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Attn:	David Rhodes	**Project:**	W-2C ASR Exploratory Production Wells System
From:	Ed Rectenwald	**Job No:**	3220194

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Project Title: **W-2C ASR Exploratory Production Wells**

Document Title: **North-South Transfer Station ASR Well System Completion Report**

December 2009

Certifications

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The engineering features of the W-2C *North-South Transfer Station ASR Well System Completion Report* for the City of Cape Coral, 2009, were prepared by, or reviewed by, a Licensed Professional Engineer in the State of Florida.

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The geological evaluation and interpretations contained in the W-2C *North-South Transfer Station ASR Well System Completion Report* for the City of Cape Coral, 2009, were prepared by, or reviewed by, a Licensed Professional Geologist in the State of Florida.

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GLOSSARY

Term	Definition
als	Above Land Surface
APT	Aquifer Performance Test
ASR	Aquifer Storage and Recovery
ASTM	American Society For Testing And Materials
BDL	Below Detection Limit
bls	Below Land Surface
CFU/100 mL	Coli Forming Units
cm/sec	Centimeters per Second
DDC	Diversified Drilling Corporation
F.A.C.	Florida Administrative Code
FAS	Floridan Aquifer System
FDEP	Florida Department of Environmental Protection
FRP	Fiberglass Reinforced Plastic
ft	Feet
gpd	Gallons Per Day
gpd/ft	Gallons Per Day Per Foot
gpm	Gallons Per Minute
gpm/ft	Gallons Per Minute Per Foot
HDPE	High Density Polyethylene
IAS	Intermediate Aquifer System
IFA/100 mL	Indirect Florescent Antibody per 100 Milliliters
lbs/gal	Pounds per gallon
mgd	Million Gallons Per Day
mg/L	Milligrams per Liter
MPN/100 mL	Most Probable Numbers per 100 Milliliters
MWH	MWH Americas, Inc.
NGVD	National Geodetic Vertical Datum
NSTS	North-South Transfer Station
OD	Outside Diameter
psi	Pounds per Square Inch
PVC	Polyvinyl Chloride
RIDS	Regional Irrigation Distribution System
SAS	Surficial Aquifer System
SFWMD	South Florida Water Management District
SMW	Shallow Monitor Well
SZMW	Storage Zone Monitor Well
TAC	Technical Advisory Committee
TDS	Total Dissolved Solids
TPW	Test Production Well
UFA	Upper Floridan Aquifer
µS/cm	Micro Siemens per Centimeter
USEPA	U.S. Environmental Protection Agency
USDW	Underground Source of Drinking Water
WTMW	Water Table Monitor Well

Executive Summary

This report summarizes the construction of the North-South Transfer Station (NSTS) Aquifer Storage and Recovery (ASR) System. The NSTS ASR System is one of three constructed for the City, each with a 1 million gallons per day storage capacity in the Upper Floridan aquifer. The NSTS ASR System consists of one ASR test production well (ASR TPW), two storage zone monitor wells (SZMW-1 and SZMW-2), and one shallow monitor well (SMW-1R). A summary of the well construction is presented below:

- On May 30, 2007, the Florida Department of Environmental Protection (FDEP) issued Construction Permit No. 247165-001-UC for one Class V, Group 7 ASR injection well with two storage zone monitor wells and one overlying zone monitor well for the NSTS ASR site.

- The ASR TPW was drilled and tested to 1,200 feet below land surface (ft bls). The well was then back plugged to 920 ft bls with neat cement and a 16.60-inch inside diameter fiberglass reinforced plastic (FRP) casing was installed to 800 feet bls.

- Water quality samples were collected at 30-foot intervals in the pilot hole during reverse-air drilling to identify changes in the salinity of groundwater with depth. Water quality of the completed production/storage interval is brackish, and contains chloride and TDS concentrations of approximately 825 mg/L and 1,630 mg/L, respectively.

- Geophysical logs were conducted after each stage of pilot hole drilling, prior to packer testing and before casing installation. The logs provide a continuous record of the geophysical properties of the subsurface formations.

- Packer tests were performed over five selected intervals: 755 to 785 feet, 880 to 910 feet, 998 to 1,028 feet, and 1,070 to 1,200 feet bls within the Upper Floridan Aquifer.

- Rock cores were collected during pilot hole drilling. Core samples were sent to Ardaman and Associates for analysis to determine vertical and horizontal hydraulic conductivity, vertical and horizontal porosity, and specific gravity. Six rock cores were evaluated from the Floridan Aquifer System from the following intervals: 645 to 663 feet, 746 to 764 feet, 839 to 859 feet, 980 to 998 feet, and 1,101 to 1,121 feet bls.

- Acid treatment was completed on the NSTS ASR TPW improving the specific capacity from an initial 5.3 gallons per minute per foot (gpm/ft) at a flow rate of 600 gpm to 9.1 gpm/ft at 1,000 gpm.

- Two wells, SZMW-1 and SZMW-2, constructed to monitor the storage zone, were completed with 6-inch diameter polyvinyl chloride (PVC) casing and open boreholes from 810 to 920 and 800 to 914 feet bls, respectively. Shallow Monitor

Well 1 (SMW-1R), constructed to monitor the aquifer overlying the storage zone, was completed with an open borehole from 445 to 545 feet bls.

- Shallow Monitor Well 1 (SMW-1) was originally completed for use as the shallow monitor well for the NSTS ASR system and was used as a monitoring well during the ASR TPW aquifer performance test (APT). Subsequent to the APT, SMW-1 was plugged and abandoned because of damaged PVC casing. The replacement well, SMW-1R, was completed approximately 20 feet to the east of the original SMW-1 location and to the same specifications as SMW-1.

- Following construction of SZMW-2, a video survey of the well revealed that the well had been short cased by 37 ft. The repair of the well included backfilling the storage zone, back-plugging the casing, milling out the existing PVC casing, and setting the final casing to the FDEP approved depth of 800 ft bls. The well was completed by drilling a 5.5-inch diameter open hole to 914 ft bls. The repaired well was completed on September 11, 2009, which essentially marked the end of the ASR System construction.

- A 72-hour aquifer performance test (APT) was conducted on the completed ASR System on April 3, 2008. The calculated transmissivity of the storage zone was averaged over three pump test analytical solutions. The data collected in SZMW-1 and SZMW-2 during the test resulted in an average transmissivity of 23,000 gallons per day per foot (gpd/ft) for the site.

- The hydrogeologic characteristics and design factors that are considered important to good performance of an ASR system are present at the NSTS ASR site. These success factors include storage zone thickness, Transmissivity, native water quality, confinement, and absence of potential bulk flow zones. These success factors are detailed in Section 5.

- Installation of surface facilities, including treatment and pumping facilities should be completed so that cycle testing can be conducted.

1.0 Introduction

In 2004, the City of Cape Coral selected MWH Americas, Inc. (MWH) as the Program Manager at Risk for the expansion of the Water, Wastewater, Irrigation Facilities, and Phase 2 Utility Extension Services. This Aquifer Storage and Recovery (ASR) well system completion report summarizes the construction and testing of the North-South Transfer Station (NSTS) ASR System permitted under the IRR-2 Work Authorization, designed under the IRR-6 Work Authorization and constructed under the W-2C Work Authorization. This report documents the methods and procedures used during well construction and analysis of testing, as well as conclusions and recommendations for operation.

1.1 Background

The City of Cape Coral is enhancing canal water usage for irrigation water supply by constructing three ASR Systems. The first of these three systems to be constructed is the NSTS ASR System. A vicinity map of the NSTS ASR System is provided as Figure 1-1. A site map showing the location of the ASR test production well (TPW) and associated monitor wells is provided as Figure 1-2. The project site is located adjacent to the North-South Transfer Station at 429 NE 5th Avenue, Cape Coral, Lee County, Florida.

The MWH Facilities Planning Report (MWH, 2004) estimates the average daily irrigation demands at build-out to be 132 million gallons per day (mgd). The reclaimed flows from the three water reclamation facilities (Everest, Southwest, and North Cape) at build-out will be approximately 50 mgd. The permitable withdrawals from the Cape Coral fresh water canal system are estimated to be approximately 47 mgd. The water available from these two sources is approximately 97 mgd, leaving a potential irrigation water source deficit of 35 mgd. Several studies have identified ASR as having a high potential to provide the City with the necessary additional supply of irrigation water (Missimer & Associates, 1989; Dames & Moore, 1998; Camp Dresser & McKee, 2005). Additionally, the City is a stakeholder in a Regional Irrigation Distribution System (RIDS) investigated by the South Florida Water Management District (SFWMD). The RIDS Master Plan for the Lower West Coast area (SFWMD, 2002) and Feasibility Study for the Cape Coral area (SFWMD, 2004) identified significant volumes of surface water and reclaimed water could be available to Cape Coral for ASR wells during the wet season. As such, construction of the ASR facilities was eligible and received funding from the SFWMD Alternative Water Supply Program.

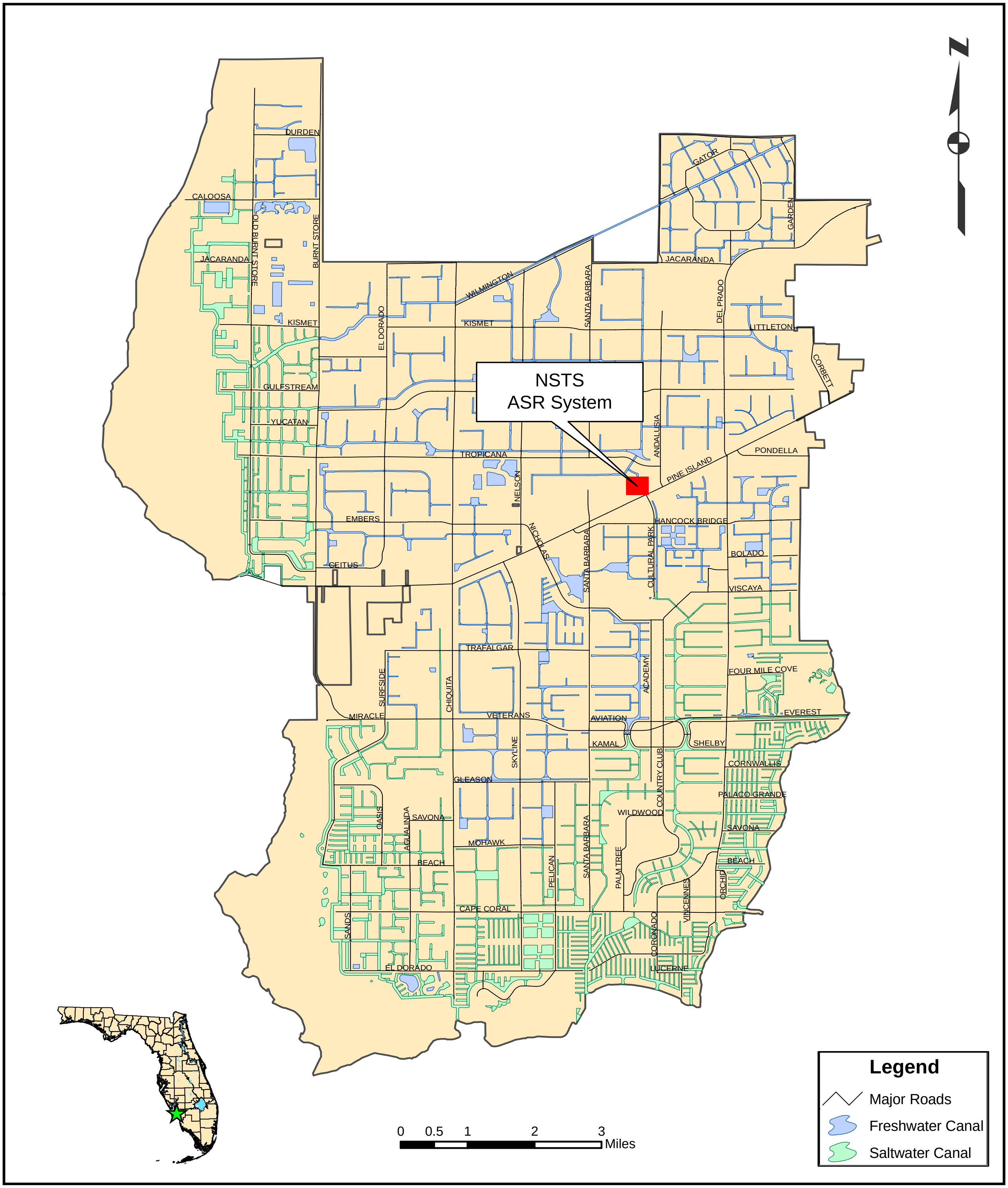

Figure 1-1 NSTS ASR System Vicinity Map

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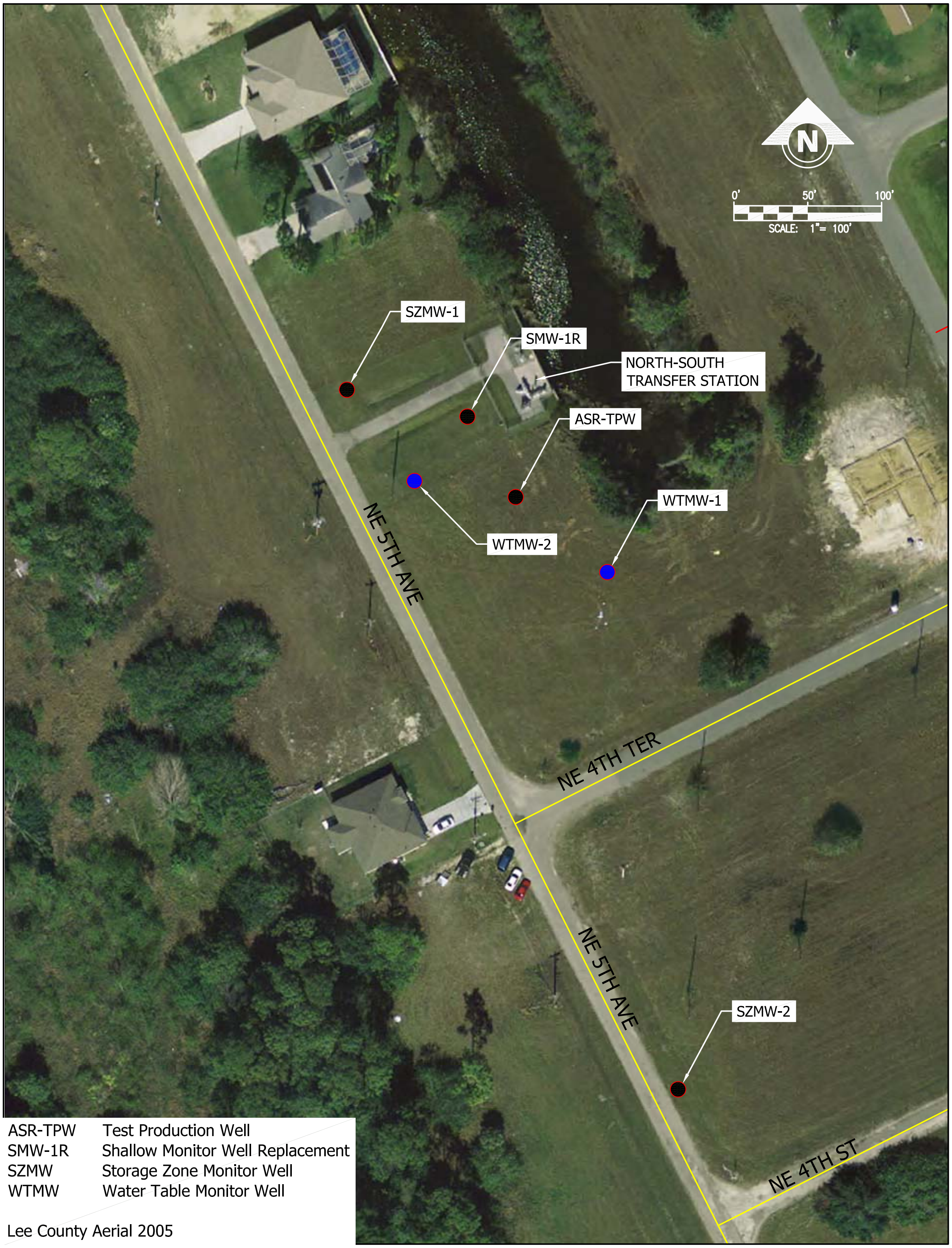

Figure 1-2 NSTS ASR System Site Map

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On May 30, 2007, the FDEP issued Construction Permit No. 247165-001-UC. This permit allowed for the construction of one Class V ASR Well System including the ASR-TPW, two storage zone monitor wells (SZMW-1 and SZMW-2) and one shallow monitor well (SMW-1R). A copy of the FDEP permit is included as Appendix A.

The work was conducted under P.O. No. 081584, Change Order #4, issued by the City on August 10, 2007. The installation of pumps and surface facilities are being designed and installed under the IRR-7 Work Authorization. Cycle testing will be initiated following completion of surface facilities.

The ASR TPW was designed to Class V Group 7 FDEP standards as required by Chapter 62-528.410 Florida Administrative Code (F.A.C.). Fiberglass-reinforced plastic (FRP) casing was used as the final casing to minimize potential problems with corrosion from the stored and recovered water. The ASR storage interval is the Suwannee Limestone of the Upper Florida aquifer located at a depth between 800 and 920 feet below land surface (bls). The ASR TPW was designed and constructed to have an injection and recovery capacity of 1 mgd, approximately 700 gallons per minute (gpm).

1.2 Purpose

The purpose of this report is to document the information obtained during the construction and testing of ASR TPW, SZMW-1, SZMW-2, and SMW-1R at the City's North-South Transfer Station site. The following information is included this report:

- Construction methods
- Description of methods used to analyze the data
- Documentation of the approved casing setting depths for the storage zone and monitoring intervals
- Verification that the ASR TPW is suitable for the designed storage and recovery rates to allow long term operational testing of the well

1.3 Scope of Services

Diversified Drilling Corporation (DDC) of Lehigh Acres, FL, as the contractor, conducted the drilling, construction, and testing activities of the NSTS ASR Well System. MWH was the City's onsite representative, providing construction observation and technical services required to comply with the construction permit.

Weekly reports documenting the construction and testing of the wells were submitted in accordance with Chapter 62-528 F.A.C., to the FDEP, and the Technical Advisory Committee (TAC). Copies of the weekly reports are included in Appendix B. The TAC includes members of local, state, and federal agencies, including state and local representatives of the FDEP, the South Florida Water Management District (SFWMD), and U.S. Environmental Protection Agency. Construction and testing activities were reported in accordance with Specific Condition 14 of the Permit. This final report was prepared as required by Specific Condition 16 of the Permit.

2.0 Geology and Hydrogeology

Lee County is underlain by rocks of Cenozoic age to a depth of about 5,000 feet below land surface (ft bls) (Meyer, 1989). These rocks are composed of carbonates, with minor amounts of evaporates in the lower portion and clastics in the upper portion (Reese, 2000). In this section, the stratigraphy and identified aquifer systems for the NSTS ASR System are described from youngest to oldest in age. Geologic formations were identified based on interpretations of the lithology, geophysical logs and/or video survey descriptions (Appendices B, C and D).

2.1 Geology

Sediments encountered during the construction of the NSTS ASR System range in age from Late Pleistocene to Oligocene. MWH collected geologic formation samples (well cuttings) from the pilot hole during drilling operations and described them based on their dominant lithologic and textural characteristics using the Folk (1980) classification system for carbonate rocks. Detailed lithologic logs for each well are provided in Appendix C. A detailed description of the lithostratigraphy and its relationship to the hydrostratigraphy of the study area is provided below. A stratigraphic and hydrostratigraphic column of the site is shown in Figure 2-1.

2.1.1 Pliocene - Pleistocene Series

The undifferentiated deposits encountered include predominately siliciclastic and carbonate deposits of the Pamlico Sand Formation and the Undifferentiated Fort Thompson/Caloosahatchee Formation. During drilling of the pilot hole, undifferentiated Plio-Pleistocene surficial deposits consisted primarily of unconsolidated sand, marine bivalvia and gastropoda shell, and small percentages of marl. This unit was observed at the NSTS site to a depth of approximately 30 feet bls.

2.1.2 Miocene Series

The Hawthorn Group unconformably underlies undifferentiated Pliocene-Pleistocene deposits, and is a lithologically complex sequence of silt, clay, calcareous clay, dolosilt, quartz sand, phosphate, limestone, and dolomite (Scott, 1988). It is a regional stratigraphic unit of early Pliocene to Miocene age that underlies all of South Florida. The Hawthorn Group is comprised of an upper, primarily clay unit (Cape Coral Member of the Peace River Formation), and a lower, primarily carbonate unit (Arcadia Formation). Locally, the base of the Peace River Formation contains the Lehigh Acres Sandstone Member (Missimer and Associates, 1985). The two formations are separated by a major regional disconformity. At the NSTS ASR site, the Hawthorn Group occurs from approximately 30 to 800 feet bls.

A regional disconformity separates the Peace River Formation from the Arcadia Formation (Scott, 1988, and Cunningham, et al, 2001). The lower 500 feet of the unit consists of 3 to 4 large scale, transgressive-regressive cycles. Each cycle consists of a lower thick limestone unit and an upper mixture of minor carbonate and clastic units (Missimer and Associates, 1985).

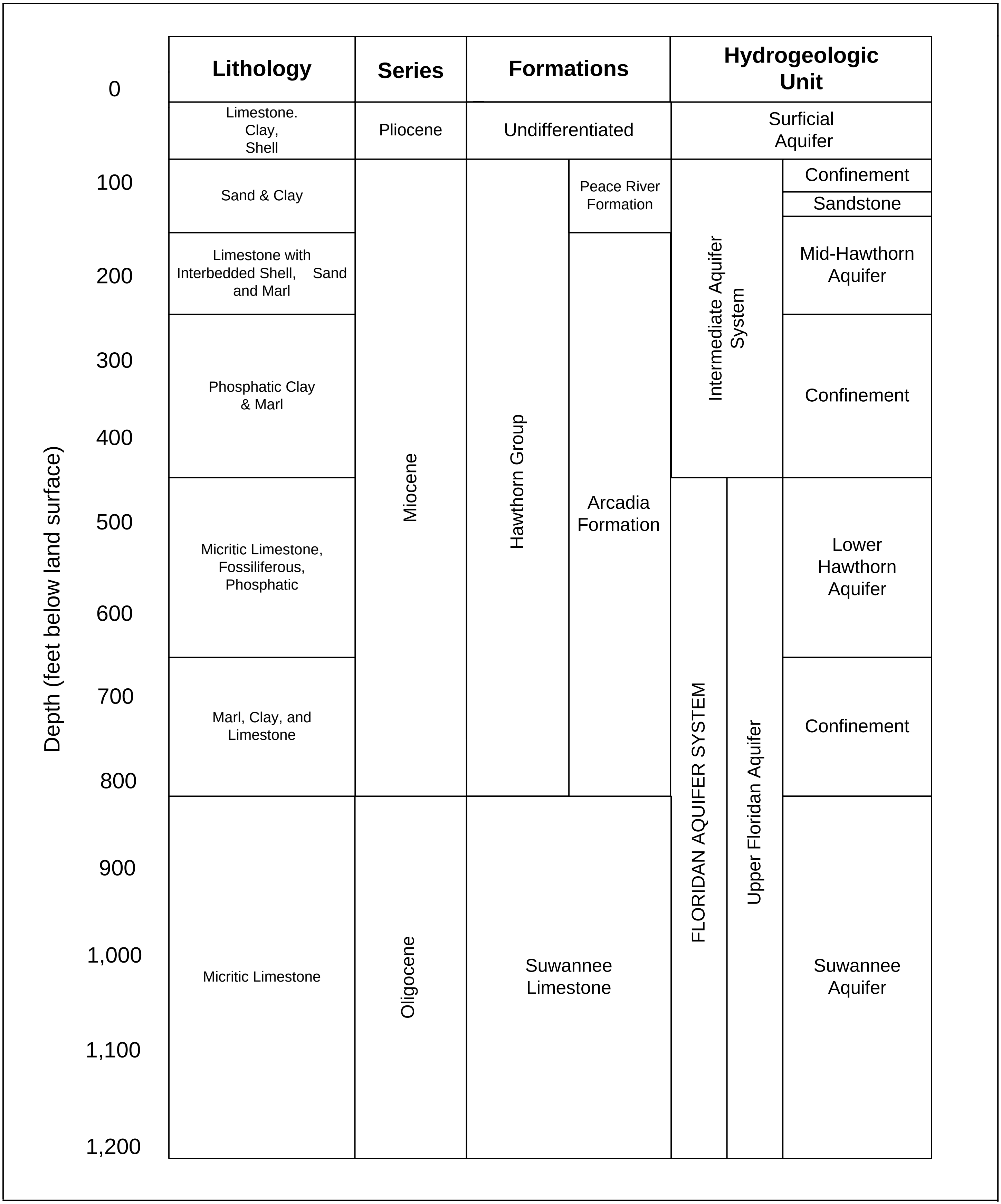

Figure 2-1 NSTS ASR System Stratigraphic and Hydrostratigraphic Column

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2.1.2.1 Peace River Formation

The Peace River Formation of the Hawthorn Group consists of sandstones, sands, sandy limestones, dolomitic clays or dolosilts, and fossilized shell material (Scott, 1988 and Bennett and Rectenwald, 2004). The formation occurs from approximately 30 to 130 feet bls. The Peace River formation has been subdivided into two named members, the Cape Coral Clay member and the Lehigh Acres Sandstone member (Missimer and Associates, 1985).

The Cape Coral Clay is predominantly a greenish gray to dark greenish gray, moderately hard, semi-cohesive clay with trace amounts of silt. This unit occurs from 30 to 70 feet bls.

The Lehigh Acres Sandstone member disconformably underlies the Cape Coral Clay. The Lehigh Acres Sandstone member consists of calcite cemented, fossiliferous, phosphatic sandstones. Minor interbedding with dark greenish gray, phosphatic clay occurs locally. In the study area, this unit is from 100 to 130 feet bls. The Lehigh Acres Sandstone member does not occur throughout the Peace River Formation within the City of Cape Coral, Florida.

2.1.2.2 Arcadia Formation

The lower part of the Hawthorn Group, the Arcadia formation, consists predominately of limestone and dolostone containing varying amounts of quartz sand, clay and phosphate grains. The Arcadia Formation is important from a resource viewpoint as a water supply source for the City of Cape Coral domestic and public water supply users. Several aquifers and confining units are identified within the Hawthorn Group.

The Arcadia Formation occurs from approximately 130 to 800 ft bls at the NSTS ASR Site. The formation is lithologically complex, containing limestone and dolosilt beds of varying thickness. The limestones are light to yellowish gray micrites and biomicrites with moderate to good porosity. The formation is interbedded with yellowish gray marl or lime mud and occasional light olive gray dolomitic silty clay. Phosphate grains are abundant throughout the Arcadia Formation. The base of the Arcadia Formation can be identified by yellowish gray marl, an immediate decrease in phosphate content in lithologic samples, and attenuation of gamma ray activity on geophysical logs. Lithologic logs are available in Appendix C and geophysical logs are available in Appendix D.

2.1.3 Oligocene Series

The top of the Suwannee Limestone of Oligocene Age occurs at 800 ft bls and is present to the total depth of the well at 1,200 ft bls at the NSTS ASR TPW. The contact between the Hawthorn Group and the Suwannee Limestone was identified based on interpretations from the lithology, geophysical logs and video survey descriptions (Appendices C, D and E). A disconformity separates the Hawthorn Group from the Suwannee Limestone (Reese, 2000).

The contact between these two formations in the study area is marked by a change in lithology described as a moderately consolidated limestones interbedded with lime mud or marl. The Suwannee Limestone is typically a very pale orange biomicrite having a medium-grained calcarenitic texture. The unit is composed of moderately to well-sorted foraminifera, pelloids, and abraded echinoderm and mollusk fragments. The contact between the Hawthorn Group and the Suwannee Limestone is also marked by an attenuation of the natural gamma activity, as depicted in the geophysical logs available in Appendix D, primarily because of the decrease in phosphate content in the upper Suwannee Limestone. In addition, the Suwannee Limestone is characterized by higher sonic transit times as compared to the basal facies of the Arcadia Formation.

2.2 Hydrogeologic Framework

Three major aquifer systems underlie the study area of Cape Coral, Florida: the Surficial Aquifer System (SAS), the Intermediate Aquifer System (IAS), and the Floridan Aquifer System (FAS), with the FAS being the focus of this study. These aquifer systems are composed of multiple, discrete aquifers separated by low permeability semi-confining units that occur throughout this Tertiary/Quaternary age sequence.

2.2.1 Surficial Aquifer System

The SAS consists of the water-table aquifer and hydraulically connected units above the top of the first occurrence of laterally extensive and vertically persistent beds of much lower permeability (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986). At the NSTS ASR Site, the SAS occurs within the undifferentiated Plio-Pleistocene water saturated sediments of the Pamlico Sand Formation, and Undifferentiated Fort Thompson/Caloosahatchee strata. The base of the surficial aquifer at the location of the ASR TPW occurs at contact with the Cape Coral Clay Member of the Hawthorn Group at a depth of 30 feet bls. The aquifer is unconfined and in direct contact with atmospheric pressure. Recharge to the aquifer originates principally from rainfall, with some secondary recharge originating from surface water bodies. Discharge from the surficial aquifer occurs mainly through evapotranspiration, drainage to surface water bodies, downward leakance to deeper aquifers, and lateral groundwater flow.

2.2.2 Intermediate Aquifer System

Aquifers that lie beneath the SAS and above the FAS in southwestern Florida are grouped within the IAS (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986). The IAS does not outcrop and contains water under confined conditions (Miller, 1986).

Two productive horizons were identified during drilling and testing operations. The Sandstone Aquifer was encountered from 100 to 130 ft bls and occurs within the Lehigh Acres Sandstone member of the Peace River formation. The aquifer consists of friable sandstone in a calcareous matrix with thin interbedding of cohesive clay towards the base.

The second productive horizon, locally called the Mid-Hawthorn Aquifer, occurs from 130 to 220 feet bls. The Mid-Hawthorn aquifer occurs within limestones in the upper portion of the Arcadia Formation of the Hawthorn Group (Miller, 1986). This aquifer is currently the major source of water supply to residents served by domestic self-supply wells in Cape Coral.

2.2.3 Floridan Aquifer System

The FAS is defined as a vertically continuous sequence of permeable carbonate rocks of Tertiary age that are hydraulically connected in varying degrees, and whose permeability is generally several orders of magnitude greater than that of the rocks that bound the system above and below (Miller, 1986). The system is subdivided into the upper Floridan Aquifer (UFA), middle confining unit and the lower Floridan Aquifer based on hydraulic characteristics. The FAS occurs within the lower Arcadia Formation, Suwannee Limestone, Ocala Limestone, Avon Park Formation, and Oldsmar Formation.

The FAS, as defined by the Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition (1986) coincides with the top of a vertically continuous permeable early Miocene to Oligocene-aged carbonate sequence. At the ASR site, the UFA was encountered from 440 to 1,200 ft bls and chiefly consists of permeable zones in the lower Hawthorn Group and Suwannee Limestone.

Two predominant permeable zones, the Lower Hawthorn and Suwannee aquifers, were identified within the UFA. The productive zones in the upper Floridan aquifer were identified using geophysical logs (i.e. fluid resistivity, flowmeter and temperature), borehole video survey (evidence of vuggy porosity), and packer testing.

The first transmissive horizon includes the lower portion of the Basal Hawthorn Unit (Reese, 2000), and occurs from 440 to 640 feet bls. This aquifer is locally named the Lower Hawthorn aquifer. The predominant lithologies present are interbedded yellowish-gray fossiliferous limestones and light gray dolomitic limestones. The limestones are generally moderately hard and have a moderate to high porosity. The Lower Hawthorn aquifer's dolomitic limestones have a variable texture, are hard, and have good porosities. The Lower Hawthorn aquifer is the major source for public water supply to the residents in Cape Coral, Florida.

The second productive interval within the UFA was identified from 800 to 1,200 ft bls in the Suwannee Limestone. This aquifer is locally named the Suwannee Aquifer. It is overlain by a semi-confining bed approximately 140 feet thick consisting of yellowish gray marls. The Suwannee Aquifer is composed of biomicritic limestones with interbedded marls. The aquifer becomes less permeable with depth because of interbedding and increased lime mud and fine-grained material. The base of the Suwannee Limestone is composed predominantly of moderately hard, low porosity limestones, interbedded with lime mud or marl.

3.0 Well Construction

This section describes the construction activities of the ASR System at the NSTS site. Four wells were constructed for this system; one ASR test production well (ASR TPW), two storage zone monitor wells (SZMW-1 and SZMW-2), and one shallow monitor well (SMW-1R). Locations of the FDEP approved monitor wells are as follows: SZMW-1 is located within 150 feet of the ASR well at nearest property boundary, SZMW-2 is located within 500 of the ASR well and monitors near the edge of the storage zone “bubble”, and SMW-1 is located within the property boundary adjacent to the ASR well and monitors the overlying aquifer above the storage zone. The locations of the wells are shown in Figure 1-2. A summary of the construction activities for each well was prepared in the form of weekly reports. The weekly summaries are provided in Appendix B.

3.1 Site Development

The construction site is essentially flat with elevations varying less than one foot from the average 12.5 feet above the North Geodectic Vertical Datum of 1929 for the site. The boundary surveys are provided in Appendix F.

Two Water Table Monitoring Wells (WTMWs) were installed prior to the start of drilling activities. The WTMWs allowed the collection of samples in order to monitor the water quality of the surficial aquifer during construction and testing of the ASR system. WTMW-1 was located near the southeast portion of Regina Canal south termination point and WTMW-2 was located west of SMW-1R near NE 5th Avenue. The locations of the WTMWs are shown in Figure 1-2 previously presented.

Each WTMW was constructed to a depth of approximately 20 feet bls. The wells were completed with 10 feet of 4-inch diameter 10-slot Schedule 40 polyvinyl chloride (PVC) casing at the base and approximately 10 feet of 4-inch diameter Schedule 40 PVC riser casing from the top of screen to land surface. The annulus of the WTMW’s were backfilled with silica sand to approximately one foot above the screen interval with a bentonite seal above the sand and grouted to land surface.

The WTMWs were developed following their construction. Water quality tests to measure conductivity, chloride, pH, and temperature were conducted to obtain initial background measurements of the parameters. Results were provided as part of the weekly report to the TAC (Appendix B). Figure 3-1 shows a schematic diagram of a typical WTMW.

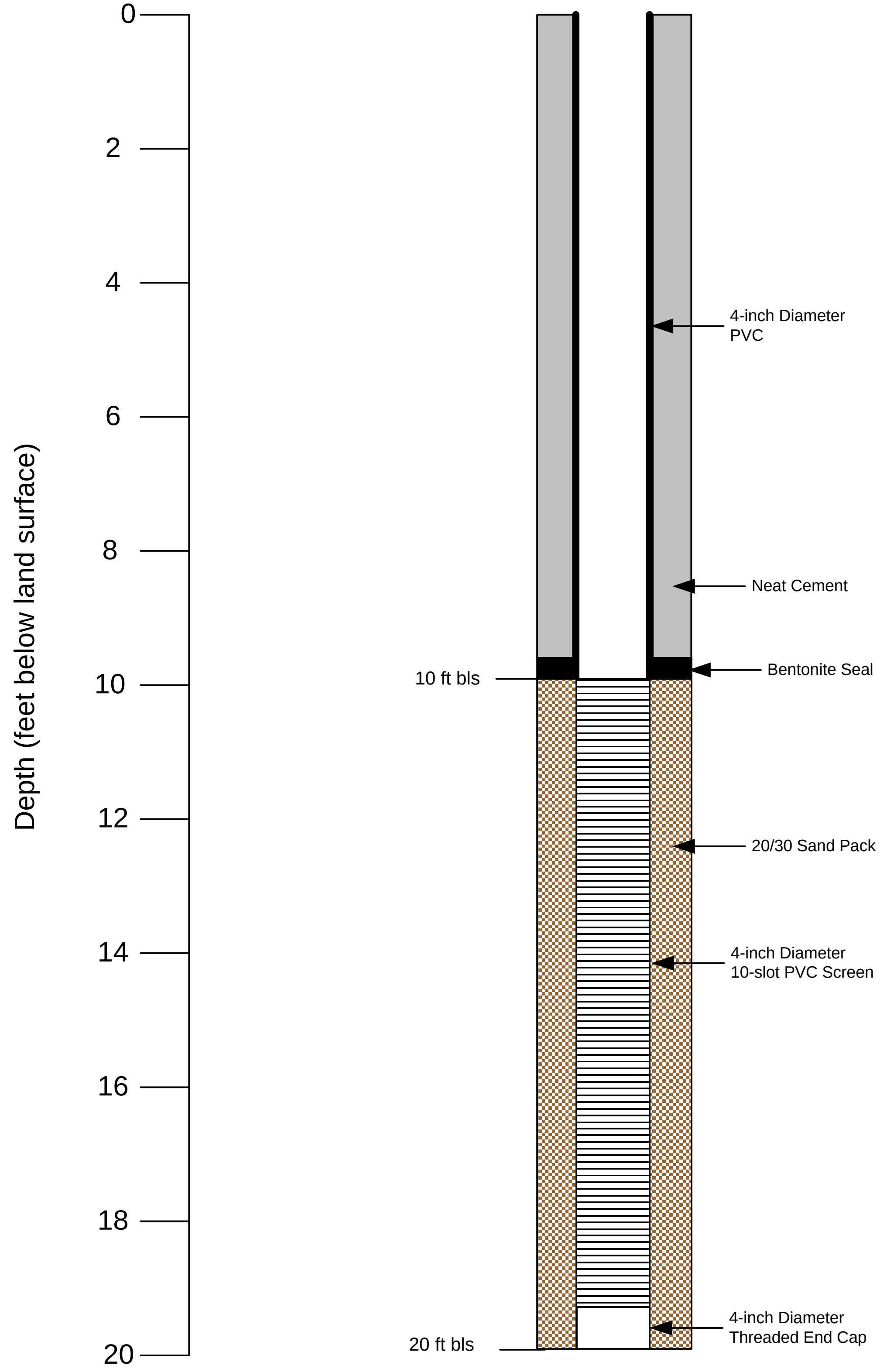


Figure 3-1 Water Table Monitor Well Schematic

3.2 ASR Test Production Well

3.2.1 Containment Pad

A temporary containment pad consisting of a crushed limestone berm approximately 2.5 feet high overlain by high-density polyethylene (HDPE) material was constructed to contain and remove drilling fluids produced during construction activities of the ASR TPW. Following completion of the ASR TPW, the HDPE material and limestone were removed from the site.

The containment pad was designed to protect the surficial aquifer by containing fluid spills and brackish formation water encountered during drilling operations. A pump was installed into the containment pad to remove fluids from the pad to an onsite storage system for transportation to and off-site disposal location approved by the FDEP.

3.2.2 Well Construction

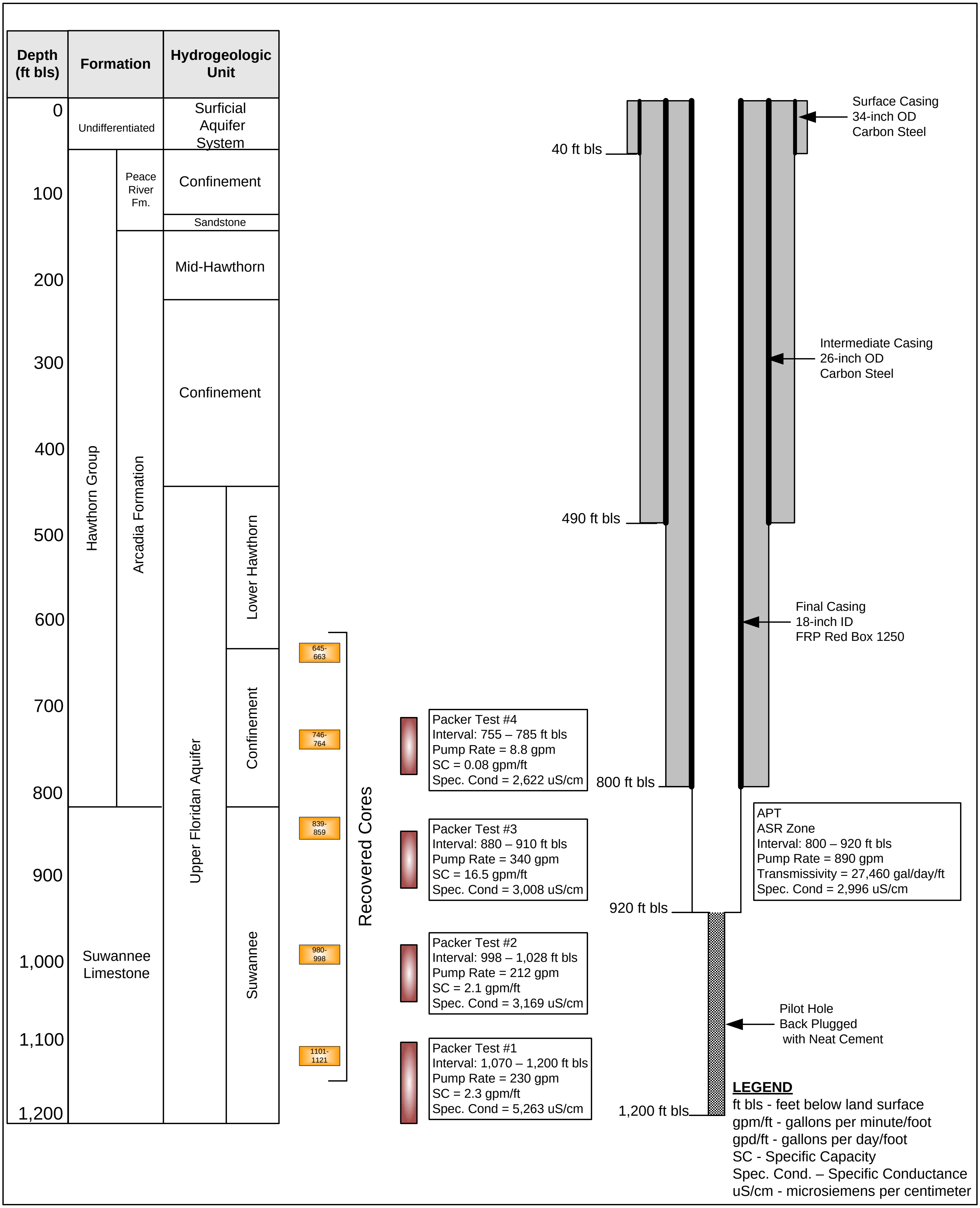
The ASR TPW drilling and construction operations began July 23, 2007 and concluded on June 5, 2008 with the disinfection of the well. Drilling operations were normally conducted 12 hours per day, 5 days per week. A schematic diagram of the completed well is presented in Figure 3-2. An As-Built diagram is available in Appendix G. A detailed summary of well construction and testing activities associated with the ASR TPW is included in Table 3-1.

The surficial aquifer and the upper portion of the Hawthorn Group were drilled using the mud rotary drilling method with bentonite based drilling mud to a depth of 529 feet bls. During mud rotary drilling operations, all drilling fluid was contained in a closed circulation system. Intermediate casing, 26-inch outside diameter (OD) Steel, was set at 490 feet bls. The borehole was drilled through the lower portion of the Hawthorn Group and into the lower portion of the Suwannee Limestone to a total depth of 1,200 ft bls using the reverse air drilling method. The reverse air drilling method allowed for the collection of formation water samples. Following evaluation of potential storage zones, the well was back-plugged with neat cement to 920 ft bls and final casing was set at 800 feet bls.

The diameter of the drill bits used and depths to which the bits penetrated were a function of geology, well design, and regulatory requirements for the project. Extensive sampling and testing was conducted within the borehole to aid in the final design of each well. Specifics of the testing program and data obtained from testing are presented in Section 4.

Table 3-1 ASR TPW Construction Chronology

Start Date	End Date	Description of Activities
7-18-07	7-23-07	Mobilized equipment and prepared site.
7-23-07	7-24-07	Drilled 34-inch diameter borehole to depth of 40 ft bls.
7-24-07	7-24-07	Set and cemented 34-inch outer diameter surface casing.
7-26-07	8-1-07	Drilled nominal 12.25-inch diameter pilot hole to 529 ft bls using direct mud rotary drilling methods.
8-2-07	8-2-07	Conducted geophysical logging suite to 529 ft bls.
8-3-07	8-15-07	Reamed the pilot hole from land surface to 494 ft bls using direct mud rotary drilling methods with a 32-inch diameter drill bit.
8-16-07	8-16-07	Conducted caliper/gamma ray logs to 494 ft bls.
8-16-07	8-16-07	Set and cemented the 26-inch outer diameter intermediate casing to 490 ft bls.
8-31-07	9-28-07	Drilled nominal 9.88-inch diameter pilot hole to a depth of 1200 ft bls using reverse-air rotary drilling methods.
9-10-07	9-10-07	Cored Interval 645 to 663 ft bls – Core #1
9-13-07	9-13-07	Cored Interval 746 to 764 ft bls – Core #2
9-17-07	9-18-07	Cored Interval 839 to 859 ft bls – Core #3
9-21-07	9-21-07	Cored Interval 980 to 998 ft bls – Core #4
9-26-07	9-26-07	Cored Interval 1,101 to 1,121 ft bls – Core #5
10-11-07	10-12-07	Performed constant-rate single packer pump test from 1070 to 1200 ft bls – Packer Test #1
10-19-07	10-20-07	Performed constant-rate straddle packer pump test from 998 to 1028 ft bls – Packer Test #2
10-23-07	10-24-07	Performed constant-rate single packer pump test from 880 to 910 ft bls – Packer Test #3
10-25-07	10-26-07	Performed constant-rate single packer pump test from 755 to 785 ft bls – Packer Test #4
10-31-07	11-2-07	Back plugged pilot hole with grout to 920 ft bls.
11-5-07	11-6-07	Backfilled pilot hole with limestone gravel to 810 ft bls.
11-12-07	11-15-07	Reamed the pilot hole from 490 to 810 ft bls with nominal 25-inch diameter bit using reverse-air rotary drilling methods.
11-16-07	11-16-07	Set bridge plug from 805 to 810 ft bls using 6-cuft silica sand and 8 sacks neat cement.
11-19-07	11-19-07	Conducted caliper/gamma ray logs from 490 to 805 ft bls.
11-19-07	11-27-07	Set and cemented the 18-inch diameter final FRP casing string to a depth of 800 ft bls.
11-29-07	12-4-07	Drilled out cement plug and gravel backfill to 920 ft bls using reverse-air rotary drilling methods.
12-5-07	12-5-07	Conducted caliper/gamma ray and video logs from surface to 920 ft bls.
1-10-08	1-10-08	Performed pressure test on FRP casing.
1-25-08	1-25-08	Pump developed well at 575-600 gpm for 6 hours.
1-28-08	1-28-08	Performed Step Drawdown Test.
2-12-08	2-12-08	Acidized well with 5000 gallons of 20% hydrochloric acid.
2-13-08	3-3-08	Performed post acidization development.
3-6-08	3-6-08	Pump developed well at 1000-1150 gpm for 5 hours.
3-7-08	3-7-08	Performed Step Drawdown Test.
4-3-08	4-8-08	Performed Aquifer Performance Test for 61 hours.
5-24-08	5-24-08	Installed a permanent wellhead assembly.
6-5-08	6-5-08	Disinfected well with chlorine at 150 to 200 ppm



MWH
BUILDING A BETTER WORLD

Figure 3-2 NSTS ASR TPW Schematic and Hydrogeologic Summary

3.2.3 Surface Casing

A 42-inch diameter borehole was initially drilled to a depth of 43 ft bls and 40 feet of 34-inch diameter steel casing was installed and grouted in place. The purpose of the surface casing was to prevent unconsolidated surficial material from collapsing into the borehole during drilling operations, maintain the strength and integrity of the surficial material from the weight and vibration of the drill rig, and to isolate the surficial aquifer from drilling materials and fluids used in the construction of the well.

3.2.4 Pilot Hole Drilling Operations

A 12.25-inch diameter pilot hole was drilled to determine an intermediate casing depth. The drilling of a pilot hole allows better identification of target zones without drilling the final borehole, minimizes attenuation effects of large diameter boreholes on geophysical logs and maintains the vertical alignment of the borehole during reaming activities.

Inclination surveys were conducted on the borehole during both pilot hole and reamed hole operations to ensure the borehole did not deviate significantly from plum and prevent, hinder, or interfere with casing and cement grout placement. Surveys were performed every 60 feet during drilling operations. The survey results were recorded with a Sure-Shot tool. The average inclination during construction of the ASR TPW was 0.51 degrees for the pilot hole and 0.47 degrees for the reamed hole. The results of the inclination surveys conducted during drilling operations are presented in Appendix H.

Lithologic samples were collected at 10-foot intervals and at changes in the lithology during pilot hole drilling operations (Appendix C). Lithologic samples were used to help determine formation changes and the hydrologic and physical properties of the aquifers and are used in conjunction with the geophysical logs to better identify specific hydrogeologic zones.

The 12.25-inch diameter pilot hole was drilled to a depth of 529 feet. Geophysical logging consisted of XY Caliper, Gamma Ray, Dual Induction, Spontaneous Potential, Borehole Compensated Sonic and Video. Geophysical logging is described in Section 4, Data Collection and Analysis. Geophysical logs are available in Appendix D. Descriptions of the video surveys are provided in Appendix E.

3.2.5 Intermediate Casing

The pilot hole was subsequently reamed with a 32-inch diameter two-stage reaming bit to 494 feet bls. A casing justification letter was submitted to the FDEP on August 10, 2007. The justification letter is provided in Appendix B. The 26-inch diameter intermediate steel casing was set at 490 ft bls as approved by the FDEP. Mill certificates for the intermediate casing are provided in Appendix I. Prior to placement of the intermediate casing, geophysical logging was performed consisting of an XY Caliper and Gamma Ray log. The XY Caliper log was used to determine the geometry of the borehole and provide annular volume information for cementing operations. Intermediate casing cementing operations are summarized in Table 3-2.

Table 3-2 ASR TPW 26-inch Steel Intermediate Casing Cement Summary

Date	Stage	Cement Type	Density (lbs/gal)	Total Volume (Barrels)	Total Volume (cubic ft)	Theoretical Tag (ft bls)	Actual Tag (ft bls)
8-16-07	1A	4% Gel	14.1	82	460	-	-
8-16-07	1B	Neat	15.6	43	242	198	116
8-17-07	2	4% Gel	14.1	36	202	land surface	0

lbs/gal –pounds per gallon

3.2.6 Pilot Hole Drilling and Testing

A 9.875-inch diameter pilot hole was advanced from the base of the intermediate casing installation using reverse air drilling techniques. The reverse air drilling method allowed water quality analyses and specific capacity measurements to be performed at approximately 30-foot intervals. Water quality and specific capacity measurements are presented in Section 4.1.5. Excess water produced from the well during reverse air drilling was discharged into Regina Canal. The groundwater produced from the ASR TPW was filtered through three settling tanks and discharged through a silt bag to retain silt-sized particles before entering the canal. In addition, a silt curtain was installed across the canal to provide an additional measure of containment.

On September 4, 2007, Sanders Laboratory of Nokomis, Florida collected groundwater samples from the open hole to fulfill the requirements of the Generic Discharge Permit as required by the FDEP when discharging groundwater into surface water bodies. At the time of sampling, the open hole depth was 531 ft bls or 41 feet below intermediate casing depth. The water produced from the ASR TPW was also sampled and analyzed by Sanders Laboratory 30 days and 6 months after the initial sampling. The results from the Generic Discharge Permit sampling are presented in Appendix J.

Testing conducted on the pilot hole included conventional coring and packer tests. During pilot hole drilling operations, five rock cores measuring 4-inches in diameter were obtained at various depths as shown in Table 3-3. The rock cores were sent to Ardaman and Associates of Orlando, Florida for additional analyses. Results of the analyses are discussed in Section 4. Packer tests were performed within the open hole over four intervals. Analyses of the packer tests are provided in Section 4.

Table 3-3 ASR TPW Rock Core Summary

Core #	**Date Cored**	**Cored Interval** (ft bls)	**Recovered** (ft)	**Recovered** (%)
1	9-10-07	645 – 663	16.0	89
2	9-13-07	746 – 764	13.0	72
3	9-18-07	839 – 859	16.0	80
4	9-21-07	980 – 998	9.4	54
5	9-26-07	1101 – 1121	14.2	71

3.2.7 Back Plugging

The open hole was back plugged from 1200 to 920 ft bls in four stages, with a total of 78 barrels of neat cement as shown in Table 3-4. The open hole was then backfilled with 162 cubic feet limestone gravel from 920 to 810 feet bls, followed by 6 cubic feet of silica sand and 1.5 barrels of neat cement to protect the integrity of the storage zone during reaming operations.

Table 3-4 ASR TPW Back Plug Summary

Date	**Stage**	**Cement Type**	**Density** (lbs/gal)	**Total Volume** (Barrels)	**Total Volume** (cubic ft)	**Theoretical Tag** (ft bls)	**Actual Tag** (ft bls)
10-31-07	1	Neat	15.6	40	224	965	1079
11-1-07	2	Neat	15.6	25	140	958	963
11-2-07	3	Neat	15.6	12	67	936	930
11-2-07	4	Neat	15.6	1	6	927	920

3.2.8 Final Casing

Prior to installation, a final casing justification letter was submitted to the FDEP on November 9, 2007 with a proposed storage zone from 805 to 915 feet bls and confinement analysis. The casing justification letter is provided in Appendix B. The pilot hole was reamed with a 25-inch diameter bit from the base of the intermediate casing (490 ft bls) to 810 feet bls. Following reaming operations, a XY caliper and a gamma ray log were performed to verify the borehole was clear of obstruction and provide annular volume information for grouting operations. On November 19, 2007, the final casing consisting of nominal 18-inch OD FRP, was set at 800 feet bls. The casing was set five feet shallower than the proposed depth of 805 feet bls because the cement bridge plug set shallower than calculated. The FRP is manufactured by Future Pipe Industries of Houston, Texas and a technical specification sheet is provided in Appendix K. The casing was grouted in place in four stages as summarized in Table 3-5. During Stage 1 pressure grouting operations, a secondary pump on the cement pump truck failed. The contractor immediately switched from 4% bentonite cement to neat cement. Pressure in the tremie increased to approximately 1,000 pounds per square inch (psi) and the valve to release the tremie pressure was opened approximately 12 hours later. MV

Geophysical, Inc. performed a temperature log and gamma ray log on the well the following day. MV Geophysical, Inc. hard tagged the cement inside the casing at 755 feet bls. The contractor hard tagged the annular cement at 749 feet bls. These tags indicated that the cement in Stage 1 had u-tubed. The top of the casing cement was six feet above the top of the annular cement. Stages 2, 3 and 4 were tremie grouted without incident.

Table 3-5 ASR TPW Final Casing Cement Summary

Date	**Stage**	**Cement Type**	**Density** (lbs/gal)	**Total Barrels**	**Total cuft**	**Theoretical Tag** (ft bls)	**Actual Tag** (ft bls)
11-20-07	1A	4% Gel	14.1	62	349	-	-
11-20-07	1B	Neat	15.6	14	79	572	749
11-21-07	2	Neat	15.6	108	605	420	393
11-26-07	3	4% Gel	14.1	92	516	95	95
11-27-07	4	4% Gel	14.1	28	157	0	0

3.2.9 Casing Pressure Test

A final casing pressure test, witnessed by FDEP and MWH, was successfully completed on January 10, 2008 on the 16.60 inside diameter FRP casing. The wellhead was sealed at the surface with a temporary wellhead to facilitate the test. The base of the casing was sealed with neat cement from the recently completed casing cementing operations. The well was filled with water and pressurized to 120 psi with a high-pressure pump. During the 60-minute test, the total pressure within the casing did not noticeably decrease as measured by the pressure gauge (total change of 0.0 psi), meeting the test tolerance limit of +/- 5 percent (Table 3-6) per FDEP requirements. A copy of the test gauge calibration certificate is contained in Appendix L.

Table 3-6 ASR TPW Pressure Test Summary

Time	**Total Minutes**	**Pressure** (psi)
1414	0	120.0
1419	5	120.0
1424	10	120.0
1429	15	120.0
1434	20	120.0
1439	25	120.0
1444	30	120.0
1449	35	120.0
1454	40	120.0
1459	45	120.0
1504	50	120.0
1509	55	120.0
1514	60	120.0

3.2.10 Well Development

Once the cement plug and sand were drilled out to 920 feet bls, the well was developed using reverse air near the bottom of the borehole for approximately 3 hours at approximately 200 gpm. Water quality samples were collected and tested for specific conductivity, dissolved oxygen, chloride, pH and temperature approximately every 30 minutes.

Following air development, the well was developed using a submersible pump. Pump development was conducted on the well on January 25, 2008 for approximately six hours at a pump rate of 575 to 600 gpm. Water quality parameters consisting of specific conductivity, dissolved oxygen, chloride, pH, and temperature were measured. Pump Development water quality measurements are available in Appendix M.

3.2.11 Acidization

An initial step drawdown test was completed on January 28, 2008. Specific capacity at the highest pump rate, 600 gpm, measured 5.3 gallons per minute per foot (gpm/ft). The results of the step drawdown test indicated that acidization would have the potential to improve production of the well. A summary of the step drawdown results are provided in Section 4.1.5.

Because of low specific capacity during the initial step drawdown test, acidization of the ASR-TPW was conducted by HydroChem Industrial Services on February 12, 2008. HydroChem Industrial Services provided an acid line to the wellhead and together with the contractor, the necessary volume of water was pumped into the well to lower the hydrochloric acid concentration from 36% to 20%. The open hole section of the borehole was acidified with 5,000 gallons of 20% hydrochloric acid. All pumping associated with well acidization was completed on February 12, 2008. After acidization operations, the well was monitored for unexpected pressure increases that would require action for approximately six hours. No increase in pressure was noted. Pump development to remove the acid began on February 13, 2008 and concluded on March 3, 2008. A total of 199,500 gallons were developed via a submersible pump from the well and removed from the site.

A second step drawdown test was conducted on March 7, 2008 that indicated the production capacity increased to an average of 9.1 gpm/ft at a pump rate of 1,000 gpm. This represents a 70% increase in production, which will reduce drawdown and injection pressures during ASR operation. A description of the methods and summary of the results are provided in Section 4.1.5.

3.3 Monitor Wells

This section of the report describes the construction activities for the three monitoring wells installed at the NSTS site. The purpose of monitor wells is to monitor changes in water quality in the vicinity of the ASR TPW when in operation.

3.3.1 Containment Pads

Temporary steel containment pads were constructed for use during drilling of the monitoring wells, SZMW-1, SZMW-2, SMW-1, and SMW-1R. Following completion of the wells, the containment pads were dismantled and removed from the site.

The containment pads were designed to protect the surficial aquifer by containing drilling fluid spills and brackish formation water encountered during the drilling of the wells. A pump was installed into the containment pads to remove fluids from the pads to an onsite storage system for removal to the approved off site disposal location.

3.3.2 Well Construction

The drilling and construction operations of the monitor wells began September 25, 2007 at SZMW-1 and concluded on June 5, 2008 with the disinfection of all the monitor wells. The locations of SZMW-1, SZMW-2[1] and SMW-1R[2] are shown in Figure 1-2. A summary of well construction and testing activities associated with SZMW-1, SZMW-2 and SMW-1R are included in Tables 3-7, 3-8 and 3-9. Drilling operations were normally conducted 12 hours per day, 5 days per week. Schematic diagrams of the completed wells are included in Figure 3-3. As-Built diagrams are available in Appendix G.

Steel surface casing was installed and grouted in place to the depths indicated in Table 3-10. The purpose of the surface casing was to prevent surficial material from collapsing into the borehole during drilling operations, maintain the strength and integrity of the surficial material from the weight and vibration of the drill rig, and to isolate the surficial aquifer from drilling materials and fluids used in the construction of the well.

The surficial aquifer and the upper portion of the Hawthorn Group at the monitor well locations were drilled using the mud rotary method with bentonite based drilling mud. During mud rotary drilling operations, all drilling fluid was contained in a closed system. The boreholes were drilled to total depth using reverse air drilling techniques. The reverse air drilling method allowed for the collection of formation water samples during the drilling process.

[1] Following construction of SZMW-2, a video survey of the well revealed that the well had been short cased by 37 ft. The repair of the well included backfilling the storage zone, back-plugging the casing, milling out the existing PVC casing, and setting the final casing to the FDEP approved depth of 800 ft bls. The well was completed by drilling a 5.5-inch diameter open hole to 914 ft bls.

[2] Following construction of SMW-1, a video log of the well indicated that the PVC casing had become damaged during final grouting. The well was subsequently back-plugged with 16.5 barrels of neat cement to the surface and abandoned. A replacement well, SMW-1R, was drilled approximately 20 feet to the east of SMW-1 to the same specifications as SMW-1.

Table 3-7 SZMW-1 Construction Chronology

Start Date	End Date	Event
10-15-07	10-15-07	Drilled 34-inch diameter borehole to depth of 38 ft bls.
10-15-07	10-15-07	Set and cemented 34.5 ft of 20-inch diameter steel surface casing.
10-26-07	10-31-07	Drilled nominal 7.88-inch diameter pilot hole to 480 ft bls using mud rotary drilling methods.
11-1-07	11-1-07	Conducted geophysical logging suite to 480 ft bls.
11-2-07	11-13-07	Reamed the pilot hole from land surface to 475 ft bls using mud rotary drilling methods with a 18.75-inch diameter drill bit.
11-16-07	11-16-07	Conducted caliper/gamma ray logs to 475 ft bls.
11-16-07	11-16-07	Set and cemented the 12-inch diameter intermediate casing to 470 ft bls.
11-30-07	1-2-08	Drilled nominal 11.88-inch diameter pilot hole to a depth of 920 ft bls using reverse-air rotary drilling methods.
1-3-08	1-3-08	Conducted geophysical logging suite to 920 ft bls.
1-15-08	1-15-08	Performed constant-rate single packer pump test from 799 to 920 ft bls.
1-22-08	1-22-08	Backfilled pilot hole with limestone gravel to 813 ft bls.
1-23-08	1-29-08	Set and cemented 6.6-inch OD PVC casing to a depth of 810 ft bls.
1-31-08	2-4-08	Drilled out cement plug and gravel backfill to 920 ft bls using reverse-air rotary drilling methods.
3-14-08	3-14-08	Pump developed well at 300 gpm for 5.5 hours.
3-17-08	3-17-08	Performed final geophysical logging suite.
4-3-08	4-8-08	Performed Aquifer Performance Test.
5-14-08	5-14-08	Purge well and collect water samples for Primary and Secondary analysis
5-24-08	5-24-08	Installed a permanent wellhead assembly.
6-5-08	6-5-08	Disinfected well with chlorine at 150 to 200 ppm
7-1-09	7-1-09	Purge well and collect water samples for bacteriological analysis

Table 3-8 SZMW-2 Construction Chronology

Start Date	End Date	Event
9-25-07	9-25-07	Drilled 25-inch diameter borehole to depth of 40 ft bls.
9-25-07	9-25-07	Set and cemented 35 ft of 20-inch diameter steel surface casing.
10-4-07	10-16-07	Drilled nominal 7.88-inch diameter pilot hole to 457 ft bls using mud rotary drilling methods.
10-16-07	10-16-07	Conducted geophysical logging suite to 457 ft bls.
10-22-07	10-24-07	Reamed the pilot hole from land surface to 455 ft bls using mud rotary drilling methods with a 18¾-inch diameter drill bit.
10-29-07	10-29-07	Conducted caliper/gamma ray logs to 455 ft bls.
10-29-07	10-31-07	Set and cemented the 12-inch diameter intermediate casing to 450 ft bls.
11-7-07	11-16-07	Drilled nominal 11.88-inch diameter pilot hole to a depth of 910 ft bls using reverse-air rotary drilling methods.
11-28-07	11-28-07	Conducted geophysical logging suite to 910 ft bls.
12-11-07	12-11-07	Performed constant-rate single packer pump test from 790 to 910 ft bls.
1-3-08	1-3-08	Backfilled pilot hole with limestone gravel to 805 ft bls.
1-3-08	1-14-08	Set and cemented 6.6-inch OD PVC casing to a depth of 763 ft bls.
1-16-08	1-18-08	Drilled out cement plug and gravel backfill to 910 ft bls using reverse-air rotary drilling methods.
3-18-08	3-18-08	Pump developed well at 300 gpm for 5.5 hours.
3-19-08	3-19-08	Performed final geophysical logging suite.
4-3-08	4-8-08	Performed Aquifer Performance Test
5-14-08	5-14-08	Purge well and collect water samples for Primary and Secondary analysis
5-24-08	5-24-08	Installed a permanent wellhead assembly.
6-5-08	6-5-08	Disinfected well with chlorine at 150 to 200 ppm
3-16-09	3-16-09	Report issue with final casing to FDEP
5-28-09	5-28-09	Submit plan for well repair.
7-8-09	7-9-09	Backfill Storage zone with 30/40 Silica Sand
7-9-09	7-9-09	Back-plug PVC casing
7-13-09	7-31-09	Mill out cement and PVC casing to 760 ft bls
8-3-09	8-3-09	Drilled 11.88-inch diameter pilot hole to a depth of 805 ft bls using reverse-air rotary drilling methods.
8-5-09	8-5-09	Conducted caliper/gamma ray logs to 805 ft bls.
8-5-09	8-11-09	Set and cemented 6.6-inch OD PVC casing to a depth of 800 ft bls.
8-13-09	8-13-09	Drilled out cement plug to 807 ft bls using reverse-air rotary drilling methods.
8-13-09	8-13-09	Drilled nominal 5.5 inch diameter pilot hole to a depth of 914 ft bls using reverse-air rotary drilling methods.
8-18-09	8-18-09	Air developed well at 320 gpm for 2 hours.
8-20-09	8-20-09	Pump developed well at 260 gpm for 3 hours.
8-20-09	8-20-09	Sample well for bacteriological water quality parameters.
8-21-09	8-21-09	Performed final geophysical logging video survey to 914 ft bls.
9-8-09	9-11-09	Installed a permanent wellhead assembly.

Table 3-9 SMW-1R Construction Chronology

Start Date	End Date	Event
4-16-08	4-17-08	Drilled 25-inch diameter borehole to depth of 43 ft bls.
4-17-08	4-17-08	Set and cemented 40.5 ft of 20-inch diameter steel surface casing.
4-24-08	5-1-08	Drilled nominal 12.25-inch diameter pilot hole to 446 ft bls using mud rotary drilling methods.
5-5-08	5-5-08	Conducted geophysical logging suite to 446 ft bls.
5-5-08	5-7-08	Set and cemented 6.6-inch OD PVC casing to 445 ft bls.
5-9-08	5-10-08	Drilled nominal 5.25-inch diameter pilot hole to a depth of 545 ft bls using reverse-air rotary drilling methods.
5-13-08	5-14-08	Pump developed well at 270 gpm for 12.5 hours.
5-14-08	5-14-08	Purge well and collect water samples for primary and secondary analysis
4-3-08	4-8-08	Performed Aquifer Performance Test
5-22-08	5-22-08	Unable to perform geophysical logging because of cement obstruction at 445 feet bls.
5-24-08	5-24-08	Installed cement pad and permanent wellhead assembly.
5-28-08	5-28-08	Clear obstruction and performed XY caliper and gamma ray geophysical logs.
5-29-08	5-29-08	Developed well to perform video survey
5-30-08	5-30-08	Unable to perform video survey because of a cement obstruction at 446 feet bls.
6-13-08	6-13-08	Clear obstruction and develop well in preparation for video survey
6-16-08	6-16-08	Performed video survey to 545 ft bls.
7-1-09	7-1-09	Purge well and collect water samples for bacteriological analysis

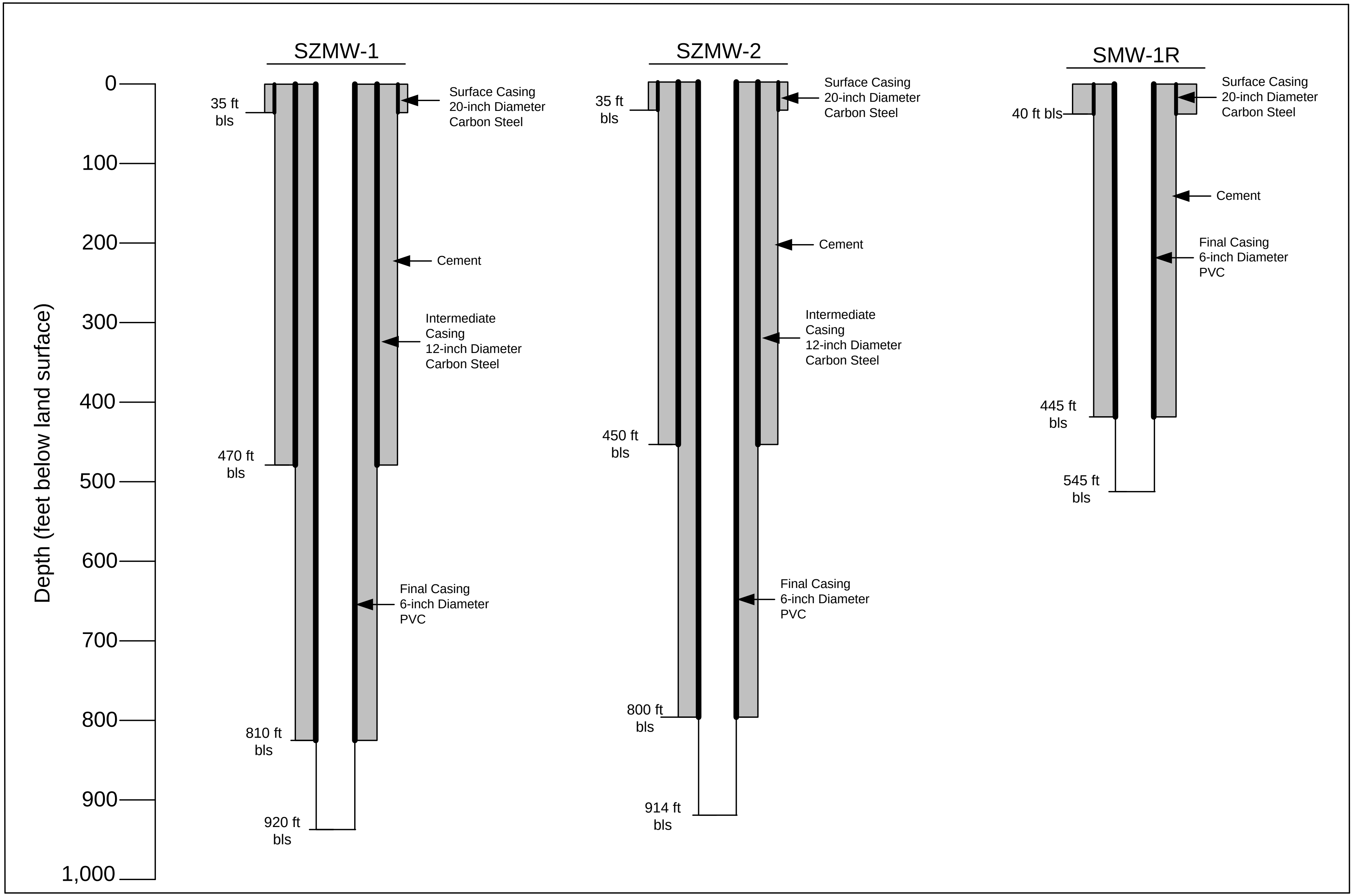


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Figure 3-3 Monitor Wells Schematic Diagram

Table 3-10 Monitor Well Construction Summary

Well	Surface Casing (ft bls)	Intermediate Casing (ft bls)	Final Casing (ft bls)	Total Depth (ft bls)
SZMW-1	35	470	810	920
SZMW-2	35	480	800	914
SMW-1R	40	NA	445	545

3.3.3 Pilot Hole Drilling Operations

A 7⅞-inch diameter pilot hole was drilled to determine an intermediate casing depth for SZMW-1 and SZMW-2. An 11.88-inch diameter pilot hole was drilled to total depth, for SMW-1R. A summary of the total well depths is provided in Table 3-10. The pilot hole was drilled to minimize negative effects of large diameter boreholes on geophysical logs and to maintain the vertical alignment of the borehole during reaming activities.

The diameter of the drill bits used and depths to which the bits penetrated was a function of the geology, well design and regulatory requirements for the project. Extensive sampling and testing were conducted in each borehole to aid in the final design of each well. Specifics of the testing program and data obtained from testing are presented in Section 4.2.

Inclination surveys were conducted on the pilot and reamed boreholes to ensure the boreholes did not deviate significantly from plum and prevent, hinder, or interfere with casing and cement grout placement. Surveys were performed every 60 feet during drilling to record the inclination of the borehole. Vertical drift specifications for the monitor wells required each inclination measurement to be not more than one degree and consecutive survey measurements differed no more than 0.5 degrees. The survey results were recorded with a 7° A-1 Sure Shot vertical drift indicator tool.

The average inclination during construction of SZMW-1 was 0.67 degrees for the pilot hole/borehole and 0.53 degrees for the reamed hole. During the construction of SZMW-1, the inclination survey became out of specification at a depth of 480 ft bls. The measurements was repeated several times to confirm the accuracy of the measurement. A second A-1 Sure Shot tool was brought on site to verify the measurements were accurate. Subsequently, a video survey was performed to determine the cause of the excessive vertical drift. The video survey indicated that a portion of the cement plug from intermediate casing grouting operations had become lodged in the borehole. The contractor was instructed to continue drilling operations with the requirement that inclination surveys for the remainder of the drilling operations be performed at every kelly down (approximately 30-foot intervals) and that the inclination surveys be brought back to specification limits. Inclination measurements returned to specification limits at the depth of 546 ft bls and remained within specifications for the remainder of the borehole. The average inclination during construction of SZMW-2 was 0.54 degrees for the pilot hole/borehole and 0.54 degrees for the reamed hole. The average inclination during construction of SMW-1R was 0.64 degrees for the pilot hole and 0.68 degrees for the reamed hole. The results of the inclination surveys conducted during drilling operations are presented in Appendix H.

Lithologic samples were collected at 10-foot intervals and at changes in the lithology during pilot hole drilling operations. The lithology tables are presented in Appendix C. Lithologic samples were used to help determine formation changes and the hydrologic and physical properties of the aquifers.

It was determined, from the lithology, that casing depths drilled for the monitor wells indicated the composition of the formation was sufficient to support the weight of the casing and provide a good seal with the grout. Geophysical logging, consisting of XY Caliper, Gamma Ray, Dual Induction, Spontaneous Potential, and Borehole Compensated Sonic Log were performed after pilot hole drilling was concluded. Geophysical logging is described in Section 4, Data Collection and Analysis.

The pilot hole for SZMW-1 and SZMW-2 was subsequently reamed with an 18.75-inch diameter two-stage bit from surface casing depths to 476 ft bls and 455 ft bls respectively. Intermediate Casing was set at the FDEP approved depths of 470 ft bls for SZMW-1, and 450 ft bls for SZMW-2. Prior to the placement of the Intermediate Casing, geophysical logging consisting of an XY Caliper and a Gamma Ray log was performed. The XY Caliper and Gamma Ray logs were used to determine the physical properties of the borehole and provide annular volume information for cementing operations.

3.3.4 Open Hole Drilling Operations

After the intermediate casing was set and grouted in place, pilot hole drilling of SZMW-1 and SZMW-2 resumed employing the reverse air drilling method using a 11.88-inch diameter bit. The reverse air drilling method allowed water quality analyses and specific capacity measurements to be taken at approximately 30-foot intervals. Excess water produced from the monitor wells during reverse air drilling was discharged into Regina Canal. The groundwater produced from the monitor wells was filtered through three setting tanks and discharged through a silt bag to retain silt-sized particles before entering the canal. In addition, a silt curtain was installed across the canal to provide an additional measure of containment.

Following the open hole drilling operations at the monitor wells, a geophysical logging suite consisting of XY Caliper, Gamma Ray, Dual Induction, Spontaneous Potential, Borehole Compensated Sonic, Temperature (Static and Dynamic), Flowmeter (Static and Dynamic), Fluid Conductivity (Static and Dynamic), and Video was performed. The geophysical logs are discussed in Section 4.

3.3.5 Packer Tests

Single packer test were performed within the open hole for SZMW-1 and SZMW-2. The packer tests are performed to allow collection of water samples for laboratory analysis and hydraulic characteristics within a discreet interval of the borehole. A single packer test was performed over the interval of 799 to 920 ft bls in SZMW-1 and over the interval of 790 to 910 ft bls in SZMW-2. Water quality laboratory results and analyses of the packer testing data are described in Section 4.

3.3.6 Final Casing

After testing, and upon approval of the proposed monitor zones for SZMW-1 and SZMW-2 by the FDEP, the open holes were backfilled with limestone gravel to 813 ft bls at SZMW-1 and to 805 ft bls at SZMW-2 to protect the integrity of the open hole during grouting operations. Cement baskets were attached to the bottom of the PVC casing and silica sand was placed both within the annulus and within the PVC casing to prevent cement from entering the monitor zones during grouting operations of the final casing. Casing justification letters and proposed monitoring intervals for each of the monitor wells are provided in Appendix B.

The final casing consisted of 6.6-inch OD PVC set in the borehole at the FDEP approved depths of 800 ft bls for SZMW-2 on August 5, 2009 and 763 feet for SZMW-1 on January 22, 2008. Following grouting operations, the sand and gravel backfill were removed with a 5.88-inch bit using the reverse air drilling method to restore the open hole monitor zone portion of the wells. The monitor zone for each SZMW was subsequently air developed and the water quality was tested.

Final casing at SMW-1R, consisting of 6.6-inch OD PVC, was set at 445 ft bls following drilling of a 12.25-inch pilot hole with the mud rotary drilling method to the depth of 446 feet bls. The open hole portion of SMW-1R was drilled with a 5.25-inch bit to the total of depth of 545 ft bls using the reverse air drilling method.

3.3.7 Pump Development

Pump development was conducted upon completion of the monitor wells until the water quality parameters, specific conductivity, dissolved oxygen, pH, temperature and chloride, stabilized. SZMW-1 was pump developed at a rate of 300 gpm for 5.5-hours, SZMW-2 was pump developed at a rate of 300 gpm for 5.5-hours and SMW-1R was pump developed at a rate of 270 gpm for 13 hours. Results of the water quality measurements from pump development are available in Appendix M.

4.0 Data Collection and Analysis

This section describes the hydrogeologic testing for the five wells at the NSTS ASR System: ASR TPW, SZMW-1, SZMW-2, SMW-1, and SMW-1R. Data collection during the drilling and construction of the NSTS Wellfield consisted of formation samples, geophysical logging, water quality sampling, and specific capacity testing. The collected data was used to characterize the lithology, water quality, and hydrogeologic characteristics of the entire ASR System. Cores were taken during drilling operations at selected depths to determine possible storage zones and hydrogeologic properties of the aquifers. Packer tests were performed to determine hydraulic characteristics and water quality of isolated intervals. An Aquifer Performance Test (APT) was performed to measure the hydraulic properties of the ASR System.

4.1 ASR Test Production Well

4.1.1 Lithologic Sampling

Formation cuttings were collected during drilling. Samples were collected every 10 feet from land surface to the total depth of the well. Samples were characterized for rock type, color, consolidation, texture, cementation, hardness/induration, fossil type, and visible porosity/permeability (Folk, 1959). The lithologic samples aided in identifying the contacts between formations, selection of core intervals, selection of packer test intervals, and understanding the overall physical characteristics of formations penetrated by the borehole. Detailed descriptions of the lithology encountered during pilot hole drilling of the ASR TPW are presented in Appendix C.

4.1.2 Rock Core Sampling and Analysis

During drilling of the NSTS ASR TPW, the contractor recovered conventional cores using a 4-inch diameter, 20-foot long, diamond-tipped core barrel. Five rock cores were retrieved between 645 and 1,121 feet bls to aid in the identification of a potential storage zone and for confinement above and below this zone. A summary of the full-diameter coring program conducted at this site is presented in Table 4-1.

Table 4-1 ASR TPW Core Summary

Core No.	Interval (ft bls)	Feet Cored (ft)	Feet Recovered (ft)	Recovery (Percent)
1	645-663	18	16.0	88.9
2	746-764	18	13.0	72.2
3	839-859	20	15.7	78.5
4	980-998	18	9.4	52.2
5	1101-1121	20	14.2	71.0

MWH sent twelve core sections obtained during coring operations to Ardaman and Associates, Inc., located in Orlando, Florida to be tested for the following parameters:

vertical and horizontal hydraulic conductivity, vertical and horizontal porosity and specific gravity. Eight of the twelve samples sent were tested for these parameters.

Hydraulic conductivity and porosity were measured in general accordance with American Society for Testing and Materials (ASTM) Standard D 5084 "Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter" using constant head (Method A). Specific gravity measurements were made in general accordance with ASTM Standard D 854 "Specific Gravity of Soil Solids by Water Pycnometer" using approximately 50 gram specimens ground to pass the U.S. Standard No. 40 sieve. Unconfined compression tests were performed in general accordance with ASTM Standard D 7012 "Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures" using the unconfined test method (Method C). The core analyses results are summarized in Table 4-2. Full laboratory reports from Ardaman and Associates, Inc are available in Appendix N.

Table 4-2 ASR TPW Core Analyses Summary

Core No.	**Sample Depth** (ft)	**Vertical Hydraulic Conductivity** (cm/sec)	**Horizontal Hydraulic Conductivity** (cm/sec)	**Vertical Porosity** (Percent)	**Horizontal Porosity** (Percent)	**Specific Gravity**
1	654.9	$3.9x10^{-8}$	$6.2x10^{-8}$	34.8	34.8	2.77
2	755.3	$1.5x10^{-8}$	$9.3x10^{-6}$	30.7	31.3	2.69
3	842.5	$8.3x10^{-7}$	-	30.6	-	2.70
3	846.8	$2.4x10^{-4}$	$4.6x10^{-4}$	41.1	40.4	2.71
4	982.4	$1.4x10^{-3}$	$5.1x10^{-4}$	43.6	42.1	2.72
4	986.8	$1.2x10^{-3}$	$2.3x10^{-3}$	38.4	38.3	2.70
5	1,105.8	$2.9x10^{-4}$	$2.9x10^{-4}$	45.1	43.0	2.73
5	1,113.2	$3.6x10^{-5}$	$7.8x10^{-5}$	34.3	34.1	2.70

cm/sec- centimeter per second

4.1.3 Geophysical Logging and Analysis

Geophysical logs were conducted in the pilot hole after each stage of pilot hole drilling and reamed hole before casing installation. The logs provide a continuous record of the geophysical properties of the subsurface formations and formation fluids. Analysis of the logs were used to assist in the interpretation of stratigraphy, to provide estimates of permeability, porosity, bulk density, electrical resistivity, and to determine the total dissolved solids of the groundwater (Archie, 1942, Reese, 1994, and Reese, 2000). Geophysical logs are presented in Appendix D.

The geophysical logs were correlated with the lithologic logs to aid in identifying geologic contacts and were used to obtain specific hydrogeologic data pertaining to the formations. The geophysical data, in conjunction with water quality results, step drawdown testing results, and lithologic descriptions were used to determine casing seat depths, packer-test intervals, and to select the storage zone interval.

Geophysical logs were run in the pilot hole, reamed hole, total depth pilot hole, and final open borehole of the NSTS ASR TPW. The geophysical logging sequence during drilling is summarized in Table 4-3.

Table 4-3 NSTS ASR TPW Geophysical Summary

Date	Logged Interval (ft bls)	XY Caliper	Gamma Ray	Spontaneous Potential	Dual Induction	Temperature	Fluid Conductivity	Flowmeter	Sonic with VDL	Video Survey
8-2-07	0-529	X	X	X	X				X	
8-16-07	0-494	X	X							
10-1-07	490-1,200	X	X	X	X	X	X	X	X	X
11-19-07	566-810	X	X							
12-5-07	0-920	X	X						X	

4.1.4 Water Quality Sampling and Analysis

4.1.4.1 Water Quality During Drilling

Water quality samples were collected at 30-foot intervals from the pilot hole during open circulation reverse-air drilling. Sampling started at a depth of 600 ft bls and continued to the total depth of the well at 1,200 feet bls. Samples were collected from the discharge point of the fluid circulation system. The samples were analyzed on-site for dissolved oxygen, temperature, pH, conductivity, and chloride. These data were used to measure water quality relative to depth and identify increased salinity of groundwater with depth if present.

The reverse-air drilling water quality results method provide an indication of water quality trends versus depth. Pilot hole water quality measurements are presented in Table 4-4. Reverse air water quality samples indicate specific conductivity and chloride measurements generally increase with depth.

Table 4-4 ASR TPW Drilling Water Quality

Date	Depth (ft bls)	Specific Conductivity (µS/cm)	Dissolved Oxygen (Percent)	pH (Standard Units)	Temperature (°Celsius)	Chloride (mg/L)
9-05-07	600	2,657	36.2	9.11	29.0	625
9-05-07	630	2,689	40.2	8.75	28.2	613
9-05-07	646	2,884	37.4	8.55	28.8	625
9-12-07	716	3,077	40.3	8.18	28.8	688
9-12-07	746	3,061	43.3	7.88	29.3	738
9-14-07	746	2,993	41.2	7.82	28.9	750
9-14-07	777	3,103	40.4	7.77	30.3	762
9-14-07	808	3,015	28.7	8.21	28.7	738
9-14-07	839	3,054	28.5	8.06	31.2	738
9-19-07	871	2,953	38.6	7.76	28.9	713
9-19-07	902	2,961	42.4	7.77	27.7	750
9-19-07	933	2,880	40.0	7.72	30.1	750
9-20-07	964	2,981	38.0	8.20	28.5	725
9-20-07	980	3,003	51.0	7.68	28.8	725
9-24-07	995	3,053	47.0	7.65	28.6	775
9-24-07	1,025	3,170	46.3	7.92	28.5	812
9-25-07	1,056	3,522	44.6	7.59	28.6	788
9-25-07	1,100	3,172	43..6	7.56	32.3	775
9-27-07	1,119	3,123	44.0	7.69	28.1	825
9-27-07	1,150	3,147	40.5	7.72	28.6	838
9-28-07	1,181	3,206	42.3	7.88	28.2	812
9-28-07	1,200	3,575	40.2	7.91	29.2	900

µS/cm -Micro Siemens per Centimeter
mg/L – Milligrams per Liter
ft bls – Feet Below Land Surface

4.1.4.2 Log Derived Total Dissolved Solids Plot

The Sonic porosity and Dual Induction log resistivity were used to calculate a log-derived Total Dissolved Solids (TDS) plot for the ASR TPW based on the method developed by Callahan (1996) and using empirical data from South Florida compiled by Reese (1994).

The log derived TDS ranged from approximately 800 to 8,000 milligrams per liter (mg/L) increasing with depth (Figure 4-1). The plot indicates that the base of the Underground Source of Drinking Water (USDW) occurs below the depth of 1,200 feet bls. The accuracy of the calculated plot is supported by similar TDS concentrations obtained during packer testing.

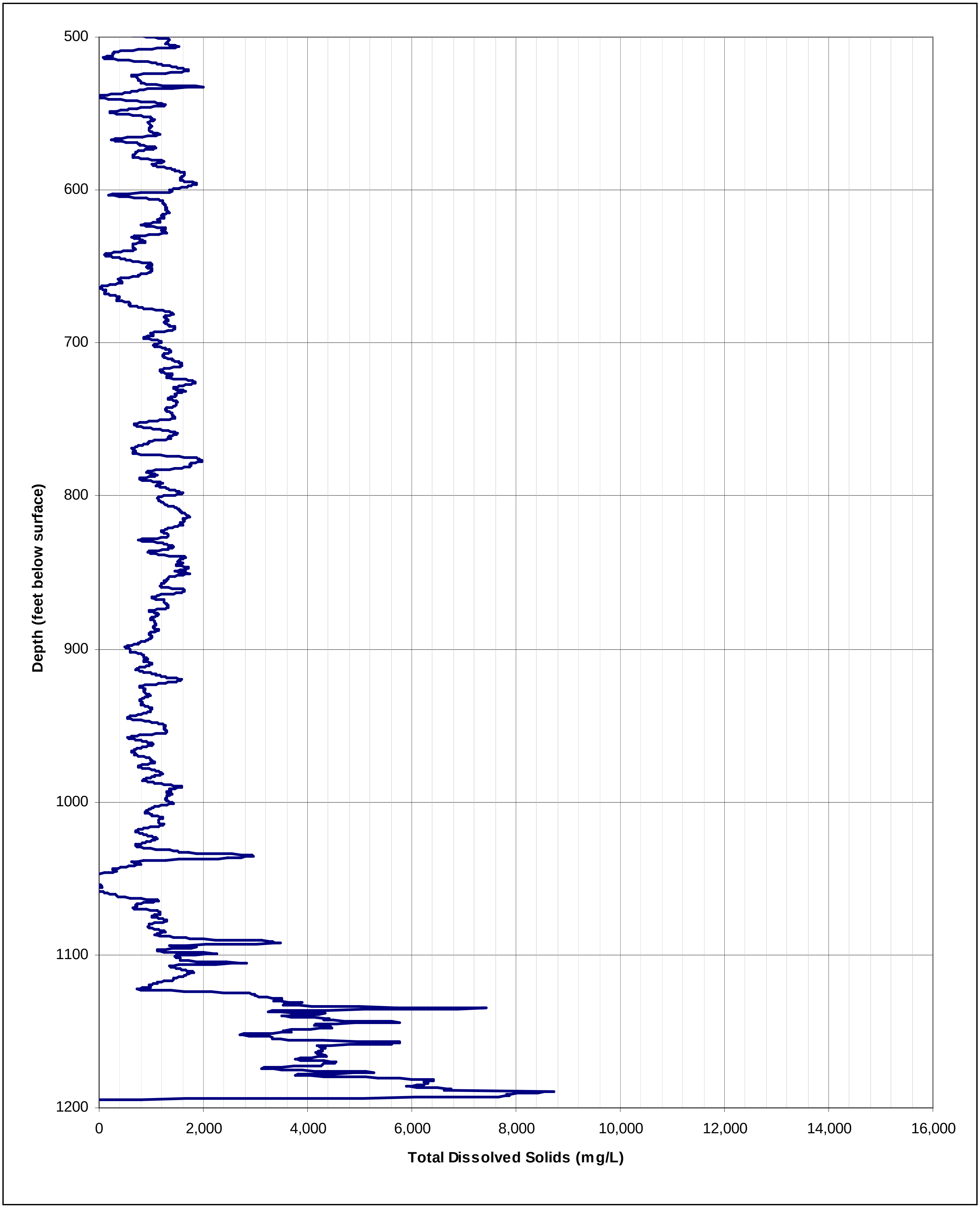

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Figure 4-1 Log Derived Total Dissolved Solids Plot for ASR TPW.

4.1.4.3 Storage Zone Background Water Quality

After construction activities were finished for the ASR TPW, the completed well was developed by evacuating at least three well volumes of water from the well and the chloride concentration, temperature, pH, and specific conductivity measurements stabilized. Water samples from the ASR TPW were collected for analysis by Sanders Laboratories, Inc. on April 3, 2008. The samples were analyzed for primary and secondary drinking water standards and minimum criteria parameters using EPA and/or Standard Method procedures. Results of primary, secondary, bacteriological, and radionuclide water quality parameters are listed in Table 4-5. The volatile and synthetic organics analyses resulted in below detection limits (BDL) and are not listed in Table 4-5. The complete laboratory results are available in Appendix O.

Table 4-5 ASR TPW Completed Water Quality Results

Type	Parameter	ASR TPW (800 – 920 ft bls)
Primary Inorganic	Antimony (mg/L)	0.002
	Arsenic (mg/L)	BDL
	Asbestos	Not Analyzed
	Barium (mg/L)	0.031
	Beryllium (mg/L)	BDL
	Cadmium (mg/L)	BDL
	Chromium (mg/L)	BDL
	Cyanide (mg/L)	BDL
	Fluoride (mg/L)	1.2
	Lead (mg/L)	BDL
	Mercury (mg/L)	BDL
	Nickel (mg/L)	0.001
	Nitrate (mg/L)	BDL
	Nitrite (mg/L)	BDL
	Total Nitrate, Nitrite(mg/L)	BDL
	Selenium (mg/L)	BDL
	Sodium (mg/L)	362
	Thallium (mg/L)	BDL
Secondary Inorganic	Aluminum (mg/L)	<0.009
	Copper (mg/L)	BDL
	Chloride (mg/L)	825
	Iron (mg/L)	0.184
	Manganese (mg/L)	0.003
	Silver (mg/L)	0.001
	Sulfate (mg/L)	271
	Color (Platinum-Cobalt Color Units)	5
	Odor (threshold odor number)	1.4
	pH (standard units)	7.87
	Total Dissolved Solids(mg/L)	1,630
	Zinc (mg/L)	0.001
	Foaming Agents (mg/L)	0.090
Bacteriological	Total Coliform (CFU/100ml)	BDL
	Enterococci (MPN/100ml)	BDL
	Cryptosporidium and Giardia (IFA/1L)	BDL
Radionuclide's	Gross Alpha (picocuries per liter)	12 ±2.6
	Radium-226 (picocuries per liter)	3.3 ±0.2
	Uranium (micrograms per liter)	BDL

mg/L -milligrams per liter

4.1.5 Hydraulic Testing and Analysis

4.1.5.1 Specific Capacity Testing while Drilling

Specific capacity testing was performed at 30-foot intervals in the pilot hole during reverse-air drilling. Testing began at a depth of 746 ft bls and continued to the total depth of the well at 1,200 feet bls. Drilling operations were halted while each test was conducted. The well was allowed to recover to determine static water level in the pilot hole. During the test the flow rate and drawdown were measured. The resultant specific capacity measurement is an indication of the flow at that depth in the pilot hole, relative to the rest of the pilot hole. Results of the specific capacity with depth are provided in Table 4-6. Specific Capacity measurements from the ASR TPW during drilling operations show a gradual increase in productivity with depth.

Table 4-6 ASR TPW Specific Capacity During Drilling Operations

Depth (ft bls)	**Static Water Level** (ft als)	**Flow Water Level** (ft als)	**Drawdown** (feet)	**Pump Rate** (gpm)	**Specific capacity** (gpm/ft)
746	27.2	3.0	24.2	800	33.1
777	20.9	3.0	17.9	800	44.7
808	21.1	3.0	18.1	878	48.5
839	20.6	3.0	17.6	973	55.3
871	20.4	3.0	17.4	900	51.7
902	22.4	3.0	19.4	1090	56.2
960	23.7	3.0	20.7	1090	52.7
995	21.6	3.0	18.6	1125	60.5
1,025	24.6	3.0	21.6	1360	63.0
1,056	20.0	3.0	17.0	1090	64.2
1,087	19.6	3.0	16.6	1140	68.7
1,119	19.3	3.0	16.3	1090	66.9
1,150	24.6	3.0	21.6	1330	61.3
1,181	21.6	3.0	18.6	1150	61.8
1,200	19.6	3.0	16.6	1255	75.6

ft als – feet above land surface

4.1.5.2 Packer Testing

Packer testing was conducted during drilling operations to isolate and test potential storage zones and confining intervals, characterize aquifer parameters and recover discreet water quality samples for analysis. Intervals were selected for packer testing based on specific capacity testing while drilling, geophysical logging, and lithologic characteristics. A summary of the packer test intervals and specific capacity results are presented in Table 4-7.

Table 4-7 ASR TPW Packer Test Summary

Packer Test Number	**Test Interval** (ft bls)	**Pump Rate** (gpm)	**Maximum Drawdown*** (ft)	**Specific Capacity*** (gpm/ft)
4	755 - 785	8.8	107.9	0.1
3	880 - 910	340	21.2	16.1
2	998 - 1,028	212	102.5	2.1
1	1,070 - 1,200	230	99.2	2.3

* Adjusted for friction loss inside pipe column

Four packer tests were performed in the ASR TPW. A single packer was used for Packer Test 1 to isolate the interval from 1,070 ft bls to the total depth of the well (1,200 feet bls). A straddle packer configuration was used for Packer Tests 2, 3, and 4 to isolate discrete borehole depth intervals. The “straddle” or distance between bottom and top packers was chosen based on the anticipated interval of each potential flow zone.
The following procedures were used to perform the packer tests:

1) To test each isolated interval a packer assembly attached to drill pipe, was lowered into the borehole. The packer(s) were then inflated to seal off the selected interval. A pressure transducer was set in the annular space between the open hole and the drill pipe above the top packer to measure water pressure/levels above the packer to verify that the packer seal was not leaking. A second pressure transducer was set in the drill pipe to monitor water levels in the isolated interval.

2) In-Situ Mini-Troll pressure transducers were used to record and store water level measurements and were used in junction with Rugged Readers to monitor the measurements during the packer tests. Data from each packer test was analyzed using Aqtesolv Pro software for calculating transmissivities and the solutions are provided in Appendix P.

3) A submersible pump was set into the drill pipe to a depth of approximately 140 feet bls. A pre-test was conducted to establish a maximum pumping rate and to stabilize water quality parameters to ambient conditions. After water quality stabilized and pump rates were selected, the pump was turned off and the water level was allowed to return to static conditions prior to the pumping portion of the packer test.

4) During the pumping phase of packer testing, water levels were monitored and recorded and water samples were collected and analyzed to monitor water quality. Each packer test was conducted for approximately 3 to 10 hours, dependent on pumping rate and/or drawdown stabilization.

5) Toward the end of the pumping phase of the test, water samples were also collected for analysis by Sanders Laboratories. The laboratory results for each packer test are summarized in Table 4-8. Because of scheduling conflicts with Sanders Laboratories, some samples were analyzed past acceptable holding times. The analysis results for the samples collected during the packer tests showed higher conductivity and chloride values at shallower depths than samples collected during reverse air drilling. This variance in water quality is because of drilling fluid water quality samples being partially diluted with fresher water of overlying flow zones. The certified laboratory water quality report for each packer test is presented in Appendix Q.

6) Following the pumping phase of the test, water level recovery was monitored and recorded until the water level had returned to pre-pumping levels. Upon completion of the test, the packer assembly was deflated and re-positioned for the next test interval. Water level data was downloaded from the Level Troll transducer after each packer test.

Packer test recovery data were used to calculate hydraulic parameters of each packer test interval. Water level data from the annular transducer was also reviewed to confirm the integrity of the top packer seal. Water levels above the packer assembly showed no effect resulting from pumping.

Packer test recovery data were analyzed using three separate solution methods that best fit the recovery curves: the Hantush (1960) method for semi-confined aquifers with aquitard storage, the Moench (1985) constant head method, and the Moench (1985) no flow method.

The Transmissivity values calculated for each packer test are presented in Table 4-9. The average Transmissivity (gal/day/ft) values calculated from analysis of packer tests 1 through 4 are 2287.4, 2208.4, 8070.2, and 61.7 respectively. Resultant transmissivity values from analysis of packer tests are not indicative of bulk conduit flow zones. The analytical results including the time-displacement curves for the packer tests are presented in Appendix P.

Table 4-8 ASR TPW Packer Test Water Quality Parameters

4.1.5.2.1 Type	4.1.5.2.2 Parameter	Packer Test 1 1,070–1,200 ft bls	Packer Test 2 998–1,028 ft bls	Packer Test 3 880–910 ft bls	Packer Test 4 755 – 785 ft bls
Primary Inorganic	Aluminum (mg/L)	0.019	BDL	BDL	BDL
	Arsenic (mg/L)	BDL	BDL	BDL	BDL
	Barium (mg/L)	0.038	0.32	0.035	0.034
	Fluoride (mg/L)	1.2	1.2	1.5	1.3
	Nitrate (mg/L)	BDL*	BDL*	BDL*	BDL*
	Sodium (mg/L)	200.7	407	405	284
Secondary Inorganic	Chloride (mg/L)	1,500	770	760	640
	Iron (mg/L)	0.223	0.074	0.077	0.066
	Manganese (mg/L)	0.008	0.009	0.007	0.037
	Sulfate (mg/L)	274	255	294	205
	Color (Platinum-Cobalt Color Units)	5*	5*	4*	6*
	Total Dissolved Solids (mg/L)	2,800*	1,690	1,720*	1,390
Additional Parameters	Ammonium (mg/L)	0.33	0.28	0.28	0.26
	Bicarbonate Alkalinity (mg/L)	135*	141	139	137
	Calcium (mg/L)	127	97.7	107	91.8
	Carbon Dioxide (mg/L)	119*	124	123	121
	Carbonate Alkalinity (mg/L)	0.78*	0.88	0.97	0.69
	Dissolved Oxygen (mg/L)	6.31*	5.81*	5.82*	3.54*
	Hydrogen Sulfide (mg/L)	0.02*	0.045*	0.21*	0.19*
	Magnesium (mg/L)	132	90.9	95.9	89.7
	Potassium (mg/L)	33.5	23.9	24.1	31.9
	Silica (mg/L)	16.8	17.3	15.9	15.2
	Strontium (mg/L)	25	18	19	16

* - Sample held beyond acceptable holding time

Table 4-9 ASR TPW Packer Testing Analysis Results

Packer Test Number	**Test Interval** (ft bls)	**Transmissivity** (gpd/ft)			
		Hantush (1960)	**Moench**[1] (1985)	**Moench**[2] (1985)	**Average**
4	755-785	45	68	72	61.7
3	880-910	2,892	3,097	18,220	8,070.2
2	998-1,028	968	1,219	4,437	2,208.4
1	1,070-1,200	1,374	2,159	3,229	2,287.4

1 Constant Head solution
2 No Flow solution

4.1.5.3 Step Drawdown Testing

Following completion of drilling activities, an initial step drawdown test was conducted on the ASR TPW on January 28, 2008. The test consisted of five steps each conducted for one hour. The well was pumped at 200, 300, 400, 500, and 600 gpm. The step drawdown test yielded an average specific capacity of 5.3 gpm/ft at a pumping rate of 600 gpm. Results for the pre-acidization step drawdown test are shown in Table 4-7. Based on the well yield results obtained, a conventional acid treatment was conducted.

Table 4-10 Pre and Post Acidization Step Drawdown Test

Test	**Step**	**Pump Rate** (gpm)	**Drawdown** (ft)	**Specific Capacity** (gpm/ft)
Pre-Acidization	1	200	38.0	5.3
	2	300	60.2	5.0
	3	400	76.5	5.2
	4	500	95.1	5.3
	5	600	112.4	5.3
Post-Acidization	1	200	21.1	9.5
	2	400	42.8	9.3
	3	600	66.0	9.0
	4	800	90.2	8.9
	5	1,000*	110.0	9.1

* Actual pump rate between 950 and 1,000 gpm

Following acidization and redevelopment, a second step drawdown test was performed on March 7, 2008 to evaluate production improvement. The well was pumped at successive increments of 200 gpm, ranging between 200 and 1,000 gpm, for one hour at each rate. Results for the post-acidization step drawdown test are summarized in Table 4-8. The results indicate that the specific capacity increased to an average of 9 gpm/ft at 600 gpm or 70 percent above the pre-acidization step drawdown test.

4.1.5.4 Aquifer Performance Test

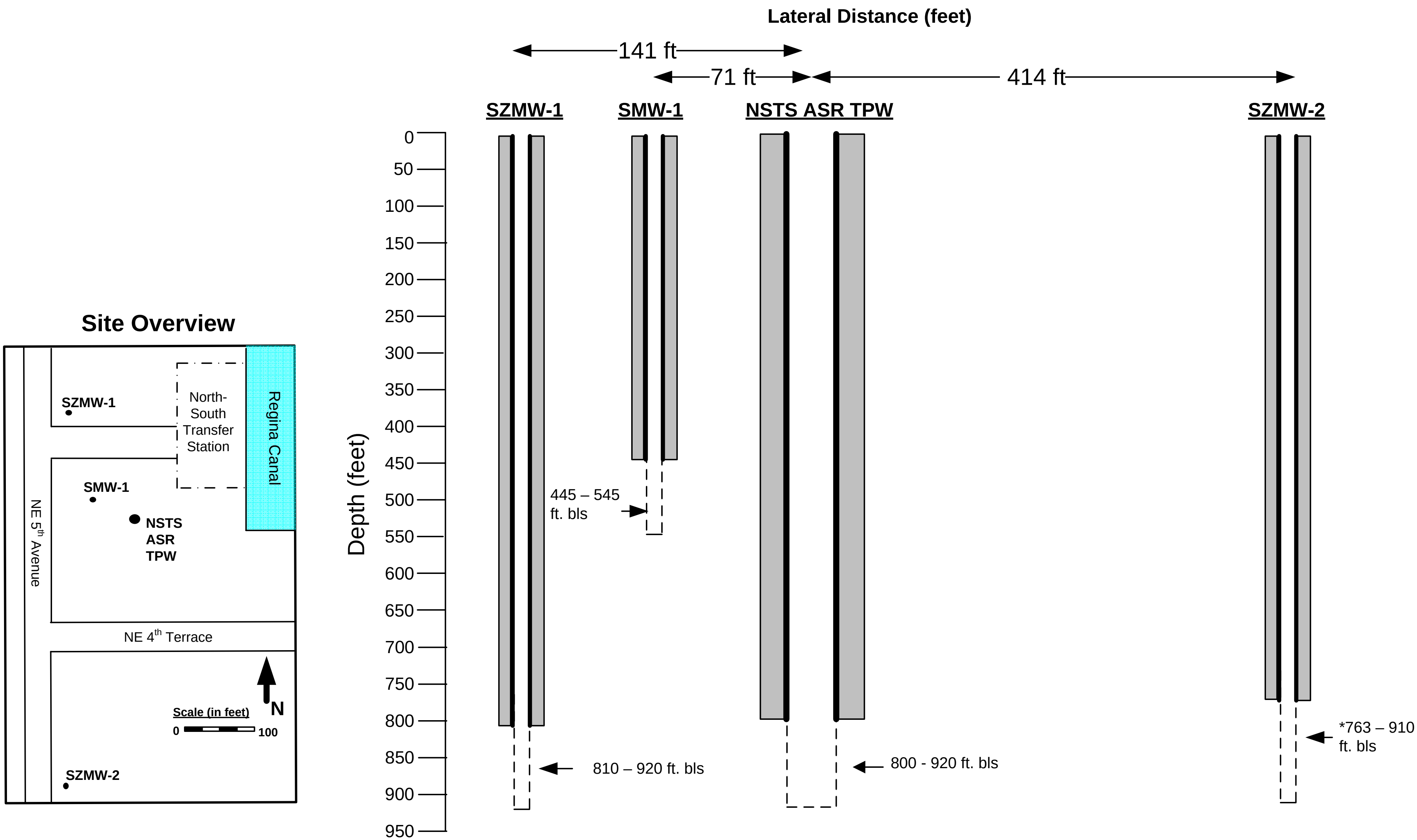
An APT was conducted on the NSTS ASR System to determine the hydraulic properties of the storage zone located from 800 to 920 feet bls. The principle factors of aquifer hydraulic properties, transmissivity and storage coefficient are calculated from the drawdown and/or recovery data obtained from the proximal monitor wells completed within the same interval. For semi-confined aquifers, the hydraulic parameter of leakance of the semi-pervious layer(s) can also be determined.

The ASR TPW was the pumped well and SZMW-1, SZMW-2, and SMW-1 were used as monitor wells. Well SZMW-1 is located approximately 141 feet to the northwest of the ASR Well. Well SZMW-2 is located approximately 414 feet to the south of the ASR well. Well SMW-1 is located approximately 71 feet to the northwest of the ASR Well. The spatial relationship of the wells is shown in Figure 4-2. The APT consisted of three phases: a background phase was conducted to determine ambient non-pumping conditions; a pumping phase to determine water level drawdown in the three monitor wells resulting from pumping the TPW; and a recovery phase to determine residual drawdown and return to static water level conditions.

The background phase consisted of recording water level measurements in all four wells for a period of 24 hours. The drawdown phase consisted of pumping the ASR TPW at a constant-rate of 850-gpm for 61-hours while recording water level changes in the ASR TPW and monitoring wells SZMW-1, SZMW-2 and SMW-1. Recovery data was monitored in all wells for 69 hours.

Prior to the pumping phase of the APT, water levels were recorded using In-Situ Level Troll transducers for approximately 24 hours at all wells (ASR TPW, SZMW-1, SZMW-2 and SMW-1) to measure the diurnal trends for the site. Water levels in the ASR TPW and monitor wells remained generally stable during the background period as shown in Figures 4-3 through 4-6. Water Use Permits within a one-mile radius were reviewed to identify any withdrawals that may influence the UFA that was monitored and pumped. During the review, no permits were identified that indicated permitted withdrawals from the UFA.

On April 3, 2008, the drawdown phase of the APT was started by pumping the ASR TPW at 890 gpm. The In-Situ Level Troll transducers continuously measured and recorded water levels during the drawdown phase. The pumping phase continued uninterrupted for 61 hours. Plots of the drawdown data for the pumped well and monitor wells are shown in Figures 4-3 to 4-6. Maximum drawdown in the ASR TPW, SZMW-1, SZMW-2 and SMW-1 was 95.7 feet, 25.6 feet, 16.4 feet and 0.3 feet, respectively.



Note
ft. bls = feet below land surface
Surface and intermediate casing are not depicted
* APT was completed before repair was made to SZMW-2

Figure 4-2 Spatial Relationship of NSTS ASR System Wells

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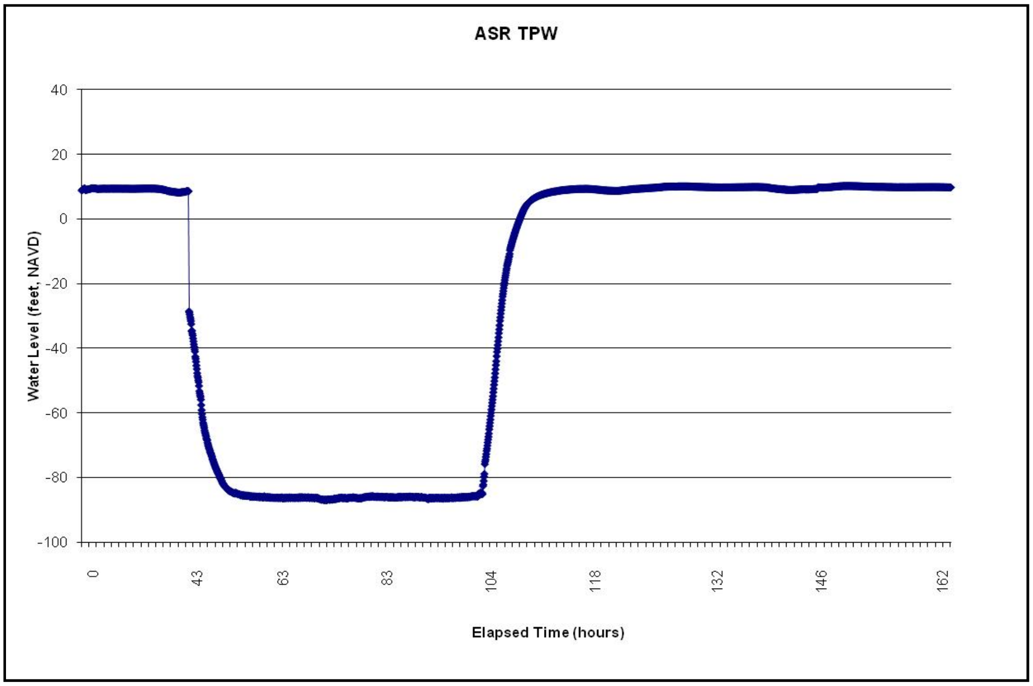

Figure 4-3 Background, Drawdown, and Recovery Data for ASR TPW

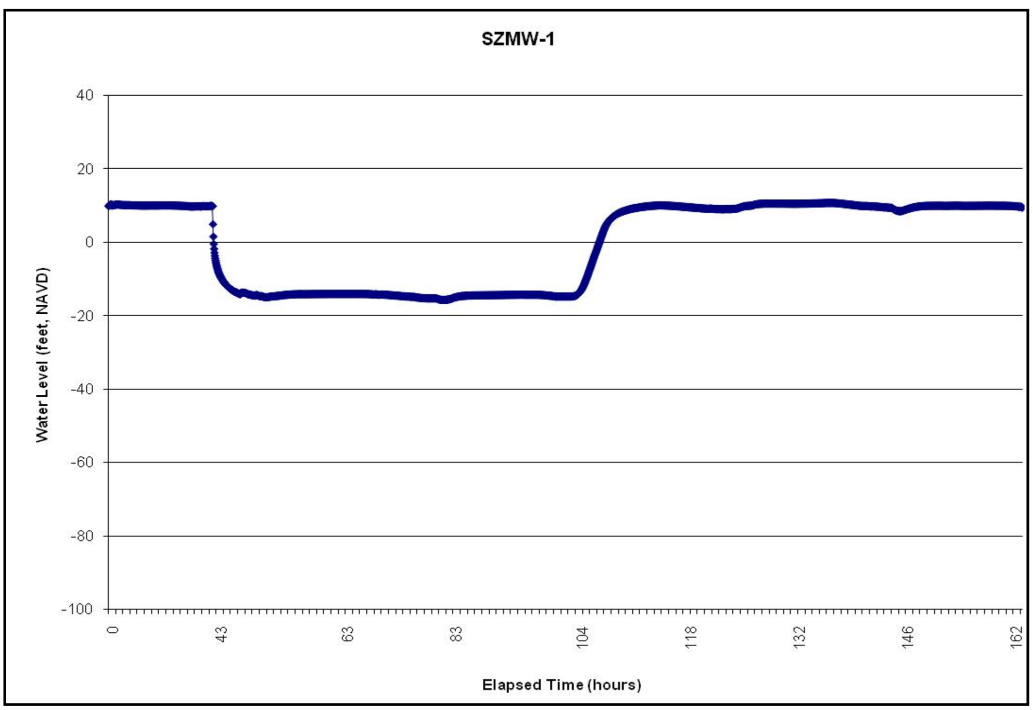

Figure 4-4 Background, Drawdown, and Recovery Data for SZMW-1

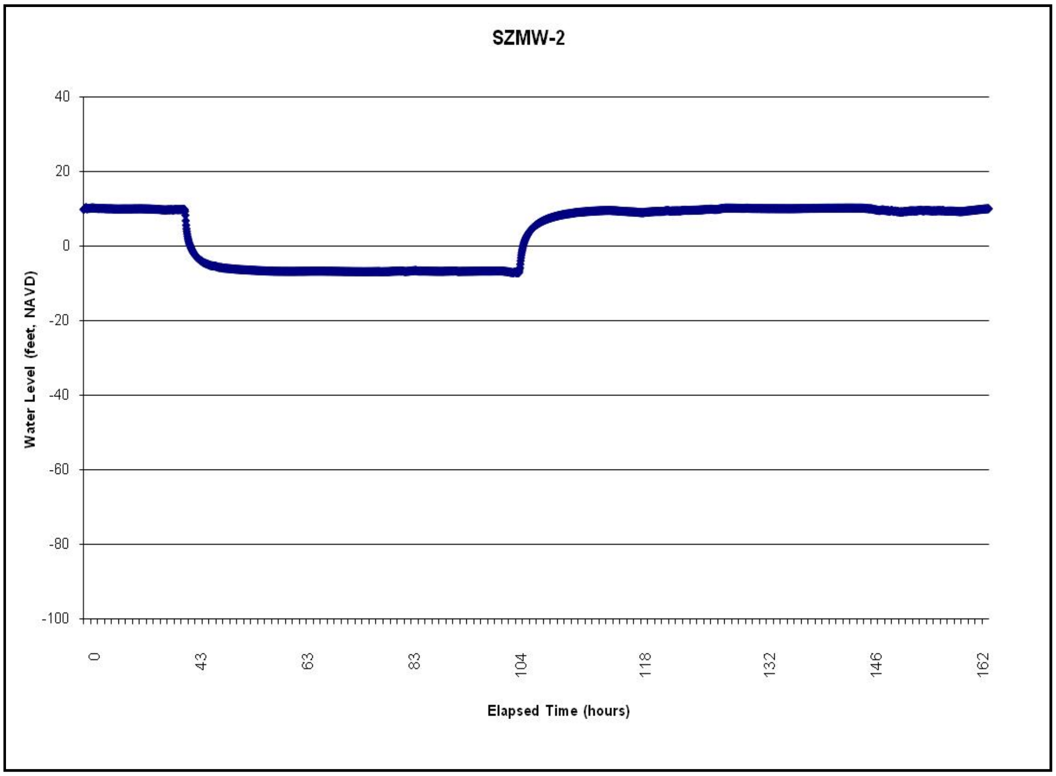

Figure 4-5 Background, Drawdown, and Recovery Data for SZMW-2

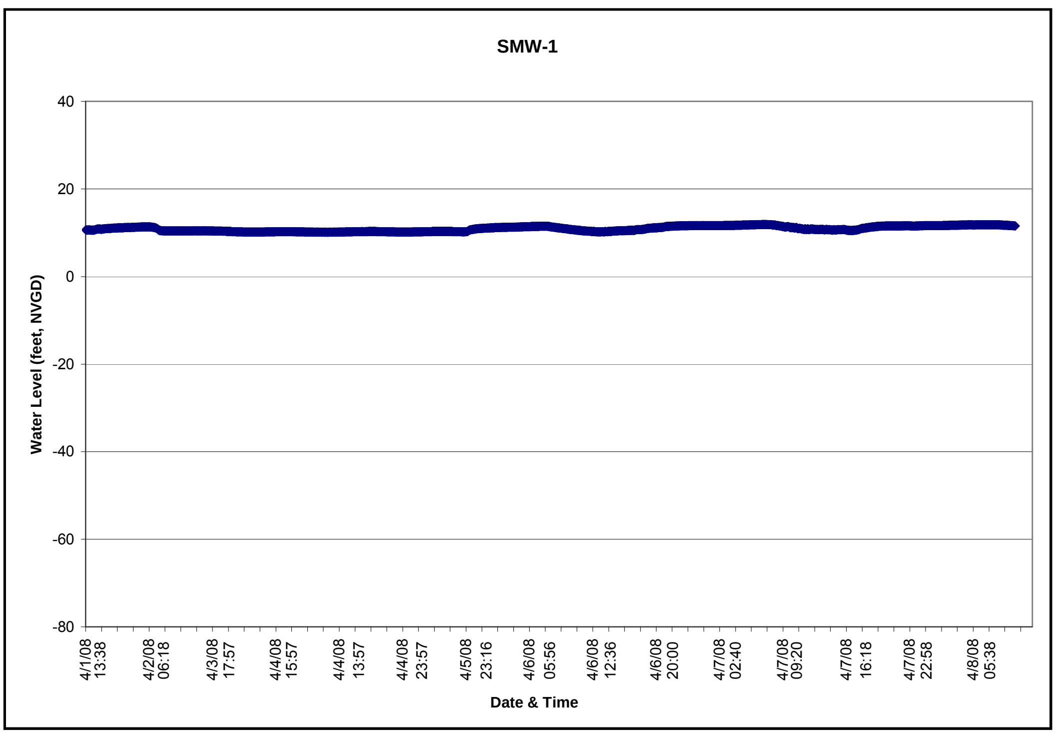

Figure 4-6 Background, Drawdown, and Recovery Data for SMW-1

Three analytical solutions were used to estimate the transmissivity, storage coefficient, and leakance at the site: Cooper-Jacob (1946), Hantush-Jacob (1955), and Hantush (1960). A summary of the APT analyses for the pumped monitoring zones (SZMW-1 and SZMW-2) are provided in Table 4-11. The transmissivity for each solution show similar results and is supported by the specific capacity tests recorded from other subject wells within the City of Cape Coral. The dimensionless parameter r/B characterizes the leakage across the aquitard(s) to the pumped aquifer, from this value leakance was calculated (Walton, 1960).

$$\text{Leakance} = \frac{4T(r/B)}{r^2}$$

Where:

T = Transmissivity (ft^2/day)
r/B = Dimensionless parameter from type curve
r = Radius between wells (ft)

Table 4-11 Storage Zone Aquifer Properties

Monitor Well	Solution Method	Transmissivity (gpd/ft)	Storage Coefficient	Leakance (1/day)
SZMW-1	Cooper-Jacob	24,830	.000213	NA
	Hantush-Jacob	18,630	.000306	0.050
	Hantush	13,660	.000229	0.073
	Average	19,040	.000249	0.061
SZMW-2	Cooper-Jacob	29,100	.00007626	NA
	Hantush-Jacob	27,460	.00004445	0.008
	Hantush	19,150	.00005218	0.012
	Average	25,237	.0005763	0.010

NA – Not Available - Method does not provide r/B required for calculation

Based on these considerations and the site-specific hydrogeologic data collected during drilling and aquifer testing, the Hantush-Jacob analytical model best represents the conditions present at this site. A log/log plot of drawdown versus time, utilizing the Hantush-Jacob (1955) solution, for the pumped monitor zones (SZMW-1 and SZMW-2) is provided in Figures 4-7 and 4-8, respectively. The raw data and log/log plots of drawdown versus time for the Cooper-Jacob solution and the Hantush solution are provided in Appendix T.

The Hantush-Jacob (1955) analytical model is a solution derived for unsteady flow to a fully penetrating well in a homogeneous, isotropic leaky confined aquifer. The solution assumes a line source for the pumped well and therefore neglects wellbore storage.

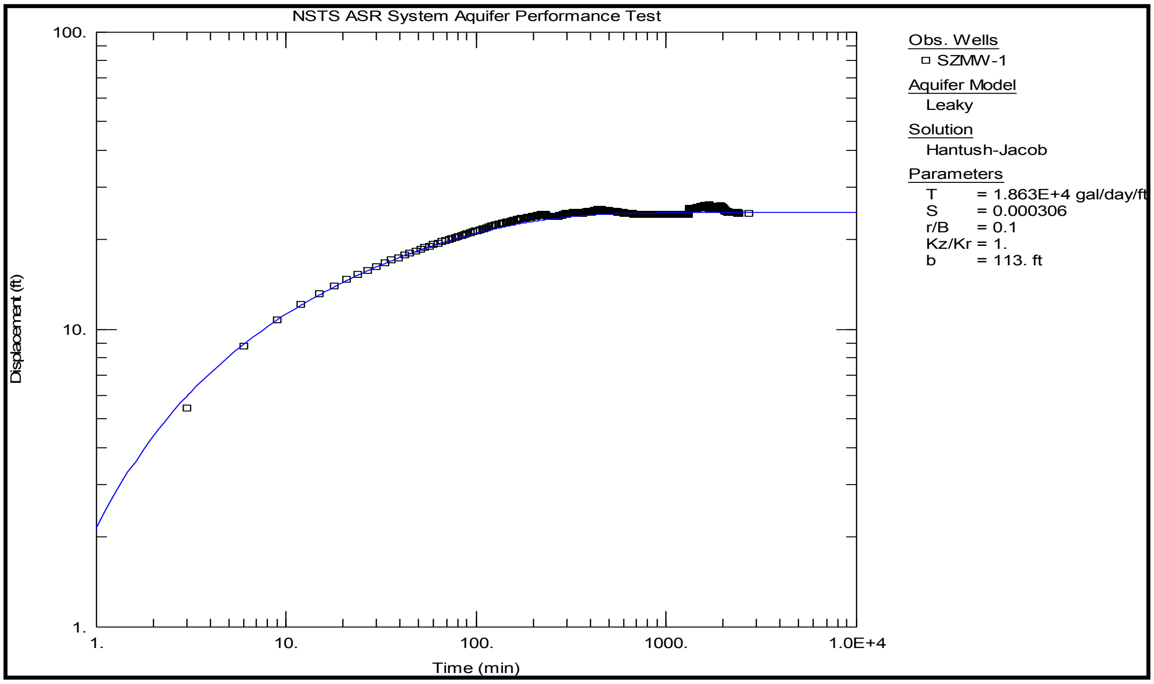

Figure 4-7 SZMW-1 Hantush-Jacob Log-Log Plot of Displacement vs. Time

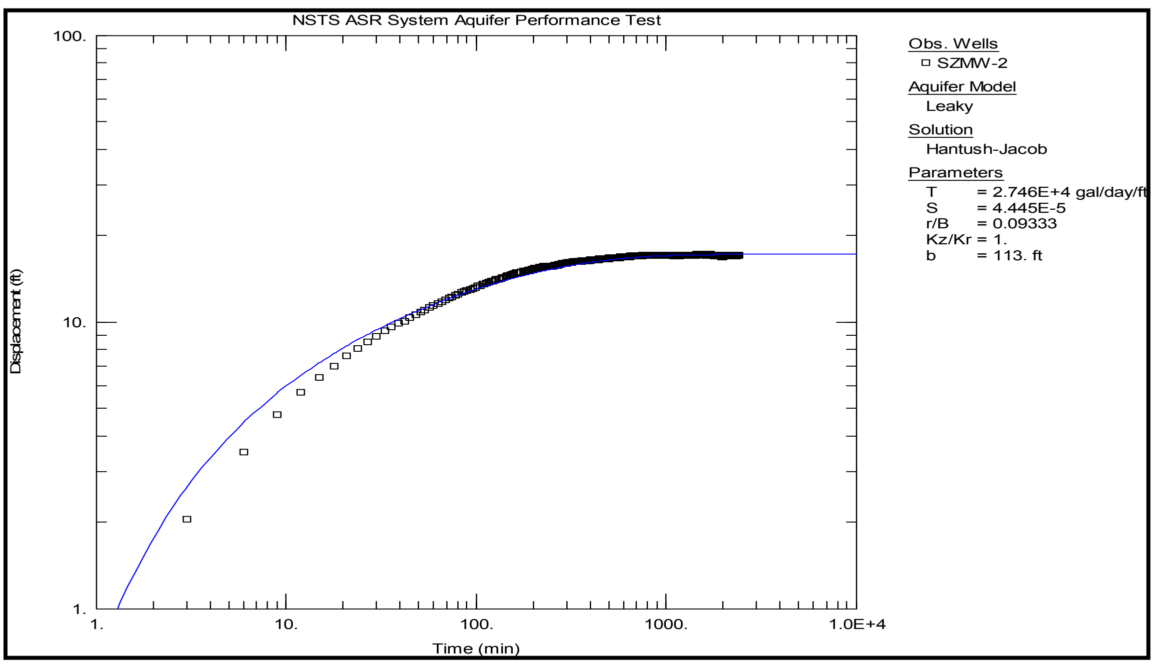

Figure 4-8 SZMW-2 Hantush-Jacob Log-Log Plot of Displacement vs. Time

The results of this solution for SZMW-1 and SZMW-2 yielded a transmissivity value of 18,630 and 27,460 gallons per day per foot (gpd/ft) for an average of 23,000 gpd/ft, a storage coefficient of 3.1 x 10^{-4} and 4.4 x 10-5, and an (r/B) value of 0.1, respectively. The dimensionless parameter r/B characterizes the leakage across the aquitard(s) to the pumped aquifer. The transmissivity calculated using the Hantush-Jacob analysis is comparable to the average of the three pump test analysis methods used as shown in Tables 4-15 and 4-16.

4.1.5.5 Injection Pressure Analysis

A three-dimensional, steady state, fully calibrated, finite difference groundwater flow model using MODFLOW2000 was developed to estimate drawdown caused by aquifer withdrawals or injection in and around the City of Cape Coral. The model has variable cell spacing, with a uniform maximum horizontal resolution of 500 $feet^2$ in the area representing the City of Cape Coral. The model vertically represents seven layers, representing alternating aquifer and confining units documented and observed in the local and semi-regional area. The model was developed for long term planning and water use permitting purposes for the City (MWH, 2008).

This model was used to estimate pressure changes resulting from injection at the NSTS ASR System into the completed storage zone at a rate of 1 mgd. The aquifer unit representing the storage zone, and aquifer units above and below the storage zone, were monitored during the injection simulation for pressure changes (Figure 4-9).

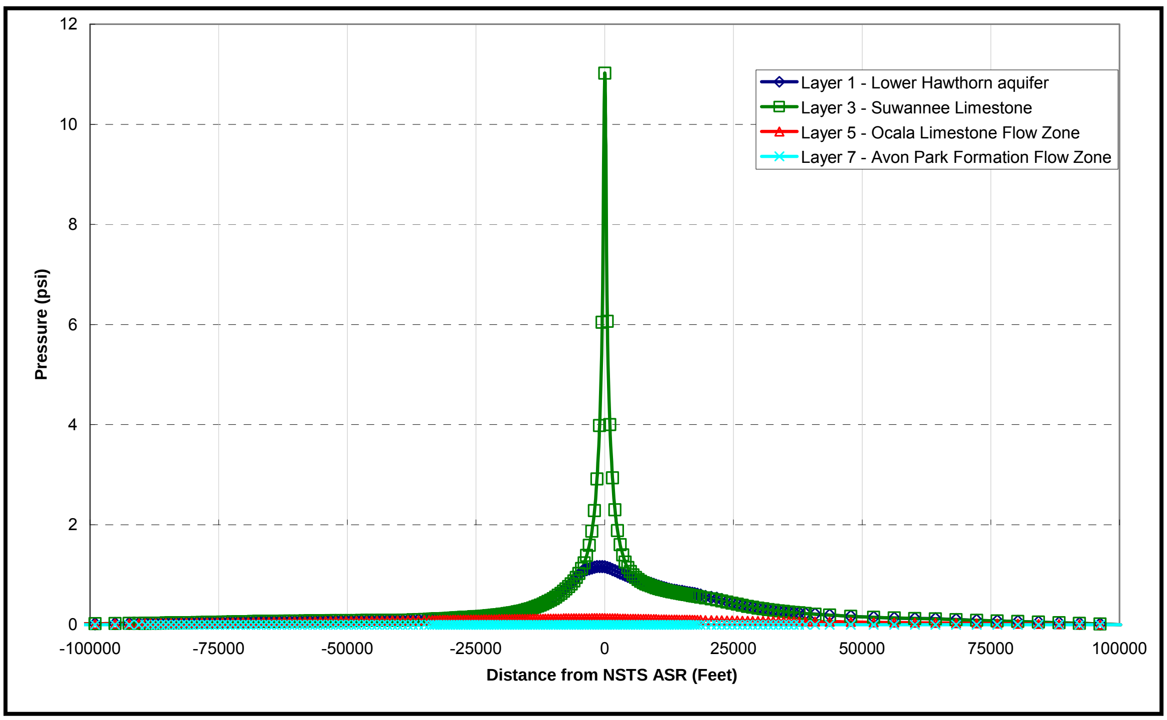

Figure 4-9 NSTS ASR Pressure Profile at 1 mgd Injection Rate

The maximum pressure increase per layer is listed on Table 4-12. Simulated pressures do not represent pressures significant enough to cause vertical or horizontal fracturing of the storage zone or overlying/underlying confining and/or aquifer layers. The overburden pressure of the uppermost aquifer layer would have to be exceeded to induce horizontal fracturing in the formation, which has been estimated at approximately 450 psi (1 psi per foot of depth to the top of the lower Hawthorn aquifer). Approximately half of the overburden pressure (0.55 psi per foot) would be required to initiate vertical fracturing (Bennett et al 2001). Based on simulation modeling of 1 mgd injection, a maximum average pressure of 11.02 psi is observed in the storage zone within a 500-foot^2 area surrounding the ASR TPW. The modeled pressure is not significant enough to cause detrimental stress on the aquifer structure.

Table 4-12 ASR TPW Maximum Modeled Pressure Increase per Layer

Model Layer	Hydrogeologic Unit	Maximum Modeled Pressure (psi)
1	Lower Hawthorn aquifer	1.16
2	Suwannee Limestone confining unit	2.89
3	Suwannee Limestone aquifer (Storage Zone)	11.02
4	Ocala Formation confining unit	5.32
5	Ocala Formation flow zone	0.31
6	Avon Park Formation confining unit	0.05
7	Avon Park Formation flow zone	0.00

4.2 Monitor Wells

4.2.1 Lithologic Sampling

Formation cuttings were collected during drilling operations of wells SZMW-1, SZMW-2 and SMW-1R every 10 feet from land surface to the total depth of the well. Samples were characterized for rock type, color, induration, texture, cementation, hardness, fossil type, and visible porosity/permeability. Lithologic sampling aided in identifying the contacts between formations, selection of packer test intervals, and understanding the overall physical characteristics of formations penetrated by the borehole. Descriptions of the lithology encountered during drilling of the monitor wells are presented in Appendix C.

4.2.2 Geophysical Logging and Analysis

Geophysical logs for the monitor wells were conducted in the pilot holes after each stage of drilling and after reaming. The logs provide a continuous record of the geophysical properties of the subsurface formations. Analyses of the logs were used to assist in the interpretation of lithology, and to provide estimates of permeability, porosity, bulk density, and resistivity. Geophysical logs are presented in Appendix D.

The geophysical logs aided in identifying geologic contacts, and were used to obtain hydrogeologic data pertaining to the formations. Geophysical logs were conducted in the pilot hole, reamed hole, and final open borehole for all monitor wells. A summary of geophysical logging conducted at the monitor wells are provided in Table 4-13. The geophysical data, in conjunction with water quality, specific capacity testing, and lithology information was used in determining optimum casing depths for each well, packer test intervals for wells SZMW-1 and SZMW-2, and to select the discrete monitor zone for the wells.

Table 4-13 Monitor Well Geophysical Summary

Well	**Date**	**Logged Interval** (ft bls)	**XY Caliper**	**Gamma Ray**	**Spontaneous Potential**	**Dual Induction**	**Temperature**	**Fluid Conductivity**	**Flow**	**Sonic Porosity**	**Video**
SZMW-1	11-1-07	0-480	X	X	X	X				X	
	11-16-07	0-475	X	X							
	1-3-08	0-920	X	X	X	X	X	X	X	X	X
	3-17-08	0-920	X	X	X	X	X	X	X	X	X
SZMW-2	10-16-07	0-457	X	X	X	X				X	
	10-29-07	0-455	X	X							
	11-28-07	0-910	X	X	X	X	X	X	X	X	X
	3-19-07	0-910	X	X	X	X	X	X	X	X	X
	8-5-09	0-805	X	X							
	8-21-09	0-914									X
SMW-1R	5-5-08	0-445	X	X	X	X				X	
	5-28-08	0-545	X	X							
	6-16-08	0-545									X

4.2.3 Water Quality Sampling and Analysis

4.2.3.1 Water Quality During Drilling

Water quality samples were collected at the end of each drill rod for the monitor wells during reverse air drilling. Samples were collected at the discharge point of the fluid circulation system. The samples were analyzed on-site for specific conductivity, dissolved oxygen, temperature, pH, and chloride. These data were used to identify increasing groundwater salinity and water quality with depth.

Reverse-air drilling at the monitor wells was conducted in an open system, with fluids generated from the well drilling operations discharged to the freshwater canal system. The water discharged from the monitor well pilot holes was a mixture of formation water from the entire open borehole. The water quality measurements are not an accurate representation of the water quality from the sampled interval. Water quality samples from reverse air drilling measure relative water quality trends versus depth and are provided in Appendix R.

4.2.3.2 Final Water Quality

Upon completion of development, the monitor wells were purged until at least three well volumes of water had been evacuated and chloride concentration, temperature, pH and specific conductivity measurements stabilized. Water samples were collected by Sanders Laboratories, Inc. following completion of each monitor well. The samples were analyzed for primary and secondary drinking water standards using EPA and/or Standard Method procedures. The complete results of these analyses are presented in Appendix O. A summary of the analysis results for the three monitor wells is provided in Table 4-14.

Table 4-14 Completed Monitor Water Quality Results

4.2.3.2.1 Type	4.2.3.2.2 Parameter	SZMW-1	SZMW-2	SMW-1R
Primary Inorganic	Antimony (mg/L)	BDL	BDL	BDL
	Arsenic (mg/L)	BDL	BDL	BDL
	Asbestos	-	-	-
	Barium (mg/L)	0.028	0.032	0.022
	Beryllium (mg/L)	BDL	BDL	BDL
	Cadmium (mg/L)	BDL	BDL	BDL
	Chromium (mg/L)	BDL	BDL	BDL
	Cyanide (mg/L)	BDL	BDL	BDL
	Fluoride (mg/L)	1.5	1.6	2.2
	Lead (mg/L)	BDL	BDL	BDL
	Mercury (mg/L)	BDL	BDL	BDL
	Nickel (mg/L)	0.001	BDL	BDL
	Nitrate (mg/L)	BDL	BDL	BDL
	Nitrite (mg/L)	BDL	BDL	BDL
	Total Nitrate (mg/L)	BDL	BDL	BDL
	Selenium (mg/L)	BDL	BDL	BDL
	Sodium (mg/L)	358	369	369
	Thallium (mg/L)	BDL	BDL	BDL
Secondary Inorganic	Aluminum (mg/L)	BDL	BDL	BDL
	Copper (mg/L)	BDL	BDL	BDL
	Chloride (mg/L)	719	735	733
	Iron (mg/L)	<0.017	<0.025	BDL
	Manganese (mg/L)	0.002	0.001	BDL
	Silver (mg/L)	0.002	BDL	0.001
	Sulfate (mg/L)	315	240	239
	Color (Platinum-Cobalt Color Units)	5	5	BDL
	Odor (threshold odor number)	8	17	35
	pH (standard units)	7.45	7.65	7.48
	Total Dissolved Solids(mg/L)	1,640	1,630	1,570
	Zinc (mg/L)	0.011	0.017	0.013
	Surfactants (mg/L)	0.045	0.042	0.030
Bacteriological	Total Coliform (CFU/100ml)	BDL	BDL	BDL
	Enterococci (MPN/100ml)	BDL	BDL	BDL
	Cryptosporidium Giardia (IFA/1L)	BDL	BDL	BDL
Radionuclide's	Gross Alpha (picocuries per liter)	29	15	52
	Radium-226 (picocuries per liter)	2.6	2.1	4.4
	Radium-228 (picocuries per liter)	0.4	0.3	0.4
	Uranium (micrograms per liter)	BDL	1.2	BDL

4.2.4 Hydrogeologic Testing and Analysis

4.2.4.1 Reverse-Air Drilling Specific Capacity Testing

Specific capacity tests were performed in the monitor wells at 30-foot intervals in the pilot hole during reverse-air drilling. Drilling operations were paused while each specific capacity test was conducted. Static water level in the pilot hole and the flow rate and drawdown were recorded. The resultant specific capacity measurement is an indication of the flow in that section of the pilot hole, relative to the rest of the pilot hole, and not an absolute value of that section of pilot hole. The specific capacity measurements during drilling operations for the monitor wells are available in Appendix S.

4.2.4.2 Packer Testing

Single packer testing was conducted in wells SZMW-1 and SZMW-2 to isolate and test potential monitor zones, characterize aquifer parameters, and collect water samples for field parameters. Depth intervals corresponding to specific geologic horizons were selected for packer testing based on specific capacity testing, geophysical logging, and lithologic characteristics. The main purpose of testing the monitor wells was to ensure the completed monitoring interval would produce sufficient water during future sampling and purging operations.

1) To test each isolated interval a single packer assembly attached to drill pipe, was lowered into the borehole. The packer was then inflated to seal off the selected interval. A pressure transducer was set in the drill pipe. The drill pipe provides a conduit to the packer assembly, to monitor water levels in the isolated interval. A second pressure transducer was set above the top packer in the annular space between the open hole and the drill pipe to measure water levels above the packer and verify that the packer seal was not leaking. In-Situ Mini-Troll pressure transducers were used to record and store water level measurements. Data loggers were used to monitor the measurements during the tests.

2) In-Situ Mini-Troll pressure transducers were used to record and store water level measurements and were used in junction with Rugged Readers to monitor the measurements during the packer tests. Data from each packer test was analyzed using Aqtesolv Pro software for calculating transmissivities and the solutions are provided in Appendix P.

3) A submersible pump was lowered into SZMW-1 and SZMW-2 to a depth of 125 ft bls and 133 feet bls, respectively. A pre-test was conducted prior to establishing a maximum pumping rate and to stabilize water quality parameters to ambient conditions. Pumping rates for the SZMW-1 and SZMW-2 packer tests were 290 gpm and 300 gpm, respectively. After water quality stabilized and pump rates were selected, the pump was turned off and the water level was allowed to return to static conditions prior to the pumping portion of the packer test.

4) During the pumping phase of packer testing, water levels were monitored and recorded and water samples were collected and analyzed to monitor water quality. The pumping phase of the SZMW-1 packer test was conducted for 6.5 hours. The pumping phase of the SZMW-2 packer test was conducted for 6 hours. Both tests were terminated after at least three volumes had been purged and water levels and water quality measurements remained stable.

5) Toward the end of the pumping phase of the test, water samples were also collected for analysis by Sanders Laboratories. The analytical results for the samples collected during the packer tests showed higher conductivity, chloride, and TDS values at shallower depths than observed during reverse air drilling. This variance in water quality is due to drilling fluid water quality samples being partially diluted with fresher water of overlying flow zones. The certified laboratory water quality report for each packer test is presented in Appendix Q.

6) Following the pumping phase of the test, water level recovery was monitored and recorded until the water level had stabilized to pre-pumping, ambient conditions. Upon completion of the test, the packer assembly was deflated and removed from the borehole. Water level data was downloaded from the data logger on site after each packer test.

Packer test recovery data were used to calculate hydraulic parameters of each tested interval for SZMW-1 and SZMW-2. Water pressure/level data from the annular transducer was also reviewed to confirm the reliability of the top packer seal. Water levels above the packer assembly showed no effect resulting from pumping. The packer test at SZMW-1 was completed on January 15, 2008 on the interval from 799 to 920 feet bls. At SZMW-2 the packer test was completed on December 11, 2007 on the interval from 790 to 910 feet bls. A summary of the packer test for each monitor well is provided in Table 4-15.

Table 4-15 Monitor Well Packer Test Summary

Well	**Test Interval** (ft bls)	**Pump Rate** (gpm)	**Maximum Drawdown*** (ft)	**Specific Capacity*** (gpm/ft)
SZMW-1	799-920	290	51.5	5.6
SZMW-2	790-910	300	38.4	7.8

* Adjusted for friction loss inside pipe column

Packer test recovery data were analyzed using three separate solution methods which best matched the recovery curves: the Hantush (1960) method for semi-confined aquifers with Aquitard storage, the $Moench_1$ (1985) Constant Head method, and the $Moench_2$ (1985) No Flow. A summary of the packer test results are presented in Table 4-

16. The analytical results including the time-displacement curves for the packer tests are presented in Appendix P.

Table 4-16 Monitor Well Packer Test Aquifer Analysis Summary

Well	**Transmissivity** (gpd/ft)			
	Hantush (1960)	**Moench**[1] (1985)	**Moench**[2] (1985)	**Average**
SZMW-1	9,770	11,280	77,060	32,703
SZMW-2	7,530	7,550	29,600	14,893
			Site Average	23,798

1 Constant Head solution
2 No Flow solution

5.0 Conclusions and Recommendations

Construction of the ASR System at the City of Cape Coral's North-South Transfer Station has been successfully completed. One 16-inch diameter ASR well with fiberglass reinforced plastic casing set to 800 ft bls and an open hole extending from 800 to 920 ft bls is now ready for installation of the surface facilities and cycle testing at a design rate of 1 mgd. The two storage zone monitor wells, SZMW-1 and SZMW-2, were completed from 810 to 920 feet and from 800 to 910 feet bls, respectively. The shallow monitor well, SMW-1R, was completed from 445 to 545 feet bls. All wells were constructed to the requirements specified under FDEP Class V Group 7 well construction permit No. 247165-001-UC.

The storage zone of the ASR TPW is completed within the Suwannee Limestone of the Upper Floridan aquifer. The storage zone interval, located between the depths of 800 and 920 feet bls, was proposed by MWH staff and approved by the FDEP TAC staff. The final casing and storage zone justification letter is provided in Appendix B. This storage interval is similar, but shallower, to that proposed in the application materials (810 – 950 feet). The proposed storage zone is comprised of calcarenitic limestone and has characteristics that are considered significant to obtain good recovery efficiencies. Hydrogeologic and design factors that contribute to good performance are discussed below, and are largely based on performance factors identified by Reese and Alvarez-Sarikian (2006) for existing South Florida ASR systems as follows.

1. Storage Zone Thickness – the thickness of the proposed storage zone is approximately 120 feet. This compares to successful ASR projects in Southwest Florida, which range from 45 feet (Marco Lakes) to 155 feet (Lee County WTP). A moderate thickness storage zone was chosen because of the uncertainties of storage zone productivity, and this conservative approach was taken to ensure an adequate interval for injection and recovery was present.

2. Transmissivity – transmissivity within the storage zone is estimated to range from 20,000 to 33,000 gpd/ft based on estimates obtained from packer testing, step drawdown tests and results from the Aquifer Performance Test (APT). Prior to setting casing, the transmissivity was estimated at 70,000 to over 100,000 gpd/ft based on specific capacity measurements during drilling, and packer tests conducted on the open hole, specifically Packer Test No.3 (See Appendix B). Packer Test #3, which was located in an interval of the planned storage zone, had a corrected specific capacity of 16.5 gpm/ft. Using the standard multiplier of 2000, Transmissivity was estimated at 33,000 gpm/ft for the 30 feet packer interval, or 121,000 for the planned 110 feet storage zone.

   Following well completion, analysis of the data collected during the APT, and Packer Tests on SZMW #1 and #2 resulted in an transmissivity of approximately 23,000 gpd/ft (see Tables 4-11 and 4-16). The relatively low Transmissivity for the storage interval is likely attributable to layers of low permeability materials interbedded with the higher permeability materials indicated in the TPW Packer

Test #3. In other words, the storage interval is likely stratified with variable permeability sediments.

The transmissivity estimates at the NSTS site is in the low range compared to neighboring ASR sites, but pump test results indicate the well would operate effectively at planned injection and withdrawal rates. The advantage of a relatively low transmissivity storage zone is that stored water would be less likely to migrate downgradient during the storage periods.

3. Native Water Quality – Based on packer test data collected, the chloride concentration of the planned storage zone is approximately 760 mg/l. Based on final sampling, the ambient water within the storage zone is slightly brackish, and contains a chloride and TDS concentration of approximately 825 mg/L and 1,630 mg/L, respectively. This represents moderately brackish conditions, and is midway between two existing successful ASR projects in Lee County – Olga (1,000 mg/l chloride) and Lee County WTP (500 mg/l chloride).

4. Confinement - Approximately 140 feet of low permeability interbedded marl and clay confinement is present above the storage zone. Packer Test Number 4 conducted within this confining interval confirmed the presence of low hydraulic conductivity (Table 4-9). Confinement above, and to a lesser extent below the storage zone are considered essential for a successful storage zone.

5. Absence of potential conduit flow - The sonic, flowmeter and video logs were reviewed for the presence of conduit flow zones, such as fracture zones or extensive secondary dissolution features that would contribute to loss of stored water. The borehole compensated (BHC) sonic variable density log and flowmeter logs indicate that there are no features within the storage zone interval that are characteristic of fracture zones. With the exception of a few bedding plane features, no significant features were observed in the video that would indicate to bulk conduit flow.

Design of the surface equipment, including recharge and recovery pumps, water treatment piping and electrical controls are currently being completed under the IRR-7 Work Authorization. MWH recommends initiation of cycle testing upon completion of facilities at the NSTS ASR site. Prior to completion of treatment facilities, a request to start cycle testing will be submitted to the FDEP. The request will include an updated Cycle testing plan. A preliminary plan was submitted in the October 14, 2006, letter from MWH to the Department.

The cycle testing plan will consist of progressively longer periods of injection, storage, and recovery of treated water from the ASR TPW. Water quality and flow information will be collected during the cycle testing period. At the conclusion of cycle testing, a report detailing and interpreting the collected information will be prepared and submitted to FDEP in support of an Operating Permit application for the system.

6.0 References

Archie, G. E., 1942, *The Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics*: Journal of Petroleum Technology, Volume 5, No. 1.

Bennett, M. W. Linton, P. F., and Rectenwald, E. R., 2001, *Hydrogeologic Investigation of the Floridan Aquifer System: Western Hillsboro Basin, Palm Beach County, Florida*, Technical Publication WS-8, 34p.

Bennett, M. W. and Rectenwald, E. R., 2004, *Hydrogeologic Investigation of the Floridan Aquifer System: Big Cypress Preserve, Collier County, Florida*, Technical Publication WS-18, 59p.

Callahan, E. X., 1996, Evaluation of Formation Salinity Using Borehole Geophysical Techniques; Everglades Geological Society Bulletin, Fort Myers, FL Volume 3, No.4, Abstract and Program, 1 p.

Camp, Dresser & McKee, 2005, *Reclaimed Water Aquifer Storage and Recovery Feasibility Report*, Consultants Report prepared for the City of Cape Coral, 49p.

Cunningham, K. J., Bukry, D., Sato, T., Barron, J. A., Guertin, L. A., and Reese, R. S., 2001, *Sequence Stratigraphy of a South Florida Carbonate Ramp and Bounding Siliciclastics (Late Miocene-Pliocene)*, Florida Geological Survey, Special Publication No. 49, p. 35-66.

Cooper, H.H., Jr., and Jacob, C.E., 1946, *A generalized graphical method for evaluating formation constants and summarizing well-field history*: American Geophysical Union Transactions, v. 27, no. 4, p. 526-534.

Dames & Moore Inc, 1998, *Supplemental Irrigation Water Source Investigation Report*, Consultant's report prepared for City of Cape Coral.

Folk, R. L., 1980, *Petrology of Sedimentary Rocks*, Hemphill Publishing Company, Austin, Texas, 198p.

Hantush, M.S., and C.E. Jacob, 1955, *Non-steady Radial Flow in an Infinite Leaky Aquifer*. Transactions, American Geophysical Union, Vol. 36, No. 1, pp. 95-100.

Hantush, M.S., 1960, *Modification of the Theory of Leaky Aquifers*. J. Geophys. Res. Vol. 65, pp. 3713-3725.

Meyer, F. W., 1989, *Hydrogeology, Ground-Water Movement, and Subsurface Storage in the Floridan Aquifer System in Southern Florida*, U.S. Geological Survey, Professional Paper 1403-G, p. G3-G10, G19-G33.

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

Missimer & Associates, Inc., 1985, *Cape Coral Reverse Osmosis Wellfield – Final Construction Report and Operation and Maintenance Recommendations*: to the City of Cape Coral, 58p.

Missimer & Associates, Inc., 1989, *City of Cape Coral Master Water Supply Plan, Phase I Report: Preliminary assessment of sources of water for future potable water supply in the City of Cape Coral*: Report No. 479-89, the City of Cape Coral, 178 p.

Moench, A.F, 1985. *Transient flow to a Large-diameter Well in an Aquifer with Storative Semiconfining layers*, Water Resources Research, vo. 21, no. 8, pp. 1121-1131.

MWH, 2004, Facilities *Planning Report for Cape Coral Water, Wastewater and Irrigation Facilities*, Consultants report prepared for City of Cape Coral, 102 pp.

MWH, 2008*, W-10 Water Supply Resource Study City of Cape Coral Groundwater Flow and Solute Transport Model*, Consultants report prepared for City of Cape Coral, 79 pp.

Reese, R. S., 1994, *Hydrogeology and the Distribution and Origin of Salinity in the Floridan Aquifer System, Southeastern Florida*, Water Resource Investigations Report 94-4010, p. 5-16, 35-40.

Reese, R.S., 2000. *Hydrogeology and the distribution of salinity in the Floridan aquifer system, southwestern Florida*. USGS Water Resources Investigation Report 98-4253, 86p.

Reese, R.S., and Alvarez-Zarikian, C.A., 2006, *Hydrogeology and Aquifer Storage and Recovery Performance in the Upper Floridan Aquifer, Southern Florida,* U.S. Geological Survey Scientific Investigations Report 2006-5239, 74 p.

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

South Florida Water Management District, 2002, *Regional Irrigation Distribution System (RIDS) Master Plan Final Report*, prepared by Boyle Engineering Corporation and Subconsultants, 109p.

South Florida Water Management District, 2004, Feasibility Study for the Regional Irrigation Distribution System (RIDS) Sub-Region 2 for the Lower West Coast Region Project C-12368, prepared by Boyle Engineering Corporation, 111p.

Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986, *Hydrogeological Units of Florida*. Florida Department of Natural Resources, Bureau of Geology, Special Publication 28, 9p.

Walton, W. C., 1960, *Leaky Artesian Aquifer Conditions in Illinois*, Report of Investigation 39, Illinois State Water Survey.

Report Supplement

Lithologic Logs:

- ASR-TPW
- SZMW-1
- SZMW-2
- SMW-1R

MWH

LITHOLOGY

W-2C ASR SYSTEM - NSTS

WELL NUMBER	ASR (L1028)
PERMIT NUMBER	247165-001-UC
JOB NUMBER	3220194.363702
OWNER	City of Cape Coral

DEPTH (ft bls)	DESCRIPTION
0-10	Shell Fragments (80%): white N9 and yellowish gray 5Y 8/1; predominantly bi-valves. Sandstone (20%): light brown 5YR 5/6; carbonate; weathered; high porosity.
10-30	Limestone (70%): very light gray N8; micrite and sparite; friable; moderately high porosity. Marl (30%): very light gray N8; soft.
30-50	Clay: dark greenish gray 5GY 4/1; moderately hard; trace of silt.
50-70	Clay: greenish gray 5GY 6/1; moderately hard; trace of silt.
70-80	Limestone: yellowish gray 5Y 8/1; biomicrite; high porosity; friable; 3-4% fine phosphate.
80-100	Shell fragments: grayish orange pink 5YR 7/2; large (1/2”); trace of Sand and Marl.
100-120	Sandstone: medium gray N5; fine to medium quartz; high porosity; well sorted; low HCl reactivity; ~5-6% phosphate.
120-130	Sandstone (50%): medium gray N5; fine to medium quartz; high porosity; well sorted; low HCl reactivity; ~5-6% phosphate. Limestone (50%): white N9 and very light gray N8; micrite; friable; high porosity; 10-15% very fine phosphate.
130-160	Limestone: white N9 and very light gray N8; biomicrite; friable; high porosity; 10-15% very fine phosphate.
160-180	Limestone: white N9 and very light gray N8; biomicrite; friable; high porosity; 5-10% very fine phosphate.
180-190	Limestone (90%): white N9 and very light gray N8; biomicrite; friable; high porosity; 5-10% very fine phosphate. Marl (10%): very light gray N8; very soft.
190-210	Limestone (80%): white N9 and very light gray N8; biomicrite; friable; high porosity; 5-10% very fine phosphate; trace of shell fragments. Marl (20%): very light gray N8; very soft.
210-220	Limestone (60%): yellowish gray 5Y 8/1; biomicrite; friable; high porosity; 4-5% fine phosphate; trace of shell fragments.

DEPTH (ft bls)	DESCRIPTION
	Marl (40%): light olive gray 5Y 6/; very soft.
220-230	Marl (60%): light olive gray 5Y 6/; very soft. Limestone (40%): yellowish gray 5Y 8/1; biomicrite; friable; high porosity; 4-5% fine phosphate; trace of shell fragments.
230-240	Marl (60%): light olive gray 5Y 6/; very soft. Limestone (30%): yellowish gray 5Y 8/1; biomicrite; moderate porosity; friable; 4-5% fine phosphate; trace of shell fragments. Clay (10%): greenish gray 5GY 6/1; soft.
240-250	Limestone (80%): very light gray N8; biomicrite; moderately high porosity; hard; 3-4% fine phosphate; trace of shell fragments; trace of coarse phosphate. Marl (20%): very light gray N8 to yellowish gray 5Y 8/1; soft.
250-270	Marl (80%): very light gray N8 to yellowish gray 5Y 8/1; soft. Limestone (20%): very light gray N8; biomicrite; moderate porosity; hard; 3-4% fine phosphate; trace of shell fragments; trace of coarse phosphate.
270-280	Marl (70%): very light gray N8 to yellowish gray 5Y 8/1; soft. Limestone (30%): very light gray N8; biomicrite; moderate porosity; moderately hard; 3-4% fine phosphate; trace of shell fragments.
280-290	Marl (60%): light greenish gray 5GY 8/1; soft. Limestone (40%): very light gray N8 to yellowish gray 5Y 8/1; biomicrite; moderate porosity; hard; 2-3% fine phosphate.
290-300	Limestone (50%): very light gray N8; biomicrite; moderate porosity; hard; 4-5% fine phosphate; trace of fossils. Marl (50%): very light gray N8; soft.
300-310	Marl (70%): light gray N7 to light olive gray 5Y 5/2; soft. Limestone (30%): very light gray N8; biomicrite; moderately high porosity; moderately hard; 3-4% fine phosphate.
310-330	Marl (90%): light gray N7 to pale olive 10Y 6/2; soft. Limestone (10%): very light gray N8; biomicrite; moderately high porosity; moderately hard; 3-4% fine phosphate.
330-340	Marl: pale olive 10Y 6/2; very soft.
340-350	Marl (90%): light gray N7 to pale olive 10Y 6/2; soft. Limestone (10%): very light gray N8; biomicrite; moderately high porosity; moderately hard; 3-4% fine phosphate.
350-380	Marl (90%): pale olive 10Y 6/2; soft; 2-3% fine phosphate. Limestone (10%): yellowish gray 5Y 7/2; micrite; moderate porosity; moderately hard.
380-390	Marl (80%): pale olive 10Y 6/2; soft; 2-3% fine phosphate. Limestone (20%): yellowish gray 5Y 7/2; micrite; moderate porosity; moderately hard.
390-410	Marl (70%): light olive gray 5Y 5/2; soft; 1-2% fine phosphate. Limestone (30%): yellowish gray 5Y 7/2; micrite; moderate porosity; moderately hard.

DEPTH (ft bls)	DESCRIPTION
410-430	Marl (80%): yellowish gray 5Y 7/2; soft; 1-2% fine phosphate. Limestone (20%): yellowish gray 5Y 7/2; micrite; moderate porosity; moderately hard.
430-440	Limestone (60%): yellowish gray 5Y 7/2; micrite; moderate porosity; moderately hard. Marl (40%): yellowish gray 5Y 7/2; soft; 1-2% fine phosphate.
440-460	Limestone (90%): yellowish gray 5Y 7/2; biomicrite; moderate porosity; moderately hard. Marl (10%): yellowish gray 5Y 7/2; soft; 1-2% fine phosphate.
460-490	Limestone: yellowish gray 5Y 7/2; biomicrite; high porosity moderately soft.
490-500	Limestone (95%): medium light gray N6; biomicrite; high porosity; moderately hard. Marl (5%): yellowish gray 5Y 7/2; soft.
500-530	Limestone (90%): yellowish gray 5Y 7/2; biomicrite; high porosity; moderately hard; fossiliferous. Marl (10%): yellowish gray 5Y 7/2; soft.
530-560	Limestone: yellowish gray 5Y 8/1; biomicrite; high moldic and vuggy porosity moderately hard; trace sparite.
560-590	Limestone: yellowish gray 5Y 8/1; biomicrite; high porosity moderately hard.
590-600	Limestone: yellowish gray 5Y 8/1; biomicrite; high porosity moderately hard; trace sparite.
600-620	Limestone (90%): yellowish gray 5Y 7/2; biomicrite; moderate moldic porosity; moderately hard; 2% fine phosphate. Marl (10%): yellowish gray 5Y 7/2; soft; 1-2% fine phosphate.
620-630	Limestone (50%): yellowish gray 5Y 7/2; biomicrite; moderate moldic porosity; moderately hard; 2% fine phosphate. Marl (50%): mottled very light gray N8 to white N9; soft; moderate to high plasticity; 7% fine to medium phosphate.
630-640	Limestone (70%): yellowish gray 5Y 7/2 and very pale orange 10YR 8/2; biomicrite; low porosity; moderately soft; 3-4% very fine phosphate. Marl (30%): very light gray N8; moderately hard; low porosity; low plasticity.
640-645	Marl: very light gray N8; moderately soft; low porosity; high plasticity.
645-650	Dolomitic Limestone: yellowish gray 5Y 8/1; biomicrite; low porosity; 4-5% very fine phosphate; trace of shell fragments.
650-660	Limestone (70%): very pale orange 10YR 8/2 and yellowish gray 5Y 7/2; biosparite; moderately low porosity; hard. Marl (30%): very light gray N8; soft; moderate plasticity.
660-690	Limestone (80%): very pale orange 10YR 8/2; biosparite; moderate to moderately low porosity; hard.

DEPTH (ft bls)	DESCRIPTION
	Marl (20%): very light gray N8; soft; moderate plasticity.
690-710	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; moderate to moderately high porosity; trace of fossil fragments.
710-720	Limestone (80%): very pale orange 10YR 8/2; biomicrite; calcarenitic; moderate to moderately high porosity; moderately friable; trace of fossil fragments. Marl (20%): very pale orange 10YR 8/2; soft.
720-750	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; moderate to moderately high porosity; moderately friable; trace of fossil fragments.
750-760	Limestone (50%): yellowish gray 5Y 8/1; biomicrite; calcarenitic moderate porosity; friable. Marl (50%): yellowish gray 5Y 8/1; moderately soft; plastic.
760-770	Clay (60%): pale yellowish brown 10YR 6/2; moderately soft; trace of silt. Limestone (40%): pale yellowish brown 10YR 6/2; biomicrite; calcarenitic; moderate porosity; friable.
770-780	Clay (80%): very pale orange 10YR 8/2; moderately soft; trace of carbonate sand. Limestone (20%): very pale orange 10YR 8/; biomicrite; calcarenitic; moderate porosity; friable; trace of fossil fragments.
780-790	Limestone: very pale orange 10YR 8/2 and pale yellowish brown 10YR 6/2; biomicrite; calcarenitic; moderate porosity; friable.
790-800	Limestone (50%): very pale orange 10YR 8/2; biomicrite; calcarenitic moderate porosity; friable. Marl (50%): very pale orange 10YR 8/2; moderately soft; plastic.
800-820	Limestone: very pale orange 10YR 8/2 and pale yellowish brown 10YR 6/2; biomicrite; calcarenitic; moderate porosity; friable.
820-840	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; moderate porosity; friable.
840-860	Limestone: yellowish gray 5Y 8/1; fossiliferous micrite; friable; high vuggy porosity; fossils include shell fragments (12%) and dictyoconus cookie (1%); marl (<1%).
860-880	Limestone: very pale orange 10 YR 8/2; micrite; friable; high vuggy porosity, moldic; shell fragments (10%); coarse grained phosphate (<1%).
880-910	Limestone: very pale orange 10 YR 8/2; micrite; friable; high vuggy porosity; fossils include shell fragments (7%).
910-920	Limestone: very pale orange 10 YR 8/2 to light gray N7; micrite; friable; high vuggy porosity.
920-940	Limestone: very pale orange 10 YR 8/2 to medium light gray N6; micrite; friable; high vuggy and moldic porosity.

DEPTH (ft bls)	DESCRIPTION
940-970	Limestone: grayish orange 10YR 7/4; micrite; friable; high vuggy and moldic porosity.
970-980	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; biogenic; high vuggy and moldic porosity; friable; D. gunteri.
980-1020	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; biogenic; high intergranular porosity; moderately friable.
1020-1030	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; high intergranular porosity; moderately friable; trace of marl.
1030-1050	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; high intergranular porosity; moderately friable.
1050-1060	Limestone (90%): very pale orange 10YR 8/2; biomicrite; calcarenitic; high intergranular porosity; moderately friable. Marl (10%): very pale orange 10YR 8/2; soft.
1060-1070	Limestone: very light gray N8; micrite; calcarenitic; high porosity; friable.
1070-1090	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; high intergranular, vuggy and moldic porosity; biogenic; moderately friable; D. gunteri.
1090-1120	Limestone: very pale orange 10YR 8/2 and very light gray N8; biomicrite; calcarenitic; high intergranular and vuggy porosity; friable; small trace of very fine phosphate.
1120-1160	Limestone: very pale orange 10YR 8/2 and very light gray N8; biomicrite; calcarenitic; high intergranular porosity; friable.
1160-1200	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; high intergranular and moldic porosity; friable; small trace of sparite.

MWH

ATTACHMENT A
LITHOLOGY

W-2C ASR SYSTEM - NSTS

WELL NUMBER	SZMW-1 (L1029)
PERMIT NUMBER	247165-001-UC
JOB NUMBER	3220194.363702
OWNER	City of Cape Coral

DEPTH (ft bls)	DESCRIPTION
0-10	Sandstone: light brown 5YR 5/6; carbonate.
10-20	Limestone: very light gray N8; micrite; high porosity; friable.
20-35	Limestone (70%): very light gray N8; micrite; high porosity; friable. Marl (30%): very light gray N8; soft.
35-60	Clay: pale olive 10Y 6/2; moderately soft; trace of silt.
60-70	Clay: greenish gray 5GY 6/1; soft; trace of silt.
70-80	Limestone: yellowish gray 5Y 8/1; biomicrite; high porosity; friable; 3-4% medium and coarse phosphate.
80-100	Limestone (80%): Limestone: yellowish gray 5Y 8/1; biomicrite; high porosity; friable; 3-4% medium and coarse phosphate. Shell fragments (20%): grayish orange pink 5YR 7/2.
100-120	Sand: greenish gray 5GY 6/1: carbonate; fine; trace of coarse phosphate; trace of shell fragments.
120-130	Limestone (70%): very light gray N8; biomicrite; high intergranular and vuggy porosity; friable; ~5% fine phosphate; trace of shell fragments. Sand (30%): greenish gray 5GY 6/1: carbonate; fine; trace of coarse phosphate; trace of shell fragments.
130-140	Limestone: very light gray N8; biomicrite; high intergranular and vuggy porosity; friable; 4-5% fine phosphate; trace of shell fragments.
140-160	Limestone: light greenish gray 5GY 8/1 and very light gray N8; biomicrite; moderate porosity; hard; fossiliferous.
160-190	Limestone: yellowish gray 5Y 8/1; biomicrite; high moldic porosity; friable; 1-2% fine phosphate; fossiliferous.
190-220	Marl (80%): light olive gray 5Y 6/1 to yellowish gray 5Y 8/1; moderately plastic. Limestone (20%): yellowish gray 5Y 8/1; biomicrite; high moldic porosity; friable; 1-2% fine phosphate; fossiliferous.

DEPTH (ft bls)	DESCRIPTION
220-230	Limestone: yellowish gray 5Y 8/1; high porosity; very friable; trace of shell fragments.
230-240	Clay: greenish gray 5GY 6/1; soft; 1-2% fine phosphate.
240-260	Marl (80%): light olive gray 5Y 6/1; soft; 7-8% fine to very fine phosphate. Limestone (20%): yellowish gray; biomicrite; moderate porosity.
260-270	Limestone (70%): yellowish gray 5Y 8/1; biomicrite; moderately high porosity; friable; 1-2% fine phosphate. Marl (30%): yellowish gray 5Y 8/1; soft.
270-300	Limestone (70%): yellowish gray 5Y 8/1; biomicrite; moderately high porosity; friable; 1-2% fine phosphate. Marl (30%): light greenish gray 5GY 6/1; soft.
300-310	Limestone (70%): yellowish gray 5Y 8/1; biomicrite; moderately high porosity; friable; fossiliferous; 1-2% fine phosphate. Marl (30%): light greenish gray 5GY 6/1; soft.
310-320	Limestone (60%): yellowish gray 5Y 8/1; biomicrite; moderately high porosity; friable; 3-4% fine phosphate. Marl (40%): yellowish gray 5Y 8/1; soft.
320-340	Marl: light greenish gray 5GY 8/1; very soft; bivalve fragments.
340-370	Marl (90%): light greenish gray 5GY 8/1; very soft; 4-5% very fine phosphate. Limestone (10%): yellowish gray 5GY 8/1; micrite; moderately hard.
370-400	Marl (80%): light greenish gray 5GY 8/1; very soft; 4-5% very fine phosphate. Limestone (20%): yellowish gray 5GY 8/1; micrite; hard.
400-430	Limestone (60%): yellowish gray 5Y 8/1; micrite; moderately high porosity; moderately friable; 2-3% fine phosphate. Marl (40%): very light gray N8; soft.
430-440	Limestone (50%): yellowish gray 5Y 8/1; micrite; moderately high porosity; moderately friable; 2-3% fine phosphate. Marl (50%): very light gray N8; soft.
440-450	Limestone (90%): yellowish gray 5Y 8/1; micrite; high porosity; moderately hard. Marl (10%): yellowish gray 5Y 8/1; soft.
450-480	Limestone: yellowish gray 5Y 8/1; micrite; high porosity; moderately hard; fossiliferous.
480-520	Limestone: yellowish gray 5Y 8/1; biomicrite; moderately high vuggy and moldic porosity; hard; fossiliferous.
520-540	Limestone: white N9 to light gray N7: biomicrite; moderate vuggy and moldic porosity; hard; 2-3% very fine phosphate.

DEPTH (ft bls)	DESCRIPTION
540-560	Limestone (50%): very light gray N8; biomicrite; intergranular and moldic porosity; 2-3% very fine phosphate. Dolomitic Limestone (50%): medium gray N5; possible fracture porosity; hard.
560-580	Dolomitic Limestone (70%): medium gray N5; possible fracture porosity; hard. Limestone (30%): very light gray N8; biomicrite; intergranular and moldic porosity; 2-3% very fine phosphate.
580-590	Limestone: light olive gray 5Y 6/1; micrite; high intergranular and vuggy porosity; friable.
590-600	Dolomitic Limestone (70%): medium gray N5; possible fracture porosity; hard. Limestone (30%): very light gray N8; biomicrite; intergranular and moldic porosity; 2-3% very fine phosphate.
600-620	Limestone (90%): yellowish gray 5Y 7/2; biomicrite; moderate moldic porosity; moderately hard; 2% fine phosphate. Marl (10%): yellowish gray 5Y 7/2; soft; 1-2% fine phosphate.
620-630	Limestone: yellowish gray 5Y 7/2; biomicrite; high moldic porosity; moderately hard; 2-3% fine phosphate.
630-660	Marl (70%): very light gray N8; moderately hard; high porosity; low plasticity. Limestone (30%): yellowish gray 5Y 7/2: biomicrite; moderate porosity; moderately soft; 3-4% very fine phosphate.
660-680	Marl (70%): very light gray N8; soft; high porosity; moderate plasticity. Limestone (30%): yellowish gray 5Y 7/2 and very light gray N8; biomicrite; moderate porosity; friable.
680-710	Marl (90%): very light gray N8; soft; plastic. Limestone (10%): very light gray N8; micrite; moderate porosity; friable.
710-720	Limestone (80%): very pale orange 10YR 8/2; biomicrite; calcarenitic; moderate to moderately high porosity; moderately friable; trace of fossil fragments. Marl (20%): very pale orange 10YR 8/2; soft.
720-750	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; moderate to moderately high porosity; moderately friable; trace of fossil fragments.
750-760	Limestone (50%): yellowish gray 5Y 8/1; biomicrite; calcarenitic moderate porosity; friable. Marl (50%): yellowish gray 5Y 8/1; moderately soft; plastic.
760-770	Clay (60%): pale yellowish brown 10YR 6/2; moderately soft; trace of silt. Limestone (40%): pale yellowish brown 10YR 6/2; biomicrite; calcarenitic; moderate porosity; friable.
770-780	Clay (80%): very pale orange 10YR 8/2; moderately soft; trace of carbonate sand. Limestone (20%): very pale orange 10YR 8/; biomicrite; calcarenitic; moderate porosity; friable; trace of fossil fragments.

DEPTH (ft bls)	DESCRIPTION
780-790	Limestone: very pale orange 10YR 8/2 and pale yellowish brown 10YR 6/2; biomicrite; calcarenitic; moderate porosity; friable.
790-800	Limestone (50%): very pale orange 10YR 8/2; biomicrite; calcarenitic moderate porosity; friable. Marl (50%): very pale orange 10YR 8/2; moderately soft; plastic.
800-820	Limestone: very pale orange 10YR 8/2 and pale yellowish brown 10YR 6/2; biomicrite; calcarenitic; moderate porosity; friable.
820-840	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; moderate porosity; friable.
840-860	Limestone: yellowish gray 5Y 8/1; fossiliferous micrite; friable; high vuggy porosity.
860-880	Limestone: very pale orange 10 YR 8/2; micrite; friable; high vuggy porosity, moldic; shell fragments (10%); coarse grained phosphate (<1%).
880-910	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; vuggy; high intergranular and vugular porosity; hard; fossiliferous.
910-920	Limestone: very pale orange 10YR 8/2; micrite; calcarenitic; high intergranular porosity; friable.

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LITHOLOGY

W-2C ASR SYSTEM - NSTS

WELL NUMBER	SZMW-2 (L1030)
PERMIT NUMBER	247165-001-UC
JOB NUMBER	3220194.363702
OWNER	City of Cape Coral

DEPTH (ft bls)	DESCRIPTION
0-10	Regolith (50%): grayish brown 5YR 3/2; unconsolidated; organic; trace of clay. Shell Fragments (50%): yellowish gray 5Y 7/2.
10-20	Limestone: yellowish gray 5Y 7/2 to very light gray N8; high porosity; friable; weathered. ; trace of shell fragments.
20-30	Limestone (60%): yellowish gray 5Y 7/2 and very light gray N8; high porosity; friable. Clay (40%): light olive gray 5Y 5/2; soft; sandy.
30-40	Clay: light olive gray 5Y 5/2; soft; sandy.
40-70	Clay: greenish gray 5GY 6/1; moderately soft; plastic.
70-80	Clay (50%): greenish gray 5GY 6/1; moderately soft; plastic. Limestone (50%): yellowish gray 5Y 8/1; moderate porosity; friable.
80-90	Limestone: yellowish gray 5Y 8/1; micrite; moderately high porosity; 3-4% very fine phosphate; trace of medium phosphate; traced of silica sand; trace of shell fragments.
90-100	Sand (50%): dark greenish gray 5GY 4/1; silica; 2-3% very fine phosphate; trace of clay; slightly cohesive. Limestone (50%): yellowish gray 5Y 8/1; micrite; moderately high porosity; friable.
100-120	Sand: dark greenish gray 5GY 4/1; silica; 4-5% very fine phosphate; trace of clay; slightly cohesive; trace of shell fragments.
120-150	Limestone (60%): yellowish gray 5Y 8/1; micrite; biogenic; high porosity; friable; bryzoans. Sand (40%): light olive gray 5Y 6/1; silica; 7-8% very fine phosphate.
150-180	Limestone (50%): yellowish gray 5Y 8/1; micrite; biogenic; high porosity; friable; bryzoans. Sand (40%): light olive gray 5Y 6/1; silica; 7-8% very fine phosphate. Shell fragments (10%); very light gray N8; predominately bi-valves.
180-190	Limestone (70%): light olive gray 5Y 6/1; micrite; biogenic; high porosity; moderately friable. Sand (40%): light olive gray 5Y 6/1; silica; 7-8% very fine phosphate.

DEPTH (ft bls)	DESCRIPTION
190-200	Limestone: yellowish gray 5Y 8/1; micrite; biogenic; high porosity; moderately friable; 1-2% very fine phosphate; trace of sand; trace of shell fragments.
200-210	Limestone (60%): yellowish gray 5Y 8/1; micrite; biogenic; high porosity; moderately friable; 1-2% very fine phosphate; trace of shell fragments. Sand (40%): light gray; silica; 10-15% very fine phosphate.
210-220	Limestone (50%): yellowish gray 5Y 8/1; micrite; moderately high porosity; moderately friable; 1-2% very fine phosphate; trace of shell fragments. Marl: (50%): light olive gray 5Y 6/1; soft.
220-230	Limestone: very light gray N8; micrite; moderate porosity; friable; trace of shell fragments.
230-240	Clay: olive gray 5Y 4/1 to greenish gray 5GY 6/1; moderately hard to hard; blocky.
240-270	Marl: very light gray N8; soft; 10-15% fine phosphate; trace of shell fragments.
270-280	Limestone (60%): very light gray N8; micrite; high intergranular porosity; friable. Marl (40%): very light gray N8; soft; 10-15% fine phosphate.
280-300	Limestone: white N9 to very light gray N8; micrite; high intergranular porosity; friable; trace of marl.
300-340	Clay: light olive gray 5Y 6/1; soft; moderately plastic; sandy; trace of limestone and shell fragments.
340-380	Clay: mottled light olive gray 5Y 6/1 and greenish gray 5GY 6/1; soft; moderately plastic; sandy; trace of limestone.
380-410	Clay (90%): mottled light olive gray 5Y 6/1 and greenish gray 5GY 6/1; soft; moderately plastic; sandy. Limestone (10%): very light gray; micrite.
410-420	Clay (80%): mottled light olive gray 5Y 6/1 and pale olive 10Y6/2; soft; moderately plastic; sandy. Limestone (20%): very light gray; micrite; moderate porosity.
420-435	Clay (80%): pale olive 10Y6/2; soft; moderately plastic; sandy. Limestone (20%): very light gray; micrite; moderate porosity.
435-460	Limestone: very light gray N8; micrite; moderately high porosity; few minor vugs; trace of marl; trace of coarse phosphate.
460-490	Limestone: very light gray N8; biomicrite; high intergranular porosity; trace of bedding/lamination; 2-3% very fine phosphate.
490-510	Limestone: very light gray N8; biomicrite; high intergranular porosity; 2-3% very fine phosphate; fossiliferous; D. gunteri.
510-515	Sand: yellowish gray 5Y 7/2; carbonate; very fine to fine; very high porosity; moderately well sorted.

DEPTH (ft bls)	DESCRIPTION
515-520	Limestone: yellowish gray 5Y 7/2; biomicrite; high porosity; moderately friable; fossiliferous; 3-4% very fine phosphate.
520-540	Limestone: light gray N7 to yellowish gray 5Y 8/1; biomicrite; high moldic porosity; hard; fossiliferous; 7-8% very fine phosphate.
540-550	Limestone: light gray N7 to yellowish gray 5Y 8/1; biomicrite; high moldic porosity; hard; fossiliferous; 10-15% very fine phosphate.
550-560	Limestone: yellowish gray 5Y 8/1 to light gray N7; biomicrite; high moldic and intergranular porosity; moderately hard; fossiliferous; 7-8% very fine phosphate.
560-580	Limestone; yellowish gray 5Y 8/1; biomicrite and biosparite; moderately high intergranular and moldic porosity; hard; 2-3% very fine phosphate; fossiliferous; D. gunteri.
580-590	Limestone; yellowish gray 5Y 8/1; biomicrite and biosparite; moderately high intergranular and moldic porosity; moderately soft; 2-3% very fine phosphate.
590-600	Limestone; yellowish gray 5Y 8/1; biomicrite and biosparite; moderately high intergranular and moldic porosity; hard; 2-3% very fine phosphate.
600-610	Marl; very light gray N8; moderately soft; plastic; 3-4% very fine phosphate.
610-620	Dolomite; medium light gray N6; possibly moderate fracture porosity; hard; 1-2% very fine phosphate.
620-630	Limestone: yellowish gray 5Y 8/1; biomicrite; high vugular and moldic porosity; hard; fossiliferous; 1-2% very fine phosphate.
630-650	Dolomitic Limestone: light olive gray 5Y 6/1; sparitic crystalline texture; moderate porosity.
650-660	Limestone (50%): very light gray N8; micrite; high intergranular porosity; friable. Marl (50%): very light gray N8; soft; trace of fine phosphate.
660-670	Limestone (90%): yellowish gray 5Y 8/1; micrite; high intergranular porosity; friable. Marl (10%): very light gray N8; soft; trace of fine phosphate.
670-680	Limestone: yellowish gray 5Y 8/1; micrite; high intergranular porosity; friable; trace of marl.
680-710	Limestone: yellowish gray 5Y 8/1; biomicrite; high intergranular porosity; moderately friable; fossiliferous.
710-715	Clay: pale yellowish brown 10YR 6/2; moderately hard; moderately plastic.
715-730	Limestone: very pale orange 10 YR 8/2; micrite; calcarenitic; high intergranular porosity; moderately friable.

DEPTH (ft bls)	DESCRIPTION
730-740	Limestone (90%): very pale orange 10 YR 8/2; micrite; calcarenitic; high intergranular porosity; moderately friable. Clay (10%): pale yellowish brown 10YR 6/2; moderately hard; moderately plastic.
740-755	Limestone: very pale orange 10YR 8/2 and yellowish gray 5Y 8/1; biomicrite; high intergranular and moldic porosity; moderately hard; fossiliferous.
755-760	Clay: very pale orange 10YR 8/2; moderately hard; moderately plastic; silty.
760-780	Limestone (70%): very pale orange 10YR 8/2; biomicrite; moderate moldic and intergranular porosity; friable; fossiliferous. Clay (30%): very pale orange 10YR 8/2; moderately hard; moderately plastic; silty.
780-790	Marl: light gray N7; soft; plastic.
790-820	Limestone (80%): very pale orange 10YR 8/2; micrite; calcarenitic; high intergranular porosity; friable. Marl (20%): light gray N7; soft; plastic.
820-850	Limestone: very pale orange 10YR 8/2; micrite; calcarenitic; high intergranular porosity; friable; trace of marl.
850-880	Limestone: very pale orange 10YR 8/2; biomicrite; calcarenitic; vuggy; high intergranular and vugular porosity; hard; fossiliferous.
880-910	Limestone: very pale orange 10YR 8/2; micrite; calcarenitic; high intergranular porosity; friable.

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LITHOLOGY

W-2C ASR SYSTEM - NSTS

WELL NUMBER	SMW-1R (L1031-R)
PERMIT NUMBER	247165-001-UC
JOB NUMBER	3220194.363702
OWNER	City of Cape Coral

DEPTH (ft bls)	DESCRIPTION
0-10	Shell Fragments (70%): white N9 and yellowish gray 5Y 8/1. Sandstone (30%): light brown 5YR 5/6; carbonate.
10-20	Limestone (80%): very light gray N8; micrite; high porosity; friable. Marl (20%): very light gray N8; soft.
20-40	Clay: pale olive 10Y 6/2; moderately soft; trace of silt.
40-70	Clay: greenish gray 5GY 6/1; moderately soft; trace of silt.
70-80	Limestone: yellowish gray 5Y 8/1; biomicrite; high porosity; friable; 3-4% medium and coarse phosphate.
80-100	Limestone (80%): Limestone: yellowish gray 5Y 8/1; biomicrite; high porosity; friable; 3-4% medium and coarse phosphate. Shell fragments (20%): grayish orange pink 5YR 7/2.
100-120	Clay: dark greenish gray 5GY 4/1; moderately soft; trace of sand; 1-2% medium phosphate.
120-130	Clay (40%): dark greenish gray 5GY 4/1; moderately soft; trace of sand; 5-6 fine phosphate. Marl (30%): yellowish gray 5Y 8/1; soft. Limestone (30%): yellowish gray 5Y 8/1; micrite; friable; trace of bi-valves.
130-140	Clay: light greenish gray 5GY 8/1; silty; soft; 1-2% medium phosphate.
140-160	Limestone (90%): yellowish gray 5Y 8/1; micrite; high porosity; friable; shell fragments (0.5-2 cm). Marl (10%): very light gray N8; soft; ~40% very fine phosphate; trace of medium phosphate.
160-180	Limestone (50%): yellowish gray 5Y 8/1 to light olive gray 5Y 6/1; spar-micrite; moderate porosity; moderately friable; 1-2% very fine phosphate. Carbonate Mud (50%): greenish gray 5GY 6/1; soft; 1-2% very fine phosphate.
180 - 200	Limestone (65%): yellowish gray 5Y 8/1 to white N9; spar micrite, friable, 25% fossils; 6% very fine grained phosphate. Carbonate Mud (35%): greenish gray 5GY 6/1; soft; low plasticity, 6% very fine grained phosphate.

DEPTH (ft bls)	DESCRIPTION
200-220	Marl (80%): very light gray N8; very soft; 3-4% very fine phosphate; trace of medium phosphate; trace of shell fragments. Limestone (20%): yellowish gray 5Y 8/1 to very light gray N8; micrite; moderate porosity; moderately friable.
240-260	Marl (90%): very light gray N8; soft; 10-15% very fine and fine phosphate. Limestone (10%): yellowish gray 5Y 8/1; biomicrite; moderate porosity; friable.
260-270	Limestone (90%): yellowish gray 5Y 8/1; biomicrite; moderate to moderately high porosity; moldic; moderately friable. Marl (10%): very light gray N8; soft; 3-4% very fine phosphate.
270-280	Marl (95%): very light gray N8; soft; 3-4% very fine phosphate. Limestone (5%): very light gray N8; micrite; friable.
280-300	Marl (80%): very light gray N8; soft; 3-4% very fine phosphate. Limestone (20%): very light gray N8; micrite; friable.
300-330	Marl: very light gray N8; very soft; 3-4% very fine phosphate; trace of limestone; trace of shell fragments.
330-360	Marl: very light gray N8 and yellowish gray 5Y 8/1; very soft; 5-6% very fine phosphate; trace of limestone; trace of shell fragments.
360-390	Marl: greenish gray 5GY 6/1 and yellowish gray 5Y 8/1; very soft; 6-7% very fine phosphate; trace of limestone; trace of shell fragments.
390-410	Marl (85%): greenish gray 5GY 6/1 and yellowish gray 5Y 8/1; very soft; 6-7% very fine phosphate. Limestone (15%): yellowish gray 5Y 8/1; micrite; moderate porosity; moderately friable.
410-430	Marl (70%): yellowish gray 5Y 8/1; very soft; 6-7% very fine phosphate; trace of shell fragments. Limestone (30%): yellowish gray 5Y 8/1; biomicrite; moderate porosity; moderately friable.
430-440	Limestone (50%): yellowish gray 5Y 8/1; biomicrite; fossiliferous; moderate porosity; moderately friable. Marl (50%): yellowish gray 5Y 8/1; very soft; 6-7% very fine phosphate; trace of shell fragments.
440-450	Limestone (60%): yellowish gray 5Y 8/1; biomicrite; fossiliferous; moderate porosity; moderately friable. Marl (40%): yellowish gray 5Y 8/1; very soft; 6-7% very fine phosphate; trace of shell fragments.
450-460	Limestone: yellowish gray 5Y 8/1 and very light gray N8; biomicrite; high vuggy and moldic porosity; hard; fossiliferous.
460-480	Limestone: very light gray N8; biomicrite; high moldic porosity; moderately hard; fossiliferous.

DEPTH (ft bls)	DESCRIPTION
480-490	Limestone: yellowish gray 5Y 8/1; biomicrite; high intergranular and moldic porosity; moderate friable; 1-2% very fine phosphate.
490-520	Limestone: very light gray N8; biomicrite; high intergranular, moldic and vuggy porosity; hard; gunteri.
520-540	Limestone: very light gray; biomicrite; high moldic and intergranular porosity; friable; trace of sparite.
540-545	Limestone: white N9; biomicrite; moderately high intergranular porosity; hard; trace of sparite.

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