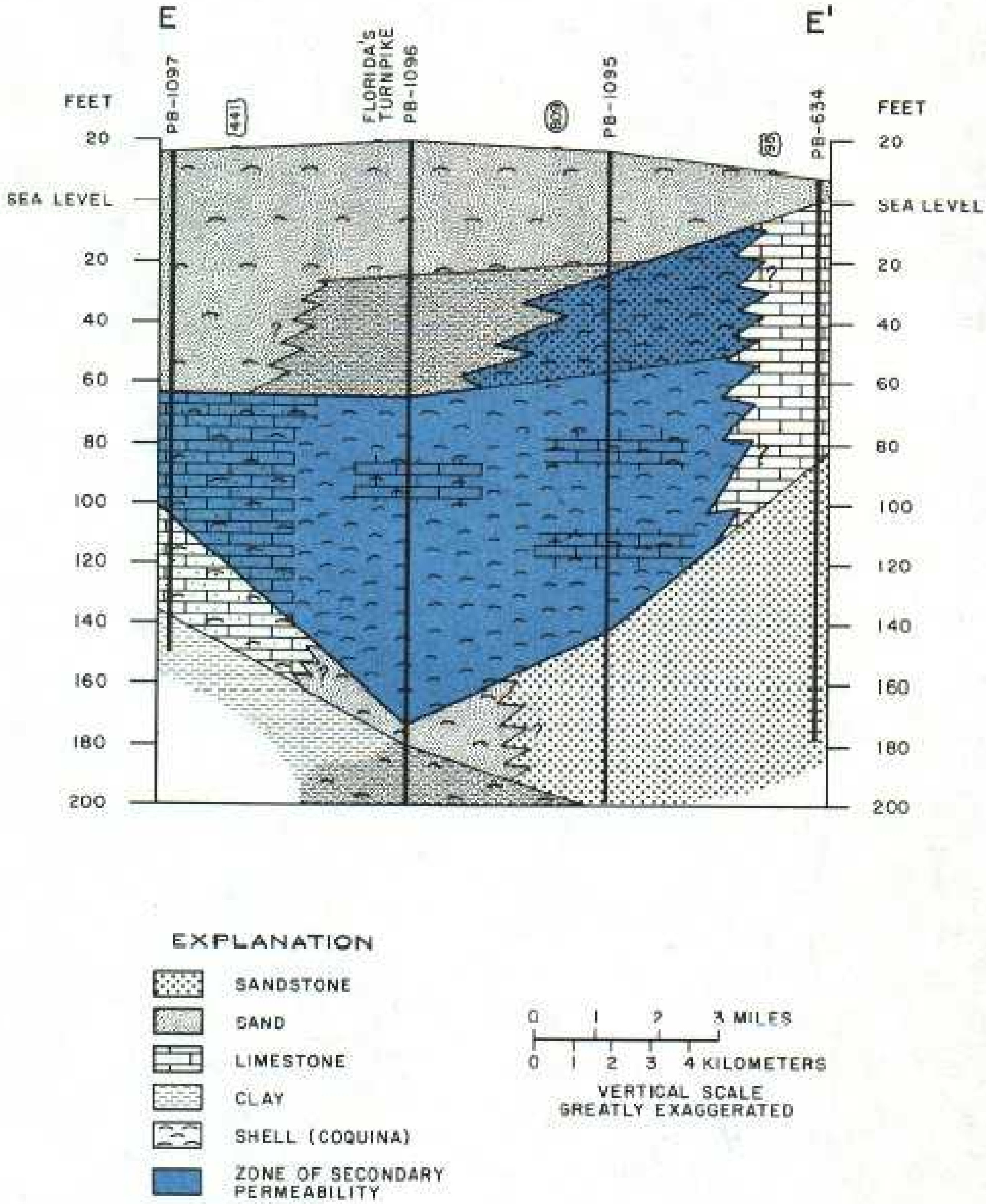

Figure 2.1.1-5.--Lithologic section E-E'.

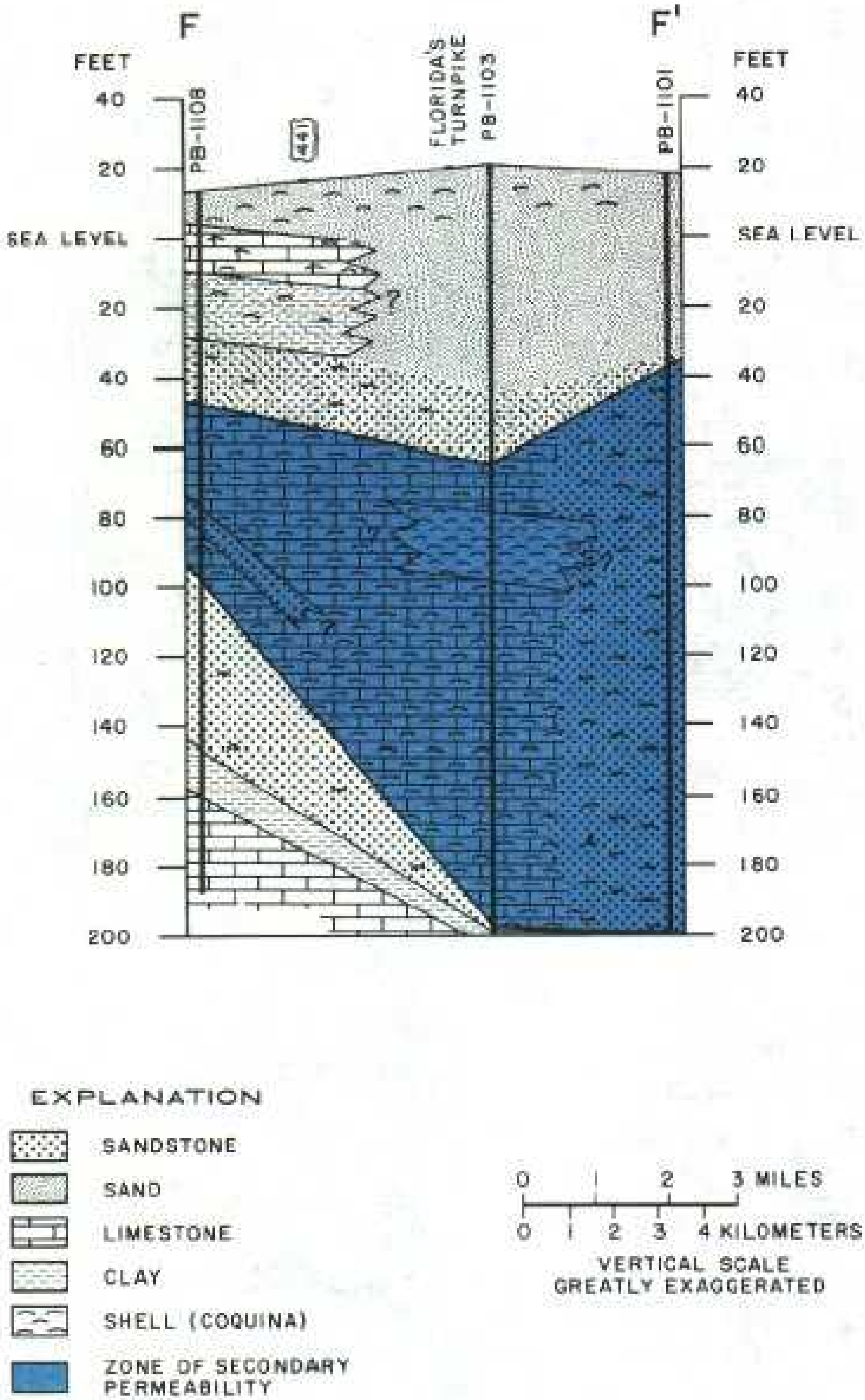

Figure 2.1.1-6.--Lithologic section F-F'.

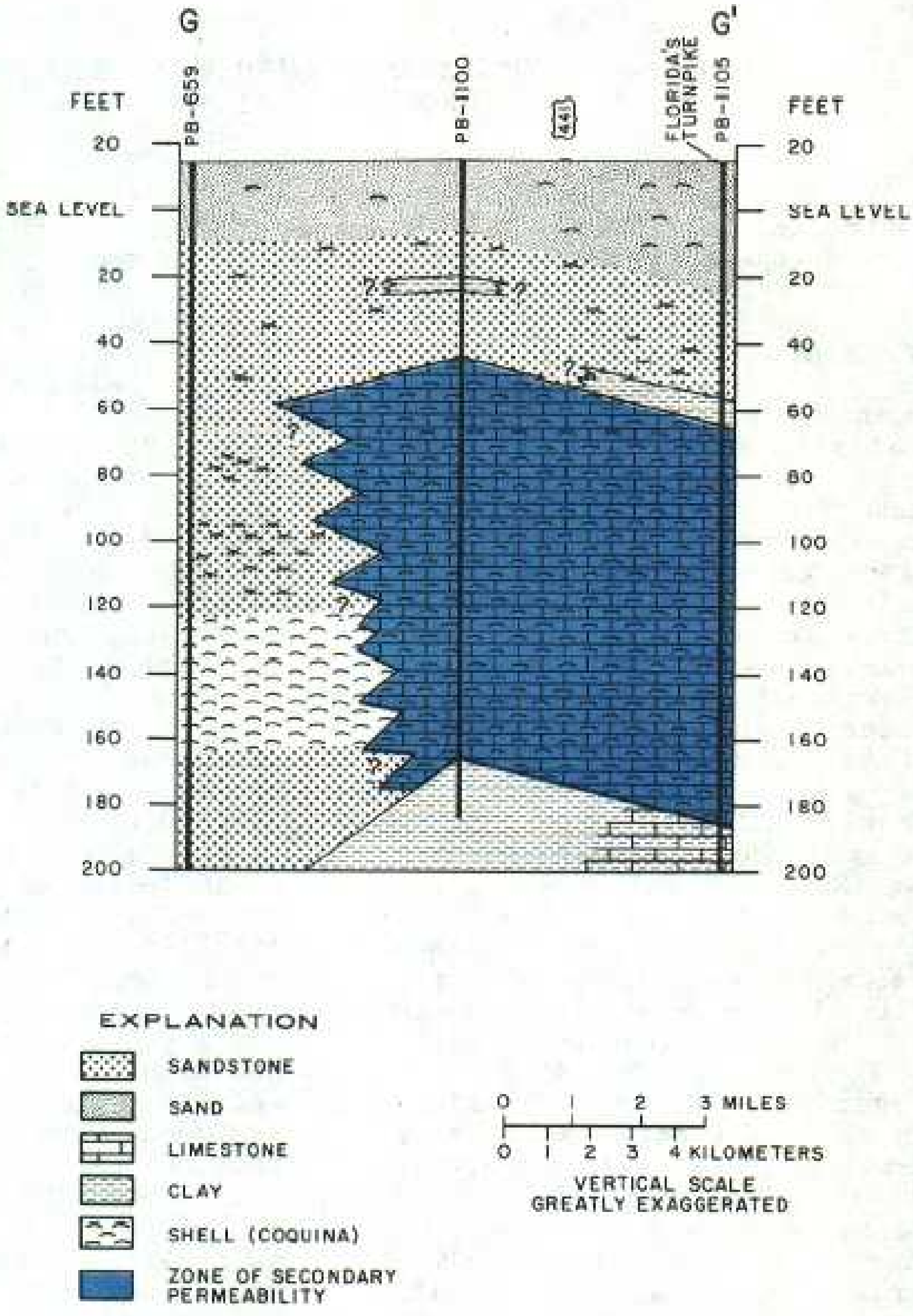

Figure 2.1.1-7.--Lithologic section G-G'.

3.0 HYDROLOGY

3.1 Water Levels

GROUND-WATER LEVELS IN EASTERN PALM BEACH COUNTY ARE CONTROLLED BY MAN

Ground-water levels in the surficial aquifer are influenced by controlled levels in canals of the South Florida Water Management and Lake Worth Drainage Districts. Recharge of the aquifer occurs by infiltration from these canals and from rainfall.

Recharge of the surficial aquifer in eastern Palm Beach County occurs by infiltration from canals and rainfall. Surface water is pumped east from the L-40 Canal and north from the Hillsboro Canal through a network of lateral and equalizing canals. Surface water is also conveyed east in Canals L-8 and M to augment water in the West Palm Beach water-catchment area which replenishes municipal surface-water supplies for West Palm Beach (fig. 3.1-1).

Yearly rainfall measured at the West Palm Beach Airport weather station (NOAA) averaged 60.07 inches between 1950 and 1980 and ranged from 37.31 to 79.75 inches (fig. 3.1-2). Comparison of daily rainfall at the West Palm Beach Airport and water levels in wells PB-99, PB-809, and PB-445 during water year 1980 (fig. 3.1-3) illustrates the different responses of ground-water level to rainfall. Well PB-99 is a shallow well (18 feet below land surface) in an area of water levels partly controlled by canals. Responses to rainfall are rapid, and the hydrograph shows seasonal water-level trends. Well PB-809, a deep well (145 feet below land surface) near well PB-99, exhibits extreme variations in water levels. These variations are due to pumpage from a nearby well field. Responses to rainfall are slower due to the time required for leakage of water through discontinuous semiconfining layers of sandy clays at shallower depths. The hydrograph also shows seasonal water-level trends. Well PB-445 is a shallow well (11.4 feet below land surface) in an area highly controlled by canals. Responses to rainfall are dampened, and very slight seasonal trends are noted.

Dry-season water levels for eastern Palm Beach County, measured on March 18-23, 1981, ranged from about 2 to almost 21 feet above sea level (fig. 3.1-1). During the previous 12 months, rainfall was about 18 percent (10.8 inches) below the long-term average. The water level in Conservation Area no. 1 was about 13.6 feet, nearly 2 feet below normal.

Ground water flows from areas of high-water levels towards areas of low-water levels in a direction perpendicular to water-level contours. A ground-water divide is a ridge in the water level from which ground water moves away in both directions. In the southern half of eastern Palm Beach County, a ground-water divide runs approximately parallel to the Florida Turnpike. Ground water flows both east and west from this line. Eastward flow is eventually discharged to the ocean or may be intercepted by canals with lower water levels. Westward flow is eventually discharged to canals bordering Conservation Area no. 1. The ground-water divide is transitory; its position can be changed by manipulating water levels in canals of the Lake Worth Drainage District.

Construction of major canals, such as the West Palm Beach and Hillsboro Canals, have altered regional ground-water flow directions considerably. Flow directions have generally changed from west to east to north and south directions in areas neighboring these canals (fig. 3.1-1). Major points of ground-water discharge are the Loxahatchee River estuary, Intracoastal Waterway, Atlantic Ocean, West Palm Beach Canal, and Hillsboro Canal.

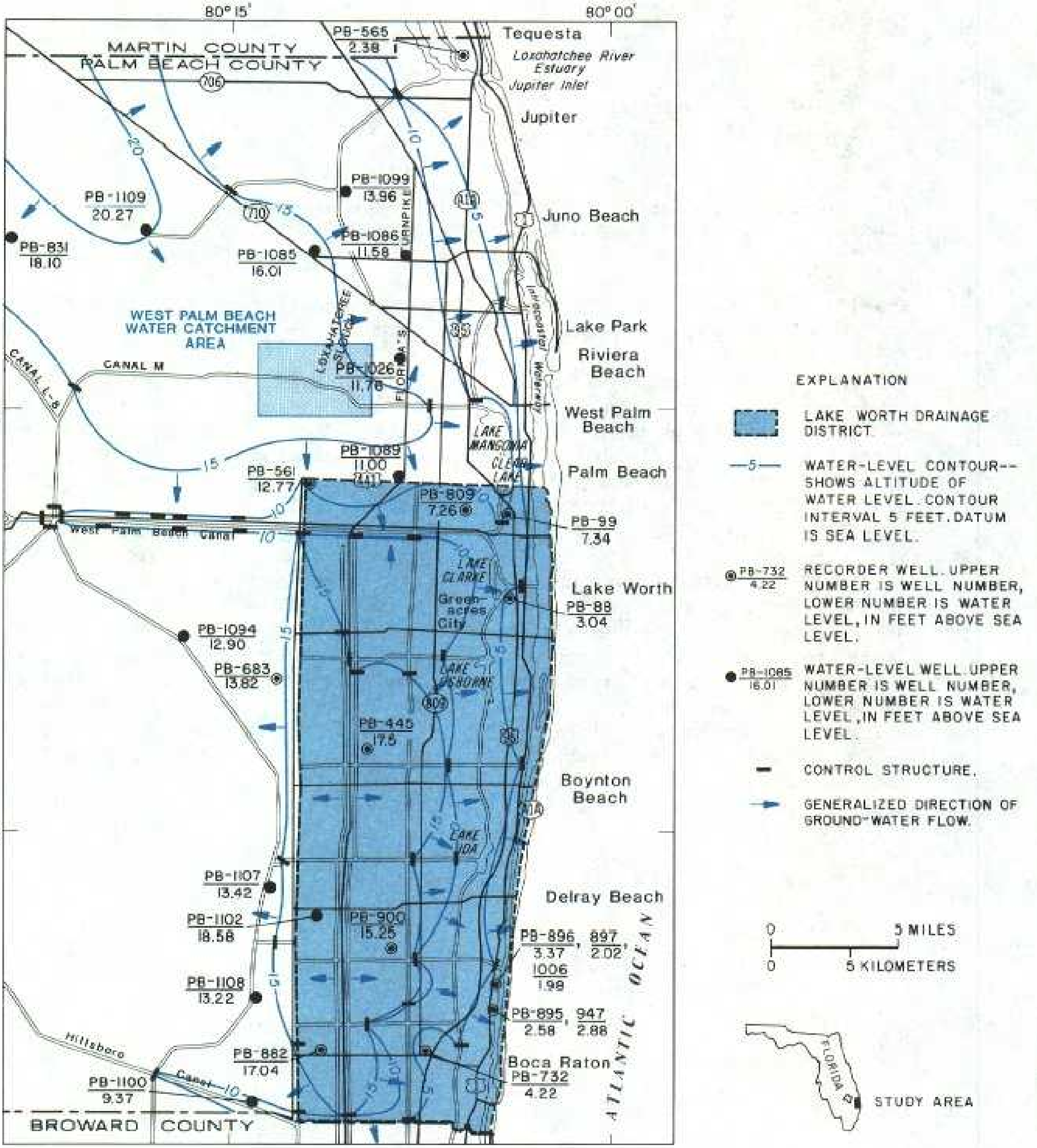

Figure 3.1-1.--Water-level contours and generalized direction of ground-water flow (surficial aquifer), eastern Palm Beach County (March 18-23, 1981).

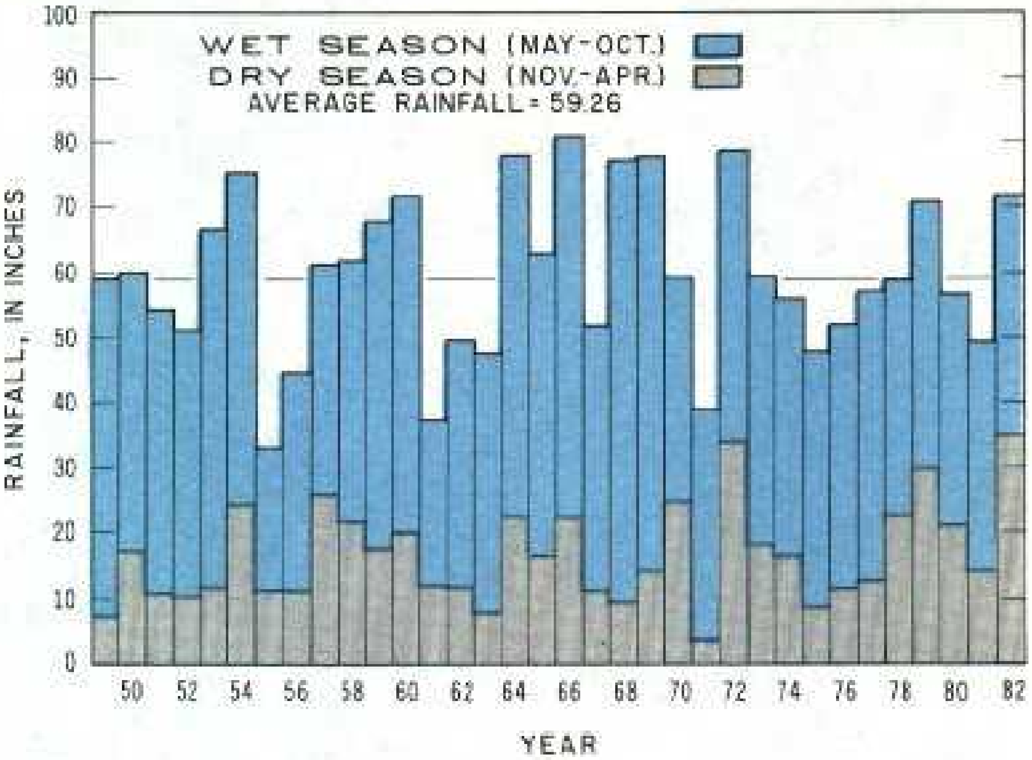

Figure 3.1-2.--Total annual rainfall, November through October 1949-82, West Palm Beach Airport (NOAA).

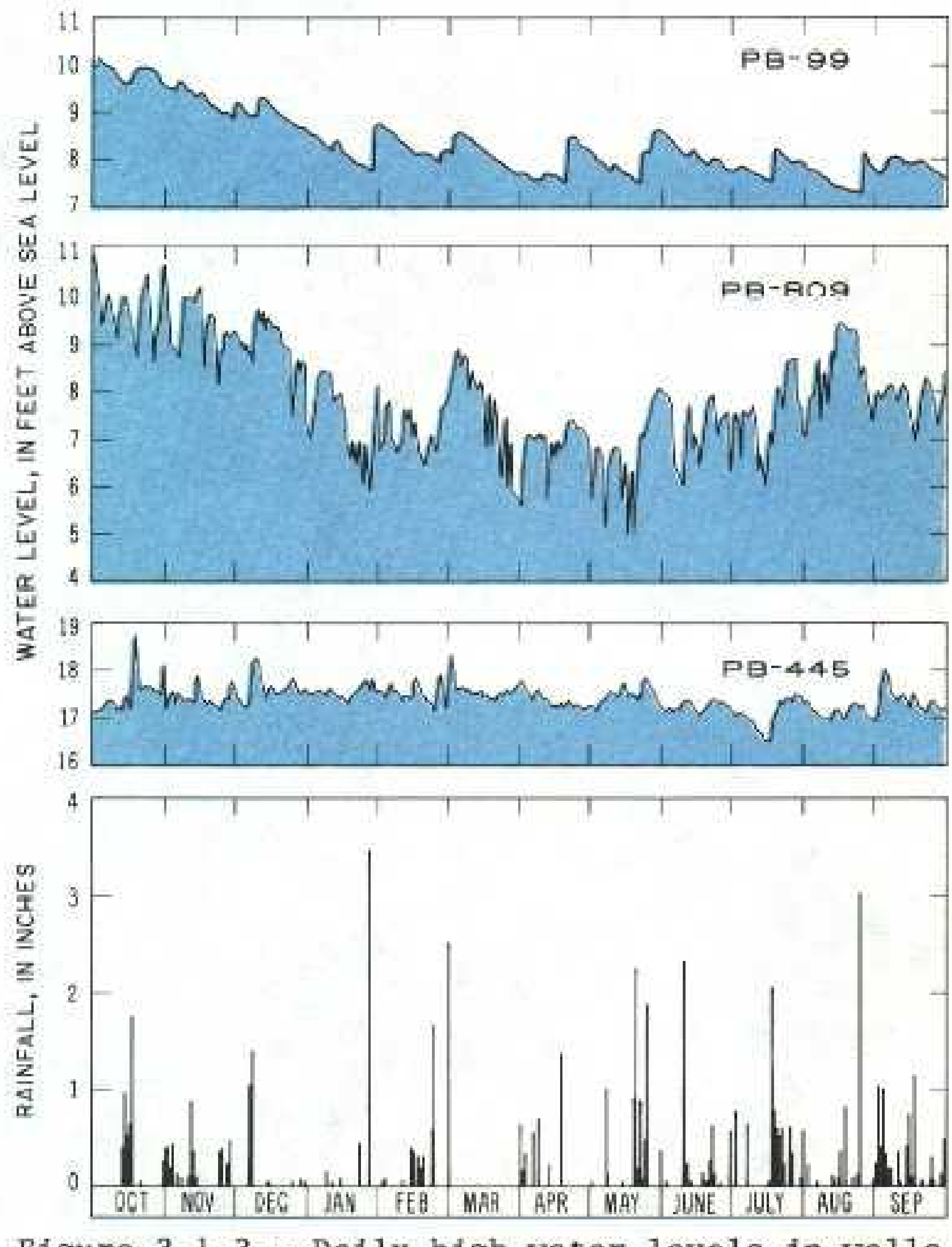

Figure 3.1-3.--Daily high water levels in wells PB-99, PB-809, and PB-445 for water year 1980 (surfical aquifer), eastern Palm Beach County, and total daily rainfall, West Palm Beach Airport.

SPECIFIC CAPACITY (PRODUCTIVITY) VALUES IN THE SURFICIAL AQUIFER VARY GREATLY BOTH LOCALLY AND REGIONALLY

Specific capacity (productivity) within the zone of secondary permeability can be as much as twice that elsewhere in the surficial aquifer.

The productivity of a well is often expressed in terms of the specific capacity, which is defined as the pumping rate divided by the associated drawdown of water levels in a well (Freeze and Cherry, 1979, p. 313). Table 3.2-1 lists the site location number (fig. 3.2-1) site ID, local number, top and bottom of the producing zone, discharge, drawdown, and specific capacity for wells in eastern Palm Beach County. Figure 3.2-1 shows the maximum measured specific capacity of wells in well fields in the surficial aquifer and their spatial relation to the zone of secondary permeability.

Specific capacity values can be used to estimate values of transmissivity for an aquifer (U.S. Bureau of Reclamation, 1977, p. 161). Specific capacity values ranged from 7 to 467 (gal/min)/ft in the surficial aquifer. These values indicate approximate transmissivities of 1,000 ft^2/d and 100,000 ft^2/d, respectively. Sites 11, 12, and 19 (fig. 3.2-1), located centrally along the axis of the zone of secondary permeability, exhibit specific capacities that are at least twice as great as sites lying outside or on the flanks of the zone, except for site 3 near Boca Raton.

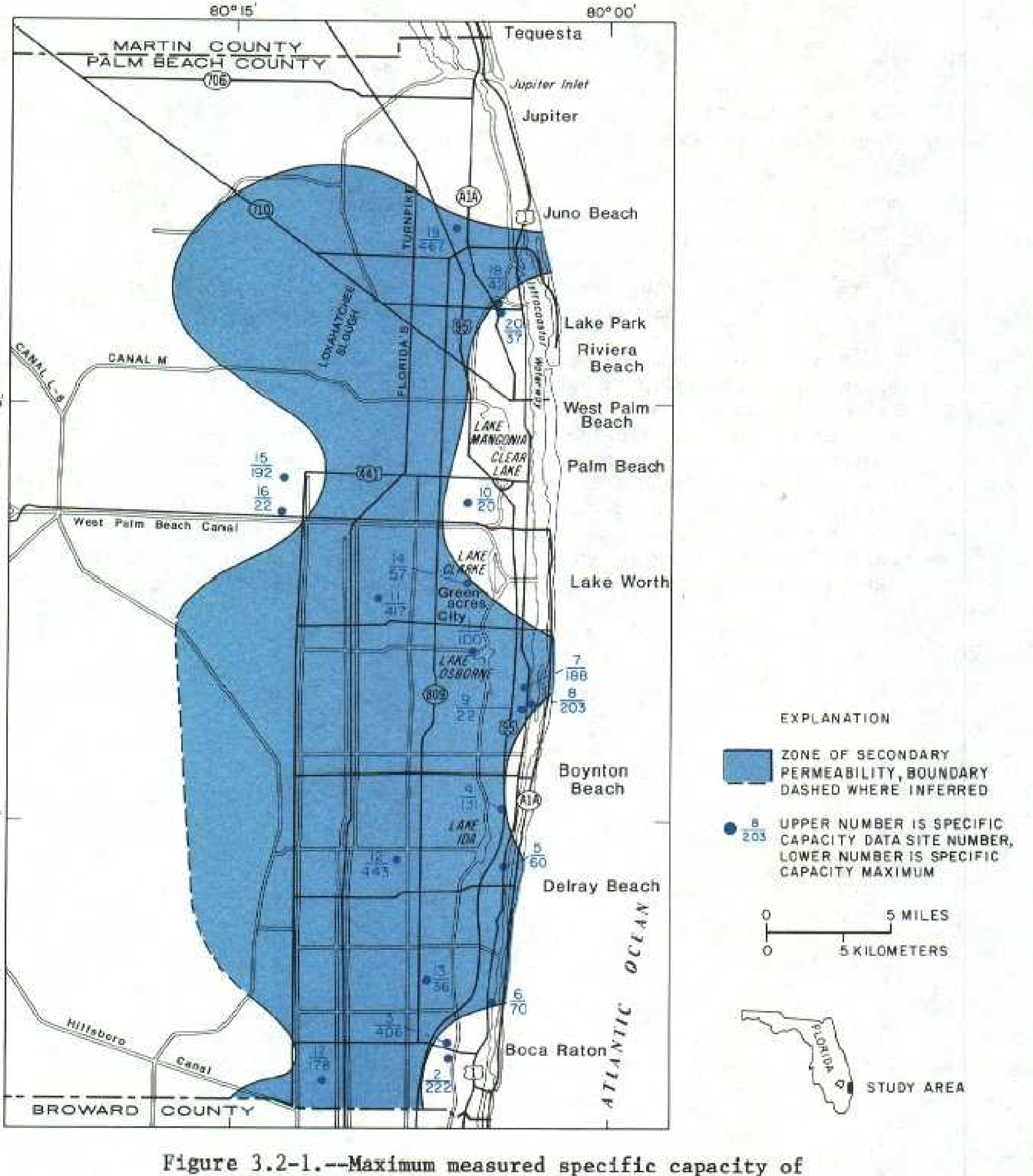

Figure 3.2-1.--Maximum measured specific capacity of wells in well fields and spatial relationships to the zone of higher secondary permeability.

Table 3.2-1.--Site location No., site ID, local No., top and bottom of the producing zone, discharge, drawdown, and specific capacity for wells in eastern Palm Beach County

Site location No.	Site ID	Local No.	Producing zone Top	Producing zone Bottom	Discharge (gal/min)	Draw-down (feet)	Specific capacity
1	263608080052501	PB-1365	95	117	500	5.00	100
2	262033080074501	808	110	150	1,870	50.80	37
2	262225080074501	1020	109	116	1,710	11.30	151
2	262144080074401	1234	104	124	1,400	24.40	57
2	262134080074401	1235	107	118	1,710	10.00	171
2	262125080074501	1236	107	110	2,440	16.40	149
2	262117080074501	1237	105	107	1,710	15.30	112
2	262109080074501	1238	105	121	2,440	12.60	194
2	262048080074501	1239	108	124	2,440	11.00	222
2	262039080074501	1240	109	150	2,010	40.50	50
3	262316080053501	1229	100	140	1,015	3.80	267
3	262204080063901	1233	100	120	2,435	6.00	406
4	263205080034401	1246	64	80	1,000	20.00	50
4	263205080033901	1247	62	81	1,000	19.00	53
4	263050080040701	1248	54	76	1,000	8.50	118
4	263050080040501	1249	54	75	1,000	8.50	118
4	263047080040501	1250	50	70	1,050	8.00	131
4	263047080040701	1251	50	70	1,040	21.00	50
4	263047080041001	1252	75	105	875	15.00	58
4	263059080041701	1254	85	115	1,015	27.00	38
4	263104080041301	1256	81	113	1,000	51.00	20
5	262755080043001	1262	55	107	1,000	44.40	23
5	262805080042701	1267	57	108	1,000	16.70	60
5	262704080042901	1274	63	114	1,000	31.50	32
5	262656080051301	1279	110	150	1,000	67.40	15
5	262649080051801	1282	110	150	1,000	23.50	43
6	262436080044401	1286	85	110	280	4.00	70
6	262437080044401	1287	85	110	280	4.00	70
7	263453080031901	1310	50	80	1,500	8.00	188
8	263422080031001	1314	—	—	295	4.10	72
8	263420080030701	1315	—	—	100	4.60	22
8	263423080031001	1316	—	—	120	5.20	23
8	263424080030901	1317	—	—	90	9.90	9
8	263423080030701	1318	—	—	150	1.80	83
8	263423080031201	1319	—	—	175	0.86	203
8	263420080031101	1320	—	—	100	3.10	32
9	263418080033401	1312	—	—	290	14.50	20
9	263416080033101	1313	—	—	298	13.50	22
10	264117080054501	1401	129	169	366	17.90	20
10	264121080055701	1402	138	178	363	49.20	7
10	264126080053901	1403	140	180	366	24.20	15
10	264127080052301	1404	140	180	363	27.70	13
11	263757080092401	1407	80	110	800	12.30	65
11	263800080092101	1408	83	110	660	2.00	330
11	263806080092101	1409	85	118	1,000	2.40	417
11	263809080092101	1410	87	120	1,000	2.50	400
12	262858080083901	1416	120	150	708	1.60	443
12	262856080083901	1417	120	150	708	10.50	67
12	262903080083601	1418	120	150	708	1.60	443
13	262455080070001	1414	125	133	100	2.80	36
13	262458080070001	1415	63	69	100	3.20	31
14	263830080053801	1329	160	200	1,210	21.10	57
15	264223080125701	1336	64	70	450	2.34	192
15	264217080131701	1337	61	66	450	3.92	115
15	264228080130201	1338	61	66	460	4.30	107
16	264056080133801	1339	103	115	400	18.00	22
16	264053080133801	1340	103	115	400	28.00	14
16	264101080133801	1341	104	125	380	22.83	17
17	262035080114501	1343	160	170	580	4.90	118
17	262037080114301	1344	105	115	1,050	10.10	104
17	262033080113601	1345	120	124	1,140	6.40	178
17	262031080112601	1346	105	111	1,040	7.80	133
17	262029080111701	1347	110	115	1,000	11.00	91
17	262037080115401	1348	110	116	1,150	9.80	117
17	262030080115401	1349	113	125	1,020	10.30	99
18	264852080045301	1373	—	—	550	13.00	42
19	265138080074301	1350	80	110	780	8.00	98
19	265131080074401	1351	90	120	700	6.30	111
19	265126080074401	1352	78	108	931	5.60	166
19	265119080074401	1353	78	108	699	8.00	88
19	265131080073601	1354	88	118	1,280	10.30	124
19	265126080073501	1355	86	120	1,080	10.00	108
19	265119080073401	1356	86	116	1,180	5.70	207
19	265109080073501	1357	85	115	1,140	8.50	134
19	265102080074401	1358	74	104	700	3.30	212
19	265102080072401	1360	72	102	703	6.00	117
19	265054080074401	1361	72	102	700	1.50	467
20	264815080043501	1380	—	—	250	14.00	18
20	264811080045001	1385	—	—	1,000	27.00	37
20	264807080045501	1387	—	—	1,000	29.00	34
20	264807080044601	1388	—	—	1,200	33.00	36

4.0 WATER QUALITY

4.1 Ground-Water Quality Sampling Sites

SAMPLING SITE LOCATIONS

Ground-water samples were collected and analyzed for 39 wells in eastern Palm Beach County.

Ground-water samples were collected from 39 wells penetrating the surficial aquifer in eastern Palm Beach County. Sampling depths ranged from 40 to 252 feet below land surface. Concentrations of selected constituents in the water were determined to evaluate water quality in the aquifer and areal water-quality trends, particularly in the zone of secondary permeability.

Figure 4.1-1 shows the location of wells selected for water-quality sampling. Complete water-quality data for these sites are available through WATSTORE. For information about WATSTORE, see section 5.0 of this report.

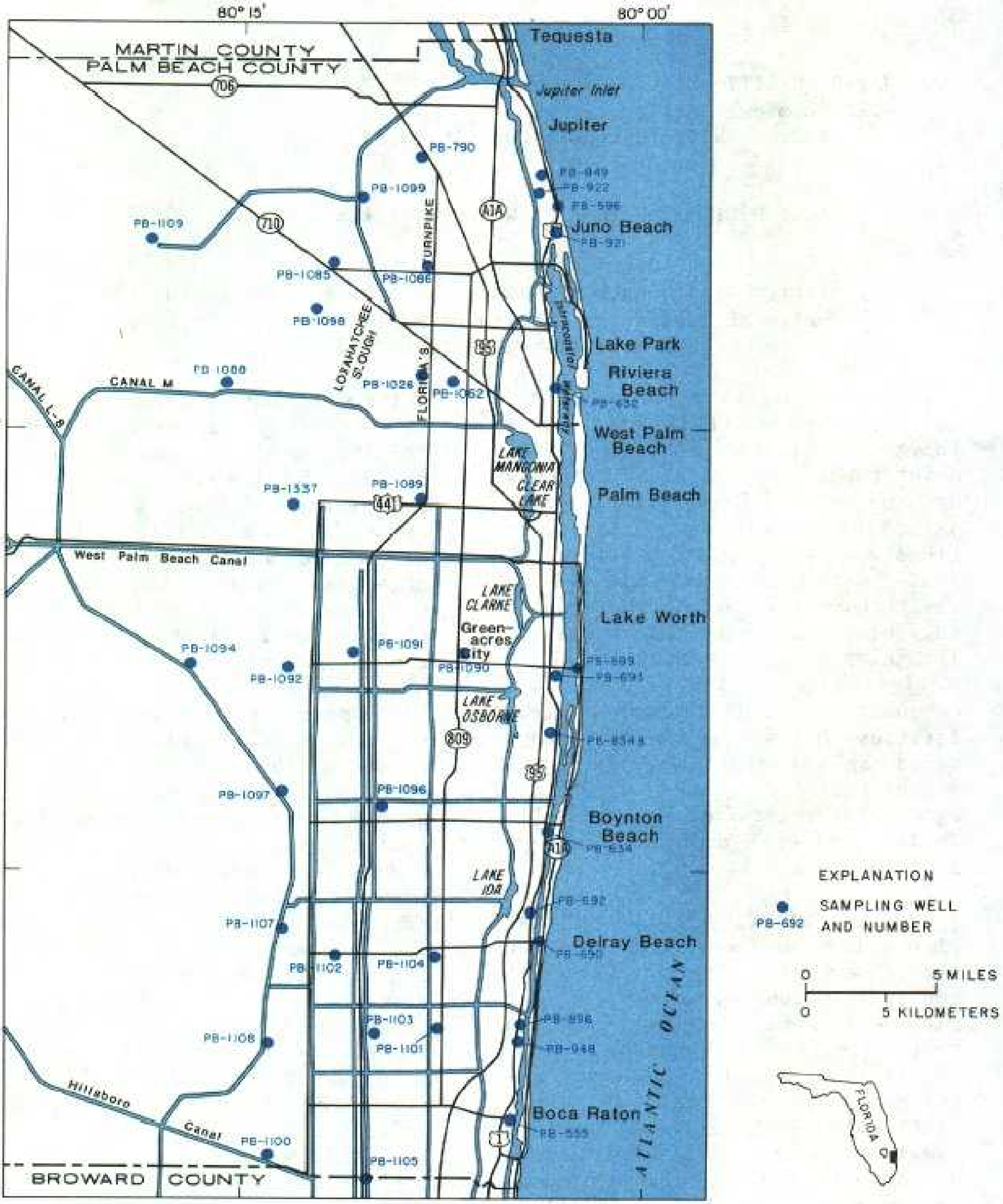

Figure 4.1-1.--Location of ground-water quality sampling sites.

4.0 WATER QUALITY

4.1 Ground-Water Quality Sampling Sites

CALCIUM BICARBONATE TYPE WATER TYPIFIES SURFICIAL AQUIFER

Calcium bicarbonate type water is dominant throughout the surficial aquifer in eastern Palm Beach County, including the zone of secondary permeability.

The composition of water can be conveniently illustrated by a polygonal diagram (Stiff, 1951), using three parallel axes extending on each side of a vertical zero axis. Concentrations of major cations and anions, in milliequivalents per liter, are plotted on their respective axis. The resulting points are connected to form an irregular polygonal shape which is a visual description of the water composition. Differences or similarities in waters can be recognized by comparing the polygonal shapes (Stiff diagrams). Stiff diagrams for water from several wells in the surficial aquifer are shown in figure 4.2.1-1.

The similarity of water samples collected along a north-south line, away from the influence of seawater intrusion, to the east and diluted residual seawater to the west is evident. Changes in concentrations expand or contract the polygons, but the basic shape has little change where the water type remains constant. As the cations and anions increase or decrease, the polygon shape changes as illustrated by the NaCl (salt) dominated sample from well PB-889.

Water is classified by its dominant cation (sodium and potassium, calcium, and magnesium) and anion (chloride, bicarbonate, and sulfate) groups. Water in the zone of secondary permeability (wells PB-1086, PB-1091, and PB-1103) is of the calcium bicarbonate type. In areas of diluted residual seawater (well PB-1094), codominance of calcium bicarbonate and sodium chloride occurs in the aquifer water, and in areas of saltwater intrusion (well PB-889), sodium chloride water dominates.

Generally, better water quality exists in the zone of secondary permeability because of higher permeabilities and higher ground-water gradients, allowing freshwater from rainfall to dilute and replace residual seawater. Because of lower permeabilities to the west, less replacement and dilution of residual seawater have occurred, yielding water of poorer quality. Lower permeabilities in western areas could be due to the presence of limestones more resistant to solution, which result in slower flushing rates or Pleistocene ground-water gradients structured to create a large area of insufficient ground-water flow necessary for the formation of secondary permeability.

Water-quality analyses of samples collected from 25 wells in eastern Palm Beach County in July 1980 are given in table 4.2.1-1.

Table 4.2.1-1.—Field measurements and major cations and anions in ground water of eastern Palm Beach County (July 28-31, 1980)

[Concentrations in milligrams per liter]

Parameter	PB-790	PB-1026	PB-1062	PB-1085	PB-1086	PB-1088	PB-1089	PB-1090	PB-1091	PB-1092	PB-1094	PB-1096	PB-1097	PB-1098
Sampling depth (ft)	112	76	77	87	90	90	130	100	95	70	100	90	90	80
Specific conductance (umhos)	785	820	—	660	775	950	855	590	690	875	1350	510	980	740
pH (units)	7.1	7.0	—	7.3	7.1	7.2	7.1	7.1	7.1	7.1	7.1	7.2	7.2	7.2
Alkalinity field (as $CaCO_3$)	240	220	190	210	190	180	160	170	140	300	350	190	190	160
Bicarbonate fet-fld (as HCO_3)	388	536	392	384	420	420	420	436	440	480	620	304	512	390
Hardness (as $CaCO_3$)	320	410	320	260	350	290	300	250	300	360	410	260	390	290
Hardness, noncarbonate (as $CaCO_3$).	79	190	130	53	160	110	140	77	160	56	62	68	200	130
Calcium, dissolved	120	150	120	95	130	100	110	92	110	130	130	100	140	100
Magnesium, dissolved	4.4	6.9	3.9	6.1	4.9	9.5	6.3	3.9	4.6	7.1	21.0	1.9	9.7	8.6
Sodium, dissolved	39	20	27	37	43	90	52	28	28	34	140	15	66	34
Potassium, dissolved	.9	1.1	.6	1.5	1.1	3.8	1.8	.6	1.3	2.2	9.3	1.1	4.4	1.6
Chloride, dissolved	69	27	45	63	75	140	90	47	42	63	210	23	96	62
Sulfate, dissolved	1.1	2.0	.3	2.1	3.7	9.8	4.7	—	1.5	3.9	23.0	.8	14.0	2.0
Fluoride, dissolved	.1	.3	.3	.2	.4	.3	.2	.2	.3	.2	.2	.3	.3	.2
Silica, dissolved	17	25	14	20	17	18	18	16	15	.6	17	19	18	19
Dissolved solids, sum	401	367	327	352	391	481	381	291	289	424	762	276	465	325

Parameter	PB-1099	PB-1100	PB-1101	PB-1102	PB-1103	PB-1104	PB-1105	PB-1107	PB-1108	PB-1109	PB-1337	Minimum	Maximum	Mean
Sampling depth (ft)	90	90	95	140	120	105	60	105	90	40	61	40	140	91
Specific conductance (umhos)	4400	860	460	575	610	600	710	1090	1180	4120	1500	460	4400	1111
pH (units)	7.0	7.1	7.2	7.1	7.1	7.3	7.0	7.0	7.1	7.0	7.1	7.0	7.3	7.1
Alkalinity field (as $CaCO_3$)	520	130	200	250	285	180	240	238	230	480	361	130	520	240
Bicarbonate fet-fld (as HCO_3)	744	568	272	328	348	332	424	290	460	752	440	272	752	444
Hardness (as $CaCO_3$)	900	370	210	250	250	260	340	320	280	630	410	210	900	349
Hardness, noncarbonate (as $CaCO_3$).	380	240	5	1	0	80	100	31	46	150	49	0	380	107
Calcium, dissolved	240	140	79	94	95	100	130	120	85	150	140	79	240	120
Magnesium, dissolved	72.0	5.2	1.9	3.6	3.3	2.3	4.0	4.9	15.0	62.0	15.0	1.9	72.0	11.5
Sodium, dissolved	610	44	17	21	22	19	23	100	110	570	140	15	610	93
Potassium, dissolved	23.0	2.0	1.1	1.1	1.2	.8	1.1	2.6	3.7	26.0	5.5	.6	26.0	3.9
Chloride, dissolved	1000	81	35	36	37	34	36	160	180	890	230	23	1000	150
Sulfate, dissolved	31.0	.1	4.7	.4	.3	.8	2.8	11.0	16.0	37.0	50.0	.1	50.0	9.2
Fluoride, dissolved	.2	.3	.2	.3	.3	.2	.4	.3	.4	.3	.2	.1	.4	.2
Silica, dissolved	23	20	13	13	16	12	21	17	21	12	18	.6	25	16
Dissolved solids, sum	2590	375	273	322	348	279	365	592	572	2240	817	273	2590	572

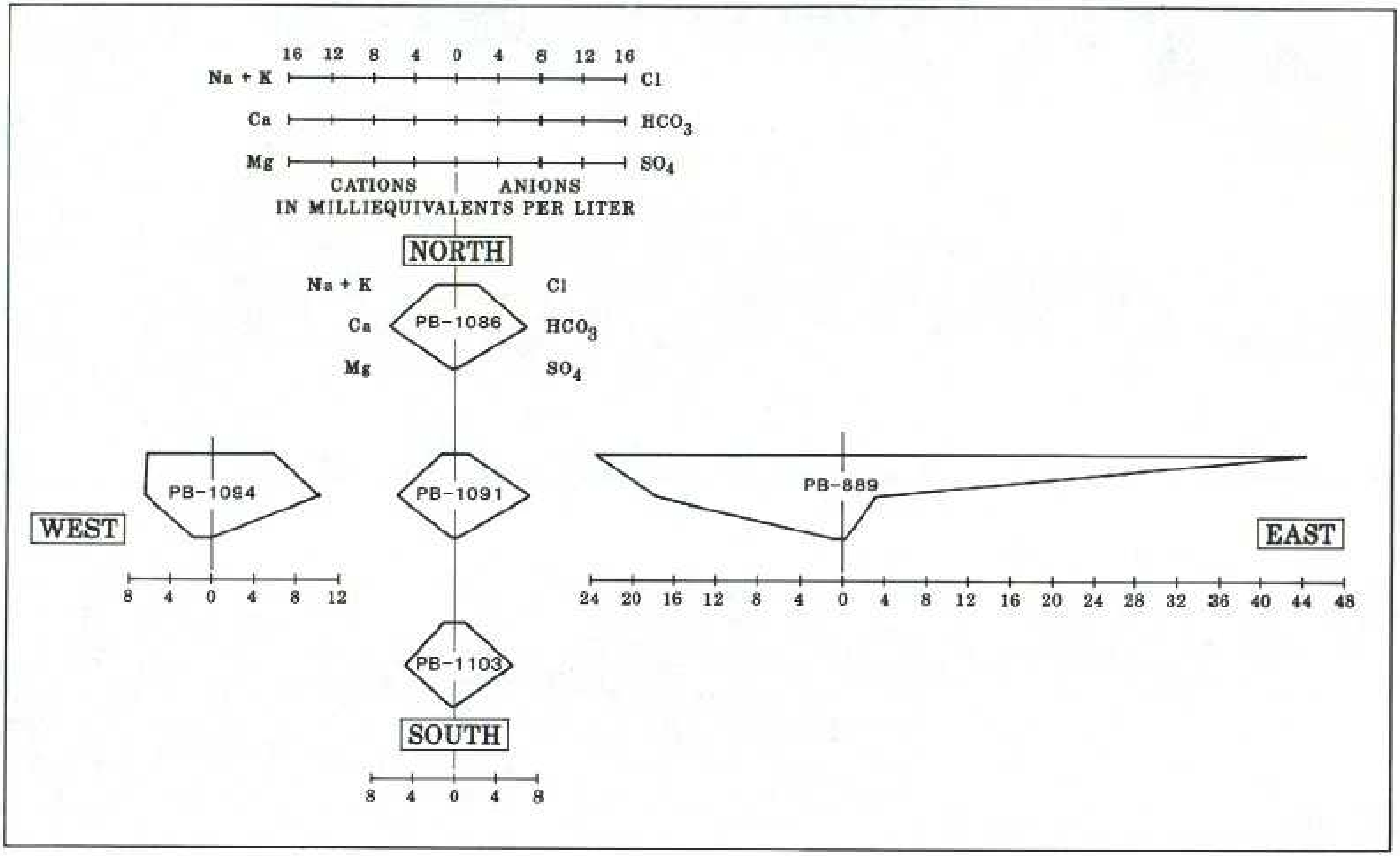

Figure 4.2.1-1.--Stiff diagrams of selected wells in eastern Palm Beach County depicting water-quality composition.

4.2.2 Dissolved Solids

DISSOLVED SOLIDS CONCENTRATIONS ARE LOWEST IN THE ZONE OF SECONDARY PERMEABILITY

Dissolved solids concentrations in Palm Beach County's surficial aquifer are highest in the saltwater-intruded coastal area. Concentrations are lower in the zone of secondary permeability away from the coast but increase to the west due to diluted residual seawater.

Dissolved solids concentration is a measure of the total amount of material dissolved in the water. Dominant constituents of dissolved solids in eastern Palm Beach County's surficial aquifer are bicarbonate, calcium, and sodium.

Figure 4.2.2-1 shows the areal distribution of dissolved solids concentration in the zone of secondary permeability of the surficial aquifer at a depth of 100 feet below land surface. The map was compiled from water-quality data collected during July 28-31, 1980.

Dissolved solids concentration for seawater is about 35,000 mg/L (milligrams per liter). In the surficial aquifer, highest dissolved solids concentrations are found along the eastern coast where saltwater from the ocean mixes with the freshwater in the aquifer. South of Palm Beach, dissolved solids concentrations decrease from the coast westward over the coastal ridge and reach a minimum along a north-south axis parallel to State Road 809. Continuing in a westerly direction, dissolved solids concentrations increase due to incomplete flushing of diluted residual seawater in materials of low permeability.

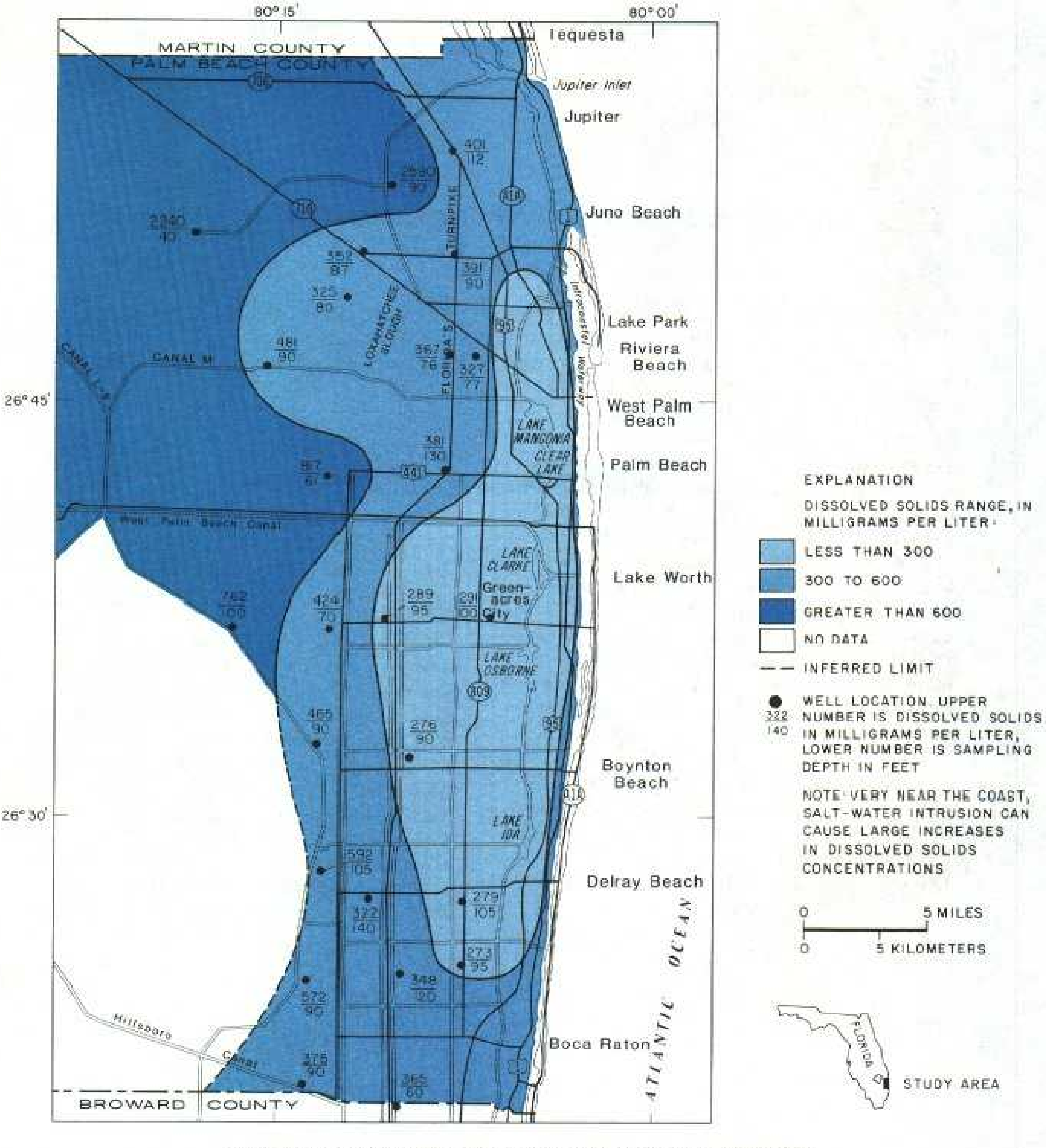

Figure 4.2.2-1.--Areal distribution of dissolved solids concentrations in the surficial aquifer at approximately 100 feet below land surface (July 28-31, 1980).

4.0 WATER QUALITY--Continued
4.2 Chemical Quality--Continued
4.2.2 Dissolved Solids

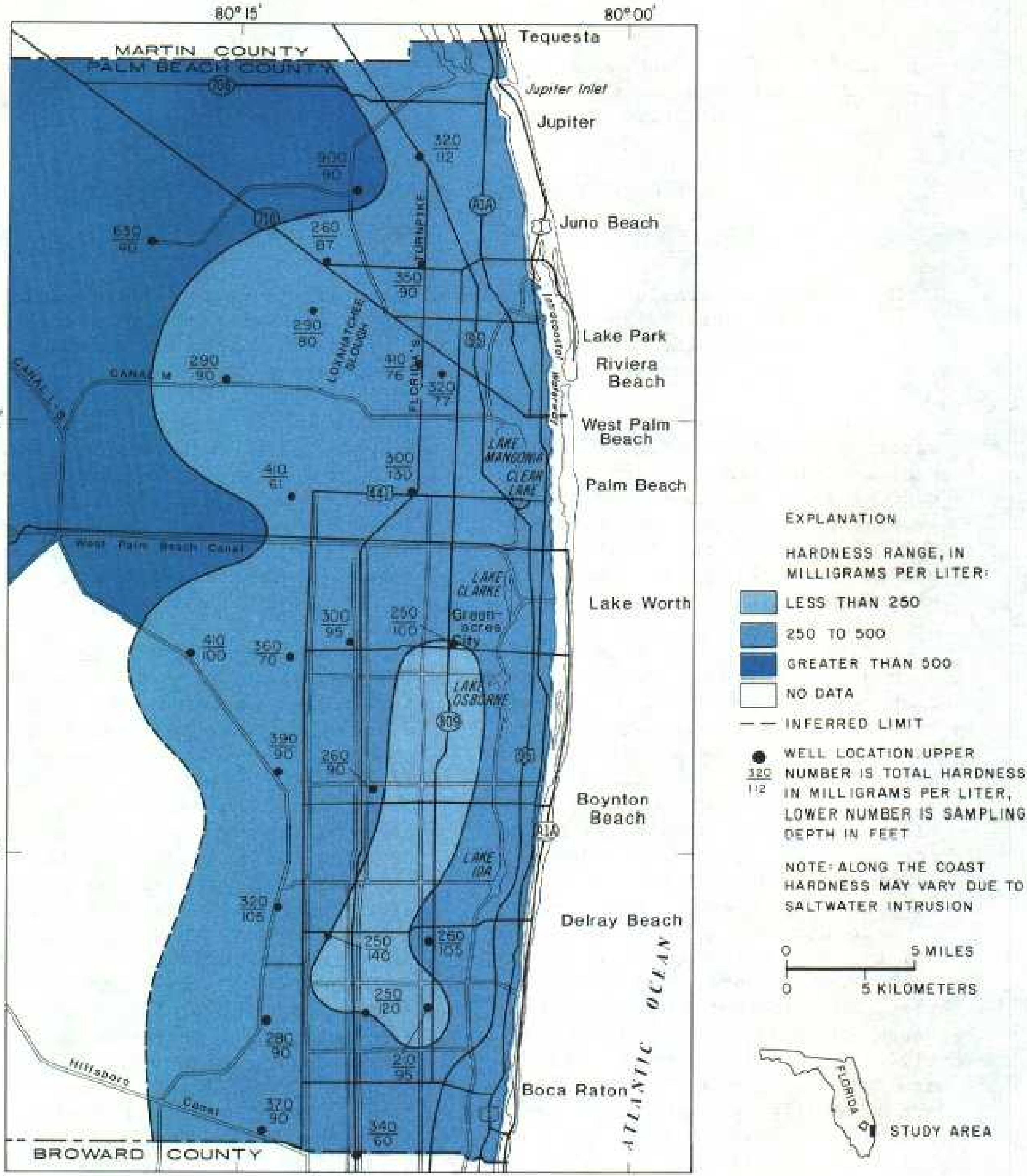

Figure 4.2.3-1.--Areal distribution of total hardness as calcium carbonate in the surficial aquifer at approximately 100 feet below land surface (July 28-31, 1980).

4.2.3 Calcium Carbonate Hardness

TOTAL HARDNESS OF WATER AS CALCIUM CARBONATE IS VERY HIGH IN THE ZONE OF SECONDARY PERMEABILITY

Total hardness of water as calcium carbonate is classified as very hard throughout the surficial aquifer in eastern Palm Beach County. Hardness increases to the west of the zone of secondary permeability.

Hardness of water is caused by calcium and magnesium ions and is expressed as an equivalent amount of calcium carbonate. In the surficial aquifer of eastern Palm Beach County, the lithology is composed primarily of calcium carbonate, and calcium is the dominant cation, except in areas of saltwater intrusion where sodium dominates in ground water. Based on mean total hardness from 25 wells, magnesium accounts for 10 percent of the total hardness.

Ground water sampled in the zone of secondary permeability is "very hard" when classified on a relative scale (Durfor and Becker, 1964). This classification scale is:

Hardness range, in mg/L as $CaCO_3$	Hardness description
0 - 60	Soft
60 - 120	Moderately hard
120 - 180	Hard
More than 180	Very hard

Figure 4.2.3-1 shows the areal distribution of hardness in the surficial aquifer at the end of July 1980. Hardness generally increases westward from the zone of secondary permeability. Analyses of water from the zone show that hardness is greatest in the vicinity of the Loxahatchee Slough and lowest west of Boynton Beach within the Lake Worth Drainage District in the southeast part of the county.

4.2.4 Chloride

ZONE OF SECONDARY PERMEABILITY FLANKED BY GROUND WATER OF POOR QUALITY

Chloride concentrations in the zone of secondary permeability are low compared to surrounding areas. Intrusion of saltwater along the coast and diluted residual seawater west of the coastal ridge are a threat to water quality in the zone of secondary permeability.

Current secondary drinking-water regulations (U.S. Environmental Protection Agency, 1980a) recommend a maximum contaminant level of 250 mg/L of chloride. This limit is based on taste, health, and water-treatment considerations.

Chloride is present in various rock types in lower concentration than most of the other major constituents of natural water (Hem, 1970, p. 171); however, its chemical activity in natural water is less than other major ions. Chloride ions do not significantly enter into oxidation or reduction reactions or form important solute complexes with other ions. They also do not form salt of low solubility, are not significantly adsorbed on mineral surfaces, and play few biochemical roles. Because of relative chemical inactivity, chloride ions in the hydrologic cycle are very mobile and are generally controlled by physical processes (Hem, 1970, p. 172). This high mobility of the chloride ion is a major concern in the south Florida hydrogeologic environment.

Figure 4.2.4-1 shows the areal distribution of chloride concentrations in the surficial aquifer. Chloride concentrations are highest along the coast where saltwater intrusion has occurred, are low in a wide zone that extends inland from the coast (including the zone of secondary permeability), then increase to the west in the area of diluted residual seawater as suggested by Parker and others (1955, p. 185).

A ground-water divide (as described in section 3.0) now controls the eastward migration of diluted residual seawater into the zone of secondary permeability. Increasing withdrawals of ground water from the zone of secondary permeability to meet future water demands could result in the alteration of ground-water flow, allowing diluted residual seawater to flow eastward into the zone of secondary permeability. This phenomenon occurs now near the intersection of U.S. Highway 441 and the West Palm Beach Canal where ground-water and surface-water levels are about 8 feet lower than levels in the central section of the Lake Worth Drainage District (fig. 3.1-1). Ground water containing 250 mg/L of chloride has migrated eastward to a point almost coincident with the zone of secondary permeability. Additional lowering of water levels in the aquifer could permit this water to enter the zone of secondary permeability.

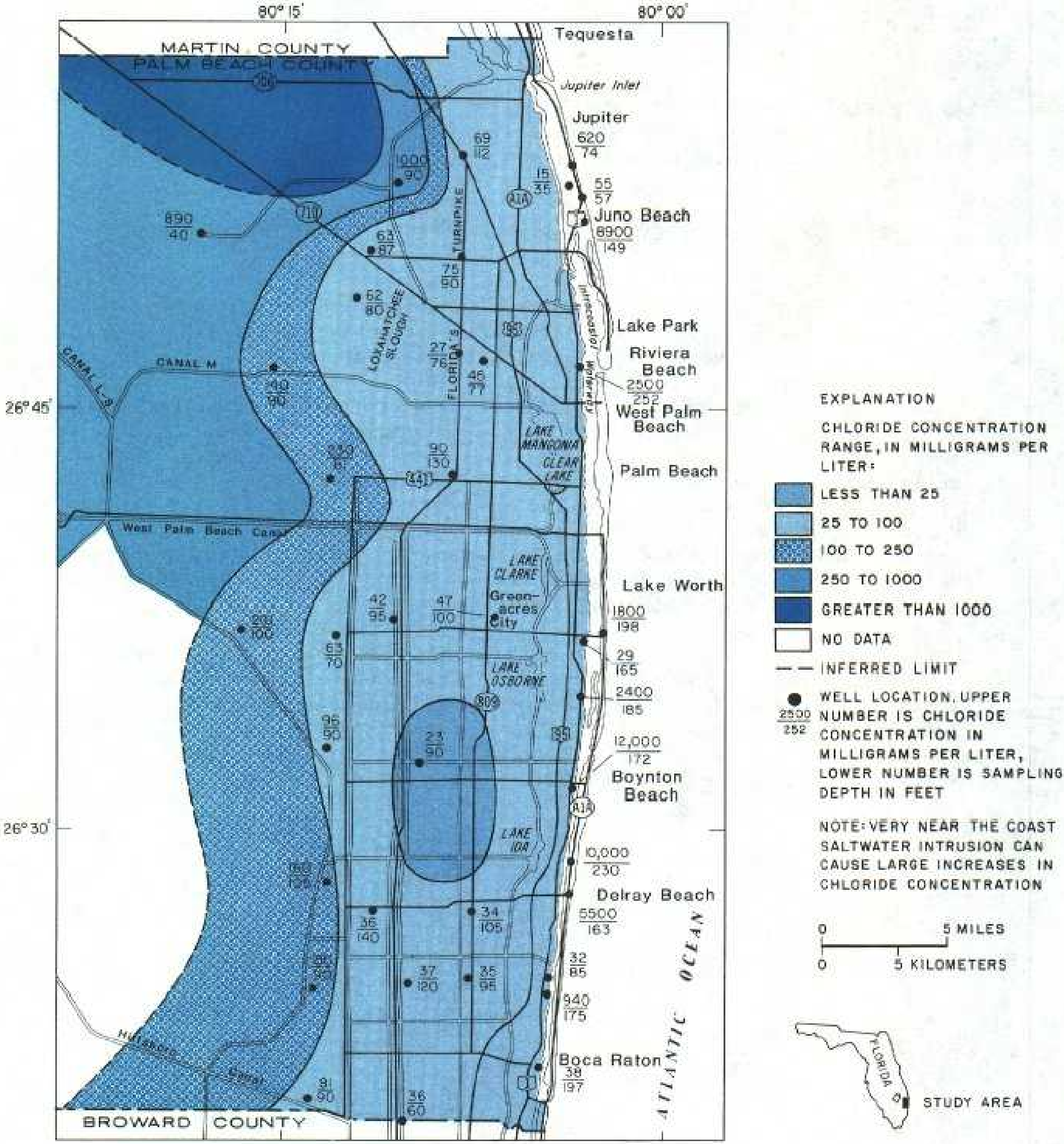

Figure 4.2.4-1.--Areal distribution of chloride concentrations in the surficial aquifer at approximately 100 feet below land surface (July 28-31, 1980).

ZONE OF SECONDARY PERMEABILITY LEAST AFFECTED BY ORGANIC CARBON

Increases in organic carbon concentrations to the west in the surficial aquifer are attributed primarily to the organic deposits in the Everglades.

Total organic carbon in ground water generally indicates that the water has infiltrated through naturally occurring organic materials or manmade contaminants. In the surficial aquifer in eastern Palm Beach County, the most likely source of organic carbon is organic deposits in the Everglades west of Florida's Turnpike.

Total organic carbon concentrations are generally lower in the zone of secondary permeability in the aquifer and increase to the west. This pattern is consistent with the occurrence of organic deposits in the area to the west. High organic carbon concentrations in the zone adjacent to the Loxahatchee Slough probably are the result of eastward migration of water that infiltrated from the Slough to the zone of secondary permeability.

Figure 4.2.5-1 shows the areal distribution of total organic carbon concentrations in the surficial aquifer and concentrations at 24 selected wells at the end of July 1980.

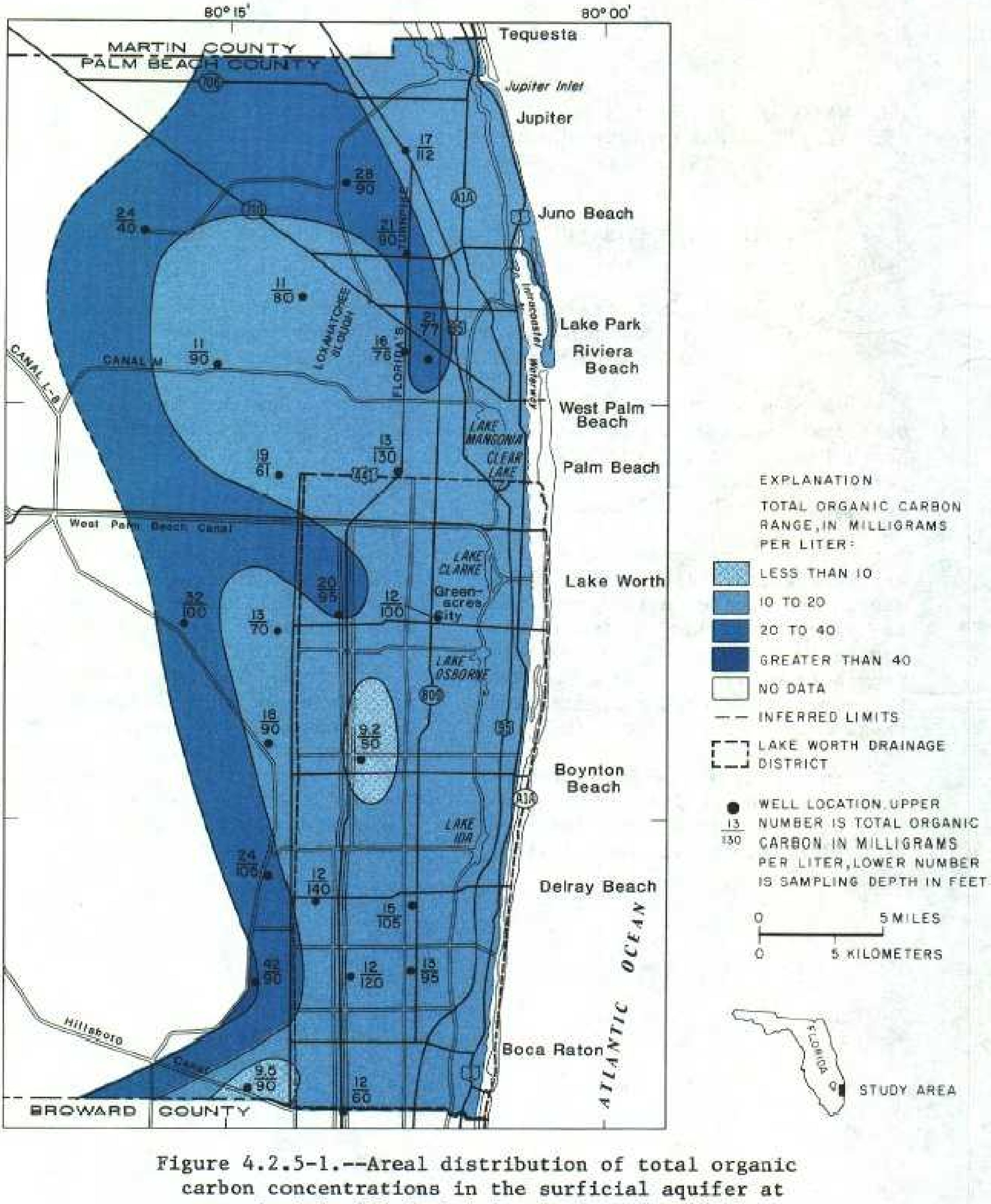

Figure 4.2.5-1.--Areal distribution of total organic carbon concentrations in the surficial aquifer at approximately 100 feet below land surface (July 28-31, 1980).

4.0 WATER QUALITY--Continued
4.2 Chemical Quality--Continued
4.2.5 Total Organic Carbon

4.2.6 Nutrients

NUTRIENT CONCENTRATIONS HIGHLY VARIABLE IN SURFICIAL AQUIFER

No significant areal trends are observed in the distribution of nitrogen and phosphorus concentrations in the surficial aquifer or its zone of secondary permeability.

Sources of nutrients in the surficial aquifer in eastern Palm Beach County are organic plant materials, animal wastes or sewage, and agricultural fertilizers.

Analyses of ground water from selected wells indicate that nitrogen in the aquifer exists primarily as organic nitrogen or its reduced species - ammonia. Total nitrogen ranges from 0.76 to 3.41 mg/L. Total ammonia nitrogen concentrations range from 0.42 to 1.50 mg/L.

In the 23 wells for which nitrate nitrogen analyses are available, concentrations range from 0.00 to 0.01 mg/L. These concentrations are much less than the U.S. Environmental Protection Agency (1980b) limit of 10 mg/L for drinking water.

Phosphorus concentrations were consistently low in wells sampled. Total phosphorus concentrations range from 0.04 to 0.58 mg/L with orthophosphate concentrations ranging from 0.03 to 0.36 mg/L.

Nutrient data for wells sampled are given in table 4.2.6-1. These data indicate no specific trends in distribution of nitrogen and phosphorus nutrient concentrations in the surficial aquifer or its zone of secondary permeability.

Table 4.2.6-1.—Nutrient concentrations in ground water of eastern Palm Beach County (July 28-31, 1980)

[Concentrations in milligrams per liter]

Parameter	PB-790	PB-1026	PB-1062	PB-1085	PB-1086	PB-1088	PB-1089	PB-1090	PB-1091	PB-1092	PB-1094	PB-1096	PB-1097	PB-1098
Carbon, organic total	17	16	21	—	21	11	13	12	20	13	32	9.2	18	11
Nitrogen, ammonia + organic total.	2.46	1.48	1.32	—	1.52	1.60	1.56	1.40	1.24	1.30	3.10	.98	1.36	1.40
Nitrogen, ammonia total	.960	.900	.730	—	.660	1.40	.950	.700	.640	.640	1.50	.610	.740	.700
Nitrogen, nitrate total	.00	.01	.00	—	.00	.00	.01	.00	.01	.01	.00	.00	.00	.01
Nitrogen, nitrite total	.010	.000	.000	—	.010	.010	.000	.000	.010	.000	.010	.010	.010	.000
Nitrogen, NO_2 + NO_3 total	.01	.01	.00	—	.01	.01	.01	.00	.02	.01	.01	.01	.01	.01
Nitrogen, organic total	1.50	.58	.59	—	.86	.20	.61	.70	.60	.66	1.60	.37	.62	.70
Nitrogen, total	2.47	1.49	1.32	—	1.53	1.61	1.57	1.40	1.26	1.31	3.11	.99	1.37	1.41
Phosphorus, orthophosphate, total.	.080	.080	.040	—	.040	.090	.040	.080	.080	.030	.060	.070	.090	.040
Phosphorus, total	.170	.100	.040	—	.060	.180	.060	.230	.220	.080	.100	.160	.180	.040

Parameter	PB-1099	PB-1100	PB-1101	PB-1102	PB-1103	PB-1104	PB-1105	PB-1107	PB-1108	PB-1109	PB-1337	Minimum	Maximum	Mean
Carbon, organic total	28	9.5	13	12	12	15	12	24	42	24	19	9.2	42	17
Nitrogen, ammonia + organic total.	2.40	1.24	1.18	1.06	1.20	1.12	.76	2.90	3.40	2.20	1.34	.76	3.40	1.64
Nitrogen, ammonia total	1.10	.560	.760	.620	.690	.510	.420	1.50	1.50	1.20	.930	.420	1.50	.871
Nitrogen, nitrate total	.01	—	.00	.00	.00	.01	.00	.00	.00	.01	.00	.00	.01	
Nitrogen, nitrite total	.010	—	.010	.000	.000	.010	.000	.010	.010	.010	.000	.000	.010	
Nitrogen, NO_2 + NO_3 total	.02	—	.01	.00	.00	.02	.00	.01	.01	.02	.00	.00	.02	
Nitrogen, organic total	1.30	.68	.42	.44	.51	.61	.34	1.40	1.90	1.00	.41	.20	1.90	.77
Nitrogen, total	2.42	—	1.19	1.06	1.20	1.14	.76	2.91	3.41	2.22	1.34	.76	3.41	1.67
Phosphorus, orthophosphate total.	.100	—	.360	.050	.050	.090	.050	.050	.060	.060	.050	.030	.360	.075
Phosphorus, total	.200	—	.580	.140	.110	.340	.080	.430	.270	.500	.070	.040	.580	.188

TRACE-ELEMENT CONCENTRATIONS IN THE SURFICIAL AQUIFER

Trace-element concentrations in the zone of secondary permeability generally fall within water-quality regulation limits.

Ground-water samples from 25 wells in the surficial aquifer in eastern Palm Beach County were analyzed to determine concentrations of trace elements. Analyses were made for metals (aluminum, barium, copper, iron, lead, manganese, mercury, strontium, and zinc) and nonmetals (arsenic and boron).

All trace-element concentrations are within U.S. Environmental Protection Agency (1980a, 1980b) regulation and recommended limits, except for mercury in well PB-1100 and for iron in wells PB-790, PB-1085, PB-1100, PB-1102, and PB-1104. Iron often exceeds these limits in south Florida. Of these wells, only PB-790 is not in the zone of secondary permeability of the surficial aquifer.

Trace elements for which regulation maximum contamination limits have been determined for drinking water by the U.S. Environmental Protection Agency (1980a, 1980b) are:

Trace elements	Regulation limit (micrograms per liter)
Arsenic	50
Barium	1,000
Copper	1,000
Iron	300
Lead	50
Manganese	50
Mercury	2
Zinc	5,000

Trace-element data for wells in the surficial aquifer are listed in table 4.2.7-1.

Table 4.2.7-1.--Trace-element concentrations in ground water of eastern Palm Beach County (July 28-31, 1980)

[Concentrations in micrograms per liter]

Parameter	PB-790	PB-1026	PB-1062	PB-1085	PB-1086	PB-1088	PB-1089	PB-1090	PB-1091	PB-1092	PB-1094	PB-1096	PB-1097	PB-1098
Aluminum, dissolved	0	100	0	0	100	100	100	100	100	100	100	100	0	100
Arsenic, dissolved	0	1	0	0	1	1	1	0	1	0	0	0	0	1
Barium, dissolved	0	0	0	0	0	0	0	100	0	0	0	0	0	0
Boron, dissolved	90	70	110	60	100	100	110	70	80	110	230	70	140	90
Copper, dissolved	10	0	0	0	1	1	1	1	1	1	10	0	0	1
Iron, dissolved	3900	220	260	500	220	50	50	40	190	30	60	100	90	120
Lead, dissolved	3	1	0	0	0	0	1	0	0	0	0	0	0	0
Manganese, dissolved	40	10	10	20	10	10	10	10	10	10	10	10	10	—
Mercury, dissolved	.1	.1	.2	.1	.2	.1	.1	.8	.3	.1	.1	.6	.1	.2
Strontium, dissolved	920	1800	1200	680	1300	690	1900	1100	1300	1900	980	740	2100	880
Zinc, dissolved	10	10	10	10	90	10	10	30	10	70	10	0	10	10

Parameter	PB-1099	PB-1100	PB-1101	PB-1102	PB-1103	PB-1104	PB-1105	PB-1107	PB-1108	PB-1109	PB-1337	Minimum	Maximum	Mean
Aluminum, dissolved	0	100	100	100	0	100	100	100	0	100	100	0	100	72
Arsenic, dissolved	0	1	0	0	0	0	1	0	1	1	0	0	1	0
Barium, dissolved	0	0	0	100	0	0	0	0	0	0	0	0	100	8
Boron, dissolved	430	70	80	60	100	60	100	140	220	520	160	60	520	134
Copper, dissolved	0	1	1	0	20	1	0	0	0	0	1	0	20	2
Iron, dissolved	110	670	160	680	160	700	100	160	90	130	60	30	3900	354
Lead, dissolved	0	0	1	0	0	0	0	0	0	0	3	0	3	
Manganese, dissolved	20	20	10	20	10	10	20	10	10	20	10	10	40	13
Mercury, dissolved	.1	2.7	.4	1.3	.5	1.3	.3	.2	.5	.3	.1	.1	2.7	.43
Strontium, dissolved	2200	3300	130	1100	970	960	2000	1400	1800	1600	1200	130	3300	1366
Zinc, dissolved	10	10	10	10	10	10	20	10	10	10	10	0	90	16

5.0 WATER-DATA SOURCES

5.1 WATSTORE

WATSTORE AUTOMATED DATA SYSTEM

The National Water Data Storage and Retrieval System (WATSTORE) of the U.S. Geological Survey provides computerized procedures and techniques for processing water data and provides effective management of data-releasing activities.

WATSTORE was established in November 1971 to computerize the U.S. Geological Survey's existing water-data system and to provide for more effective and efficient management of its data-releasing activities. The system is operated and maintained on the central computer facilities of the Survey at its National Center in Reston, Va. Data may be obtained from WATSTORE through the Water Resources Division's 46 district offices. General inquiries about WATSTORE may be directed to:

Chief Hydrologist
U.S. Geological Survey
437 National Center
Reston, VA 22092

or

U.S. Geological Survey
P.O. Box 026052
Miami, FL 33102

Table 5.1-1 shows a cross reference of local well numbers used in this report and corresponding station identification numbers used by the WATSTORE system.

Table 5.1-1.--Cross reference of local well numbers and corresponding station identification numbers

Local well No.	Station identification No.	Local well No.	Station identification No.
PB-88	263652080033801	PB-834B	263455080030802
99	264005080233501	835B	264103080025902
109	264841080114901	845	264653080063701
445	263328080085201	849	265323080032401
490	262117080055001	889	263627080030402
555	262118080051501	895	262435080042901
561	264230080120501	896	262435080042902
565	265812080053901	897	262436080042801
596	265200080031201	900	262554080085102
632	264646080031401	921	265153080031401
633	264646080031403	922	265209080032301
634	263050080033501	947	262435080042903
639	265604080091101	948	262435080042904
640	265532080135601	1006	262436080042802
653	264656080052901	1026	264715080082301
654	264708080065801	1029	264802080081301
655	264838080092001	1031	264619080064301
657	263758080092501	1033	264624080071801
658	262201080091301	1038	264817080062301
659	262113080175001	1062	264043080070001
665	262147080121301	1078	265202080031701
666	262213080065201	1082	265034080050001
667	264122080054601	1083	265027080060001
668	263634080051201	1084	265027080100201
670	263517080061801	1085	265027080115702
671	263523080085201	1086	265018080075801
672	263527080121701	1087	264566080115201
673	262859080094801	1088	264555080134401
674	262902080065401	1089	264225080084701
675	262818080051801	1090	263745080064001
678	264058080175201	1091	263728080102501
679	264842080172201	1092	263622080132601
681	265802080053801	1093	263626080151501
682	262203080112001	1094	263629080171401
683	263524080124301	1095	263138080064701
690	262712080040701	1096	263138080095201
692	262853080035501	1097	263144080134001
693	263527080030601	1098	265835080130201
694	263627080030401	1099	265250080103601
695	263746080025601	1100	262007080134501
699	264043080092701	1101	262405080071801
700	264142080110801	1102	262711080111401
712	265510080080701	1103	262403080101601
732	262218080070101	1104	262645080071801
790	265440080084101	1105	261938080101001
798	264537080085601	1106	262227080215001
799	264619080054601	1107	262808080131701
800	264612080044601	1108	262403080141301
809	265123080053801	1109	265115080173101
831	265106080241402	1337	264217080131701
833	264258080054001		