SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Aquifer Performance Testing
The Nature Conservancy
Disney Wilderness Preserve Site
Polk County, Florida

Technical Publication WS-36

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Executive Summary

The South Florida Water Management District's (SFWMD's) *Kissimmee Basin Water Supply Plan* (SFWMD 2000) found that in areas of Orange, Osceola and Polk counties, groundwater supplies may be insufficient to meet projected 2020 (1-in-10 year drought) water supply demand from the Floridan aquifer system. These findings are based on limited hydrologic and geologic data for the region. The continuing use of the Floridan aquifer may be a contributing factor to potential harm to wetlands, reduced spring flow and the formation of more sinkholes within the region. In order to address this deficiency, the *Kissimmee Basin Water Supply Plan* recommended that additional hydrogeologic data be gathered. The data collected from the site discussed in this publication will be beneficial for addressing the uncertainty of future water use and its impact on wetlands. The refinement of the current understanding of the interactions between the upper Floridan aquifer (UFA), intermediate confining unit (ICU) and surficial aquifer system (SAS) will be instrumental in the revision of conceptual hydrogeologic and groundwater models and development of a wetlands impact constraint.

The Nature Conservancy site known as the Disney Wilderness Preserve is located partially in eastern Polk County, and partially in western Osceola County, Florida on the eastern side of Lake Hatchineha. Surface elevation is approximately 70 feet National Geodetic Vertical Datum of 1929. A total of three production wells were constructed, each with a completion interval in one of the principal hydrogeologic units (SAS, ICU and UFA). Five corresponding monitor wells are also onsite and were utilized during aquifer performance tests (APTs).

The scope of the investigation consisted of the construction of a series of production and monitor wells and APTs. The UFA production well FPW1 was drilled to a total depth of 461 feet below land surface (ft bls). The corresponding monitor well (FMW1) was completed to a depth of 432 ft bls and is approximately 100 feet to the south of production well. The Hawthorn production and monitor wells (HPW1 and HMW1) were installed to depths of 180 and 131 ft bls, respectively. The four SAS wells were completed to the following depths: SPW1 to 94 ft bls, SMW1 to 13 ft bls, SMW2 to 38 ft bls and SMW3 to 205 ft bls.

The SFWMD provided oversight during well drilling, construction and testing of FPW1 and FMW1. Diversified Drilling Corporation was responsible for all drilling, well construction and testing services at the site under SFWMD contract C-12352. The UFA production well is now designated as part of the long-term monitoring program under the SFWMD water level monitoring network.

The main findings of the exploratory drilling and testing program at this site are as follows:

1. Lithologic information and geophysical logs obtained from FPW1 indicate that clays, silts, quartz sands and mudstones of the Hawthorn Group predominate from 120 to 237 ft bls. These ICU sediments separate the SAS from the underlying FAS and are semi-confining.

2. The top of the FAS was identified at a depth of approximately 237 ft bls at this site as defined by Reese and Richardson (2008).

3. Lithologic logs, geophysical logs and APT results indicate moderate production capacity in the UFA.

4. The UFA test interval (199 to 461 ft bls) yielded a mean transmissivity value of 5,463 square feet per day, storage coefficient of 0.00033 and a leakance coefficient of 0.027 based on APT data.

5. The ICU slug test (110 to 180 ft bls) yielded an average hydraulic horizontal conductivity for the Hawthorn sediments of 0.0039 feet per day.

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Abbreviations and Acronyms

APT	aquifer performance test
ASCII	American Standard Code for Information Interchange
FAS	Floridan aquifer system
ft bls	feet below land surface
ft/day	feet per day
ft^2/day	square feet per day
gpm	gallons per minute
ICU	intermediate confining unit
KBWSP 2000	*Kissimmee Basin Water Supply Plan* published in 2000
NGVD	National Geodetic Vertical Datum of 1929
PDF	portable document format
PVC	polyvinyl casing
SAS	surficial aquifer system
SFWMD	South Florida Water Management District
UFA	upper Floridan aquifer

1 Introduction

1.1 BACKGROUND

The South Florida Water Management District (SFWMD) developed the *Kissimmee Basin Water Supply Plan* in 2000 (KBWSP 2000) and found that groundwater supplies in areas of Orange, Osceola and Polk counties may not be sufficient to meet projected 2020 (1-in-10 year drought) water supply needs (SFWMD, 2000). The ongoing use of the upper Floridan aquifer (UFA) in this area may contribute to potential harm of wetlands, reduction in spring flow and be a factor in the formation of sinkholes. The findings of the KBWSP 2000 are based on limited hydrologic and geologic data for this region. Information regarding the interactions between the UFA, intermediate confining unit (ICU) and surficial aquifer system (SAS) is insufficient. In order to better address the uncertainty of future water use and its impact on wetlands, the KBWSP 2000 and subsequent update (SFWMD, 2006) recommended additional hydrologic data be gathered to meet this deficiency. The Nature Conservancy property named the Disney Wilderness Preserve is located partially in eastern Polk County and partially in western Osceola County. It was selected as a suitable site for obtaining additional hydrologic information. The location of the study area is shown in **Figure 1**.

1.2 PURPOSE

The purpose of this report is to document the hydrologic and geologic data collected during the construction of a series of eight wells and subsequent aquifer performance testing that will support the KBWSP 2000 and its recommendations. The information includes a summary of the well construction details, lithology and hydrogeology, geophysical logging, and aquifer performance tests (APTs), and analyses of the APTs. The analyses will assist in quantifying the interactions of the aquifers and leakance values between them in eastern Polk County and western Osceola County. Data collected from the testing and monitoring of the wells at this site will be instrumental in the revision of the current groundwater model and the development of a wetland impact constraint. Upon completion of the APTs, the site was designated as part of the long-term monitoring program under the SFWMD water level monitoring network.

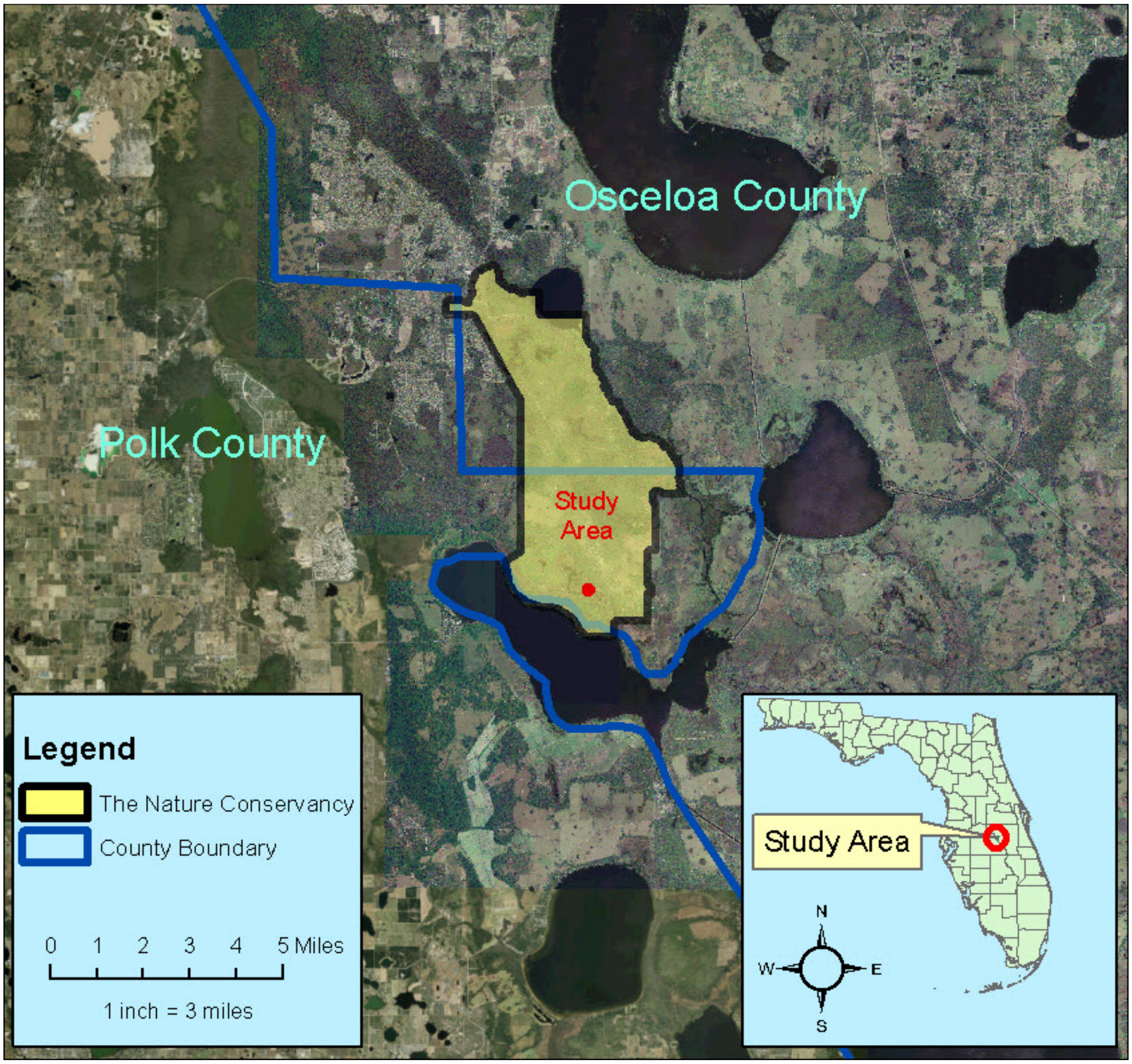

Figure 1. Project location map.

1.3 PROJECT DESCRIPTION

SFWMD previously completed installation of a series of wells within the Disney Wilderness Preserve located in Polk County. The surface elevation is approximately 70 feet National Geodetic Vertical Datum of 1929 (NGVD). Two UFA wells were constructed: one 10-inch diameter production well (FPW1) and one 4-inch observation well (FMW1, later identified as POF-22). Both wells were completed in the UFA to a depths of 461 and 432 feet below land surface (ft bls), respectively. Two wells were completed in the ICU; one 6-inch diameter production well (HPW1) and one 2-inch diameter observation well (HMW1, later identified as POS-13). The production well was completed to a depth of 180 ft bls (HPW1), with the associated monitor well (HMW1) reaching a depth of 131 ft bls. In addition, four SAS wells were installed and utilized during the testing: one 6-inch production well (SPW1) and three 2-inch observation wells (SMW1, SMW2 and SMW3). The SAS production well (SPW1) was finished to a depth of 94 ft bls. SMW1 (known as POS-11) was screened to 13 ft bls; SMW2 (also identified as POS-12) reached a total depth of 38 ft bls, with screen from 31 ft bls; and SMW3 is screened from 26 ft bls to 205 ft bls.

SFWMD provided oversight and Diversified Drilling Corporation was responsible for drilling, construction and testing services associated with the two UFA wells under SFWMD contract C-12352. Specific objectives for this site included evaluation of the hydraulic properties of the SAS and UFA, and the degree of leakance between the units.

1.4 REGIONAL DESCRIPTION

The well investigation falls within the boundaries of Polk County. The surface elevation is approximately 70 feet NGVD in the study area and lies in the physiographic region known as the Osceola Plain. Polk County encompasses approximately 1,823 square miles with 187 square miles being water bodies (Purdum et al., 1988). Eastern Polk County falls under the jurisdiction of SFWMD and western Polk County falls under the jurisdiction of the Southwest Florida Water Management District. Polk County is bounded by Osceola County to the east, Sumter and Lake counties to the north, Hillsborough County to the west and Hardee and Highlands counties to the south. Polk County has a humid subtropical climate with hot, wet summers and mild dry winters. Over half of the rainfall occurs during the months of June through September. Long-term records (1931 to 2003) indicate an average annual rainfall at the Lakeland station is approximately 51 inches, although there is considerable variation year to year. In 1961, annual rainfall was 35.83 inches while in 1959 a total of 70.24 inches were recorded at this station (Spechler and Kroening, 2007).

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Exploratory Drilling and Well Construction

The objective of this project was to construct and test a series of wells that will support the KBWSP 2000 and its recommendations. Diversified Drilling Corporation installed one UFA production well, FPW1, and one UFA monitor well, FMW1 (POF-22). The remaining six wells were installed by others under a separate contract. The naming convention for the wells is as follows: PW identifies production wells and MW corresponds to monitor wells. It should be noted that SMW3 is screened in both the SAS and ICU units. During drilling, SFWMD collected drill cuttings every ten feet or at noticeable formation changes for the Floridan production well (FPW1). The lithologic log for FPW1 is presented in **Appendix A**. Hydrogeologic testing was performed after completion of the wells in 2001. **Figure 2** shows the site layout.

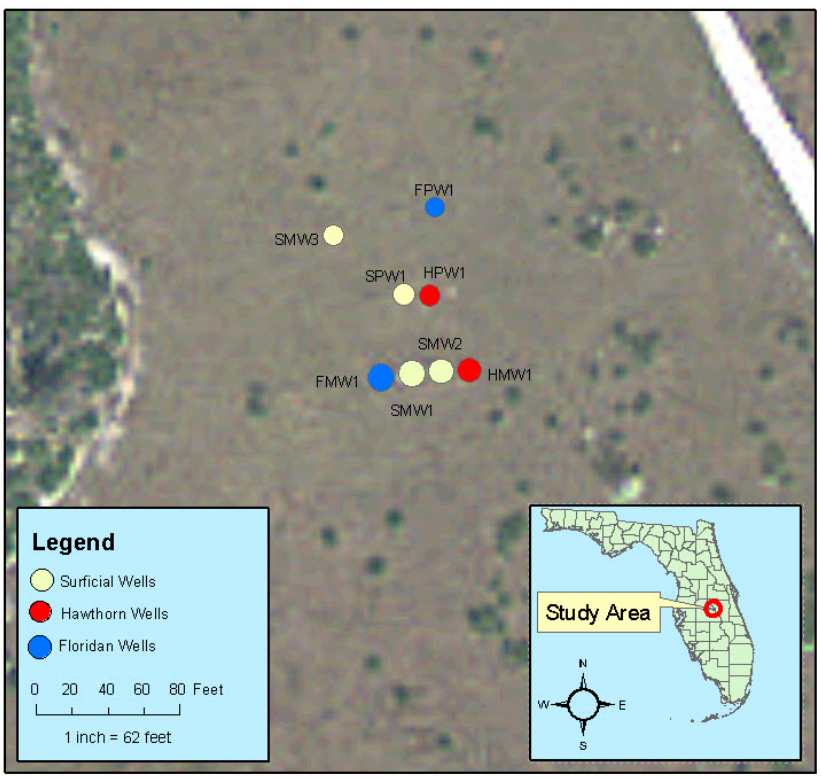

Figure 2. Site layout for The Nature Conservancy APTs.

Geophysical logging was conducted on FPW1, FMW1, SMW1, SMW2 and HMW1 in 2012. Wells HPW1, SPW1 and SMW3 could not be located at the site in 2012.

2.1 FPW1 AND FMW1 WELL CONSTRUCTION

The two Floridan aquifer wells, one 10-inch diameter production well (FPW1) and one 4-inch diameter UFA observation well (FMW1), were drilled using the mud-rotary method to the base of the ICU. Stainless steel casing was set at 199 ft bls and 205 ft bls, respectively. The casings were then pressure grouted back to land surface. The open hole portion of each well was drilled using reverse-air and extends to a total depth of 461 ft bls in FPW1 and 432 ft bls in FMW1. Wellheads for FPW1 and FMW1 were 10-inch and 4-inch stainless steel. The wells were developed by reverse-air and airlift methods until all visible particulate matter had been removed. **Figure 3** shows the well completion diagram for FPW1 and **Figure 4** corresponds to FMW1. The well depths were verified by post geophysical logging conducted by SFWMD staff in 2012.

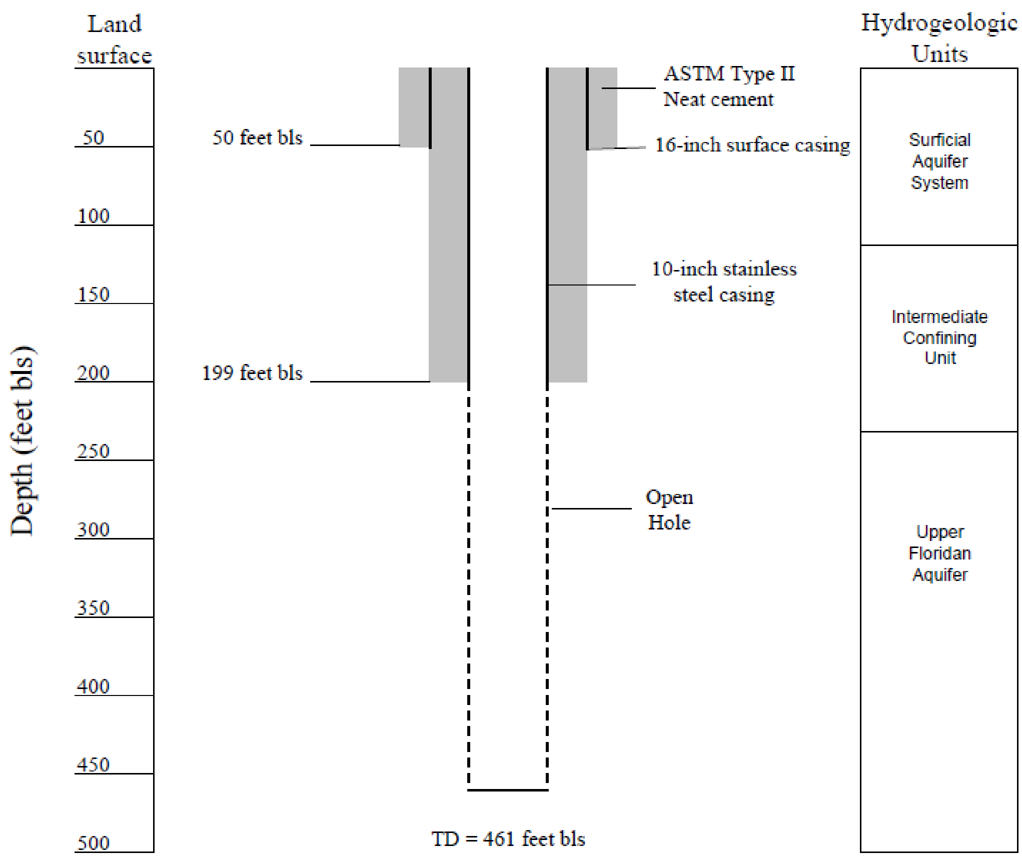

Figure 3. FPW1 well completion diagram.
(Note: ASTM – American Society for Testing and Materials and TD – total depth.)

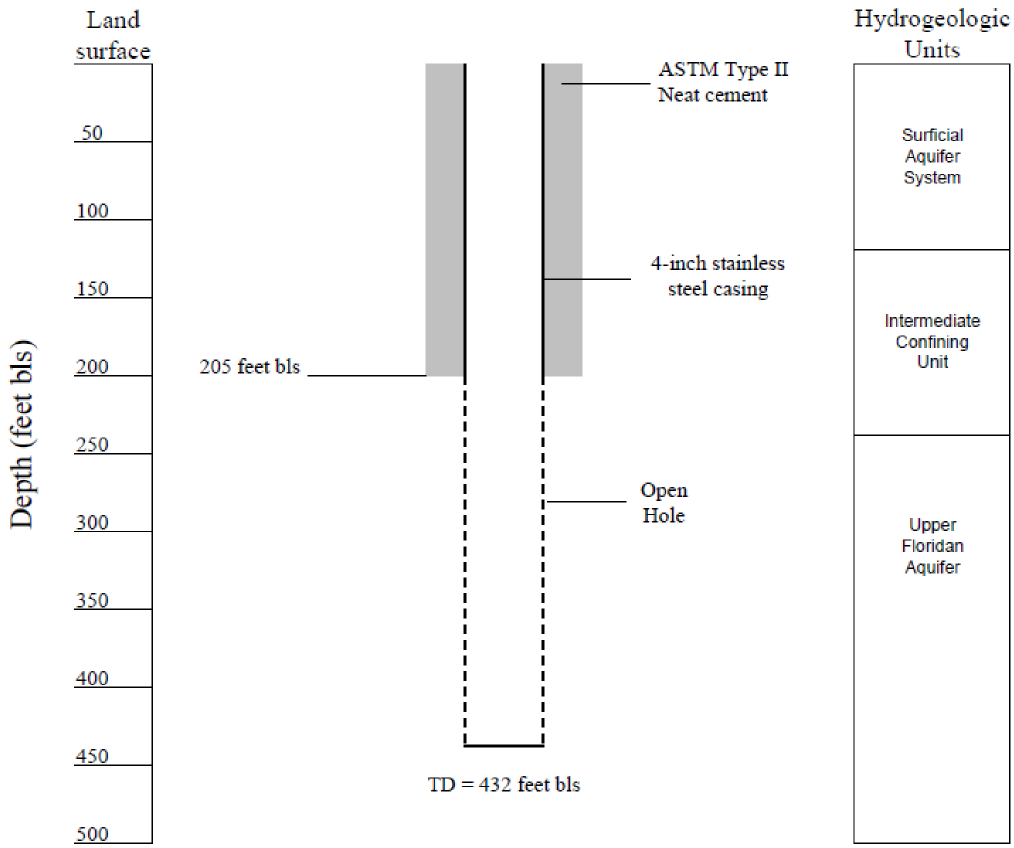

Figure 4. FMW1 (POF-22) well completion diagram.
(Note: ASTM – American Society for Testing and Materials and TD – total depth.)

Lithologic cuttings were collected at 10-foot intervals and geophysical logs were conducted on the FPW1 pilot hole during construction. These data were used to identify the depths of formations and flow zones. The casing installed to 199 ft bls in FPW1 and 205 ft bls in FMW1 was designed to seal off the ICU. Review of the geophysical logs conducted in 2012 indicate the ICU extends to a depth of approximately 237 ft bls in FPW1. Clays dominating the base of this unit possibly swelled partially closing the open hole portion of the smaller diameter monitor well. FMW1 borehole was partially blocked immediately below the casing (205 ft bls) when video logging was conducted in 2012. Unless otherwise specified, all vertical positions in this report should be understood to be depth in units of ft bls.

2.2 HPW1 AND HMW1 WELL CONSTRUCTION

Two wells were installed in the ICU. The Hawthorn production well (HPW1) polyvinyl chloride (PVC) casing extends to a depth of 110 ft bls and the screened interval extends to 180 ft bls. The Hawthorn monitor well (HMW1) is cased to 118 ft bls with PVC and then screened to a total depth of 131 ft bls. An 8/20 silica sand filter pack was tremied into the annular space from total depth to three feet above the top of the screen. Two feet of bentonite pellets were placed above the filter pack in each well and hydrated to provide a seal between the filter pack and the cement grout. The remaining annular space was filled with neat cement to land surface. The wells were developed until all visible particulate had been removed. **Figure 5** and **Figure 6** are well completion diagrams for HPW1 and HMW1, respectively. Depths for HMW1 were verified during geophysical logging in 2012. HPW1 could not be located at the site.

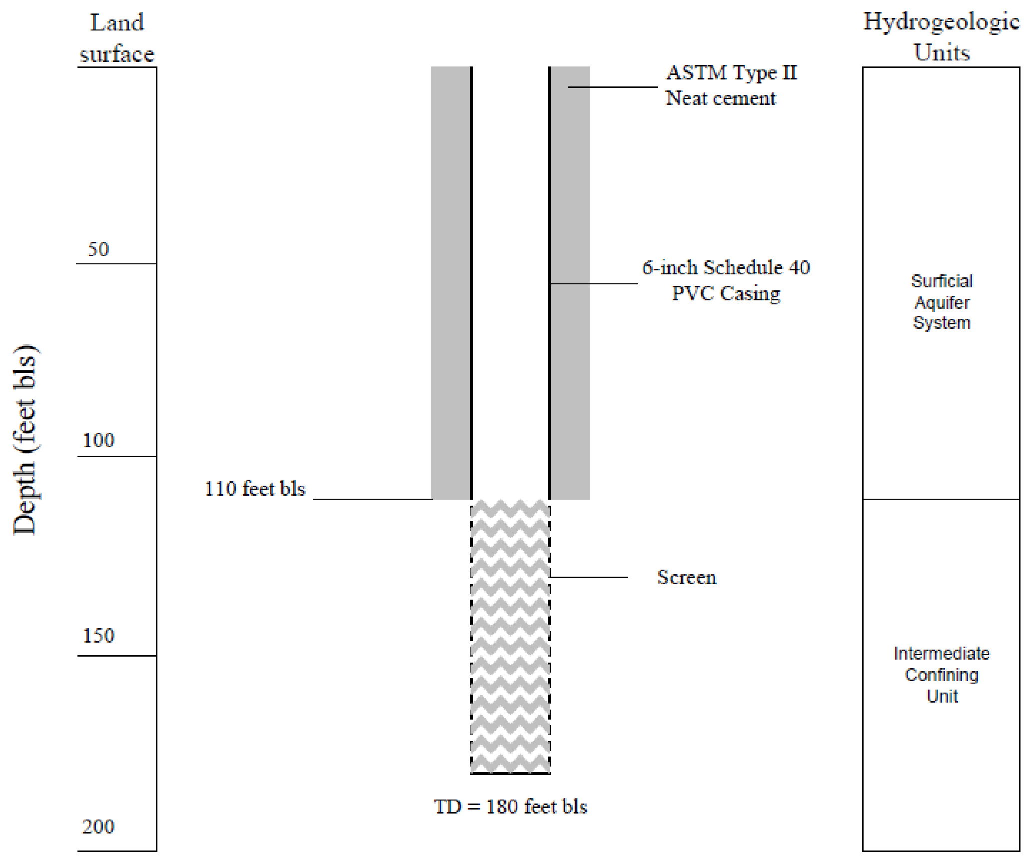

Figure 5. HPW1 well completion diagram.
(Note: ASTM – American Society for Testing and Materials and TD – total depth.)

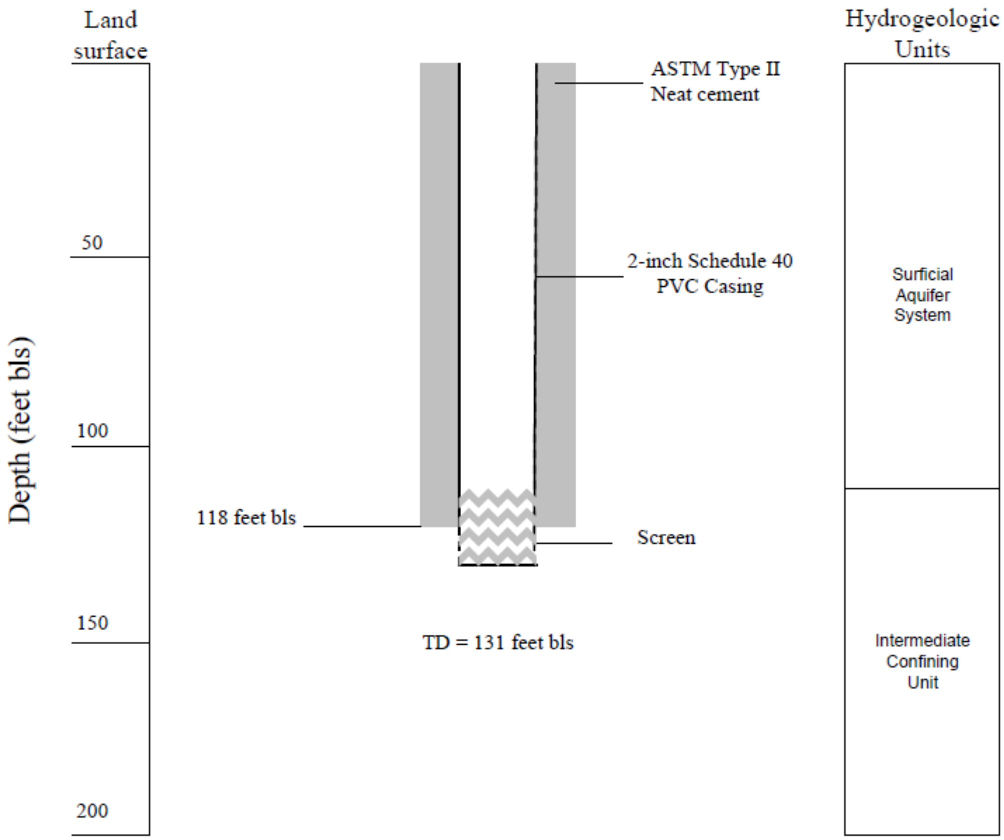

Figure 6. HMW1 (POS-13) well completion diagram.
(Note: ASTM – American Society for Testing and Materials and TD – total depth.)

2.3 SPW1, SMW1, SMW2 AND SMW3 WELL CONSTRUCTION

There are a series of three monitor wells and one production well completed in the SAS at the site. The SAS production well (SPW1) is 8 inches in diameter and the PVC casing extends to 26 ft bls. The screened portion of the well extends to a total depth of 94 ft bls. All monitor wells are 2 inches in diameter with their upper portions cased in PVC and lower zones screened. SMW1 is the shallowest monitor well and is screened from 5 to 13 ft bls. The second SAS monitor well has a total depth of 38 ft bls. The deepest 7 feet are screened. SMW3 is screened from 26 to 205 ft bls. This series of surficial wells were previously screened, gravel packed, cemented and developed using the methods described for the Hawthorn wells. **Figure 7** shows the well completion diagram for the four SAS wells. The depths of SMW1 and SMW2 were verified during geophysical logging in 2012. SPW1 and SMW3 could not be located at the site at that time. Details of the locations and completion intervals of the wells are summarized in **Table 1**.

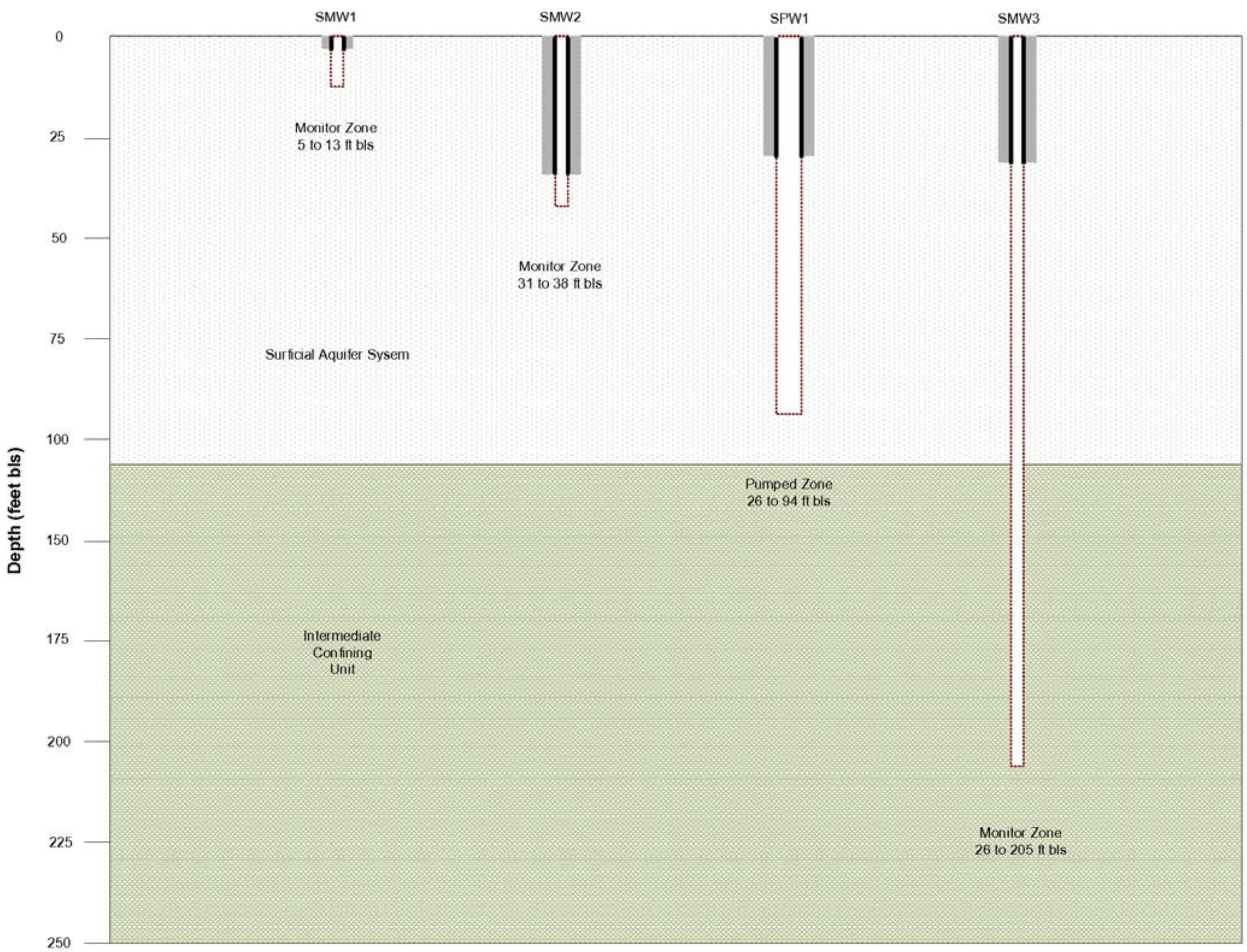

Figure 7. Well completion diagram for SMW1, SMW2, SPW1 and SMW3.

Table 1. Location and completion intervals of production and monitor wells at the Disney Wilderness Preserve Site.

Well Name(s)	Northing (feet)	Easting (feet)	Casing Diameter (inches)	Casing Depth (feet bls)	Total Depth (feet bls)	Land Elevation (feet NGVD)	Casing/ Screen Material	Screen/ Open Hole
FPW1 [1]	527118.7	1350763.7	10	199	461	68.51	Stainless Steel	Open Hole
FMW1 [1] (POF-22 [2])	527098.2	1350667.4	4	205	432	68.75	Stainless Steel	Open Hole
HPW1	527115.6	1350714.6	6	110	180	67.29	PVC	Screen
HMW1 [1] (POS-13 [2])	527129.9	1350671.0	2	118	131	70.22	PVC	Screen
SPW1	527101.9	1350715.8	6	26	94	68.77	PVC	Screen
SMW1 [1] (POS-11 [2])	527107.8	1350669.6	2	5	13	69.44	PVC	Screen
SMW2 [1] (POS-12 [2])	527118.5	1350670.6	2	31	38	69.53	PVC	Screen
SMW3	527060.2	1350763.7	2	26	205	66.88	PVC	Screen

1. Depths verified by geophysical logging in 2012.
2. POF and POS prefixes refer to DBHYDRO, SFWMD's corporate environmental database, well names..

3 Stratigraphic Framework

SFWMD collected geologic formation samples (drill cuttings) from the pilot hole during drilling of FPW1, and described them based on their dominant lithologic and textural characteristics. Geophysical logs were also helpful in describing the geologic formations encountered during drilling. This section describes the stratigraphic framework encountered at the site based on lithologic and geophysical logs conducted in the drilled well bores.

3.1 HOLOCENE, PLEISTOCENE AND PLIOCENE SERIES

Undifferentiated sediments of the Pliocene, Pleistocene and Holocene occur from land surface to a depth of approximately 120 ft bls at this site. These surficial deposits are primarily comprised of quartz sands, clayey sands and clay. The sand ranges from fine to coarse grain. The area is characteristic of a karstic terrain. Water percolates through the uppermost soils and reacts with carbon dioxide producing a moderately acidic solution. When the water reaches the underlying carbonate rock, it slowly passes through, gradually dissolving the rock and, in time, produces cavities and conduits. As the solution caverns increase in size, some collapse under the weight of overlying sediments and rock. These are called sinkholes. Sinkholes are very common throughout Polk County (Spechler and Kroening, 2007). The water bodies surrounding the study area in **Figure 1** are examples of sinkholes. Some sinkholes have coalesced forming larger lakes. The presence of such karstic features allows for direct recharge from the SAS and lakes to the underlying Floridan aquifer.

3.2 MIOCENE SERIES

The Hawthorn Group is Miocene in age and consists of the Peace River and Arcadia Formations. It has also been interpreted to include late Oligocene sediments (Scott et al., 2001). The top of the Peace River Formation at this site is approximately 120 ft bls. It is typically interbedded quartz sand, carbonates and clays. Siliciclastics typically make up two-thirds of the formation and quartz sands are generally poorly consolidated. Clays are also common. The remaining third of the formation is carbonate. Phosphate occurs throughout as sand to gravel size grains (Bryan et al., 2011). It is mined in Polk County from the Bone Valley Member of this formation (Arthur et al., 2007). The Peace River Formation sits unconformably above the Arcadia Formation. The contact between the overlying Peace River

Formation and underlying Arcadia Formation is one of gradation (Bryan et al., 2011). The Arcadia Formation includes limestone and dolostone with thin beds of sand and clay throughout. Phosphate grains are present (Scott, 1988). While no index fossils exist, the occurrence of *Lepidocyclinia* and *Miogypsina* together are diagnostic of this formation. The Hawthorn Group extends to a depth of about 237 ft bls at this site.

3.3 OLIGOCENE SERIES

The Suwannee Limestone underlies the Hawthorn Group and can be distinguished by the absence of phosphatic sand. It is Oligocene in age. However extensive erosion has removed Suwannee Limestone in eastern Polk County (Arthur et al., 2007). It is not present at the study site.

3.4 EOCENE SERIES

The Arcadia Formation overlies the Ocala Limestone of the late Eocene at the site. The Ocala Limestone is comprised of two lithologic units. The upper unit is fossiliferous, poorly indurated limestone. Chert is common in the upper facies. The lower unit is well indurated limestone and dolostone. It is recognized by the presence of the foraminifera *Lepidocyclina ocalana*. The wells completed in the FAS in the study area partially penetrate the upper units of the Ocala Limestone. Below the erosional unconformity at the base of the Ocala Limestone lies the Avon Park Formation. It is a thick sequence of marine dolostone and limestone. Layers of well-indurated, fossiliferous limestone alternate with dolostone. This formation is distinguished by the presence of cone shaped *Cushmania americana* foraminifera fossils (previously *Dictyoconus*, Stewart, 1966). **Figure 8** is a diagram of the relationships between the stratigraphic and hydrogeologic units discussed in the following section.

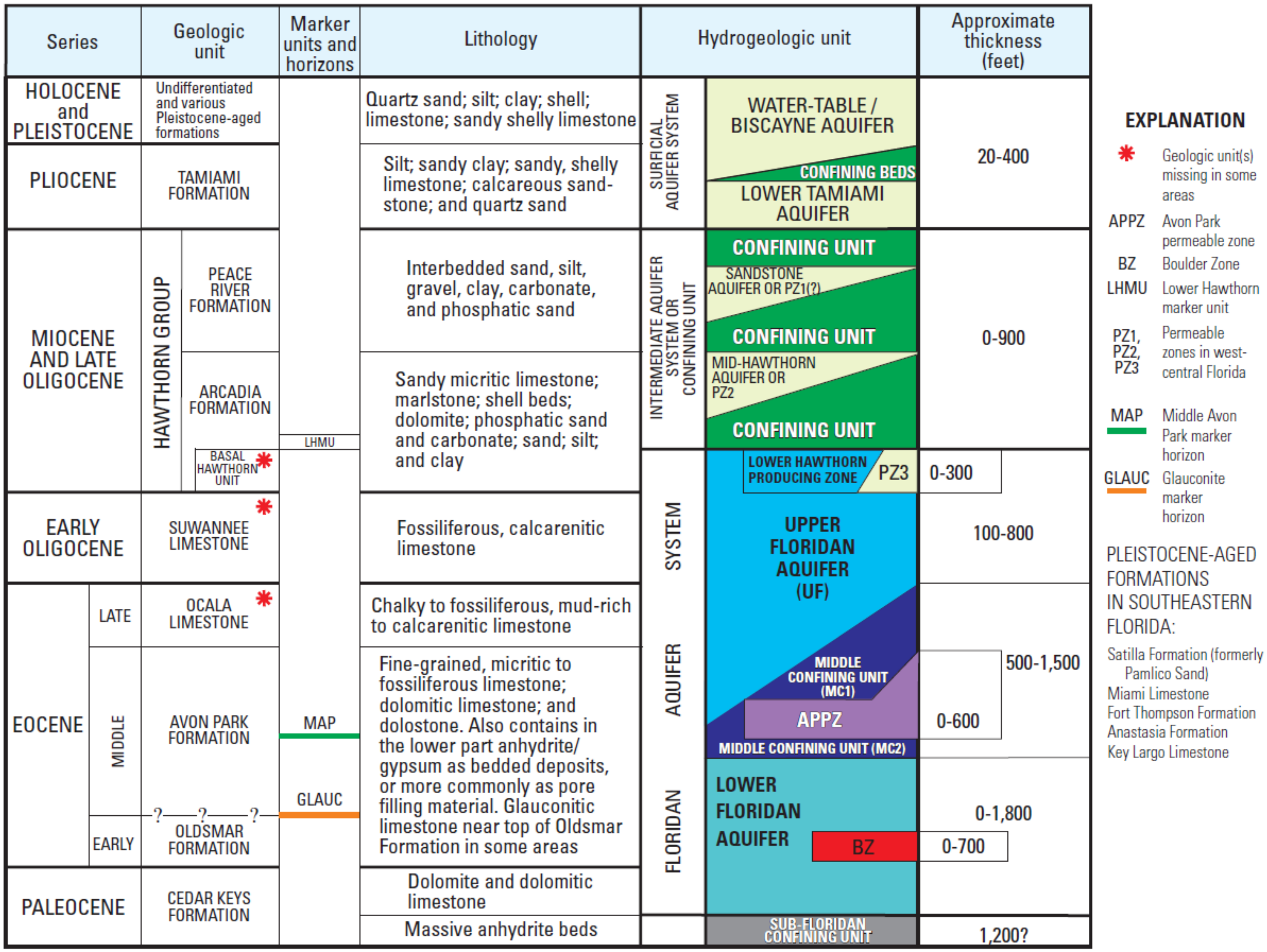

Figure 8. Geologic and hydrogeologic units in central and southern Florida (Reese and Richardson, 2007).

4
Hydrogeologic Framework

Three hydrogeologic units underlie Polk County. These are the unconfined SAS, the ICU and the Floridan aquifer system (FAS). The FAS is subdivided into units: the UFA, a confining unit, and the lower Floridan aquifer (LFA). The ICU restricts the movement of water between the SAS and the UFA. The UFA is the main source for potable water in Polk County (Sprechler and Kroening, 2007).

4.1 SURFICIAL AQUIFER SYSTEM

The SAS is unconfined and is composed primarily of quartz sand that grades into silty and clay sands. It is recharged by precipitation and in the easternmost areas the SAS can be recharged by upward leakage from the UFA. This happens when the head in the underlying UFA is higher than the SAS. However, the majority of leakage is downward to the underlying aquifer. Due to the lower permeability of the SAS compared to the UFA, and the presence of high concentrations of iron, nutrients and pesticides, the SAS is not utilized as a significant source of water. Yields from wells typically range from 10 to 50 gallons per minute (gpm) in the SAS (Barr, 1992).

4.2 INTERMEDIATE CONFINING UNIT

The ICU restricts the vertical movement of water between the SAS and UFA. It varies in permeability and is primarily composed of clays, sandy clay, clayey carbonates and sands. There are two water bearing zones within the confining unit; however, as a whole, it restricts vertical groundwater movement. Recharge to the ICU is primarily through leakance from the overlying SAS and via sinkholes. Sinkholes are common in Polk County. A comprehensive understanding of groundwater flow within the ICU does not exist at this time. When leakage occurs, it can be to the SAS or the underlying UFA. The United States Geological Survey simulated leakance of the lower confining unit of the ICU with ranges from 1×10^{-6} per day to 1×10^{-3} per day. For the upper confining unit, the leakance modeled ranged from 1×10^{-6} per day to 6×10^{-4} per day (Sepulveda, 2002). Tibbals (1990) reported leakance values for the ICU derived from modeling with values ranging from 1×10^{-5} per day to 3×10^{-4} per day for Polk County.

4.3 FLORIDAN AQUIFER SYSTEM

The main source of groundwater in Polk County is the FAS. It is composed of two aquifers separated by a middle semi-confining unit and a confining unit. The UFA includes the Ocala Limestone and the upper portion of the Avon Park Formation. At the test site, the Suwannee Limestone has been removed by erosion. The Ocala Limestone is the primary water-bearing unit. Both FPW1 and FMW1 reach total depth within the UFA. In 2002, approximately 95% of groundwater withdrawals were from the UFA in Polk County. The UFA is anisotropic and heterogeneous in this area. Previous specific capacity and APTs in Polk County have produced a range of transmissivity values from 1,200 in the southeast to 179,000 square feet per day (ft^2/day) in the northwest (Sprechler and Kroening, 2007). Richardson et al. (2013) reported a mean transmissivity of 3,600 ft^2/day for the UFA in Polk County. The test site is located approximately four miles south of the study area.

5

Hydrogeologic Testing

5.1 GEOPHYSICAL LOGGING

Hydrogeologic testing at the site consisted of geophysical logging and APTs. Geophysical logging was undertaken at the time of construction to determine intervals for casing installation and to evaluate borehole characteristics. These data assisted in the final design of the production well and were used in site-specific APTs. The logging was conducted in the pilot hole before reaming for casing installation and enlarging the open hole portion. Four-arm caliper and natural gamma logs were run on the 6-inch pilot hole to 200 ft bls during construction of FPW1. The following logs were run on the 10-inch borehole from 200 ft bls to the total depth of 460 ft bls: 4-arm caliper, natural gamma, dual induction focused log with LL3, spontaneous potential, sonic, temperature and pumped flow logs. In 2012, additional logging was conducted on the five wells that could be located (FPW1, FMW1, HMW1, SMW1 and SMW2). **Table 2** summarizes the geophysical logs conducted at this site.

The caliper log measures the diameter of the borehole in two perpendicular planes and is useful in identifying fractures and solution features, and providing indirect evidence concerning the mechanical strength of the formational material. It aids in identification of suitable casing depths. The 2012 caliper log indicates a wash out at the base of the casing to a depth of approximately 203 ft bls. The borehole has a generally irregular shape to about 400 feet. This interval has some enlarged cavities or fractures. Below 400 ft bls, the borehole tightens up and is close to bit size to total depth. The log is also used together with the flow meter log to assist in interpretation of intervals where flow is entering the borehole.

The gamma ray log measures the natural gamma radiation produced by the decay of uranium (^{238}Ur) and the daughter products (^{40}K and ^{232}Th) in the rock formation. The sources of gamma radiation are mostly associated with clays and phosphates. These components are important in identifying geologic formations and give clues about the origins of the formational layers. The distinctive peak (pink colored) in this log (**Figure 9**) from approximately 200 to 240 ft bls is indicative of clay at the base of the Hawthorn Group sediments. Phosphate was noted in the lithologic descriptions between 321 and 360 ft bls, from 381 to 400 ft bls, and from 441 ft bls to total depth.

Table 2. Summary of geophysical logging at the Disney Wilderness Preserve Site.

Date	Well	Logged Interval (ft bls)	Borehole Diameter (inches)	Caliper	Natural Gamma	Dual Induction	Flow Meter	Temperature	Fluid Resistivity	Video
September 2001	FPW1	0–200	6	X	X					
October 2001	FPW1	200–460	10	X	X	X	X	X	X	
June 2012	SMW1	0–13	2							X
June 2012	SMW2	0–38	2							X
June 2012	HMW 1	0–131	2							X
June 2012	FMW1	0–431	4	X	X					X[1]
September 2012	FPW1	0–461	10	X	X					X

1. The video was obstructed just below the casing (205 ft bls).

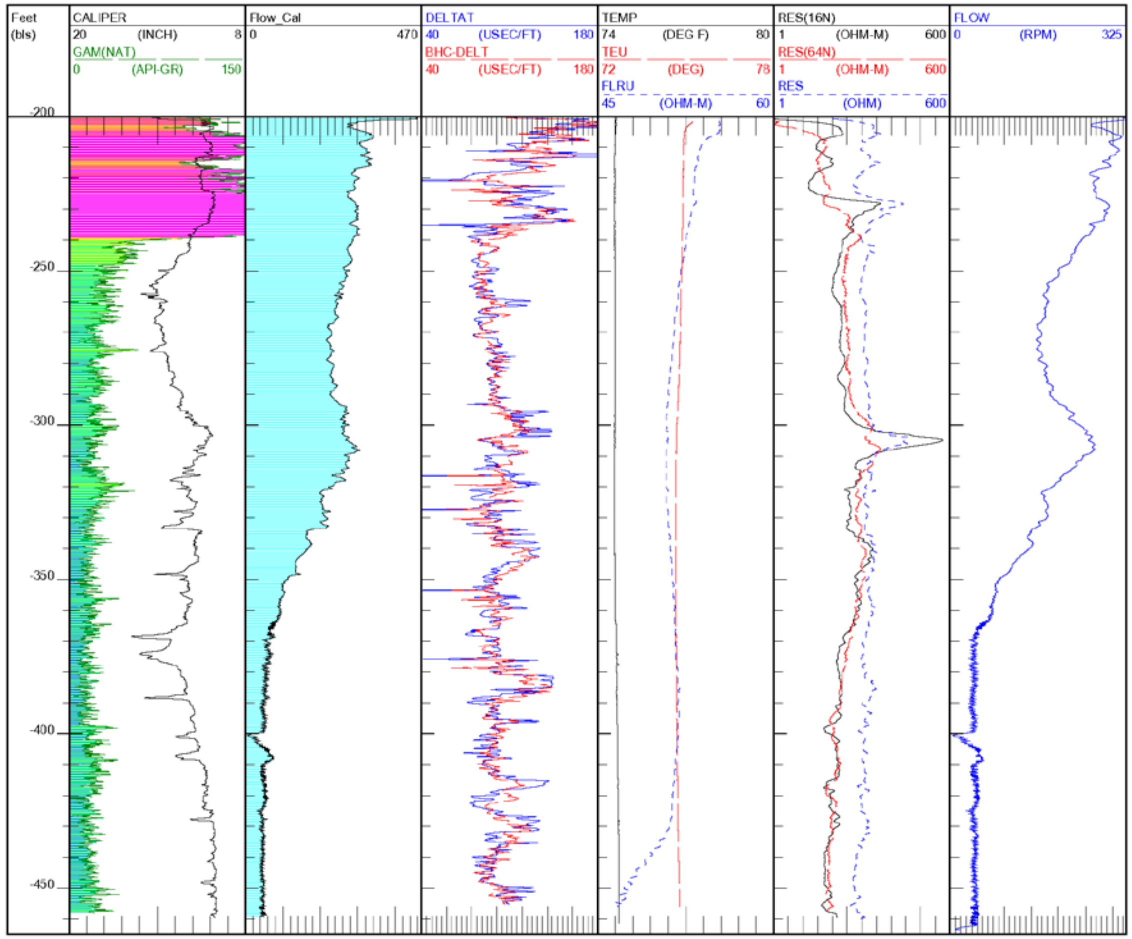

Figure 9. Summary of FPW1 geophysical logs (2001).
(Note: API-GR – American Petroleum Institute units – gamma radiation; BHC-DELT – borehole compensated delta; DEG – degrees; DEG F – degrees Fahrenheit; DELTAT – delta time; FLRU – fluid resistivity ; GAM(NAT) – Gamma radiation (natural); OHM-M– Ohm-meter; RES – Resistivity; RES(16N) – 16-inch (short) normal resistivity; RES(64N) – 64-inch (long) normal resistivity; RPM – revolutions per minute; TEMP – temperature; TEU – temperature unpumped)

The flow meter log measures the rate of fluid movement in the borehole and detects the entry of water into the borehole especially as the well is pumped. Data on in-hole flow is related to well construction, differences in head, and the relative magnitude of permeability of the water-bearing units open to the well (Keys and MacCary, 1971). The flowmeter log was conducted during both static and pumped conditions. With static conditions, the log indicates cross-flow—water moving vertically between different aquifers intersecting the borehole due to head differences between the units. In dynamic conditions, the flow log indicates the primary production zones. The flow logs indicate the primary interval for flow is from the bottom of the casing to about 300 ft bls. From 300 to 350 ft bls, the flow tapers off.

Borehole compensated sonic log 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 borehole has an enlarged irregular shape from between 250 and 300 ft bls. The borehole compensated sonic log shows a slower travel time in this interval.

The temperature and fluid resistivity log measures the temperature and resistivity of the fluid filling the borehole. These logs are used to measure the characteristics of the formation fluid under static and dynamic flow conditions. They provide information on the points of influx into the borehole, production horizons and confinement, and variation in salinity with depth. The temperature remained uniform throughout the open hole section of FPW1 while fluid resistivity decreases below 430 ft bls, indicating an increase in salinity.

The dual induction/sonic potential log is used to measure the electrical properties of the formation. The electrical resistivities of the formation are affected by porosity and water quality. These logs give important information concerning water quality, porosity of the formation, possible producing and confining zones, and mixing of formation water with drilling fluid in the borehole. The peak in resistivity observed below 300 ft bls concurs with a dolomite stringer noted in the lithology at 318 ft bls.

After completing the 2001 suite of logs, the data were downloaded onto compact disks using Log American Standard Code for Information Interchange (ASCII) Standard (LAS) version 2.0 format. The 2012 suite of logs are on digital video disks (DVDs). They are in LAS, portable document format (PDF) and movie file format. The 2001 geophysical logs from this project are archived and available for review at the SFWMD headquarters in West Palm Beach, Florida. The 2012 suite of logs are provided in **Appendix B**.

5.2 AQUIFER PERFORMANCE TESTING

Three APTs were conducted in the series of on-site wells to gather data to determine the interaction between the SAS, ICU and UFA. Monitoring zones above and below the tested intervals can be used to estimate the leakance of semi-pervious layers. FPW1 underwent a constant-rate APT for a duration of 136.5 hours. For the first 70.5 hours the well was pumped at a constant rate of 950 gpm and then allowed to recover for the next 66 hours. Water levels were recorded in the remaining 7 wells on-site during the test. Similarly, SPW1 underwent a 72-hour APT with the final 24 hours in recovery. The constant pumping rate for the test was 28 gpm and water levels were recorded in the other on-site wells.

A slug test was performed on HPW1 after the SAS testing was completed. The wellbore was filled with approximately 5 gallons of water, filling the entire borehole and allowed to return to static conditions. An Insitu® MiniTroll data logger unit was installed within the borehole to collect continuous data as the water level returned to background conditions. Data was collected over a 48-hour period. **Figure 10** shows the cross-section of the well configuration.

5.2.1 Upper Floridan Aquifer Performance Test Analyses

SFWMD conducted an APT of FPW1 on November 26, 2001 to determine the hydraulic performance of the UFA interval of FPW1 from 199 to 461 ft bls. This interval included the Ocala Limestone and the upper portion of the Avon Park Formation. This upper producing zone extends from about 237 ft bls to approximately 600 ft bls. FPW1 partially penetrates the production zone, being cased to 199 ft bls and finished at a depth of 461 ft bls. Large diameter wells completed in this zone can yield between 2,000 to 3,000 gpm (Basso, 2003).

The drilling contractor installed a submersible pump in FPW1 and set it at a depth based on the anticipated drawdown in the production well and the static water depth. The wellhead was reinstalled, bolted down and the pump motor wiring was routed to the generator. Discharge was directed towards a nearby retention pond. A pressure transducer was installed for continuous data recording and additional transducers installed in the remaining on-site wells and connected to a Hermit 3000 Insitu® data logger. The transducers and data logger were configured to measure and record water level changes at predetermined intervals during the test.

During the APT, it was assumed that the changes in water level are caused by pumping. Additional stresses may also effect changes in hydraulic head. These can include tidal impacts and changes in barometric pressure. The site is located in central Florida, so tidal impacts are of minimal concern. Barometric pressure was recorded in inches of mercury during the test. An increase in barometric pressure can cause a decrease in water level in wells open to the atmosphere (Clark, 1967). Measurements fluctuated between approximately 29.9 and 30.2 inches mercury. The drawdown induced by pumping in the UFA monitor well FMW1 was significant (22.7 feet). Correcting for barometric fluctuations would have made virtually no impact on results and was therefore excluded for the analyses. **Figure 11** shows the graph of barometric pressure during the pumping phase of the APT.

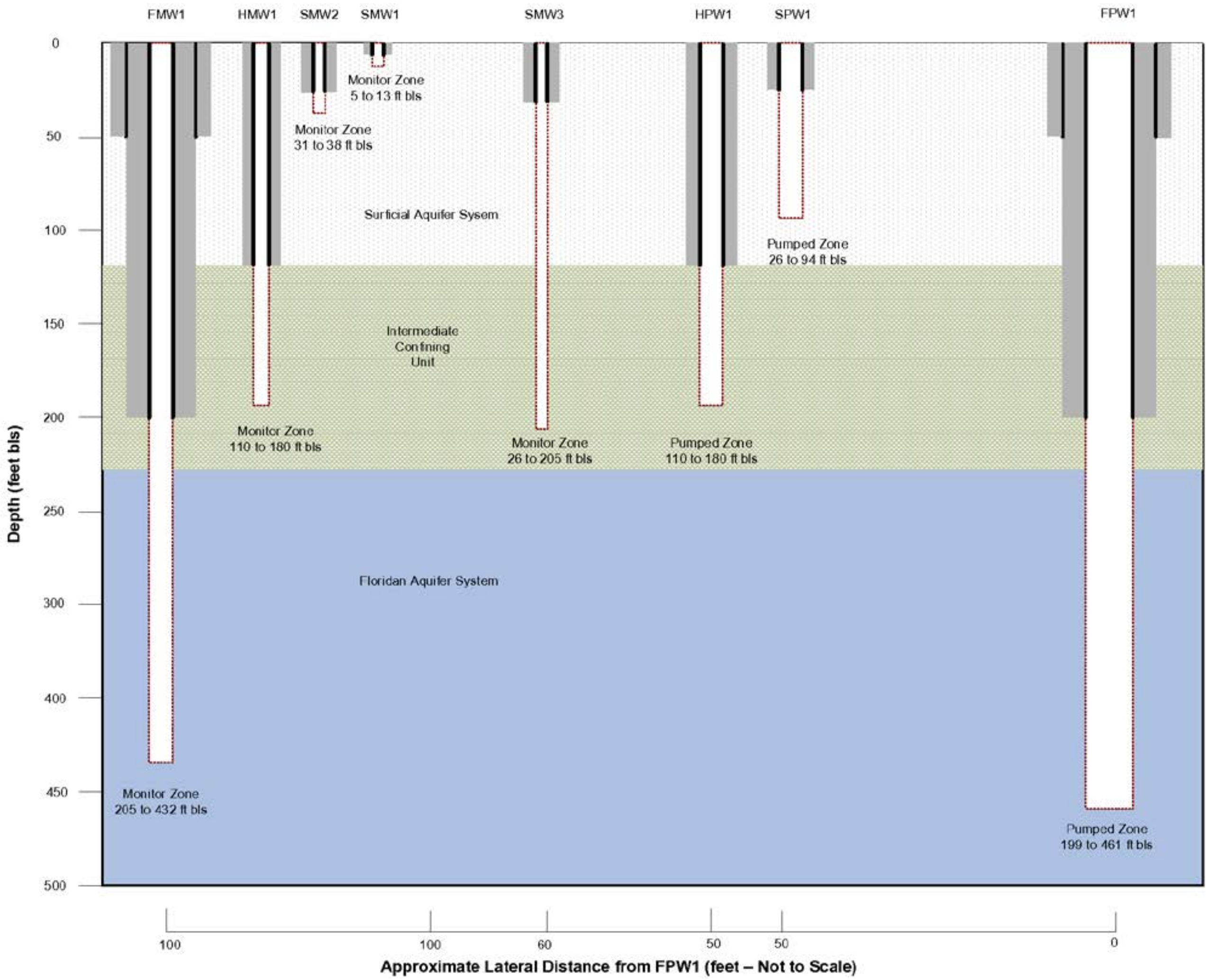

Figure 10. Cross-section of monitor and production wells at the Disney Wilderness Preserve Site.

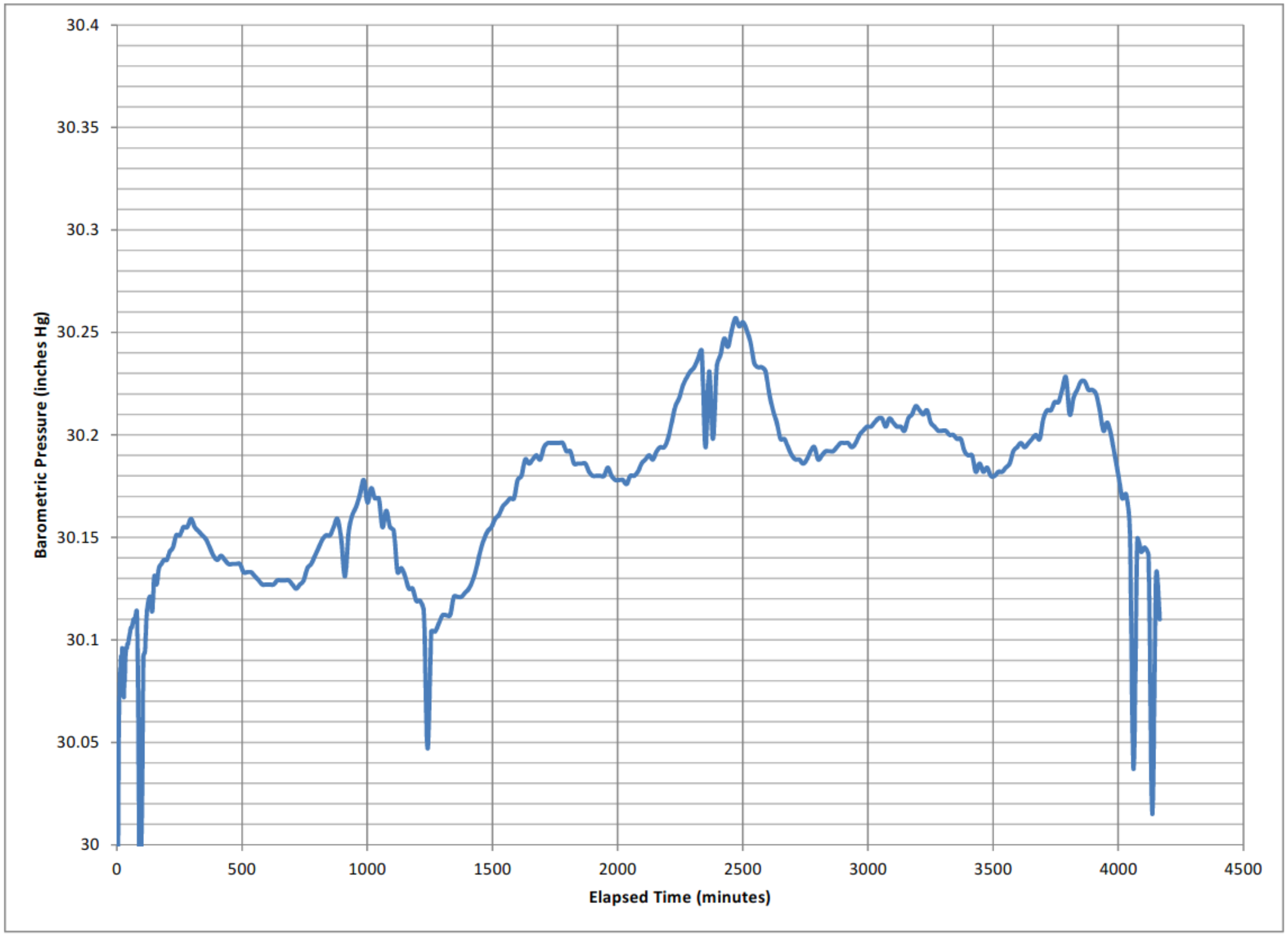

Figure 11. Barometric pressure in inches mercury (Hg) recorded during pumping phase of UFA APT at the Disney Wilderness Preserve Site.

The drawdown phase consisted of pumping water from the UFA via the FPW1 production well at a constant rate of 950 gpm for 70.5 hours while recording water level changes in FPW1 and the remaining seven on-site wells. The drawdown was monitored by the installed electronic devices, which continuously measured and recorded water levels. The pumping phase was followed by a 66-hour recovery phase, where pumping stopped and the water levels returned to background conditions in the production and monitor wells. As the pumping phase came to a close, the data logger was programmed to collect recovery data. Field data collected as part of this test are provided in **Appendix C**.

Figure 12 shows the drawdown in FPW1 and other onsite wells during the pumping phase. Maximum drawdown in FPW1 and FMW1 were 50.5 feet and 22.7 feet, respectively. HPW1 registered a maximum drawdown of 7.1 feet and SMW3 had a maximum drawdown of 24.8 feet. The drawdown in HPW1 is greater than HMW1 because their respective lateral distances from FPW 1 are 50 feet and 100 feet. It is possible the drawdown in SMW3 is greater than the drawdown in FMW1 because it is 40 feet closer to the pumping well and with leakance, there is a dewatering effect in the overlying semi-confining unit within which SMW3 is finished.

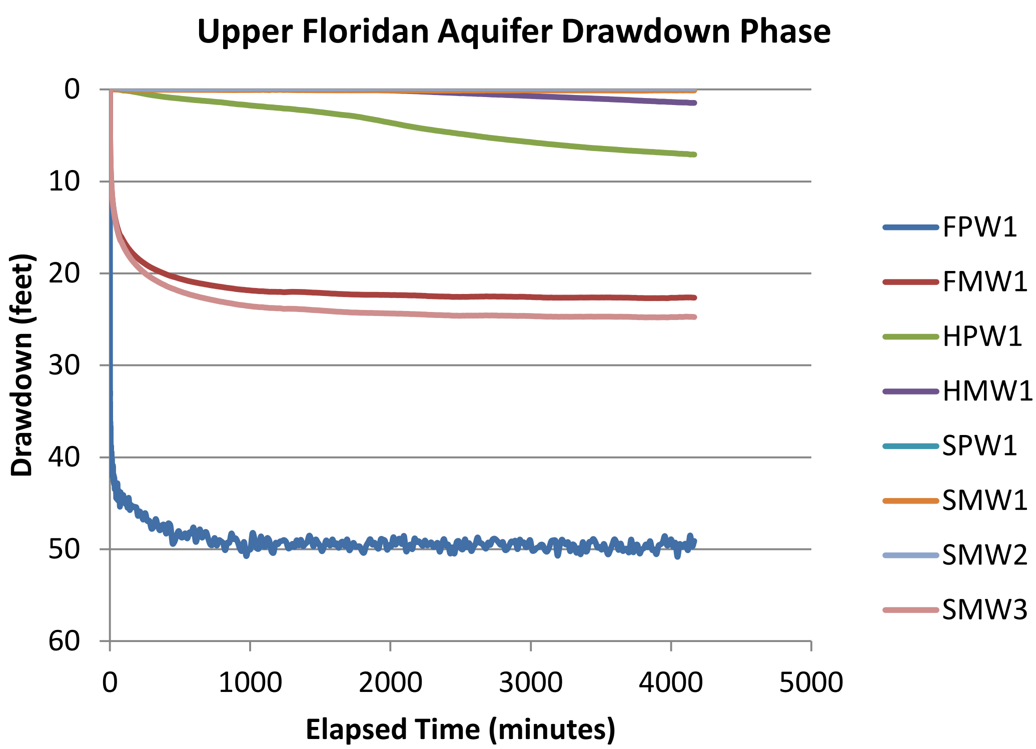

Figure 12. Time series plot of drawdown for the UFA APT at the Disney Wilderness Preserve Site.

Based on the hydrogeologic data collected at the test site, a number of analytical models were applied to the drawdown data collected during the APT to determine the hydraulic properties of the aquifer and the semi-confining unit. Data analyses were computed using AQTESOLV™ software (HydroSOLVE, 2007) for interpretation of aquifer tests.

A diagnostic plot (**Figure 13**) of the drawdown and its derivative for the monitor interval (FMW1) was used to determine the appropriate solutions to apply for analyses. The analytical methods included both confined and semi-confined "leaky" solutions. The confined analytical solutions include the Theis (1935) non-equilibrium method, Cooper-Jacob (1946) approximation and Dougherty-Babu (1984) solution. The semi-confined "leaky" analytical models include Hantush-Jacob (1955), Neuman-Witherspoon (1969) and Moench (1985). The methods referenced are based on various assumptions and the reader is referred to Kruseman and de Ridder (1991) for further details.

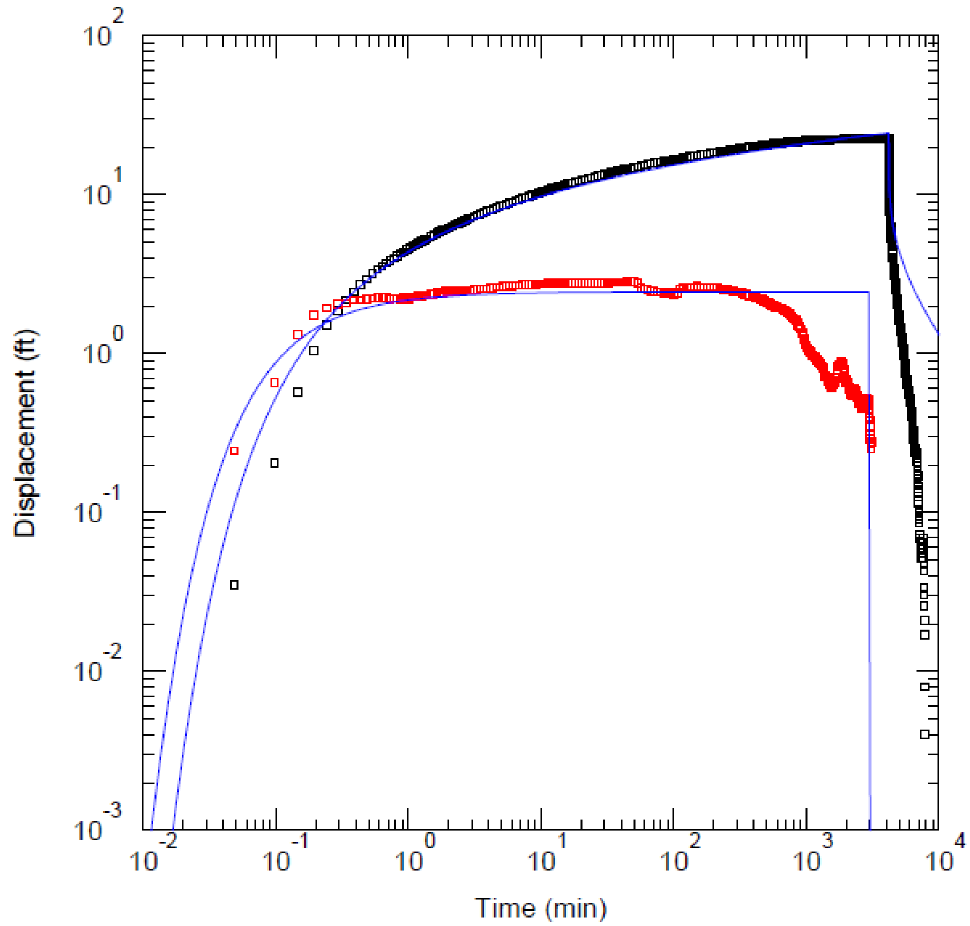

Figure 13. Diagnostic plot of drawdown and derivative (black and red squares, respectively) for FMW1 during the UFA APT.
(Note: ft – feet and min – minutes.)

Theis (1935) developed a method to estimate the hydraulic properties of nonleaky 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 W (μ) (the well function of μ) against the inverse of μ (1/μ). Drawdown versus time data of an observation well is graphed and the two curves are matched. Within the area of overlap, estimations of transmissivity (T) and the storage coefficient (S) are solved. Applying the Theis solution to the field data yielded a transmissivity value of 5,964 square foot per day (ft^2/day) with a storage coefficient of 0.00016. The derivative in the diagnostic plot (red squares in **Figures 13** through **15**) indicates well bore storage and skin effect in the initial moments of the test. Towards the end of the pumping phase, the derivative falls off and tends towards zero. This is interpreted to be a leaky aquifer (Renard et al., 2008).

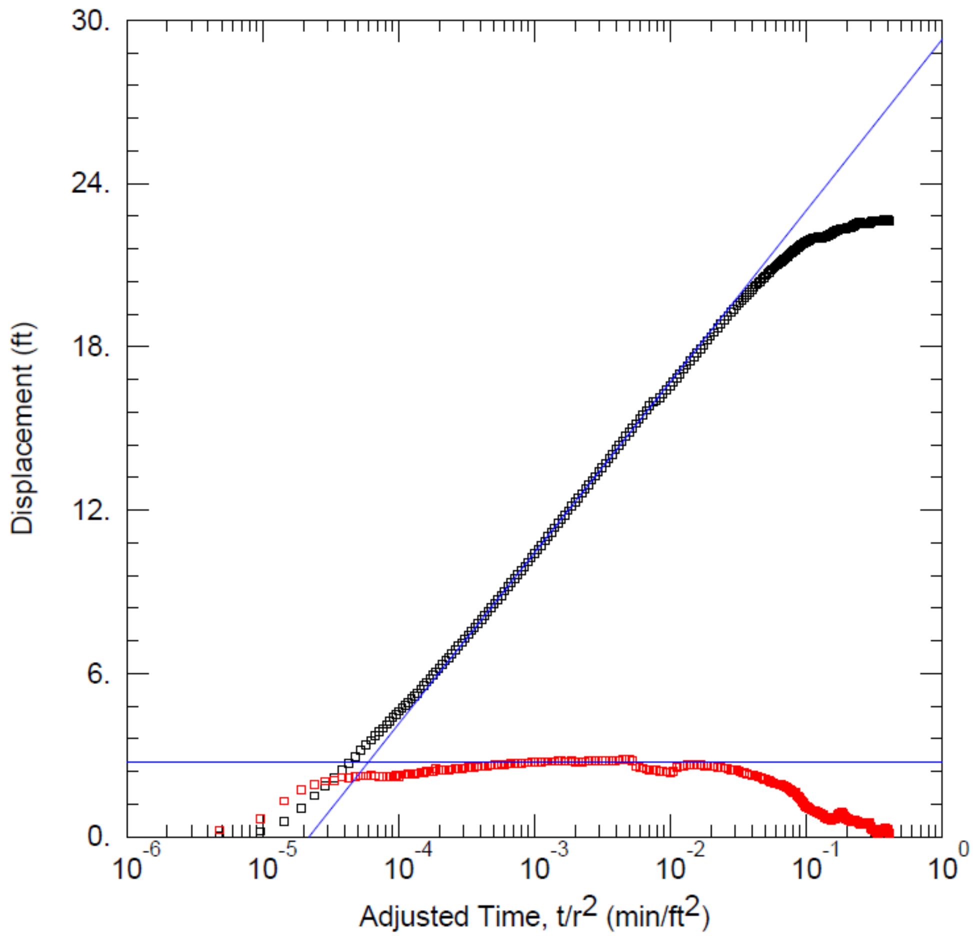

Figure 14. Cooper-Jacob (1946) plot of drawdown and its derivative (black and red squares, respectively) for FMW1, UFA APT.
(Note: ft – feet; min/f^2 – minutes per square foot; and t/r^2 – time per radial distance square)

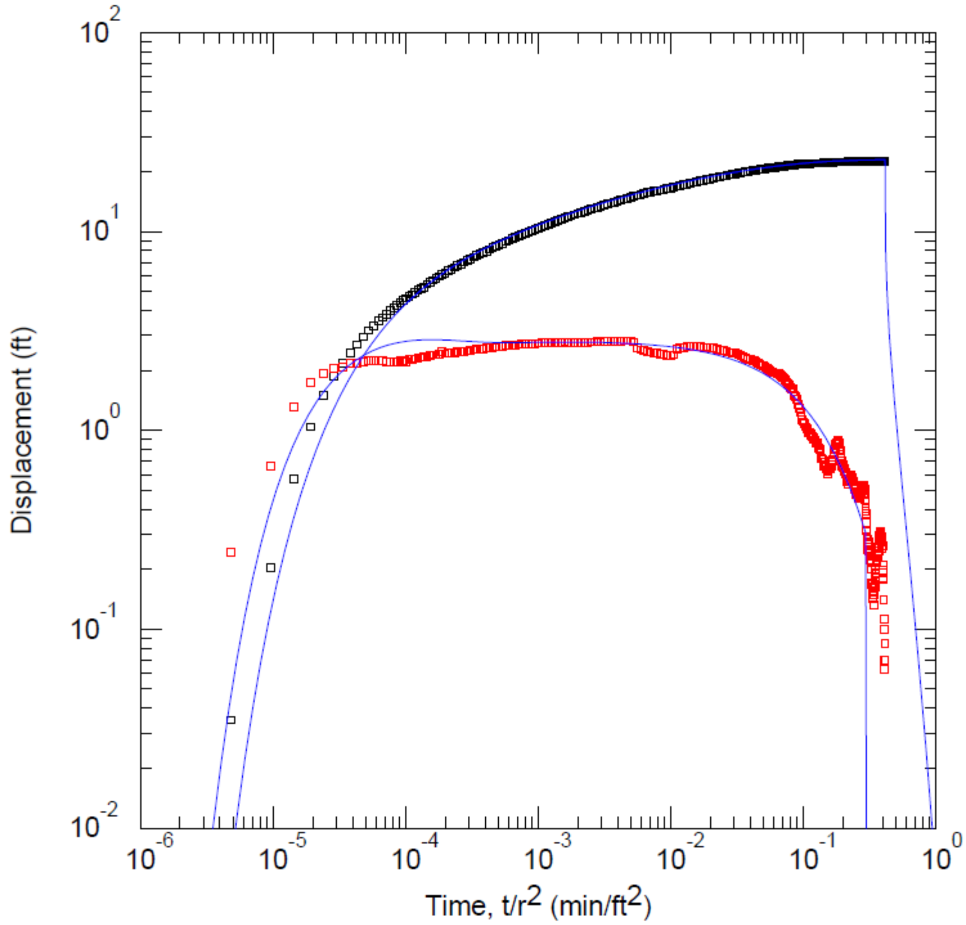

Figure 15. Hantush-Jacob (1955) diagnostic plot (derivative shown as red squares) for FMW1, UFA APT.

(Note: ft – feet; min/f^2 – minutes per square foot; and t/r^2 – time per radial distance square)

Cooper and Jacob (1946) simplified the Theis solution under simplifying assumptions that allowed data to be plotted on semi-logarithmic axes. This produces a straight line during later stages of an APT, given steady-state conditions (rate of drawdown remains constant) and μ is small (ideally less than 0.02). This method is also used to gain preliminary estimates of aquifer properties. The Cooper-Jacob (1946) solution was applied to the field data and yielded a transmissivity value of 5,327 ft^2/day with a storage coefficient of 0.00018. **Figure 14** is the semi-log plot of this solution and its derivative.

The Cooper-Jacob (1946) method is a confined aquifer solution, and in the presence of vertical leakance will tend to over-estimate transmissivity in comparison to leaky-confined analyses. The Dougherty-Babu (1984) solution was of limited value as it did not fit the curve and produced a transmissivity estimate significantly greater than Cooper-Jacob. The standard error results were poor (t-ratio of less than 2).

Semi-confined "Leaky" Analyses

Hantush and Jacob (1955) derived an analytical solution for predicting drawdown in response to a pumped well that penetrates a leaky confined aquifer. The semi-log plot of drawdown and its derivative (**Figure 15**) using this solution can be interpreted as a combination of wellbore storage and an infinite linear constant head boundary (Renard et al., 2008). Other solutions used were Neuman-Witherspoon (1969) and Moench (1985). Both Hantush-Jacob (1955) and Neuman-Witherspoon (1969) assume unsteady state flow to a fully penetrating well, and that the aquifer is homogeneous and has an 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. Analysis using the Neuman-Witherspoon (1969) method did not produce a good curve match. Moench (1985) identified a distinct signature in aquifer response that indicates wellbore storage of a pumped well early on in an APT. However, results of analysis of the drawdown data using this solution did not match the curve adequately to be considered valid.

Analyses of drawdown and recovery data from a single observation well provide estimates of hydraulic properties (**Table 3**). Many type curves share similarities and so do not provide a unique match to any given data set.

Table 3. Summary of analytical results from UFA APT using FMW1 well data.

Solution	Transmissivity of UFA (ft^2/day)	Storativity of UFA	Leakage Coefficient of ICU (per day)
Theis (1935)	5,964	0.00016	-
Cooper Jacob (1946)	5,327	0.00018	-
Hantush Jacob (1955)	5,099	0.00033	0.02669

Of the three solutions, Hantush Jacob (1955) provides the best overall fit for all of the data. The leakage coefficient indicates a good degree of interconnection between the UFA and Hawthorn semi-confining unit.

During the pumping phase of the UFA APT, a maximum drawdown of 7.1 feet was recorded in HPW1. This well is completed in the overlying ICU and is located 50.6 feet away from FPW1. Various "leaky" solutions were applied to the data for analysis including Hantush Jacob (1955), Hantush (1960), Neuman Witherspoon (1969) and Moench (1985). The data did not fit any of these solutions closely except for the Neuman Witherspoon (1969) method. However, the t ratios for the majority of estimated parameters using this solution were below 2, so there is low confidence in the computed estimates. The plot and diagnostic statistics for this analysis are included in **Appendix C**.

5.2.2 Surficial Aquifer APT

The second APT was conducted from December 4 through 7, 2001. The SAS was stressed by pumping SPW1 at a rate of 28 gpm. Data from the production and monitor wells were analyzed to estimate the aquifer properties of the SAS. Again, barometric pressure changes were negligible during both the pumping and recovery phases of the test. **Figure 16** is a plot of the fluctuation in inches of mercury during the pumping phase of the APT.

The data collected during the SAS APT consisted of water levels from the pumped well, SPW1, and monitor wells SMW1 and SMW2. SMW2 showed negligible change in water level. The drop in water level in SMW2 at the end of the drawdown phase was 0.418 feet, and at the beginning of the recovery phase was recorded at 0.931 feet, 47 minutes later. Typically recovery data is analyzed simultaneously with drawdown data. It is not possible to analyze the drawdown and recovery as an integrated whole with such a discrepancy within the data. The drawdown data for the pumping phase was analyzed using Theis (1935) and Cooper-Jacob (1946). No corrections for dewatering are necessary as drawdown is relatively small (0.4 compared to the aquifer's thickness, which is approximately 110 feet). The results of analyses yielded transmissivities of more than double the maximum values reported in the literature (Sprechler and Kroening, 2007). The analyses did not fit the Theis or Cooper-Jacob curves precisely enough to be considered valid. Neuman (1974), Moench (1997), and Tartakovsky-Neuman (2007) solutions are also commonly used for unconfined analysis and these also proved unsuccessful given the data collected. Data were also analyzed from the pumping well (SPW1) drawdown and recovery data. Again, results did not fit any of the above solutions precisely enough to be considered valid. The data for the SAS APT and corresponding analyses are presented in **Appendix C**.

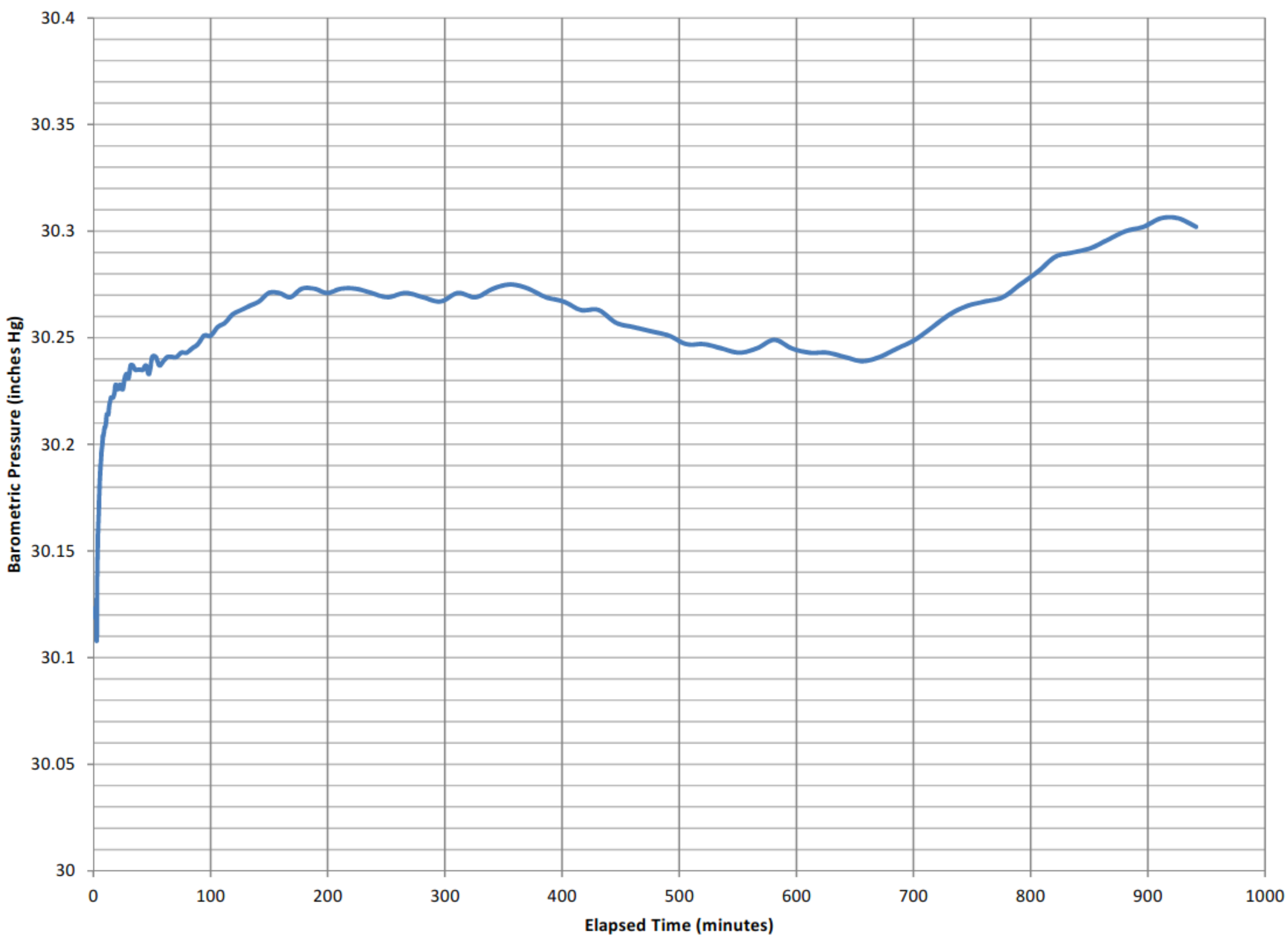

Figure 16. Barometric pressure during the pumping phase of the SAS APT.

5.2.3 ICU Slug Test

On December 3, 2001, SFWMD staff performed a slug test on the Hawthorn well HPW1. Slug testing is generally considered to provide reasonable estimates of the order of magnitude of hydraulic conductivity, but lacks precision (Thompson, 1987). The wellbore was filled with approximately 5 gallons of water to completely fill the borehole and allowed to return to static conditions. An Insitu Mini Troll™ data logger was installed in the well to continuously collect data as the water level returned to background conditions. Data was recorded for a 24-hour period. Different analytical solutions were applied to the data to determine hydraulic conductivity of the ICU. **Figure 17** shows the change in head versus time for the slug test. Field data collected as part of this test are provided in **Appendix C**. Barometric measurements were recorded and no correction was necessary given the insignificant changes.

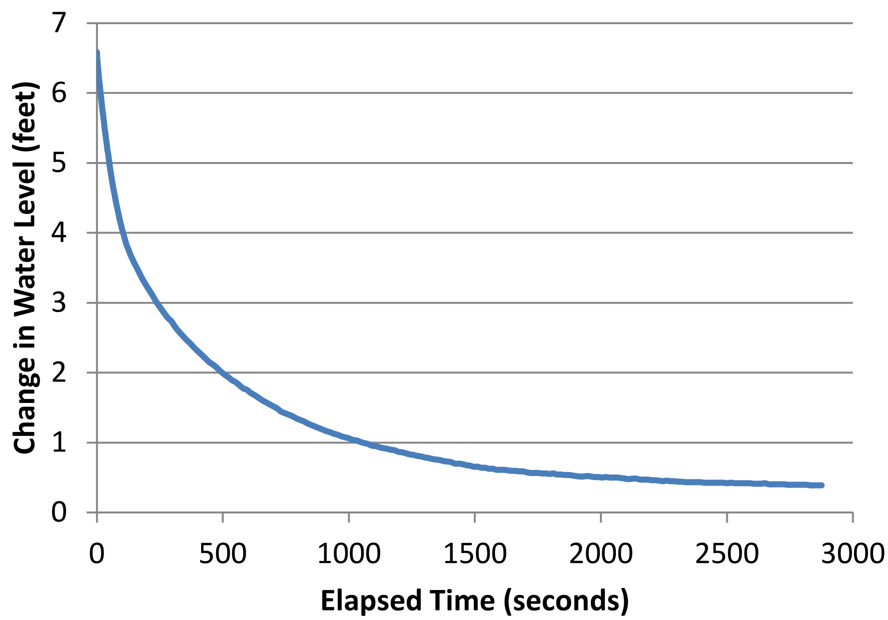

Figure 17. ICU slug test (HPW1).

Bouwer and Rice (1976) developed a method to analyze slug test data and determine the aquifer hydraulic conductivity around boreholes. Wells may be partially penetrating, partially screened, perforated or open hole. The method was originally developed for unconfined aquifers, but can also be used for confined or stratified aquifers if the top of the screen is some distance below the upper confining layer (Bouwer, 1989). Applying the Bouwer-Rice method, the hydraulic conductivity for the ICU around the screened interval of HPW1 (110 to 180 ft bls) is 0.004135 feet per day (ft/day). **Figure 18** is a plot of the HPW1 slug test data with the Bouwer-Rice (1976) best-fit line. The data are matched to the slope of the line between the two dashed lines, which represents the recommended head range. The concave curvature in data from overdampened slug tests can make straight line analyses ambiguous. Butler (1998) developed the straight line matching technique to data within the recommended head range to improve reliability of results.

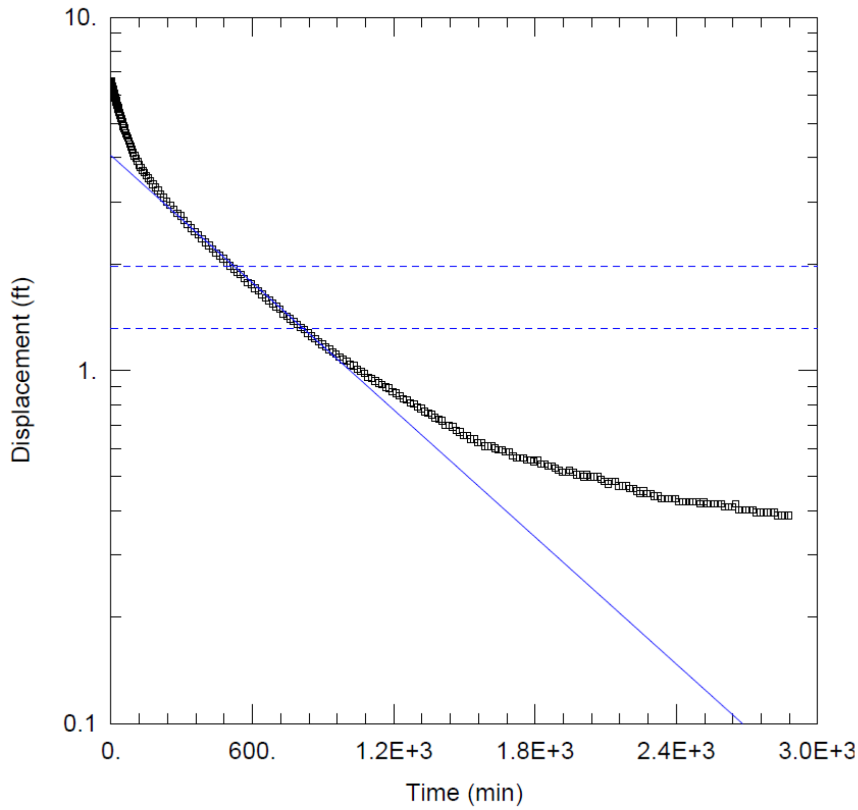

Figure 18. Bouwer-Rice (1976) solution of the HPW1 slug test of the ICU.

The Bouwer-Rice (1976) solution is based on the quasi-steady-state (storage is negligible) slug test model that ignores elastic storage in the aquifer. The Hvorslev (1951) is based on the same assumption and is another straight-line method used to analyze slug tests. Hydraulic conductivity was estimated to be 0.004186 ft/day using this solution (**Figure 19**).

Hydraulic conductivity estimates using both of the above methods were very similar. Hyder et al. (1994) developed an analytical solution known as the KGS Model for slug test analyses. This solution takes into account the skin effect (i.e. the disturbed nature of the drilled borehole wall). In addition to hydraulic conductivity, specific storage is also estimated. The data from this slug test are graphed with the solution in **Figure 20**. Of the three solutions used in the analyses, the best fit for the data is with the KGS Model. Hydraulic conductivity was estimated to be 0.003429 ft/day using this solution.

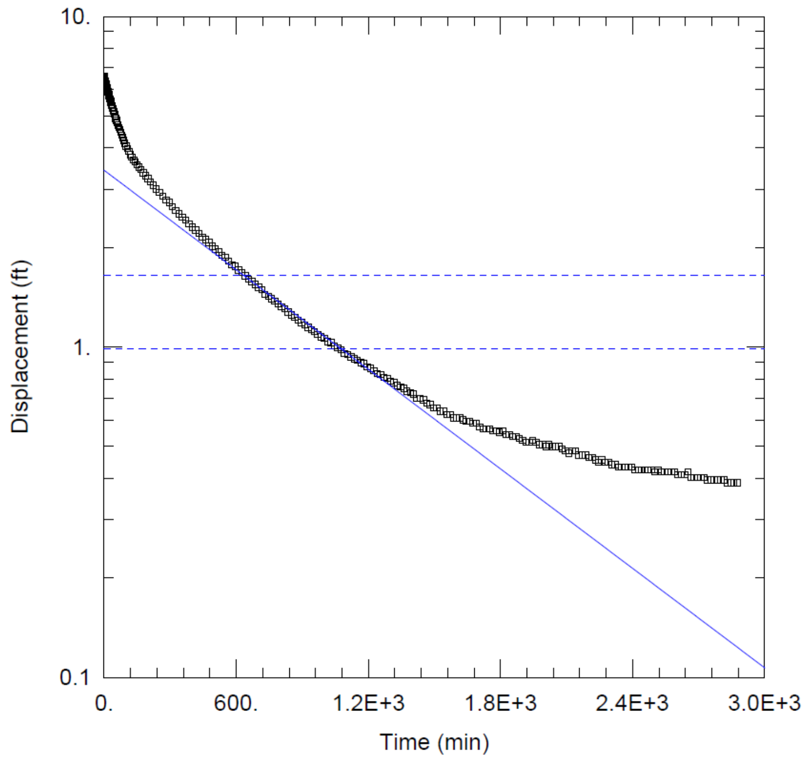

Figure 19. Hvorslev (1951) solution of the HPW1 slug test of the ICU.

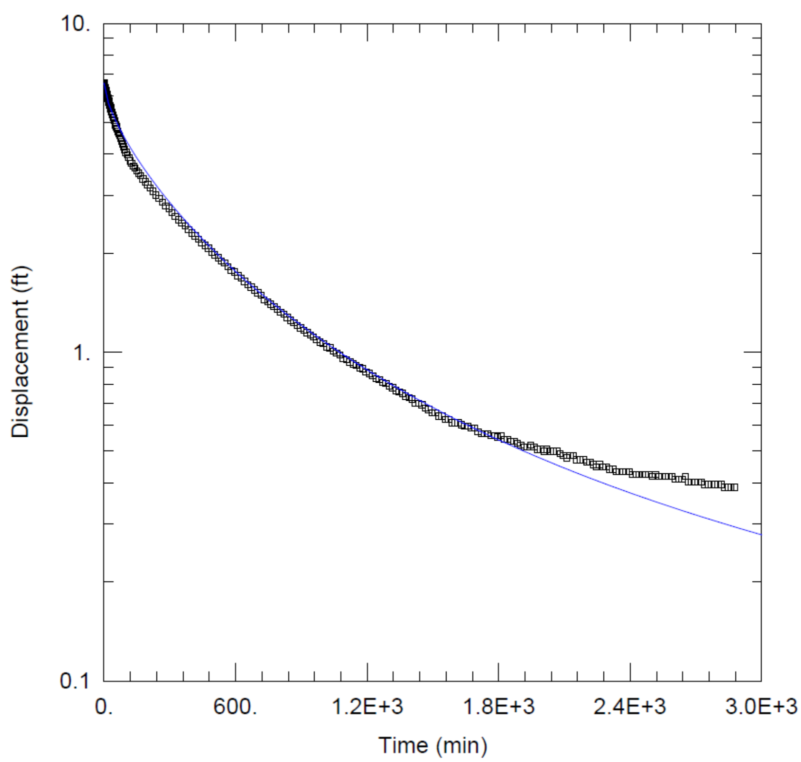

Figure 20. KGS Model of the HPW1 slug test of the ICU.

6
Summary

Lithologic information and geophysical logs obtained from FPW1 indicates that clays, silts and quartz sands, and mudstones of the Hawthorn Group predominate from 120 to 237 ft bls. These ICU sediments separate the SAS from the underlying FAS and are semi-confining. The top of the FAS was identified at a depth of approximately 237 ft bls at this site as defined by Reese and Richardson (2007).

The Theis (1935) solution was used to provide an initial estimate of transmissivity for the FPW1 APT. Cooper Jacob (1946), Dougherty Babu (1984), Neuman Witherspoon (1969), Moench (1985), and Hantush Jacob (1955) solutions were all used for analysis. The latter provided the best fit for the data and the overlying confining unit leakance was computed using this solution. The data used to calculate aquifer hydraulic properties and graphical solutions to the analyses are presented in **Appendix C**. The transmissivity of the UFA of 3,600 ft^2/day reported by Richardson, et al. (2013) was for a slightly deeper interval in this aquifer (300 to 520 ft bls). The site is located approximately four miles away. These factors will contribute to difference in results in this report. A concise summary of the UFA APT results is shown in **Table 4**.

Table 4. Summary of UFA APT results

Test Period	November 26 through 30, 2001
Tested Aquifer	UFA
Tested Interval	199–461 ft bls
Mean Transmissivity of UFA	5,463 ft^2/day
Storage Coefficient of UFA	0.00033
Leakance Coefficient of ICU	0.02669 per day

The data used to calculate aquitard hydraulic properties and graphical solutions to the analyses of the ICU slug test are presented in **Appendix C**. Bouwer-Rice (1976), Hvorslev (1951) and the KGS Model (Hyder et al., 1994) solutions were all used for analysis. The latter provided the best fit for the data. The results fall within the range of values previously utilized in groundwater modeling in this locality and are shown in **Table 5**. Slug testing is generally considered good for providing reasonable estimates of order of magnitude for hydraulic conductivity (Thompson, 1987).

Table 5. Summary of ICU slug test results

Test Period	December 10 through 12, 2001
Tested Aquifer	ICU
Tested Interval	110–180 ft bls
Mean Hydraulic Conductivity	0.0039 ft/day
Specific Storage	0.0005 per foot

7

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Appendix A
Lithologic Field Log

Depth (ft bls)	Lithologic Description	Comments
0–12	Sand, medium grain size, intergranular porosity, organic matter, clay	Some saturation
13–25	Hard pan, well cemented, intergranular porosity, sand	No water
26–30	Sand, light gray color, small grain to silt size	
31–40	As above	
41–50	No sample	Driller reports very little water
51–60	Sand, transparent medium to fine, sub-angular to rounded, poorly indurated	
61–70	Sand, very light gray, microcrystalline to fine, quartz sand 30%	
71–80	Sand, cream color, microcrystalline, to silt, quartz sand 30%	Driller reports water in formation
81–90	As above	
91–100	Sandy clay, silty light gray to blue-green color, 2–3 millimeters sandstone pellets, microcrystalline, poorly indurated, clay	
101–110	Sandy clay, silty, light gray to blue-green color, microcrystalline, poor induration, clay, small pellets of organic matter	
111–120	Sandy clay, silty, light gray to blue-green color, microcrystalline, poor induration, clay, small pellets of organic matter and sandstone, phosphate, shell fragments	
121–130	Clay, sandy, silty, light gray to blue-green color, microcrystalline, poorly indurated, small pellets of organic matter and sandstone, phosphate, shell fragments	Based on gamma and 16-64 induction logs, clay formation starts approximately at 120 ft bls

Depth (ft bls)	Lithologic Description	Comments
131–140	Clay, silt and sand, light to medium gray, indurated, microcrystalline, light brown limestone and 5% shell fragments, phosphate	
141–150	Clay 85%, sand 5%, silt 10%, medium to light gray, indurated, microcrystalline, shell fragments, phosphate	
151–160	Clay, sand, silt, medium to light gray, indurated, microcrystalline, limestone and siltstone, shell fragments, phosphate	
161–170	Clay, silt, shell fragments, light gray indurated, microcrystalline 25% shell fragments with sandstone, phosphate	
171–180	Clay, 50% shell fragments, sand, silt, medium to light gray, 20% shell fragments, phosphate	
181–190	Limestone, medium light gray, clay, 25% shell fragments, phosphate	Based on gamma log, clay unit 120–190 ft bls
191–200	Limestone, shell, sand, silt, medium to light gray, 25% shell fragments, phosphate	
201–210	Limestone, shell, sand, medium to light gray, 10% shell fragments, top of sample limestone, phosphate	Set casing
211–220	As above	
221–230	Limestone, light gray to cream, phosphatic sand. Fragmented at 230 feet, very hard calcite layer	
231–240	Limestone, light to dark gray, soft to hard, phosphatic sand interbedded in limestone.	
241–250	Limestone, light gray to dark gray. Shell fragments 60%	
251–260	Limestone, cream to tan, hard to soft, with 65% shell fragments	
261–270	Limestone, tan to cream, light gray, with cream colored shell fragments 60%	
271–280	As above	
281–290	Limestone, tan to cream, light gray, with cream colored shell fragments 55%, soft to hard	
291–300	Limestone, tan to cream, light gray, with cream colored shell fragments 50%, soft to hard. Echinoids present.	

Depth (ft bls)	Lithologic Description	Comments
301–310	Limestone, tan to cream, light gray, with cream colored shell fragments 55%, soft to hard. Benthic foraminifera, echinoids	
311–320	Limestone, tan to cream, light gray, with cream colored shell fragments 55%, soft to hard. Benthic foraminifera, echinoids, calcilutite. At 318 feet there appears to be a stringer of hard dolostones	
321–330	Limestone, light tan, sandy with forams and echinoids, hard to soft, phosphate?	
331–340	Limestone, light tan, sandy with forams and echinoids, hard to soft, phosphate?	
341–350	Limestone, light tan, sandy with benthic foraminifera and echinoids, hard to soft, phosphate?	
351–360	Limestone, light tan, sandy with benthic foraminifera and echinoids, hard to soft, phosphate?	
361–370	Limestone, light tan to light brown, sandy, 20% benthic foraminifera, echinoids.	
371–380	Limestone, light tan to light brown, sandy, 20% benthic foraminifera, echinoids.	
381–390	Limestone, light tan, sandy with benthic, forams and echinoids, hard to soft, phosphate?	
391–400	Limestone, light tan, sandy with benthic forams and echinoids, hard to soft, phosphate?	
401–410	Limestone, light tan to cream, sandy with benthic foraminifera and echinoids, hard to soft.	
411–420	Limestone, light tan to cream, sandy with forams and echinoids, hard to soft. Larger echinoids	
421–430	Limestone, light tan, sandy with benthic foraminifera and echinoids, hard to soft.	
431–440	Limestone, light tan, sandy, silty with benthic forams, echinoids hard to soft	
441–450	Limestone, light tan and cream, sandy to silty with forams and echinoids, hard to soft, phosphate?	
451–460	As above	

Appendix B
Geophysical Logs

On DVD.

Appendix C
Aquifer Performance Test Data and Analysis

On DVD.