Correspondence of Geophysical Log Correlation Markers to Hydrostratigraphic Units

The hydrostratigraphic units found to contain the most productive parts of the surficial aquifer system in this study are the Tamiami, Anastasia, and Fort Thompson Formations (fig. 1). The Tamiami Formation was identified as being an important unit within the surficial aquifer system in Broward County just south of Palm Beach County (Causaras, 1985; Fish, 1988), and in southwestern Palm Beach County (Reese and Cunningham, 2000). This finding is in contrast with some previous studies, such as Land and others (1973), who indicate that only the few upper feet of the Tamiami Formation is productive. In an older study of Palm Beach County, the Tamiami Formation is indicated to be part of the confining unit below the surficial aquifer system, and the Caloosahatchee marl (Formation) is indicated to be the lowest permeable formation (Schroeder and others, 1954).

The Biscayne aquifer, identified and mapped by Shine and others (1989), and the zone of (high) secondary permeability, delineated by Swayze and Miller (1984), are indicated on hydrostratigraphic sections *A-A′* and *B-B′* (figs. 4 and 5). The Biscayne aquifer is best developed in the southern part of the eastern one-third of Palm Beach County (Shine and others, 1989); the aquifer also extends into the northern part of the eastern one-third of the county (Shine and others, 1989) but not in the Atlantic Coastal Ridge province through which hydrostratigraphic section *B-B′* extends or parallels (figs. 1 and 5). Only the extent of the zone of secondary permeability, also referred to as the Biscayne aquifer, was mapped by Swayze and Miller (1984); the top and thickness were not mapped. This zone is present only in the approximately eastern one-fourth to one-third of the county.

The correlation marker H is generally at or close to the base of the surficial aquifer system; however, thick intervals of sand of low to moderate hydraulic conductivity that are still considered to be in the surficial aquifer system can be present below marker H. For example, a sand interval is present below this marker in wells PB-1703 in fig. 4 (the unnamed formation) and PB-1693 in fig. 5.

The Ochopee Limestone Member, as defined by markers H and O, contains the gray limestone aquifer, which has been mapped in southwestern Palm Beach County and adjoining areas to the west and south (Reese and Cunningham, 2000) (figs. 3 and 4). The gray limestone aquifer is identified in four wells in hydrostratigraphic section *A-A′*. The lower part of the zone of secondary permeability in eastern Palm Beach County (Swayze and Miller, 1984) commonly includes the upper part of the interval defined by markers O and H and is equivalent to the gray limestone aquifer to the west (figs. 4 and 5, for example, compare well PB-1765 with wells PB-1775 and PB-1105 in fig. 4). A recent replacement water-supply well constructed for the City of Lake Worth well field has most of its production zone in this interval (fig. 5, well PB-600).

The top of the zone of secondary permeability (Swayze and Miller, 1984) approximately coincides with marker T in the western part of the area of southeastern Palm Beach County, lying between the water-conservation areas and the coast (fig. 1), as shown by wells PB-1775 and PB-1105 (fig. 4). Development of the Biscayne aquifer (Shine and others, 1989) in this area is principally restricted to the Pinecrest Sand Member, as defined by markers T and O (fig. 4). The top of the zone of secondary permeability is about as high as or above marker F in the following areas: (1) near the coast, as shown by wells PB-675, PB-600, and PB-1082 (hydrostratigraphic section *B-B′*, figs. 1 and 5); and (2) in most of the northeastern part of the county (eastern one-third to one-half of the area between the coast and Lake Okeechobee) based on review of other wells in figure 1.

Structure in the surficial aquifer system in the study area is shown by variations in altitude of the O marker (fig. 6). In the mapped area, the altitude of marker O ranges from as shallow as 14 feet below NGVD 29 in eastern Hendry County just west of the western Palm Beach County border, to as deep as 250 feet below NGVD 29 along the coast in the southeastern part of Palm Beach County. Generally, the surface defined by this marker has a high rate of dip toward the coast in the eastern one-fourth of Palm Beach County, and a structurally low area is present in the central part of Palm Beach County extending eastward and southeastward from the southeastern shoreline of Lake Okeechobee to the coast.

SUMMARY AND CONCLUSIONS

This report defines a preliminary hydrostratigraphic framework of the surficial aquifer system in Palm Beach County through the selection, correlation, and mapping of GR geophysical log markers that have hydrostratigraphic significance. Most previous studies have not placed the hydrogeology in a framework in which stratigraphic units in this complex aquifer system are defined and correlated between wells. Four geophysical log markers that approximately correspond to important stratigraphic unit boundaries in key wells with good lithologic control were correlated to 105 wells with adequate data in the study area. This was accomplished primarily using GR log signatures and secondarily, lithologic descriptions.

The lithostratigraphic units that contain the most productive parts of the surficial aquifer system are the Tamiami, Anastasia, and Fort Thompson Formations. The top of the deepest formation, the Tamiami Formation is placed higher in the section in this study than in most previous studies, based on analysis of core samples from test coreholes. The Tamiami Formation as defined by the geophysical log markers is widespread throughout the county and contains two members: the lower Ochopee Limestone Member and the upper Pinecrest Sand Member, both of which are important hydrogeologically. The Ochopee Limestone Member contains the gray limestone aquifer in southern Palm Beach County; in the southeastern part of the county, the lower part of the Biscayne aquifer can include the upper part of this member. In the western part of the area of southeastern Palm Beach County lying between the water-conservation areas and the coast, the Biscayne aquifer principally consists of the Pinecrest Sand Member.

The upper and lower boundaries of the Ochopee Limestone Member, which are regional-scale depositional sequence boundaries, were approximately defined by two of the geophysical log markers. The marker near the upper boundary of the Ochopee Limestone Member was commonly found to be highly correlative because of a characteristic GR log pattern. This marker exhibits a pronounced GR log peak or peaks, and this peak was observed to correspond with blackened limestone crusts and a laminated calcrete layer in continuously drilled core samples. These lithologic features have been interpreted to represent a subaerial exposure surface or surfaces in previous studies.

Structure within the surficial aquifer system is indicated by mapping of the marker near the top of the Ochopee Limestone Member. Generally, the surface defined by this marker has a high rate of dip toward the coast in the eastern one-fourth of Palm Beach County. The area of high dip of this surface to the east in southeastern Palm Beach County generally coincides with the previously mapped extent of the Biscayne aquifer.

Meaningful simulation of ground-water flow in the surficial aquifer system in Palm Beach County requires model construction based on lithostratigraphic unit delineation and determination of hydraulic properties of these units. To adequately define the hydrostratigraphic framework additional test coreholes need to be drilled and logged with a complete geophysical log suite, including an optical borehole log. Additionally, hydraulic data on permeable zones and confining or semiconfining units are needed.

REFERENCES CITED

Ardaman and Associates, Inc., 2003, Central Everglades Restoration Plan Everglades agricultural area reservoirs phase 1, effort 1: Conceptual report of geotechnical exploration, 13 p. and attachments including drilling logs.
Bennett, M.W., Linton, P.F., and Rectenwald, E.E., 2001, Completion report for the exploratory well EXW-1, western Hillsboro basin site, Palm Beach County: South Florida Water Management District hydrogeologic investigation of the Floridan aquifer system, 34 p., 7 app.
Causaras, C.R., 1985, Geology of the surficial aquifer system, Broward County, Florida: U.S. Geological Survey Water-Resources Investigations Report 84-4068, 167 p., 2 sheets.
CH2M HILL, 1993, Boynton Beach aquifer storage and recovery system: Engineering report prepared for the City of Boynton Beach, Florida, p. 1-1 to 7-1, 13 app.
CH2M HILL, 1997, Construction and testing of the aquifer storage and recovery (ASR) system at the BCOES 2A Water Treatment Plant: Engineering report prepared for the Broward County Office of Environmental Services and Montgomery Watson, p. 1-1 to 6-3, 13 app.
CH2M HILL, 1998, Construction and testing of the aquifer storage and recovery facility at the West Palm Beach Water Treatment Plant: Engineering report prepared for the City of West Palm Beach, Florida, p. 1-1 to 7-1, 15 app.
CH2M HILL, 2004, Shallow injection well system for the Highland Beach Reverse Osmosis WTP: Engineering report for construction and testing prepared for the town of Highland Beach, p. 1-1 to 5-3, 10 app.
Cunningham, K.J., Bukry, David, Sato, Tokiyuki, and others, 2001, Sequence stratigraphy of a south Florida carbonate ramp and bounding siliciclastics (Late Miocene-Pliocene), *in* Missimer, T.M., and Scott, T.M., eds., Geology and hydrology of Lee County, Florida: Durward H. Boggess Memorial Symposium: Florida Geological Survey Special Publication no. 49, p. 35-66.
Cunningham, K.J., Carlson, J.L., Wingard, G.L., and others, 2004, Characterization of aquifer heterogeneity using cyclostratigraphy and geophysical methods in the upper part of the karstic Biscayne aquifer, southeastern Florida: U.S. Geological Survey Water-Resources Investigations Report 03-4208, 66 p., 5 pls.
Fish, J.E., 1988, Hydrogeology, aquifer characteristics, and ground-water flow of the surficial aquifer system, Broward County, Florida: U.S. Geological Survey Water-Resources Investigations Report 87-4034, 92 p.
Harvey, J.W., Krupa, S.L., Gefvert, Cynthia, and others, 2002, Interactions between surface water and ground water and effects on mercury transport in the north-central Everglades: U.S. Geological Survey Water-Resources Investigations Report 02-4050, 82 p.
Johnson R., 1988, Lithologic logs and interpretation of formation tops for wells W-12438 (PB-652A), W-12450 (PB-667), W-12454 (PB-665), and W-12590 (PB-833): Florida Geological Survey, 20 p.
Krupa, S.L., 1999, Recognition and analysis of secondary depositional crusts in the surficial aquifer system of southeast Florida: Florida Atlantic University, Boca Raton, unpublished Master's thesis, 273 p.
Land, L.F., Rodis, H.G., and Schneider, J.J., 1973, Appraisal of the water resources of eastern Palm Beach County, Florida: Florida Geological Survey Report of Investigations no. 67, 64 p.
Miller, W.L., 1987, Lithology and base of the surficial aquifer system, Palm Beach County, Florida: U.S. Geological Survey Water-Resources Investigations Report 86-4067, 1 sheet.
Palm Beach County Water Utilities Department, 2003, Eastern Hillsboro Canal Water Treatment Plant #9 aquifer storage and recovery well: Well construction report and operational testing request, p.1-1 to 4-1, 16 app.
Perkins, R.D., 1977, Depositional framework of Pleistocene rocks in south Florida, *in* Enos, Paul, and Perkins, R.D., eds., Quaternary Sedimentation in south Florida, part II: Geological Society of America Memoir 147, p. 131-198.
Reese, R.S., and Cunningham, K.J., 2000, Hydrogeology of the gray limestone aquifer in southern Florida: U.S. Geological Survey Water-Resources Investigations Report 99-4213, 244 p.
Schneider, J.J., 1976, Geologic data from test drilling in Palm Beach County, Florida since 1970: U.S. Geological Survey Open-File Report 76-713, 99 p.
Schroeder, M.C., Milliken, D.L., and Love, S.K., 1954, Water resources of Palm Beach County, Florida: Florida Geological Survey Report of Investigations no. 13, 63 p.
Scott, T.M, 1992, Coastal plains stratigraphy: the dichotomy of biostratigraphy and lithostratigraphy – a philosophical approach to an old problem, *in* Scott, T.M., and Allmon, W.D., eds., Plio-Pleistocene stratigraphy and paleontology of southern Florida: Florida Geological Survey Special Publication no. 36, p. 21-25
Shine, M.J., Padgett, D.G.J., Barfknecht, W.M., 1989, Ground water resource assessment of eastern Palm Beach County, Florida: South Florida Water Management District Technical Publication 89-4, 372 p. and appendixes
Swayze, L.J., and Miller, W.L., 1984, Hydrogeology of a zone of secondary permeability in the surficial aquifer of eastern Palm Beach County, Florida: U.S. Geological Survey Water-Resources Investigations Report 83-4249, 39 p.
Swayze, L.J., McGovern, M.C., and Fischer, J.N., 1980, Lithologic logs and geophysical logs from test drilling in Palm Beach County, Florida, since 1974: U.S. Geological Survey Open-File Report 81-68, 93 p.
U.S. Army Corps of Engineers and South Florida Water Management District, 1999, Central and Southern Florida Project Comprehensive Review Study: Final Integrated Feasibility Report and Programmatic Environment Impact Statement, 27 p.

Table 1. Wells used in this study

[Depths are in feet below land surface; horizontal datum for wells highlighted in pink is the North American Datum of 1983, horizontal datum for all other wells is the North American Datum of 1927; NGVD 29 is the National Geodetic Vertical Datum of 1929; USGS, U.S. Geological Survey; dd mm ss.s, degrees, minutes, seconds]

USGS local well no.	Latitude (dd mm ss.s)	Longitude (dd mm ss.s)	Altitude of land surface (feet NGVD 1929)	Total hole depth (feet)
G-2315	26º 19' 58"	80º 34' 21"	18.00	249
G-2916	26º 17' 36"	80º 06' 24"	17.00	1,200
HE-1110	26º 23' 09"	80º 55' 48"	15.00	160
HE-1116	26º 30' 23"	80º 56' 52"	18.00	195
HE-1142	26º 25' 55.6"	80º 53' 04.4"	14.09	184
HE-1143	26º 21' 42.7"	80º 54' 22.8"	14.63	180.5
HE-1144	26º 24' 12.7"	80º 54' 27.2"	15.85	182
M-1361	26º 59' 17"	80º 36' 20"	22.20	1,380
M-1367	26º 57' 57.2"	80º 25' 17.4	27.10	205.7
PB-600	26º 36' 33"	80º 03' 57"	15.00	345
PB-634	26º 30' 50"	80º 03' 35"	10.00	188
PB-640	26º 55' 32"	80º 13' 56"	19.00	236
PB-649	26º 56' 33"	80º 20' 52"	26.00	205
PB-650	26º 57' 28"	80º 29' 00"	7.00	193
PB-651	26º 54' 32"	80º 36' 45"	22.00	236
PB-652A	26º 47' 08"	80º 03' 51"	20.00	314
PB-653	26º 46' 56"	80º 05' 29"	12.00	314
PB-657	26º 37' 58"	80º 09' 25"	18.00	281
PB-658	26º 22' 01"	80º 09' 13"	15.00	365
PB-665	26º 21' 47"	80º 12' 13"	18.00	225
PB-666	26º 22' 13"	80º 06' 52"	13.00	415
PB-667	26º 41' 22"	80º 05' 46"	15.00	357
PB-668	26º 36' 34"	80º 05' 12"	10.00	358
PB-669	26º 35' 15"	80º 04' 52"	12.00	345
PB-670	26º 35' 18"	80º 06' 17"	15.00	325
PB-671	26º 35' 23"	80º 08' 52"	18.00	119
PB-672	26º 35' 27"	80º 12' 17"	18.00	234
PB-673	26º 28' 59"	80º 09' 48"	19.00	248
PB-674	26º 29' 02"	80º 06' 54"	17.00	302
PB-675	26º 28' 18"	80º 05' 18"	14.00	387
PB-676	26º 41' 13"	80º 23' 56"	15.00	175
PB-677	26º 41' 04"	80º 20' 06"	16.00	190
PB-678	26º 40' 58"	80º 17' 52"	20.00	189
PB-679	26º 48' 42"	80º 17' 22"	22.00	174
PB-681	26º 58' 02"	80º 05' 38"	12.00	248
PB-712	26º 55' 10"	80º 08' 07"	14.00	280
PB-747	26º 56' 06"	80º 08' 24"	13.00	1,280
PB-830	26º 51' 06"	80º 24' 14"	22.00	220
PB-833	26º 52' 58"	80º 05' 40"	10.00	131
PB-834B	26º 34' 55"	80º 03' 08"	8.00	201
PB-836	26º 40' 49"	80º 32' 22"	12.00	240
PB-837	26º 47' 02"	80º 31' 34"	12.00	200
PB-838	26º 51' 34"	80º 37' 38"	14.00	84
PB-839	26º 41' 12"	80º 40' 03"	15.00	220
PB-841	26º 20' 00"	80º 32' 20"	20.00	250
PB-842	26º 20' 00"	80º 46' 40"	16.00	240
PB-843	26º 41' 53"	80º 48' 33"	13.00	575
PB-880	26º 54' 39"	80º 10' 29"	17.06	118
PB-1082	26º 50' 34"	80º 05' 01"	12.00	200
PB-1083	26º 50' 27"	80º 06' 00"	12.00	200
PB-1084	26º 50' 27"	80º 10' 02"	18.00	200
PB-1085	26º 50' 27"	80º 11' 57"	18.00	200
PB-1086	26º 50' 18"	80º 07' 58"	18.00	200
PB-1087	26º 45' 55"	80º 11' 52"	18.00	200
PB-1088	26º 45' 55"	80º 13' 44"	19.00	200
PB-1089	26º 42' 25"	80º 08' 47"	17.00	240
PB-1090	26º 37' 45"	80º 06' 40"	16.00	200
PB-1091	26º 37' 28"	80º 10' 25"	17.00	160
PB-1092	26º 36' 23"	80º 13' 25"	18.00	200
PB-1093	26º 36' 26"	80º 15' 15"	18.00	200
PB-1094	26º 36' 29"	80º 17' 14"	18.00	180
PB-1095	26º 31' 38"	80º 06' 47"	17.00	300
PB-1096	26º 31' 38"	80º 09' 52"	20.00	220
PB-1097	26º 31' 45"	80º 13' 43"	16.00	160
PB-1098	26º 48' 36"	80º 13' 01"	20.00	180
PB-1099	26º 52' 50"	80º 10' 36"	18.00	90
PB-1100	26º 20' 07"	80º 13' 45"	15.00	200
PB-1101	26º 24' 05"	80º 07' 18"	19.00	220
PB-1102	26º 27' 11"	80º 11' 14"	18.00	235
PB-1103	26º 24' 03"	80º 10' 16"	21.00	240
PB-1104	26º 26' 45"	80º 07' 18"	20.00	340
PB-1105	26º 19' 39"	80º 10' 09"	15.00	221
PB-1106	26º 22' 28"	80º 21' 49"	23.00	217
PB-1107	26º 28' 09"	80º 13' 16"	15.00	105
PB-1108	26º 24' 03"	80º 14' 13"	14.00	200
PB-1109	26º 51' 15"	80º 17' 31"	23.00	171
PB-1144	26º 58' 11"	80º 05' 13"	13.00	1,165
PB-1166	26º 54' 06"	80º 18' 22"	25.00	3,310
PB-1168	26º 23' 34"	80º 12' 11"	20.00	3,300
PB-1173	26º 38' 04"	80º 13' 57"	17.00	2,010
PB-1176	26º 44' 04"	80º 14' 04"	17.83	3,300
PB-1184	26º 48' 01"	80º 39' 59"	13.03	3,510
PB-1192	26º 31' 44"	80º 07' 17"	19.42	3,312
PB-1195	26º 30' 49"	80º 03' 45"	18.90	435
PB-1197	26º 55' 24"	80º 09' 22"	17.00	1,900
PB-1613	26º 54' 27"	80º 24' 15"	25.00	162
PB-1693	26º 42' 58"	80º 03' 49"	18.97	1,410
PB-1695	26º 40' 34"	80º 06' 09"	15.00	2,490
PB-1702	26º 28' 01"	80º 05' 59"	21.20	1,201
PB-1703	26º 26' 07"	80º 48' 37"	20.00	221
PB-1704	26º 23' 59"	80º 34' 34"	11.00	200.5
PB-1761	26º 21' 19.1"	80º 17' 41.8"	10.00	120
PB-1765	26º 21' 19"	80º 17' 42"	10.00	1,225
PB-1769	26º 35' 22"	80º 03' 30"	17.76	337
PB-1775	26º 20' 00"	80º 13' 13"	16.33	1,650
PB-1777	26º 41' 58"	80º 42' 57"	10.00	2,504
PB-1781	26º 42' 00.2"	80º 21' 50.6"	13.90	205
PB-1782	26º 45' 32.6"	80º 08' 18"	17.80	205.5
PB-1783	26º 45' 28.1"	80º 15' 48"	21.60	205
PB-1784	26º 24' 40"	80º 03' 54"	8.00	425
PB-1785	26º 26' 07.3"	80º 37' 00.4"	11.84	180
PB-1786	26º 28' 00.1"	80º 45' 13.7"	13.38	182
PB-1787	26º 27' 49.0"	80º 41' 21.0"	12.15	183
PB-1788	26º 22' 39.0"	80º 31' 46.0"	11.39	184.5
W-5435	26º 47' 28"	80º 58' 14"	5.00	1,025

Table 2. Sources of information and interpretations for wells on hydrostratigraphic sections *A-A′* and *B-B′* (figs. 4 and 5).

[All depths are in feet below land surface; abbreviations: FAS, Florida aquifer system; FGS, Florida Geological Survey, PBCWUD, Palm Beach County Water Utilities Department; SAS, surficial aquifer system; SPT, standard penetration test (split-barrel sampler); USGS, U.S. Geological survey]

USGS local well no.	Total depth (ft)/ aquifer system	Lithologic sampling method	Source of lithologic description	Author of lithologic description	Source of geologic and hydrogeologic unit boundary interpretations shown on figures 4 and 5
Hydrostratigraphic section *A-A′* (fig. 4)					
HE-1110	160 SAS	Continuous core	Reese and Cunningham, 2000	Cunningham, K.J.	Reese and Cunningham, 2000
PB-1703	221 SAS	Continuous core	Reese and Cunningham, 2000	Cunningham, K.J.	Reese and Cunningham, 2000
PB-1787	180 SAS	SPT with minor cored intervals	Ardaman and Assoc, Inc., 2003	Harrison, T.	none
PB-1785	180 SAS	SPT with minor cored intervals	Ardaman and Assoc, Inc., 2003	Scott, N.	none
PB-1704	200.5 SAS	Continuous core	Reese and Cunningham, 2000	Cunningham, K.J.	Reese and Cunningham, 2000
PB-1788	180 SAS	SPT with minor cored intervals	Ardaman and Assoc, Inc., 2003	Scott, N.	none
PB-1106	217 SAS	Rotary cuttings	Swayze and others, 1980	WAL	This study (base of SAS and top of Hawthorn Group only)
PB-1765 and	1,225 FAS	Rotary cuttings	FGS, well no. W-17986	Fischler, C.	For below 120 ft.: Fish, 1988 and Bennett and others, 2001
PB-1761 (at same site)	120 SAS	Continuous core	This study	Reese, R.S.	This study, including paleontologic study by G. L. Wingard, written comm., 2006
PB-1775	1,650 FAS	Rotary cuttings	PBCWUD, 2003	unknown	PBCWUD, 2003
PB-1105	220 SAS	Rotary cuttings	Swayze and others, 1980	unknown	none
G-2916	1,200 FAS	Rotary cuttings	CH2M HILL, 1997	unknown	CH2M HILL, 1997
Hydrostratigraphic section *B-B′* (fig. 5)					
PB-1784	425 SAS	Rotary cuttings	CH2M HILL, 2004	STS and AJS	CH2M HILL, 2004
PB-675	387 SAS	Rotary cuttings	Schneider, 1976	Land, L.F.	This study (base of SAS and top of Hawthorn Group only)
PB-1195	435 SAS	Rotary cuttings	CH2M HILL, 1993	unknown	CH2M HILL, 1993
PB-669	345 SAS	Rotary cuttings	Schneider, 1976	Land, L.F.	This study (base of SAS and top of Hawthorn Group only)
PB-600	345 SAS	Rotary cuttings	Schneider, 1976	unknown	This study (base of SAS and top of Hawthorn Group only)
PB-1693	1,191 FAS	Rotary cuttings	CH2M HILL, 1998	unknown	CH2M HILL, 1998
PB-652A	314 SAS	Rotary cuttings	Schneider, 1976	Land, L.F.	Johnson, 1988 and this study for base SAS
PB-1082	200 SAS	Rotary cuttings	Swayze and others, 1980	Fischer, J.N.	none
PB-833	520 SAS	Rotary cuttings	Schneider, 1976	Scott, W.B.	Johnson, 1988 and Miller, 1987 for base of SAS
PB-1144	1,038 FAS	Rotary cuttings	USGS well files	unknown	USGS well files and this study

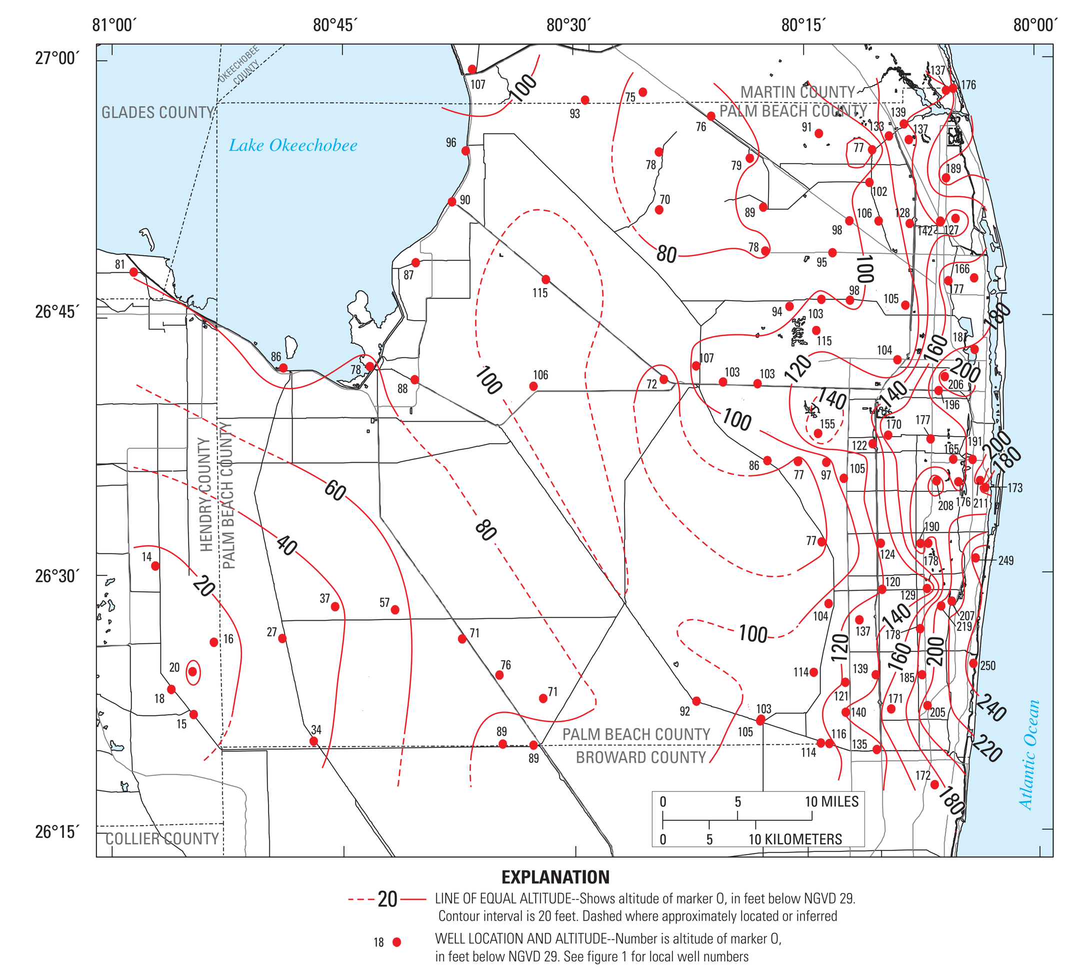

Figure 6. Altitude of marker O in the surficial aquifer system. This marker is approximately at the top of the Ochopee Limestone Member of the Tamiami Formation.

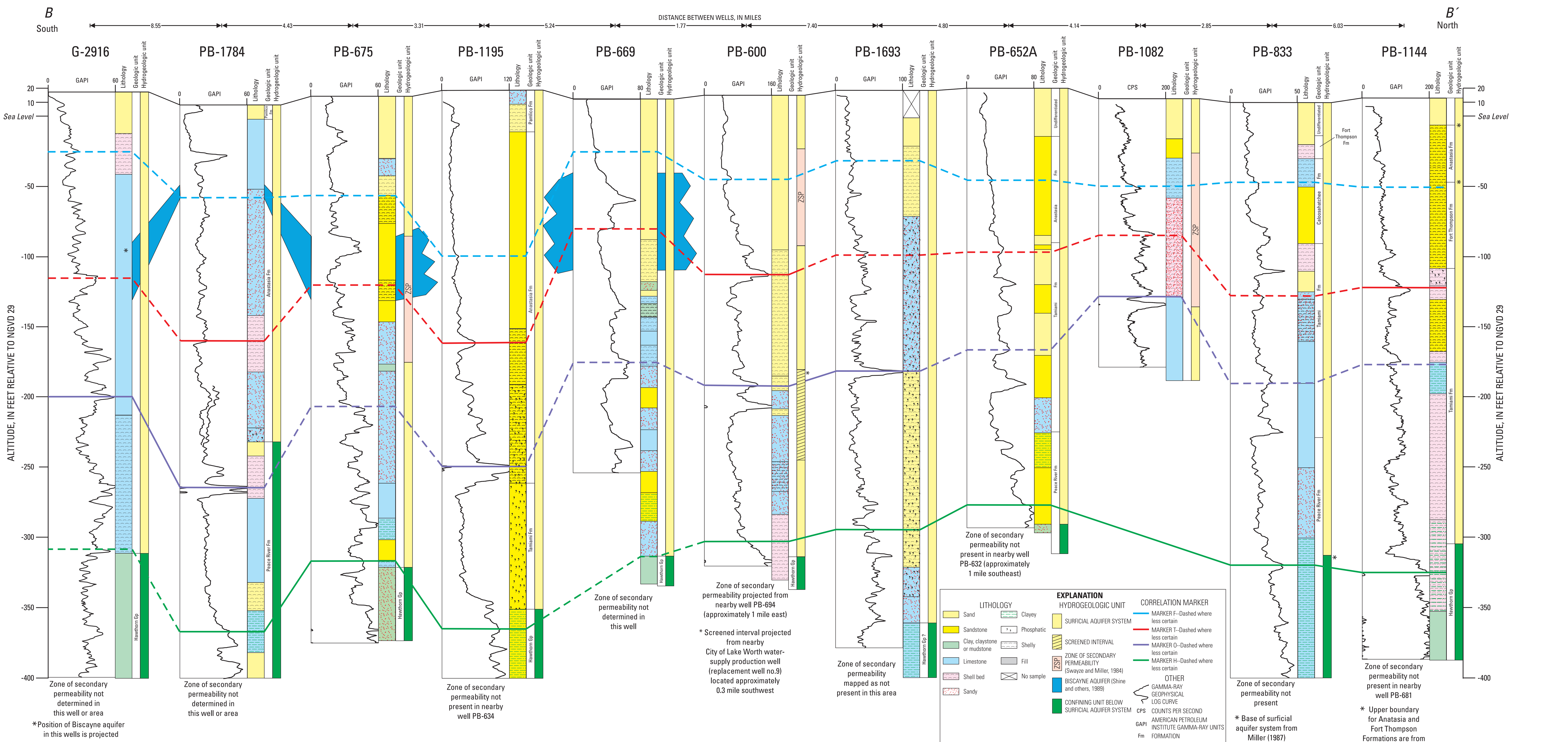

Figure 5. Hydrostratigraphic section *B-B′*.

HYDROSTRATIGRAPHIC FRAMEWORK AND SELECTION AND CORRELATION OF GEOPHYSICAL LOG MARKERS IN THE SURFICIAL AQUIFER SYSTEM, PALM BEACH COUNTY, FLORIDA

By
Ronald S. Reese and Michael A. Wacker
2007