Southwest Florida
Water Management District

Construction of a Saltwater Interface Monitor Well at Tom Bennett Park in Manatee County, Florida

Southwest Florida Water Management District
Geohydrologic Data Section

April 2015

Cover Photo: George DeGroot, Senior Driller and Barry Morely, Well Driller Assistant II, with the Geohydrologic Data Section, constructing the Tom Bennett Park saltwater interface monitor well, December 2013.

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By Michael T. Gates, P.G.

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Suggested citation:
Gates, M. T., 2015, Construction of a Saltwater Interface Monitor Well at Tom Bennett Park in Manatee County, Florida: Southwest Florida Water Management District, 45 p.

The hydrogeologic evaluations and interpretations contained in *Construction of a Saltwater Interface Monitor Well at Tom Bennett Park in Manatee County, Florida* have been prepared by or approved by a licensed Professional Geologist in the State of Florida, in accordance with Chapter 492, Florida Statutes.

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Date: 4/27/2015

Foreword

The Geohydrologic Data Section administers the Regional Observation and Monitor-well Program (ROMP) at the Southwest Florida Water Management District (District). The ROMP was started in 1974 in response to the need for hydrogeologic information by the District. The focus of the ROMP is to determine the flow characteristics and water quality of the groundwater systems which serve as the primary source of water supply within southwest Florida. The original design of the ROMP consisted of an inland 10-mile grid network composed of 122 well sites and a coastal transect network composed of 24 coastal monitor transects of two to three well sites each. The number of wells at a well site varies with specific regional needs; usually two to five permanent monitor wells are constructed at each site. The numbering system for both networks generally increase from south to north with ROMP-labeled wells representing the inland grid network and TR-labeled wells representing the coastal transect network.

The ROMP networks have been the primary means for data collection; however, in recent years, changing District directives have created the need for more project-specific data collection networks outside the original two well networks for various programs throughout the District. The broad objectives at each well site are to determine the geology, hydrology, water quality, and hydraulic properties, and to install wells for long-term monitoring, depending on the goal of each project. Site activities include coring, testing, and well construction. These activities provide data for the hydrogeologic and groundwater quality characterization of the well sites. These characterizations are used to ensure the monitor wells are properly constructed. At the completion of each well site, a summary report is generated and can be found at the District's website at www.watermatters.org/data. The monitor wells form the backbone of the District's long-term aquifer monitoring networks, which supply critical data for the District's regional models and hydrologic conditions reporting.

Sandie Will

Manager

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
ton (short ton)	907.18474	kilograms (kg)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
	Flow Rate	
gallons per minute (gpm)	0.003785	cubic meters per minute (m^3/min)

Acronyms and Abbreviations

APT	aquifer performance test
BLS	below land surface
CGWQMN	Coastal Groundwater Quality Monitoring Network
CME	Central Mining Equipment
District	Southwest Florida Water Management District
GEO	Geohydrologic Data Section
MIA	Most Impacted Area
ROMP	Regional Observation and Monitor-well Program
SWUCA	Southern Water Use Caution Area
UDR	Universal Drill Rigs
WMIS	Water Management Information System

Construction of a Saltwater Interface Monitor Well at Tom Bennett Park in Manatee County, Florida

By Michael T. Gates, P.G.

Introduction

The District constructed a saltwater interface monitor well in the county-owned Tom Bennett Park (Bennett Park) in Manatee County in 2014. An unused 10-inch diameter well on the property was converted to a monitor well that will be used to monitor the position of the saltwater interface (saltwater-freshwater interface) in the Upper Floridan aquifer. The saltwater interface is defined in this report as the depth at which the chloride concentration of the groundwater is between 250 milligrams per liter (mg/L) and 1,000 mg/L. The Manatee County well location was selected to infill a gap in the coastal monitor well network used to monitor saltwater intrusion in the Southern Water Use Caution Area (SWUCA). Figure 1 shows the location of the SWUCA and the location of the Bennett Park well site.

The District defines a Water Use Caution Area (WUCA) as an area where regional action is necessary to address cumulative water withdrawals, which are causing or may cause adverse impacts to the water and related natural resources or the public interests (SWFWMD, 2014). The SWUCA encompasses all of Manatee, Sarasota, Hardee, and DeSoto counties and portions of Hillsborough, Charlotte, Polk and Highlands counties. A recovery strategy for the SWUCA (SWFWMD, 2006) was enacted by administrative rule in 2007. The rule mandates a review process every five years to evaluate progress and to make recommendations for further actions regarding the management of water resources in the SWUCA, which includes continued groundwater-quality monitoring for saltwater intrusion.

The Bennett Park monitor well was constructed in two phases: (1) exploratory core drilling and water quality testing to locate the saltwater interface within the Upper Floridan aquifer, and (2) design and construction of the monitor well. District staff conducted the exploratory core drilling and testing from August 5, 2013, to September 18, 2013, using the District's Central Mining Equipment (CME) 85 drilling rig. District staff began constructing the monitor well on September 18, 2013, and completed the well on February 14, 2014, using the CME 85 drilling rig. The Bennett Park monitor well has now been included in the District's Coastal Groundwater Quality Monitoring Network (CGWQMN) and Water Use Permit Network (WUPNET). These combined networks comprise more than 350 monitor wells across 13 counties. The CGWQMN and WUPNET were established to monitor the groundwater quality in areas of the District susceptible to saltwater intrusion and/or upwelling of mineralized groundwater (Kraft and others, 2011).

Site Location

Bennett Park is a 180-acre county-owned park located west of Interstate 75 in the City of Bradenton in Manatee County, Florida. The park is located just east of the confluence of the Manatee River and the Braden River (fig. 2) and is approximately 11 miles east of Tampa Bay. The well site is located in the southeast corner of the park in the eastern half of Section 27, Township 34 South, Range 18 East, at latitude 27° 29' 50.37" north and longitude 82° 29' 00.23" west. The land surface elevation of the well site is approximately 10 feet above the National Geodetic Vertical Datum of 1929 (NGVD 29). The location of the well site is shown in figure 2.

Driving directions to the well site are as follows: From Interstate 75 in Manatee County, take exit 220 onto State Road 64 west. Drive west for 0.8 miles, turn right (north) onto Cypress Creek Boulevard. Drive north 0.3 miles, well is located on west side of Cypress Creek Boulevard inside Bennett Park. Access to the well is from Cypress Creek Boulevard.

Methods

Data collected during the drilling and construction of the Bennett Park well include lithologic, water level, and water quality data. Geologic core samples were collected for lithologic description using the hydraulic rotary coring method. Water levels were measured with electronic water level meters. An off-bottom, inflatable packer was used to isolate sections of the borehole for collection of discrete water quality samples. In addition, geophysical logs and video logs were collected at various intervals while drilling and constructing the well. Appendix A presents a detailed description of the data collection methods used by the Geohydrologic Data Section.

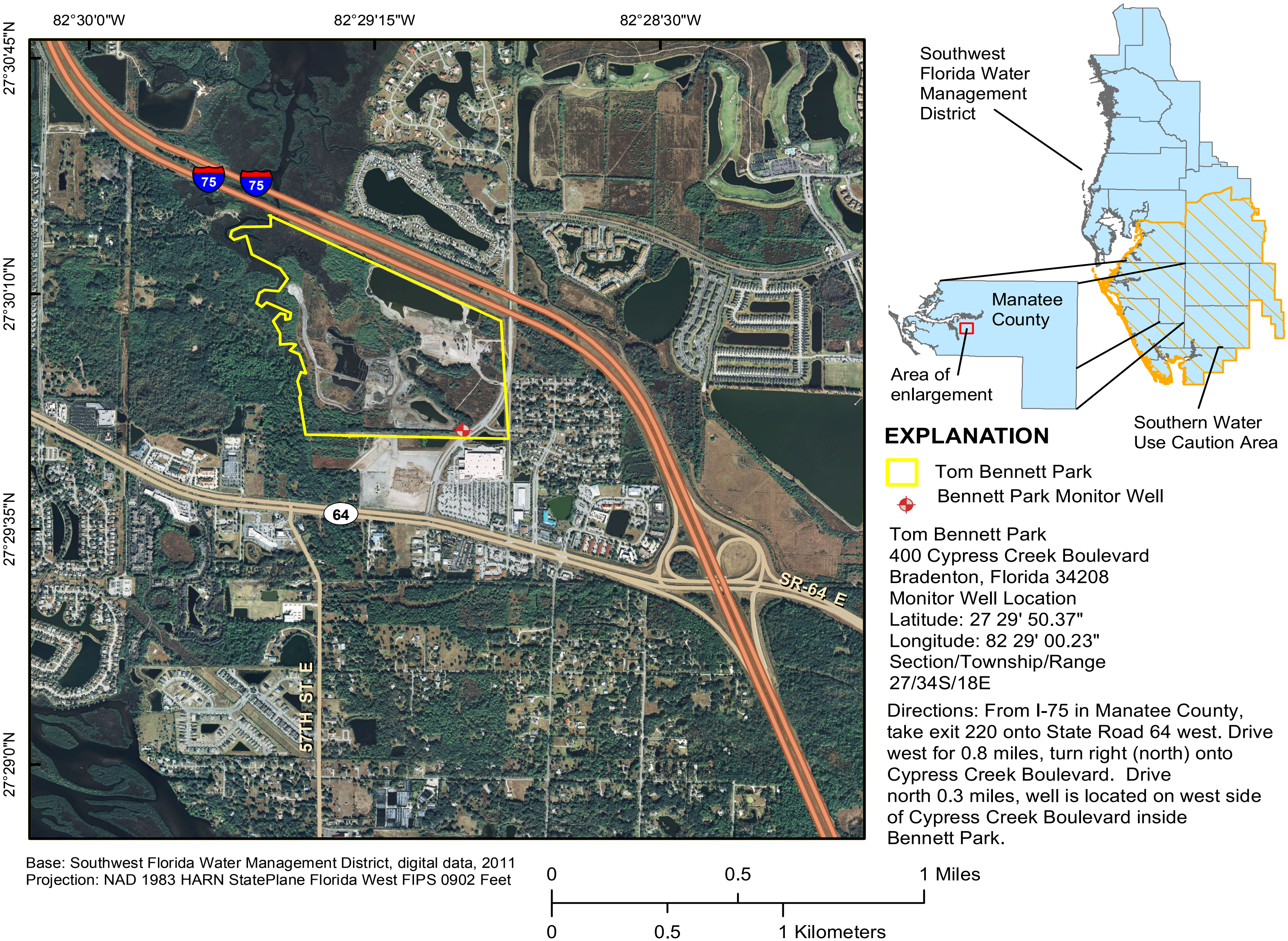


Figure 1. General location of the Bennett Park well site in Manatee County, Florida.

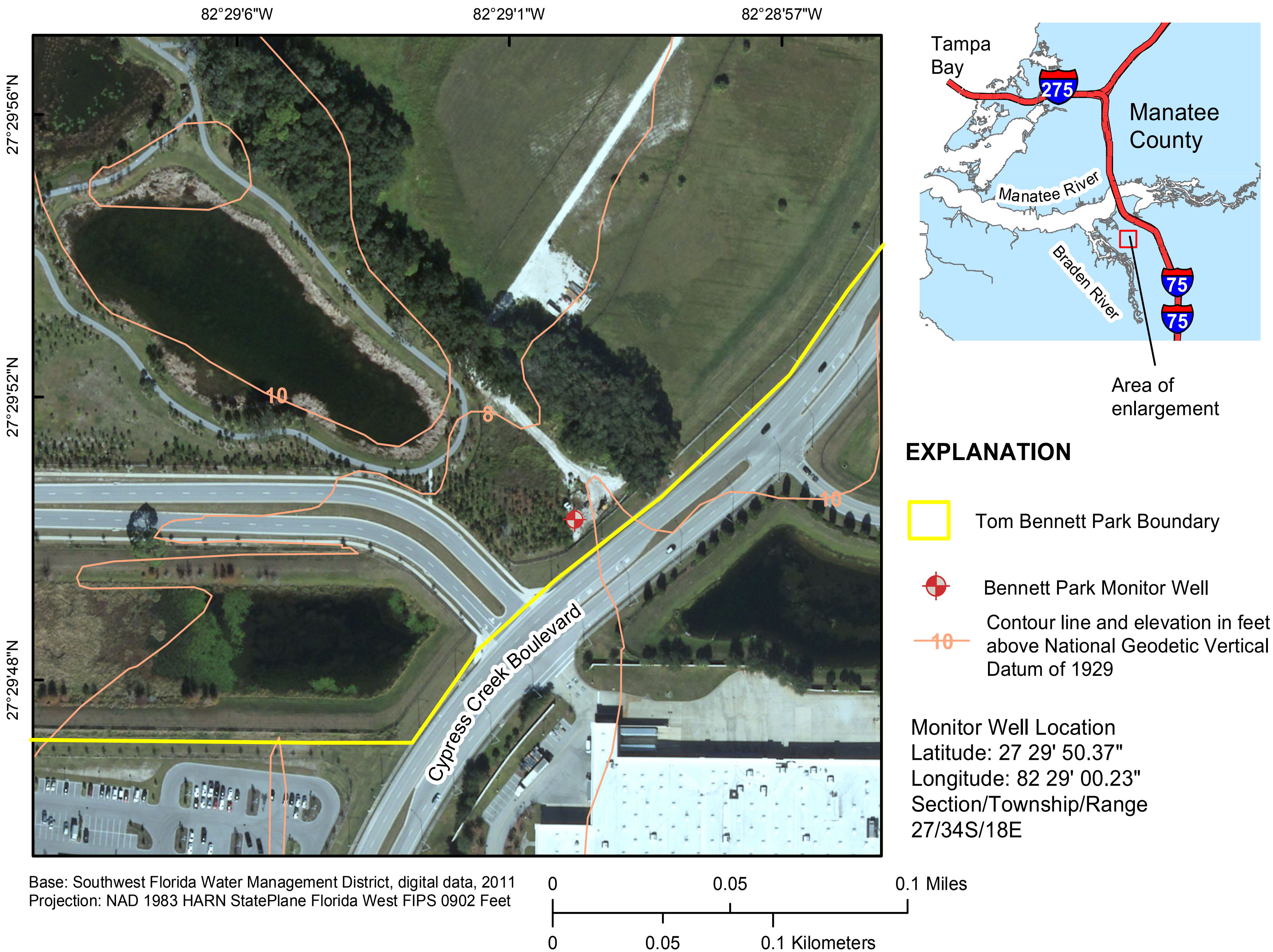


Figure 2. Well site location at Bennett Park in Manatee County, Florida.

Lithologic Sampling

Geohydrologic Data staff performed core drilling to collect continuous rock samples from 925 feet below land surface (bls) to 1,280 feet bls using the District-owned CME 85 drilling rig. Prior to core drilling, the existing 10-inch diameter, 890 foot deep well was reconfigured by installing and grouting 5-inch diameter poly vinyl chloride (PVC) casing in the existing borehole. Continuous 2-inch diameter core samples were collected using a 5-foot long core barrel, and retrieved using the wire line retrieval method. The on-site geologist collected, described, and boxed the samples for further description and storage.

Water Quality Sampling

Thirteen groundwater samples were collected at specified depths for laboratory analysis while core drilling. The samples were collected either from the open borehole interval below the casing or from discrete borehole intervals isolated with the off-bottom packer. All samples were collected from the discharge line after allowing the interval to flow or by pumping the borehole via the airlifting method. A portion of each sample was analyzed in the field for temperature, specific conductance, pH, chloride, and sulfate. The remainder of each sample was prepared and delivered to the District's Chemistry Laboratory for analyses of specific conductance, chloride and sulfate. Twenty-four additional samples collected while drilling, were analyzed in the field for specific conductance, temperature, pH, chloride, and sulfate.

Geophysical Logging

Borehole geophysical logs were collected during exploratory core drilling and during well construction to help identify stratigraphic boundaries, delineate permeable zones and confining units, characterize water quality, and determine casing points and grouting requirements. All logs were collected using the District-owned Century® geophysical logging equipment. In addition, video logs were collected during well construction to observe obstructions and fractured intervals in the borehole. Geophysical logs were collected to a depth of 1,150 feet bls. Attempts to log below 1,150 feet were unsuccessful because the borehole was partially obstructed by rock fragments. Table 1 presents a summary of the geophysical logs run at the Bennett Park well site. The geophysical logs are presented in appendix B.

Exploratory Drilling and Well Construction

The District began mobilizing equipment to the Bennett Park well site on June 10, 2013. The unpaved path to the well site became rutted and impassable after several days of heavy rainfall. Approximately 2,800 tons of shell was delivered to the site for construction of a shell road between the well site and the paved road at the park entrance. District staff installed and spread the shell from June 10, 2013, to June 15, 2013, creating a 1,000-foot temporary road to the well site.

The District-owned CME 85 was used for all exploratory core drilling, testing, and well construction. Modification of the existing 10-inch diameter steel cased well began on June 17, 2013. The existing well consisted of 10-inch steel casing extending from land surface to 215 feet bls and a nominal 8-inch borehole extending from 215 to 890 feet bls (appendix B, fig. B-1). The Upper Floridan aquifer head level in the well was approximately 4 feet above land surface during June 2013 and the well flowed approximately 150 gallons per minute (gpm). In an effort to lower the head level in the well so that the CME 85 drill rig could be positioned over the well, District staff cut the steel well casing below ground and installed an 8-inch diameter PVC tee. The plan was to lower the head level by diverting the flow of the well through an 8-inch PVC discharge pipe plumbed to the tee. The discharge pipe was connected to silt collection bags that emptied into a creek north of the well. This plan proved ineffective at controlling the flow because the head level in the well continued to rise daily. Eight-inch PVC casing was then installed to 7 feet above land surface to keep the well from flowing. District staff installed a scaffolding platform approximately 5 feet above land surface in order to work on the well.

Geophysical and video logs run in the existing well showed that the 10-inch steel casing was highly corroded and in very poor condition. In addition, the caliper log showed the open hole interval below the casing ranged from eight to 12-inches in diameter (appendix B, fig. B-1). The poor condition of the existing 10-inch steel casing and the large diameter of the open hole necessitated the installation of additional casing to support the drill string in the open hole interval while drilling.

Eight hundred and ninety feet of 5-inch diameter standard dimension ratio 17 (SDR 17) PVC casing was installed to land surface from July 1 to 2, 2013. From July 3 to 29, 2013, District staff grouted the 5-inch PVC casing in stages. The first stage of grout was installed using the pressure grouting method. The remainder of the annulus was grouted using the tremie method. A 4.75-inch tri-cone rotary bit installed on 3-inch HQ drill rods was used to drill out the grout inside the 5-inch PVC casing from 500 to 890 feet bls starting on July 29, 2013. Drilling with the tri-cone bit continued below the casing to 925 feet bls.

Hydraulic rotary core drilling to locate the saltwater interface began at 925 feet bls on August 5, 2013. A nominal 3-inch diameter hole was drilled using a diamond core bit. Core drilling continued until reaching 1,280 feet bls on September 16, 2013.

After locating the saltwater interface, drilling to prepare the well for installation of the final casing began on September 18, 2013. The 3-inch nominal core hole was reamed to 4.75-

Table 1. Summary of borehole geophysical logs collected at the Bennett Park well site in Manatee County, Florida.

[BLS, below land surface; PVC, poly-vinyl chloride]

Date	Geophysical tool number	Geophysical logs	Borehole Diameter (inches)	Casing Type	Casing Depth (feet BLS)	Total Depth (feet BLS)	Reason for Logging
3/2/2013	9165C	Caliper/gamma	8	Steel	220	894	Inspection of existing well
3/7/2013	8144C	Multifunction[1]	8	Steel	220	895	Inspection of existing well
3/7/2013	9511C	Induction	8	Steel	220	891	Inspection of existing well
12/2/1013	8144C	Multifunction	5	PVC	890	1155	Inspect borehole
12/2/2013	9511C	Induction	5	PVC	890	1153	Inspect borehole
12/3/2013	9465C	Caliper/gamma	5	PVC	890	1146	Inspect borehole for obstructions

[1] Multifunction- includes natural gamma, 16-inch normal resistivity, 64-inch normal resistivity, fluid resistivity, lateral resistivity, spontaneous potential, single point resistance, temperature and delta temperature

inches from 925 to 1,150 feet bls using a tri-cone rotary bit. Drilling was difficult through the hard dolostone of the Avon Park Formation. Loose fragments of rock were encountered in the numerous fractured intervals below 925 feet bls, as indicated on the caliper log (appendix B, fig. B-2). Numerous sections of the borehole required re-drilling because of dolostone rock fragments falling into the borehole.

On December 3, 2013, at a depth of 1,150 feet bls, the 4.75-inch tri-cone drill bit was replaced with a nominal 4-inch HQ core bit fitted with a tri-cone insert bit (termed casing advancer) in an effort to improve the drilling rate while reaming the remainder of the borehole. Reaming with the 4-inch casing advancer continued from 1,150 feet bls until reaching 1,250 feet bls on January 13, 2014.

On January 15, 2014, the HQ casing was installed to the bottom of the borehole (1,250 feet bls) to ensure that the borehole was unobstructed before installing the final well casing and screen. After determining the borehole was unobstructed, the HQ casing was retrieved from 1,250 feet bls to 1,140 feet bls and temporarily secured. The HQ casing was used to keep loose rock fragments from falling into the borehole during installation of the final casing and screen. On January 16, 2014, staff began installing 1.5-inch diameter, schedule 40 PVC screen, two 1-inch x 4-inch diameter rubber formation packers, and 1-inch diameter, schedule 40 PVC casing (through HQ casing) into the borehole. In addition, 0.75-inch, schedule 40 tremie pipe was installed in the borehole to 1,140 feet bls. The tremie pipe was used to pump grout from the surface to the bottom of the borehole in stages. The 1.5-inch PVC screen was fabricated on-site by drilling 0.25-inch holes in the pipe at 1-foot intervals. The 1.5-inch PVC screen was installed from 1,250 to 1,151 feet bls, the two 1-inch x 4-inch formation packers were attached to the 1-inch casing and installed at 1,151 feet bls and 1,149 feet bls, and the 1-inch diameter PVC casing was installed from 1,151 feet bls to land surface.

Quartz sand was installed through the 0.75-inch PVC tremie pipe into the annulus between the 1-inch PVC casing and the borehole in an attempt to form a bridge above the formation packers, prior to installing the cement grout. Six bags of 6-20 grain size quartz sand were installed in the annulus of the borehole above the formation packers. Measurements made inside the 1-inch casing revealed that the 6-20 quartz sand had fallen past the formation packers installed at 1,149 feet bls and 1,151 feet bls and filled the borehole and PVC screen from 1,250 to 1,229 feet bls. Eight bags of silica gravel were then installed in the borehole, successfully forming a bridge above the formation packers from 1,140 to 1,150 feet bls. Portland cement grout was then pumped into the borehole through the 0.75-inch PVC tremie pipe. The grout was installed in the borehole annulus from 1,140 to 1,095 feet bls in 10-gallon increments.

After the grout installation, 2-inch diameter PVC casing was installed around the 1-inch PVC casing from 1,095 feet bls to land surface to provide additional support for the 1-inch casing in the open section of the borehole between 889 feet bls and 1,095 feet bls. Finally, the HQ casing was removed from the borehole. The well was completed on February 14, 2014.

The Bennett Park monitor well was completed as a dual-zone well, monitoring two separate intervals of the Upper Floridan aquifer. The U FLDN (APHPZ) SALTWATER INTERFACE MONITOR (well number 1) well consists of 99 feet of 1.5-inch PVC screen placed in a 4-inch diameter open hole interval from 1,151 to 1,250 feet bls and is designed to monitor the chloride concentration in the Avon Park high-permeability zone. One-inch PVC casing is attached to the 1.5-inch screen and extends from 1,149 feet bls to 4.5 feet above land surface. The U FLDN AQ MONITOR (well number 2) well was designed to monitor the water level in the Upper Floridan aquifer above the saltwater interface. This monitor well consists of a 5-inch open hole interval from 889 to 1,095 feet bls and 5-inch casing extending from 889 feet bls to 4.5 feet above land surface. The wellhead consists of a 5-inch PVC flange bolted to the top of the 5-inch PVC casing.

The U FLDN (APHPZ) SALTWATER INTERFACE MONITOR well is accessed through a 1-inch valve that is plumbed to the 5-inch casing flange. The U FLDN AQ MONITOR well is accessed through a 1.5-inch valve that is also plumbed to the 5-inch casing flange. The U FLDN (APHPZ) SALTWATER INTERFACE MONITOR well was developed at nine gpm for 1 hour. The U FLDN AQ MONITOR well was developed at 50 gpm for 1 hour. The discharge water for both wells was clear and sediment free at the end of development. The as-built diagram for the completed well is presented in figure 3 and the well construction details are presented in table 2.

Geology

A review of published reports from the area indicate the geologic units underlying the well site include in ascending order: the Avon Park Formation, Ocala Limestone, Suwannee Limestone, Hawthorn Group sediments (including the Tampa Member of the Arcadia Formation, the undifferentiated Arcadia Formation, and the Peace River Formation), and undifferentiated sand and clay deposits. Exploratory core drilling began at 925 feet bls in the Ocala Limestone and continued to 1,280 feet bls, ending in the Avon Park Formation. The Avon Park Formation and the Ocala Limestone are the only units described in this study. A diagram of the general stratigraphy underlying the site is shown in figure 4. The lithologic log of the core samples is presented in appendix C. Digital photographs of the core samples are presented in appendix D.

Avon Park Formation (Middle Eocene)

The middle Eocene age Avon Park Formation extends from approximately 985 to more than 1,280 feet bls (end of core drilling). A layer of organic-rich clay (indicated by the gamma-ray response in appendix B, fig. B-1) marks the top of the Avon Park Formation at a depth of 985 feet bls. Additionally, numerous molds of the echinoid Neoloaganum dalli, an index fossil of the Avon Park Formation, were observed below 985 feet bls. The average core recovery in the Avon Park Formation was 89 percent.

From 985 to 997 feet bls, the lithology is yellowish gray to dark, yellowish brown, well indurated, sucrosic dolostone. The dolostone is hard, dense, and contains numerous echinoid molds and casts. Fractures are present below 990 feet bls.

Between 997 and 1,047 feet bls, the Avon Park Formation consists of yellowish gray, moderate to well indurated, argillaceous dolostone. The formation is highly fractured and less dense than the section above as indicated by the decrease in resistivity on the single-point (RES), short normal [RES (16N)], and long normal [RES964N)] resistivity logs (appendix B, fig. B-2). Fractures, some extending to more than 20-inches are indicated on the caliper log (appendix B, fig. B-2).

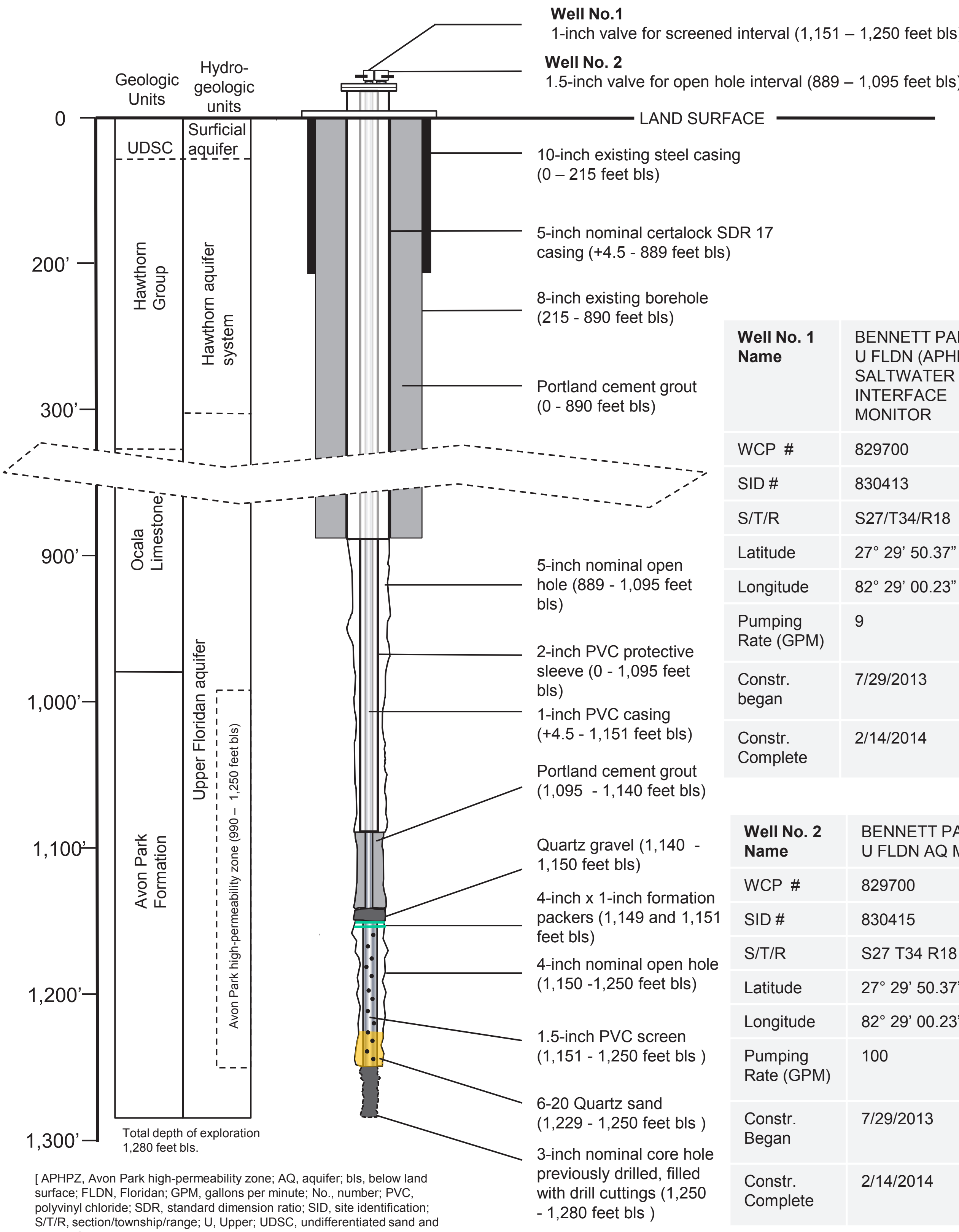
Very pale orange to yellowish gray, moderately indurated wackestone is present from 1,047 to 1,056 feet bls. Fossils are not common and fracturing is less common than the interval above. A lens of highly weathered, organic-rich limestone is present from 1,055 to 1,056 feet bls.

From 1,056 to 1,080 feet bls hard, crystalline dolostone predominates. The dolostone is very light gray to yellowish gray, well indurated, and fractured. This section of the forma-

Table 2. Well construction details for the saltwater interface monitor well at the Bennett Park well site in Manatee County, Florida.

[als, above land surface; APHPZ, Avon Park highly permeable zone; AQ, aquifer; bls, below land surface; deg, degree; min, minutes; sec, seconds; PVC, polyvinyl chloride; SID, site identification; U FLDN, Upper Floridan; WCP, well construction permit]

Well Name	SID	WCP	Well Type	Well Diameter (inches)	Casing Depth (feet bls)	Total Depth (feet bls)	Depth to Water (feet als) 2/20/2014	Latitude (deg min sec)	Longitude (deg min sec)
BENNETT PARK U FLDN (APHPZ) SALTWATER INTERFACE MONITOR	830413	829700	PVC Screen	Casing - 1 Screen - 1.5	1,150	1,250	4.17	27 29 50.37	82 29 00.23
BENNETT PARK U FLDN AQ MONITOR	830415	829700	Open hole	Casing - 5 Borehole - 5	889	1,095	4.08	27 29 50.37	82 00.23



Well No. 1 Name	BENNETT PARK U FLDN (APHPZ) SALTWATER INTERFACE MONITOR
WCP #	829700
SID #	830413
S/T/R	S27/T34/R18
Latitude	27° 29’ 50.37”
Longitude	82° 29’ 00.23”
Pumping Rate (GPM)	9
Constr. began	7/29/2013
Constr. Complete	2/14/2014

Well No. 2 Name	BENNETT PARK U FLDN AQ MONITOR
WCP #	829700
SID #	830415
S/T/R	S27 T34 R18
Latitude	27° 29’ 50.37”
Longitude	82° 29’ 00.23”
Pumping Rate (GPM)	100
Constr. Began	7/29/2013
Constr. Complete	2/14/2014

[APHPZ, Avon Park high-permeability zone; AQ, aquifer; bls, below land surface; FLDN, Floridan; GPM, gallons per minute; No., number; PVC, polyvinyl chloride; SDR, standard dimension ratio; SID, site identification; S/T/R, section/township/range; U, Upper; UDSC, undifferentiated sand and clay; WCP, well construction permit; latitude and longitude are in degrees, minutes, seconds]

Figure 3. As-built diagram for the salt-water interface monitor well at the Bennett Park well site in Manatee County, Florida.

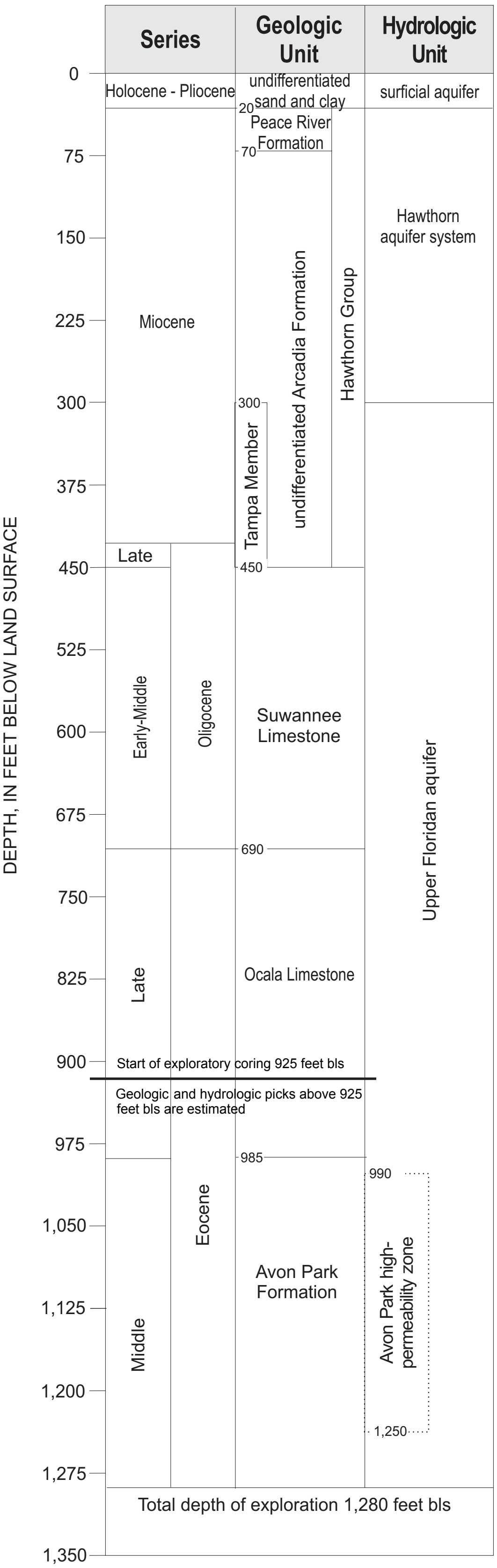


Figure 4. Stratigraphic column detailing the hydrogeologic setting at the Bennett Park well site in Manatee County, Florida.

tion is very hard and dense as indicated by the increase in resistivity (appendix B, fig. B-2).

A section of moldic, fossiliferous dolostone is present from 1,080 to 1,084 feet bls. This section is dark yellowish brown, well indurated, and contains numerous echinoid molds. A fracture extending to 12-inches is indicated on the caliper log at 1,080 feet bls (appendix B, fig. B-2). A decrease in resistivity also occurs in this interval as indicated on the resistivity logs (appendix B, fig. B-2).

Between 1,084 and 1,119 feet bls, the lithology is predominantly light gray to brownish gray, crystalline dolostone. This section is hard, dense, and contains numerous fractures. Small euhedral dolomite crystals are common in the fractures and on the broken faces of rock fragments. The borehole wall shows less evidence of fractures in this section of the formation as indicated by the caliper log trace (appendix B, fig. B-2).

From 1,119 to 1,136.5 feet bls the lithology is yellowish gray to dark yellowish brown, well-indurated, moldic, dolostone. The dolostone is hard, dense, and highly fractured. Dolomite crystals are present in fractures and on the broken faces of rock fragments. Lenses of organics are present at 1,116, 1,125, and 1,131 feet bls as indicated by the counts per second (CPS) on the natural gamma-ray log [GAMMA (NAT)] for this section (appendix B, fig. B-2).

Below 1,136.5 feet bls, hard, dense, crystalline dolostone predominates. From 1,136.5 to 1,197 feet bls, the lithology is light gray to dark, yellowish brown, well-indurated dolostone. Dolomite crystals are common in fractures. Some fractures in this section have been completely filled with euhedral dolomite crystals. Sections of moldic, weathered dolostone and interbedded organics are present from 1,145 to 1,154 feet bls and from 1,160.2 to 1,162 feet bls.

From 1,197 to 1,215 feet bls, the lithology is light gray to yellowish gray, well-indurated dolostone. Some dolomite crystal-filled fractures and fossils are present. The bottom of the section appears to be recrystallized with angular fragments scattered in a calcareous cement matrix.

From 1,215 to 1,280 feet bls, the lithology consists of yellowish brown to dark yellowish brown moderately-indurated dolostone. Molds are common and some organic laminations are present between 1,247 and 1,253 feet bls. This section of the formation appears more weathered than the section above.

Ocala Limestone (Late Eocene)

The Ocala Limestone is late Eocene in age and extends from approximately 690 to 985 feet bls. At the Bennett Park site, core samples were collected only in the lower section of the Ocala Limestone, from 925 to 985 feet bls. The Ocala Limestone is predominantly white to yellowish gray, well-indurated, fossiliferous limestone. The texture varies from moldic packstone to grainstone. The interval from 945 to 960 feet bls is highly fractured. A caliper log shows this section of the borehole extending to more than 20 inches (appendix B, fig. B-2). An interval of very hard, dense dolostone extending from 965 to 985 feet bls marks the contact with the underlying Avon Park Formation. This interval is indicated by the increase in the resistivity on the single-point (RES), short-normal [RES (16N)], and long-normal [RES (64N)] resistivity logs (appendix B, fig. B-2). Common fossils in the Ocala Limestone include mollusks, gastropods, pelecypods, corals, and foraminifera including Lepidocyclina sp. (Arthur and others, 2008).

Hydrogeology

Hydrogeologic units present at the Bennett Park well site include in descending order: the surficial aquifer, Hawthorn aquifer system (also termed intermediate aquifer system), and the Floridan aquifer system. The exploratory drilling and data collection began at 925 feet bls and ended at 1,280 feet bls in the Upper Floridan aquifer. A limited section of the Upper Floridan aquifer was characterized during the test drilling. The tops and thicknesses of the hydrologic units present at the site were estimated from the hydrogeologic delineations in Arthur and others (2008) and Decker (1989). Figure 4 presents a depiction of the hydrogeology at the Bennett Park well site.

The naming convention for the hydrogeologic units in this report is consistent with guidelines proposed by Laney and Davidson (1986) and the North American Stratigraphic Code (2005). A comparison of nomenclature used in this report (District nomenclature that is not site-specific) and previously published reports is presented in appendix E.

The Upper Floridan aquifer extends from approximately 300 feet bls to more than 1,280 feet bls (the end of exploratory drilling) at the well site. The Upper Floridan aquifer consists of the Tampa Member of the Arcadia Formation, the Suwannee Limestone, the Ocala Limestone, and the Avon Park Formation (Decker, 1989). The most permeable section of the Upper Floridan aquifer is present from approximately 990 to 1,250 feet bls in a highly fractured dolostone section of the Avon Park Formation (fig. 3). This section of the formation is termed the Avon Park high-permeability zone in this report. The numerous fractures within this interval are visible on the caliper (CALIPER) log (appendix B, fig. B-2).

The most recent maps of the potentiometric surface of the Upper Floridan aquifer in the area near the Bennett Park well show groundwater levels ranged from about 10 feet NGVD 29 in May 2010 to around 20 feet NGVD 29 in September 2010 (fig. 5). The highest water level recorded during construction of the well was 12 feet above land surface or about 22 feet NGVD 29 on October 2, 2013. A water level of 4.08 feet above land surface was measured in the U FLDN AQ MONITOR on February 20, 2014. This well will be added to a network of monitor wells used to produce seasonal potentiometric surface maps of the Upper Floridan aquifer in the Most Impacted Area (MIA) of the SWUCA.

Groundwater Quality

Groundwater samples were collected during exploratory drilling to determine the depth of the saltwater interface at the Bennett Park well site. Thirteen groundwater samples were collected and sent to the District Chemistry Laboratory for analyses, and an additional 24 groundwater samples were analyzed in the field. The laboratory samples were collected from 925 to 1,280 feet bls and analyzed for chloride, sulfate, and specific conductance, only. The laboratory results from the groundwater samples are presented in table 3 and the field analyses are presented in appendix F.

The national secondary drinking water standards for sulfate and chloride are 250 mg/L, and 250 mg/L, respectively (USEPA, 2011). The chloride concentration of samples collected while exploratory drilling ranged from 30 mg/L to 315 mg/L. The chloride concentration began to exceed the secondary standard below 1,140 feet bls. The secondary standard for sulfate was exceeded in all laboratory-analyzed samples collected. Sulfate concentration ranged from 470 mg/L to 1,370 mg/L. Specific conductance values ranged from 1,147 micromhos per centimeter (µmhos/cm) to 3,001 µmhos/cm.

The location of the saltwater interface as determined from chloride concentrations in groundwater (250 mg/L to 1,000 mg/L) occurs between 1,140 feet and 1,200 feet bls. The first sample to exceed the 250 mg/l chloride concentration (286 mg/L) was collected after drilling from 1,140 to 1,150 feet bls. The open hole interval at the time the sample was collected extended from 930 feet bls (casing depth) to 1,150 feet bls. The chloride concentration of the sample was 286 mg/L (table 3). The highest chloride concentration (315 mg/L) was collected with the off-bottom packer installed at 1,190 feet bls and the bottom of the borehole at 1,200 feet bls. The chloride concentration began to decrease in samples collected below 1,200 feet bls. The chloride concentration was 112 mg/L in the sample collected between 1,272 and 1,280 feet bls (table 3). Figure 6 presents a graph of the chloride and sulfate concentrations of samples analyzed by the laboratory. A groundwater sample was collected from the completed U FLDN (APHPZ) SALTWATER INTERFACE MONITOR well by the District's Water Quality Monitoring Program on March 4, 2014. The laboratory-analyzed sample from the completed well had a chloride concentration of 313 mg/L.

Summary

A saltwater interface monitor well was constructed at Bennett Park in Manatee County, Florida to fill a gap in the coastal groundwater monitor network that is used to monitor saltwater intrusion in the SWUCA. The saltwater interface, in this report, refers to a chloride concentration between 250 and 1,000 mg/L

Drilling, testing, and monitor well construction was performed from July 2013 to February 2014. Exploratory core

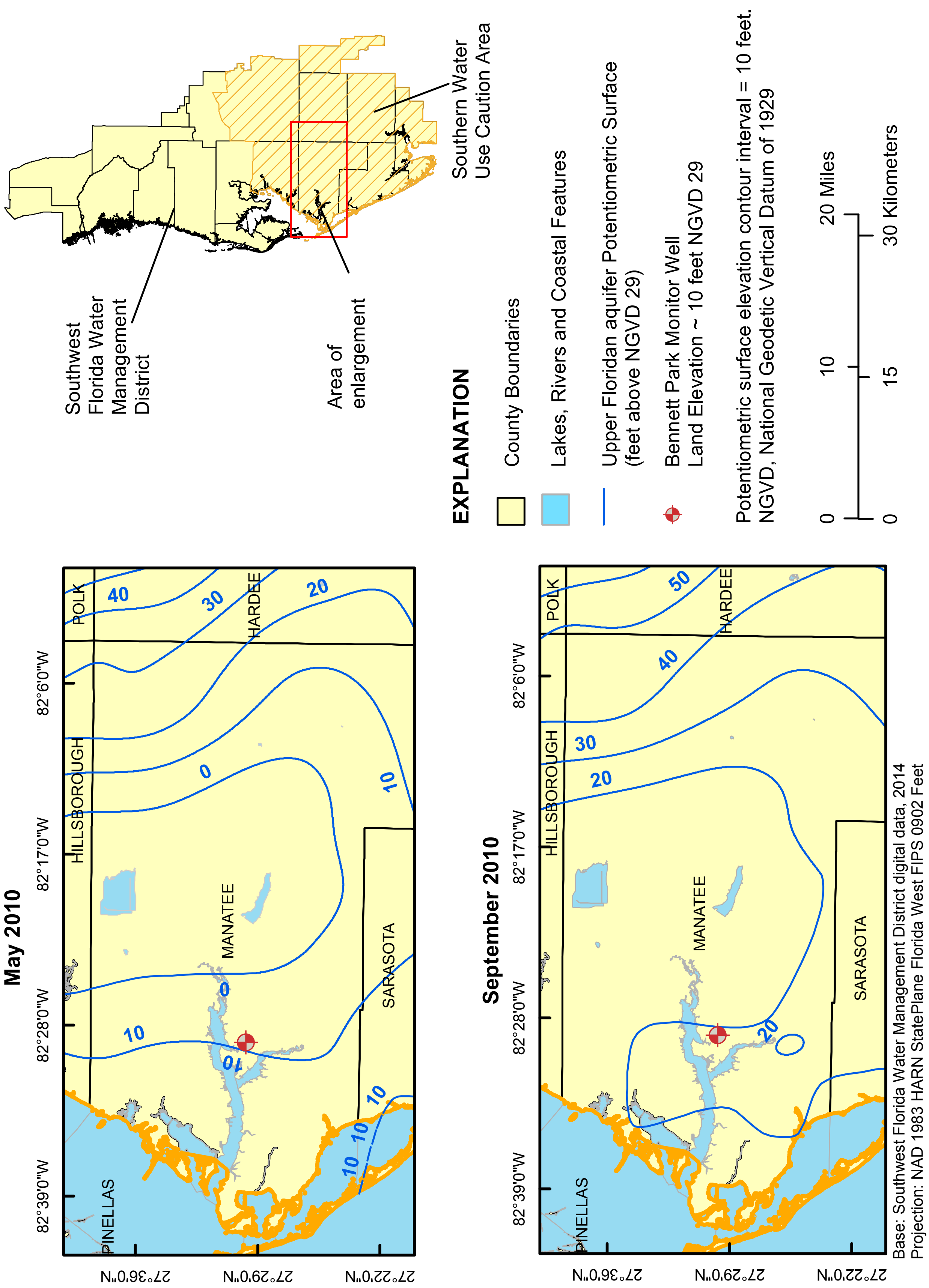


Figure 5. Potentiometric surface of the Upper Floridan aquifer in the area of the Bennett Park well site in Manatee County, Florida.

Table 3. Results of the laboratory analyzed groundwater samples collected during core drilling at the Bennett Park well site in Manatee County, Florida.

[bls, below land surface; Cl^{1-}, chloride; mg/L, milligrams per liter; MM/DD/YYYY, month, day, year; SO_4^{2-}, sulfate; umhos/cm, micromhos per centimeter]

Water Quality Sample Number	Date (MM/DD/YYYY)	Time (hours : minutes	Sample Interval (feet bls)	Specific Conductance (µmhos/cm)	ANIONS		Collection Notes
					Cl^{1-}	SO_4^{2-}	
1	8/9/2013	10:38	925-945	1,147	30.4	470	Collected from open hole below well casing
2	8/15/2013	9:10	1,025-1,050	1,243	35.8	483	Collected with packer during wire line coring
3	8/16/2013	8:40	1,075-1,090	1,627	77.8	663	Collected with packer during wire line coring
4	8/20/2013	10:35	1,098-1,120	1,971	134.0	818	Collected with packer during wire line coring
5	8/23/2013	15:15	930-1,140	2,573	248.0	1,020	Collected from open hole below well casing
6	8/27/2013	13:50	930-1,150	2,784	286.0	1,120	Collected from open hole below well casing
7	9/4/2013	10:15	930-1,180	2,980	307.0	1,210	Collected from open hole below well casing
8	9/5/2013	15:45	1,190-1,200	3,001	315.0	1,220	Collected with packer during wire line coring
9	9/9/2013	16:05	1,210-1,220	2,773	208.0	1,280	Collected with packer during wire line coring
10	9/11/2013	15:40	1,230-1,240	2,767	209.0	1,270	Collected with packer during wire line coring
11	9/16/2013	11:00	1,253-1,260	2,641	150.0	1,300	Collected with packer during wire line coring
12	9/17/2013	15:50	1,272-1,280	2,568	112.0	1,370	Collected with packer during wire line coring
13	9/18/2013	14:20	1,140-1,280	2,679	264.0	1,070	Collected with packer during wire line coring

drilling and testing to locate the depth of the saltwater interface in the Upper Floridan aquifer was conducted from August 5, 2013 to September 18, 2013. The construction phase of the well was from September 18, 2013 to February 14, 2014.

A dual zone well monitoring two separate intervals of the Upper Floridan aquifer was completed at the Bennett Park well site. The U FLDN (APHPZ) SALTWATER INTERFACE MONITOR (well number 1) well monitors the chloride concentration in a section of the Avon Park high permeability zone between 1,151 to 1,250 feet bls. The U FLDN AQ MONITOR (well number 2) well monitors the water level in the Upper Floridan aquifer between 890 to 1,095 feet bls.

The geologic formations present in the area of the well site include in ascending order: the Avon Park Formation, Ocala Limestone, Suwannee Limestone, Hawthorn Group (including the Tampa Member, undifferentiated Arcadia Formation, and Peace River Formation), and undifferentiated sand and clay deposits. Exploratory core drilling began at 925 feet bls in the Ocala Limestone and ended at 1,280 feet bls in the Avon Park Formation. The Avon Park Formation and the Ocala Limestone were the only units described in the study. The Avon Park Formation extends from 985 feet bls to more than 1,280 feet bls and consists primarily of light gray to dark yellowish brown, moderate to well indurated, fossiliferous dolostone. The Ocala Limestone consists primarily of white to yellowish gray, well-indurated, fossiliferous limestone and some dolostone.

The hydrogeologic units present at the site include the surficial aquifer, Hawthorn aquifer system, and the Upper Floridan aquifer. The Upper Floridan aquifer was the only aquifer characterized during the study. The Upper Floridan aquifer extends from 300 feet bls to more than 1,280 feet bls and consists of the Tampa Member of the Arcadia Formation, Suwannee Limestone, Ocala Limestone, and Avon Park Formation. A highly fractured section of dolostone, termed the Avon Park high-permeability zone, is present in the Avon Park Formation from 990 to 1,200 feet bls.

Thirteen groundwater samples were sent to the District Chemistry Laboratory for analyses during drilling and testing to locate the saltwater interface. The groundwater samples were analyzed to determine the concentrations of chloride, sulfate, and specific conductance. The secondary drinking water standard of 250 mg/L for sulfate concentration was exceeded in all samples collected. The secondary drinking water standard of 250 mg/L for chloride concentration was exceeded after drilling from 1,140 to 1,150 feet bls. The highest chloride concentration of 315 mg/L was collected from 1,190 to 1,200 feet bls. The chloride concentrations of samples decreased below 1,200 feet bls. The deepest sample was collected from 1,272 to 1,280 feet bls and had a chloride concentration of 112 mg/L. The saltwater interface occurs between 1,140 and 1,200 feet bls at the Bennett Park well site.

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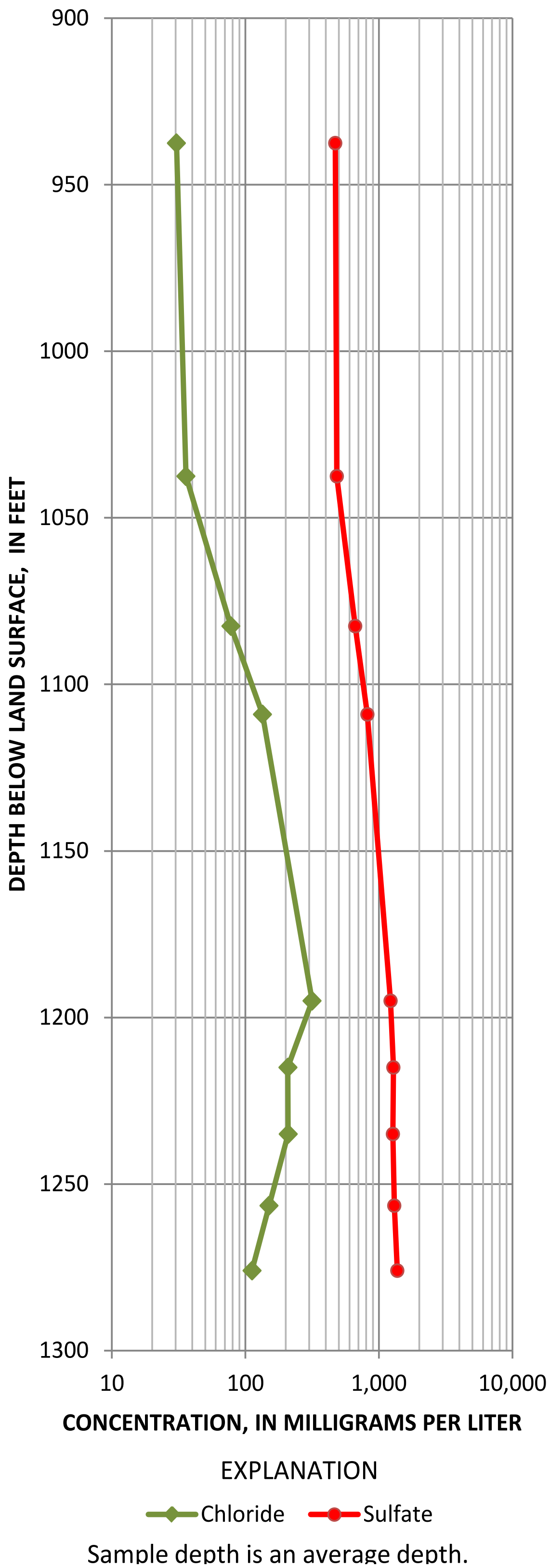

Figure 6. Chloride and sulfate concentrations for laboratory analyzed groundwater quality samples collected from discrete borehole intervals at the Bennett Park well site in Manatee County, Florida.

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Appendix A. Methods of the Geohydrologic Data Section

Methods of the Geohydrologic Data Section

The Southwest Florida Water Management District (District) collects the majority of the hydrogeologic data during the exploratory core drilling phase of the project. Lithologic samples are collected during the core drilling process. Hydraulic and water quality data are collected primarily during packer tests as the core hole is advanced. Geophysical logging is conducted on the core hole providing additional hydrogeologic data. After well construction, an aquifer performance test (APT) is conducted on each of the major freshwater aquifers or producing zones encountered at the project site. These data will be uploaded into the District's Water Management Information System (WMIS).

Collection of Lithologic Samples

The District conducts hydraulic rotary core drilling, referred to as diamond drilling, with a Central Mining Equipment (CME) 85 core drilling rig and an Universal Drilling Rigs (UDR) 200D LS. The basic techniques involved in hydraulic rotary core drilling are the same as in hydraulic rotary drilling (Shuter and Teasdale, 1989). The District applies a combination of HQ, HW, NW, and PW gauge working casings along with NQ or NRQ core drilling rods, associated bits, and reaming shells from Boart Longyear®. The HQ, HW, NW, and PW working casings are set and advanced as necessary to maintain a competent core hole. The NQ and NRQ size core bits produce a nominal 3-inch hole. The HQ, HW, NW, and PW working casings and NQ and NRQ coring rods are removed at the end of the project. Details on the core drilling activities are recorded on daily drilling logs completed by the District's drilling crew and hydrogeologists.

Recovery of the core samples is accomplished using a wireline recovery system (fig. A1). The District's drilling crew uses the Boart Longyear® NQ wireline inner barrel assembly. This system allows a 1.87-inch by 5 or 10-foot section and a 1.99-inch by 10-foot section of core to be retrieved with the CME 85 rig and UDR 200D LS rig, respectively. The core is retrieved without having to remove the core rods from the core hole. Grab samples of core hole cuttings are collected and bagged where poor core recovery occurs because of drilling conditions or where the formation is unconsolidated or poorly indurated. The core samples are placed in core boxes, depths marked, and recovery estimates calculated. Core descriptions are made in the field using standard description procedures. Rock color names are taken from the "Rock-Color Chart" of the National Research Council (Goddard and others, 1948). The textural terms used to characterize carbonate rocks are based on the classification system of Dunham (1962). The core samples are shipped to the Florida Geological Survey for detailed lithologic descriptions of core, cuttings, and unconsolidated sediments. All lithologic samples will be archived at the Florida Geological Survey in Tallahassee, Florida.

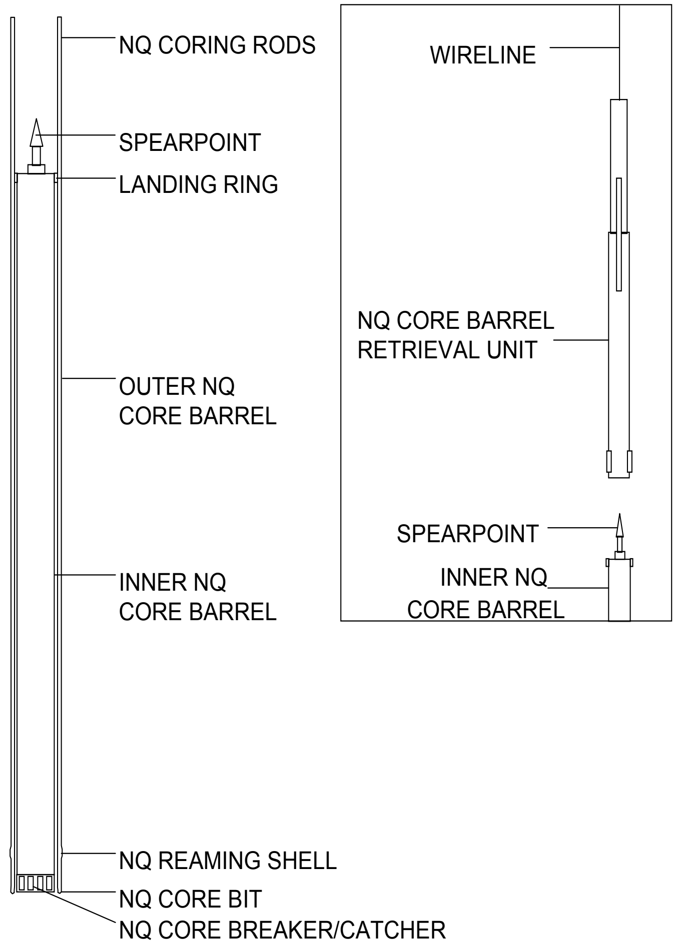


Figure A1. Boart Longyear® NQ Wireline Coring Apparatus.

Unconsolidated Coring

Various methods exist for obtaining unconsolidated material core samples, which is extremely difficult as compared to rock coring (Shuter and Teasdale, 1989). To ensure maximum sample recovery, the District drilling crew utilizes a punch shoe adapter on the bottom of the inner barrel along with an unconsolidated core catcher. The punch shoe extends the inner barrel beyond the bit allowing collection of the sample prior to disturbance by the bit or drilling fluid. A variety of bottom-discharge bits are used during unconsolidated coring. A thin bentonite mud may be used to help stabilize the unconsolidated material.

Rock Coring

During rock coring, the District drilling crew utilizes HQ, HW, NW, and PW working casings as well as permanent casings to stabilize the core hole. NQ and NRQ core drilling rods and associated products are employed during the core drilling process. Core drilling is conducted by direct-circulation rotary methods using fresh water for drilling fluid. Direct water is not effective in removing the cuttings from the core hole, therefore, a reverse-air (air-lift) pumping discharge method (fig. A2) is used to develop the core hole every 20 feet or as necessary. The District typically uses face-discharge bits for well indurated rock core drilling.

Formation Packer Testing

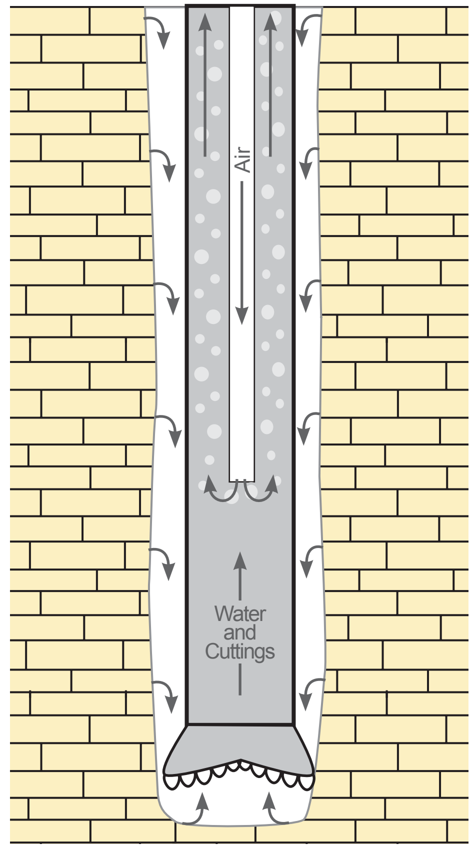
Formation (off-bottom) packer testing allows discrete testing of water levels, water quality, and hydraulic parameters. A competent core hole is necessary for packer testing, meaning unconsolidated sediments and some of the shallow weathered limestone cannot be tested using this technique. The packer assembly (fig. A3) is employed by raising the NQ or NRQ coring rods to a predetermined point, lowering the packer to the bottom of the rods by using a combination cable/air inflation line, and inflating the packer with nitrogen gas. This process isolates the test interval, which extends from the packer to the total depth of the core hole. Sometimes, the working casing may be used in place of the packer assembly. Test intervals are selected based on a regular routine of testing or at any distinct hydrogeologic change that warrants testing.

Collection of Water Level Data

Water level data is collected daily before core drilling. Additionally, water levels are recorded during each formation packer test after the necessary equilibration time. Equilibration is determined when the change in water level per unit time is negligible. Water levels are measured using a Solinst® water level meter. The water level is measured relative to an arbitrary datum near land surface, which is maintained throughout the project. These data provide a depiction of water level with core hole depth. However, these data are normally collected over several months and will include temporal variation.

Collection of Water Quality Data

Water quality samples are collected during each formation packer test. Sampling methods are consistent with the “Standard Operating Procedures for the Collection of Water Quality Samples” (Water Quality Monitoring Program, 2009). The procedure involves isolating the test interval with the off-bottom packer (fig. A3) as explained above, and air-lifting the water in the NQ or NRQ coring rods. To ensure a representative sample is collected, three core hole volumes of water are removed and temperature, pH, and specific conductance are monitored for stabilization using a YSI® multi-parameter meter. Samples are collected either directly from the air-lift discharge point, with a wireline retrievable stainless steel bailer (fig. A4), or with a nested bailer. When sampling a



Reverse-air pumping
Reverse-air pumping allows cuttings to be removed without the introduction of man-made drilling fluids. As air bubbles leave the airline and move up inside the rods, they expand and draw water with them, creating suction at the bit. Groundwater comes from up-hole permeable zones and is natural formation water. Suction at the bit draws water and drill cuttings up the rods to be discharged at the surface.

Figure A2. Reverse-air drilling and water sampling procedure.

poorly producing interval, the purge time may be substantial. The nested bailer is an alternative that is attached directly to the packer orifice thereby reducing the volume of water to be evacuated from the core hole because it collects water directly from the isolated interval through the orifice. Bailers are better for obtaining non-aerated samples, which are more representative because aerated samples may have elevated pH and consequently iron precipitation.

Once the water samples are at the surface, they are transferred into a clean polypropylene beaker. A portion of the sample is bottled according to standard District procedure for laboratory analysis (SWFWMD, 2009). A 500 ml bottle is filled with unfiltered water. Two bottles, one 250 ml and one 500 ml, are filled with water filtered through a 0.45-micron filter. A Masterflex® console pump is used to dispense the water into the bottles. The sample in the 250 ml bottle is acidified with nitric acid to a pH of 2 in order to preserve metals for analysis. The remainder is used to collect field parameters including specific conductance, temperature, pH, and chloride and sulfate concentrations. Temperature, specific conductance, and pH are measured using a YSI® multi-parameter hand-held meter. Chloride and sulfate concentrations are analyzed with a YSI® 9300 photometer. The samples are delivered to the District's chemistry laboratory for additional analysis. A "Standard Complete" analysis that includes pH, calcium, chloride, ion balance, iron, magnesium, potassium, silica, sodium, strontium, specific conductance, sulfate, total dissolved solids (TDS), and total alkalinity is performed on each set of samples (SWFWMD, 2009). Chain of Custody forms are used to track the samples.

The analysis of the water quality data includes the evaluation of relative ion abundance and ion or molar ratios, and the determination of water type(s). The laboratory data are used to calculate milliequivalents per liter (meq/L) and percent meq/L. Using the criteria of 50 percent or greater of relative abundance of cations and anions, the water type for each sample is determined (Hem, 1985). The data are plotted on a Piper (1944) diagram to give a graphical depiction of the relative abundance of ions in an individual sample (Domenico and Schwartz, 1998) as well as how the individual samples compare to each other. Select ion ratios are calculated for each sample to further evaluate chemical similarities or differences among waters and to help explain why certain ions change with depth. Field pH is used in analyses because it is more likely to represent the actual conditions in the water since pH is sensitive to environmental changes (Driscolll, 1986; Fetter, 2001). Additionally, total alkalinity is used as bicarbonate concentration because hydroxyl ions generally are insignificant in natural groundwater and carbonate ions typically are not present in groundwater with a pH less than 8.3 (Fetter, 2001).

Collection of Slug Test Data

Some hydraulic properties can be estimated by conducting a series of slug tests. During slug tests, the static water level in the test interval is suddenly displaced, either up or down, and the water level response is recorded as it returns to a static state. Typically, the slug tests are conducted using the off-bottom packer assembly to isolate test intervals as the core hole is advanced. KPSI® pressure transducers are used to measure the water level changes in the test interval and the annulus between the HQ or HW casing and the NQ or NRQ coring rods. The annulus pressure transducer is used as a quality control device to detect water level changes indicative of a poorly seated packer or physical connection (i.e. fractures or very permeable rocks) within the formation. A third pressure transducer is used to measure air pressure during pneumatic slug testing. All pressure transducer output is recorded on a Campbell Scientific, Inc. CR800 datalogger. Prior to all slug tests, the test interval is thoroughly developed.

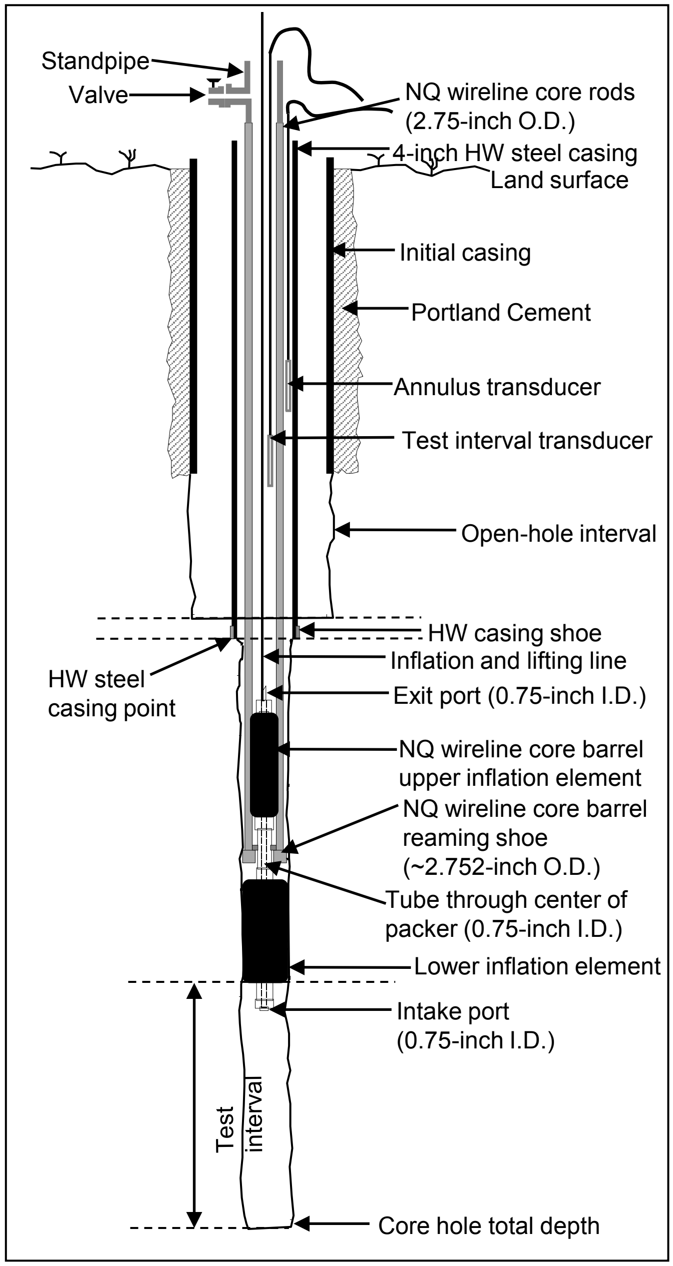


Figure A3. Formation (off-bottom) packer assembly deployed in the core hole.

Slug tests can be initiated several ways. The primary methods used by the District are the pneumatic slug method and the drop slug method. Core hole conditions and apparent formation properties dictate which method is used. The pneumatic slug method is used for moderate to high hydraulic conductivity formations because of the near instantaneous slug initiation. The pneumatic slug method uses a NQ rod modified to include a pressure gauge and regulator, and an electronic or manual valve. The opening is sealed with compression fittings. Air pressure is used to depress the static water level. The water level is monitored for equilibration and once it returns to the initial static water level the test is initiated. The electronic

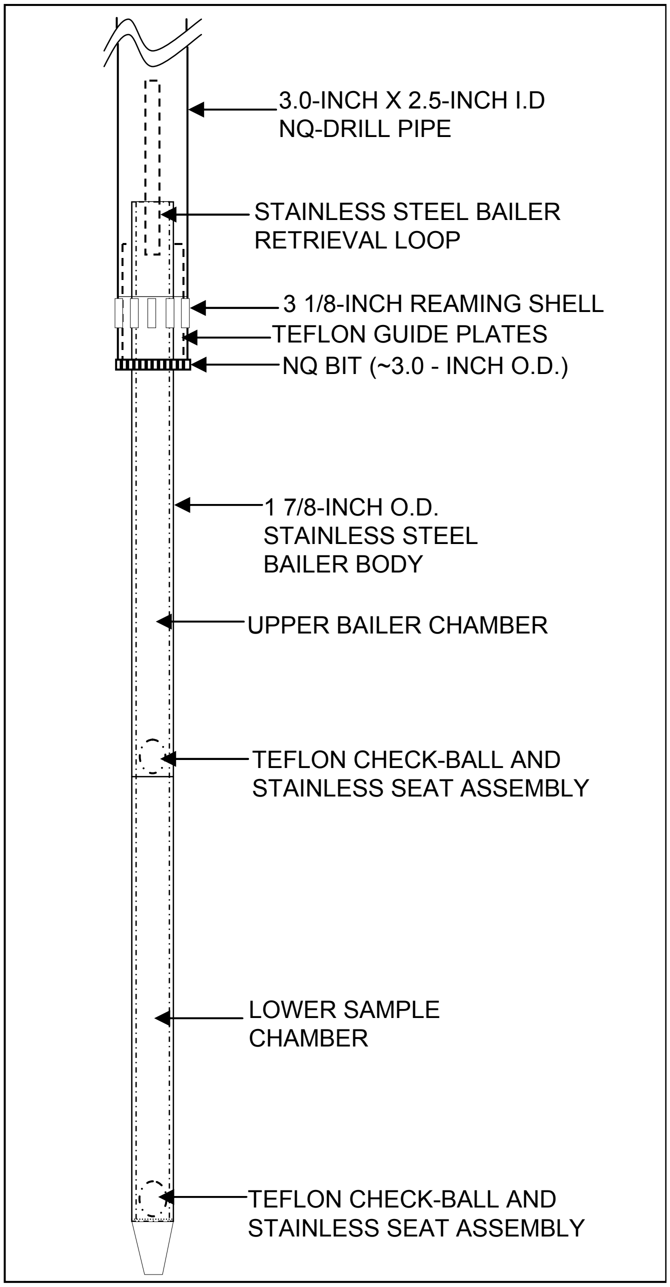


Figure A4. Diagram of the wireline retrievable bailer.

or manual valve is opened to release the air pressure causing the water level to rise (rising head test). The water level is recorded until it reaches the initial static water level. The drop slug method is used for low hydraulic conductivity formations because of the slow slug initiation. This test initiation method is slower than the pneumatic method because the water has to travel down the core hole before reaching the test interval. The drop slug method involves adding a predetermined volume of water into the NQ or NRQ rods raising the static water level. A specially designed PVC funnel fitted with a ball valve placed over the NQ or NRQ rods is used to deliver the water. The valve is opened releasing the water causing the water level to rise. The water level is recorded until the raised level falls (falling head test) back to static level.

Several quality assurance tests are conducted in the field in order to identify any potential sources of error in the slug test data. The quality assurance tests include evaluation of the discrepancy between the expected and observed initial displacements (Butler, 1998), evaluation of the normalized plots for head dependence and evolving skin effects, and the evaluation of the annulus water level for movement. Lastly, estimates of the hydraulic conductivity values are made based on the slug test data using AQTESOLV® (Duffield, 2007) software by applying the appropriate analytical solution.

Slug tests in which the formation packer assembly is used all have one common source of error resulting from the orifice restriction (fig. A3). The water during the slug tests moves through NQ or NRQ coring rods with an inner diameter of 2.38 inches, the orifice on the packer assembly that has an inner diameter of 0.75 inch, and the core hole that has a diameter of approximately 3 inches. The error associated with this restriction is evident as head dependence in the response data of multiple tests conducted on the same test interval with varying initial displacements. The error associated with the orifice restriction will result in an underestimation of the hydraulic conductivity values. In order to reduce the error associated with the orifice restriction, the District inserts a spacer within the zone of water level fluctuation thereby reducing the effective casing radius from 1.19 inches to 0.81 inch. A second technique used to minimize the effects caused by the orifice restriction is the use of initial displacements (slugs) of less than 1.5-feet in height. Also, if the working casing is used instead of the packer, the error is eliminated.

Geophysical Logging

Geophysical logs are useful in determining subsurface geologic and groundwater characteristics (Fetter, 2001). Geophysical logs provide three major types of information from water wells: hydrologic (water quality, aquifer characteristics, porosity, and flow zone detection), geologic (lithology, formation delineation), and physical characteristics (depth, diameter, casing depth, texture of well bore, packer points, and integrity of well construction).

Geophysical logging entails lowering the geophysical tool into the monitor well on a wireline and measuring the tool's response to the formations and water quality in and near the core hole during retrieval. Core hole geophysical logs are run during various stages of core drilling. When feasible, geophysical logs are run prior to casing advancements, while the core hole is still open to the formation.

The District uses Century® geophysical logging equipment. The three types of geophysical probes used are the caliper/gamma, induction, and multifunction. The multifunction tool measures natural gamma-ray [GAM (NAT)], spontaneous potential (SP), single-point resistivity (RES), short [RES(16N)], long [RES(64N)] normal resistivity, fluid temperature (TEMP) and fluid specific conductance (SP COND). Each log type is explained below.

Caliper (CAL)

Caliper logs are used to measure the diameter of the borehole. This log can identify deviations from the nominal borehole diameter and, in turn, locate cavities, washouts, and build-up. This log is useful for determining packer and casing placement because competent, well-indurated layers can be located. The caliper log also aids in calculating volumes of material such as cement, gravel, sand, and bentonite needed when installing casing during well construction and filling open hole intervals for abandonment.

Gamma [GAM(NAT)]

Natural gamma-ray logs measure the amount of natural radiation emitted by materials surrounding the borehole. Natural gamma radiation is emitted from decaying radioactive elements present in certain types of geologic materials, thus specific rock materials can be identified from the log. Some of these materials include clays that trap radioactive isotopes as they migrate with groundwater, organic deposits, and phosphates. Clays contain high amounts of radioactive isotopes in contrast to more stable rock materials like carbonates and sands, therefore, can be identified easily. One advantage using natural gamma-ray radiation is that it can be measured through PVC and steel casing, although it is subdued by steel casing. Gamma-ray logs are used chiefly to identify rock lithology and correlate stratigraphic units because gamma-ray radiation can be measured through casing and is relatively consistent.

Spontaneous Potential (SP)

Spontaneous potential logs measure the electrical potential (voltages) that result from chemical and physical changes at the contacts between different types of geological materials (Driscoll, 1986). They must be run in fluid-filled, uncased boreholes, and function best when the fluid in the borehole is different from that in the formation. They are useful in identifying contacts between different lithologies and stratigraphic correlation.

Single-Point Resistance (RES)

Single-point resistance logs measure the electrical resistance, in ohms, from rocks and fluids in the borehole to a point at land surface. Electrical resistance of the borehole materials is a measure of the current drop between a current electrode placed in the borehole and the electrode placed on land surface. The log must be run in a fluid-filled, uncased borehole. They are used for geologic correlation, such as bed boundaries, changes in lithology, and identification of fractures in resistive rocks (Keys and MacCary, 1971).

Short-Normal [RES (16N)] and Long-Normal [RES (64N)]

Short-normal and long-normal resistivity logs measure the electrical resistivity of the borehole materials and the surrounding rocks and water by using two electrodes. The 16 and 64 refers to the space, in inches, between the potential electrodes on the logging probe. The short-normal curve indicates the resistivity of the zone close to the borehole and the long-normal has more spacing between the electrodes, therefore measures the resistivity of materials further away from the borehole (Fetter, 2001). Short-normal and long-normal logs are useful in locating highly resistive geologic materials such as limestone, dolostone, and pure, homogenous sand and low resistivity materials like clay or clayey, silty sand. Also, the logs indicate water quality changes because fresh water has high resistivity whereas poor quality water has low resistivity. Resistivity logs must be run in fluid-filled, open boreholes.

Temperature (TEMP)

Temperature logs record the water temperature in the borehole. Temperature variations may indicate water entering or exiting the borehole from different aquifers. Thus, the log is useful in locating permeable zones. The log must be run in fluid-filled boreholes.

Specific Conductance (SP COND)

Specific Conductance logs measure the capacity of borehole fluid to conduct an electrical current with depth. The log indicates the total dissolved solids concentration of the borehole fluid. The specific conductance log may be useful in determining permeable zones because zones of increased inflow or outflow may show a change in water quality.

Aquifer Performance Tests

An APT is a controlled field experiment conducted to determine the hydraulic properties of water-bearing (aquifers) units (Stallman, 1976). APTs can be either single-well or multi-well and may partially or fully penetrate the aquifer. An APT involves pumping the aquifer at a known rate and monitoring the water level response. The general procedure, applied by the District, for conducting an APT involves design, field observation, and data analysis. Test design is based on the geologic and hydraulic setting of the site, such as knowledge of the aquifer thickness, probable range in transmissivity and storage, the presence of uncontrolled boundaries (sources/sinks), and any practical limitations imposed by equipment. Field observations of the discharge and water levels are recorded to ensure a successful test. The District measures the discharge rate using an impeller meter and circular orifice weir. The District measures water levels using pressure transducers and an electric tape. All the recording devices are calibrated and traceable to the National Institute of Standards and Technology.

Data analysis includes first making estimates of drawdown observed during the test and then using analytical and numerical methods to estimate hydraulic properties of the aquifer and adjacent confining units. Diagnostic radial flow plots and derivative analyses of APT data are valuable tools in characterizing the type of aquifer present and specific boundary conditions that may be acting on the system during an APT.

Single-Well Aquifer Performance Test

Single-well APTs includes one test (pumped) well within the production zone used for both pumping and monitoring the water level response. A single-well APT may include monitoring the background water level in the test well for a duration of at least twice the pumping period (Stallman, 1976). Background data collection may not be necessary if the duration of the single-well test is short and the on-site hydrogeologist does not consider background data necessary. After background data collection is complete and it is determined that a successful test can be accomplished, pumping is started. During the test, the discharge rate is monitored and controlled to less than 10 percent fluctuation to ensure a constant rate test. The water level is recorded in the test well during the drawdown (pumping) and recovery phases. Other wells outside of the production zone may be monitored in order to provide additional information on the flow system. The response data are used to estimate drawdown and then analyzed using analytical methods to estimate the hydraulic properties of the aquifer and adjacent confining units. Typically, response data is analyzed using AQTESOLV® (Duffield, 2007) software by applying the appropriate analytical solution.

Multi-Well Aquifer Performance Test

Multi-well APTs involve a test (pumped) well and at least one observation well for monitoring the water level response in the production zone. Background water level data is collected for a period of at least twice the planned pumping period (Stallman, 1976). The background data allows for the determination of whether a successful test can be conducted and permits the estimation of drawdown. After the background data collection period is complete and it is determined that a successful test can be completed, pumping is started. During the test, the discharge rate is monitored and controlled to less than 10 percent fluctuation. The water level response is recorded in both the test well and the observation well(s) during the drawdown (pumping) and recovery phases. Other wells outside of the production zone may be monitored in order to provide additional information on the flow system. The response data are used to estimate drawdown and then analyzed using analytical or numerical methods to estimate the hydraulic properties of the aquifer and adjacent confining units. Typically, response data is analyzed using AQTESOLV® (Duffield, 2007) software by applying the appropriate analytical solution.

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Appendix B. Geophysical Logs

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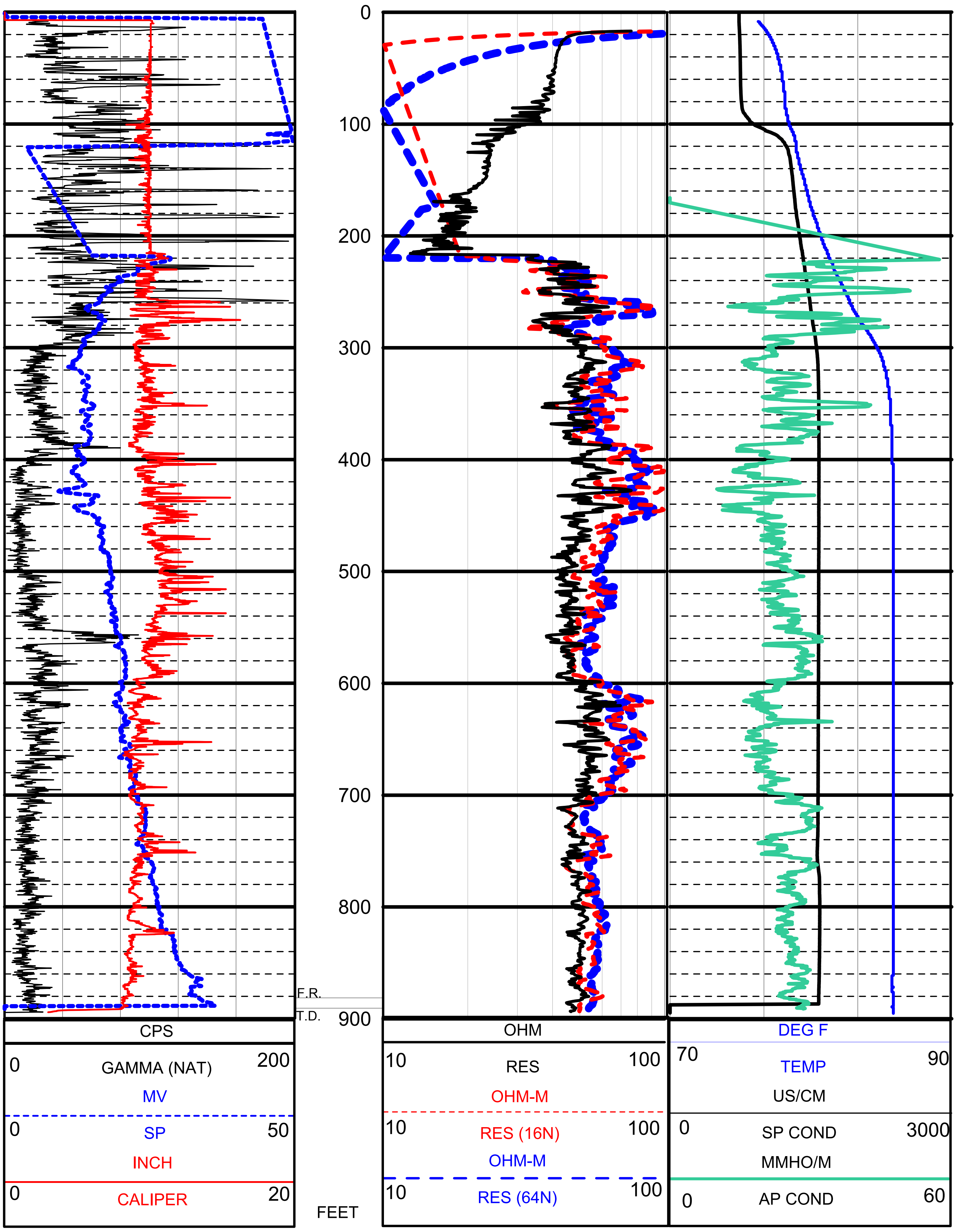


Figure B-1. Geophysical log suite run from land surface to 900 feet below land surface on the exising 10-inch diameter well at the Bennett Park well site in Manatee County, Florida. The logs were run on March 2, 2013 and March 7, 2013, using the 9165C (caliper/gamma-ray), 8144C (multi-function), and 9511C (induction) tools. The steel casing depth at the time of logging was 215 feet below land surface. The vertical log scale is 1 inch per 100 feet. Tracks 1 and 3 are in linear scale and track 2 is in logarithmic scale.

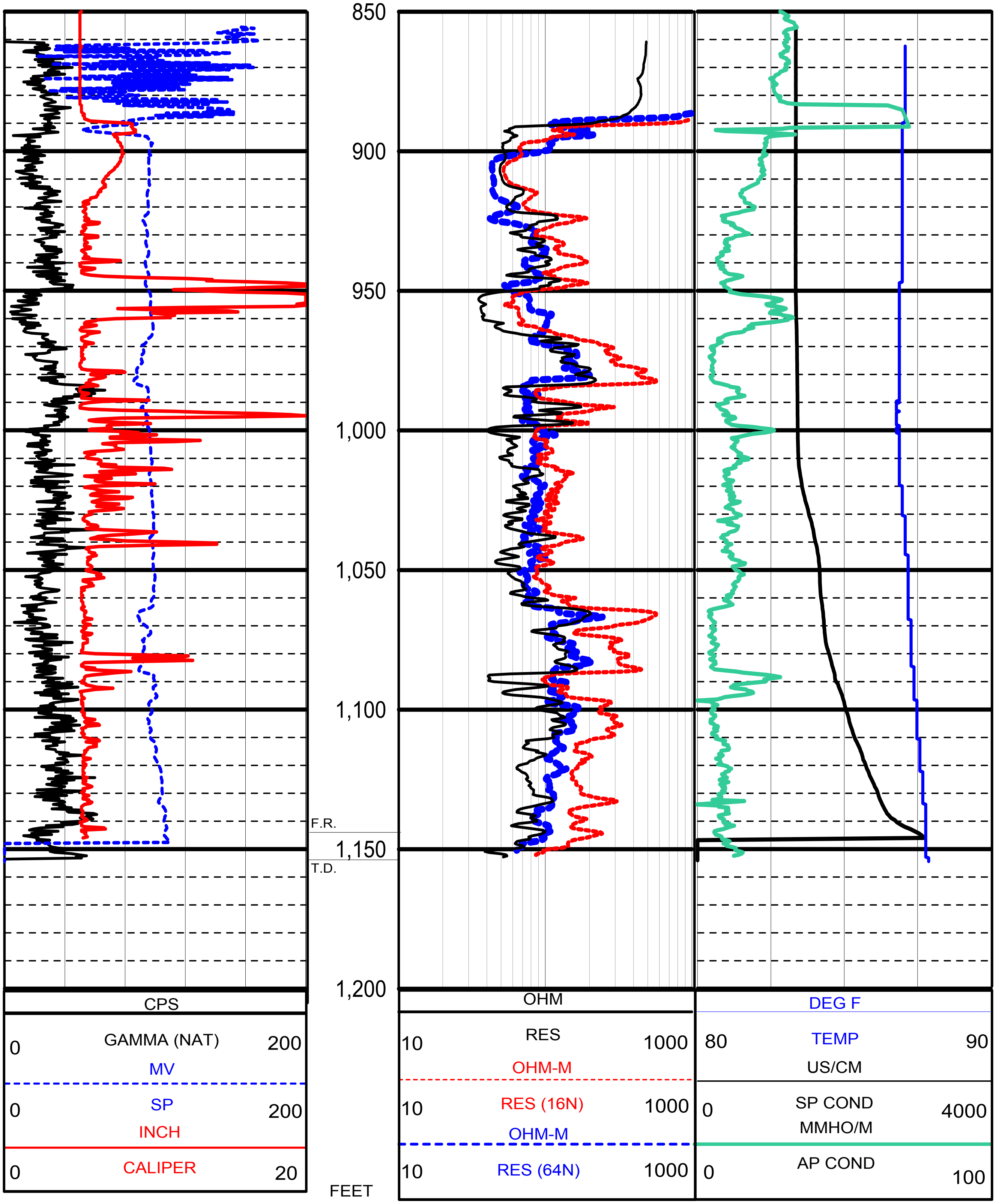


Figure B-2. Geophysical log suit run from 890 feet below land surface (bls) to 1,155 feet bls in the 5-inch borehole while exploratory drilling at the Bennett Park well site in Manatee County, Florida. The logs were run on December 2, 2013, and December 3, 2013, using the 9165C (caliper/gamma-ray), 8144C (multi-function), and 9165C (induction) tools. The polyvinyl chloride casing depth at the time of logging was 890 feet bls. The vertical log scale is 1 inch per 50 feet. Tracks 1 and 3 are linear scale and track 2 is in logarithmic scale.

Appendix C. Lithologic Description of Core Samples

Lithologic core description by the Florida Geological Survey not available at time of report publication.

Appendix D. Photographs of Core Samples


Bennett PARK
926'
929.5
934.5
939
GSA
CM
IN
mm


Bennett PARK
939
939.5
944.5
951.5'
GSA
CM
IN
mm


Bennett PARK
951.5'
955'
960'
965
GSA
CM
IN
mm


Bennett Park
965
970
975
GSA
CM
IN
mm


Bennett PARK
975
980
985
987.5
GSA
CM
IN
Grain Size Scale
mm


Bennett PARK
987.5
990'
995'
1000'
1000.5
GSA
CM
IN
Grain Size Scale
mm


Bennett Park
1000.5
1010'
1014'
GSA
CM
IN
Grain Size Scale
mm


Bennett Park
1014'
1015'
1020'
1025'
1029
GSA
CM
IN
Grain Size Scale
mm


Bennett PARK
1029
1030'
1035'
1040'
1045
GSA
CM
IN


Bennett PARK
1045'
1050'
1055
1056
GSA
CM
IN


Bennett Park
1056
1060
1065
1067.5
GSA
CM
IN


Bennett Park
1067.5
1070
1075
1077'
GSA
CM
IN


Bennett Park
1077'
1080'
1085'
1087'
GSA
CM
IN


Bennett Park
1087'
1090'
1093.5'
1096.7'
GSA
CM
IN


Bennett Park
1096.7'
1100'
1105'
1108'
GSA
CM
IN


Bennett PARK
1108'
1110'
1115'
1112.5'
GSA
CM
IN


Bennett Park
1117.5
1025
1120
1026.5
GSA
CM
IN


Bennett Park
1026.5
1130
1135'
1136.5'
GSA
CM
IN


Bennett Park
1136.5
1138'
MOVED
to next row to preserve fracture
1140
1145
GSA
CM
IN


Bennett Park
1145
1155
1150
1157
GSA
CM
IN


Bennett PARK
1157
1165
1160
1168
GSA
CM
IN


Bennett Park
1168
1175
1170
1178'
GSA
CM
IN


Bennett Park
1178'
1180'
1185
1189
GSA
CM
IN


1189
1190
1195
1198.5
GSA
CM
IN


Bennett
Park
1198.5
1200
1205
1209
GSA
CM
IN


Bennett
Park
1209
1210
1215
1218.3
GSA
CM
IN


1218.3
1225
1220
1230
1230.5
GSA
CM
IN


Bennett
Park
1230.5
1235
1239.5
GSA
CM
IN


Bennett Park
1239.5
1240'
1245
1249.5
GSA
CM
IN
mm


Bennett Park
1249.5
1250
1255
1259
GSA
CM
IN
mm


Bennett Park
1259
1260'
1265
1268.2
GSA
CM
IN
mm


Bennett Park
1268.2
1270
1275
1278
GSA
CM
IN
mm


1278
1280
GSA
CM
IN
mm

Appendix E. Hydrogeologic Correlation Charts

A

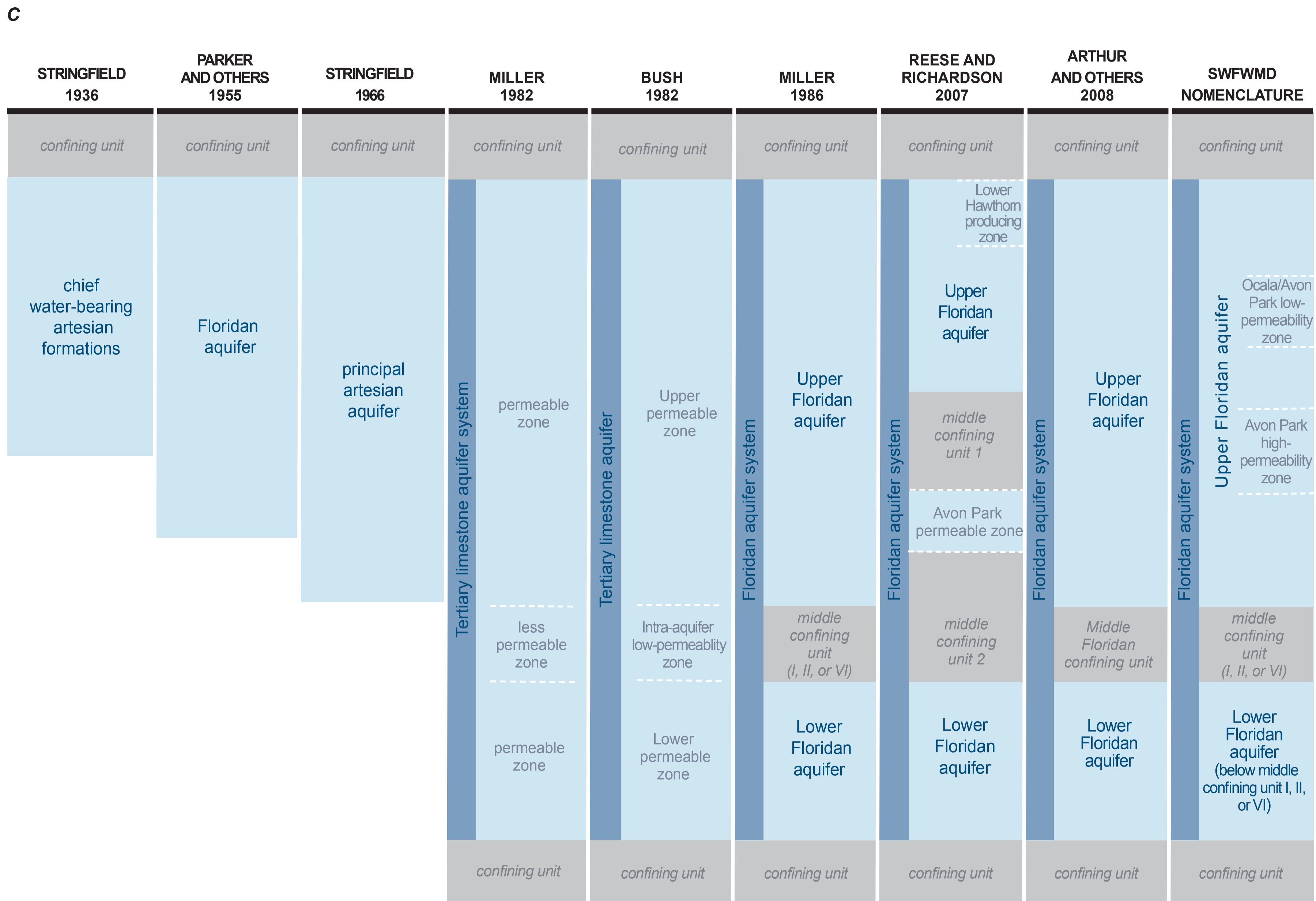
WYRICK 1960	LICHTLER 1960	CLARKE 1964	LEVE 1966	WOLANSKY 1978	MILLER 1980	BOGGESS 1986 & ARTHUR AND OTHERS 2008	SWFWMD NOMENCLATURE
nonartesian aquifer	Shallow aquifer	water-table aquifer	shallow aquifer system	unconfined aquifer	surficial aquifer	surficial aquifer system	surficial aquifer
confining unit	*confining unit*	*confining unit*	*confining unit*	*confining unit*	*confining unit*	*confining unit*	*confining unit*

B

SPROUL AND OTHERS 1972	JOYNER, SUTCLIFFE 1976	WEDDERBURN AND OTHERS 1982	WOLANSKY 1983	BARR 1996	TORRES AND OTHERS 2001	KNOCHENMUS 2006	ARTHUR AND OTHERS 2008	SWFWMD NOMENCLATURE
		Hawthorn Aquifer System (upper units); FAS (lower units)	Intermediate aquifers	Intermediate aquifer system	Intermediate aquifer system	Intermediate aquifer system	Intermediate aquifer system / intermediate confining unit	Hawthorn aquifer system
confining unit	*confining unit*	*confining unit*	*confining unit*	*confining unit*	*confining unit*	*confining unit*	*confining unit*	*confining unit*
sandstone aquifer	Zone 1	Sandstone aquifer	Tamiami - upper Hawthorn aquifer	Permeable Zone 1	Tamiami/ Peace River zone (PZ1)	Zone 1	zones/ aquifers were not delineated	Peace River aquifer
confining unit	*confining unit*	*confining unit*		*confining unit*	*confining unit*	*confining unit*		*confining unit*
upper Hawthorn aquifer	Zone 2	mid-Hawthorn aquifer		Permeable Zone 2	Upper Arcadia zone (PZ2)	Zone 2		upper Arcadia aquifer
confining unit	*confining unit*	*confining unit*	*confining unit*	*confining unit*	*confining unit*	*confining unit*		*confining unit*
lower Hawthorn aquifer	Zone 3	lower Hawthorn / Tampa producing zone	Lower Hawthorn - upper Tampa aquifer	Permeable Zone 3	Lower Arcadia zone (PZ3)	Zone 3		lower Arcadia aquifer
confining unit	*confining unit*	*confining unit*	*confining unit*	*confining unit*	*confining unit*	*confining unit*	*confining unit*	*confining unit*

[FAS, Floridan aquifer system; PZ, permeable zone]

Figure E-1. Nomenclature of (A), the surficial aquifer, (B), the Hawthorn aquifer system, and (C), the Floridan aquifer system used for the Bennett Park well site compared to names in previous reports.



[Terms shown are for hydrogeologic units present within the Southwest Florida Water Management District]

Figure E-1 (Continued). Nomenclature of (A), the surficial aquifer, (B), the Hawthorn aquifer system, and (C), the Floridan aquifer system used for the Bennett Park well site compared to names in previous reports.

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Appendix F. Field Analyzed Water Quality Samples

Table F- 1. Field analyzed groundwater samples collected during core drilling at the Bennett Park well site in Manatee County, Florida

[-, not measured; bls, below land surface; Cl^{1-}, chloride; HH:MM, hours:minutes; MM/DD/YYYY, month, day, year; mg/L, milligrams per liter; No., number; SO_4^{2-}, sulfate; SU, standard unit; umhos/cm, micromhos per centimeter; >, greater than; °F, degrees Fahrenheit]

Water Quality Sample Number	Date (MM/DD/YYYY)	Time (HH:MM)	Sample Interval (feet bls)	Temperature (F)	pH (SU)	Specific Conductance (µmhos/cm)	Anions: Cl^{1-} (mg/L)	Anions: SO_4^{2-} (mg/L)	Collection Notes
1	8/5/2013	14:30	890-915	31.0	8.41	1,030	-	-	Collected from open hole below well casing
2	8/6/2013	10:15	890-920	28.7	8.00	1,103	-	-	Collected from open hole below well casing
3	**8/9/2013**	**10:38**	**925-945**	**28.7**	**8.07**	**1,256**	**-**	**-**	**Collected from open hole below well casing**
4	8/12/2013	11:24	899-926	28.6	7.49	1,169	-	195	Collected from open hole below well casing
5	8/12/2013	17:00	970-985	29.0	7.54	1,210	24	>200	Collected with packer during wire line coring
6	8/13/2013	13:10	988-1,005	29.3	7.54	1,195	23	520	Collected with packer during wire line coring
7	8/14/2013	12:40	890-1,030	29.3	7.43	1,195	22	-	Collected from open hole below well casing
8	8/14/2013	15:25	890-1,040	29.0	7.47	1,261	23	550	Collected from open hole below well casing
9	**8/15/2013**	**9:10**	**1,025-1,050**	**28.9**	**7.54**	**1,186**	**33**	**525**	**Collected with packer during wire line coring**
10	8/15/2013	14:40	890-1,070	29.1	7.62	1,250	32	495	Collected from open hole below well casing
11	8/15/2013	15:40	890-1,090	30.0	7.56	1,160	-	-	Collected from open hole below well casing
12	**8/16/2013**	**8:40**	**1,075-1,090**	**28.3**	**7.28**	**1,586**	**60**	**195**	**Collected with packer during wire line coring**
13	8/16/2013	16:50	890-1,100	29.2	8.05	1,623	-	-	Collected from open hole below well casing
14	8/19/2013	10:30	890-1,100	28.8	7.60	1,727	38	775	Collected from open hole below well casing
15	8/19/2013	14:45	890-1,110	29.5	7.74	1,863	36	800	Collected from open hole below well casing
16	**8/20/2013**	**10:35**	**1,098-1,120**	**29.0**	**7.46**	**1,940**	**115**	**570**	**Collected with packer during wire line coring**
17	8/21/2013	8:30	890-1,130	-	-	2,200	-	-	Collected from open hole below well casing
18	8/22/2013	9:00	890-1,138	-	-	2,808	-	-	Collected from open hole below well casing
19	**8/23/2013**	**15:15**	**930-1,140**	**29.1**	**7.47**	**2,574**	**175**	**950**	**Collected from open hole below well casing**
20	**8/27/2013**	**13:50**	**930-1,150**	**29.1**	**7.24**	**2,848**	**225**	**925**	**Collected from open hole below well casing**
21	8/27/2013	15:40	1,137-1,150	29.1	7.24	2,848	225	925	Collected with packer during wire line coring
22	8/28/2013	10:30	1,111-1,150	-	-	1,982	125	585	Collected with packer during wire line coring

Table F- 1 (continued). Field analyzed groundwater samples collected during core drilling at the Bennett Park well site in Manatee County, Florida

[-, not measured; bls, below land surface; Cl^{1-}, chloride; HH:MM, hours:minutes; MM/DD/YYYY, month, day, year; mg/L, milligrams per liter; No., number; SO_4^{2-}, sulfate; SU, standard unit; umhos/cm, micromhos per centimeter; >, greater than; °F, degrees Fahrenheit]

Water Quality Sample Number	Date (MM/DD/YYYY)	Time (HH:MM)	Sample Interval (feet bls)	Temperature (F)	pH (SU)	Specific Conductance (µmhos/cm)	Anions Cl^{1-} (mg/L)	Anions SO_4^{2-} (mg/L)	Collection Notes
23	8/28/2013	13:00	890-1,155	29.5	7.76	2,829	-	-	Collected from open hole below well casing
24	8/28/2013	16:20	890-1,160	-	-	2,876	-	-	Collected from open hole below well casing
25	9/3/2013	14:30	890-1,170	29.2	7.90	3,000	225	975	Collected from open hole below well casing
26	**9/4/2013**	**10:15**	**930-1,180**	**29.3**	**7.00**	**2,800**	**230**	**-**	**Collected from open hole below well casing**
27	9/5/2013	10:10	1,180-1,190	29.3	7.25	3,000	220	975	Collected with packer during wire line coring
28	**9/5/2013**	**15:45**	**1,190-1,200**	**29.5**	**7.34**	**2,990**	**-**	**-**	**Collected with packer during wire line coring**
29	9/9/2013	10:00	1,200-1,210	25.5	-	2,953	210	-	Collected with packer during wire line coring
30	**9/9/2013**	**16:05**	**1,210-1,220**	**29.1**	**-**	**2,932**	**-**	**-**	**Collected with packer during wire line coring**
31	9/10/2013	14:40	1,220-1,230	29.3	-	2,834	140	900	Collected with packer during wire line coring
32	**9/11/2013**	**15:40**	**1,230-1,240**	**29.1**	**-**	**2,719**	**170**	**925**	**Collected with packer during wire line coring**
33	9/12/2013	13:50	1240-1250	29.4	7.80	2,621	125	950	Collected with packer during wire line coring
34	**9/16/2013**	**11:00**	**1253-1260**	**29.2**	**7.24**	**2,650**	**98**	**975**	**Collected with packer during wire line coring**
35	9/17/2013	9:45	1262-1270	29.0	7.25	2,587	92	925	Collected with packer during wire line coring
36	**9/17/2013**	**15:50**	**1272-1280**	**29.4**	**7.98**	**2,498**	**69**	**975**	**Collected with packer during wire line coring**
37	**9/18/2013**	**14:20**	**1140-1280**	**29.6**	**8.02**	**2,701**	**165**	**950**	**Collected with packer during wire line coring**

[1]tems in bold had a portion of the sample delivered for laboratory analysis.

Southwest Florida
Water Management District