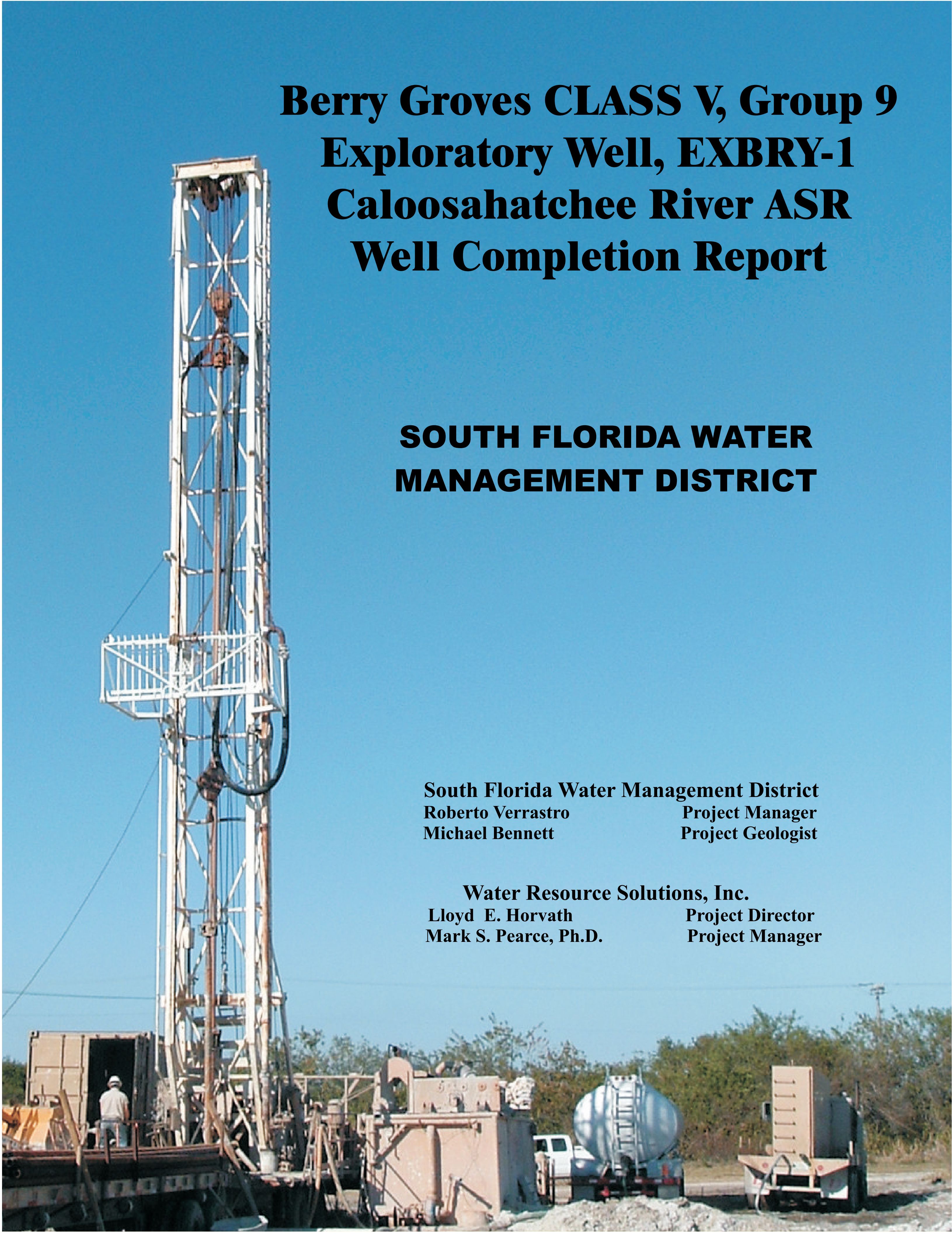
# Berry Groves CLASS V, Group 9 Exploratory Well, EXBRY-1 Caloosahatchee River ASR Well Completion Report



## SOUTH FLORIDA WATER MANAGEMENT DISTRICT

**South Florida Water Management District**

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| Roberto Verrastro | Project Manager |
| Michael Bennett | Project Geologist |

**Water Resource Solutions, Inc.**

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| Lloyd E. Horvath | Project Director |
| Mark S. Pearce, Ph.D. | Project Manager |

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# Exploratory Well EXBRY-1
# Caloosahatchee River
# ASR Pilot Project
# Well Completion Report

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February, 2005

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# EXECUTIVE SUMMARY

The purpose of this project is to provide site-specific hydrogeologic information to address storage zone selection and well capacity, and to obtain information concerning confinement, hydraulic properties, lithology, and stratigraphic information about the Floridan Aquifer System at the Berry Groves Site, in Hendry County, Florida. Data collected from the testing and monitoring of the constructed exploratory well, coupled with additional information from the other wells completed on site, will be instrumental in the development of this project.

This report primarily describes the drilling, construction, and testing of the 24-inch Class V exploratory well identified as EXBRY-1. Well EXBRY-1 is the designation assigned by the Florida Department of Environmental Protection (FDEP) under permit number 201247-001-UC. The ASR pilot project site is on SFWMD-owned land referred to as "Berry Groves", adjacent to State Road 80 and just east of the Townsend Canal. The site is accessible through Berry Groves citrus farm.

The scope of the investigation included drilling the test hole to a maximum depth of 1,398 feet, performing a geophysical logging program, setting 24-inch, 0.5-inch wall mild steel casing to a depth of 634 feet, and performing reverse air drilling and testing to total depth to identify an appropriate ASR storage interval. Significant drilling difficulties were encountered between 650 and 900 feet below land surface (bls) due to unconsolidated sediments and high sand production associated with caving of the wellbore. In the end, the total depth of the well remained slightly deeper than 650 feet bls due to continued sloughing of very fine "sugar" sand into the wellbore.

The main findings from this exploratory well include:

- The top of the FAS was identified at a depth of 520 feet bls based on log interpretation and correlation with nearby wells.

- Lithologic descriptions and geophysical logs were not sufficient to identify the boundary of the flow zone intercepted in the subsurface near 634 feet bls, but the geophysical logs were especially useful in identifying the troublesome sand producing intervals encountered when drilling by reverse-air circulation.

- Specific capacity testing performed during reverse-air drilling indicated the existence of a good flow zone that appears to be below 634 feet bls. Specific capacity values ranged up to 35 gpm/ft for the interval between the base of casing and 900 feet bls. The final value of specific capacity for the interval immediately below the casing, 634 to 658 feet bls, measured 23 gpm/ft.

- Analysis of the data developed from an Aquifer Performance Test (APT) performed at the end of well construction indicated that a flow zone was intercepted near the base of the casing. The transmissivity of the flow zone, from the hydraulic analysis, was determined to be approximately 20,000 gpd/ft (2,700 $ft^2/d$).

- Water quality data indicate that the potential storage interval has a TDS value near 2,000 mg/l and a chloride level near 900 mg/l. This water quality is excellent for highly efficient recovery if other formation attributes are good.

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# 1.0 INTRODUCTION

## 1.1 Background

The South Florida Water Management District (SFWMD), in association with U.S. Army Corps of Engineers (USACE), selected the Berry Groves site as the location for the Caloosahatchee River Basin Aquifer Storage and Recovery (ASR) Pilot Project. The purpose of the Caloosahatchee River ASR Pilot Project is to address technical and regulatory uncertainties associated with implementing ASR systems in the Caloosahatchee River Basin. As an initial part of that program, it was determined that an exploratory well would be drilled at this location to develop site-specific hydrogeological data in preparation for the construction of a Pilot ASR system at this site. The construction of this well was permitted through the Florida Department of Environmental Protection (FDEP).

The SFWMD awarded the contract to construct this well to Diversified Drilling Corporation (DDC) of Tampa, Florida. DDC mobilized to the site on May 6, 2003.

## 1.2 Scope

This report primarily describes the drilling, construction, and testing of the Class V ASR exploratory well identified as EXBRY-1. Analysis of the data obtained during the construction of this well is also provided.

## 1.3 Project Description

The EXBRY-1 site is located in the northwestern quadrant of the northeastern corner of Section 6, Township 44 South, Range 28 East, southwest of the City of LaBelle, in Hendry County, Florida. The site is on property owned by the SFWMD that is referred to as “Berry Groves”. The project site is adjacent to State Road 80 and borders the eastern edge of the Townsend Canal, and it is accessible through Berry Groves citrus farm. The well is located approximately 1,280 feet east of the Townsend Canal and approximately 350 feet south of the east-west trending Header Canal. The well coordinates are latitude 26$^o$41’13.22” and longitude 81$^o$33’13.69” (NAD83) as measured by the SFWMD using GPS. The site and test well locations are shown on Figure 1-1.

Permit number 201247-001-UC was issued by the Florida Department of Environmental Protection (FDEP) on April 14, 2003 to construct the exploratory well, EXBRY-1. The permit was issued by the FDEP’s West Palm Beach, Florida office. A copy of the Underground Injection Control Permit is presented in Appendix 1-1.

## 2.0 EXPLORATORY DRILLING AND WELL CONSTRUCTION

Drilling of the exploratory well (EXBRY-1) was performed by Diversified Drilling Corporation (DDC) using a platform-mounted table-driven rotary rig equipped with a blowout preventor at the wellhead for fluid control. Final well construction details are presented on Figure 2-1. Wellhead construction details are illustrated on Figure 2-2.

An approved containment pad for well construction activities, Figure 2-3, was installed prior to initiation of drilling activities. The pad consisted of a buried, high-density polyethylene (HDPE) liner and a two-foot-high, earthen berm, which was also covered with an HDPE layer. On May 12, 2003, pad monitoring wells were installed at the four corners of the containment pad using an 8-inch-diameter auger bit. Each of the pad monitoring wells was constructed of PVC and completed above land surface. Table 2-1 provides a summary of the pad monitoring well construction details. A schematic of the typical monitoring well construction details is presented on Figure 2-4. A survey was conducted to establish the elevation values of the pad monitoring well risers and vault box lids relative to the National Geodetic Vertical Datum of 1929 (NGVD, 29). A copy of the survey is presented in Appendix 2-1. Following the completion of well development, the initial groundwater sampling for background concentrations was performed on May 12, 2003. Table 2-2 presents field-measured results for groundwater samples collected during the initial sampling event. Pad monitoring well water levels were measured weekly and the water level elevation values charted (Appendix 2-2A). Each of the pad monitoring wells was sampled on a weekly basis throughout the duration of the project. Field-measured parameters included chloride, pH, temperature, and specific conductance. Pad monitoring well water quality for each reporting period is graphically depicted in Appendix 2-2B and summarized in tables in Appendix 2-2C. Groundwater samples collected from the pad monitoring wells were periodically analyzed by Sanders Laboratory for chloride, pH, total dissolved solids (TDS), and specific conductance for comparison with field analyses.

Formation samples, i.e. drill cuttings, were collected and described at 5-foot depth intervals during pilot-hole drilling (See Geologist's Log in Appendix 3-1). Lithologic descriptions in question, from poor cuttings recovery during pilot-hole drilling, were verified as needed during reaming operations. Weight-on-bit and rate-of-penetration data were recorded every five feet while advancing the pilot hole. A summary of this information and a graphical depiction of the data are presented in Appendix 2-3

Four-inch-diameter cores were collected at specified depths during pilot-hole drilling. A coring log detailing lithology, core length, and sample percent recovery is provided in Table 2-3. Inclination surveys were performed at 60-foot depth intervals in both pilot and reamed boreholes using a wire-line inclination survey instrument with an inclination unit capable of measuring from 0 to 1.5 degrees of deviation from vertical. Inclination survey results are provided in Table 2-4. The inclination survey results indicate deviation values within an acceptable range. A summary of geophysical logging events performed during the well construction is provided in Table 4-1 of this report.

## 2.1 42-inch Surface Casing Installation

On May 6, 2003, DDC mobilized the drilling rig and all equipment to the site. Well construction at the site began with installation of 60-inch-diameter steel pit casing to five feet below pad level (bpl). The single joint of casing was installed to support the surficial sediments and act as a sump for drilling fluids. On May 7, 2003, a 42-inch-diameter steel surface casing was driven to 40 feet bpl positioned concentrically inside the 60-inch pit casing. Mill certificates for the surface casing are provided in Appendix 2-4.

## 2.2 34-inch Intermediate Casing Installation

On May 15, 2003, pilot-hole drilling using the mud-rotary method was initiated from the base of the 42-inch pit casing with a 9-5/8-inch-diameter bit. On May 19, 2003, following pilot-hole drilling to 235 feet bpl, the borehole was conditioned for geophysical logging. Geophysical logging performed that same day included caliper/natural gamma ray, dual induction w/SP log, and borehole compensated (BHC) sonic with variable density log (VDL). Based on an analysis of drill cuttings and geophysical logs, a casing setting depth of approximately 225 feet bpl was selected for the intermediate casing. This casing string was set at this depth in accordance with the construction specifications developed by the SFWMD to provide additional hole stability in the upper portion of the wellbore.

Pilot-hole reaming began on May 21, 2003 and was completed at a depth of 225 feet bpl on May 23, 2003 using a 40-inch-diameter staged bit. On May 28, 2003, after completion of geophysical logging (caliper/natural gamma ray), installation of the 34-inch intermediate casing was attempted. However, the casing string could not be advanced past a depth of ±185 feet bpl. The casing string was therefore removed from the borehole.

On May 30, 2003, after the borehole was re-reamed to 225 feet bpl and after completion of the caliper and natural gamma ray logging runs, the 34-inch casing was re-installed to a depth of 218.8 feet bpl. The intermediate casing string consists of three approximate 60-foot-long pipe joints and a 44.44-foot-long cut joint. The casing string length measured 225.5 feet. There was 6.7 feet of pipe left above pad level prior to the final cut. Certified welders welded each casing joint at the rig floor before lowering the casing into the borehole. A tally of the 34-inch casing string is presented in Table 2-5. Mill certificates for the intermediate casing are provided in Appendix 2-4.

On May 30, 2003, the intermediate, 34-inch casing was grouted in place using the pressure grouting method. Approximately 675 cubic feet (572 sacks) of neat cement were pumped. The annular fill from this first stage was 96% of the theoretical fill volume and covered the depth interval from 225 to 105 feet bpl. A temperature log to determine the top of cement was performed after pressure grouting the first stage for the intermediate casing installation. The temperature log also indicated the top of cement was at 105 feet bpl. The cement plug inside the 34-inch casing was tagged at 213 feet bpl. Cementing of the remaining annulus was accomplished on June 2, 2003 in a second stage by tremie grouting from 105 feet bpl to pad level. A total volume of 432 cubic feet (366 sacks) of neat cement was used for this second cementing event. ASTM Type II Portland cement was used in all grouting operations.

### 2.3 Pilot-Hole Drilling to Total Depth

On June 4, 2003, the cement plug inside the 34-inch casing was drilled out and the wellbore cleaned out to an approximate depth of 225 feet bpl. Pilot-hole drilling by the mud-rotary method was initiated on June 5, 2003 in the interval from 223 to 555 feet bpl using a 9-5/8-inch-diameter bit. Drill cuttings continued to be collected and described on a five-foot basis during all stages of pilot-hole drilling. Two sets of well cuttings were collected and provided to the SFWMD. The SFWMD maintained one set for their use and forwarded the second set to the Florida Geological Survey (FGS) in Tallahassee. Cores were collected in the intervals 300 to 305 feet bpl (2.6 feet recovered), 305 to 312 feet bpl (1.9 feet recovered), and 312 to 320 feet bpl (8.4 feet recovered). See Table 2-3 for detailed coring results.

On June 16, 2003, pilot-hole drilling resumed using a 7-7/8-inch-diameter drill bit for the purpose of enhancing the resolution of the logs specified to be run on the completed pilot hole. The nominal 8-inch-diameter pilot hole was advanced to 1,074 feet bpl by June 25, 2003. Cores were collected in the intervals 555 to 575 feet bpl (7.4 feet recovered), 756 to 776 feet bpl (8.15 feet recovered), and 901 to 921 feet bpl (16.0 feet recovered) while drilling the nominal 8-inch hole. At a depth of 1,074 feet, it appeared that one of the mud circulating pumps failed, and the drill string became lodged in the borehole.

During the next nine weeks, DDC worked to remove the lodged drill string from the wellbore. On June 30, 2003, 751 feet of drill pipe were removed from the wellbore. DDC made the decision to use casing jars to free the stuck pipe from the hole. On July

15, 2003, while pulling up on the stuck drill string, the upper section of this rig's derrick collapsed. On July 29, 2003, the damaged rig was removed.

On August 5, 2003, a replacement-drilling rig was centered over the well. On August 15, 2003, the drill pipe was freed to a depth of 1,036 feet. Between August 18th to the 21st, the free portion of the drill string was tripped out of the wellbore. On August 27, 2003, the pilot-hole was reamed using a 9-5/8-inch bit from 555 feet bpl to the top of the remaining drill pipe lodged at 1,036 feet bpl. On August 29, 2003, an 8-5/8-inch core barrel was used to over-drill the remaining drilling assembly and remove it from the wellbore.

Pilot-hole drilling using a 9-5/8-inch bit with intermittent coring was resumed on September 3, 2003 in the interval from 1,074 to 1,090 feet bpl. Cores were collected in the intervals 1,090 to 1,110 feet bpl (2.9 feet recovered) and 1,110 to 1,120 feet bpl (3.7 feet recovered). Core intervals and core recovery are summarized in Table 2-3. On September 11, 2003, pilot-hole drilling resumed using the previously identified 7-7/8-inch drill bit in the interval from 1,116 to 1,305 feet bpl. A core was collected in the interval from 1,305 to 1,325 feet bpl with 9.3 feet of recovery. On September 15, 2003, the 7-7/8-inch pilot-hole was advanced from 1,305 to 1,398 feet bpl. While drilling this interval, mud circulation was lost at approximately 1,385 feet bpl. A one-foot bit drop also occurred at this depth indicating the presence of a cavity. A second cavity, approximately three feet in height, was encountered at a depth of 1,390 feet bpl. The pilot hole was terminated at 1,398 feet bpl as efforts to restore circulation failed. On September 16, 2003, approximately 7.5 cubic feet of limestone gravel were poured down the drill string from the surface to backplug the open intervals where circulation was lost. The top of gravel inside the pilot hole was tagged at 1,320 feet bpl. Schlumberger arrived on-site on September 16, 2003 to perform specialty geophysical logging of the pilot hole.

Geophysical logging, including spectral gamma ray, array induction, lithodensity/compensated neutron, and elemental capture spectroscopy logs, were run on September 16, 2003. On the following day, geophysical logging continued and included full-bore micro imager, caliper, dual induction, dipole sonic, long space sonic, and dipmeter logs. On September 22, 2003, a cement plug consisting of 12 cubic feet (10 sacks) of neat cement was placed atop the gravel. The plug was tagged the following day at 1,313 feet bpl. On September 24, 2003, a cement bridge plug was installed in the pilot hole at 750 feet bpl in preparation for reaming of the 34-inch borehole and setting of the 24-inch casing. A bridge plug was utilized as an alternative to filling the hole with gravel since it would be easier and faster to clean mud from the original drilled hole then to clean the gravel from the hole once the 24-inch casing was set. The bridge plug was cemented in place by pumping 24 cubic feet (20 sacks) of neat cement on top of the bridge plug. From September 25th to the 26th, after tagging the cement top inside the pilot hole at 740 feet bpl, approximately 82.5 cubic feet (165 sacks) of ¾-inch gravel were placed atop the cemented bridge plug. The top of gravel was tagged on September 26th at a depth of 625 feet bpl.

### 2.4 24-inch Production Casing Installation

After discussions between the SFWMD staff and the WRS project team, a casing seat point of 635 feet bpl was selected. Once permission was received from the FDEP to set the production casing at 635 feet bpl, reaming operations were initiated on October 2, 2003. A 34-inch flat-bottom bit was used to begin reaming the pilot hole using the mud-rotary method from the base of the 34-inch-diameter casing set at 218.8 feet bpl to a depth of 635 feet. On October 14, 2003, a target depth of 635 feet bpl was reached. The following day, a caliper/natural gamma ray logging run was performed in the reamed interval from 635 feet bpl to pad level in preparation for setting the production casing.

On October 16, 2003, the 24-inch casing was installed in the reamed borehole to 634 feet bpl. The production casing string consisted of 15 whole joints ranging in length from 39.95 to 42.05 feet, a 25.55-foot cut joint, and a 0.75-foot header joint. The casing string length measured 637.65 feet with 3.6 feet of stick-up above pad level. Certified welders welded each casing joint at the rig floor before placement in the borehole. A tally of the 24-inch casing string is presented in Table 2-6. Mill certificates for the production casing are provided in Appendix 2-4.

On October 16, 2003, the first grouting of the production casing was initiated using the pressure grouting method. The first stage consisted of 1,245 cubic feet (222 barrels) of neat cement. A temperature log was performed after the initial cementing event to estimate the cement top surface. The top of this cement stage was tagged at 303 feet bpl, approximately 16 feet deeper than the estimated top of cement reported at 287 feet bpl from the temperature log data. The annular fill volume for this first cement stage was 86% of the theoretical fill value. Grouting of the remaining annulus was accomplished later that day in a second stage by tremie grouting to pad level. A volume of 926 cubic feet (165 barrels) of cement containing 6% bentonite was used for this second cementing event.

The mechanical integrity of the 24-inch production casing was demonstrated on October 22, 2003, by the satisfactory performance of a 60-minute casing pressure test. A pressure of 101.5 psi was applied to the inside of the casing at the start of the test. A 1.8-psi loss (1.8%) of pressure was recorded over the duration of the 60-minute test. The calibration record for the pressure gauge used in the official test is presented in Appendix 2-5.

### 2.5 Reverse-Air Drilling

On October 28, 2003, the cement plug inside the 24-inch casing was drilled out by reverse-air circulation using a 23-inch-diameter drill bit. The borehole was advanced to 645 feet bpl. Formation water recovered at the surface during reverse-air drilling was routed through pits to provide for the settlement of fines and then discharged to the Header Canal. A sediment barrier was installed around the discharge point in the canal. Aquifer head pressures, discharge volumes, and totalizing flow readings were recorded daily and reported in weekly summary reports. Discharged water volumes are presented in Table 2-7.

On October 29, 2003, a sample of formation water was collected and sent for analysis of the NPDES-screening parameters. On October 30, 2003, laboratory analytical results indicated NPDES-parameter concentrations within acceptable limits for discharge to fresh water. Therefore, water from the well was allowed to flow to the Header Canal. Results for the initial NPDES screening are presented in Appendix 2-6.

On November 3, 2003, drilling operations utilizing the reverse-air method were initiated to remove the gravel backfill using a 9-5/8-inch-diameter drill bit. Large volumes of fine quartz sand were produced from the formation below a depth of approximately 650 feet bpl. From November 6, 2003 to December 5, 2003, intermittent drilling (9-5/8-inch borehole), sand dredging, and cementing operations were performed in attempts to stabilize the formation sand and advance the open hole. A cumulative total of 1,888 cubic feet (336.5 barrels) of neat cement in seven nonconsecutive stages were pumped into the open-hole section of the well. Cement stage volumes ranged from 59 cubic feet (10.5 barrels) to 353 cubic feet (63 barrels). On November 13, 2003, the cement inside the production casing was drilled out to 632 feet bpl using a staged reaming bit (23-inch by 12-inch). The staged bit was also used to center the borehole. The open hole was advanced from 632 feet bpl using a 9-5/8-inch drill bit. On December 8, 2003, the top of cement inside the open hole was tagged at a depth of 722 feet bpl. Table 2-8 serves as a chronology of cementing events and includes cement stage volumes and the tag depths of cement tops and borehole fill.

### 2.6 Revised Open-Hole Drilling Program

Changes to the drilling program were initiated following a re-evaluation of subsurface conditions. These changes, based on recommendations by the driller, included drilling with a larger diameter drill bit, drill pipe, airlines, and using a larger air compressor for increased airlift capacity. This drilling method was selected in an effort to move beyond the sand producing interval and allow flow testing of the upper interval between the base of the casing and 900 feet bpl. On January 7, 2004, drilling operations by reverse-air circulation resumed using a 23-inch drill bit and 6-5/8-inch drill pipe. From January 7th to February 9th, 2004, drilling and intermittent dredging advanced the open hole from 634 to 740 feet bpl. On February 10th, in preparation for a scheduled pump test, the base of the borehole was tagged at 677 feet bpl during the fluid resistivity logging of the hole, indicating the hole had back-filled. Representatives from the SFWMD decided to cancel the planned geophysical logging and pump test due to excessive sand in the wellbore. On February 16, 2004, a specific capacity test was performed prior to cleaning out the accumulated sediment from the wellbore. The results of this testing and other specific capacity testing are presented in Section 4.0.

From February 17th to March 10th, 2004, the open hole was advanced from 661 to 900 feet bpl (total depth). Large volumes of quartz sand and sandstone were removed while dredging in this interval. As the hole was advanced, it was not possible to determine conclusively from which intervals the quartz sand was produced. Specific capacity tests were performed intermittently throughout the drilling and dredging operations within the interval. Section 4.4 of this report details the specific capacity testing. Table 4-3 summarizes the specific capacity test intervals and results. On March 18, 2004, geophysical logging was performed in the open hole to 900 feet bpl. The logging suite included caliper, natural gamma ray, temperature/fluid resistivity (static and dynamic), and impeller flowmeter (static and dynamic).

From March 23rd to June 19th, 2004, intermittent reverse-air drilling, dredging, and well development were performed in the open-hole section of the well between 640 and 900 feet bpl. During this time, sand production was measured using a Rossum sand sampler. Additionally, drawdown measurements were recorded and both specific capacity tests and constant-rate pumping tests were performed during this time interval. Throughout reverse-air drilling operations, the formation produced large quantities of quartz sand that continually filled the borehole whenever drilling/dredging was suspended. Between March 23rd and June 19th, the open hole was never advanced past a depth of 900 feet bpl. It is estimated that a minimum of 500 cubic yards of sand were recovered from this well prior to suspending dredging based on the volume of sand accumulated on-site. The major pile had a trapezoidal shape 15 feet high, 75 feet long, a 20-feet-wide base and a 3-feet-wide top.

On June 7, 2004, a sonic/VDL log was performed to evaluate the cement bond of the production casing due to concerns that formation material from above the casing setting depth may have been falling into the well. The cement bond log was not sufficiently conclusive to determine the degree of cement bond behind the casing due to the large casing size (24 inches) and the poor nature of the formation signal. On June 9, 2004, it was decided that two additional days would be spent in an effort to clean out the well to 670 feet or deeper and then a final aquifer performance test (APT) would be performed over the available open interval.

On June 17, 2004, the bottom of the wellbore was tagged at 658 feet bpl. At that point, DDC was directed to perform the final 24-hour constant-rate APT. The final APT was performed on June 18, 2004. The well was pumped at an average rate of 1,885 gpm for 24 hours and then shut-in for an additional 24 hours. At the end of the APT, water samples were collected for the SFWMD, FGS, and the SFWMD-subcontracted laboratory, U.S. Biosystems. On Monday, June 21, 2004, the well was purged again so that Foster-Wheeler could collect additional water samples for analysis of the Primary and Secondary Drinking Water Standards. At the end of this test period, DDC began to demobilize from the site.

### 2.7 Final Wellhead Installation

After completion of the well construction, a 24-inch flange and 3-foot-long, 24-inch-diameter ASTM A53 steel pipe were welded to the 24-inch production casing with the bottom edge of the lower 24-inch flange set 9 inches above a finished concrete slab. A 2-inch brass ball valve and 6-inch flanged steel gate valve, set above a 6-inch ASTM

A53 steel pipe with flange, are set above the upper 24-inch flange. Wellhead construction details may be reviewed on Figure 2-2.

## 3.0 HYDROGEOLOGIC FRAMEWORK

This section of the report describes the hydrostratigraphy of the project site based on the geologist's field log, geophysical logs from exploratory well EXBRY-1, and correlations with nearby sites. The geologist's lithologic field log, Appendix 3-1, is based on drill cuttings collected and described on site using the Dunham Classification scheme (Dunham, 1962). The FGS have prepared their own lithologic log (Appendix 3-2). Three principal aquifer systems were penetrated in the exploratory well borehole. In descending order of occurrence, they are the surficial aquifer system, intermediate aquifer system, and Floridan aquifer system. Figure 3-1 provides an illustration of a hydrogeologic section for the Caloosahatchee River site. Additionally included are North-South and East-West hydrogeologic cross sections of the site and nearby wells presented as Figure 3-2 and 3-3, respectively. Figure 3-4 provides a map showing the location of the wells utilized in the cross section.

### 3.1 Surficial Aquifer System

Lithologic data indicate that the surficial aquifer is less than 10 feet thick at the project site. The aquifer is comprised of fine grained quartz sand that contains some organic detritus. Similar surficial quartz sand deposits blanket much of the region and are generally considered to have been deposited on the Pamlico terrace, as described by Healey (1975).

### 3.2 Intermediate Aquifer System

The intermediate aquifer system comprises all sediments present between the base of the surficial aquifer system and the top of the Floridan aquifer system. Lithologic data indicate that the intermediate aquifer system is 510 feet thick at the project site. The stratigraphic units that form the intermediate aquifer system at the project site consist of the Buckingham Marl Member of the Tamiami Formation, Peace River Formation of the Hawthorn Group, and the upper 190 feet of the Arcadia Formation of the Hawthorn

Group. The principal hydrostratigraphic units that occur within this interval are the Sandstone and mid-Hawthorn aquifers, however only the Sandstone aquifer contains productive aquifer components at the project site. These productive zones represent 90 feet (<18%) of strata within the intermediate aquifer system. Confining units comprise 300 feet within the system including a 35-foot-thick semi-confining unit of sandy clay. The remaining 120 feet of strata, representing the uppermost Arcadia Formation, consists of sediments of low to moderate permeability, and are not considered productive.

The Buckingham Marl Member of the Tamiami Formation is comprised of gray to green lime mud that typically contains variable amounts of fossil shell, phosphate grains, and quartz sand. The permeability of the unit is generally low. However, lenses of moldic limestone that yield moderate amounts of water are interbedded with the marl in some parts of the region (Weinberg and Cowart, (2001). The Buckingham Marl at the project site extends from 10 to 20 feet below land surface (bls). The marl has low apparent permeability and forms the uppermost confining unit below the surficial aquifer system.

The Peace River Formation of the Hawthorn Group consists of clastic sediments and subordinate amounts of carbonate rocks (Scott, 1988). The formation is about 300 feet thick at the project site and is directly underlain by carbonate rocks of the Arcadia Formation.

The upper part of the Peace River Formation at the project site, between the depths of 20 and 65 feet bls, consists mainly of gray to olive dolomitic clay with variable amounts of quartz and phosphatic sand and gravel. These clayey sediments extend throughout much of Lee County and northwestern Hendry County, and are informally referred to as the Cape Coral Clay. The Cape Coral Clay also confines the base of the surficial aquifer system.

The Sandstone aquifer is comprised of an upper clastic section and an underlying carbonate unit. The clastic sediments consist predominantly of shelly, phosphatic, quartz sand and calcareous sandstone deposits present between the depths of 65 and 110 feet bls. Most of these strata are reported to have good apparent porosity and permeability in the lithologic log for EXBRY-1.

The carbonate section of the Sandstone aquifer extends from 145 to 190 feet bls, and is separated from the overlying clastic sediments by approximately 35 feet of very phosphatic clayey sand and sandy clay, which forms a semi-confining unit in this area. The upper 30 feet of carbonate rock consists of quartz sandy to micritic limestone (wackestone to mudstone) with low to moderate apparent porosity and permeability. The lower 20 feet of the unit is comprised of more granular limestone and dolomitic limestone (wackestone to packstone) reported to have moderate to good apparent porosity and permeability.

The basal strata of the Peace River Formation, between 190 and 330 feet bls, are comprised of low permeability, greenish gray clay with interbeds of marl and marly limestone. Accessory components include quartz and phosphatic sand and fossil shell. These fine-grained sediments confine the base of the Sandstone aquifer.

The top of the Arcadia Formation occurs at a depth of 330 feet bls at the project site. The upper 120 feet of the formation consists of interbedded limestone, clay, and marl. The limestone strata range from granular to micritic (packstone to wackestone), with variable amounts of quartz and phosphatic sand. Carbonate rocks of the upper Arcadia Formation present in some portions of Southwest Florida comprise an important water yielding interval that is informally referred to as the mid-Hawthorn aquifer. However, these strata at the project site and in adjacent areas typically have low to moderate permeability and are not considered to represent a productive aquifer.

The Arcadia Formation sediments present between 450 and 520 feet bls consist of greenish-gray clay and thin limestone interbeds that contain minor amounts of quartz and phosphatic sand. These fine-grained sediments form the basal confining unit of the intermediate aquifer system at the project site.

### 3.3 Floridan Aquifer System

Miller (1986) broadly divides the Floridan aquifer system into upper and lower carbonate units that have good overall water-yielding properties (upper and lower Floridan aquifers). They are separated by intervening sediments of generally lower permeability (middle confining unit). The borehole for EXBRY-1 terminated in the middle confining unit at a depth of 1,398 feet bls. The stratigraphic units penetrated in descending order of occurrence consist of the lower 110 feet of the Arcadia Formation, Suwannee Limestone, Ocala Limestone, and the upper Avon Park Formation strata.

The basal Arcadia Formation sediments that comprise the upper part of the Floridan aquifer at the project site extend from 520 to 630 feet bls. They consist mainly of gray to olive, phosphatic, granular to micritic limestone strata (packstone to wackestone). Correlative carbonate rocks in the region are generally assigned to the lower Hawthorn aquifer. The lithologic log for EXBRY-1 indicates that the upper half of this limestone sequence has low apparent porosity and permeability, while the lower half exhibits moderate to low permeability. The log suggests that the lower Hawthorn aquifer may not be very productive in this area. Specific capacity data and packer test results for the Lee County Utilities Olga ASR facility, located approximately 1.5 miles northwest of the project site, suggest that transmissivity there is on the order of 30,000 gpd/ft (Water Resource Solutions, 2000).

The top of the Suwannee Limestone was interpreted to be at 630 feet bls at the project site based on a sharp decrease in natural gamma activity below that depth. The thickness of this unit appears to be slightly less than 300 feet, which is similar to the Olga ASR facility. East of the project site, the Suwannee Limestone thins considerably (SFWMD, 2002).

The geologist's field log for the exploratory well indicates that the Suwannee Limestone consists mainly of yellowish gray, orange brown, or olive, micritic to granular limestone (mudstone to packstone) that contains variable amounts of quartz sand. The apparent porosity and permeability of these rocks is reported to be low to moderate.

The elemental capture spectroscopy log run in EXBRY-1 suggests that quartz sand is a major lithologic component of the Suwannee Limestone between the depths of 650 and 715 feet, and also from 785 to 865 feet bls. A review of data collected for the Olga ASR project also shows the presence of two quartz sandy intervals within the formation. The upper interval, which ranges from 15 to 60 feet thick, consists of sandy limestone present near the top of the Suwannee Limestone. A deeper sequence of sandstone and poorly cemented quartz sand that ranges from 10 to 50 feet thick occurs near the middle of the formation. The apparent correlation of these two intervals at Olga with the results for the project site suggests that the quartz sand deposits may have some lateral continuity.

The top of the Ocala Limestone is tentatively picked at a depth of 920 feet bls at the project site. This selection is, in part, based on a general decrease in natural gamma activity below the contact with clay and marl interbeds present in the lower Suwannee Limestone. This interpretation also agrees with the stratigraphic designations applied for the Olga ASR site, which places the Ocala contact below a thin sequence of clay and marl at the base of the Suwannee Limestone. The dual-induction log for the Olga ASR project, however, shows a uniform response below the upper Ocala contact. In this respect, a deeper pick of 990 feet bls may provide a better correlation between the two sites. The lithologic characteristics of the Ocala Limestone are similar to those reported for the Suwannee Limestone at the project site. The predominant lithology is yellowish gray, micritic to granular limestone (mudstone to packstone) with low to moderate apparent porosity and permeability. A minor amount of quartz and phosphatic sand is reported to be present in many intervals of the formation. Since quartz and phosphatic sand are generally not common components of the unit, this may represent sediment washout from shallower strata.

The top of Avon Park Formation is tentatively picked at a depth of 1,180 feet bls at the project site. This is based on the description of more granular limestone strata with moderate to good apparent porosity occurring between the depths of 1,180 and 1,305 feet bls in the geologist's field logs, which is more typical of upper Avon Park Formation carbonate rocks. This pick for the top of the formation is also supported to some extent by correlation of the porosity log suite with the SFWMD La Belle Test Well, where index Avon Park microfossils (Dictyoconus Sp.) were also reported. The sediments between 1,305 and 1,385 feet bpl in the exploratory well borehole consist of yellowish gray to olive limestone that is generally reported to have low to moderate apparent porosity and permeability. A cavernous limestone, indicated by drilling action as discussed in Section 2.3 of this report, was encountered between 1,385 and 1,398 feet bpl. Since drilling was discontinued at this point without recovering circulation, little information is available from this depth.

## 4.0 HYDROGEOLOGIC TESTING

### 4.1 Geophysical Logging

Geophysical logging was performed in the pilot hole after each stage of drilling and before reaming activities were initiated. These logs were performed to provide a continuous record of the physical properties of the subsurface formations. These logs were then used to aid in the interpretation of lithology, to provide estimates of porosity, bulk density, resistivity of the formations, and, through the use of Archie's equation (Archie, 1942), the salinity of the native formation water. The geophysical logs were also utilized to identify casing setting depths. A schedule of geophysical logging events is presented in Table 4-1. All geophysical logs are provided in Appendix 4-1. A geophysical logging composite plot is also presented in Appendix 4-1.

### 4.2 Core Analyses

Nine sets of 4-inch-diameter rock cores were recovered while advancing the pilot hole of EXBRY-1, employing standard coring procedures. The cores were collected from a depth range between 300 and 1,325 feet bpl, over the following intervals: 300 to 305 feet bpl; 305 to 312 feet bpl; 312 to 320 feet bpl; 555 to 575 feet bpl; 756 to 776 feet bpl; 901 to 921 feet bpl; 1,090 to 1,110 feet bpl; 1,110 to 1,120 feet bpl; and 1,305 to 1,325 feet bpl. Twenty-eight core samples from the nine cored intervals were sent out for laboratory testing by Core Lab Petroleum Services. Eleven core samples, from the cored interval 302 to 1,092 feet bpl, were tested for grain density, porosity, and permeability (K air). Sixteen core samples, from the cored interval 555 to 1,325 feet bpl, were tested for grain density, porosity, anisotropy ratio, and horizontal and vertical permeability. A sample set collected from 320 feet bpl was tested for grain density, bulk density, porosity fraction, unconfined compressive strength, moisture content, and specific permeability to fluid. Additionally, a rate type compaction test (RTCT) and uniaxial compaction test were performed on the sample set representing a coring depth of 320 feet bpl. The laboratory reports, which include selected testing parameters and lithologic descriptions of each rock-core sample as well as test results, are presented in Appendix 4-2.

Sections of cores were selected for permeability testing using air as a medium from representative depths of 302.2, 304.3, 305.8, 308.0, 309.7, 558.1, 558.9, 756.6, 760.3, 1,090.4, and 1,092.2 feet bpl. Permeability (K air) values from the laboratory-tested core samples range from 2.36 to 1,640 millidarcys (mD).

Sections of cores were selected for horizontal (maximum and minimum) and vertical permeability testing from representative depths of 555.2, 555.9, 562.0, 901.6, 903.3, 905.4, 906.8, 908.7, 910.3, 911.1, 1,305.0, 1,307.6, 1,309.0, 1,322.0, 1,323.6, and 1,324.4 feet bpl. Minimum horizontal permeability values from the laboratory-tested core samples range from 4.2 to 5,043.9 mD. Maximum horizontal permeability values from the laboratory-tested core samples range from 4.3 to 5,153.5 mD. Vertical permeability values range from 4.3 to 2,070.0 mD.

A section of core was selected for unconfined compressive strength testing and specific permeability to fluid testing from a representative depth of 320.0 feet bpl. An unconfined compressive strength value from the laboratory-tested core sample measured 319 psi. A specific permeability to fluid value from the same core sample set measured 7.29 millidarcys.

### 4.3 Formation Fluid Sampling and Field Testing

Water samples were collected from fluids recovered during reverse-air drilling and dredging operations from depths ranging from approximately 663 to 752 feet bpl. Field-testing parameters including pH, temperature, conductance, chloride, and total dissolved solids (TDS) were measured for each sample and the results recorded. With the exception of the January 15th, 2004 sampling event, field-determined chloride and TDS values ranged from 780 to 875 mg/L and 1,690 to 1,890 mg/L, respectively. Chloride and TDS readings from the sample collected on January 15th were recorded at

1,025 and 1,820 mg/L, respectively (Table 4-2). Additional water samples were collected during the pumping phase of the 4-step drawdown test performed on March 25, 2004 (open hole tagged at 900 feet bpl) and during the final APT performed on June 18th and 19th, 2004 (open hole tagged at 658 feet bpl). Field-determined chloride ranged from 900 to 940 mg/L reported for the sample collected on March 25th, and 880 mg/L for samples collected on June 18th and 19th. Table 4-2 shows field-testing results with respect to sampling depth.

### 4.4 Specific Capacity Testing and Development

After setting the 24-inch casing, and at several stages during open-hole reaming, dredging, and development operations, the well's specific capacity (s.c.), defined as production rate (Q) divided by drawdown (dd) or s.c. = Q/dd, was measured to assess the flow characteristics of the formation. These tests were conducted using several different pumping arrangements.

On February 16, 2004, prior to cleaning out accumulated sediment in the bottom of the wellbore, reverse-air pumping through an 8-inch pipe set at 210 feet bpl proceeded for one hour and 47 minutes. Based on a sustained pumping rate of 1,153 gallons per minute (gpm), specific capacity was reported at 16.1 gpm/ft. The bottom-hole depth was recorded at 661 feet bpl on this date. From February 17th through February 19th, 2004, while dredging fill by reverse-air from 661 to 740 feet bpl, specific capacity values ranged from 15.1 to 19.1 gpm/ft. On March 9th and 10th, 2004, while reaming the borehole to 23 inches from 740 to 900 feet bpl, specific capacity values ranged from 18.4 to 23.2 gpm/ft. After reaming to a total depth of 900 feet bpl, geophysical logging of the wellbore was performed on March 18, 2004. Details of the specific capacity tests including pumping rates, drill string positions or hole tag depths are presented in Table 4-3.

On March 25, 2004, a step drawdown test was performed in the open-hole interval to 900 feet bpl (total depth) using a line-shaft turbine pump. The wellbore was pumped at four successively increased flow rates of 880, 1,475, 1,950, and 2,450 gpm for 60 minutes or until the drawdown measurements stabilized. Specific capacity values calculated at the conclusion of steps 1 through 4, were 30.1, 26.8, 24.4, and 23.8 gpm/ft, respectively. Periodic water samples were collected from the discharge stream during the test and field-tested. Test results indicate that water quality remained relatively consistent throughout the test without any noted degradation of water quality with increased pumping rate. Water samples were also collected for laboratory analysis. After the completion of this interval test, the sediment that collected in the open hole immediately after the conclusion of the test was removed by dredging from 817 to 900 feet bpl. Elapsed time, maximum drawdown, pumping rate, and specific capacity data for each step are also presented in Table 4-3.

Airlift pumping operations were performed on April 6th and April 7th, 2004, using a 2-7/8-inch air injection line and an 8-inch discharge pipe installed in the well approximately 200 feet below the top of the wellhead. After tagging the bottom of the open hole at 900 feet bpl, the airline was tripped up inside the casing and well development began. A sustained discharge rate of 1,500 gpm was maintained over the two days with minimal sand removal. Specific capacity values at the end of the first and second days measured 30.7 and 30.3 gpm/ft, respectively. On April 14, 2004, the air delivery system was revised to allow manifolding of a second air compressor that increased the air supply to approximately 1,600 cubic feet per minute (cfm). The air manifold led into an 8-inch injection line with return flow through the 24-inch casing. The manometer was replaced with a pressure gauge. The initial discharge rate was measured at 2,000 gpm and averaged 1,724 gpm over the next several days. On April 21, 2004, a final attempt to increase airlift capacity was made by again altering the existing discharge piping. The discharge system set-up was modified to increase storage and allow for an increased rate of discharge by reducing restrictions in the previous discharge piping. Development continued through the 8-inch pipe used as an air supply line with return flow through the 24-inch casing. Discharge was now conveyed to a lined impoundment area through a 12-inch discharge line. The water from the impoundment area was then repumped through the metered discharge system. The discharge rate was initially measured at 2,700 gpm but steadily declined throughout the day. In the days that followed, the flow rate averaged approximately 2,300 gpm over an entire day.

On May 18, 2004, a submersible pump (16-inch diameter, 2-stage Goulds Model 16DMC-2) was set in the wellbore at approximately 120 feet bpl. From May 18th to May 27th, 2004, pumping proceeded at increasing rates of 1,200, 1,500, 1,900, 2,500, 2,900, 4,000, and 4,200 gpm, while measuring drawdown and sand production using a Rossum sand sampler. Specific capacity values ranged from 25.1 to 35.8 gpm/ft at these variable pumping rates. Elapsed time, maximum drawdown, pumping rate, specific capacity, and maximum Rossum sand content data from the submersible pumping operations are presented in Table 4-3.

### 4.5 Aquifer Performance Test

On June 18th and 19th, 2004, an aquifer performance test (APT) was performed on EXBRY-1 to establish the transmissivity of the formation. Hole depth prior to starting this test was 658 feet bls. The specific capacity testing indicated that the current zone may have sufficient capacity to meet the design flow rate assumption of 5 MGD. The APT required 24 hours of pumping followed by a 24-hour shut-in period.

The actual test was performed at an average pumping rate of 1,885 gpm based on the total volume of water pumped over the 24-hour period. Initial rates varied around 2,000 gpm and the final rate was measured at 1,875 gpm. The raw data recorded during the test is provided in Appendix 4-5 of this report. Figure 4-1 provides an overview of the drawdown and recovery that occurred during this testing.

A standard analysis of the recovery using reduced time (Driscol, pg 257) was used to determine the formation transmissivity, 20,000 gpd/ft. The graphical analysis and associated manual method are provided on Figure 4-2. This analysis used a constant pumping rate of 1,885 gpm for 24 hours, which is considered to be suitable for this test based on the observed flow rates and total volume pumped.

The basic analysis utilized the following equation to relate transmissivity to pumping rate.

$T = 264\ Q/S$

Where:

$T$ = Transmissivity (gpd/ft)

$Q$ = Constant pumping rate (gpm)

$S$ = Slope of the straight-line portion of the semi-log plot of recovery in feet versus the log of time. The units for S are ft/log cycle as indicated on Figure 4-2.

Since no monitoring wells were available, a value for transmissivity could not be properly developed from the pumping data. However, if a semi-log plot is made of the drawdown, then a T of 28,000 gpd/ft can be estimated (Figure 4-3). It is relevant to note that the measured transmissivity values are characteristic of a zone with good secondary porosity development.

In an effort to gain additional information regarding the performance of the well from the recovery data, a skin analysis was performed using the equation provided by Mathews and Russell (1967), but revised to reflect standard water industry units rather than the oilfield units.

The equation for the skin analysis is:

$$(s) = 1.151[((H_{1hr} - H_{fl})/m) - \log\{(0.3Tt(\Delta t))/((r_w^2)S(t+\Delta t))\}]$$

Where:

$(s)$ = skin factor

$H_{1hr}$ = Head obtained from the straight-line portion of the graph one hour after well is shut-in.

$H_{fl}$ = Head prior to shutting-in the well.

$m$ = Slope of straight line from semi-log plot of recovery versus reduced time.

$r_w$ = Wellbore radius

$S$ = Storativity

$T$ = Formation transmissivity (gpd/ft)

$t$ = Total injection time in days. (This time does not include shut-in time)

$\Delta t$ = Time in days since well was shut-in. (Taken as 0.042 days in this analysis)

An estimate of the skin factor using the above equation yields the following value:

$$
\begin{aligned}
(s) &= 1.151[(65-0)/25-\log(0.3\mathrm{x}20{,}000\mathrm{x}1\mathrm{x}0.042/(1\mathrm{x}10^{-3}\mathrm{x}1.042))] \\
&= -3.2
\end{aligned}
$$

A negative skin value is interpreted as an increase in flow into the wellbore from the production zone at a lower head drop. A negative skin value can be associated with an increase in the radius of the wellbore or fracturing and is consistent with the volume of sand produced from this well. An estimated increase in the wellbore radius to approximately 30 feet is calculated assuming the relationship that the radius of the wellbore ($r_w$) is equal to the original radius ($r_{wi}$) times e raised to the negative value for skin ($e^{-(s)}$).

An alternative analysis can also be developed using slope 2, as provided on Figure 4-3. In this case, a transmissivity of 189,000 gpd/ft is obtained, and a positive skin of 21 is calculated. This interpretation would suggest that the tested interval is only partially open to the current wellbore. Normally, in a confined aquifer the second analysis, using the later time date, would be the analysis of choice, since it would more likely reflect the response when wellbore storage no longer impacts the response curve. However, the skin analysis would tend to favor the earlier time analysis, slope 1, and is considered to reflect a value that is more consistent with transmissivity values for non-fractured limestone formations in the area.

Finally, inspection of the semi-log build-up curve for the recovery also shows a clear change in curve characteristics at a reduced time of approximately 4,000 or a shut-in time of 0.36 minutes. Although other explanations are plausible, it is likely that the change in curve characteristics is associated with after flow into the wellbore. This flow is also called wellbore fill-up (Mathews and Russell). It is also relevant to note that the curve then takes on the characteristics of a stimulated well – i.e. a well with a significantly increased radius, which favors the first interpretation and known enlargement of the hole in the sand producing interval.

### 4.6 Water Quality Analyses

Native water samples were collected from formation depths between approximately 630 and 900 feet bpl at times during the construction and testing of this well. Water samples were collected and analyzed to meet generic surface water discharge permit requirements as well as to provide detailed information needed to assess potential ASR storage zone water quality and meet regulatory requirements. Once the samples were collected, the bottles were preserved (if necessary) and immediately placed on ice in a closed container. The samples were then shipped to the designated laboratory for analyses following standard chain-of-custody protocol.

Results of the laboratory analyses indicate that water quality is similar in the interval from approximately 630 to 900 feet bpl (total depth). Chloride concentrations ranged from 860 to 950 mg/L. TDS concentrations ranged from 1,730 to 2,100 mg/L. Analyses for generic surface water discharge permit parameters showed that the water met regulatory criteria for discharge. On June 21, 2004, after completion of the APT and immediately following required well purging, a representative of Foster Wheeler collected the final set of water samples for analysis. The water quality results are summarized in Table 4-4. Table 4-5 provides a schedule of all laboratory analyses performed showing sample source, analysis description, and the associated contracted laboratory. The results of these analyses are presented in the laboratory reports. Laboratory reports and associated chain-of-custody forms are provided in Appendix 4-6.

### 4.7 Final Water Level Measurement

On June 22, 2004, after completing the 24-hour APT but before the discharge piping was dismantled and the test pump removed from the well, a final shut-in pressure was reported at 12 psi. This pressure reading would equate to 27.7 feet of head above the gauge. Given the position of the pressure gauge on the wellhead measured at 5.35 feet above pad level, and assuming that pad level is 24.5 feet above NGVD, the artesian water-level elevation value in NGVD was reported at 57.55 feet. Given a specific capacity of 25 gpm/ft, the artesian flow rate at the surface is estimated to approach 800 gpm.

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