SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Hydrogeologic Investigation for the Kissimmee Basin Lower Floridan Aquifer Reconnaissance Project, Site B

Polk County, Florida
Technical Publication WS-33

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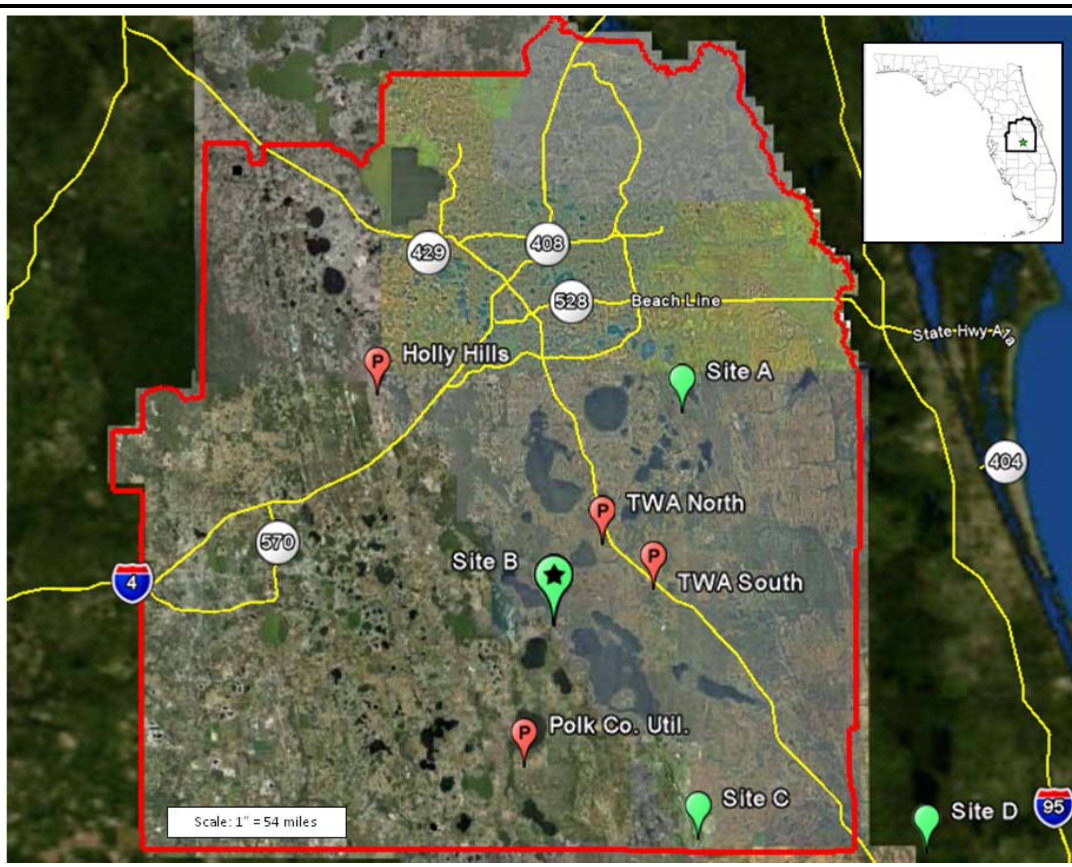
EXECUTIVE SUMMARY

The Lower Floridan aquifer (LFA) has been targeted as a key source of alternative water supply as part of the Central Florida Water Initiative (CFWI) in the Kissimmee Basin planning area. It is recognized, however, that there are many hydrogeologic uncertainties associated with development of the LFA that affect the suitability and sustainability of its use as a long-term water supply source.

The South Florida Water Management District (SFWMD) laid out a five-year plan, the Lower Floridan Aquifer Investigation, Kissimmee Basin (LFAKB) Project, for a hydrogeologic reconnaissance of the LFA within the Kissimmee Basin region, with the express purpose of addressing uncertainties in LFA development. The LFAKB project was funded fiscal year 2011.

A major component of the LFAKB Project was drilling and testing exploratory wells at four sites to bridge the largest data gaps within the LFA. This report documents the results from the first of those sites, LFAKB Site B.



Lower Floridan Aquifer Investigation, Kissimmee Basin Project study area with proposed exploratory drilling sites of the project (green markers) shown in relation to planned Lower Floridan aquifer production wellfields (red markers). This report is on results from Site B.

The Site B testing program includes:

- Construction and logging of three wells in the Floridan aquifer system:
  - A dual-zone Upper Floridan aquifer (UFA)/Avon Park permeable zone (APPZ) monitor well (POF-27)
  - A LFA exploratory well (POF-28), completed as a dual-zone LFA monitor well
  - A LFA production well for aquifer performance testing (POF-29)
- Construction of a surficial aquifer system (SAS) monitor well for aquifer performance testing (POS-14)
- Determination of water quality with depth, and sampling for field and laboratory analysis of formation waters during:
  - Drilling (drill-stem and interval test sampling)
  - Straddle-packer testing from six select zones
  - Aquifer performance testing
  - Development of completed monitor zones
- Implementation and analysis of aquifer performance tests, discretely evaluating the UFA, APPZ, and a portion of the LFA.

Drilling at Site B penetrated to a maximum depth of 2,728 feet below land surface (ft bls). Major findings from the drilling and testing program include:

- The following boundaries of the major hydrogeologic units at this location identified based on lithology, geophysical logs, and water quality, water level and hydraulic data:
  - Top of the intermediate confining unit (ICU): 77 ft bls
  - Top of the Floridan aquifer system (FAS): 276 ft bls
  - Top of the upper Middle confining unit (MC1) between the UFA and the APPZ: 529 ft bls
  - Top of the APPZ: 750 ft bls
  - Top of the lower Middle confining unit (MC2) between the APPZ and the LFA: 1,109 ft bls
  - Top of the LFA: 1,296 ft bls
  - Base of the Floridan aquifer system/top of the sub-Floridan confining unit (SFCU): 2,486 ft bls
- Five discrete productive intervals, or flow zones, with varying degrees of confinement between them were identified within the LFA at Site B. For ease of reporting, these zones are numbered sequentially, from shallowest to deepest (LF1–LF5).

Flow Zone	Top Depth (ft bls)	Base Depth (ft bls)	Relative Productivity Estimate
LF1	1,296	1,350	Low
LF2	1,538	1,680	High
LF3	1,732	1,823	Moderate
LF4	2,168	2,247	Very High
LF5	2,369	2,409	Moderate

- Lower Floridan aquifer zones LF4 and LF5 appear to be hydrostratigraphically equivalent to the Boulder Zone of southern Florida. Based on log, drill stem, and packer test data, the position of the base of the underground source of drinking water (USDW) (total dissolved solids [TDS] of 10,000 milligrams per liter [mg/L]), was identified within LF4 at 2,234 ft bls.
- Formation water sampling and analysis yielded the following distribution of dominant ions and TDS for the hydrogeologic units sampled:

Hydrogeologic Unit	Dominant Ion Pairs	TDS (mg/L)	Sample Source
UFA	Ca^{2+}- HCO_3^-	90	POF-27 Upper Zone
APPZ	Ca^{2+}- HCO_3^-	118	POF-27 Lower Zone
MC2	Ca^{2+}- SO_4^{2-}	316	POF-27 Packer Test 2
LF1	Ca^{2+}- SO_4^{2-}	1,190	POF-28 Interval Test 1
LF2	Na^+-Cl^--Ca^{2+}- SO_4^{2-}	790	POF-29 Aquifer Test
LF3	Na^+-Cl^--Ca^{2+}- SO_4^{2-}	1,392	POF-28 Packer Test 4
LF4	Na^+-Cl^-	3,956	POF-28 Lower Zone
LF5	Na^+-Cl^-	30,437	Drill Stem

Discrete, referenced water level measurements within the hydrogeologic units identified at Site B were taken at different points during construction and testing. From these data it appears that the highest heads are in the UFA, decreasing both above and below that unit. There is an approximate 5-foot head drop between the APPZ and LFA at this site, and an additional 3-foot drop within the LFA between flow zones LF2 and LF4.

Hydrogeologic Unit	Water Level (ft NAVD 88)	Measurement Source	Measurement Date
SAS	50.74	POS-14	20-Mar-12
UFA	55.95	POF-27U	20-Mar-12
APPZ	55.24	POF-27L	20-Mar-12
MC2	50.58	POF-27 PT2	17-Jun-11
LF1 LF2	50.11	POF-28U	20-Mar-12
LF3	50.25	POF-28 PT4	5-Jan-12
Between LF3 & LF4	48.9	POF-28 PT3	3-Jan-12
LF4 - above USDW	47.28	POF-28L	20-Mar-12
LF4 - below USDW	14.4	POF-28 PT2	3-Jan-12

Hydraulic testing yielded the following results:

- A 24-hour aquifer performance test (APT) of the UFA using wells open from 300 to 520 ft bls at a discharge rate of 1,100 gallons per minute (gpm) yielded a mean transmissivity of 3,627 ft^2/day and a mean storage coefficient of 2.4×10^{-4}.
- A 48-hour aquifer performance test of the APPZ using wells open from 700 to 1,105 ft bls at a discharge rate of 4,300 gpm yielded a mean transmissivity of 38,606 ft^2/day and a mean storage coefficient of 2.3×10^{-4}.

- A leakance coefficient of 0.001/day, yielding an average vertical hydraulic conductivity of 0.25 ft/day, was estimated for MC1 (529 to 750 ft bls) from the UFA and APPZ tests.
- A transmissivity of 1,991 ft^2/day for LF1 was estimated from the specific capacity of that unit when the depth interval from 1,300 to 1,420 ft bls was pumped at a sustained rate of 350 gpm.
- Based on water quality and geophysical log data, flow zone LF2 of the Lower Floridan aquifer was targeted for more extensive hydraulic testing. A 90-hour APT of LF2 (1,350 to 1,685 ft bls) at a discharge rate of 3,906 gpm yielded a mean transmissivity of 41,760 ft^2/day and a mean storage coefficient of 2.0×10^{-3}.
- It was not possible to estimate a leakance across MC2 from the APT results. No drawdown was observed in the APPZ during the LF2 testing and the cavernous nature of monitor well POF-28U limited its usefulness as a production zone monitor well data. There is a significant head gradient across MC2, but geophysical log data indicate MC2 is leaky. One packer test completed in MC2 yielded an estimated horizontal hydraulic conductivity ranging from 3.1 to 7.5 ft/day.
- The confinement between LF1 and LF2 appears to be more restrictive than MC2. The packer test completed in this interval yielded an estimated horizontal hydraulic conductivity ranging from 0.67 to 1.61 ft/day. The presence of fresh water in the packer test interval with more saline water above it also implies good confinement of this unit There is also a significant difference in the water chemistry between LF1 and LF2.

The results of drilling and testing at LFAKB Project Site B confirm the presence of a series of permeable intervals in the LFA which are potentially viable for future development. Productivity within the LFA is not evenly distributed, however, and the shallowest flow zone (LF1) is less permeable than deeper units at this site. In terms of alternative water supply development, the LF2 horizon, from 1,538 to 1,680 ft bls, is the most promising zone of the Lower Floridan at the Site B location. LF2 offers the best combination of water quality and productivity. If developed independently of LF1, there would be considerable added confinement to isolate it from the highly developed APPZ and UFA units.

At Site B, aquifer yield in the tested intervals of the Lower Floridan compares well to results from other nearby tests in Polk and Osceola Counties, but is low in comparison to tests of the LFA in Orange County. Well yields could be improved by incorporating deeper zones of the LFA, but only at the risk of encountering higher salinity.

ABBREVIATIONS AND ACRONYMS

%	percent
APPZ	Avon Park permeable zone
APT	aquifer performance test
AWE	All Webbs Enterprises, Inc.
BDL	below detection limit
BE	barometric efficiency
BHCS	borehole-compensated sonic log
bls	below land surface
bpl	below pad level
BVL	borehole video log
°C	degrees Celsius
CFWI	Central Florida Water Initiative
cps	counts per second
CRDT	constant rate discharge test (constant rate portion of an APT)
DI	dual induction
FAS	Floridan aquifer system
ft	feet
ft/day	feet per day
ft^2/day	square feet per day
FRP	fiberglass reinforced plastic
gpd/ft	gallons per day per foot
gpm	gallons per minute
gpm/ft	gallons per minute per foot
ICU	intermediate confining unit
IT	interval test
K	hydraulic conductivity
LF1 – LF5	permeable zones in the LFA , from shallowest to deepest
LFA	Lower Floridan aquifer
LFAKB	Lower Floridan Aquifer Investigation, Kissimmee Basin Project

MC1	Floridan confining unit between the UFA and APPZ
MC2	Floridan confining unit between the APPZ and LFA
mg/L	milligrams per liter
MW	monitor well
NAVD88	North American Vertical Datum of 1988
NGVD	National Geodetic Vertical Datum of 1929
OBI	optical borehole image
ohm-m	ohm-meter
psi	pounds per square inch
PT	packer test
Q	pumping or discharge rate
S	storativity
s	drawdown
SAS	surficial aquifer system
S_C	specific capacity
SFCU	sub-Floridan confining unit
SFWMD	South Florida Water Management District
SP	spontaneous potential
SPT	standard penetration test
Ss	specific storage
T	transmissivity
TDS	total dissolved solids
TWA	Toho Water Authority
μS/cm	microsiemens per centimeter
UFA	Upper Floridan aquifer
USDW	underground source of drinking water
USGS	Unites States Geological Survey
VDL	Variable Density Log
YSI	Yellow Springs Instruments

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1
INTRODUCTION

1.1 Background

The Lower Floridan aquifer (LFA) has been targeted as a key source of alternative water supply for the Central Florida Water Initiative (CFWI) in the Kissimmee Basin planning area. It is recognized, however, that there are many uncertainties associated with development of the LFA, including:

- Its productivity south of Orange County, Florida
- The extent and quality of 'fresher' water zones being targeted for water supply
- The extent of the high capacity Boulder Zone for disposal of brine from reverse osmosis water treatment or potential water supply
- The degree of confinement between the LFA and the Upper Floridan aquifer (UFA) and overlying water bodies that the water management districts involved in the CFWI are trying to protect
- The extent to which the LFA currently receives recharge

Each of these uncertainties affects the suitability and sustainability of the LFA as a long-term water supply source.

In 2010, the South Florida Water Management District (SFWMD) laid out a five-year plan for a hydrogeologic reconnaissance of the Lower Floridan aquifer within the Kissimmee Basin region to address uncertainties in LFA development. In fiscal year 2011, this plan was funded and became the Lower Floridan Aquifer Investigation, Kissimmee Basin (LFAKB) Project. A major component of the LFAKB Project is drilling and testing exploratory wells at four sites to bridge the largest data gaps within the Lower Floridan aquifer. This report documents the results from the first of those sites.

1.2 Purpose

The LFAKB Project Site B is located on the west bank of the Kissimmee River in east-central Polk County between lakes Kissimmee and Hatchineha (Figure 1). The site is situated between two proposed Lower Floridan aquifer wellfields, Toho Water Authority's (TWA) Cypress Lake Wellfield to the northeast, and Polk County's Southeast Polk Wellfield to the southwest.

The site was selected for multiple reasons. Given its position, the quality of water in the uppermost zone of the LFA was expected to be relatively fresh, but the productivity or aquifer yield of the zone in this area was less certain. The availability of a high-permeability zone below the underground source for drinking water (USDW) for potential reverse osmosis brine storage was also in question. This site, on the floodplain of the Kissimmee River, was also targeted for a detailed evaluation of confinement between the producing zones of the Floridan aquifer system (FAS) and the overlying ecosystem. At the time of this writing, the public supply wellfields at Cypress Lakes and Southeast Polk are in the permitting phase of development. Site B will provide a monitoring location to track changes in the LFA and overlying units as those wellfields come on line.

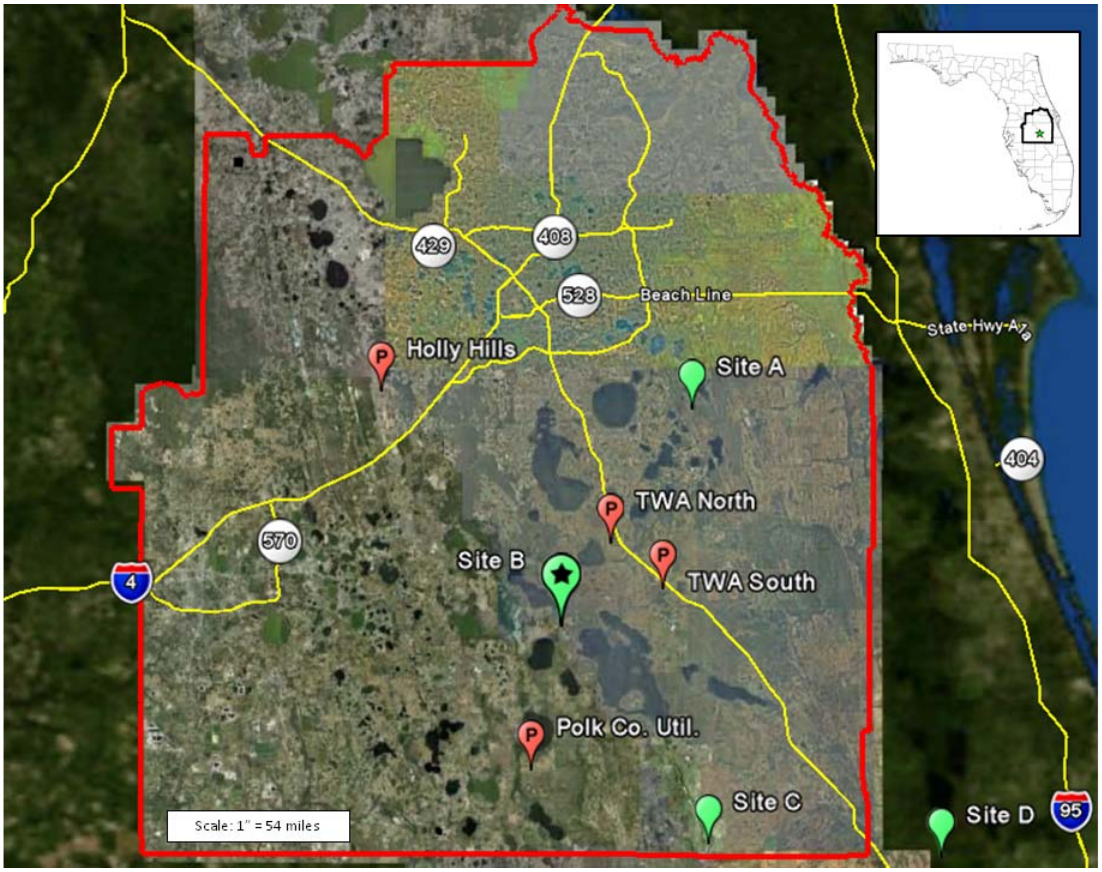

Figure 1. LFAKB project study area. Proposed exploratory drilling sites of the LFAKB Project (green markers) in relation to planned Lower Floridan aquifer production wellfields (red markers).

1.3 Project Description

The SFWMD contracted with All Webbs Enterprises, Inc. (AWE) for drilling, testing, and construction of wells at Site B (CN#6000000412). The scope of the investigation at this site involved exploratory drilling, testing, and construction of two, dual-zone, FAS test wells (POF-27 and POF-28), and one FAS test production well (POF-29) (Figure 2). Well locations, drilled depths, and construction duration are provided in Table 1. Specific objectives for this site included identifying any productive horizons within the LFA and the quality of water in those horizons; evaluating the hydraulic properties of LFA zones of interest; and evaluating the degree of confinement between the LFA and overlying units. Construction of the wells was sequenced to facilitate these testing objectives.

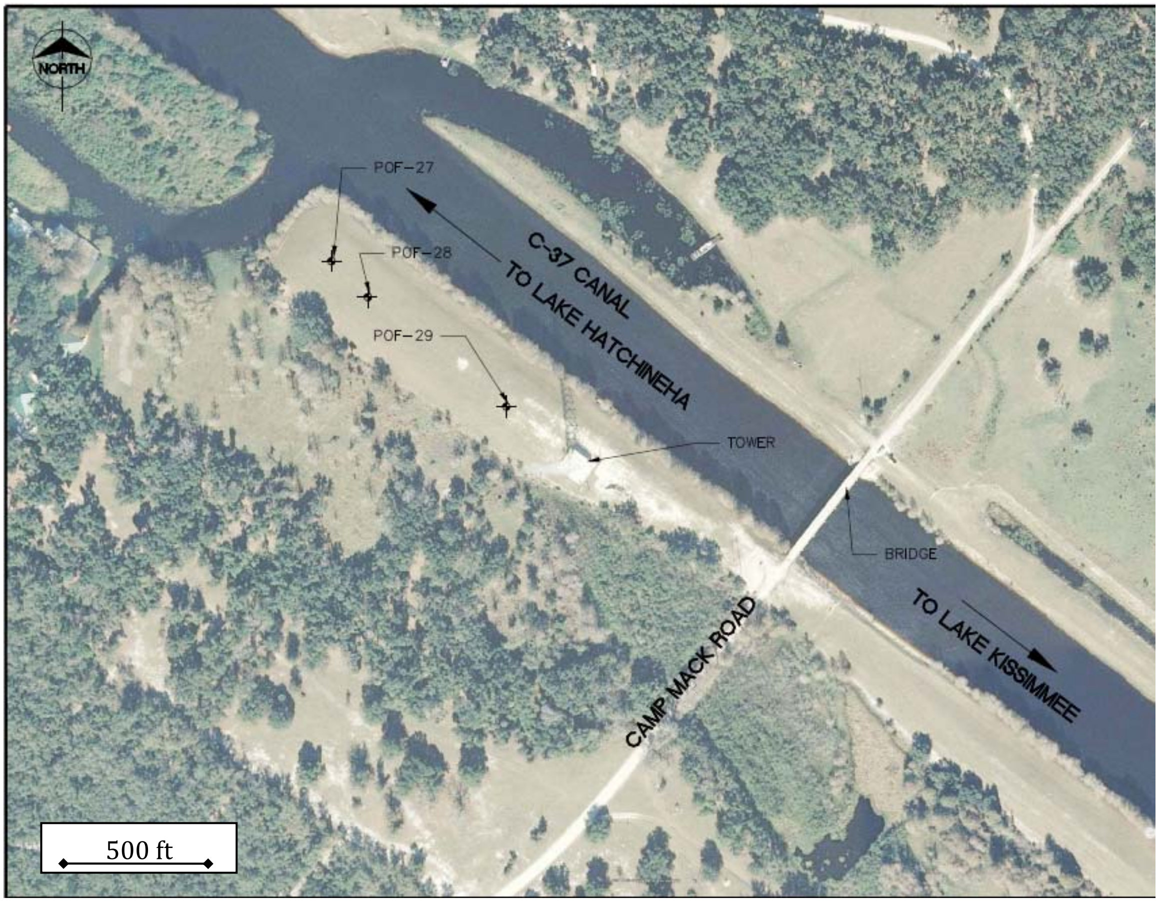

Figure 2. Site B general layout.

Table 1. Well completion information, Site B.

Well	Latitude	Longitude	Land Elevation (NAVD 88)	Start Date	Completion Date	Total Depth Drilled (ft bls)
POF-27	27°58’36.691”	81°22’21.229”	61.33	5-May-11	29-Jun-11	1,403
POF-28	27°58’36.177”	81°22’20.312”	62.45	6-Jul-11	17-Feb-12	2,728
POF-29	27°58’34.601”	81°22’17.749”	63.17	8-Sep-11	15-Feb-12	1,685
POS-14	27°58’34.400”	81°22’17.400”	—	30-Jun-11	01-Jul-11	75

Unless otherwise specified, all vertical positions in this report should be understood to be depth in feet below land surface (bls).

2

EXPLORATORY DRILLING AND WELL CONSTRUCTION

2.1 POS-14 Well Construction

Well POS-14 was installed as a surficial aquifer system (SAS) monitoring well (MW) to determine any interconnectivity between the SAS and the FAS. POS-14 was drilled via the mud-rotary method to a depth of 80 feet below the land surface (ft bls). Standard penetration test (SPT) split-spoon cores were collected at 2-foot intervals. The split-spoon samples indicated a relatively clean fine- to medium-grained sand from 25 to 65 ft bls. This was underlain by clay/sand materials with much lower permeability to the total depth. A 4-inch diameter PVC casing was installed to a depth of 75 ft, with the screened interval near the base of the clean sand unit, from 55 to 65 ft. The screen was 10-slot PVC. A filter pack of 20/30 silica sand was installed around this from 55 ft to 75 ft with a Bentonite seal from 53 ft to 55 ft. The well was grouted from 53 ft to land surface using ASTM Type II neat cement then developed for 1 hour the following day to remove sediments so that clear formation water was obtained. A well construction diagram for POS-14 is presented in Figure 3, and a geologist's log for the borehole can be found in Appendix B.

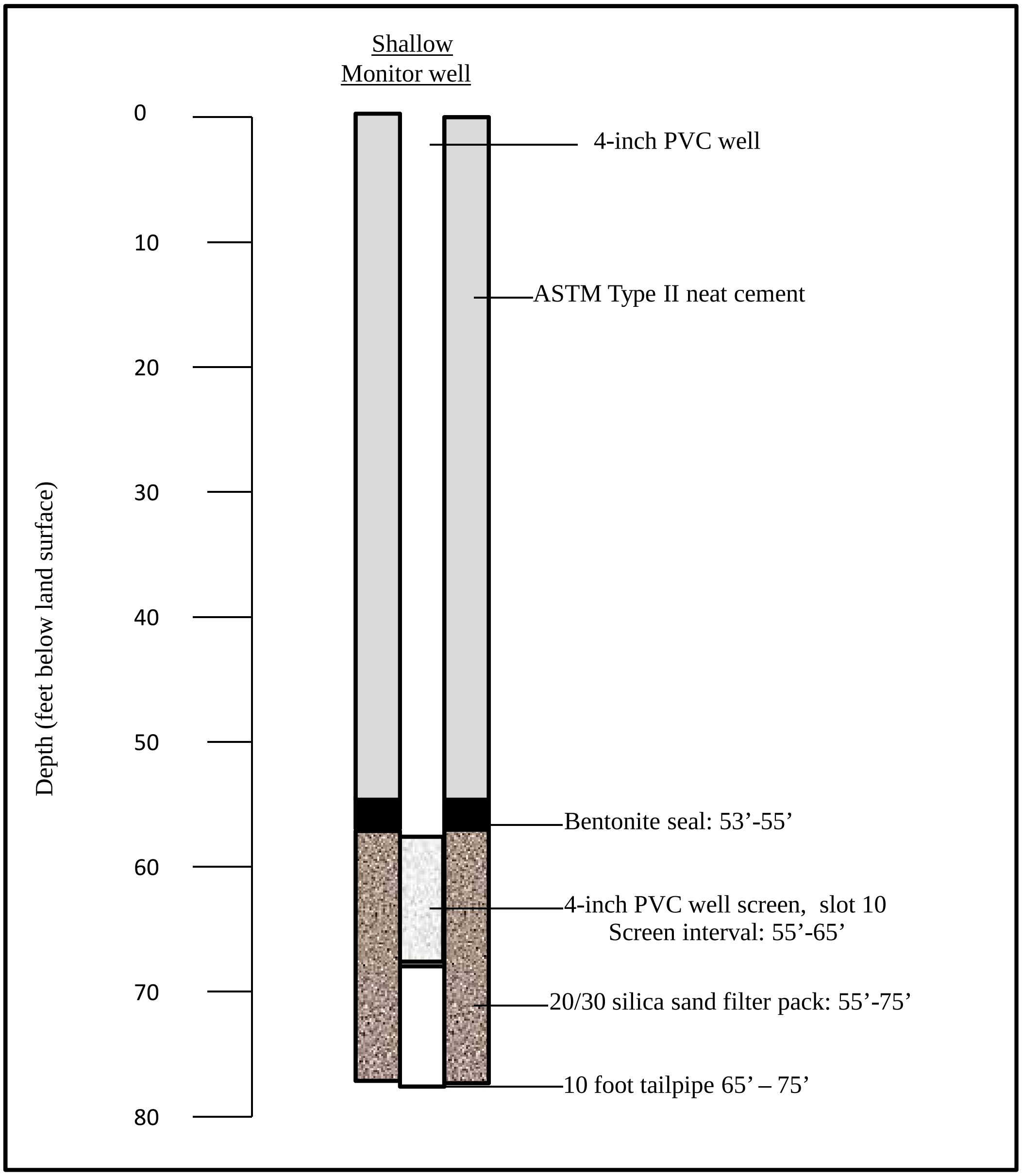

Figure 3. POS-14 completed well construction.

2.2 POF-27 Well Construction

Well POF-27 was drilled prior to the other FAS wells. The well was drilled via the mud-rotary method to a depth of 400 ft bls. Lithologic cuttings were collected, and geophysical logs were run on the pilot hole. These data were used to identify the top of the FAS at Site B. The unconsolidated sediments of the ICU were sealed off by cementing in place a 14-inch diameter carbon steel casing to a depth of 275 ft bls, and the rig was reconfigured for reverse-air drilling.

The nominal 8-inch diameter pilot hole was advanced to a depth of 1,403 ft bls using open-circulation, reverse-air drilling, followed by formation and production logging on the open hole. Based on the lithologic and geophysical log data, the SFWMD selected two packer test intervals where drill-stem and geophysical log data indicated the influx of higher salinity waters into the borehole. AWE configured the dual-packer assembly with a separation of 15 ft. Packer testing was conducted on the intervals from 1,259 to 1,274 ft bls and from 1,359 to 1,374 ft bls. SFWMD personnel collected discrete water quality and hydraulic data from these intervals. Results from testing are presented in Section 5.5.1. After completing the packer testing, the well was backfilled with crushed limestone gravel to a depth of 1,025 ft bls, and sealed with 20 ft of ASTM Type II neat cement to a depth of 1,105 ft bls. A 6-inch diameter steel casing was set to the top of the Avon Park permeable zone (APPZ) at a depth of 750 ft bls. Using cement baskets, the 6-inch diameter casing was cemented back to the base of the UFA, completing the borehole as a dual-zone monitor well (Figure 4). Table 2 shows the monitor intervals and completion details for POF-27. Figure 5 presents the final wellhead configuration for POF-27.

Table 2. Monitor intervals for dual-zone monitor well POF-27.

Identifier	Monitor Interval (ft bls)	Completion Method	Aquifer
POF-27U	275 – 529	Annular Zone	Upper Floridan
POF-27L	750 – 1,105	Open Hole	Avon Park Permeable Zone

Data collected from this section of the pilot hole (i.e., lithology, geophysical logs, packer tests, and water chemistry analysis) were used to identify the base of the Upper Floridan (Suwannee-Ocala) producing zone and the top and base of the APPZ. The data were also used to calculate a preliminary estimate for the depth to the top of the LFA.

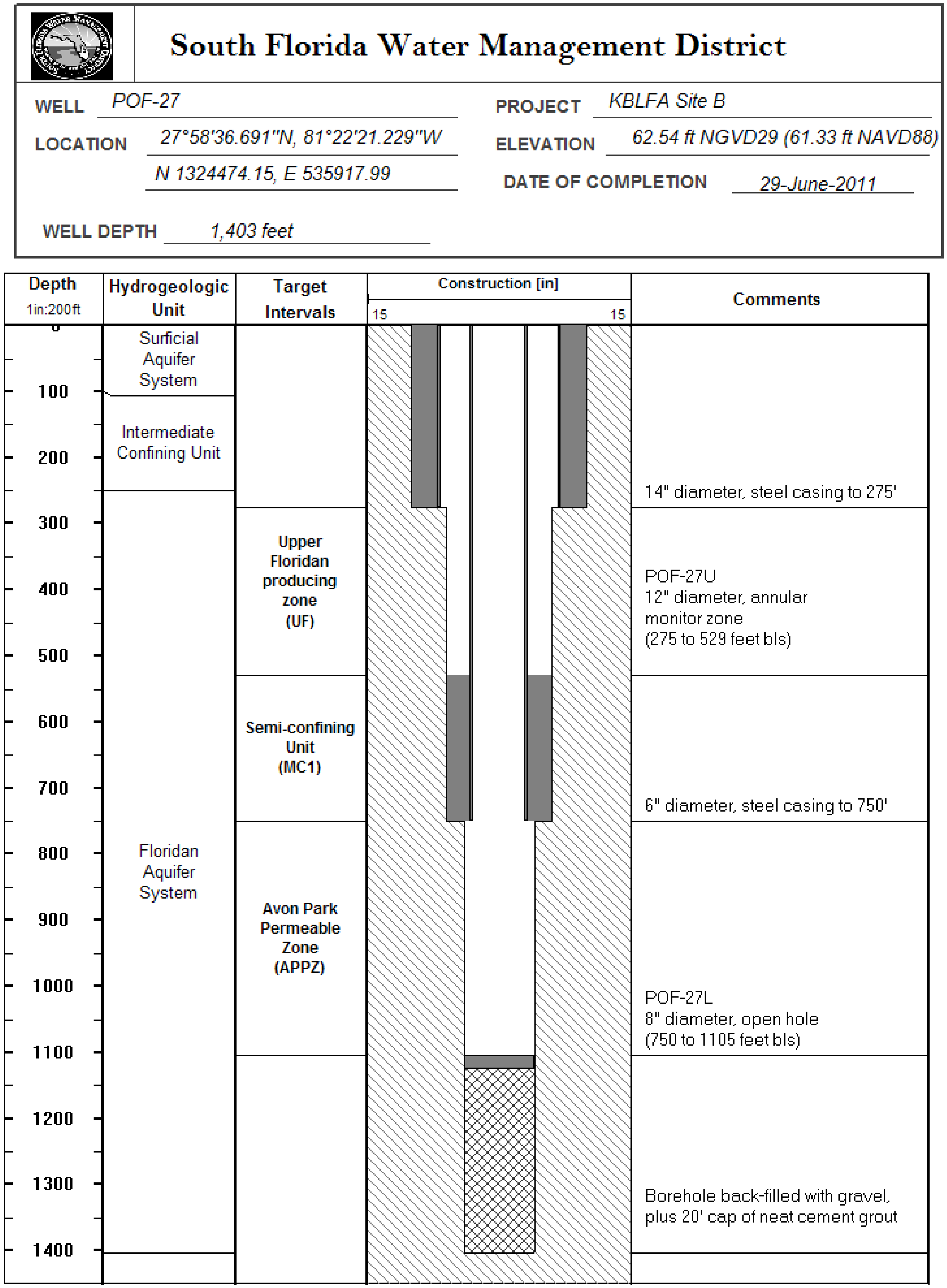

Figure 4. Well completion diagram, POF-27.

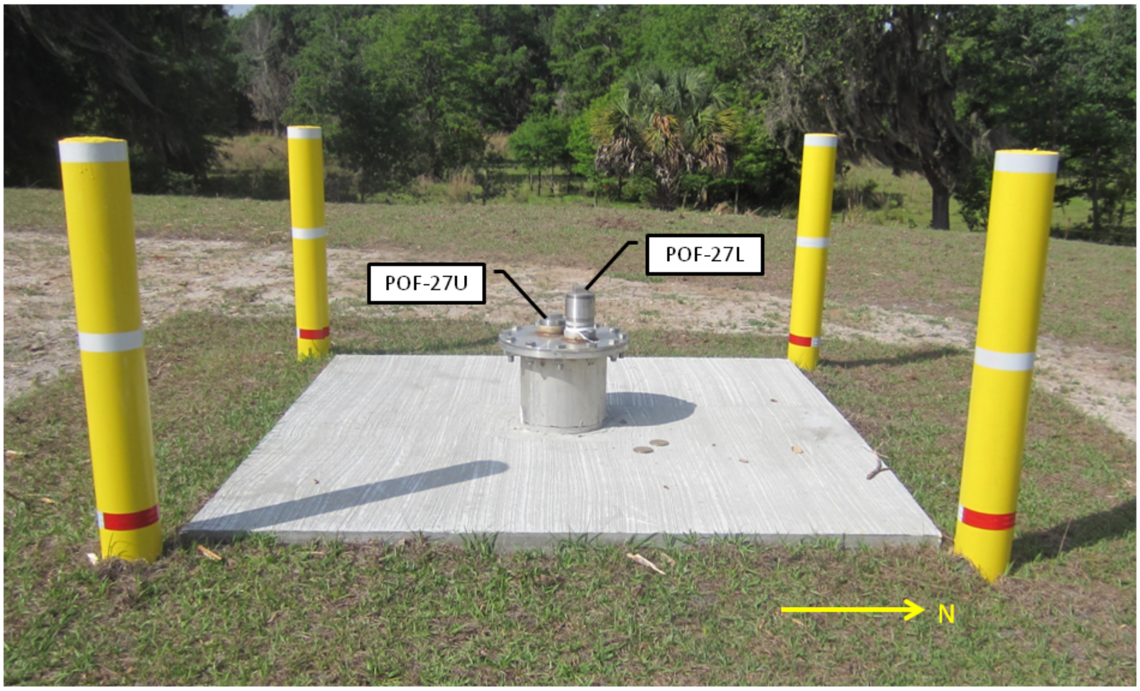

Figure 5. Final wellhead, POF-27.

2.3 POF-28 Well Construction

Upon completion of POF-27, the rig was moved approximately 100 ft to the southeast, where mud-rotary drilling began on well POF-28. The well was drilled to 357 ft bls with mud, where a lost-circulation zone prevented further advancement of the pilot hole. A 24-inch casing was set and cemented in place with ASTM Type II neat cement to the top of the Upper Floridan (270 ft bls), and the rig was reconfigured for reverse-air drilling.

A 12-inch diameter pilot hole was advanced to the top of the APPZ using the reverse-air method. This section of the borehole was drilled using closed reverse-air circulation to prevent capture of high turbidity fluids from the previous mud-drilled portion of the borehole. All other reverse-air drilling was conducted via open-circulation. An 18-inch diameter steel casing was set to the top of the APPZ and grouted with neat cement to the base of the UFA, leaving a temporary annular zone monitor interval from 270 to 530 ft bls. AWE then advanced the borehole with a 12-inch diameter bit to the base of the APPZ (1,105 ft bls).

At this point, construction was halted temporarily, and a 48-hour, constant rate discharge test (CRDT) was conducted on the APPZ. The open hole on POF-28 (750–1,105 ft bls) served as the production well for this test. POF-27L was the production zone observation well, and POF-27U and the temporary annular zone on POF-28 provided data from the overlying producing zone. Results of this CRDT are presented in Section 5.4

Upon completion of the CRDT, AWE advanced the borehole to a depth of 1,300 ft bls. The borehole was then logged and reamed to 18 inches in diameter. Using the left-hand back-off method, a 12-inch diameter casing was set from 715 to 1,297 ft bls. This casing served to isolate the Lower Floridan aquifer from the fresher waters of the overlying aquifers.

After setting the 12-inch diameter casing, AWE advanced the borehole with a nominal 10-inch diameter drill bit to the total drilled depth of 2,728 ft bls. At two points during this phase of construction the drilling was stopped to allow short-term specific capacity testing of various intervals within the LFA. Interval tests were conducted when the pilot hole was at 1,420 ft bls and at 1,950 ft bls to provide rough estimates of incremental change in productivity during drilling. At total depth, the drill string was removed and the hole was logged. Based on the logging results, four intervals were selected for straddle-packer testing (see Section 5.5). Upon completion of the packer testing operations, the bottom of the nominal 10-inch diameter pilot hole was permanently back-plugged. The pilot hole was filled with crushed limestone gravel to a depth of 2,249 ft bls and capped with ASTM Type II neat cement to a depth of 2,221 ft bls. At this point, a final, short-term specific capacity test was conducted on the interval from 1,297 ft bls to the final completed depth of 2,221 ft bls. Results from the interval testing are documented in Section 5.3.

After completing the final interval test, 5-inch diameter FRP tubing was hung in the borehole to a depth of 1,950 ft bls. Using cement baskets, the FRP tubing was grouted in place to a depth of 1,683 ft bls with Type II neat and 4% bentonite cement. When grouting operations were complete, a packer was set in the FRP tubing at a depth of 1,800 ft and a temporary well header was placed on the tubing in preparation for mechanical integrity (pressure testing) operations. The well was filled with fresh water and pressurized to 97 pounds per square inch (psi). The wellhead was shut in for one hour with less than 1% drop in pressure, well within the 5% tolerance level. Both zones of the completed well were developed until clear of visible turbidity and water quality field parameters (pH, temperature, and specific conductance) had stabilized. After all on-site testing was complete, the temporary annular zone monitor interval (270–530 ft bls) was backfilled with 12% bentonite grout slurry, and a final wellhead and pad were installed. Table 3 and Figure 6 show the monitor intervals and completion details, and Figure 7 shows the final wellhead configuration for POF-28.

Table 3. Monitor intervals for dual-zone monitor well POF-28.

Identifier	Monitor Interval (ft bls)	Completion Method	Aquifer
POF-28U	1,297 – 1,683	Annular Zone	LF1 & LF2
POF-28L	1,950 – 2,221	Open Hole	LF4

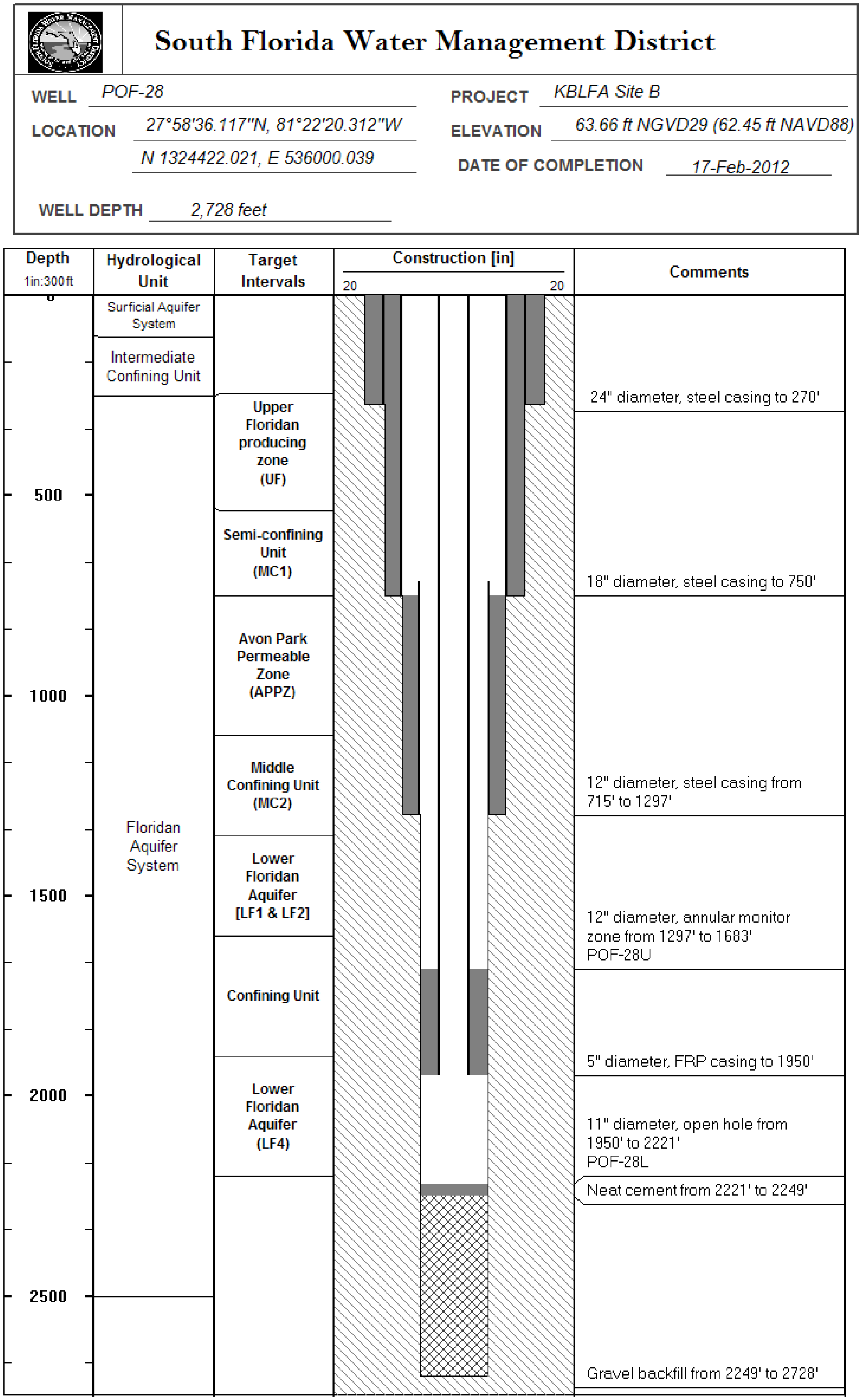

Figure 6. Well completion diagram, POF-28.

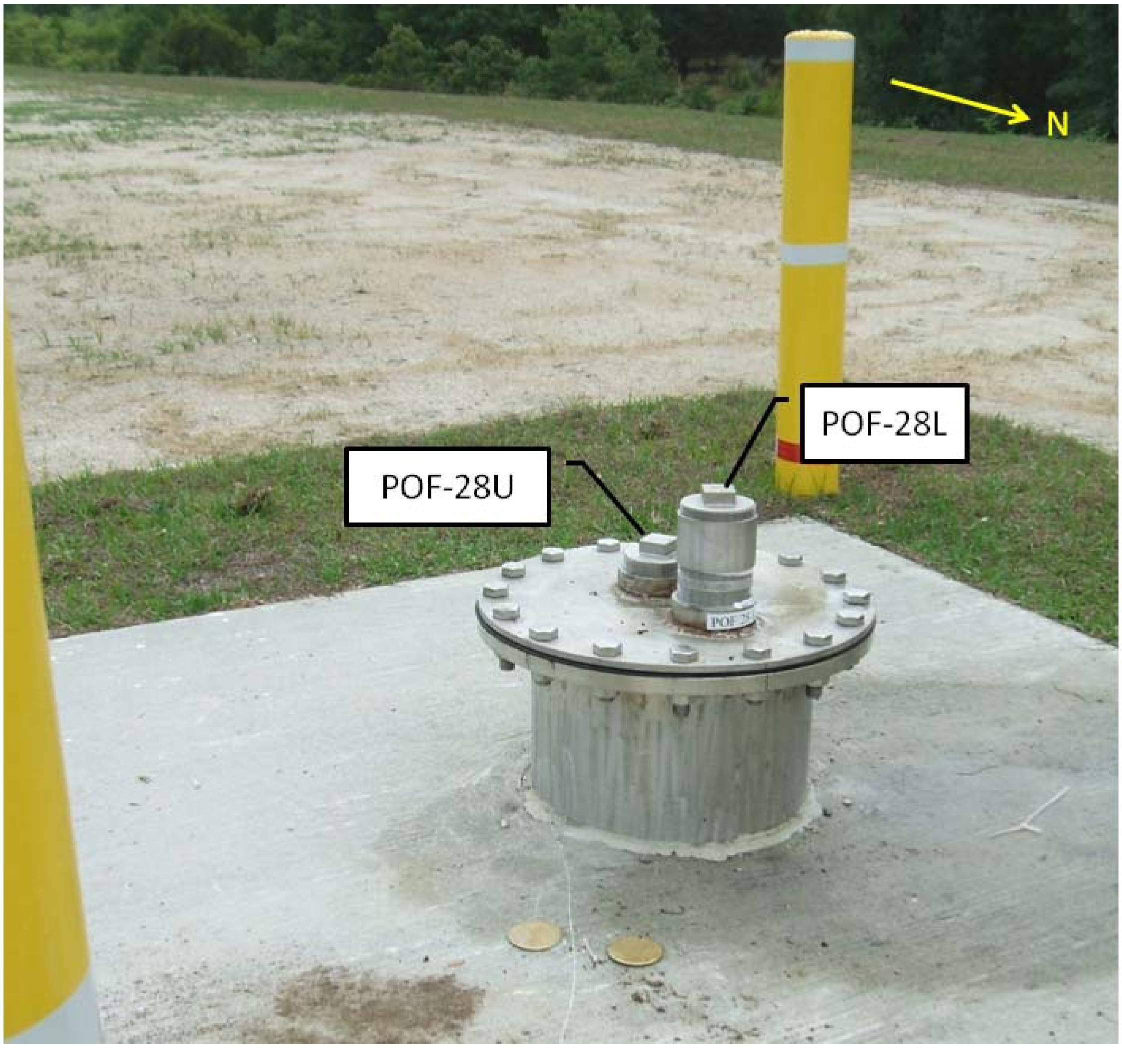

Figure 7. Final wellhead, POF-28.

2.4 POF-29 Well Construction

In August 2011, during construction of POF-28, AWE mobilized a second drilling rig to the site and began preparation for construction of test production well POF-29 at a location approximately 280 ft southeast of POF-28. Lithologic samples, packer tests, and borehole geophysical log data from wells POF-27 and POF-28 were used to determine the casing setting depths for well POF-29. Two concentric steel casings of 24 inches and 18 inches in diameter were used in the construction of POF-29 to facilitate aquifer testing of two distinct productive horizons within the FAS.

In the early stages of construction of POF-29, the combined drilling discharges from POF-29 and POF-28 outstripped available on-site storage. The turbidity of the drilling fluids precluded discharge to the river, so lack of on-site storage became a serious obstacle to drilling progress. To manage this problem, a temporary settling/percolation pond was constructed in the spoil bank of the canal right-of-way south of the access road to the site. This required 1,200 ft of 12-inch diameter piping from the well settling tanks to the pond and increased pumping costs due to the head loss across this distance. However, this method alleviated the turbidity problem and allowed work to progress.

AWE initiated drilling on September 8, 2011, advancing a 12-inch nominal diameter pilot hole by the mud-rotary method to the approximate top of the FAS at 300 ft bls. The hole was logged and then reamed to a nominal 30 inches in diameter. AWE set a 24-inch diameter steel casing in place and grouted the annular space to land surface with ASTM Type II neat cement.

After retooling for reverse-air drilling, AWE advanced the 12-inch nominal diameter pilot hole to the base of the uppermost FAS production zone, approximately 520 ft bls. At this point, construction was halted temporarily and a 24-hour CRDT was run on the uppermost production zone. The open hole on POF-29 (300–520 ft bls) served as the production well for this test. POF-27U and the temporary annular zone monitor well in POF-28 served as production-zone observation wells, POF-27L monitored the underlying aquifer, and POS-14 provided data from the overlying surficial aquifer unit. Results of this testing are presented in Section 5.4.

Upon completion of the CRDT, AWE resumed drilling, advancing the borehole to the base of the APPZ at a depth of 1,100 ft bls. A second, 24-hour CRDT was then run on the interval from 300 to 1,100 ft bls, representing the full thickness of what is generally considered the UFA in the central Florida region. The monitor well configuration for this test was the same as the previous one. After completing this test, AWE resumed drilling and advanced the borehole to a depth of 1,350 ft bls. The pilot hole was logged and then reamed to a nominal 24 inches in diameter. AWE installed 1,350 ft of 18-inch diameter steel casing, and cemented it in place back to the base of the APPZ, leaving a temporary annular monitoring zone from 300 to 1,100 ft bls.

AWE resumed drilling inside the 18-inch diameter casing with the drill-string and advanced the 12-inch nominal diameter pilot hole to the final target depth of 1,685 ft bls. At this total depth, the drill string was removed, and final geophysical logs were run on the borehole. At this point, AWE demobilized the rig from POF-29 and reconfigured for the final CRDT on the LFA. POF-29 served as the production well for this test. When testing was complete, the temporary annular monitoring zone was permanently back filled with a 12% bentonite grout slurry and a final wellhead and pad were installed as shown in Figure 8. Table 4 and Figure 9 present a summary of monitoring intervals and well construction details for POF-29.

A complete chronology of Site B well construction and casing and grout installation is provided in Appendix A.

Figure 8. Final wellhead, POF-29.

Table 4. Monitor interval for production test well POF-29.

Identifier	Monitor Interval (ft bls)	Completion Method	Aquifer
POF-29	1,350 – 1,685	Open Hole	LF2

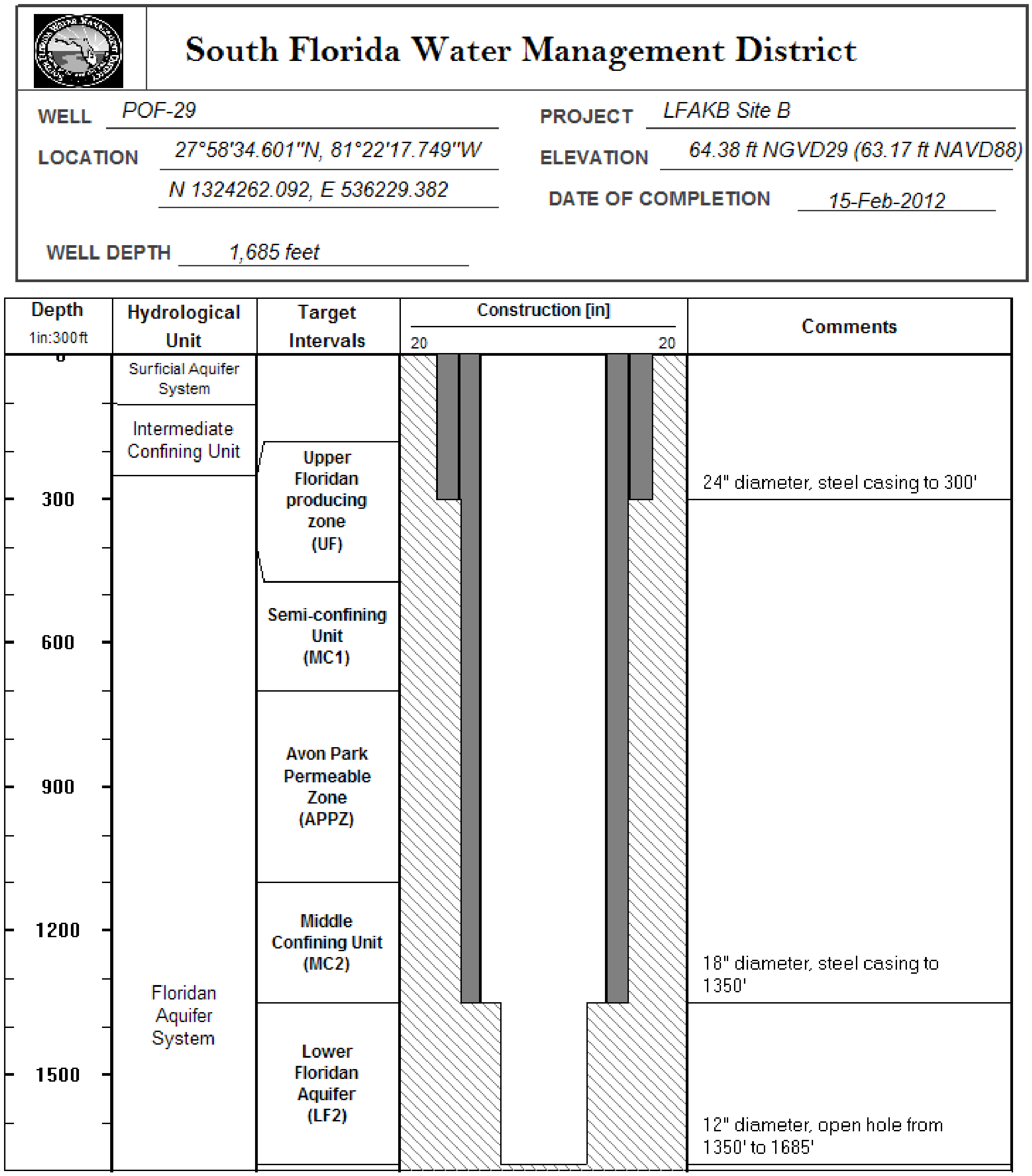

Figure 9. Well completion diagram, POF-29.

3 STRATIGRAPHIC FRAMEWORK

The SFWMD collected geologic formation samples (well cuttings) from pilot holes during the drilling of POF-27 and POF-28 and described them based on their dominant lithologic and textural characteristics and, to a lesser extent, color. The SFWMD's geologists described samples (presented in Appendix B) using the Dunham (1962) classification for carbonates. Geophysical logs and the borehole video log (BVL) and optical borehole image (OBI) log were also helpful in describing the geologic formations encountered during drilling.

3.1 Holocene, Pleistocene, and Pliocene Series

Undifferentiated sediments of Holocene, Pleistocene, and/or Pliocene age occur from land surface to approximately 77 ft bls. At this depth, the natural gamma ray counts spike due to the presence of phosphate, indicative of the Hawthorn Group. These undifferentiated sediments consist of pale to dark yellowish brown, fine- to medium-grained, sub-angular and angular, quartz sand with lesser amounts of silt. Wood fragments indicative of tree roots were present in concentrations up to 30% between 20 and 55 ft bls.

3.2 Miocene Series

The Hawthorn Group is composed of a heterogeneous mixture of silt, clay, calcareous clay, quartz sand, phosphatic sand and silt, limestone, and dolostone. Scott (1988) elevated the Hawthorn Formation to group status in Florida. It consists of two formations, the Peace River Formation, composed of predominantly siliciclastic material, and the underlying Arcadia Formation, composed principally of carbonates.

3.2.1 Peace River Formation

The top of the Peace River Formation consists of olive gray to olive black, unconsolidated sand and silt with a minor phosphate component (1 to 20% phosphatic sand, silt, and clay). These sands begin at a depth of 77 ft bls at this site. An olive black, sandy clay layer occurs from 95 to 110 ft bls, and predominately fine-grained quartz sand occurs from 110 to 115 ft bls. Olive grey to olive black, very fine-grained quartz sand, silt, and carbonate mud with approximately 10 to 20% phosphatic sand and silt and varying amounts of shell fragments occur from 115 ft bls to the base of the formation at 235 ft bls. From 140 to 170 ft bls, the percentage of shell fragments increase to approximately 80%. From 230 to 235 ft bls, sediments include approximately 20% brownish grey, poorly indurated dolostone. The Peace River Formation is approximately 158 ft thick at this site and extends to a depth of 235 ft bls.

Deposition of the Peace River Formation sediments began in the Middle Miocene when siliciclastic sediments overran Florida's carbonate bank environment (Scott 1988). As sea level rose during this period, large amounts of siliciclastic material made their way to southern Florida, restricting carbonate sedimentation. Although the sediments of the Hawthorn Group show significant reworking, it appears that the depositional setting was a shallow to marginal marine environment.

3.2.2 Arcadia Formation

A lithologic change from predominately siliciclastic to mixed siliciclastic-carbonate sediments differentiates the Arcadia Formation from the overlying Peace River Formation. A distinctive lithologic change occurs at 235 ft bls, where the predominant lithology changes to a yellowish gray to light olive gray, microcrystalline, moderately indurated dolostone with phosphatic sand. The contact between the overlying Peace River Formation and underlying Arcadia Formation is transitional/gradational (Bryan et al. 2011) and is placed where carbonate beds are more abundant than siliciclastic beds. The base of the Arcadia Formation occurs at approximately 295 ft bls, based on a change in lithology to predominantly pale yellow brown limestone of the Ocala Limestone and a strong reduction in the response from the gamma ray log. The Arcadia Formation is approximately 60 ft thick at this site.

The Arcadia Formation developed during the Lower Miocene in a carbonate bank environment with the deposition of siliciclastics from a southward flowing, long shore current (Scott 1988). The depositional setting appears to have been a quiet water (low energy) lagoon, similar to the environment currently present in Florida Bay (King 1979).

3.3 Oligocene Series

3.3.1 Suwannee Limestone

The Suwannee limestone was not present at this location.

3.4 Eocene Series

3.4.1 Ocala Limestone

The Upper Eocene Ocala Limestone is identified at a depth of 295 ft bls at the site. Lithology of the Ocala Limestone consists of a poorly indurated, pale yellow orange to pale yellow brown, pelletal, fossiliferous, wackestone with little observable porosity. Secondary porosity features consisting of vugs and cavities are observed on the BVL and OBI log. The first occurrence of the diagnostic microfossil *Lepidocyclina* was at 305 ft bls. The upper 40 ft of the unit contains up to 20% coarse-grained quartz sand with phosphatic staining and is characterized by a gradual reduction in gamma ray response from approximately 200 API units to 80 API units. The base of the Ocala Limestone occurs at a depth of approximately 355 ft bls.

The Ocala Limestone was deposited on a warm, shallow carbonate bank, similar to the modern day Bahamas (Miller 1986). This low-energy environment probably had low to moderate water circulation (Tucker and Wright 1990).

3.4.2 Avon Park Formation

The top of the Middle Eocene Avon Park Formation is identified from lithologic samples at a depth of 355 ft bls in POF-28. At this depth, a change in lithology was noted, from very pale orange, poorly indurated wackestone with *Lepidocyclina,* to a pale yellow brown, well-indurated, foraminiferal grainstone unit, grading to packstone, approximately 35 ft thick. The first occurrence of *Fallotella* and *Neolagnum* diagnostic microfossils used as biostratigraphic indicators for the Avon Park Formation (Bryan et al. 2011) occurs within the grainstone unit at a depth of approximately 365 to 370 ft bls. The unit is also characterized by an increase in gamma ray response, which can be diagnostic of the Ocala/Avon Park formational contact (Bryan et al. 2011). The Avon Park Formation is present to a depth of approximately 1,824 ft bls at the site.

From approximately 390 to 745 ft bls, the unit consists of poorly to moderately indurated wackestones and packstones with few dolomite interbeds and up to 20% intergranular porosity. The lithology changes at approximately 745 ft bls to a dark yellow brown to pale yellow brown, microcrystalline to sucrosic, well-indurated dolostone that is present to a depth of approximately 1,750 ft bls. The dolostone unit typically includes visible vuggy, fossil moldic, and pinpoint porosity. Interbeds of dark brown lamination and calcareous clay are present throughout this unit. Trace amounts of gypsum/anhydrite infilling is first observed at a depth of 1,065 ft bls; peat interbeds are observed from approximately 1,070 to 1,085 ft bls; distinctive, blue-grey calcareous clay is present from 1,295 to 1,305 ft bls; and limestone (packstone) interbeds are present from 1,425 to 1,470 ft bls. Drill cuttings were often returned as unconsolidated, fine- to coarse-grained dolomitic sand and silt that are interpreted to be representative of poorly consolidated zones or unconsolidated sediments within cavernous solution zones.

From approximately 1,750 to 1,800 ft bls, the dolostone unit grades to a grayish orange, microcrystalline, moderately indurated dolostone with little visible porosity and up to 20% crystalline anhydrite. The base of the formation, from 1,800 to 1,824 ft bls, consists of a grayish orange, mottled, poorly indurated dolostone with calcareous clay and interstitial calcite.

Numerous intervals containing large-scale solution features, such as brecciation, washed out boreholes, caverns, and solution-enhanced fractures, are observed on the BVL and OBI logs within the Avon Park Formation from approximately 755 ft bls to the base.

The abundance of dolostone, larger foraminifera, and sedimentary structures within the Avon Park Formation indicate peritidal to shallow, open marine deposition (Bryan et al. 2011).

3.4.3 Oldsmar Formation

The top of the early Eocene Oldsmar Formation occurs at 1,824 ft bls, where the lithology changes to a very pale orange, calcareous clay and silt with an increased gamma ray response characteristic of the glauconitic marker (Duncan et al. 1994). Glauconitic packstone is present from 1,830 to 1,865 ft bls, and dolomitic wackestones, packstones, and grainstones with abundant fossil fragments, visible intergranular porosity, and moderate induration, are present to approximately 2,100 ft bls. From 2,100 to 2,425 ft bls, the lithology changes to a pale to dark yellow brown, microcrystalline, well-indurated dolomite with little observable porosity. Numerous intervals containing large-scale solution features, such as brecciation, washed out boreholes, caverns, and solution-enhanced fractures, are observed on the BVL and OBI log within the Oldsmar Formation from approximately 2,159 to 2,409 ft bls. From 2,425 to 2,475 ft bls, the formation changes to a grayish orange to dark yellow brown, microcrystalline, well-indurated dolostone with abundant fossil fragments and visible intergranular porosity.

The sediments of the Oldsmar Formation were deposited on a warm, shallow carbonate bank (Miller 1986) or tidal flat (Duncan et al. 1994) environment. The presence of evaporite minerals suggests at times that the banks were exposed to the atmosphere, allowing evaporation of the mineralized water in short-lived sabkha conditions (Miller 1986). The occurrence of glauconite in the deeper limestone confirms that the environment was low energy and slightly reducing, with a low sedimentation rate. Odin and Fullagar (1988) found that glauconitization occurs in open marine waters at depths below 195 ft and at temperatures below 15°C. In this environment, there are very low sedimentation rates and minimal disturbance of the settled sediments.

3.5 Paleocene Series

3.5.1 Cedar Keys Formation

The top of the Paleocene Cedar Keys Formation occurs at 2,475 ft bls, where the lithology changes to a medium grey to dark yellow brown, microcrystalline, poorly indurated dolostone with approximately 30% gypsum/anhydrite, 5% organic material, trace amounts of chert, and little observable porosity. Gypsum/anhydrite occurs in beds, nodules, and as interstitial filling in pores. From approximately 2,585 to 2,640 ft bls, the formation changes to an olive grey to very pale orange, poorly indurated, dolomitic mudstone with gypsum/anhydrite, calcareous clay, glauconite, and little observable porosity. From 2,640 ft bls to total depth (2,700 ft bls), dolomitic limestone grades into a pale yellow brown, speckled, grainstone unit with visible fossil moldic porosity.

The sediments of the Cedar Keys Formation were deposited in an extensive, tidal flat environment (sabkha) or evaporative lagoon, as indicated by the abundant gypsum/anhydrite (Bryan et al. 2011).

4
HYDROGEOLOGIC FRAMEWORK

Two major aquifer systems underlie this site within the Tertiary/Quaternary sequence, the surficial aquifer system (SAS) and the Floridan aquifer system (FAS). The FAS is the primary focus of this investigation. Aquifers within the FAS are composed of multiple discrete, highly permeable zones, many characterized by karst solution and fracturing, separated by lower permeability units of various degrees of confinement. These sub-units of the FAS are not consistently labeled in the literature. This report will follow the nomenclature described in Reese and Richardson (2007) (see Figure 10). A comparison between this, traditional nomenclature (Miller 1986), and recently published reports from neighboring water management districts (Figure 11) is included for clarity.

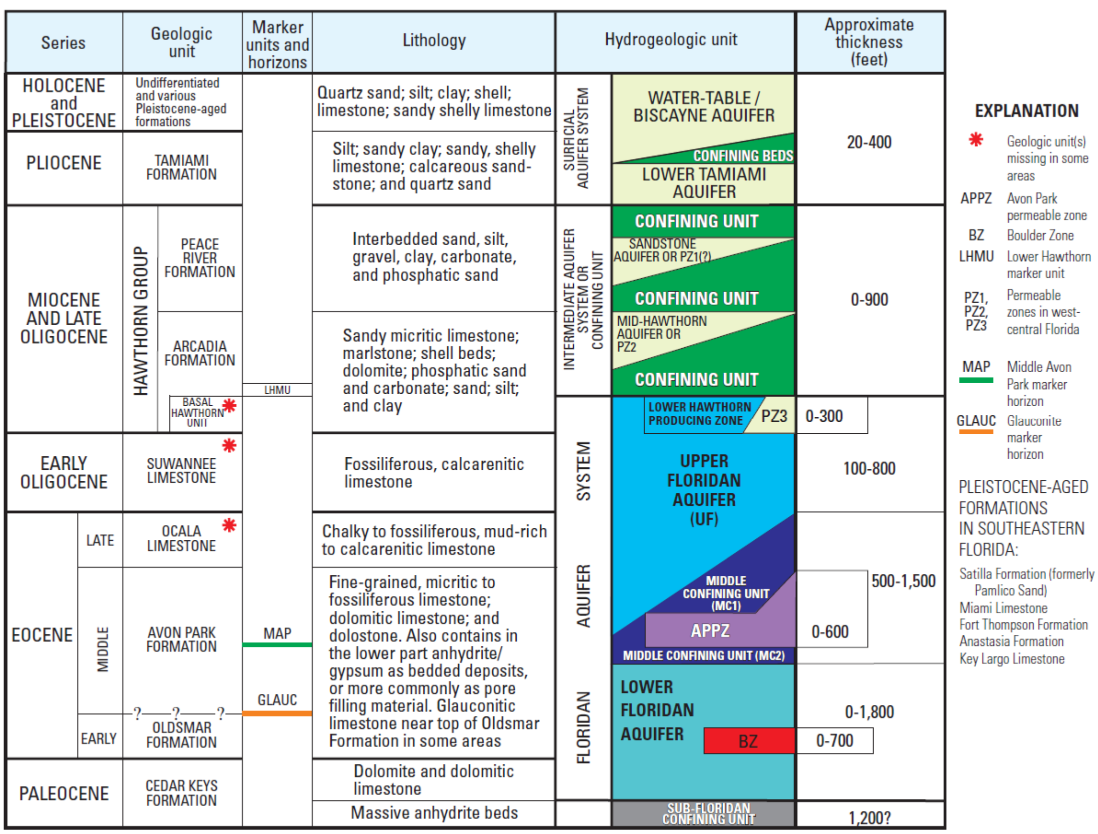

Figure 10. Geologic and hydrogeologic units in central and southern Florida (from Reese and Richardson 2007).

	Miller, 1986	**SWFWMD** (after Horstman, 2011)	**SJRWMD** (after Davis & Boniol, 2011)	**This Publication** (after Reese & Richardson, 2007)
Floridan aquifer system	Upper Floridan Aquifer	Upper Floridan aquifer: Suwannee permeable zone	Upper Floridan aquifer: Upper permeable zone	Upper Floridan Aquifer
		Ocala low-permeability zone	Ocala / Avon Park low permeable zone	middle confining / semi-confining unit 1
		Avon Park permeable zone	Avon Park permeable zone	Avon Park permeable zone
	middle confining unit (I, Ii or VI)	middle confining unit (I, Ii or VI)	Middle confining unit I Middle confining unit II	middle confining unit 2
	Lower Floridan aquifer	Lower Floridan aquifer (below middle confining unit I, II or VI)	Lower Floridan aquifer: Upper permeable zone Confining unit Lower permeable zone Boulder zone Fernandina zone	Lower Floridan aquifer
Sub-Floridan confining unit				

Figure 11. Hydrogeologic units within the Floridan aquifer system, a nomenclature comparison.

4.1 Surficial Aquifer System (SAS)

The SAS in east-central Polk County varies in thickness from approximately 50 to 150 ft thick (Spechler and Kroening 2007). At this location, the SAS consists of undifferentiated Holocene sediments that occur from land surface to a depth of 77 ft bls. The sediments consist of a dark yellowish brown, fine- to medium-grained, sub-angular and angular quartz sand. The SAS is not a major source of potable water in the Kissimmee Basin.

4.2 Intermediate Confining Unit (ICU)

The ICU in east-central Polk County varies in thickness from approximately 50 to 200 ft thick (Spechler and Kroening 2007). At this location, the ICU extends from 77 to approximately 276 ft bls. The sediments of this unit act as a confining unit, separating the FAS from the overlying SAS. Hawthorn Group sediments that make up the ICU consist of unconsolidated shell beds; soft, non-indurated clay, silt, and phosphatic sand; quartz sand; and poorly to moderately indurated mudstones/wackestones of the Arcadia Formation. The base of the ICU is approximately 19 ft above the base of the Arcadia Formation at the site, where the sonic log indicates the first zone of high porosity and a spike in formation resistivity occurs on the dual-induction log.

Spechler and Kroening (2007) describe sediments within the Hawthorn Group in western Polk County with sufficient permeability to warrant being referred to as an aquifer system (intermediate aquifer system). This has not been reported as far east as site B, however, and significant permeability was not observed during the drilling and testing here. Confinement within the ICU was evidenced by the lack of drawdown observed in POS-14, completed within the SAS, during CRDT 2 on the underlying UFA. An approximate 5-foot head differential exists between the SAS and the UFA at the site (see Section 5.6).

4.3 Floridan Aquifer System (FAS)

The FAS consists of a series of Tertiary limestone and dolostone units. At this site, the system includes permeable sediments of the lower Arcadia Formation, the Ocala Limestone, the Avon Park Formation, and the Oldsmar Formation. The base of the FAS occurs in the Paleocene Cedar Keys Formation, which includes massive beds of gypsum and anhydrite (Miller 1986).

4.3.1 Upper Floridan Aquifer (UFA)

At Site B, the top of the FAS occurs at a depth of approximately 276 ft bls, within the lower portion of the Arcadia Formation, and the base of the UFA is located at 529 ft bls, within the Avon Park Formation. The SFWMD selected the depth interval of 275 to 529 ft bls in POF-27U for long-term monitoring and hydraulic testing because this interval includes the significant productive intervals of the UFA.

The lithology of the UFA generally consists of fossiliferous limestone (wackestone to grainstone) with abundant foraminifera, echinoids, and shell fragments. Quartz sand is present in the upper portions, and thin stringers of dolomitic limestone and dolostone are present in the lower portions. Abundant secondary porosity features such as vugs and cavities are observed on the BVL and OBI logs, but relatively few large-scale karstic solution features are observed compared to lower aquifer zones. The primary source of permeability in this section of the FAS is most likely due to karst solution processes (i.e., secondary permeability), in addition to intergranular permeability within fossiliferous limestone intervals. In many older publications regarding the central Floridan region, this unit would be referred to as zone A of the Upper Floridan aquifer.

The following intervals of higher permeability and potential productive capacity within the UFA are inferred from drill cuttings, borehole video/OBI, geophysical, and production logging:

- An upper productive interval at the top of the UFA is evident from increasing flow on the dynamic flow log (POF-27) in the interval 284 to 294 ft bls, which includes the lower part of the Arcadia Formation. The borehole-compensated sonic (BHCS) log shows an approximately 4 ft thick zone with over 60% porosity from 286 to 290 ft bls, and corresponding vugs and cavities are observed on the BVL.

- A productive interval from 350 to 374 ft bls, is evident on the dynamic flow log. This zone corresponds to a foraminiferal grainstone unit that occurs at the top of the

Avon Park Formation at approximately 355 ft bls, and has greater than 60% porosity on the BHCS log. The BVL and OBI logs indicate brecciation, solution enhanced fractures, cavities, and vugs within this interval.

- Increased flow was observed on the dynamic flow log from 488 to 494 ft bls and from 518 to 530 ft bls, within the upper portions of the Avon Park Formation. These intervals correspond to dolomite stringers approximately 3 to 6 ft thick and the adjacent underlying limestone (wackestone to packstone). These intervals did not appear to correlate with increased porosity observed from the BHCS log and the BVL.

Testing results of the UFA in Polk County have reported a wide range transmissivity, from greater than 100,000 ft^2/day in the northwest, to less than 5,000 ft^2/day in the east and southeast. Productivity of the UFA at the site is consistent with the lower values observed in the eastern portion of the county. Aquifer performance test (APT) 2 stressed the interval from 300 to 520 ft bls, which encompassed all but the uppermost permeable interval described above, and yielded a mean transmissivity of 3,627 ft^2/day (Section 5.4.2).

4.3.2 Middle Semi-Confining Unit (MC1)

The base of the UFA and top of the middle semi-confining unit (MC1) is interpreted at approximately 529 ft bls, based on a flow reduction shown in the dynamic flow log and a reduction in vuggy porosity evident in the BVL. A borehole washout was observed on the caliper log at the top of this unit, considered an indication of poor induration and low permeability. The interval from approximately 610 ft bls to the top of the APPZ at 750 ft bls is characterized by a significant reduction in sonic porosity, an increase in fine-grained sediments (wackestones), and a decrease in fossil content and intergranular porosity in drill cuttings. The video/OBI logs indicate numerous small-scale solution features such as vugs and cavities within MC1, but few solution-enhanced fractures.

The confining properties of MC1 are inferred based on the lithology described above and the following test results. Vertical permeabilities were calculated from APT 1 (POF-28), which pumped the underlying APPZ and monitored water levels in the overlying UFA and the underlying APPZ; and APT 2 (POF-29), which pumped the UFA and monitored water levels in the underlying APPZ. Mean vertical hydraulic conductivity values were 0.247 ft/day and 0.298 ft/day for APT 1 and APT 2, respectively.

Although the dynamic flow log indicated a general reduction of flow within MC1, increased flow was observed from 664 to 672 ft bls. This interval corresponds to a thin unit of dolomite with 20% pinpoint and vuggy porosity observed in the drill cuttings and brecciation and cavities observed on the BVL. This interval is considered hydrologically isolated by overlying and underlying strata.

In keeping with Reese and Richardson (2007), this unit is designated MC1 in this report as it is the first semi-confining unit of significant thickness below the UFA. The MC1 unit thickens and becomes increasingly confining to the south, but in northern central Florida, it may be absent altogether (Reese and Richardson 2007). This regional variability has led often to conflicting nomenclature. Where present within the CFWI area, MC1 is most often considered to be a subunit of the UFA. In many areas of western Florida, it consists almost entirely of rocks of the Ocala Limestone. Many recent publications now refer to this unit as the Ocala low permeability zone (Horstman 2011, Sepulveda et al. 2012) or Ocala Avon Park low permeability zone (Davis and Boniol 2011).

4.3.3 Avon Park Permeable Zone (APPZ)

Reese and Richardson (2007) describe the APPZ as lying between the upper and lower Floridan aquifers and correlate the unit across central and southern Florida. Older publications from the central Florida region tend to refer to this unit as zone B of the Upper Floridan aquifer. The term APPZ is now in common usage by the South Florida, Southwest Florida, and St. Johns River water management districts, but its position within the FAS in not agreed upon. In the south, particularly southwest and south-central Florida, where MC1 is very thick and confining, the hydrology and water-quality of the APPZ are very distinctive, the argument for its placement as an aquifer within the middle confining unit (Reese and Richardson, 2007) is very reasonable. In central Florida, the distinction is less clear because the MC1 unit may be very thin or absent entirely. Consequently, the APPZ is considered to be a part of the Upper Floridan aquifer in this region. At Site B, the water quality and water levels in the APPZ are more akin to those in the UFA than MC2.

The APPZ is approximately 200 to 300 ft thick in eastern Polk County (Reese and Richardson 2007). At this site, the top of the APPZ occurs at a depth of about 750 ft bls and the base at 1,109 ft bls, but the permeability is not distributed evenly across this thickness. The SFWMD selected the depth interval of 750 to 1,105 ft bls in POF-27L for long-term monitoring and hydraulic testing because this interval includes all significant productive intervals of the APPZ.

The APPZ consists predominantly of moderate to dark yellow brown, microcrystalline to sucrosic, well indurated dolostone. This zone occurs entirely within the middle of the Avon Park Formation. The top of the APPZ is coincident with the top of the first, thick sequence of dolostone at the site. Vuggy and fossil moldic porosity is observed in drill cuttings throughout most of the section. Drill cuttings from approximately 985 to 1,040 ft bls consist primarily of fine- to coarse-grained dolomitic sand. The high porosity and permeability of the APPZ appears to be associated with large-scale secondary porosity features such as brecciation and solution-enhanced fractures and large cavities, rather than primary porosity features or smaller-scale secondary porosity features such as vugs.

The following intervals of high permeability and potential productive capacity within the APPZ are inferred from borehole video/OBI logs, geophysical logs, and production logging:

An upper productive interval at the top of the APPZ is evident from increasing flow on the dynamic flow log from 758 to 832 ft bls. This interval includes three significant solution zones from 750 to 768 ft bls, 779 to 794 ft bls, and from 825 to 836 ft bls. These solution zones are characterized by brecciation, solution-enhanced bedding planes, and fractures, with corresponding high sonic porosities (over 50%). A groundwater transition from poor water clarity to predominantly good water clarity is observed on the BVL within this interval.

Productive intervals are evident from increasing flow on the dynamic flow log from 874 to 886 ft bls and 920 to 944 ft bls. The upper interval is characterized by brecciation and solution-enhanced fractures, but the lower interval lacks significant fracturing. Permeability in this lower interval is dominated by solution-enhanced bedding planes and small cavities. Both intervals exhibit high sonic porosities (over 50%).

The dynamic flow log indicates more diffuse flow from 994 to 1,105 ft bls. This portion of the APPZ consists of sequences of highly permeable zones evidenced by large cavities, brecciated zones, and solution-enhanced fractures alternating with zones of lesser permeability with predominantly pinpoint and vuggy porosity and relatively few large scale solution features.

Reported values for transmissivity of the APPZ in the site vicinity typically fall in the 30,000 to 50,000 ft^2/day range. APT 1 pumped the interval from 700 to 1,105 ft bls and yielded a mean transmissivity of 38,606 ft^2 per day, consistent with regional data.

4.3.4 Middle Confining Unit (MC2)

The base of the APPZ, and top of the middle Floridan confining unit (MC2), is placed at approximately 1,109 ft bls based on lack of flow observed on the dynamic flow log, a significant reduction of large-scale solution features on the BVL/OBI log, and few high porosity zones observed on the BHS log. The interval from the base of the APPZ to the top of the uppermost producing zone of the LFA (LF1) at 1,296 ft bls is characterized by reduced sonic porosity, a more consistent (less spiky) sonic transit time, a predominantly gauged borehole, few large-scale solution features seen on the BVL and OBI log, and predominantly vuggy and fossil moldic porosity in the drill cuttings. Lithology is predominantly a well-indurated, microcrystalline dolostone with fossil moldic, vuggy, and pinpoint porosity, and abundant dark brown lamination. Up to 5% interstitial and crystalline gypsum/anhydrite was observed in drill cuttings from POF-27 from 1,275 to 1,290 ft bls. Significant evaporite mineralization within this interval is also inferred by groundwater quality analysis of POF-27 Packer Test 2, from 1,260 to 1,275 ft bls, which shows calcium sulfate is the dominant ion pair.

Confining properties of this interval are inferred based on the lithology described above and the geochemical transition into the underlying LF1. Water quality sample results from POF-27 Packer Test 2 (within the MC2 confining zone) indicated a specific conductance and total dissolved solids (TDS) of 466 µS/cm and 316 mg/L, respectively. Results from POF-28 Interval Test 1 (1,297 to 1,420 ft bls), which included LF1, were 1,369 µS/cm and 1,190 mg/L, indicating a significant increase in mineralization of the underlying aquifer zone (LF1). The water type from the POF-28 Interval Test 1 was predominantly calcium-sulfate.

A horizontal transmissivity of 3.10 to 7.49 ft/day was calculated from POF-27 Packer Test 2 (1,259 ft to 1,274 ft bls) within the lower part of this interval. The BHS log shows this test interval was within a zone of relatively high sonic porosity within MC2, however, so this test is likely to under represent the confining properties of MC2. The differences in formation water quality and the presence of a 5 ft head drop across this unit (see Section 5.6) confirm the confining nature of MC2. The unit designated MC2 in this report is a semi-confining unit of significant thickness between the APPZ and the underlying LFA.

4.3.5 Lower Floridan Aquifer (LFA)

The Lower Floridan aquifer (LFA) is a thick sequence of carbonate rocks that contains several permeable zones separated by thick semi-confining units (Miller 1986). For central and southern Florida, the LFA permeable zones above the Boulder Zone are described by

Reese and Richardson (2007) and labeled sequentially (LF1, LF2, etc.) from highest to lowest. This report uses the same nomenclature system. It is important to note, however, that this labeling convention is specific to an individual site. These flow zones have not been correlated regionally, so it should not be assumed that LF2 at this site is the same hydraulic unit as LF2 at Miami Beach, for example. Further work will be required to make these kinds of interpolations from a regional perspective.

At this site, the top of the LFA occurs at a depth of approximately 1,296 ft bls and the base at 2,486 ft bls. Five discrete permeable zones, with varying degrees of confinement between them, were identified within the LFA at site B (see figure 12).

LF1

The first highly permeable and potential production interval in the Lower Floridan aquifer (LF1) occurs from approximately 1,296 to 1,350 ft bls. LF1 is included in the monitoring interval at POF-28U (1,297 to 1,685 ft bls), in addition to LF2, for long-term monitoring.

LF1 consists of a moderate- to well-indurated, microcrystalline dolostone with little visible porosity. Drill cuttings from approximately 1,305 to 1,315 ft bls consist of dolomitic sand. The BHCS log indicates five separate zones of greater than 50% porosity up to 14 ft thick, and the caliper log indicates borehole enlargement over much of these intervals. The video and OBI logs indicate numerous large cavities, breccia zones, solution-enhanced fractures, and good water clarity. One cavernous feature was observed at the base of this zone from approximately 1,346 to 1,349 ft bls.

As discussed previously, a significant increase in mineralization of LF1 was evidenced by the specific conductance of produced water from POF-28 Interval Test 1. The production interval in LF1 is considered to be relatively thin based on the induction log, which indicates a relatively sharp negative deflection in formation resistivity over an approximately 5 ft thick interval from 1,298 to 1,303 ft bls, a potential source for the highly mineralized water. This interval corresponds to a large cavity and solution fracture observed on the BVL.

An estimated transmissivity for LF1 of 2,001 ft^2/day was derived from drawdown observed during POF-28 Interval Test 1 (from 1,297 to 1,420 ft bls), which included all of LF1. The dynamic flow log does not show significant flow through this interval.

A confining interval from 1,350 to 1,540 ft bls separates LF1 from LF2 and is characterized by a reduction in sonic porosity, a more consistent (less spiky) sonic transit time, and few large-scale solution features seen on the video and OBI logs. Lithology in the upper portion of this interval, 1,350 to 1,490 ft bls, consists of interbedded, well-indurated, microcrystalline dolostone and moderately indurated limestone with moldic and vuggy porosity and a trace of interstitial gypsum/anhydrite. Drill cuttings consist primarily of dolomitic sand from approximately 1,480 to 1,540 ft bls.

Confinement within this interval is inferred based on the lithology described above and the following hydraulic and geochemical test results:

- Confinement is inferred based on a water quality transition evident from POF-28 drill-stem water quality samples collected during drilling through the base of the unit and into the underlying LF2 (see Section 5.2). Chlorides results from 1,545 ft bls (7 ft below the top of LF2) and above were approximately 9 mg/L or less, and from 1,585 and 1,615 ft bls (within LF2) were approximately 87 to 93 mg/L, respectively.

- Water quality transition from highly mineralized water in LF1 to relatively fresh water below is evidenced by drill-stem water quality samples (POF-28).

- A horizontal hydraulic conductivity of 0.67 to 1.61 ft/day was calculated from POF-27 Packer Test 1 (1,360 to 1,375 ft bls), immediately below LF1. The BHCS log shows that an approximately 5 ft thick interval of relatively high sonic porosity within the confining interval was included in the packer test; therefore, this test is considered underrepresentative of this interval's confining properties. A detailed discussion of packer tests is presented in Section 5.5.

LF2

The second highly permeable interval is present from 1,538 ft to 1,680 ft bls. The SFWMD selected the depth intervals of 1,297 to 1,685 ft bls in POF-28U (including LF1) for long-term monitoring and 1,350 to 1,685 ft bls in POF-29 for hydraulic testing of LF2.

LF2 consists of well-indurated, microcrystalline dolostone with recrystallized calcite and fossil moldic and vuggy porosity observable in cuttings. Numerous intervals of very fine-grained dolomitic sand were encountered, the greatest percentage from approximately 1,625 to 1,675 ft bls. The BHCS log indicates intervals of greater than 50% porosity up to 42 ft thick, and the caliper log indicates borehole enlargement over much of LF2. The video and OBI logs from POF-28 indicate numerous collapse caverns, large cavities, brecciated zones, and solution-enhanced fractures. In POF-29, this zone exhibited well-developed cavities and solution-enhanced fractures, but without the cavernous intervals seen in POF-28.

The interval from 1,538 to 1,680 ft bls is considered to have high permeability and potential productive capacity based on the dynamic flow log and results of POF-29 APT 4 as highlighted below:

- The dynamic flow log indicates diffuse flow entering the borehole from 1,538 to 1,636 ft bls. Below that, a major flow zone in the interval of 1,636 to 1646 ft bls corresponds to a cavernous interval on the BVL and caliper log. At a pumping rate of approximately 3,800 gpm, upward flow on the dynamic flow log increased from less than 100 counts per second (cps) below this zone to greater than 180 cps above this zone. The static flow log did not indicate significant change over this interval, but significant deflections were observed in the fluid temperature and conductance logs indicative of flow in this interval.

- APT 4 (1,350 to 1,685 ft bls) included LF2 in the pumped interval. The test yielded a mean transmissivity of 41,760 ft^2/day and a mean storage coefficient of 0.00028 (fractures) and 0.0037 (matrix). A detailed discussion of the APTs is presented in Section 5.4.

A relatively thin, low porosity zone from 1,676 to 1,732 ft bls is present below LF2 at the project site. This interval is characterized by reduced porosity and inferred permeability based on a decrease in sonic porosity and few large-scale solution features such as caverns and solution-enhanced fractures as observed on the BVL and OBI log. Drill cuttings analysis indicates a lithology change to a poor to well-indurated, microcrystalline dolostone with visible fossil moldic and vuggy porosity.

LF3

The third highly permeable zone in the LFA is present from 1,732 to 1,823 ft bls at the base of the Avon Park Formation. Water quality data from drill-stem and packer testing indicated increasing salinity relative to LF2; therefore, this interval was not included for long-term monitoring and hydraulic testing.

LF3 consists of a moderately indurated, sucrosic dolostone with recrystallized calcite, calcareous clay, and little porosity observable in cuttings. Interstitial gypsum/anhydrite, up to approximately 10% in cuttings, is present from approximately 1,750 to 1,800 ft bls. The BHCS log indicates greater than 50% porosity over most of LF3. The video and OBI logs indicate numerous caverns, large cavities, brecciated zones, and solution-enhanced fractures.

Although treatment requirements would be more extensive than LF2, LF3 is considered a potential productive horizon, based on the results of POF-28 Packer Test 1 and POF-28 Packer Test 4, which included LF3. Mean transmissivities were 4,378 ft^2/day and 3,252 ft^2/day, respectively. Packer test results are discussed in detail in Section 5.5.

The interval below LF3 and above LF4, from 1,823 to 2,168 ft bls, is characterized by a reduction in porosity as indicated by the sonic log, a more consistent (less spiky) sonic transit time, and relatively few large-scale solution features seen on the video and OBI logs. This interval begins approximately 6 ft above the top of the lower Eocene Oldsmar Formation. Lithology consists of interbedded, fossiliferous, microcrystalline dolostone, dolomitic limestone, and limestone (packstones to grainstone) with visible intergranular matrix porosity. The upper portion of this section, from 1,823 to approximately 2,052 ft bls, is primarily dolomitic limestone and limestone that appears chalky and to have in-filled vugs and poor water clarity as seen on the BVL. Sonic porosity decreases from approximately 2,052 ft bls to the top of LF4 (2,168 ft bls), and the lithology changes to a predominantly sucrosic, well-indurated dolostone with little visible porosity from 2,095 to 2,180 ft bls, with fewer chalky interbeds evident on the borehole video log. Numerous intervals of dolomitic sand were encountered, the greatest percentage from approximately 1,965 to 2,180 ft bls.

Confinement of this interval is inferred based on the lithology described above, measured head drop between LF2 (POF-28U) and LF4 (POF-28L) in the completed well, and a water quality transition within underlying LF4 indicative of significant confinement above it (discussed in more detail in Section 5). This confining unit appears to correlate to MCU VIII, as defined by Miller (1986).

LF4

The fourth highly permeable zone in the LFA is present from 2,168 to 2,247 ft bls, within the middle portion of the Oldsmar Formation. The SFWMD selected the depth interval of 1,950 to 2,221 ft bls in POF-28L for long-term monitoring and hydraulic testing because this interval appears to be a significant production zone in the LFA.

LF4 consists of well-indurated, microcrystalline dolostone with dark brown lamination and little observable porosity. The video and OBI logs indicate numerous caverns, large cavities, breccia zones, solution-enhanced fractures, and good water clarity. The BHCS log indicates a nearly continuous section of greater than 50% porosity over this interval, and the caliper log indicates borehole enlargement and a washout from 2,136 to 2,210 ft bls.

Based on POF-28 Packer Test 3, POF-28 Packer Test 2, and geophysical log data, the base of the underground source for drinking water (USDW) lies at 2,234 ft bls, within LF4. As shown in drill-stem test results from POF-28 (Figure 3, Section 5), chlorides, sulfate, and TDS concentrations increase by at least an order of magnitude through LF4.

The LF4 interval from 2,168 to 2,247 ft bls is considered a significant productive horizon based on the following findings:

- The dynamic flow log indicates significant flow from the interval 2,180 to 2,192 ft bls. At a pumping rate of approximately 3,800 gpm, upward flow on the dynamic flow log increased from less than 10 cps below this zone to greater than 50 cps above this zone. The static flow log did not indicate significant change over this interval.

- Visible up-hole flow was observed on the BVL above approximately 2,183 ft bls.

- The mean transmissivity from POF-28 Packer Test 2, from 2,229 to 2,269 ft bls, was 907 ft^2/day, and the horizontal conductivity was 22.7 ft/day. The test interval included the lower 18 ft of LF4. Packer test results are discussed in detail in Section 5.5.

The interval from the base of LF4 to the top of LF5, from 2,247 to 2,369 ft bls, is characterized by a reduction in sonic porosity, a more consistent (less spiky) sonic transit time, relatively few large-scale solution features seen on the borehole video and OBI logs, and decreased water clarity evident on the borehole video. Drill cuttings consist of microcrystalline, well-indurated dolostone with little observable porosity.

LF5

The fifth high permeability zone occurs from approximately 2,369 to 2,409 ft bls, based on extensive solution and fracture porosity development evident on the caliper/BHCS logs, and numerous caverns, large cavities, breccia zones, solution-enhanced fractures, and good water clarity evident on the video and/or OBI log. Drill cuttings indicate this interval consists of microcrystalline, well-indurated dolostone with little observable porosity. The BHCS log indicates increased porosity development with approximately 12 ft of 50% porosity over this interval.

The dynamic flow log does not show observable flow through this interval. This may be due to the inability of the production pump to overcome the increased density from this high-salinity zone, in addition to high productivity from up-hole intervals. Production tests were not conducted from LF5.

The interval from the base of LF5 to the top of the sub-Floridan confining unit (base of the LFA) from approximately 2,409 to 2,486 ft bls is characterized by a reduction in sonic porosity, a more consistent (less spiky) sonic transit time, and relatively few large-scale solution features, chalky texture, and poor water clarity seen on the borehole video and/or OBI log. Drill cuttings analysis indicates the interval consists of microcrystalline, well-indurated dolostone with little observable porosity.

4.3.6 Sub-Floridan Confining Unit (SFCU)

The sub-Floridan confining unit (SFCU) at Site B corresponds to the top of the Paleocene Cedar Keys Formation at approximately 2,486 ft bls. The upper 75 ft of this unit consists of a thick sequence of predominantly gypsum/anhydrite pods, nodules, and interbeds with poorly indurated, microcrystalline dolostone and relatively low sonic porosity. The interval below approximately 2,561 ft bls to total depth (approximately 2,700 ft bls) consisted of predominately dolostone and dolomitic limestone with interstitial gypsum/anhydrite and thin beds of calcareous clay. Few solution features, the presence of evaporite pods and nodules, and poor water clarity are visible on the BVL and/or OBI log.

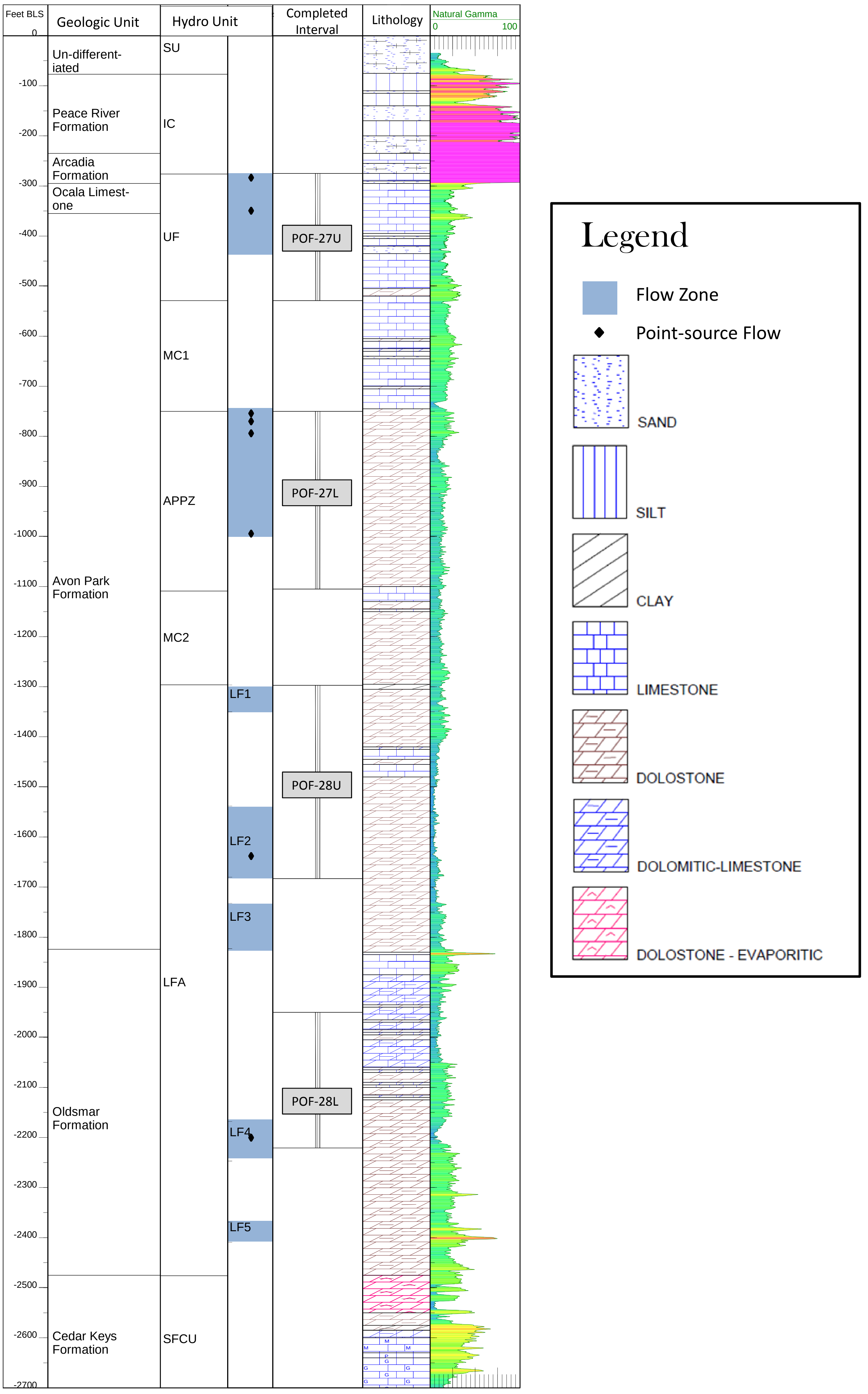

Figure 12. Representative hydrogeologic section for Site B.

5
HYDROGEOLOGIC TESTING

5.1 Geophysical Logging

Geophysical logging was conducted in the pilot hole of each well after each stage of drilling and following reaming of the borehole prior to casing installations. The logs provide a continuous record of the physical properties of the sub-surface formations and the fluids they contain. The log data were used to assist with casing seat selection and lithologic determination, to identify potential production and confining zones, and to assist in correlation among the wells.

Table 5 summarizes the logging program at Site B. A complete dataset of the logs collected at this site is provided in Appendix C. A brief description of the information provided by each type of log is provided below:

XY Caliper – This is a mechanical measure of the dimensions of the borehole in two planes at 90 degrees from each other. It is required for correction of borehole flowmeter logs and also indicates the presence of secondary permeability (vugs, caverns, or fractures). The caliper curve's shape and degree of deviation from the nominal bit size also provides an indicator of the relative induration of the rock and is important for selection of casing setting depths.

Natural Gamma – The gamma ray tool measures the presence of natural gamma radiation produced by the decay of potassium (^{40}K), uranium (^{238}U), and its daughter product (^{232}Th) in the rock formation. Clay and phosphatic rocks are generally rich in these elements. This tool was used for confirming lithologic determination, identifying bed boundaries, correlating among wells, and depth control for the different logging instruments.

Resistivity Logs – These logs measure the combined electrical properties of the rock matrix and the fluids contained within it. In a formation of uniform water quality, the resistivity will be a good indicator of the porosity of the rock, with resistivity decreasing as the water content (porosity) increases. The instrument is also affected by water quality, providing an excellent indication of changes in salinity within the formation.

Normal Resistivity – measures resistivity at two extents within the formation (16 and 64 inches) and is best applied in freshwater environments.

Dual Induction (DI) – measures the resistivity at three extents, the shallowest within and immediately adjacent to the borehole, and the deepest being the best representation of native rock and water resistivity. This tool gives important information on water quality and is a qualitative indicator of possible confining and producing zones.

Spontaneous Potential (SP) – measures naturally occurring electrochemical voltage differential between drilling fluids and formation fluids, providing an indication of the permeability of a formational unit. It works best in saltwater environments.

Borehole Compensated Sonic (BHCS) and Variable Density Log (VDL) – This instrument measures the velocity of sound waves through the rock adjacent to the borehole and is directly correlated to the porosity of the rock. The more porous a formation, the slower the travel time. The sonic log measures only matrix porosity; therefore, sonic derived porosity can be underestimated in vuggy or fractured formations. The VDL provides a visual representation of the borehole wall, indicating the presence of fractures and solution features.

Temperature and **Fluid Resistivity** – This instrument measures the temperature and resistivity of the fluids filling the borehole. These are generally run under both static and dynamic (pumped) conditions. They provide information on the points of influx into the borehole, confinement and production horizons, and salinity variation with depth.

Flow Meter Log – The flow meter log measures the vertical velocity of fluids in the borehole. This log was run under both static and dynamic conditions. Under static conditions, the log indicates cross-flow, water moving vertically between different aquifers intersecting the borehole due to the head difference between the units. Under dynamic conditions, the log indicates the primary production zones within the borehole.

Borehole Video Log (BVL) – Where possible, a digital video of the complete borehole was taken under pumping conditions: downhole view from land surface to total depth and side view from total depth to the base of the casing. The video provides qualitative information on lithologic bedding and secondary permeability (solution features and fractures) that is not always obvious from the cuttings and formation logs. The BVL is also used to inspect the integrity of the casing joints.

Optical Borehole Image (OBI) – The OBI log produces an oriented, continuous, 360-degree digital image of the borehole wall. From these, the character and orientation of lithologic and structural planar features can be quantitatively analyzed. Like standing before a rock outcrop, the optical imagery allows for direct viewing of the character and relationship between lithology, bedding, and secondary permeability of the formation. The OBI logs were used extensively to assist in the interpretation of lithology and formation boundaries, as well as to support the interpretation of hydrogeologic units.

Table 5. Summary of the geophysical logging program at Site B.

Well	Run No.	Date	Logging Company	Logged Interval (feet bls)	Caliper	Natural Gamma	Normal Resistivity	DI /SP	BHCS and VDL	Flow Meter	Temp.	Fluid Res.	Flow Meter	BVL	OBI
POF-27	1	11-May-11	AWE	0 - 350	✓	✓	✓		✓						
POF-27	2	16-May-11	AWE	0 - 285	✓	✓									
POF-27	3	8-Jun-11	AWE	209 - 1403	✓	✓		✓	✓	✓	✓	✓	✓	✓	
POF-27		13-Jun-11	USGS	275 - 1403											✓
POF-28	1	21-Jul-11	AWE	0 - 357	✓	✓		✓	✓						
POF-28	2	27-Jul-11	AWE	0 - 290	✓	✓									
POF-28	3	11-Aug-11	AWE	275 - 530	✓	✓		✓	✓						
POF-28	4	13-Sep-11	AWE	530 - 750	✓	✓		✓	✓						
POF-28	5	21-Sep-11	AWE	275-750	✓	✓									
POF-28	6	18-Oct-11	AWE	750-1305	✓	✓		✓	✓	✓	✓	✓	✓	✓	
POF-28	7	27-Oct-11	AWE	750-1305	✓	✓									
POF-28	8	20-Dec-11	AWE	1300 - 2700	✓	✓		✓	✓	✓	✓	✓	✓	✓	
POF-28		21-Dec-11	USGS	1300 - 2700											✓
POF-29	1	27-Sep-11	AWE	0 - 300	✓	✓	✓		✓						
POF-29	2	04-Oct-11	AWE	0 - 300	✓	✓									
POF-29	3	6-Dec-11	AWE	300 - 1350	✓	✓		✓	✓					✓	
POF-29	4	11-Jan-12	AWE	300 - 1350	✓	✓									
POF-29	5	22-Jan-12	AWE	1350-1685	✓	✓		✓	✓	✓	✓	✓	✓	✓	

5.2 Water Quality and Inorganic Chemistry

Various sampling methods were used to assess the chemistry of the formation water at Site B. Drill-stem sampling and fluid resistivity logging were used to provide a continuous vertical profile of the water within the borehole. Straddle packers were employed at six select intervals to provide a more extensive and accurate assessment of those discrete zones. Composite samples were also collected during aquifer performance testing and on the final completed intervals from each well.

5.2.1 Drill Stem Water Quality Sampling

Groundwater samples were collected at 30-ft intervals during open-circulation reverse-air drilling on wells POF-27 and POF-28. The site geologist analyzed the samples in the field for pH, temperature, and specific conductance using a calibrated YSI 600 multi-probe. From 1,300 ft bls to the base of POF-28, laboratory analyses of these samples were also performed for TDS, chloride, and sulfate.

Changes in water quality during drilling can be good indications that the borehole is crossing distinct hydrogeologic layers. Figure 13 shows drill-stem specific conductance and fluid logs from well POF-27. From the beginning of reverse-air drilling to approximately 1,210 ft bls, the specific conductance from the drill-stem data is relatively constant, around 200 µS/cm. This is consistent with the logged values from the static specific conductance log (blue line). Below this depth, drill-stem specific conductance begins to rise and deviates from the static log. The maximum value of 449 µS/cm from the drill-stem data was reached at a depth of 1,300 ft bls. There is a major drop in the formation resistivity at this depth also, in keeping with an increase in salinity. When the well was logged during pumping (red line), it indicated that higher salinity water was being produced by the formation from approximately 1,280 to 1,340 ft bls. Above that depth, the borehole conductance gradually decreases. Subsequent discrete sampling near the bottom of this borehole indicated that the salinity at this depth is underestimated in the drill-stem samples and fluid logs. This is to be expected, as both drill-stem and fluid log data are imprecise in that the entire open section of the borehole can contribute to the water quality of the sample. Consequently, the presence of a significant producing zone, like the APPZ, can mask water quality changes in deeper or less productive units.

Drill-stem data collection from the second exploratory well, POF-28, was conducted from 1,300 to 2,700 ft bls (Figures 14 and 15). Without the diluting effect of the overlying APPZ, specific conductance from the drill-stem samples exceeded 1,000 µS/cm across the depth range that overlapped with POF-27. As seen in Figure 15, the total salinity of the formation water as represented by the TDS concentration is fairly consistent, around 1,000 mg/L, to a depth of over 2,000 ft bls. There is significant variation, however, in the primary constituents of that salinity. Above 1,545 ft bls, sulfate (SO_4^{2-}) is the dominant anion, with chloride (Cl^-) concentrations of less than 10 mg/L. Below 1,545 ft bls, the sulfate concentration begins to drop as chloride concentration increases, until the distribution of these two anions begins to converge around 1,645 ft bls. Below a depth of 2,130 ft bls, chloride begins to rise much more rapidly than sulfate and remains the dominant constituent from there to the total depth of the well.

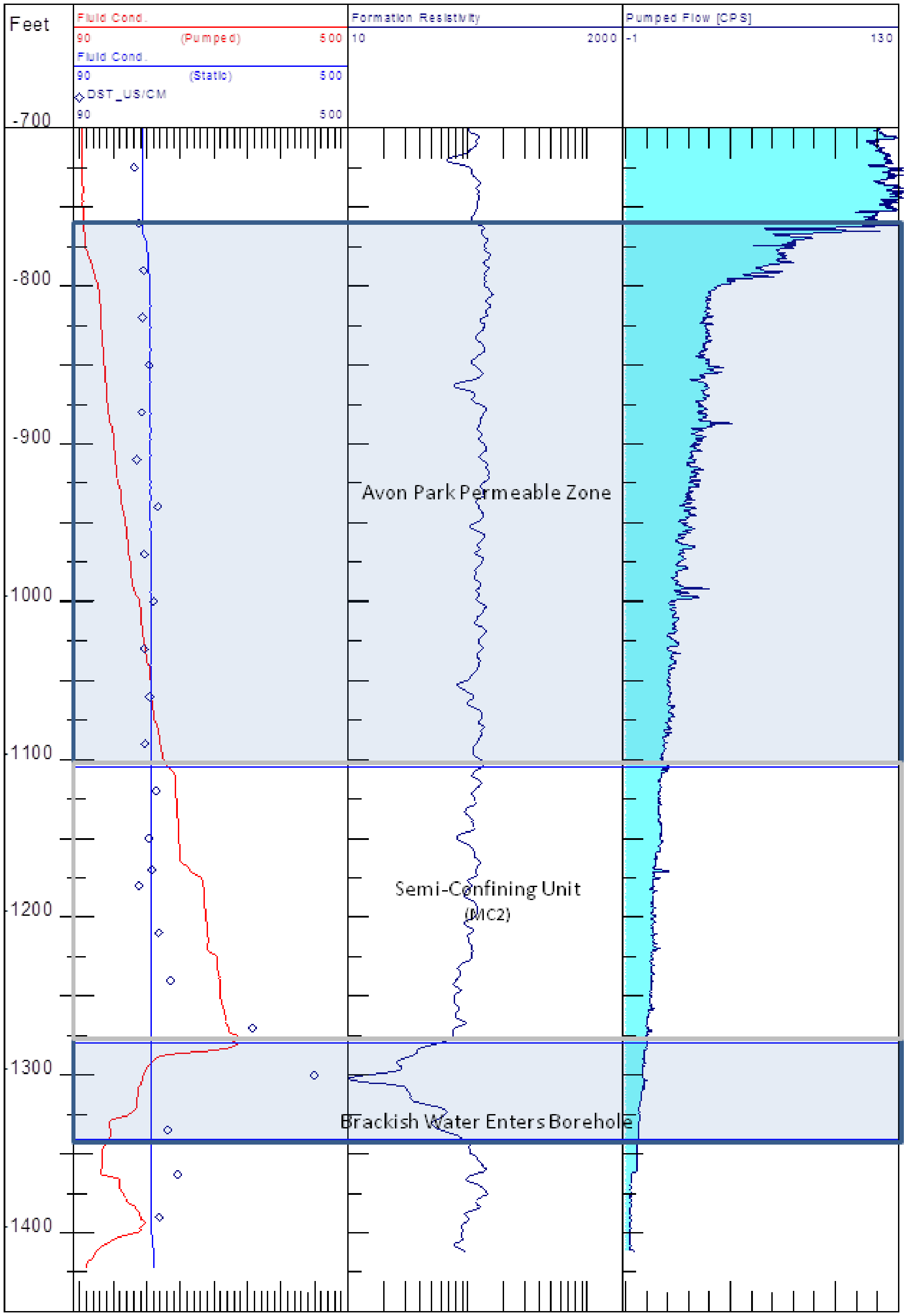

Figure 13. POF-27 drill-stem specific conductance (diamonds) and supporting geophysical log data: pumped and static fluid conductance (µS/cm), formation resistivity (ohm-m), and flow (cps).

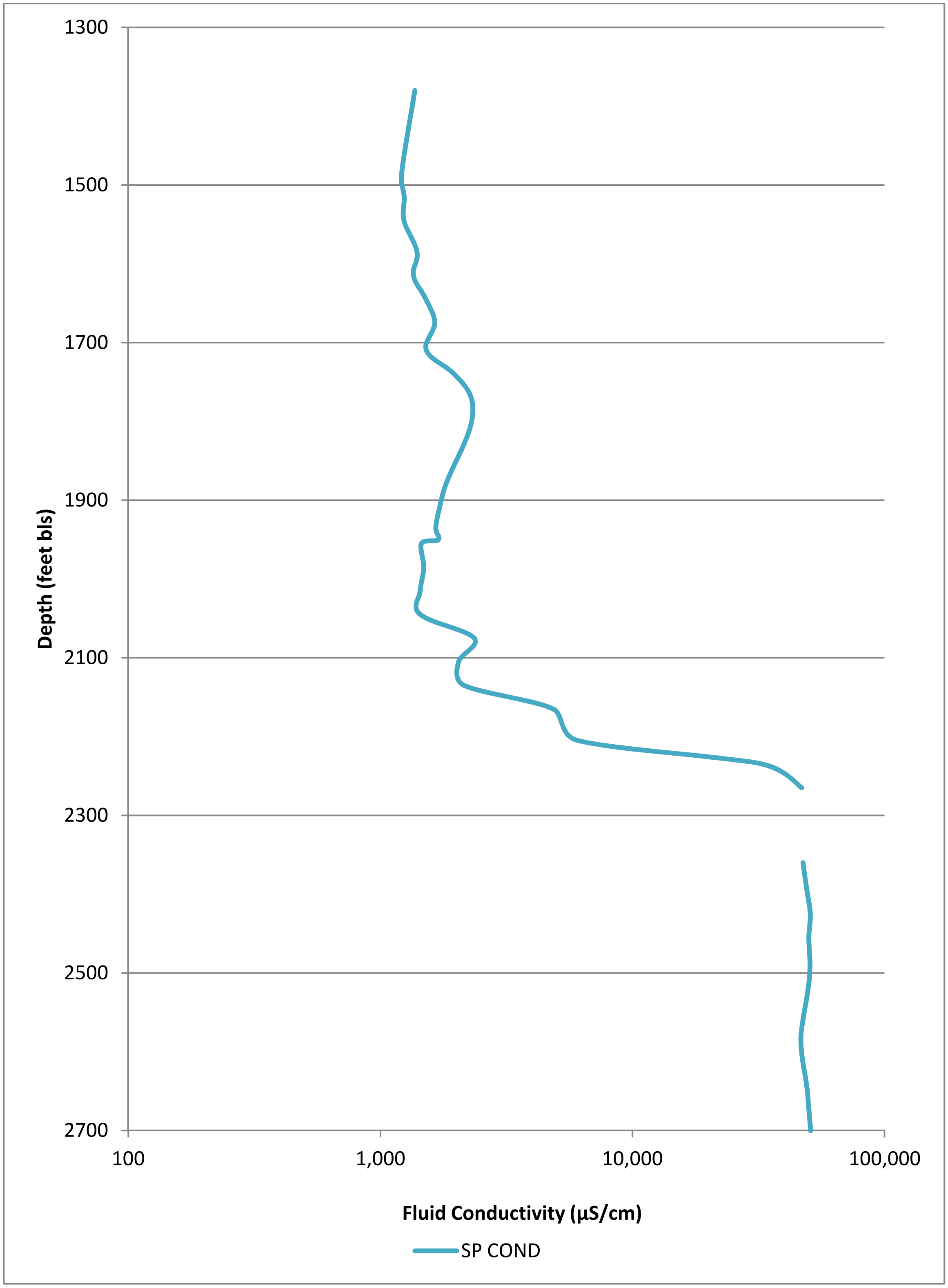

Figure 14. Drill-stem specific conductance from POF-28 (data gap due to an electrical short in the sensor).

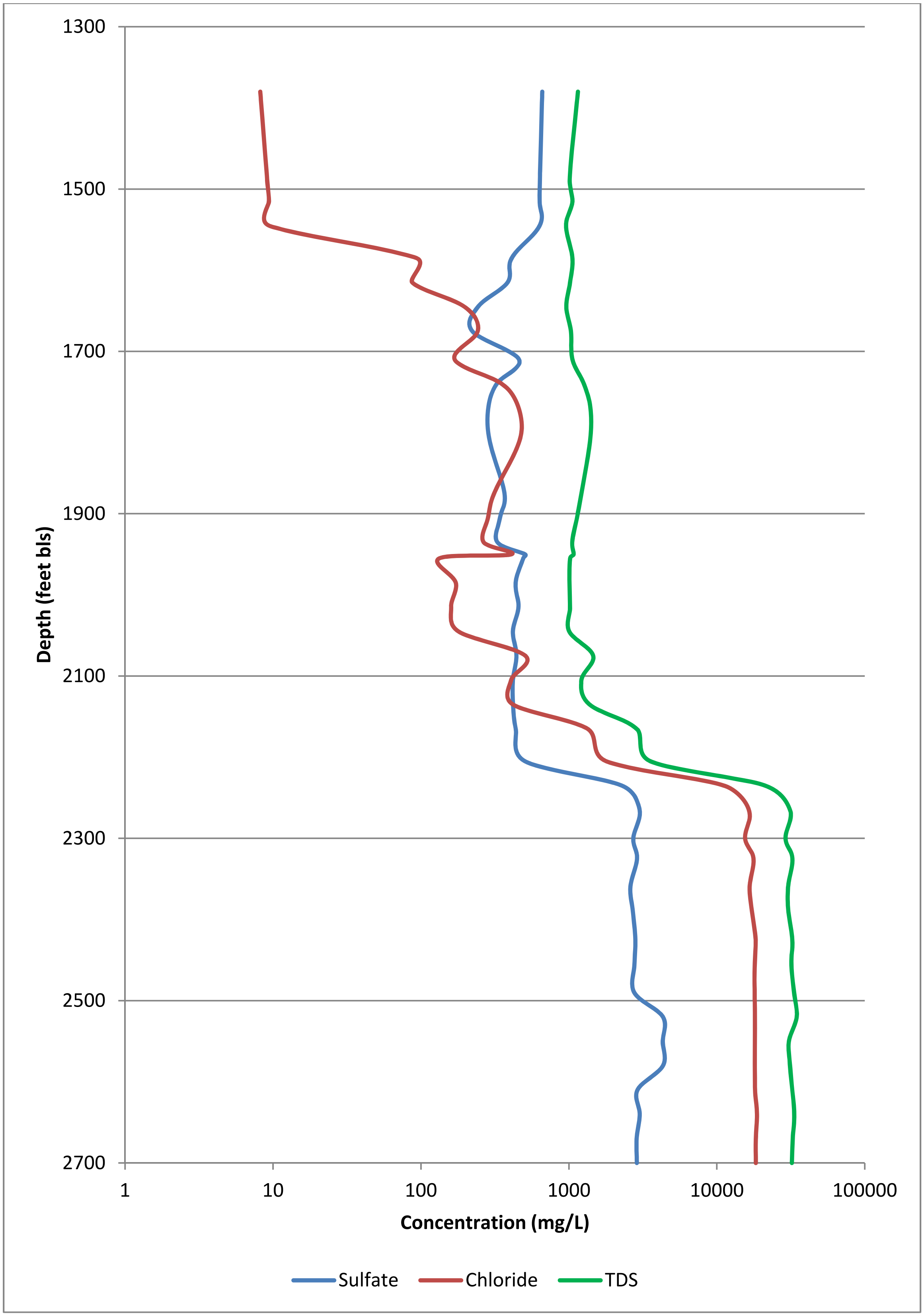

Figure 15. Chloride, sulfate, and TDS data from POF-28 drill stem water quality samples.

5.2.2 Discrete Water Quality Sampling

Numerous water-quality samples were collected during hydraulic testing (packer tests, long-term CRDTs, and short-duration interval tests) and development of the completed monitor intervals of the exploratory wells. A summary of those sample analysis results is provided here. Complete results from the testing program are available for public download from the SFWMD's DBHYDRO database[1].

The data from individual samples are summarized in Tables 6 through 9. Figure 16 illustrates the depth intervals from which these samples were collected. A vertical profile of Cl^-, SO_4^{-2}, TDS, and specific conductance is provided to allow for easy comparison with the drill-stem data. For the most part, the results are comparable, but there are some differences that highlight interesting variations in the formation water.

Near the base of POF-27, it was noted in the drill-stem and conductance log data that higher salinity water was entering the borehole. The same datasets from POF-28 implied much higher salinity than in POF-27. The results from packer tests PT1 and PT2, and interval test IT1, help to clarify this dichotomy. POF-27 PT2 and POF-27 PT1 sampled two, 40 ft intervals (1,260 to 1,275 and 1,360 to 1,375 ft bls), while IT1 in POF-28 encompassed the interval from 1,297 to 1,420 ft bls. The packer test results were consistent with the POF-27 drill-stem data, with the upper test yielding waters with a specific conductance of 466 µS/cm, while the deeper test was fresher, with a specific conductance of less than half that. The highest salinities came from IT1, with a specific conductance of 1,369 µS/cm and a TDS of 1,190 mg/L. This result helps to confirm the presence of a relatively isolated productive horizon between PT1 and PT2, constituting the first permeable zone of the Lower Floridan (LF1) at this site. The influence of this permeable zone is also observed in the differences between the samples from POF-28U (1,297 to 1,683 ft bls) and APT4 (1,350 to 1,685 ft bls), the first including, and the latter excluding LF1. The next deepest productive interval in the Lower Floridan (LF2), though significantly deeper, is somewhat fresher and less sulfurous as well. The sample from POF-29 APT4 is most representative of the chemistry of LF2.

As indicated by POF-28 PT1 and POF-28 PT4, the salinity of the formation water begins to trend upward again below LF2. POF-28 PT3 (2,084 to 2,124 ft bls) and POF-28 PT2 (2,229 to 2,269 ft bls) bracket the saltwater interface (as defined by the base of the USDW) at this site. POF-28 PT3 was completed in a low permeability limestone. The deep monitor interval POF-28L (1,950 to 2,221 ft bls) encompasses this limestone unit and most of a cavernous dolostone (LF4) below it. The sample results from POF-28L are most representative, however, of that very productive dolostone unit. Reflecting this, the graphical representations of salinity are placed at the depth of that productive horizon (see 16) rather than centered in the open interval, which would imply a salinity inversion that does not exist. Based on the packer and geophysical log data, the saltwater interface (base of the USDW) lies within LF4, occurring quite sharply at 2,234 ft bls.

The POF-28L monitor zone was constructed to avoid the higher salinity water observed in POF-28 PT2, but there is nothing in the log or packer data to indicate significant confinement between the interface and the base of the monitored zone. That, combined

[1] http://www.sfwmd.gov/dbhydroplsql/water_quality_interface.main_page

with the sharpness of the interface, implies that its position is largely a function of density rather than any formational impediment.

Table 6. Interval test water quality data, POF-28.

Test Configuration						Field Parameters		
Station Test ID	**Date**	**Time**	**Sample ID**	**Upper Depth (ft bls)**	**Lower Depth (ft bls)**	**Temp. (°C)**	**Specific Cond. (µS/cm)**	**pH**
POF-28 IT1	16-Nov-11	10:33	P53846-1	1,297	1,420	26.4	1,369	7.8
POF-28 IT2	05-Dec-11	12:10	P54736-1	1,297	1,950	26.6	1,481	7.7
POF-28 IT3	13-Jan-12	16:10	P55130-1	1,297	2,221	27.2	2,550	7.4

Analytes					
Station Test ID	**Upper Depth (ft bls)**	**Lower Depth (ft bls)**	**Chlorides (mg/L)**	**Sulfates (mg/L)**	**TDS (mg/L)**
POF-28 IT1	1,297	1,420	8.5	695	1,190
POF-28 IT2	1,297	1,950	226	296	898
POF-28 IT3	1,297	2,221	439	335	1,422

Table 7. CRDT water quality data, POF-29.

Test Configuration						Field Parameters			
Station Test ID	**Date**	**Time**	**Sample ID**	**Upper Depth (ft bls)**	**Lower Depth (ft bls)**	**Temp. (°C)**	**Specific Cond. (µS/cm)**	**pH**	**TDS (mg/L)**
POF-29 APT2	03-Nov-11	12:20	P54649-1	300	520	24.6	176	8.1	90
POF-29 APT4	02-Feb 12	10:20	P54650-1	1,350	1,685	27.5	1,322	7.5	790

Anions							
Station Test ID	**Upper Depth (ft bls)**	**Lower Depth (ft bls)**	**Chlorides (mg/L)**	**Sulfates (mg/L)**	**Bromide (mg/L)**	**Fluoride (mg/L)**	**Alkalinity (as $CaCO_3$)**
POF-29 APT2	300	520	5.5	9.2	BDL	0.19	77
POF-29 APT4	1,350	1,685	237	198	0.73	0.38	78

Cations							
Station Test ID	**Upper Depth (ft bls)**	**Lower Depth (ft bls)**	**Sodium (mg/L)**	**Potassium (mg/L)**	**Calcium (mg/L)**	**Magnesium (mg/L)**	**Total Strontium (mg/L)**
POF-29 APT2	300	520	3.3	0.6	23.3	6.4	0.536
POF-29 APT4	1,350	1,685	126.6	4.9	70.2	36.2	8.240

Table 8. Summary of packer test water quality data from shallow to deep, POF-27 and POF-28.

Test Configuration						Field Parameters			
Station Test ID	Date	Time	Sample ID	Upper Depth (ft bls)	Lower Depth (ft bls)	Temp. (°C)	Specific Cond. (µS/cm)	pH	TDS (mg/L)
POF-27 PT2	17-Jun-11	12:30	P52866-3	1,260	1,275	25.50	466	7.80	316
POF-27 PT1	16-Jun-11	16:53	P52866-2	1,360	1,375	25.80	203	8.00	130
POF-28 PT1	30-Dec-11	19:35	P55182-2	1,708	1,748	25.90	1,557	8.11	1,094
POF-28 PT4	05-Jan-12	14:05	P55185-3	1,765	1,805	26.40	2,058	7.90	1,392
POF-28 PT3	03-Jan-12	14:33	P55184-3	2,084	2,124	25.90	4,568	7.90	2,635
POF-28 PT2	03-Jan-12	12:46	P55183-2	2,229	2,269	25.70	43,226	7.10	26,573

Anions							
Station Test ID	Upper Depth (ft bls)	Lower Depth (ft bls)	Chlorides (mg/L)	Sulfates (mg/L)	Bromide (mg/L)	Fluoride (mg/L)	Alkalinity (as $CaCO_3$)
POF-27 PT2	1,260	1,275	6	124	<.03		90
POF-27 PT1	1,360	1,375	6	15	<.03		78
POF-28 PT1	1,708	1,748	169	501	0.64	0.65	84
POF-28 PT4	1,765	1,805	389	459	0.95	0.62	77
POF-28 PT3	2,084	2,124	1,174	394	4.55	0.37	88
POF-28 PT2	2,229	2,269	15,646	2,561		2.60	113

Cations								
Station Test ID	Upper Depth (ft bls)	Lower Depth (ft bls)	Sodium (mg/l)	Potassium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Total Strontium (mg/L)	Total Iron (mg/L)
POF-27 PT2	1,260	1,275	4.36	1.0	45	17	36.0	0.2
POF-27 PT1	1,360	1,375	3.98	0.7	23	7	3.6	0.3
POF-28 PT1	1,708	1,748	95.2	4.6	162	58	10.9	0.4
POF-28 PT4	1,765	1,805	208.6	8.2	151	63	9.9	0.7
POF-28 PT3	2,084	2,124	661.8	23.5	141	94	8.1	0.6
POF-28 PT2	2,229	2,269	8525	299.0	760	903	27.7	3.2

Table 9. Summary of final completed interval water quality data.

Test Configuration						Field Parameters			
Station Test ID	Date	Time	Sample ID	Upper Depth (ft bls)	Lower Depth (ft bls)	Temp. (°C)	Specific Cond. (µS/cm)	pH	TDS (mg/L)
POF-27L	11-Aug-11	10:15	P53691-1	750	1,105	25	204	8.3	118
POF-28U	20-Mar-12	12:45	P54733-1	1,297	1,683	25.9	1,770*	7.8	1,052
POF-28L	06-Feb-12	17:45	P54732-1	1,950	2,221	27.3	6,707	7.6	3,852

Anions							
Station Test ID	Upper Depth (ft bls)	Lower Depth (ft bls)	Chlorides (mg/L)	Sulfates (mg/L)	Bromide (mg/L)	Fluoride (mg/L)	Alkalinity (as $CaCO_3$)
POF-27L	750	1,105	6.6	18.4	0.19	0.18	70
POF-28U	1,297	1,683	155	480	0.49	0.81	61
POF-28L	1,950	2,221	1,953	436	6.7	0.8	81

Cations							
Station Test ID	Upper Depth (ft bls)	Lower Depth (ft bls)	Sodium (mg/L)	Potassium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Total Strontium (mg/L)
POF-27L	750	1,105	3.9	0.6	23.7	8.2	4.6
POF-28U	1,297	1,683	81.4	3.9	142.3	51.8	10.5
POF-28L	1,950	2,221	1,099	38.9	140.6	134	8.2

Notes:

*	Laboratory quality control flag on this parameter
°C	degrees Celsius
µS/cm	microsiemens per centimeter
mg/L	milligrams per liter
BDL	below detection limit

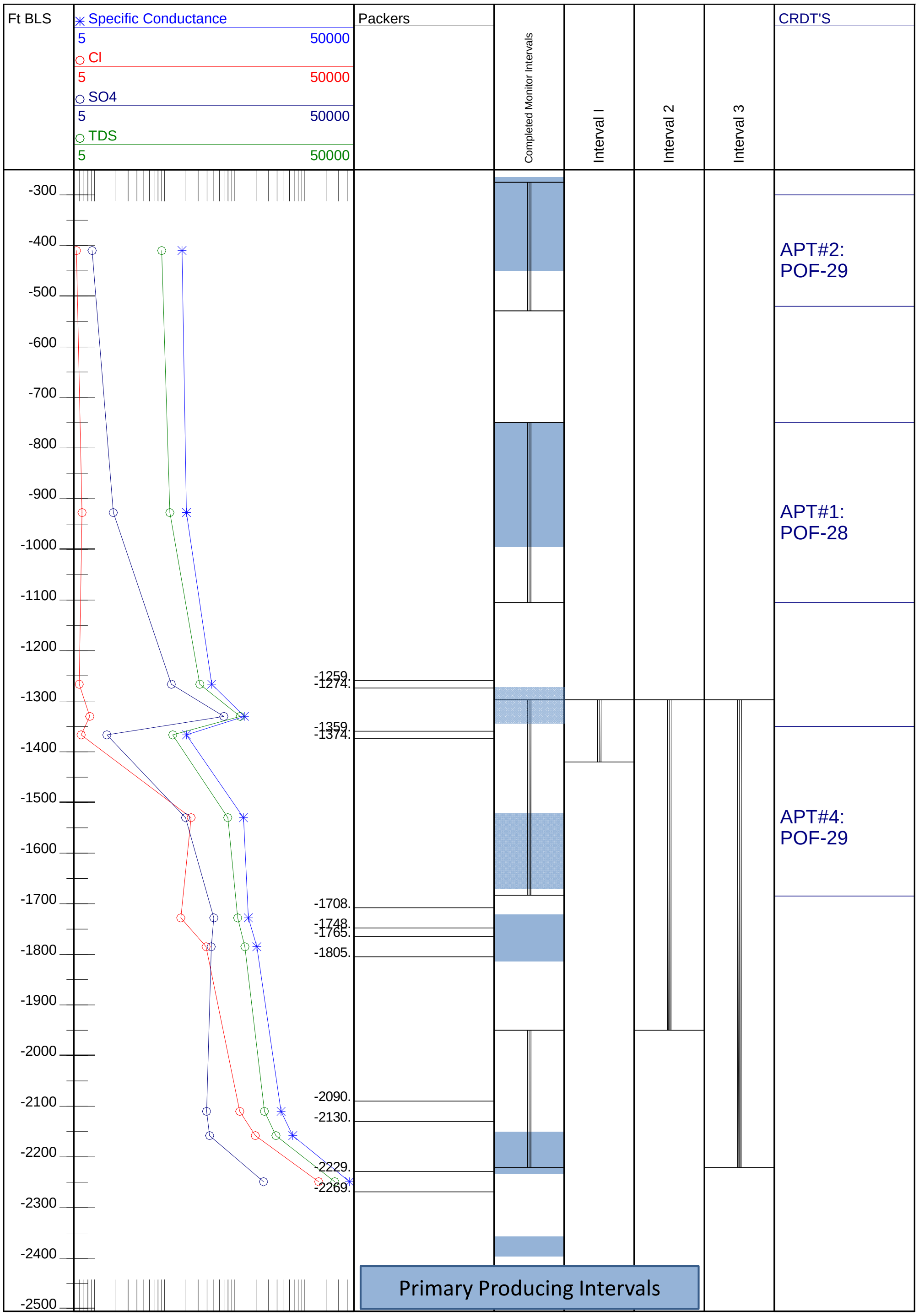

Figure 16. Locations of sample depth intervals, most productive intervals, and distribution of specific conductance (µS/cm), and Cl^-, SO_4^{2-}, and TDS concentrations (mg/L) from those sample results from POF-27, POF-28, and POF-29. For packer tests, the water quality results are centered between the two packer depths. For larger sampled intervals, results are positioned in the graph according to the most likely source depth based on flow logging interpretation of the most productive section of the borehole open to that sample.

The major cations and anions from these samples were plotted on Stiff diagrams and displayed according to depth interval (Figure 17) to illustrate the changing character of the water within different hydrogeologic units. Calcium bicarbonate was the dominant major ion water type in samples POF-29 APT2, POF-27L, and POF-27 PT1. Samples POF-27 PT2 and POF-28 IT1 retain a significant bicarbonate fraction, but calcium sulfate is dominant. Below POF-27 PT1 are mixed waters, a transition zone between calcium sulfate and sodium chloride ion dominance. This is exemplified in the APT4 sample and POF-28 PT1 and PT4, while the three deepest samples are clearly sodium chloride dominant. These variations in the character of the formation waters with depth provide an indication of the rock constituents, the water's residence time within the rock, and the boundaries of hydrogeologic units.

The samples were also examined using the geochemical pattern analysis method developed for the Floridan aquifer system by Frazee (1982) to relate the chemical signature to recharge source, residence time, and saltwater intrusion. The Frazee water types are described in Table 10. Figure 18 shows how the water samples from Site B conform to the water types on Frazee's pattern overlay, and this data is summarized in Table 11.

The formation water samples were also compared to primary and secondary drinking water standards for the parameters tested. No primary drinking water standards were exceeded but one or more secondary drinking water standards were in nine of the twelve samples collected (Table 12).

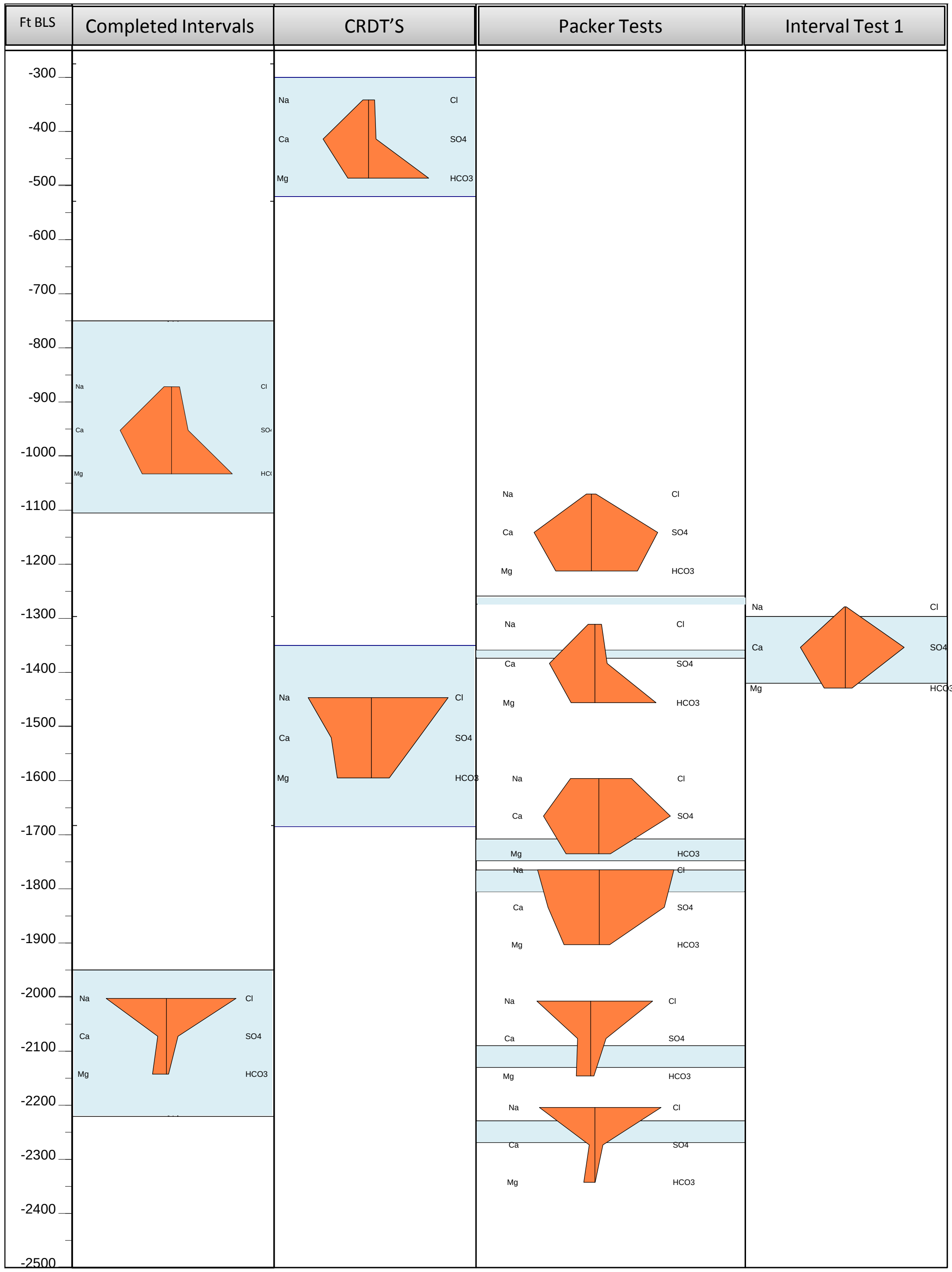

Figure 17. Stiff plots illustrating the relative distribution of major cations (Na^+, Ca^{2+}, Mg^{2+}) and anions (Cl^-, $SO4^{2-}$, $HCO3^-$) with depth (milliequivalents per liter). Each plot represents a discretely sampled depth interval within the Floridan aquifer system at Site B.

Table 10. Description of Frazee (1982) water types.

Abbreviation	Description	Characteristics
FW-I	Fresh Recharge Water Type I	Rapid infiltration through sands, high calcium bicarbonate ($CaHCO_3$).
FW-II	Fresh Recharge Water Type II	Infiltration through sands and clay lenses, $CaHCO_3$ with sodium (Na), sulfate (SO_4), and chloride (Cl). Marginal type II waters are beginning to transition toward FW IV.
FW-III	Fresh Recharge Water Type III	Infiltration through clay-silt estuarine depositional environment, high sodium bicarbonate ($CaHCO_3$).
FW-IV	Fresh Recharge Water Type IV	Fresh water, low calcium (Ca), magnesium (Mg), sulfate (SO_4), and chloride (Cl). Vertical infiltration insignificant. Older form of FW-II or FW-III.
TW-I	Transitional Water Type I	Seawater begins to dominate source water; chloride (Cl) begins to dominate bicarbonate (HCO_3) with increasing NaCl percentage.
TW-II	Transitional Water Type II	Transitional water with source water still dominant, $HCO_4 – SO_4$ mixing zone with increasing chloride (Cl).
TCW	Transitional Connate Water	Connate water dominates source water, sulfate (SO_4) begins to dominate HCO_3 with increasing chloride (Cl).
TRSW	Transitional Seawater	Transitional water with seawater dominating source water.
CW	Connate Water	Highly mineralized fresh water with high TDS and $CaSO_4$ dominance. Presence of highly soluble minerals; H_2S gas prevalent.
[1]RSW	Relict Seawater	Unflushed seawater with NaCl.

[1]Note: Strongly Na-Cl dominant waters may plot in this category even if the overall salinity is significantly less than seawater.

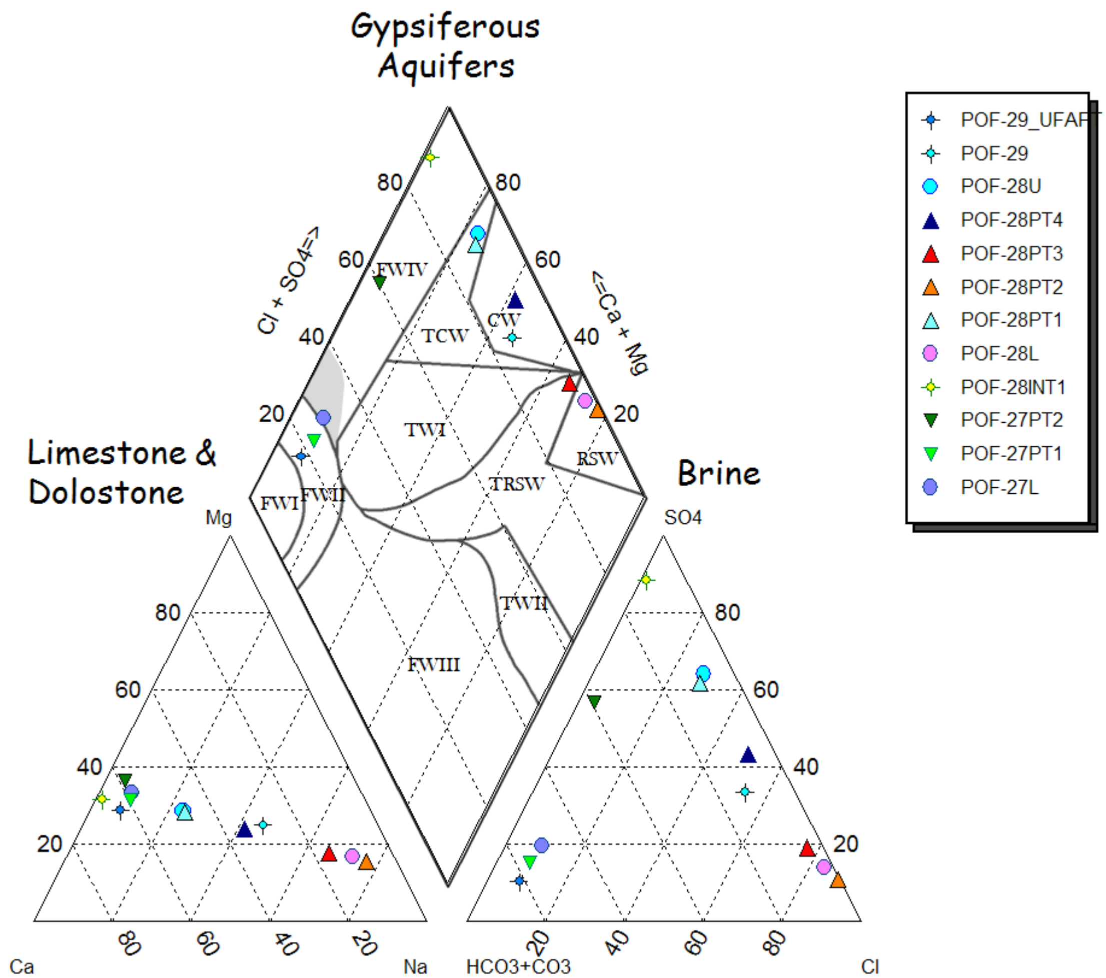

Figure 18. Water type classification of Site B sample data (after Frazee 1982).

Table 11. Water classification summary for the Site B samples.

Sample ID	Station ID	Upper Depth (ft bls)	Lower Depth (ft bls)	Dominant Ion Pair	Frazee Water Type
P54649-1	POF-29_UF APT	300	520	$Ca-HCO_3$	FW-II
P53691-1	POF-27L	750	1,105	$Ca-HCO_3$	FW-II Marginal
P52866-3	POF-27 PT2	1,259	1,274	$Ca-SO_4$	FW-IV
P52866-2	POF-27 PT1	1,359	1,374	$Ca-HCO_3$	FW-II
P53846-1	POF-28 IN1	1,297	1,420	$Ca-SO_4$	FW-IV
P54733-1	POF-28U	1,297	1,683	$Ca-SO_4$-Na-Cl	TCW
P54650-1	POF-29	1,350	1,685	Na-Cl-$Ca-SO_4$	CW
P55182-2	POF-28 PT1	1,708	1,748	$Ca-SO_4$-Na-Cl	TCW
P55185-3	POF-28 PT4	1,765	1,805	Na-Cl-$Ca-SO_4$	CW
P55184-3	POF-28 PT3	2,090	2,130	Na-Cl	TRSW
P54732-1	POF-28L	1,950	2,221	Na-Cl	RSW
P55183-2	POF-28 PT2	2,229	2,269	Na-Cl	RSW

Table 12. Samples with parameters exceeding secondary drinking water standards.

				Secondary Drinking Standards (mg/L)					
				2	250	250	500	0.05	0.3
Sample ID	Station ID	Upper Depth (ft bls)	Lower Depth (ft bls)	Fluorine (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)	Man-ganese (mg/L)	Iron (mg/L)
P52866-2	POF-27 PT1	1,359	1,374					0.06	
P53846-1	POF-28 IT1	1,297	1,420			695	1,190		0.586
P54733-1	POF-28U	1,297	1,683			480	1,052	0.108	0.901
P54650-1	POF-29	1,350	1,685				790		
P55182-2	POF-28 PT1	1,708	1,748			501	1,094		0.445
P55185-3	POF-28 PT4	1,765	1,805		389	459	1,392		0.701
P55184-3	POF-28 PT3	2,090	2,130		1,174	394	2,635		0.592
P54732-1	POF-28L	1,950	2,221		1,953	436	3,852		
P55183-2	POF-28 PT2	2,229	2,269	2.6	15,646	2,561	26,573		3.213

5.3 Interval Testing

Interval testing on POF-28 was performed at specific depth ranges as drilling of the 10-inch diameter pilot hole progressed. Transmissivity for these intervals was estimated using the following equation for confined aquifers (Driscoll 1986):

$$T = 2{,}000\left(\frac{Q}{s}\right) \qquad \textbf{Equation 1}$$

where T = transmissivity (gpd/ft)
Q = pumping or discharge rate (gpm)
s = drawdown (ft)

The first interval test was conducted at 1,300 to 1,420 ft bls on November 16, 2011. The drawdown was approximately 47 ft at a pumping rate of 350 gpm. Using Equation 1, the transmissivity was estimated to be 14,894 gallons per day per foot (gpd/ft) or 1,991 square feet per day (ft^2/day). Some component of the drawdown is due to friction loss within the steel casing rather than the formation. When this loss is included in the transmissivity calculation, transmissivity will be underestimated. Tables for friction losses for water flowing through schedule 40 steel pipe are provided in many engineering handbooks. All friction loss values for the POF-28 casing configuration were extracted from Heald (1994). At 350 gpm, this loss is relatively minor, less than a quarter of a foot, with a correspondingly minor increase in transmissivity to 2,001 ft^2/d.

The second interval test was conducted at 1,300 to 1,950 ft bls on December 5, 2011. The drawdown was approximately 8 ft at a pumping rate of 1,875 gpm. Friction losses of 4.9 ft were calculated for this test, yielding an adjusted drawdown of 3.1 ft. Using the above equation, the transmissivity was estimated to be 468,751 to 1,209,677 gpd/ft, or 62,663 to 161,722 ft^2/day.

The third interval test was conducted at 1,300 to 2,221 ft bls on January 13, 2012. The drawdown was approximately 12.5 ft at a pumping rate of 2,800 gpm. Friction losses of 10.5 ft were calculated for this test, yielding an adjusted drawdown of 2.0 ft. Using Equation 1, the transmissivity was estimated to be 448,000 to 2,800,000 gpd/ft or 59,889 to 376,213ft^2/day. Table 13 summarizes the transmissivity estimations.

Table 13. Transmissivity estimations from specific capacity data.

Interval	Tested Depth (ft bls)	Pumping Rate (gpm)	Total Drawdown (ft)	[1]Corrected Drawdown (ft)	Specific Capacity (gpm/ft)	Transmissivity (ft^2/day)
1	1,300 – 1,420	350	47.0	46.8	7	1,991 – [1]2,001
2	1,300 – 1,950	1,875	8.0	3.1	234 - 605	62,663 – 161,722
3	1,300 – 2,221	2,800	12.5	2.0	224 – 1,400	59,889 – 376,213

[1] Value adjusted for friction loss within the casing.

As can been seen in Table 13, the transmissivity increases between intervals 1 and 2. This response would be expected due to the increased borehole length. The unadjusted transmissivity between intervals 2 and 3 decreases, however, despite an increase in borehole length. This anomalous response highlights the necessity of accounting for head losses outside of the formation. In well tests of various pumping rates in a single borehole, the specific capacity decreases as the pumping rate increases due to turbulent flow in the well. Turbulence is most significant in interval test 3, hence the much larger variance of transmissivity estimated from the raw and corrected drawdown values.

These short-term specific capacity tests were used to provide an order of magnitude estimate of the productive capacity of the formation during drilling. It was clear from this testing series that the capacity of the first interval was relatively minor, and most of the capacity within the Lower Floridan aquifer was significantly deeper than anticipated at this site prior to drilling. This guided the design of the production well for the LFA performance test.

5.4 Aquifer Performance Testing

Four aquifer performance tests (APTs), consisting of a preliminary step-drawdown test and longer duration constant rate discharge test (CRDT), were conducted at different stages in the well construction at site B. These tests were used to determine hydraulic characteristics of the aquifers.

5.4.1 APT 1 (Avon Park Permeable Zone: 700–1,105 feet)

On October 5, 2011, AWE initiated aquifer performance testing on the Avon Park permeable zone at Site B. A preliminary step-drawdown test was conducted to evaluate discharge rates for the CRDT and to ensure that monitoring equipment was configured and reading correctly. A discharge rate of 4,300 gpm was selected based on the preliminary testing and water levels were allowed to return to background conditions.

The duration of the constant rate test was planned to cover 72 hours: 48 hours of pumping followed by a 24-hour recovery period. An in-line totalizing flow meter was used to determine pumping rates, which were recorded hourly. The production well (POF-28) and all monitor intervals were instrumented with downhole pressure transducers that recorded the changes in water levels. A log-cycle time step was programmed into the instrumentation and water levels were recorded initially in short time increments at the start of pumping, then gradually increasing to regular one-minute interval readings. Manual water level readings were also collected at hourly intervals as a backup to the instrumentation. Figure 19 illustrates the configuration of the site during this test.

The pumping portion of the test began at 21:08 on October 5. The following morning, October 6, after 23 hours of pumping, the generator shut down for 11 minutes due to a fuel filter issue. At 14:12 the same day, the generator shut down for a second time and remained offline due to contaminated fuel. A second generator was ordered.

On October 6, the pumping was restarted at 22:06, approximately 8 hours after the second interruption of the test. A mean pumping rate of 4,300 gpm was maintained for the first 29 hours, followed by an 8-hour break due to equipment failure. The remaining 13 hours of the pumping phase ran at a mean rate of 4,270 gpm. On October 7, at 11:12 water level instrumentation was reconfigured to record on a log-cycle time interval, AWE manually shut down the pump, and the test was stepped into recovery. Field data collected as part of this test are provided in Appendix D.

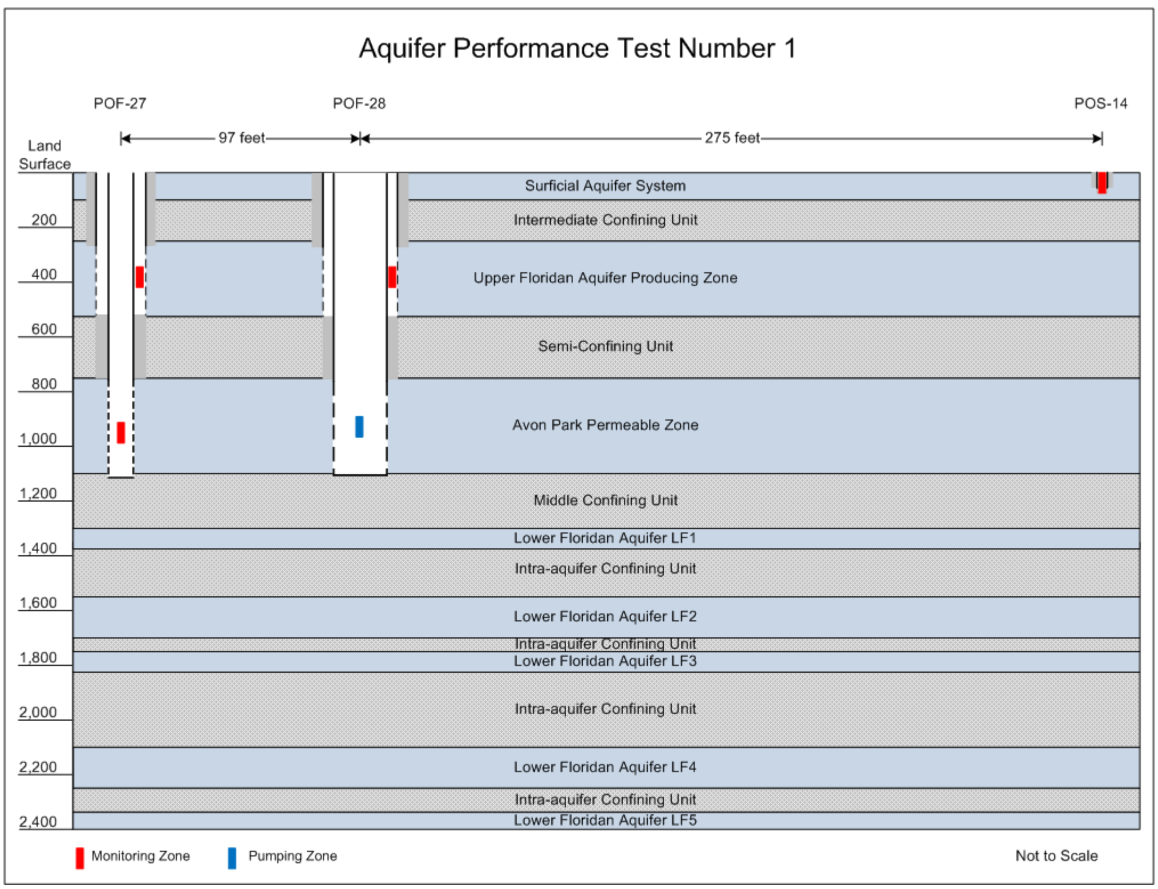

Figure 19. Well configuration for APT 1.

Analyses

During an APT, it is assumed that changes in water level are caused by pumping. Additional stresses may also effect changes in hydraulic head. These can include tidal influence and changes in barometric pressure. This site is in central Florida, so ocean tidal impacts are of minimal concern. Data were collected on October 8 and 9 to establish the relationship between water levels and barometric pressure in the aquifers. An increase in barometric pressure causes a decrease in the height of the water column in a well open to the atmosphere. Barometric efficiency (BE) of the APPZ (POF-27L) and overlying upper permeable zone of the Upper Floridan aquifer (POF-27U) was estimated using Clark's method for estimating barometric efficiency in confined aquifers (Clark 1967). POF-27U (UFA producing zone) had a BE of 40.3%, and POF-27L (APPZ) a BE of 35.1%. The barometric efficiency was sufficiently low and pumping induced drawdown sufficiently large, that it was not necessary to remove this effect from the data. The following analyses were conducted on the raw data, as the BE correction would have made virtually no impact on results.

Data from the APT were analyzed to evaluate the transmissivity, storativity, and leakance properties of this portion of the Avon Park permeable zone. Data from the step-drawdown test conducted during the construction of POF-28 were analyzed using the Cooper-Jacob (1946) solution, and an initial transmissivity of 35,000 ft^2/day was estimated for the interval.

Figure 20 shows the recorded drawdown from the production well (POF-28) and corresponding changes in water level in the upper and lower monitor intervals of POF-27 during this test. The sharp increase and decrease seen on the graph at approximately 18:00 on October 6 represents the changes in water level due to equipment failure and recommencement of pumping after the 8-hour break. Under normal testing circumstances, one would expect the water levels to decrease and stabilize, and when recovery is initiated, an initially abrupt climb in water levels to approximately background conditions. Two periods of recovery are evident in the data, at the time of equipment malfunction as described above and at the end of the pumping phase.

The maximum drawdowns in POF-28, POF-27U, and POF-27L were approximately 53 ft, 1.5 ft, and 14 ft, respectively. The wells are 97 ft apart. POF-27L is finished in the production zone (APPZ) and mimics the changes in water level seen in POF-28.

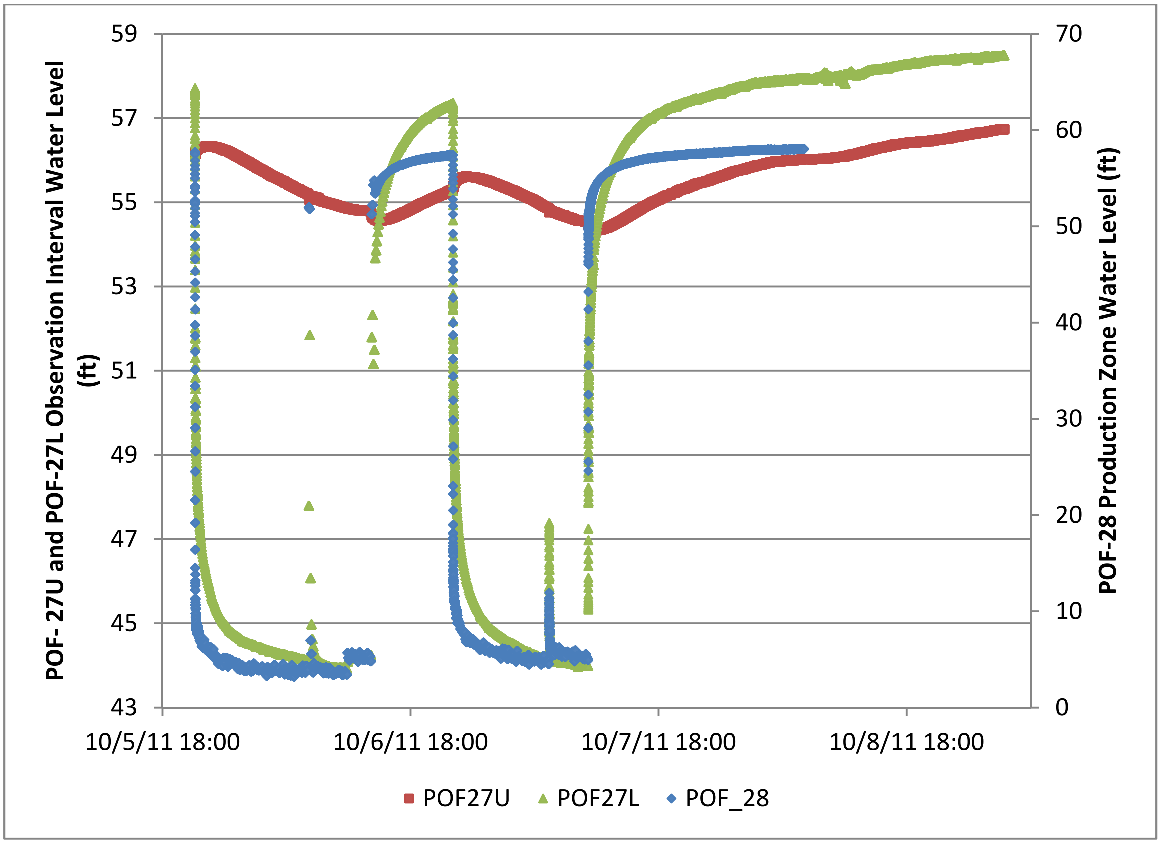

Figure 20. Observed drawdown in the production zone and monitor intervals during the CRDT of the Avon Park permeable zone.

Based on the hydrogeological data collected at the test site, numerous analytical models were applied using AQTESOLV Pro software (Duffield 2007). The drawdown data collected during the APT was used to determine the hydraulic properties of the aquifer. A diagnostic plot of the drawdown and its derivative for the monitor intervals (POF-27U and POF-27L) was used to determine the appropriate solutions to apply for analyses. The analytical methods included both confined and semi-confined "leaky" solutions.

The derivative in the diagnostic plot using POF-27L (Figure 21 red diamonds) indicates well bore storage and skin effect in the initial measurements (initial hump). The skin is the area immediately surrounding the production zone that has been altered by the drilling process, which affects the connectivity of the borehole to the aquifer. In later time, the derivative levels off and then trends towards zero. This can be interpreted as a leaky aquifer (Renard et al. 2009).

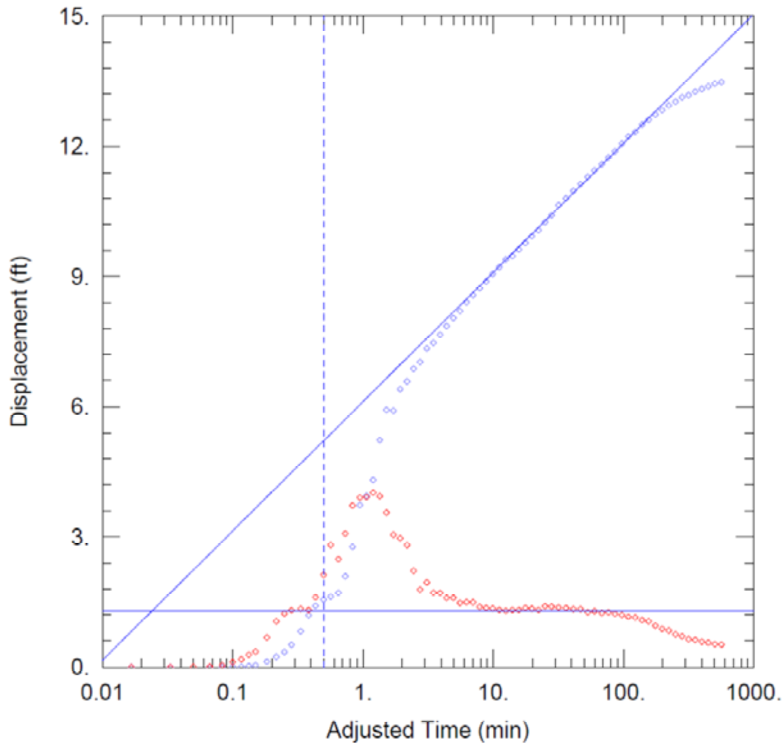

Figure 21. Diagnostic plot of drawdown (blue diamond) and its derivative (red diamond) in monitor interval POF-27L.

The interruption of the test due to equipment failure meant that data beyond 29 hours of pumping are not valid for analyses. The 8-hour break allowed for some recovery in POF-27U, POF-27L, and POF-28. Had the pumping continued uninterrupted, the POF-27U drawdown may possibly have reached equilibrium and therefore have been more useful for interpretation.

The confined solutions applied using AQTESOLV Pro (Duffield 2007) were the Cooper-Jacob (1946) approximation and the Dougherty-Babu (1984) method. The semi-confined, "leaky" analytical models were Hantush-Jacob (1955), Moench (1985), and Neuman-Witherspoon (1969). The methods referenced are based on various assumptions, and the reader is referred to Kruseman and de Ridder (1990) for further details.

Theis (1935) developed a method to estimate the hydraulic properties of non-leaky confined aquifers of infinite extent, assuming homogeneity and isotropic characteristics. This is accomplished by the curve matching of logarithmic graphs – a type curve and data curve. The Theis-type curve graphs the W(u) (the well function u) against the inverse of u ($1/u$). Drawdown versus time data of an observation well is graphed, and the two curves are matched. Cooper and Jacob (1946) took the Theis solution and plotted it on semi-logarithmic axes. This produces a straight line during later stages of an aquifer test, given steady-rate conditions (rate of drawdown remains constant) and u is small (ideally less than 0.02). This method was used to gain preliminary estimates of aquifer properties. The Cooper-Jacob (1946) solution was applied to the field data for POF-27L (finished in the APPZ) and yielded a transmissivity value of 50,920 ft^2/day with a storage coefficient of 0.000072. The Cooper-Jacob (1946) solution is a confined aquifer solution and, in the presence of vertical leakance, will tend to overestimate transmissivity. The second "confined" approach, the Dougherty-Babu (1984) solution, was of limited value as the standard error results were poor (t-ratio [estimate / standard error] <2).

Hantush and Jacob (1955) derived an analytical solution for predicting drawdown in response to a pumped well that penetrates a leaky confined aquifer. Both Hantush-Jacob (1955) and Neuman-Witherspoon (1969) assume unsteady flow to a fully penetrating well and that the aquifer has a homogeneous and isotropic matrix. Wellbore storage is not taken into account in either solution, and as the hydraulic head declines, it is assumed that water is immediately supplied from storage. A plot of the field data using the latter solution shows the drawdown and derivative match well after the first two to three minutes of pumping (once well-bore storage is eliminated) (Figure 22)

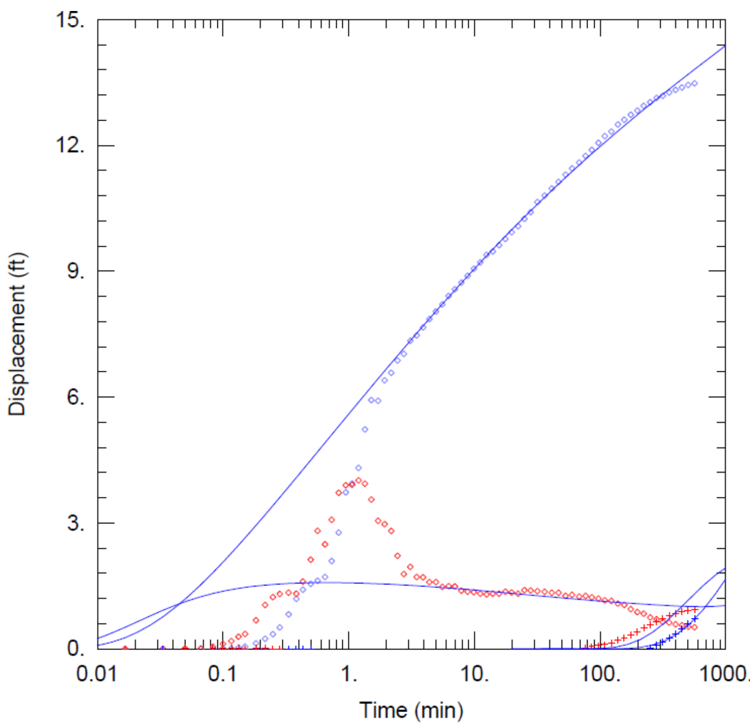

Figure 22. Neuman-Witherspoon (1969) POF-27L plot and derivative (blue diamonds and red diamonds, respectively), and POF-27U plot and derivative (red and blue crosses, respectively).

Moench (1985) derived a solution for unsteady flow to a well that allows compensation for well-bore storage and skin effects. Data from this APT was analyzed with the Moench solution, and yielded a fit to the drawdown data and its derivative after the first few minutes of the test.

The results from all the leaky confined analyses are shown in Table 14.

Table 14. Summary of analytical results from APT 1.

Solution	Transmissivity of APPZ (ft^2/day)	Storativity of APPZ	Leakance Coefficient of Semi-confining Unit (per day)	Vertical K of Semi-confining Unit (ft/day)
Hantush-Jacob (1955)	44,520	0.00024	0.00759	1.500
Moench (1985)	33,940	0.00029	0.00300	0.809
Neuman-Witherspoon (1969)	37,360	0.00023	0.00120	0.247

Of the three leaky solutions, Neuman-Witherspoon (1969) provides the overall best fit for all of the data (Figure 22). Because it estimates leakance based on the monitor well response of the overlying aquifer, the Neuman-Witherspoon result is also the only method for which leakance must specifically be from the overlying confining unit. This would explain why the leakance coefficient is lowest for this solution. In addition to aquitard properties, this solution also estimated the transmissivity and storativity of the overlying Upper Floridan aquifer producing zone. Transmissivity was computed to be 3,450 ft^2/day, with a storage coefficient 0.0002.

Summary

The data used to calculate aquifer and aquitard hydraulic properties and graphical solutions to the analyses described above are presented in Appendix E. The data available for analysis was limited by equipment failure 29 hours into the 48-hour pumping phase. The Cooper-Jacob (1946) solution was used to provide an initial estimate of transmissivity. Dougherty-Babu (1984), Hantush-Jacob (1955), Moench (1985), and Neuman-Witherspoon (1969) solutions were all used for analysis. The latter provided the best fit for the data and confining unit leakance was calculated using this solution. Summary data are rounded to the nearest significant digit.

Test Period	October 5–8, 2011
Tested Aquifer	Avon Park permeable zone
Tested Interval	750–1,100 ft bls
Pumped Well Dimensions	Casing radius = 0.75 ft Borehole radius = 0 .60 ft
Transmissivity of APPZ	37,000ft^2/day
Storage Coefficient of APPZ	0.00023
Leakance Coefficient of overlying semi-confining unit	0.0012 per day
Vertical Hydraulic Conductivity (K) of overlying semi-confining unit	0.25 ft/day

5.4.2 APT 2 (Upper Floridan Aquifer: 300–520 feet)

On November 3, 2011, AWE initiated aquifer performance testing on the Upper Floridan aquifer producing zone at Site B. Figure 23 illustrates the site configuration during this test.

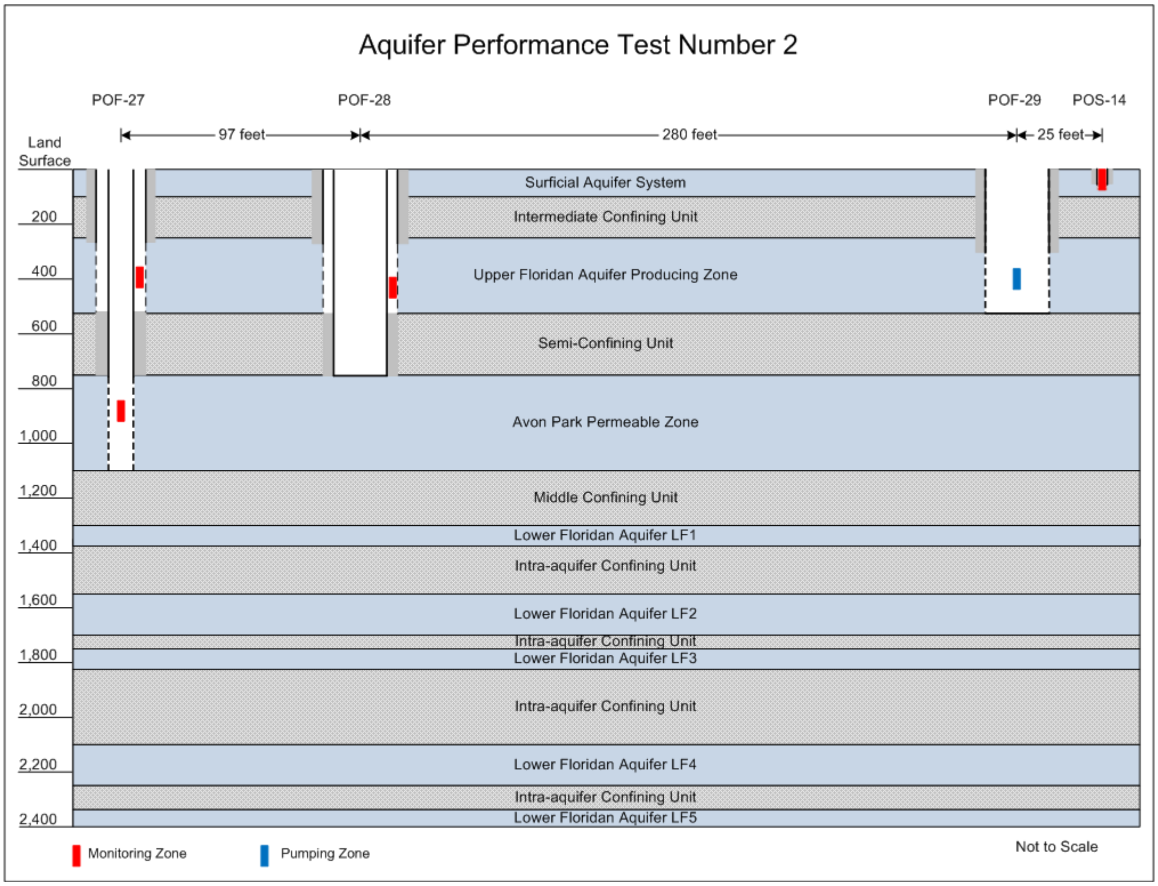

Figure 23. Well configuration for APT 2.

A preliminary step test was not conducted since the well was being developed to address turbidity discharge concerns. A discharge rate of 1,100 gpm was selected to maximize the discharge rate without increasing the turbidity beyond allowable levels.

The duration of the constant rate test was planned to cover 48 hours, 24 hours of pumping followed by a 24-hour recovery period. The pumping portion of the test began at 19:15 on November 3. Several technical problems were experienced during this test. As with APT 1, generator reliability was an issue. The pumping rate was not steady for the duration of the test. The totalizer measured 1,142,600 gallons pumped before recovery, which averaged 793 gpm for the 24-hour period. Manual observations of the pumping rate during the test included flows of 1,035 gpm, 1,100 gpm, 1,090 gpm, and 1,200 gpm. In addition to continued generator issues, there was a problem with the water-level instrumentation in the production well, which led to the test being initiated prior to full background recovery and loss of any recovery data from the production well. At 19:15 the following evening (November 4), the pumping phase of the test ended. Field data collected as part of this test are provided in Appendix D.

Analyses

Drawdown data during the pumping phase of APT 2 were analyzed to evaluate transmissivity, storativity, and leakance properties of this portion of the Upper Floridan aquifer. Figure 24 shows the recorded drawdown from the production well (POF-29) of approximately 90 ft and corresponding changes in water level in the monitor intervals of POF-28U (17.4 ft) and POF-27U (16.5 ft) during this test. POF-28U is 280 ft and POF-27U is 377 ft from the pumping well (POF-29).

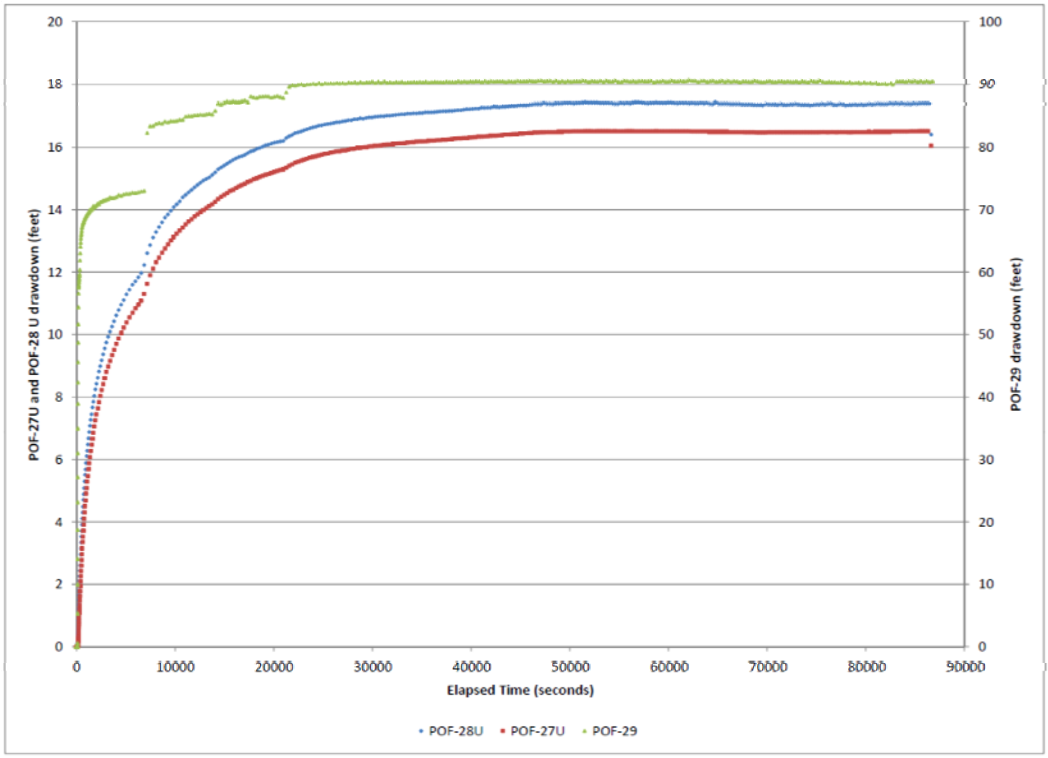

Figure 24. Observed drawdown in the production-zone and monitor wells during APT 2.

The drawdown data collected during the APT were used to estimate the hydraulic properties of this section of the Upper Floridan aquifer production zone. In combination with the hydrogeologic data from the test site, analytical models of the test were run using AQTESOLV Pro software (Duffield 2007). Caution must be exercised with the values resulting from the analyses, as the pumping rates fluctuated during the test. In addition, the water levels were marginally lower than background conditions, which will also impact results. When the solutions were run using the average pumping rate for the 24-hour period, the data did not fit the curves. Analyses were therefore based upon known pumping rates at specific times. The Cooper-Jacob (1946) method is a confined aquifer solution and provides preliminary estimates of aquifer properties. The diagnostic plot (Figure 25) of drawdown and its derivative using this solution yielded a transmissivity of 5,000 ft^2/day and storativity of 0.00019.

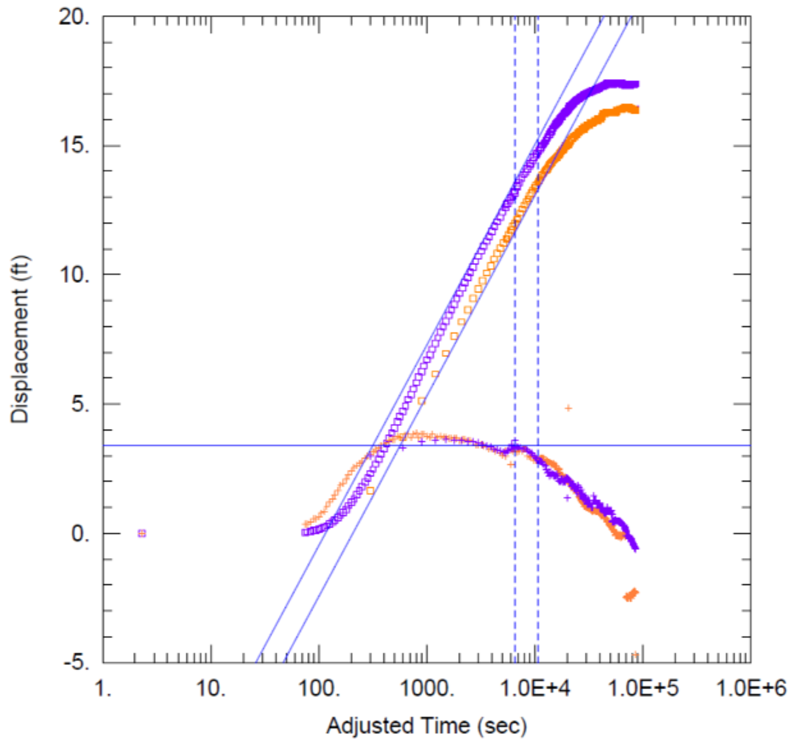

Figure 25. Diagnostic plot of drawdown (purple diamonds and orange squares) and their derivatives (purple and orange crosses) in monitor intervals POF-28U and POF-27U, respectively. The valid time for Theis (1935) falls between the two vertical dashed lines.

Since the production and monitor wells had not returned fully to background conditions prior to the beginning of the test, an early time indication of any wellbore storage or skin effect cannot be readily inferred. Semi-confining, leaky solutions were applied to the data and derivative. The Moench (1985) method, discussed in the previous section, was also used for this analysis. A sharp peak was observed in the derivative at approximately 2.5 hours into the test (Figure 26). It is unclear what caused this, and it does not match any of the typical diagnostic plots discussed in Renard et al. (2009). It is possible a change in the pumping rate was initiated at this time during the test and is more prominent in the derivative.

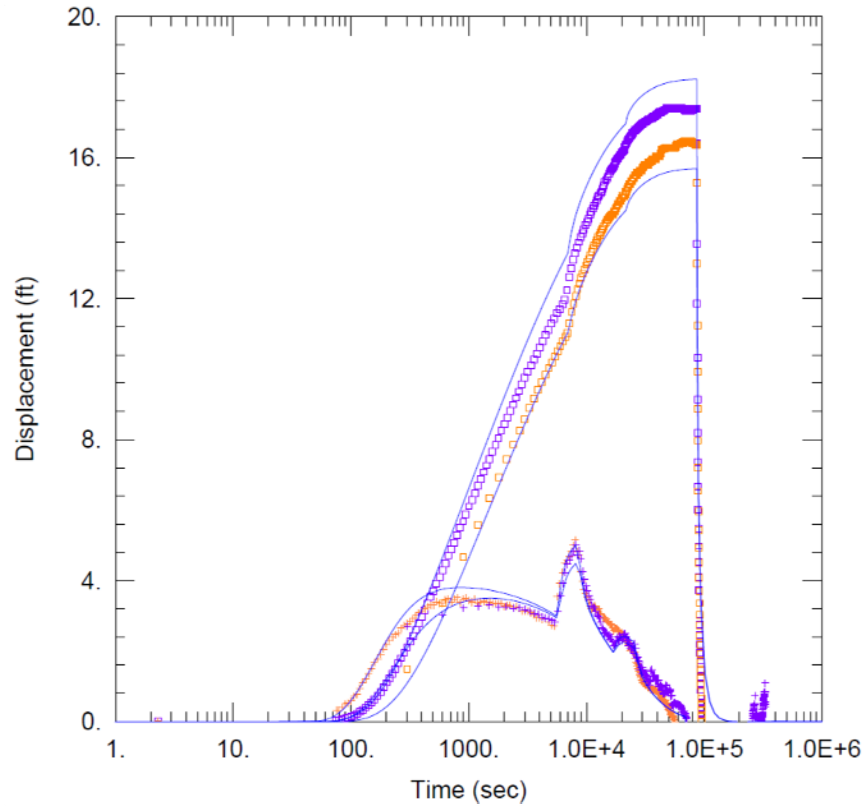

Figure 26. Semi-log plot of drawdown and corresponding derivative for observation wells POF-27U (orange squares and crosses) and POF-28 (purple squares and crosses) using the Moench (1985) solution.

Hantush (1960) derived a solution for a fully penetrating well in a leaky, homogeneous, isotropic aquifer. The solution ignores wellbore storage and assumes that constant head source aquifers provide leakage across overlying and underlying aquitards. Both solutions are in close agreement with each other. The estimated value for transmissivity for this section of the UFA from APT 1 analysis (3,450 ft^2/day) falls between the two. Table 15 shows the average values of the estimated parameters by the Moench (1985) and Hantush (1960) solutions using APT 2 data. Because of the high productivity of the underlying APPZ and the more confining nature of the overlying ICU, all leakance is assumed to be from below.

Table 15. Summary of analytical results from APT 2.

Solution	Transmissivity of UFA Producing Zone (ft^2/day)	Storativity of UFA Producing Zone	Leakage Coefficient of Semi-confining Unit (per day)	Vertical K of Semi-confining Unit (ft/day)
Moench (1985)	3,800	0.00022	0.00109	0.24
Hantush (1960)	3,455	0.00026	0.00146	0.357

Summary

Given the complications that occurred during this APT, it would be reasonable to consider the results a gross approximation of the hydraulics of the system. Despite the uncertainties in the data, the results are remarkably consistent with the Neuman-Witherspoon (1969) analysis of APT 1. Summary data are rounded to the nearest significant digit.

Test Period	November 3–5, 2011
Tested Aquifer	Upper Floridan aquifer (UFA)
Depth Interval	300–520 ft bpl
Pumped Well Dimensions	Casing radius = 1 ft Borehole radius = 0.5 ft
Mean Transmissivity of the UFA producing zone	3,600 ft^2/day
Mean Storage Coefficient of the UFA producing zone	0.00024
Mean Leakance Coefficient of underlying semi-confining unit	0.0013 per day
Mean Vertical Hydraulic Conductivity (K) of underlying semi-confining unit	0.30 ft/day

5.4.3 APT 3 (Composite: 300–1,105 feet)

On November 28, 2011, AWE initiated an aquifer performance test in POF-29 at Site B. The well is open to the Upper Floridan aquifer production zone, the semi-confining unit beneath it, and the underlying Avon Park permeable zone. Figure 27 shows the well configuration for APT 3.

This test served a purpose besides data collection. The fresh water produced during this APT was channeled to an on-site settling pond. During the latter stages of construction and testing of POF-28, the high salinity water from these processes was impounded in the settling pond awaiting discharge to the Kissimmee River. This existing water in the pond blended with the water produced from APT 3, which ensured the generic discharge permit requirements for the river were met.

Although the primary purpose of the pumping was to produce enough blending water in the on-site settling pond, it was hoped that potentially useful data could be gleaned from this test. It was instrumented and evaluated like an ordinary pumping test, and a pumping rate of 4,000 gpm, commensurate with APT 1, was selected.

The duration of the constant rate test was 48 hours, with 24 hours of pumping followed by 24 hours of recovery. The test began at 16:25 on November 28, and the pumping phase ended at 16:25 on November 29. At the end of this phase, the instrumentation was reprogrammed, the pump shut off, and the test stepped into the 24-hour recovery period. Field data collected as part of this test are provided in Appendix D.

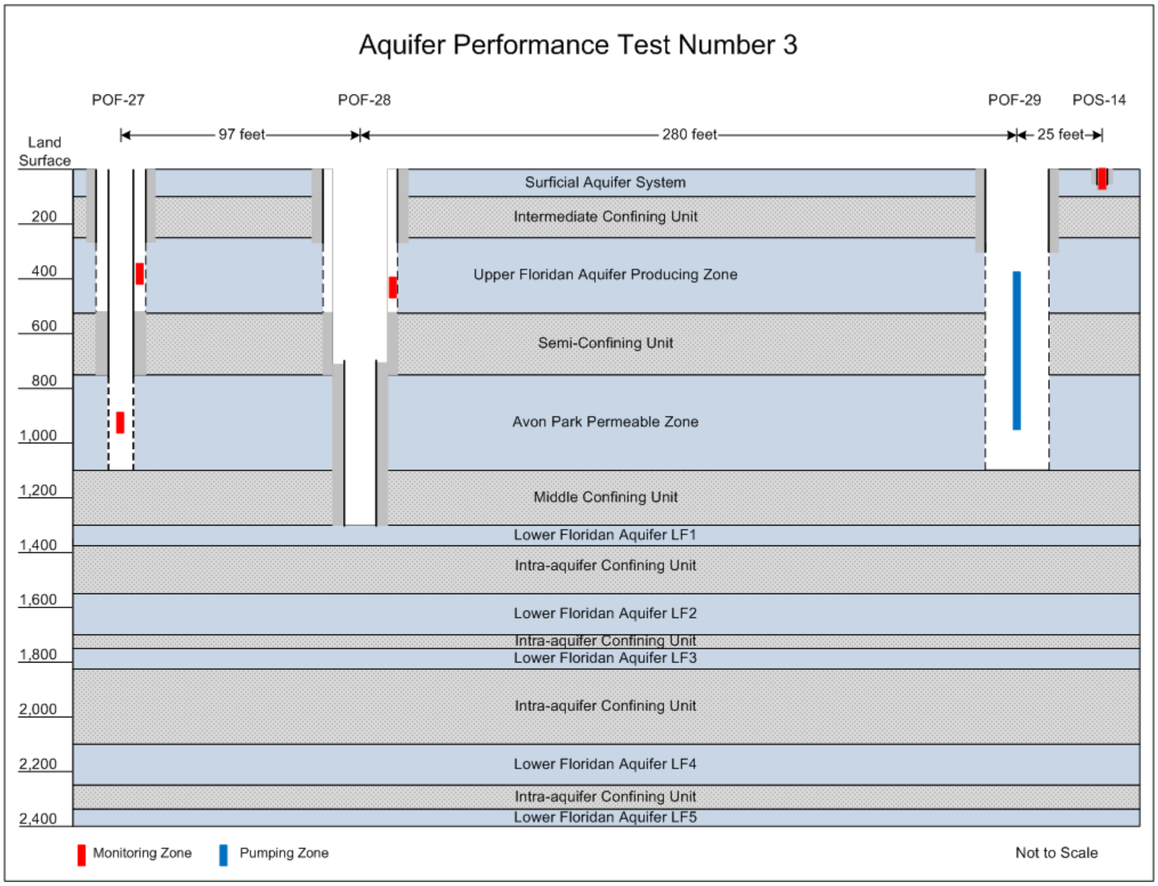

Figure 27. Well configuration for APT 3.

Analyses

Data collected during APT 3 were used to estimate transmissivity and storativity properties of the combined aquifers and aquitard. The open hole portion of POF-29 spans two known flow zones: the Upper Floridan aquifer production zone (APT 2) and the Avon Park permeable zone (APT 1). This came to 805 ft of open hole with a semi-confining interval of over 100 ft in thickness between the two aquifers. The drawdown and recovery plot is shown in Figure 28.

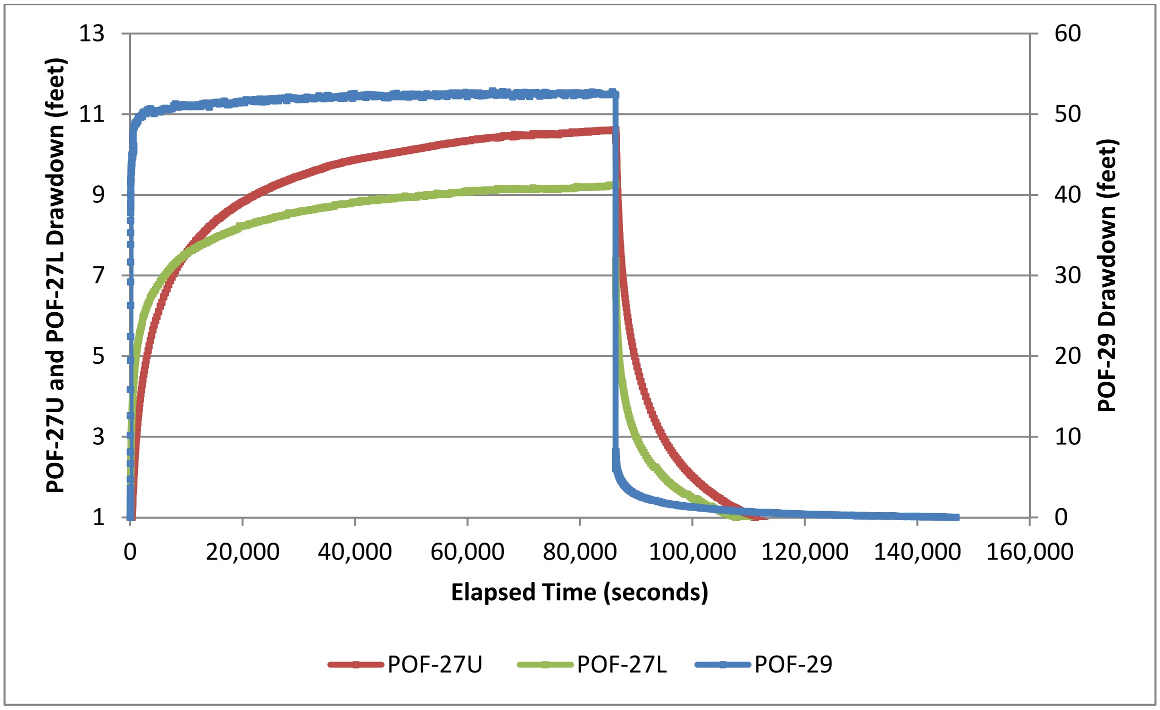

Figure 28. Observed drawdown in the production-zone during APT 3.

Data were analyzed in AQTESOLV Pro (Duffield 2007) using the POF-27U monitor interval only, the POF-27L monitor interval only, and then the combined intervals. The residual drawdown data from the pumping well (POF-29) was analyzed using the Theis-Recovery method. The pumping well drawdown was approximately 53 ft, while the monitor intervals at POF-27U and POF-27L recorded 10.5 ft and 9.1 ft of drawdown, respectively.

Diagnostic plots were drawn using the monitor data using the Cooper-Jacob (1946) confined solution for initial estimates of transmissivity and storativity. Figure 29 shows the diagnostic plot for the combined POF-27U and POF-27L analysis. This plot is illustrative of the problem with attempting to solve for both monitor wells at the same time. Although the pumping well is open to both the UFA and APPZ intervals and the intervening semi-confining zone, the monitor wells monitor these upper and lower producing zones discretely. The two wells are the same horizontal distance from the pumping well, but represent intervals that differ greatly, both in productive capacity and character (UFA: low production, high storage capacity, diffuse flow; APPZ: good production, low storage capacity, fracture flow). Consequently, the best-fit analytical solution to the combined monitor wells does not yield the composite transmissivity, but some value between the two. For this reason, additional analyses were conducted on each well independently.

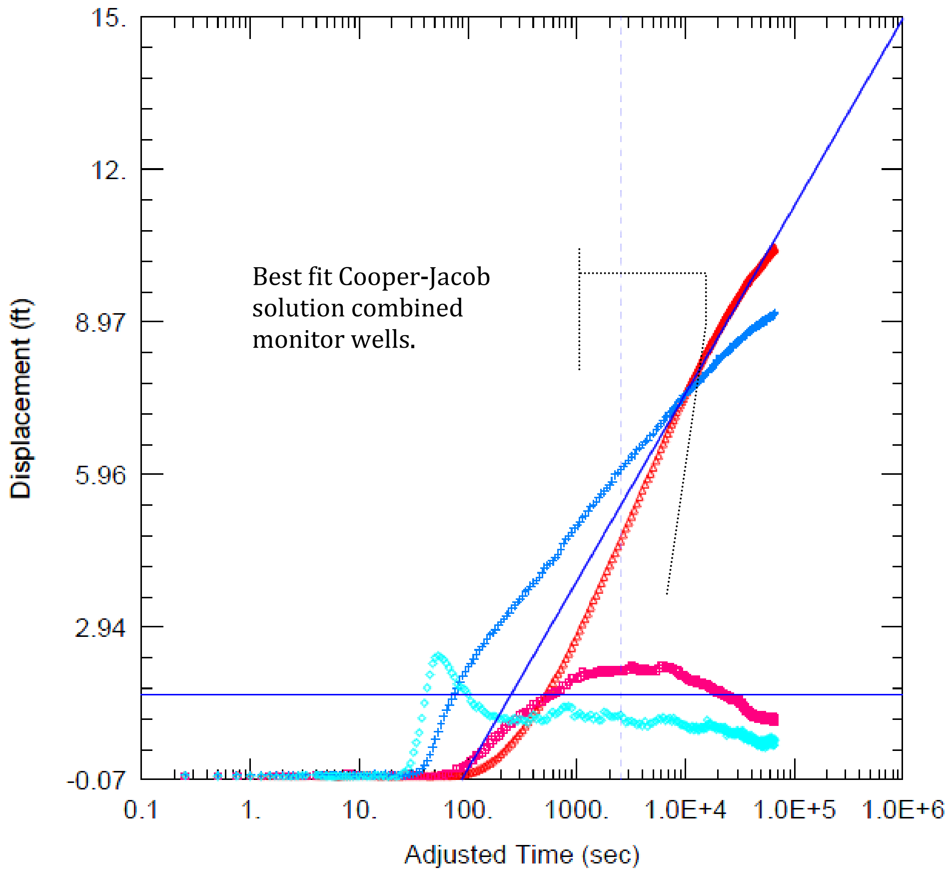

Figure 29. Cooper-Jacob diagnostic plot of APT 3 pumping phase. POF-27L drawdown and derivative are shown in dark and light blue, respectively; POF-27U drawdown and derivative are represented by red and pink, respectively.

In addition to the Cooper-Jacob solution, the well data was evaluated using a leaky-aquifer solution, Hantush-Jacob (1955), and Theis-recovery (1935). Appendix D contains the field data and Appendix E contains the analyses. Table 16 is a summary of the transmissivity and storativity calculated using the above methods that gave approximate fits to the solution curves. The results and the average values are shown at the bottom of the table.

Table 16. Summary of analytical results from APT 3.

Monitor Interval	Solution	Transmissivity (ft^2/day)	Storativity
POF-27U	Cooper-Jacob	28,030	0.001404
	Hantush-Jacob	22,970	0.001698
POF-27L	Cooper-Jacob	50,250	0.000138
	Hantush-Jacob	52,070	0.000124
POF-27U and POF-27L	Cooper-Jacob	36,590	0.000611
POF-29	Theis-Recovery	49,520	—
	Average	**40,000**	**0.0008**

APT 2 analysis estimated a transmissivity of 3,627 ft^2/day for the Upper Floridan aquifer producing zone and APT 1 38,606 ft^2/day for the APPZ. It would be reasonable to expect the transmissivities of the two aquifers to combine and show an additive result. Cumulatively, this would give 42,233 ft^2/day. This is slightly higher, however, than the average transmissivity computed from APT 3 results. The explanation for this probably lies with the problems inherent in the configuration of the test wells. The problem with the combined POF-27U / POF-27L analysis has already been discussed, but there are problems with the independent evaluation of these wells also. Both monitor wells only partially penetrate the production well interval. The Hantush-Jacob solution can compensate for partial penetration in a homogenous aquifer, but not in a highly heterogeneous situation, as seen here. Of the APT 3 analyses, the most reliable (i.e., not clearly violating any conditional assumptions of the analytical solution) is the analysis of the recovery data from the pumping well. That yielded an estimated transmissivity of 49,520 ft^2/day, slightly higher than would be anticipated from the additive results of the first two APTs. The additional transmissivity could be attributable to contribution from MC1, failure to compensate for leakance, or, most likely, some combination of the two.

Summary

The data used to calculate aquifer hydraulic properties is presented in Appendix D and the graphical solutions to the analyses described above are presented in Appendix E. The test analysis was limited by the problems associated with the open-hole area encompassing two aquifers and a semi-confining unit. Analysis results from the monitor well data are not considered reliable. The estimated transmissivity from analysis of the pumping well recovery data could be considered a reasonable approximation of the combined confining and production zones.

5.4.4 APT 4 (Lower Floridan Aquifer [LF2]: 1,350–1,685 feet)

On January 27, 2012, AWE initiated aquifer performance testing on the Lower Floridan aquifer at site B. A preliminary step-drawdown test was conducted to evaluate discharge rates for the CRDT and to ensure that monitoring equipment was configured and reading correctly. A discharge rate of 4,000 gpm was selected based on the preliminary testing. Water levels were allowed to recover over the weekend (January 28–29).

The duration of the constant rate test was planned to cover 120 hours, 96 hours of pumping followed by a 24-hour recovery period. The pumping portion of the test began 15:28 on January 30. On January 31, after only 22 hours of pumping, the generator that was powering the pump began to experience problems. It shut down briefly and was restarted but continued to fluctuate, yielding unstable discharge rates. The source of the problem was eventually identified as contaminated fuel. At 20:04 the decision was made to stop the test until a new fuel tank and fuel supply could be acquired. Water levels in the aquifer were allowed to recover to background conditions.

On February 1 at 09:35, with a new fuel tank and generator in place, the test was restarted. A mean pumping rate of 3,906 gpm was maintained for 90 hours. The pumping rate was tracked at hourly intervals using an inline totalizing flow meter. The production well and all monitor wells were instrumented with downhole pressure transducers to record the changes in water levels. The instrumentation was programmed to read on a log cycle time step with short time increments at the start of pumping that gradually increased to regular one-minute intervals. During pumping, manual water level readings were also collected hourly as a back-up to the instrumentation.

At 03:00 on the morning of February 5, the generator began to show signs of instability. Rather than chance an uncontrolled shut down, the decision was made to stop the pumping phase of the test. The water level instrumentation was reconfigured to record on a log cycle time interval, AWE manually shut down the pump, and the test was stepped into recovery. Field data collected as part of this test are provided in Appendix D. Figure 30 illustrates the configuration of the site during this test.

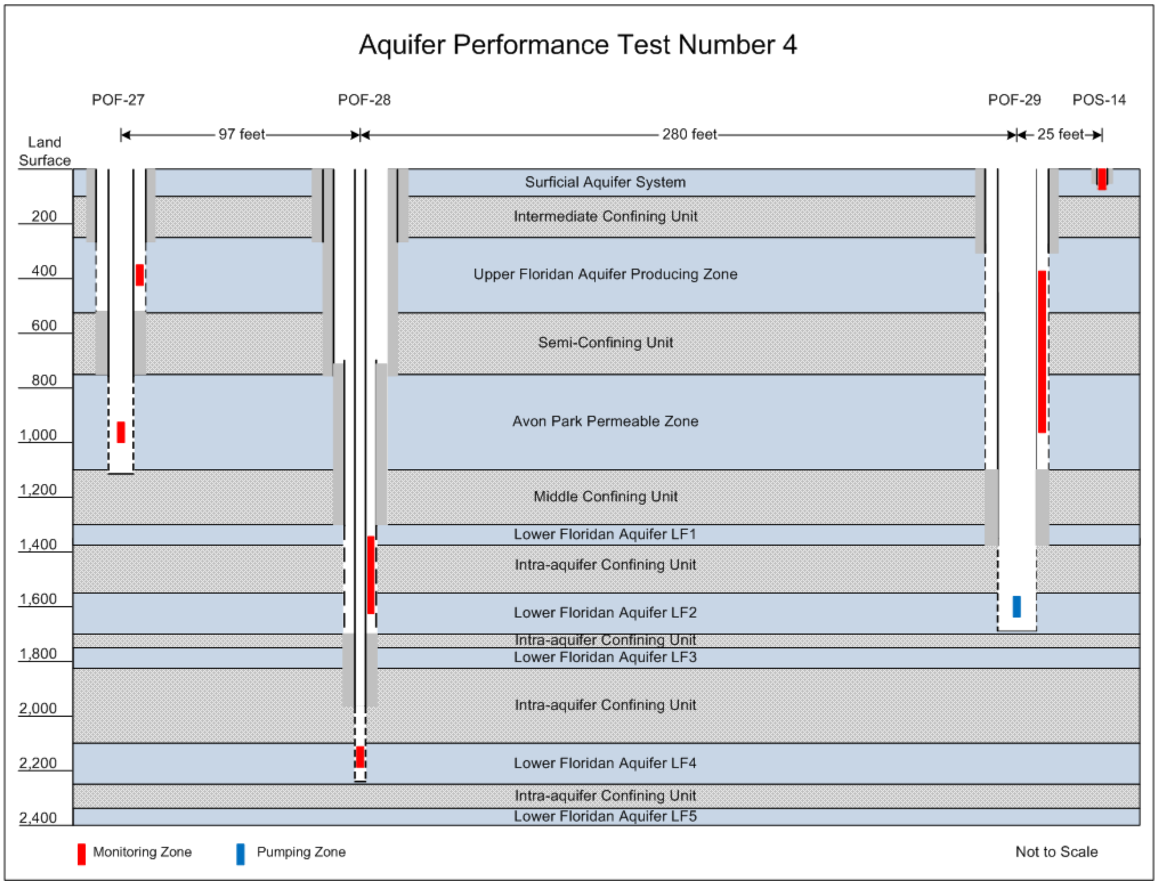

Figure 30. Well configuration for APT 4.

Analyses

Data from the CRDT were analyzed to evaluate the transmissivity, storativity, and leakance properties of this portion of the Lower Floridan aquifer. As previously discussed, an initial transmissivity estimate for this aquifer of 62,663 to 161,722 ft^2/day was derived from interval test two during construction and testing of well POF-28. Forward modeling of an aquifer transmissivity in this range, at a pumping rate of 4,000 gpm, indicates that drawdown in an observation well 280 ft away should be from 5 to greater than 10 ft. Figure 31, shows the recorded drawdown from the production well (POF-29) and production-zone monitor well (POF-28U). While the production well experienced almost 80 ft of drawdown, neither the instrument nor hand-measured drawdowns in POF-28U ever exceeded 0.70 ft, the majority of which was achieved in the initial seconds of the test.

The hand measurement verification rules out the possibility of instrument failure in the observation well data, so we must assume that the dichotomy between the production and observation well data is an accurate reflection of what is happening in the aquifer. These results present some interesting questions and one obvious implication, that there is considerable heterogeneity in the aquifer.

Most analytical methods for evaluating aquifer tests assume a homogeneous, isotropic aquifer as a condition of the solution. One key reason for that requirement is that if flow is not uniform across the area of influence, there is no way to know what discharge rate is influencing the drawdown at observation wells. In fractured or otherwise heterogeneous rock, the discharge rate can only be known accurately at the production well, so it is most appropriate to estimate transmissivity from the production well data.

For the production well data, drawdown and its logarithmic derivative vs. time were plotted to evaluate appropriate conceptual models for its analysis (Figure 32). Renard et al. (2009) provide a synopsis of typical diagnostic responses to different hydrogeologic conditions. Based on that work, a clear well-bore storage and skin effect is indicated in the early-time data from POF-29 by the distinct hump in the derivative plot. Less defined is a dip in the derivative data around 1,000 seconds into the test. This response could indicate a dual-porosity system (Renard et al. 2009) or a similar response might also be returned in a leaky aquifer system with aquitard storage and an overlying no-flow boundary (Duffield, Personal Communication, May 4, 2012).

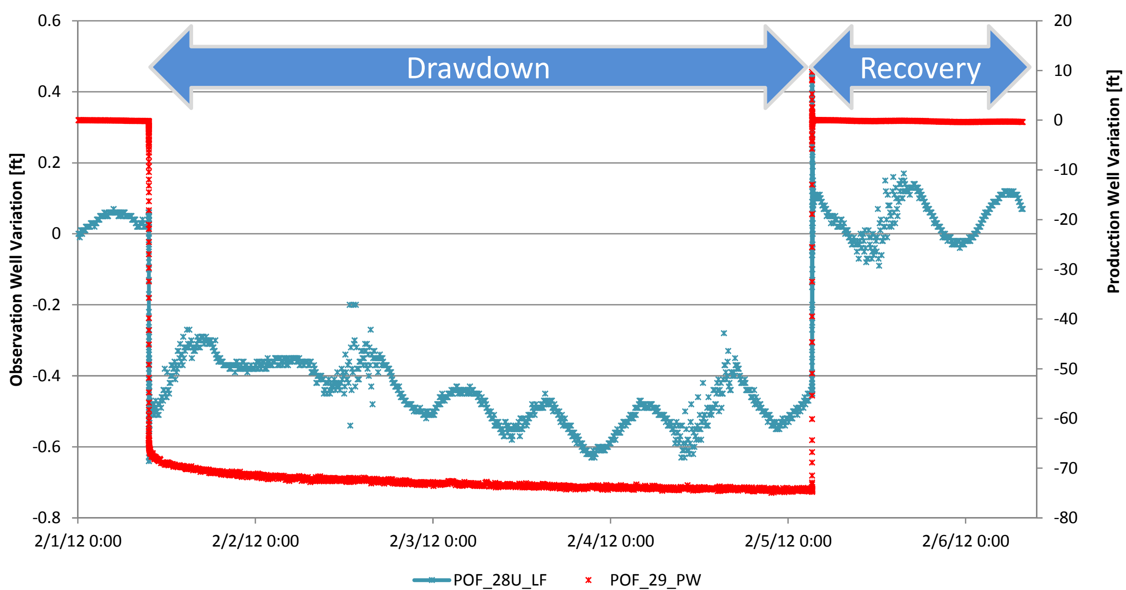

Figure 31. Observed drawdown [ft] in the production zone during the CRDT.

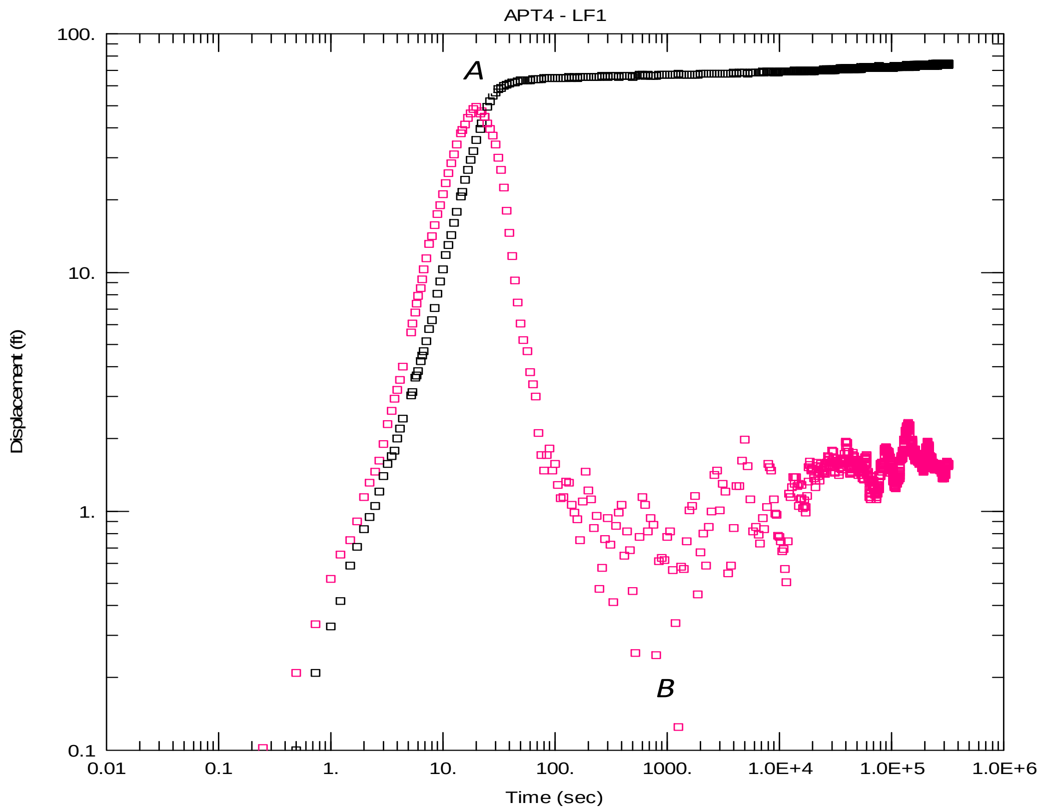

Figure 32. Diagnostic plot of well POF-29 (black squares represent drawdown; pink squares represent the derivative). **A** indicates well-bore storage/well skin effect. **B** indicates possible dual-porosity response or leakance with aquitard storage and a no-flow boundary.

Two confined aquifer methods, Cooper-Jacob (1946) and Dougherty-Babu (1984), were used to provide initial estimates of transmissivity from the pumping well. The Cooper-Jacob solution technique requires fitting a straight-line through the measured drawdown over at least one log cycle of time. Cooper-Jacob is a confined aquifer solution and, in the presence of vertical leakance, will tend to overestimate transmissivity. As illustrated in Figure 33, two distinct linear fits could be drawn through the data at different points in the test. The rate of drawdown increased after approximately 10,000 seconds (approximately 3 hours) of pumping. Consequently, the early-time plot yields a significantly higher transmissivity than the later time (74,610 ft^2/day and 37,810 ft^2/day, respectively). This could indicate a no-flow boundary, but a similar response could be seen in a dual-porosity system, where the early-time data reflects fracture or solution feature transmissivity. Such features have high transmissivity but low storage capacity. Once the local storage is exhausted, the fractures must be fed from matrix storage and the apparent transmissivity decreases. There are significant fractures and bedding plane solution features in this portion of the well, and this interpretation is supported by the diagnostic plot results.

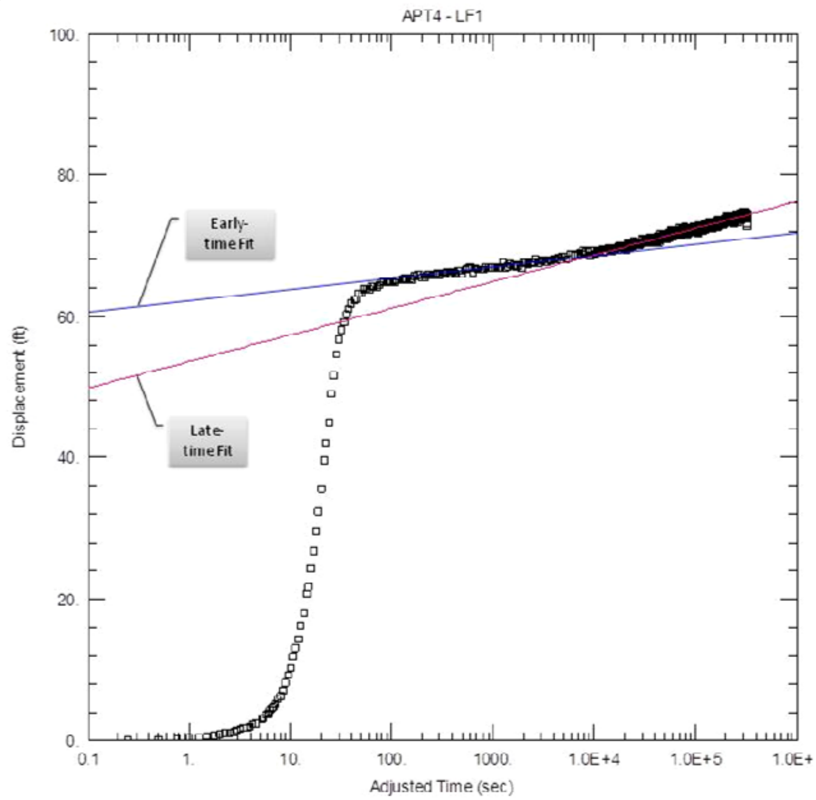

Figure 33. Cooper-Jacob straight-line fits at different points in the drawdown time-series from POF-29.

Storativity could not be derived from the Cooper-Jacob (1946) solution for this well because of the large well-bore storage effect, which cannot be accounted for by the solution. Storativity was estimated, however, based on the response of the observation well, POF-28U. Streltsova (1988) derived a method of calculating the diffusivity (transmissivity [T] divided by storativity [S]) in a heterogeneous aquifer based on the travel time of the pressure wave through the aquifer:

$$\eta = \frac{1}{t}\left(\frac{r}{C}\right)^2 \qquad \textbf{Equation 2}$$

where η = diffusivity (T/S)
t = travel time
r = radial distance between the production and observation wells
C = constant, generally 1.89–2.0

There was a 10-second lag in the pressure response to pumping between the production and observation wells, yielding a diffusivity of 3,217 to 2,873 ft^2/second. Coupled with the Cooper-Jacob (1946) transmissivity results, this yields a storativity range from 1.99E-04 to 24.34E-04. Given that this calculation is based on the first response time, it is expected to be better representative of the fracture/flow-zone storage rather than the matrix storage.

A follow-up analysis was run using the Dougherty-Babu (1984) solution, which allows for well-bore storage and skin effects. It produced similar transmissivity results and yielded storativity estimates in line with the independent values derived from Streltsova. The

standard error results were good for this solution (t-ratio > 2); however, the Dougherty-Babu solution could not account for the mid-time dip observed in the diagnostic plots.
The mid-time dip could be accounted for using a dual-porosity solution for flow in fractured rocks. This approach does not yield a bulk transmissivity and storativity for the entire unit, making comparison difficult, but does provide independent estimates of hydraulic conductivity (K) and specific storage (Ss) from the fractures and rock matrix. The best fit application of the Moench (1984) dual-porosity solution yielded fracture permeability 50 times greater than the matrix permeability and fracture-specific storage an order of magnitude less than the rock matrix.

The Moench (1985) Case II solution was also run to evaluate the possibility of a leaky aquifer with aquitard storage bounded by a no-flow boundary. With this solution, it was possible to replicate the mid-time dip observed on the diagnostic plots, but the error statistics for this solution were poor (t-ratio < 2). Observations from POF-29U were noisy due to casing vibrations during pumping, but in keeping with levels from POF-27, indicated no discernable drawdown response to pumping in the overlying APPZ, consequently, leakance in this test is most likely to be internal to the Lower Floridan aquifer. There is a small flow zone at the top of the Lower Floridan (see interval test 1) just above the casing in POF-29, and a second, lower flow zone exists 50 ft below the open interval. These zones were omitted from the tested interval due to slightly degraded water quality, but both are potential sources of leakance for the test.

The production zone observation well data from POF-28U was also examined. Given the small amount of drawdown in POF-28U, it was necessary to correct the data for barometric effects and regional trends that might obscure the pumping response. Figure 34 shows the normalized level response (initial level subtracted from all data-points) for POF-28U and a distant observation well in the same aquifer unit (OSF-28L) for the duration of the CRDT. Both wells show a very similar sinusoidal barometric pressure response. A downward regional trend was also observed during the CRDT, both in OSF-82L and several other Floridan observation wells in the region. The OSF-82L data was used to remove these extraneous effects from the observation well data.

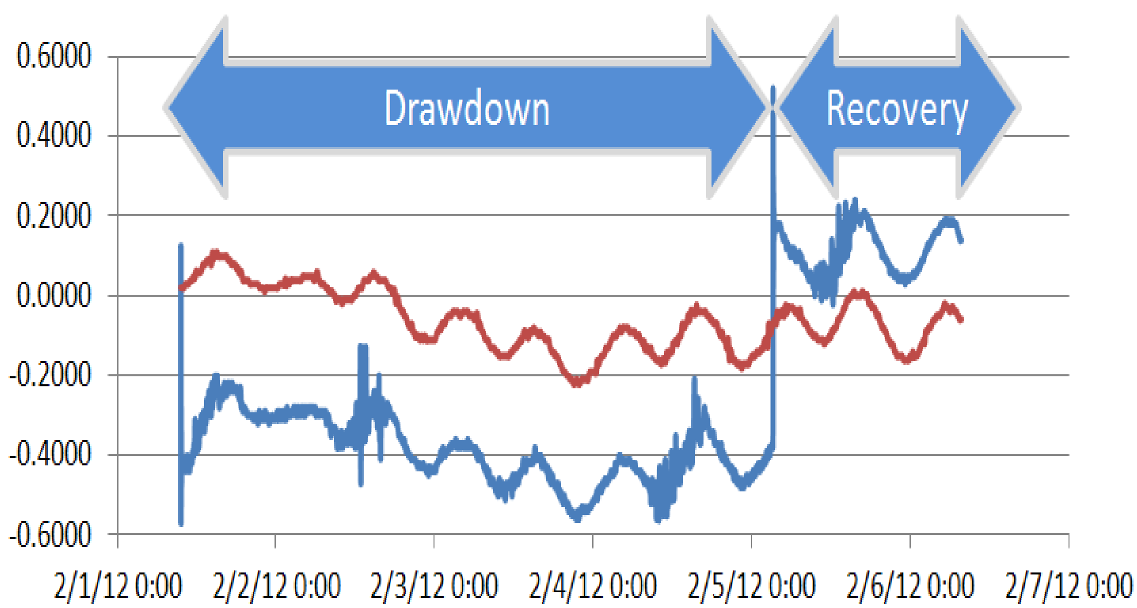

Figure 34. Normalized water level response during the APT in the production zone monitor well POF-28U (blue) and a background monitor well 19 miles away (red).

A review of Figure 35 shows an initial oscillatory response in the monitor well. This type of under-damped aquifer response, most frequently seen in production wells, is common in aquifers with high hydraulic conductivity. The data oscillates to an equilibrium position approximately 8 minutes into the test, then continues a very slow drawdown until approximately 100 minutes into the test. At that point, it recovers almost 0.2 ft of its total 0.6 ft of drawdown. There it remains for the duration of the CRDT. It is probably unwise to read too much into that 0.2 ft recovery in the middle of the test. It could be representing a significant recharge boundary, but is just as apt to be reflecting inadequacies in the data correction or a gradual uncurling of the transducer cable over time. Even ignoring this apparent semi-recovery, however, the drawdown in this well implies much different aquifer conditions than those observed in the production well. There were no analytical solutions capable of fitting the drawdown data from both POF-29 and POF-28U simultaneously. To match the POF-28U data, transmissivity values an order of magnitude higher than the production well are required, or if transmissivity is fixed to a range commensurate with the production well results, a vertical leakance with a confining unit conductivity greater than that of the aquifer is needed. Neither of these explanations appears to be realistic.

The second interval test conducted on POF-28 encompassed the interval to which POF-28U is open and the flow zone below it. Transmissivity of up to 161,722 ft^2/day was estimated from specific capacity from that test. That is significantly higher than POF-29, but well below the order of magnitude required to achieve a match in the analytical solutions. There is one difference between the wells, however, that could lead to the observed testing response. The majority of the production from both wells is from a fractured interval near the base of the open hole, from 1,530 ft bls to 1,680 ft bls. Both wells are fractured, but in POF-28, the fractures are more open and include a 10 ft cavernous section at 1,628 ft bls that is absent in the production well. This cavernous interval provides a tremendous volume of stored water available to the observation well. If the two wells are connected by their fracture systems, a rapid pressure response to pumping would be expected, as happened here. Storage rapidly runs out in the shared fractures, however, and the pumping well must switch to the slower mechanism of delivering water into the fracture system from matrix storage. This is why the late-time data yields the lower transmissivity values. Where the production well drawdown accelerates with time, POF-28 drawdown flattens out as if hitting a constant-head boundary. Effectively, this is what is happening, but instead of an outside source of water, like a river, the water comes from within its own local storage pool. If POF-28 were the production well rather than the observation well, it would be possible to overcome this large borehole storage, as happened in interval test 2, but the storage drastically limits this well's usefulness as an observation well for the CRDT. Table 17 summarizes the results of APT 4.

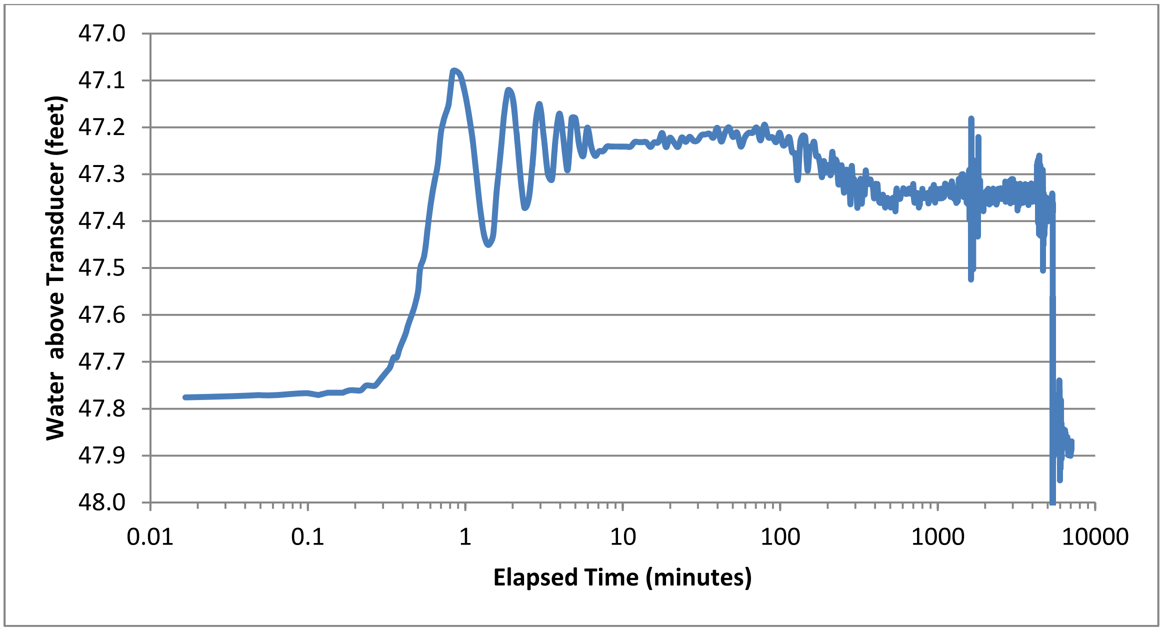

Figure 35. Semi-log plot of the POF-28U drawdown response corrected for barometric pressure effect and regional trend. Horizontal axis is elapsed time in minutes.

Table 17. Summary of analytical results from APT 4.

Monitor Interval	Solution	Transmissivity of Lower Floridan Producing Zone (ft^2/day)	Storativity of Lower Floridan Producing Zone	Leakage Coefficient of Middle Confining Unit (per day)	Vertical K of Middle Confining Unit (ft/day)
POF-29	Cooper-Jacob	37,810	—	—	—
POF-29	Dougherty-Babu	45,710	0.003720	—	—
POF-29	Moench	39,350	0.000400	—	91.8
POF-28U	Hantush-Jacob	40,000	0.000548	0.0000158	76

Summary

The data used to calculate aquifer hydraulic properties are presented in Appendix D, and graphical solutions to the analyses described above are presented in Appendix E. The test analysis was limited by the problems with the production-zone observation well, but reliable estimates for transmissivity were derivable from the production well data. The late-time Cooper-Jacob (1946) and Dougherty-Babu (1984) solutions provided the best estimates of bulk transmissivity (combined fracture and matrix). Fracture storage is estimated from Streltsova (1988) and the early-time Cooper-Jacob (1946) results, and matrix storage from the Dougherty-Babu (1984) solution. The limitations of the production-zone monitor well and lack of drawdown in the overlying aquifer monitor wells prevented calculation of confining unit leakance from this test. Summary data are rounded to the nearest significant digit.

Test Period	February 1–6, 2012
Tested Aquifer	Lower Floridan aquifer [LF2]
Tested Interval	1,350–1,685 ft bpl
Pumped Well Dimensions	Casing radius = 0.75 ft Borehole radius = 0.58 ft
Mean Transmissivity (Cooper-Jacob and Dougherty-Babu)	42,000 ft^2/d
Storage Coefficient	Fracture = 0.00028 Matrix = 0.0037

5.5 Packer Testing

Six straddle-packer tests were conducted during exploratory drilling at Site B (Table 18) to determine hydrologic properties and collect representative formation water samples.

Table 18. Packer test depth summary.

Test No.	Well	Test Date	Depth (ft bls)
1	POF-27	16-Jun-2011	1,360 – 1,375
2	POF-27	17-Jun-2011	1,260 – 1,275
1	POF-28	30-Dec-2011	1,708 – 1,748
2	POF-28	3-Jan-2012	2,229 – 2,269
3	POF-28	3-Jan-2012	2,084 – 2,124
4	POF-28	5-Jan-2012	1,765 – 1,805

As part of the set-up for the testing, a submersible pump and pressure transducer were installed inside the drill pipe. A transducer was also set outside of the drill pipe to monitor changes in pressure (head) that might be indicative of leakage around the packer. Manual measurements in the test interval and annular space were taken before, during, and after the test to confirm transducer readings.

Prior to each test, the isolated zone was developed, and a preliminary specific capacity test was run to determine the potential range of pumping rates. The packed-off interval was allowed to recover to background prior to initiating the test. Each test consisted of a drawdown and recovery phase, during which heads in the packed-off interval were continuously recorded. The pumps did not have check valves installed, which impacted the recovery test data, so the hydraulic properties were calculated using the drawdown data only.

The drawdown data were corrected for head loss due to friction in the pipe using the Hazen-Williams equation (Finnemore and Franzini 2002). Correcting for head loss is necessary to avoid underestimating specific capacity for each tested interval. Using this corrected drawdown data, hydraulic properties were calculated by two different methods:

1. Driscoll (1986) presented an empirical formula for estimating transmissivity in a confined aquifer based on the specific capacity:

$$T = 2{,}000\left(\frac{Q}{s}\right) \qquad \textbf{Equation 1}^{2}$$

   where:
   - T = transmissivity (gpd/ft)
   - Q = pumping or discharge rate (gpm)
   - s = drawdown (feet)

   and by definition:

$$K = \left(\frac{T}{b}\right) \qquad \textbf{Equation 3}$$

   where:
   - K = hydraulic conductivity (gpd/ft^2)
   - b = thickness of the tested interval (feet)

2. Cedergren (1977) presented the following formula for estimating the coefficient of permeability (hydraulic conductivity) from packer test data:

$$K = \frac{q}{2\pi Ls}\ln\frac{L}{r} \qquad \textbf{Equation 4}$$

   where consistent units are used, and:
   - K = hydraulic conductivity (length/time [l/t])
   - q = constant rate of flow into the borehole (l^3/t)
   - s = drawdown (l)
   - L = length of the section of hole being tested (l)
   - r = radius of the section of hole being tested (l)

At the end of the drawdown phase, water quality samples were collected for screening in the field for pH, temperature, and specific conductance, as well as laboratory analyses for major anions, major cations, TDS, and bromide. Each sample sent for laboratory analysis was collected in the appropriate container, field filtered and preserved (if necessary), and placed in a cooler on ice for shipping to a certified facility for analysis. The field measurements were recorded using a YSI 6920 multi-parameter probe that was calibrated for pH and specific conductance before and after sample collection. The water quality results are provided in Section 5.2.2. The following sections provide a summary of the individual packer test set-up and hydraulic properties calculations.

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[2] Originally referenced in Section 5.3, Interval Testing (page 61)

5.5.1 POF-27 Packer Tests

Two packer tests were run during the construction phase of POF-27 for the primary purposes of evaluating the formation water quality and assessing confinement below the APPZ. The target test interval was 15 ft thick. No drop in annular zone heads was observed during either of the POF-27 packer tests, indicating a good seal around the packers during testing.

POF-27 Packer Test 1 (1,360 ft bls to 1,375 ft bls)

Under pumped conditions, fluid specific conductance logs from POF-27 showed a curious anomaly near the base of the borehole. They indicated that higher salinity water entered the borehole between 1,282 and 1,327 ft bls, but showed the presence of fresher water below this depth. A deflection in the static flow log at 1,365 ft bls also indicated the possible presence of downward flow. This packer interval was selected to evaluate these log features.

Preliminary testing was conducted to determine an appropriate pumping rate for the test. An initial rate of 66 gpm was utilized, but a steady discharge rate could not be sustained due to high drawdowns. A sustainable rate of 15 gpm was selected for the final test. The packed-off interval was pumped at 15 gpm for 86 minutes with a measured drawdown of 165.9 ft. Friction losses were insignificant. Hydraulic property estimates (see Table 19) indicated good confinement within this interval. As the geophysical log data implied, the quality of the water in this interval was very fresh. The presence of higher salinity water above this zone helps to confirm the hydraulic property estimates, indicating this portion of the formation is providing a barrier to groundwater movement. A static head value of 50.64 ft NAVD 88 was returned at the end of recovery.

POF-27 Packer Test 2 (1,260 ft bls to 1,275 ft bls)

This packer interval lies immediately above the source of higher salinity water identified in the logs at 1,282 ft bls, near the peak of the observed specific conductance in the pumped borehole.

Based on preliminary testing, a discharge rate of 40 gpm was selected for the constant rate packer test. The packed-off interval was pumped at 40 gpm for 145 minutes, then allowed to recover to background. A friction head loss of 0.46 ft was calculated using the Hazen-Williams equation, yielding a corrected total drawdown of 94.76 ft. The estimated hydraulic properties are shown in Table 19. A static head value of 50.58 ft NAVD 88 was returned at the end of recovery.

Table 19. Summary of packer test hydraulic data from POF-27.

Test No.	Depth (ft bls)	Pumping Rate (gpm)	Drawdown (ft)	Drawdown Phase		
				[1] Transmissivity (ft^2/day)	[1] Hydraulic Conductivity (ft/day)	[2] Hydraulic Conductivity (ft/day)
1	1,360 – 1,375	15	165.9	24	1.61	0.67
2	1,260 – 1,275	40	94.76	112	7.52	3.11

[1] from Driscoll (1986)
[2] from Cedergren (1977)

5.5.2 POF-28 Packer Tests

The SFWMD ran four packer tests during the construction phase of POF-28. The purpose of these tests was to collect formation water samples from discrete intervals to determine the hydraulics of the strata and to locate the USDW. The intervals tested were 1,708 to 1,748 ft bls, 1,765 to 1,805 ft bls, 2,084 to 2,124 ft bls, and 2,229 to 2,269 ft bls. The hydraulic data for the packer tests are summarized in Table 20.

The caliper log from the pilot hole was reviewed to determine the optimal depth to set the packers. Based on this review, a target test interval of 40 ft was selected. AWE connected two inflatable packers to the drill pipe to effectively isolate the test zone. The packer zone was developed using a submersible pump. At a minimum, the zone was developed until at least one volume of water was purged from the zone. The water level (head) of the packer zone was allowed to recover to background conditions. Initial water quality samples were recorded for specific conductance, temperature, and pH. The pumping durations of the tests were 145 minutes for interval 1,708 ft bls to 1,748 ft bls, 140 minutes for interval 1,765 ft bls to 1,805 ft bls, 143 minutes for interval 2,084 ft bls to 2,124 ft bls, and 150 minutes for interval 2,229 ft bls to 2,269 ft bls.

During each packer test, the annular transducer recorded changes in water level indicating possible leakage around the packers. Proper sealing results in no changes in water level in the zone above the upper packer. During packer tests one and two, the water level rose in the annular zone by 0.216 ft and 0.405 ft, and during packer tests three and four the water level fell by 0.247 ft and 0.329 ft, respectively. It is unclear why water levels rose in two instances. The drop in water levels is likely because of an incomplete seal allowing water to be drawn into the test zone from above the upper packer. It should be noted that a poor seal would tend to bias transmissivity and hydraulic conductivity values upward. This should be taken into consideration before applying the results of these tests.

POF-28 Packer Test 1 (1,708 ft bls to 1,748 ft bls)

This interval was selected as it was the nearest zone beneath the production zone that was suitable for seating a packer. The test indicated the level of confinement between the overlying production zone and underlying higher-salinity water.

During this test, AWE pumped the interval for 145 minutes at a discharge rate of 105 gpm with a sustained drawdown of 6.43 ft (corrected using the Hazen-Williams equation). The specific capacity of this interval was 16.3 gpm/ft at 145 minutes. The transmissivity for this zone was 32,675 gpd/ft, or 4,378 ft^2/day, calculated using Equation 1 (Driscoll, 1986). Water quality data collected from this packer test interval is discussed in Section 5.2.

POF-28 Packer Test 2 (2,229 ft bls to 2,269 ft bls)

According to the fluid logs, this interval is below the USDW. There is an abrupt increase in fluid conductance in this zone from 7,000 to 60,000 µS/cm. The purpose of this test was to bracket an area below the USDW, collect water quality data in the discrete interval, calculate specific capacity, and determine the production capacity of the zone at the tested flow rate.

During this test AWE pumped the interval for 150 minutes at a discharge rate of 75 gpm with a sustained drawdown of 22.07 ft (corrected using the Hazen-Williams equation). The specific capacity of this interval was 3.4 gpm/ft at 150 minutes, and the estimated transmissivity was 6,767 gpd/ft (907 ft^2/day). The water quality data collected is discussed in Section 5.2.

POF-28 Packer Test 3 (2,084 ft bls to 2,124 ft bls)

This interval is immediately above the USDW. The purpose of this test was to bracket an area above the USDW and provide confinement information about the lower production zone. Water quality data was collected at this discrete interval, and the production capacity and the specific capacity calculated for this zone.

AWE pumped the interval for 143 minutes at a discharge rate of 55 gpm with a sustained drawdown of 107.23 ft (corrected using the Hazen-Williams equation). The specific capacity of the interval was 0.51 gpm/ft at 143 minutes, and the estimated transmissivity was 1,026 gpd/ft (137 ft^2/day). Section 5.2 discusses the water quality data collected from this packer test interval.

POF-28 Packer Test 4 (1,765 ft bls to 1,805 feet bls)

This interval was chosen to assist in identification of the location of the USDW. Again, water quality data were collected, and specific capacity and production capacity were computed for this zone.

During this test, AWE pumped the interval for 140 minutes with a discharge rate of 83 gpm and a sustained drawdown of 6.84 ft (corrected using the Hazen-Williams equation). The specific capacity of the interval was 12.1 gpm/ft at 140 minutes, and the estimated transmissivity was 24,265 gpd/ft (3,252 ft^2/day). Water quality data is discussed in Section 5.2.

Table 20. Summary of packer test hydraulic data from POF-28.

Test No.	Depth (ft bls)	Pumping Rate (gpm)	Drawdown (ft)	Drawdown Phase		
				[1] Transmissivity (ft^2/day)	[1] Hydraulic Conductivity (ft/day)	[2] Hydraulic Conductivity (ft/day)
1	1,708 – 1,748	105	6.43	4,378	109.5	128.76
4	1,765 – 1,805	83	6.84	3,252	81.3	13.32
3	2,084 – 2,124	55	107.23	137	3.4	1.74
2	2,229 – 2,269	75	22.07	907	22.7	64.47

[1] from Driscoll (1986)
[2] from Cedergren (1977)

5.6 Hydraulic Heads

As a component of the LFAKB project, the two dual-zone wells, POF-27 and POF-28, will be instrumented for continuous recording of water level data. As of this writing, that instrumentation is not complete, so continuous time-series data are not available. Discrete, referenced water level measurements within the hydrogeologic units identified at Site B were taken, however, at different points during construction and testing. Table 21 provides a summary of referenced level data from packer testing and completed intervals.

Table 21. Referenced water level data variation with depth, measured during construction of Site B. Contemporaneous data are highlighted in uniform color.

Hydrogeologic Unit	Water Level (ft NAVD 88)	Measurement Source	Measurement Date
SAS	50.74	POS-14	20-Mar-12
UF	55.95	POF-27U	20-Mar-12
APPZ	55.24	POF-27L	20-Mar-12
MC2	50.58	POF-27 PT2	17-Jun-11
LF1	50.11	POF-28U	20-Mar-12
LF2			
LF3	50.25	POF-28 PT4	5-Jan-12
Between LF3 & LF4	48.90	POF-28 PT3	3-Jan-12
LF4 - above USDW	47.28	POF-28L	20-Mar-12
LF4 - below USDW	14.40	POF-28 PT2	3-Jan-12

Information on vertical head gradients may be gleaned from these data. Looking only at the contemporaneous data from the final completed intervals (highlighted in blue), it appears that the highest heads are in the UF, and decrease in all directions from that unit. The gradient between the UFA and APPZ is slight, but there is an approximate 5 ft head drop between the APPZ and LFA at this site, indicating good confinement within MC2. There is an additional 3 ft drop within the LFA between flow zones LF2 and LF4.

The lowest head at the site was observed in packer test 2 from well POF-28. This was the only available data point below the USDW. The TDS concentration from that packer was 26,573 mg/L, an order of magnitude larger than packer test 3 (TDS of 2,635 mg/L), which was run the same day. The 34 ft difference between the measured head from these two tests illustrates the effect of salinity-induced density variations in head.

6 SUMMARY

The Site B drilling and testing program included:

- Construction and logging of three wells in the Floridan Aquifer System:
    - A dual-zone Upper Floridan aquifer (UFA)/Avon Park permeable zone (APPZ) monitor well (POF-27)
    - A Lower Floridan aquifer (LFA) exploratory well (POF-28), completed as a dual-zone LFA monitor well
    - A LFA production well for aquifer performance testing (POF-29)
- Construction of a surficial aquifer system (SAS) monitor well for aquifer performance testing (POS-14)
- Determination of water quality variation with depth, and sampling for field and laboratory analysis of formation waters
- Implementation and analysis of aquifer performance tests, discretely evaluating the UFA, the APPZ, and a portion of the LFA

Drilling at Site B penetrated to a maximum depth of 2,728 feet below land surface (ft bls). Major findings include:

- Boundaries of the major hydrogeologic units at this location were identified based on lithology, geophysical logs, and water quality, water-level and hydraulic data.
    - Top of the intermediate confining unit (ICU): 77 ft bls
    - Top of the Floridan aquifer system (FAS): 276 ft bls
    - Top of the upper Middle confining unit (MC1) between the UFA and the APPZ: 529 ft bls
    - Top of the APPZ: 750 ft bls
    - Top of the lower Middle confining unit (MC2) between the APPZ and the LFA: 1,109 ft bls
    - Top of the LFA: 1,296 ft bls
    - Base of the Floridan aquifer system/top of the sub-Floridan confining unit (SFCU): 2,486 ft bls

- Five discrete productive intervals, or flow zones, with varying degrees of confinement between them were identified within the LFA at Site B. For ease of reporting, these zones are numbered sequentially, from shallowest to deepest (LF1–LF5).

Flow Zone	Top Depth (ft bls)	Base Depth (ft bls)	Relative Productivity Estimate
LF1	1,296	1,350	Low
LF2	1,538	1,680	High
LF3	1,732	1,823	Moderate
LF4	2,168	2,247	Very High
LF5	2,369	2,409	Moderate

- Lower Floridan aquifer zones LF4 and LF5 are hydrostratigraphically equivalent to the Boulder Zone of southern Florida.
- Based on log, drill stem, and packer test data, the position of the base of the underground source of drinking water (USDW) (total dissolved solids [TDS] of 10,000 milligrams per liter [mg/L]), was identified within LF4 at 2,234 ft bls.
- Formation water sampling and analysis yielded the following distribution of dominant ions and TDS for the hydrogeologic units sampled:

Hydrogeologic Unit	Dominant Ion Pairs	TDS (mg/L)	Sample Source
UFA	Ca^{2+}- HCO_3^-	90	POF-27 Upper Zone
APPZ	Ca^{2+}- HCO_3^-	118	POF-27 Lower Zone
MC2	Ca^{2+}- SO_4^{2-}	316	POF-27 Packer Test 2
LF1	Ca^{2+}- SO_4^{2-}	1,190	POF-28 Interval Test 1
LF2	Na^+-Cl^--Ca^{2+}- SO_4^{2-}	790	POF-29 Aquifer Test
LF3	Na^+-Cl^--Ca^{2+}- SO_4^{2-}	1,392	POF-28 Packer Test 4
LF4	Na^+-Cl^-	3,956	POF-28 Lower Zone
LF5	Na^+-Cl^-	30,437	Drill Stem

- Discrete, referenced water level measurements within the hydrogeologic units identified at Site B were taken at different points during construction and testing. The highest heads are in the UFA, with water levels decreasing both above and below that unit. There is an approximate 5 ft head drop between the APPZ and LFA at this site, and an additional 3 ft drop within the LFA between flow zones LF2 and LF4.
- Hydraulic testing yielded the following results:
    - A 24-hour aquifer performance test (APT) of the UFA (discharge rate [Q] of 1,100 gallons per minute [gpm]) yielded a mean transmissivity of 3,627 ft2/day and a mean storage coefficient of 2.4×10^{-4}.
    - A 48-hour aquifer performance test of the APPZ (Q = 4,300 gpm) yielded a mean transmissivity of 38,606 ft2/day and a mean storage coefficient of 2.3×10^{-4}.

- A leakance coefficient of 0.001/day, yielding an average vertical hydraulic conductivity of 0.25 ft/day was estimated for MC1, from the UFA and APPZ tests.
- A transmissivity of 2,001 ft^2/day for LF1 was estimated from the specific capacity of that unit when pumped at a sustained rate of 350 gpm.
- Based on water quality and geophysical log data, flow zone LF2 of the Lower Floridan aquifer was targeted for more extensive hydraulic testing. A 90-hour APT of LF2 (Q = 3,906 gpm) yielded a mean transmissivity of 41,760 ft^2/day and a mean storage coefficient of 2.0×10^{-3}.
- It was not possible to estimate a leakance across MC2 from the APT results. No drawdown was observed in the APPZ during the LF2 testing and the cavernous nature of monitor well POF-28U limited the usefulness of the production zone monitor well data. There is a significant head gradient across MC2, but geophysical log data indicate MC2 is leaky. One packer test completed in MC2 yielded an estimated horizontal hydraulic conductivity ranging from 3.1 to 7.5 ft/day.
- The confinement between LF1 and LF2 appears to be more restrictive than MC2. The packer test completed in this interval yielded an estimated horizontal hydraulic conductivity ranging from 0.67 to 1.61 ft/day. The presence of fresh water in the packer test interval with more saline water above it also implies good confinement of this unit. There is also a significant difference in the water chemistry between LF1 and LF2.

The results of drilling and testing at LFAKB Site B confirm the presence of a series of permeable intervals in the LFA which are potentially viable for future development. Productivity within the LFA is not evenly distributed, however, and the shallowest flow zone (LF1) is less permeable than deeper units at this site. In terms of alternative water supply development, the LF2 horizon, from 1,538 to 1,680 ft bls, is the most promising zone of the Lower Floridan at the Site B location, offering the best combination of water quality and productivity. If developed independent of LF1, there is also considerable added confinement to isolate it from the highly developed APPZ and UFA units. Aquifer yield is low at Site B in comparison to tests of the LFA in Orange County, but compares well to results from other tests in Polk and Osceola Counties. Well yields could be improved by incorporating deeper zones of the LFA, but only at the risk of intercepting higher salinity.

REFERENCES

Bryan, J.R., R.C. Green and G.H. Means. 2011. *An Illustrated Guide to the Identification of Hydrogeologically Important Formations in the South Florida Water Management District.* Unpublished Contract Deliverable to SFWMD.

Cedergren, H.R. 1977. *Seepage, Drainage & Flow Nets*. Wiley & Sons., p 64.

Clark, L. 1967. Computing the Barometric Efficiency of a Well. *Journal of Hydraulic Engineering*, 93(HY4):93-98.

Cooper, H.H. and C.E. Jacob. 1946. A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well Field History. *Transactions of the American Geophysical Union*, 27:526–534.

Davis, J.D. and D. Boniol. 2011. Grids representing the altitude of top and/or bottom of hydrostratigraphic units for the ECFT 2012 groundwater model area. St. Johns River Water Management District, Bureau of Engineering and Hydrologic Sciences electronic file archives.

Dougherty, D.E. and D.K. Babu. 1984. Flow to a Partially Penetrating Well in a Double-Porosity Reservoir. *Water Resources Research*, 20(8):1116-1122.

Driscoll, F.G. (ed.). 1986. Groundwater and Wells (Second edition). Johnson Division, St. Paul, MN.

Duffield, G.M. 2007. *AQTESOLV for Windows, Version 4.5, Professional*. HydroSOLVE Inc., Reston, VA.

Duncan, J.C., W.L. Evan, III and K.L. Taylor. 1994. The Geologic Framework of the Lower Floridan Aquifer System in Brevard County, Florida. Bulletin 64:90. *Florida Geological Survey*.

Dunham, R.J. 1962. "Classification of Carbonate Rocks According to Depositional Texture." In Classification of Carbonate Rocks, W.E. Ham (ed). *American Association of Petroleum Geologists*, 1:108–121.

Finnemore, E.J. and J.B. Franzini. 2002. *Fluid Mechanics with Engineering Applications*. McGraw Hill Higher Education, 790p.

Frazee, Jr., J.M. 1982. *Geochemical Pattern Analysis: Method of Describing the Southeastern Limestone Regional Aquifer System*. Studies of Hydrogeology of the Southeastern United States, Special Publications: Number 1, Georgia Southwestern College, Americus, GA, 46–58.

Hantush, M.S. 1960. Modification of the Theory of Leaky Aquifers. *Journal of Geophysical Research*, 65(11):3713–3725.

Hantush, M.S., and C. E. Jacob, 1955. Nonsteady Radial Flow in an Infinite Leaky Aquifer. *EOS Transactions of the American Geophysical Union*, 36(1):95–100.

Heald, C.C., ed. 1994. *Cameron Hydraulic Data.* 18th edition. Ingersoll-Dresser Pumps. Liberty Corner, NJ.

Horstman, T. 2011. *Hydrogeology, Water Quality, and Well Construction at ROMP 45.5 – Progress Energy Well Site in Polk County, Florida.* Southwest Florida Water Management District. Brooksville, FL, 40p.

King, K.C. 1979. *Tampa Formation of Peninsular Florida, a Formal Definition.* Master's Thesis, Florida State University, Tallahassee, FL 83 p.

Kruseman, G.P. and N.A. de Ridder. 1990. *Analysis and Evaluation of Pumping Test Data*. International Institute for Land Reclamation and Improvement ILRI: The Netherlands, 200 p.

Miller, J.A. 1986. *Hydrogeologic Framework of the Floridan Aquifer System in Florida and Parts of Georgia, Alabama and South Carolina*. USGS Professional Paper 1403-B. U.S. Geological Survey, Washington, DC, 91 p.

Moench, A.F. 1984. Double-porosity Models for a Fissured Groundwater Reservoir with Fracture Skin. *Water Resources Research*, 20:831–846.

Moench, A.F. 1985. Transient Flow to a Large-diameter Well in an Aquifer with Storative Semiconfining Layers. *Water Resources Research*, 21(8):1121–1131.

Neuman, S.P. and P.A. Witherspoon. 1969. Theory of Flow in a Confined Two Aquifer System. *Water Resources Research*, 5(4):803-816.

Odin, G.S. and P.D. Fullagar. 1988. "Geological Significance of the Glaucony Facies" in Green Marine Clays: Olitic Ironstone Facies, Verdine Facies, Glaucony Facies and Celadonite-Bearing Facies – A Comparative Study (Developments in Sedimentology 45), G.S. Odin (ed.). Elsevier Science Publishing Company, Inc., New York, NY, 295-331.

Reese, R.S. and E. Richardson. 2007. *Synthesis of the Hydrogeologic Framework of the Floridan Aquifer System, Delineation of a Major Avon Park Permeable Zone in Central and Southern Florida.* U.S. Geological Survey Scientific Investigations Report 2007-5207, U.S. Geological Survey, Reston, VA.

Renard, P., D. Glenz and M. Mejias. 2009. Understanding Diagnostic Plots for Well-test Interpretation. *Hydrogeology Journal*, 17(3):589-600.

Scott, T.M. 1988. *The Lithostratigraphy of the Hawthorn Group (Miocene) of Florida.* Florida Geological Survey, Bulletin No.59.

Sepulveda, N., C.R. Tiedeman, A.M. O'Reilly, J.B. Davis and P. Burger. 2012. *Groundwater Flow and Water Budget in the Surficial and Floridan Aquifer Systems in East-Central Florida.* U.S. Geological Survey Open-File Report 2012-1132, U. S. Geological Survey, Reston, VA.

Spechler, R.M., and S.E. Kroening. 2007. *Hydrology of Polk County, Florida*. U.S. Geological Survey Scientific Investigations Report 2006-5320, U. S. Geological Survey, Reston, VA.

Streltsova, T.D. 1988. *Well Testing in Heterogeneous Formations*. John Wiley & Sons: New York, NY, 413p.

Theis, C.V. 1935. The Relation between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Groundwater Storage. *American Geophysical Union Transactions*, 16:519–524.

Tucker, M.E., and V.P. Wright. 1990. *Carbonate Sedimentology*. Blackwell Science, Oxford, 482.