SWCC-IW1
SWCC-DZMW1

Program Management at Risk Services for Water, Wastewater & Irrigation Facilities

WW-4C.1
Southwest Plant
Class I Deep Injection Well System

Drilling and Testing Report

January 2009

MWH

Cape Coral FLORIDA

Program Management at Risk Services for Water, Wastewater & Irrigation Facilities

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Southwest Plant
Class I Deep Injection Well System

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January 2009

January 9, 2009

Mr. David Rhodes, P.G.
Florida Department of Environmental Protection
Underground Injection Control Division
P.O. Box 2549
Fort Myers, Florida, 33902

Subject: City of Cape Coral, Lee County, Florida
Southwest WTP & WRF IW-1 Class I Injection Well
Permit No. 254598-001-UC

Dear Mr. Rhodes:

In accordance with Specific Condition (5)(f) of the above-referenced permit, the City of Cape Coral is pleased to submit the attached Drilling and Testing Report for the City's Southwest Plant Class I Injection Well System. The report was prepared for the City by MWH Americas, Inc. (MWH).

In accordance with Rule 62-528.340(4), F.A.C, I provide the following certification:

"I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."

Please address any technical questions directly to Neil Johnson, P.G., or Ron Cass, P.E., the hydrogeologist and engineer-of-record with MWH, respectively. The City is in the process of completing the Operational Testing Request for the facility and is anxious to begin operational testing of the well system. Your assistance in this matter is greatly appreciated.

Sincerely,

PUBLIC WORKS DEPARTMENT

Charles G. Pavlos, P.E.
Public Works Director

C: Distribution List

Attachments: Drilling and Testing Report

PROFESSIONAL ENGINEER

The engineering features of the *WW-4C.1 Southwest Plant Class I Deep Injection Well System Drilling and Testing Report* for the City of Cape Coral, 2009, were prepared by, or reviewed by, a Licensed Professional Engineer in the State of Florida.

Ronald M. Cass, P.E.

1-7-09
Date

64922
License No.

PROFESSIONAL GEOLOGIST

The geological evaluation and interpretations contained in the *WW-4C.1 Southwest Plant Class I Deep Injection Well System Drilling and Testing Report* for the City of Cape Coral, 2009, were prepared by, or reviewed by, a Licensed Professional Geologist in the State of Florida.

Neil A. Johnson, P.G.

1/6/09
Date

2052
License No.

City of Cape Coral
Southwest WRF and ROWTP – WW-4C.1
Class I Injection Well Permit No. 254598-001-UC
Technical Advisory Committee/Distribution List

Mr. Steven D. Anderson, P.G.
South Florida Water Management District
P.O. Box 24680
West Palm Beach, FL 33416
Work Phone: 561/686-8800
Fax Phone: 561/687-6896

Mr. Joe Haberfeld, P.G.
FDEP, Underground Injection Program
Twin Towers Mail Station #3530
2600 Blair Stone Road
Tallahassee, FL 32399
Work Phone: 850/921-9417
Fax Phone: 850/487-3618

Mr. David Rhodes, P.G.
UIC/GW Technical Support Supervisor
FDEP South District, Underground Injection Program
P.O. Box 2549
Fort Myers, FL 33902
Work Phone: 239/332-6975
Fax Phone: 239/332-6969

Mr. Bill Peak, P.E.
City of Cape Coral
1015 Cultural Park Boulevard
Cape Coral, FL 33915

Ms. Kelly Bremer
MWH Americas, Inc.
2503 Del Prado Blvd., Suite 430
Cape Coral, FL 33904
Work Phone: 239/573-5959
Fax Phone: 239/573-6007

Mr. Ron Cass, P.E.
MWH Americas, Inc.
2503 Del Prado Blvd., Suite 430
Cape Coral, FL 33904
Work Phone: 239/573-5959
Fax Phone: 239/573-6007

Mr. Neil Johnson, P.G.
MWH Americas, Inc.
490 Sawgrass Corp. Pkwy., Suite 300
Sunrise, FL 33325
Work Phone: 954/846-0401
Fax Phone: 954/846-0424

Ms. Brooke Allen
MWH Constructors, Inc.
1200 Kismet Parkway West
Cape Coral, FL 33990
Work Phone: 239/772-1764
Fax Phone: 239/574-6453

Mr. John Largey
MWH Americas, Inc.
490 Sawgrass Corp. Pkwy., Suite 300
Sunrise, FL 33325
Work Phone: 954/846-0401
Fax Phone: 954/846-0424

Mr. James Alexander, P.G.
FDEP, Underground Injection Program
Twin Towers Mail Station #3530
2600 Blair Stone Road
Tallahassee, FL 32399
Work Phone: 850/921-9417
Fax Phone: 850/487-3618

Document Control Sheet

Client: **The City of Cape Coral**
Project Title: **WW-4C.1 Southwest Plant Class I Deep Injection Well System**
Document Title: **Drilling and Testing Report**

Project Number: 3220269
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Intra-Discipline Review

Scope Element	Prepared (Author)	Checked by (Reviewer)
Construction	James/Majewski/Largey	Johnson/Rectenwald
Data Collection and Analysis	James/Majewski/Largey	Johnson/Rectenwald
Hydrogeology	James/Majewski/Largey	Johnson/Rectenwald
Figures	James/Majewski/Largey	Johnson/Rectenwald

Inter-Discipline Review

Discipline	Checked by (Reviewer)

Document Control

Rev	Date	Revision Description	Prepared (Lead Author)	Reviewed	Approved
1	12/2008	Draft	Largey	Johnson	
2	12/2008	Draft	Largey	Rectenwald	
3					
4					

Distribution

Name	Name

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Section 1
Injection Well Program

1.1 INTRODUCTION

As a growing community, Cape Coral, Florida has a pressing need to expand its utility infrastructure. To provide sufficient capacity for disposal of treated effluent from the Southwest Water Reclamation Facility (WRF) and membrane concentrate from the Southwest Reverse Osmosis Water Treatment Plant (RO WTP). The City of Cape Coral (City) is expanding its wastewater treatment capability by constructing a WRF in the southwestern part of the City. The project site, shown on **Figure 1-1**, is located at 3310 S.W. 20th Avenue, Cape Coral, FL 33914.

The Southwest RO WTP will treat brackish water from upper Floridan aquifer system production wells to meet projected potable water demand. Phase 1 of the project, scheduled to be completed by 2009, was designed to treat 15 million gallons per day (mgd) of raw water. The RO process will result in an estimated maximum flow of 2.5 mgd of concentrate (brine) produced as a byproduct of the treatment process by 2010.

The Southwest RO WRF is also being designed and constructed in phases and will treat domestic wastewater to reclaimed water standards to supplement the City's irrigation system. The planned completion of the WRF and RO plants is 2009, with peak reclaimed water effluent flows of 9.6 mgd. Excess reclaimed water, not utilized by the City's irrigation system, will be disposed of through deep well injection.

On behalf of the City, a Construction Permit Application for the Southwest Cape deep injection well system was prepared and submitted by MWH Americas, Inc. (MWH) to the Florida Department of Environmental Protection (FDEP). On November 1, 2006, the FDEP issued Construction Permit No. 254598-001-UC. This permit allowed for the construction of one Class I injection well (IW-1) and an associated dual zone monitoring well (DZMW-1) for disposal of concentrate and excess reclaimed water from the Southwest WRF and WTP. A copy of the FDEP permit is included as **Appendix A**.

Injection well IW-1 was designed to Class I industrial standards and includes a tubing and packer alternative design to accommodate injection of concentrate, as required by the Florida Administrative Code (FAC) 62-528.410. Fiberglass-reinforced pipe (FRP) cemented within the final casing was used as the injection tubing to minimize potential problems with corrosion from the injected fluids. The injection interval is the Boulder Zone of the lower Oldsmar Formation at a depth between approximately 2,950 and 3,270 feet below land surface (bls). The injection well will have a maximum injection rate of 9.6 MGD, approximately 6,642 gallons per minute (gpm).

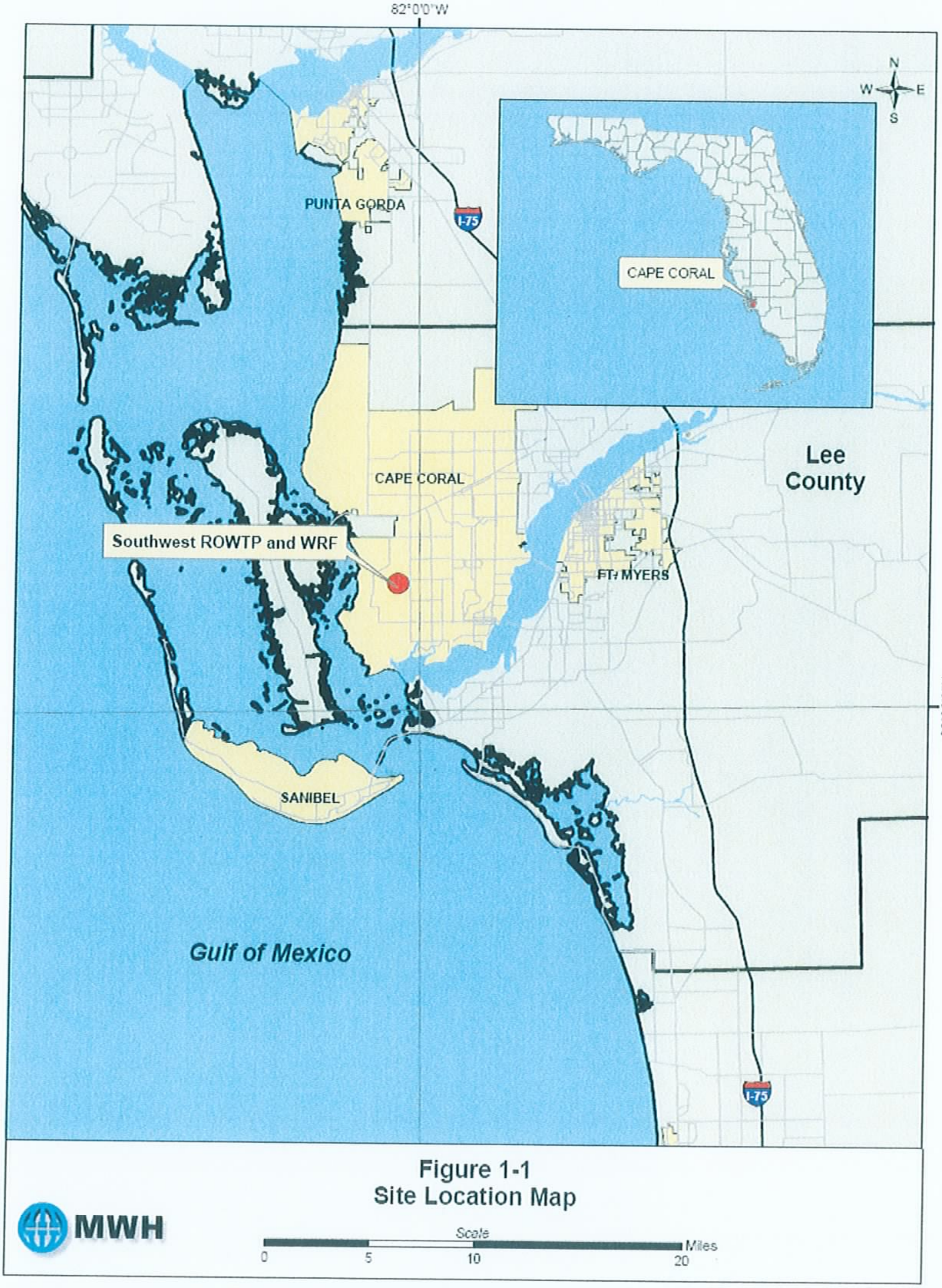


Figure 1-1
Site Location Map

1.2 PURPOSE

The purpose of this report is to summarize the information obtained during the construction and testing of IW-1 and DZMW-1 at the City's Southwest WRF and WTP site. The following information is included in this report:

- Description of methods used to analyze the data
- Documentation of the approved casing setting depths and monitoring zones
- Demonstration of mechanical integrity of the injection well
- Identification of confinement above the injection zone
- Verification that the injection well is suitable for the designed pumping rates to allow long term operational testing of the well

1.3 SCOPE

Youngquist Brothers, Inc. (YBI) of Fort Myers, FL conducted the drilling, construction, and testing activities of the deep injection well system. MWH was the City's onsite representative, providing construction observation and technical services required to comply with the construction permit.

Construction and testing of the wells were performed in accordance with Chapter 62-528 F.A.C., recommendations of the FDEP, the Technical Advisory Committee (TAC), and requirements of the Permit. This report was prepared as required by Specific Condition 5.f of the Permit.

1.4 PROJECT OVERVIEW

The project specifications contained provisions for the construction and testing of the injection well and associated monitor well. The 18-inch diameter injection well was constructed to approximately 3,283 feet bls. The dual-zone monitor well was constructed to a total depth of 1,660 feet bls. The Notice-to-Proceed was issued January 2007. Major construction activities were completed July 15, 2008.

Construction and testing activities were reported weekly to the FDEP and TAC. 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), the U.S. Environmental Protection Agency (EPA), and the United States Geological Survey (USGS).

Provisions of the project included:

- Monitoring depth, weight on bit, rate of penetration, inclination, and drilling fluid properties during construction of the wells
- Collecting and logging formation cuttings (samples) to confirm lithologic boundaries and gross lithologic properties
- Collecting and analyzing conventional cores to complement the geologic logging and to identify hydrogeologic properties of the formations
- Conducting the following geophysical logs at various points during the well construction: X-Y caliper, gamma ray, fluid conductivity, dual induction, borehole compensated sonic/VDL, temperature, flowmeter and borehole televiewer
- Conducting open hole video (television) surveys
- Conducting straddle packer tests in discrete zones of the injection well and monitor well pilot holes to determine the hydrologic properties of distinct lithologic horizons
- Collecting and analyzing water samples collected during the packer tests to determine water quality variations with depth
- Conducting casing cement top temperature logs and cement bond logs on various casing strings during cementing operations
- Collecting and analyzing background water samples from the injection zone and the upper and lower monitor zones
- Conducting a hydrostatic pressure test, video survey and radioactive tracer survey on the final casing string to determine the mechanical integrity of the injection well
- Conducting a short term injection test in the completed injection well to demonstrate the ability of the well to accept fluids at the design flow rate

Section 2
Construction Details

2.1 INTRODUCTION

This section of the report describes the construction activities for IW-1 and DZMW-1. The approximate locations of IW-1 and DZMW-1 at the Southwest WRF and WTP site are shown on **Figure 2-1.** A summary of the construction activities for each well was prepared for each shift in the form of a daily shift report. The daily shift reports have been previously submitted to the Department and the TAC with the Weekly Summary Reports.

2.2 WELL CONSTRUCTION

Drilling and construction of IW-1 began October 10, 2007, with major construction activities completed on April 25, 2008. Drilling and construction of DZMW-1 began on May 8, 2007, with major construction activities completed July 15, 2008. Drilling operations were generally conducted on a 24 hours a day, 7 days per week schedule.

The monitor well was constructed approximately 140 feet south of IW-1 as shown in **Figure 2-1**. During the drilling of the wells, geophysical logging and testing were performed. Well construction was in accordance with the FDEP construction permit. Refer to **Appendix A** for a copy of the permit.

The drilling of IW-1 and DZMW-1 proceeded generally as identified in the project specifications with modifications approved by FDEP. The project specifications identified an outline of a drilling plan with the intention of making modifications to the plan as site specific conditions warranted. The plan included setting steel casing at selected depths in order to maintain the formation during drilling and to facilitate the proposed testing. Drilling activities are summarized in the following outlines, which identify nominal depths.

To consistently record downhole depth, all well measurements are recorded in terms of depth below land surface (bls).

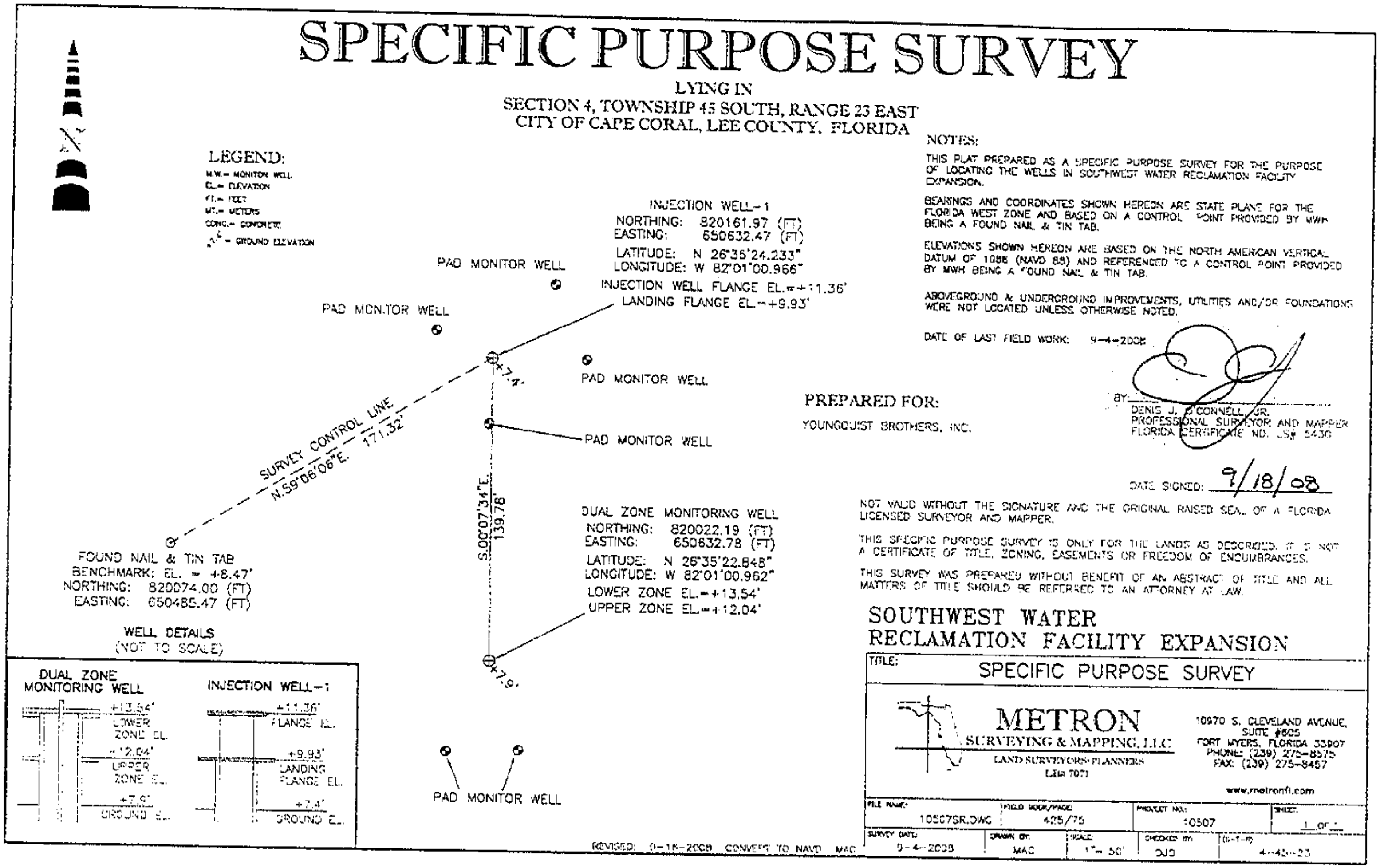


Figure 2-1
Site Survey

Actual depths of casings are identified in the profile of the completed wells IW-1 and DZMW-1 presented in **Figure 2-2.**

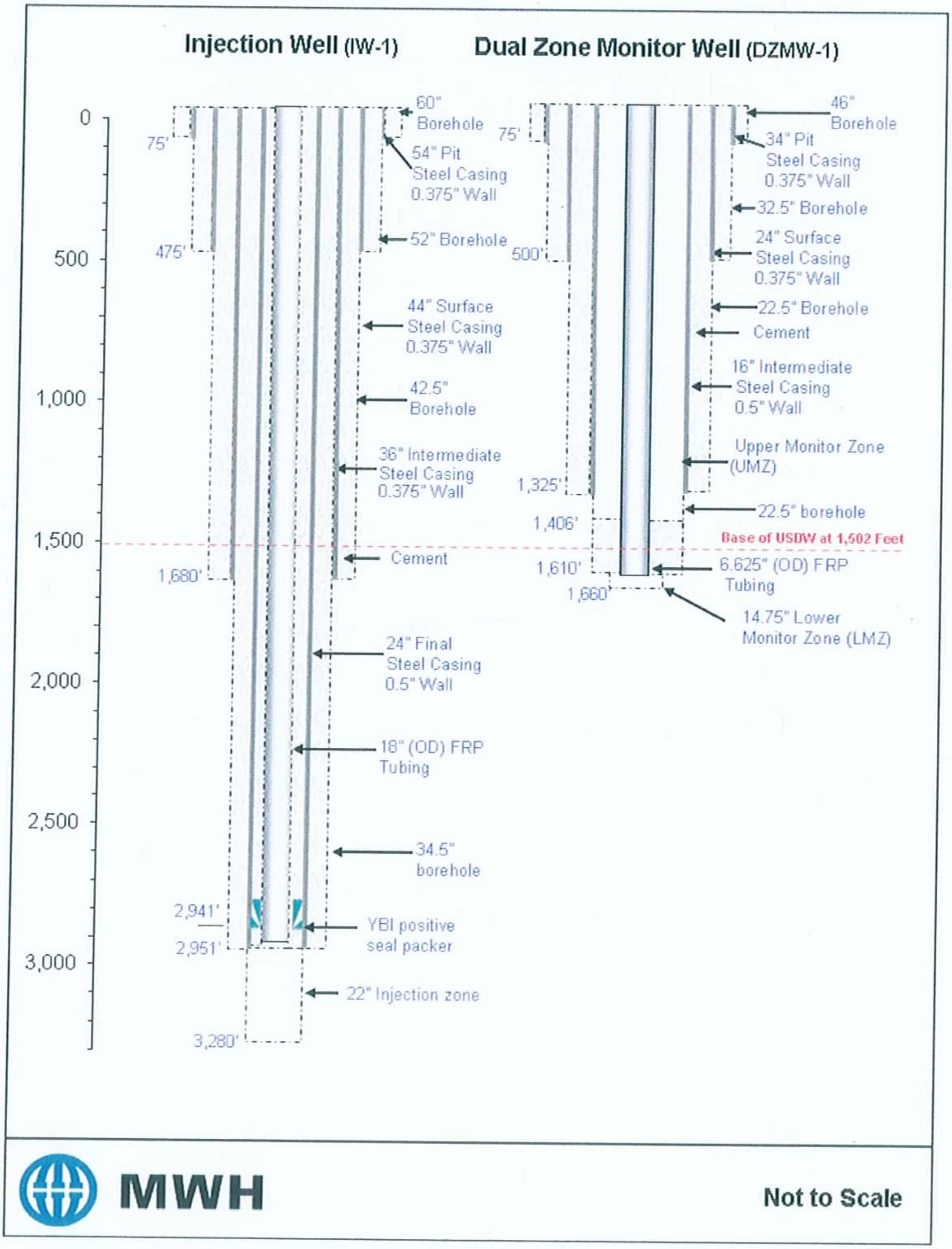


Figure 2-2
Injection Well and Monitor Well Casing Details

The injection well was generally constructed as follows:

- Drill a nominal 60-inch diameter borehole to approximately 80 feet bls using the mud rotary method.
- Set and cement 54-inch diameter steel casing to a depth of 75 feet bls.
- Drill a nominal 12.25 -inch diameter pilot hole to approximately 515 feet bls using the mud rotary method
- Drill a nominal 52-inch diameter borehole to approximately 486 feet bls using the mud rotary method.
- Set and cement 44-inch diameter steel casing to a depth of 475 feet bls.
- Drill a nominal 12.25 -inch diameter pilot hole to approximately 1,749 feet bls using the reverse air method.
- Back plug pilot hole with cement.
- Drill a nominal 42.5-inch diameter borehole to approximately 1,686 feet bls using the reverse air method.
- Set and cement 36-inch diameter steel casing to a depth of 1,680 feet bls
- Drill a nominal 12.25 -inch diameter pilot hole to approximately 3,280 feet bls using the reverse air method and core at depths selected by the Engineer.
- Back plug pilot hole with cement.
- Drill a nominal 34.5-inch diameter borehole to approximately 2,951 feet bls using the reverse air method.
- Drill a nominal 22-inch diameter borehole to approximately 3,280 feet bls using the reverse air method.
- Set and cement 24-inch diameter steel casing to a depth of 2,951 feet bls.
- Set and cement a 18-inch diameter FRP tubing and packer assembly at 2,941 feet bls.

A summary of the IW-1 drilling and testing is presented in **Figure 2-3**

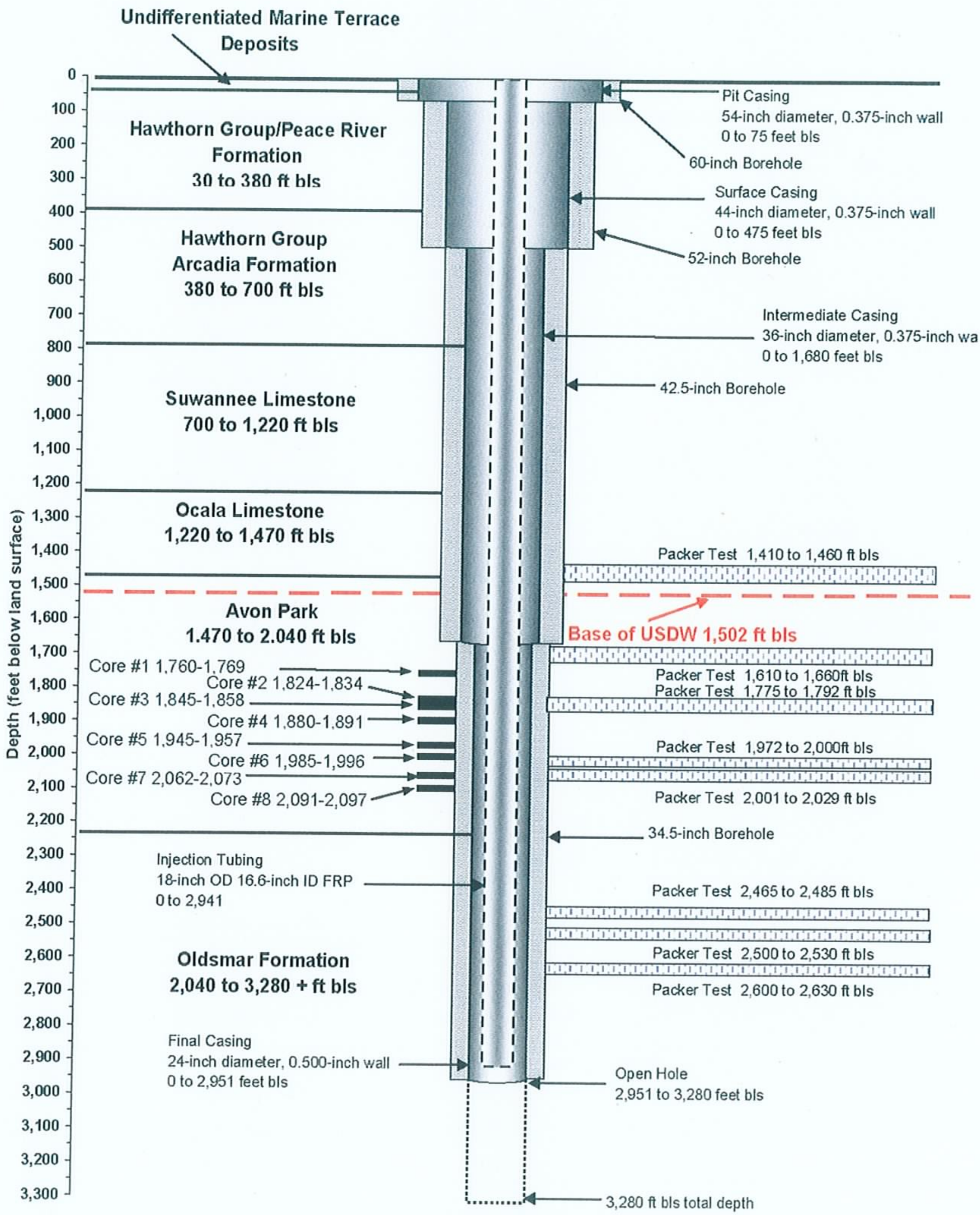


Figure 2-3
Injection Well IW-1 Construction Details

The drilling of DZMW-1 proceeded generally as identified in the project specifications. Drilling activities are summarized in the following outline. The depth of the monitor zones was based on the data collected during the drilling and testing of IW-1 and DZMW-1. The selection of the monitor zone depths is discussed later in the report. The dual-zone monitor well was constructed as generally follows:

- Drill a nominal 46-inch diameter borehole to approximately 78 feet bls using the mud rotary method.
- Set and cement in place 34-inch diameter steel pit casing at 75 feet bls.
- Drill a nominal 12.25 -inch diameter pilot hole to approximately 500 feet bls using the mud rotary method.
- Drill a nominal 32.5-inch diameter borehole to approximately 500 feet bls using the mud rotary method.
- Set and cement in place 24-inch diameter steel casing at 500 feet bls.
- Drill a nominal 12.25 -inch diameter borehole to approximately 1,660 feet bls using the reverse air method and core at depths selected by the Engineer.
- Back plug pilot hole with cement.
- Drill a nominal 22.5-inch diameter borehole to approximately 1,325 feet bls using the reverse air method.
- Set and cement in place 16-inch diameter steel casing at 1,325 feet bls.
- Drill a nominal 14.75-inch diameter borehole to approximately 1,660 feet bls using the reverse air method
- Set and cement in place 6.625-inch diameter FRP tubing at 1,610 feet bls using cement baskets, filling the annular space of the final casing with cement from 1,406 to 1,610 feet bls.

The upper monitor zone (UMZ) was established between 1,325 and 1,406 feet bls and the lower monitor zone (LMZ) between 1,610 and 1,660 feet bls. An as-built profile of the completed DZMW-1 is presented in **Figure 2-4**. A summary of casing depths and materials is presented in **Table 2-1.**

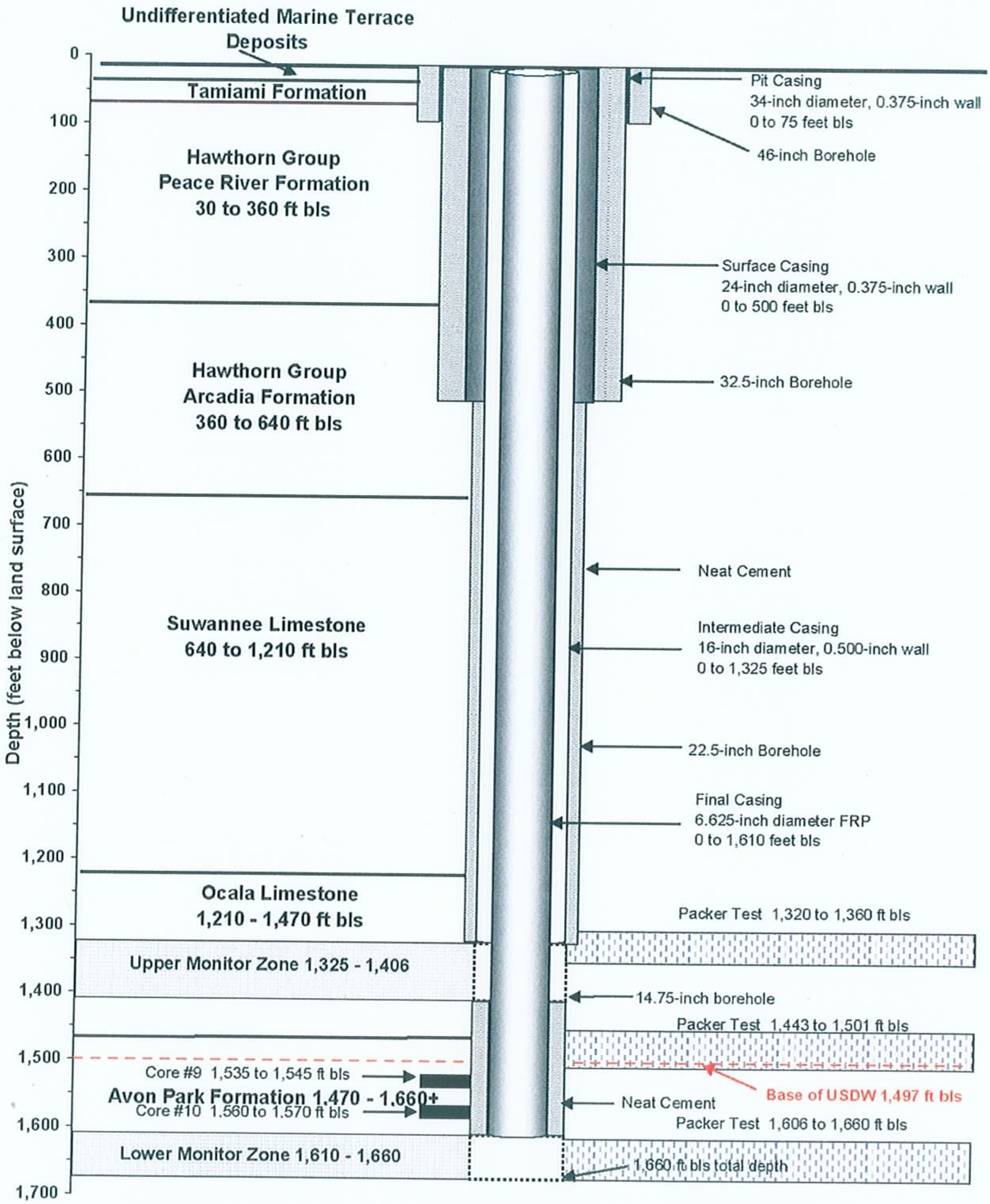


Figure 2-3
Dual-Zone Monitor Well DZMW-1 Construction Details

Table 2-1
Casing Summary

WELL	DIAMETER (Inches)		CASING THICKNESS (inches)	CASING MATERIAL	CASING DEPTH (feet)
	Inside	Outside			
Injection Well No. 1					
Pit	53.25	54.00	0.375	Steel	75
Surface	43.25	44.00	0.375	Steel	475
Intermediate	35.25	36.00	0.375	Steel	1,680
Final Casing	23.00	24.00	0.500	Steel	2,951
FRP Tubing	16.62	18.04	0.710	FRP	2,941
Total Depth	n/a	n/a	n/a	n/a	3,280
Monitor Well No. 1					
Pit	33.25	34.00	0.375	Steel	75
Surface	23.25	24.00	0.375	Steel	500
Final Casing (Upper Monitor Zone)	15.00	16.00	0.500	Steel	1,325
FRP Tubing (Lower Monitor Zone)	5.47	6.63	0.580	FRP	1,610
Total Depth	n/a	n/a	n/a	n/a	1,660

2.3 DATA COLLECTION

Data was collected during the construction of the wells using various methods and procedures as described in this Section. Geophysical logging was performed by the Youngquist Brothers Inc., Geophysical Logging Division. Independent testing and laboratory analyses were performed by subcontractors of Youngquist Brothers, Inc. including the following: water quality analyses were performed by Sanders Laboratories and testing of rock cores was performed by Ardaman & Associates, Inc.

Except where noted, measurements of footage in the wells are referenced to the land surface. The North American Vertical Datum (NAVD) elevation of IW-1 and DZMW-1 are 11.4 feet and 13.5 feet, respectively.

Daily progress and activities were monitored and recorded. The Engineer and the Contractor prepared independent daily progress reports during well construction. In addition to recording daily drilling progress, the reports included other pertinent drilling information such as weight on bit, penetration rates, and relative hardness of the formations. Problems encountered during drilling were also observed and noted. All activities related to the installation of well casings, cementing or other materials, as well as their quantities, were recorded. Detailed descriptions of test procedures and data collection, including results of inclination surveys to verify hole straightness, were recorded. The length and configuration of tools introduced into the borehole were noted. Copies of the daily and weekly progress reports were transmitted to the TAC members on a weekly basis.

A deviation survey was conducted every 90 feet in all pilot and reamed holes to confirm the plumbness of each well. The results from deviation surveys are presented in **Appendix B.**

2.4 GEOLOGIC SAMPLES

Samples of drilled cuttings were collected and analyzed during the drilling of the injection well and monitor well. Circulation time (the time required for drilled cuttings to reach the surface) was calculated regularly to ensure that accurate sample depths were recorded. After initial examination, the Engineer's on-site personnel described the samples. A geologic description of each sample was entered into a log. The limestone cuttings were classified in accordance with the scheme of Dunham (1962). These logs are presented in **Appendix C**. Two sets of drill cuttings were bagged in 10-foot intervals. After the wells were completed, the Contractor sent one set of these samples to the Florida Geological Survey in Tallahassee, Florida. The second set has been retained by the City.

2.5 CORES

During the drilling of the injection well pilot hole, eight conventional cores were recovered. Two conventional cores were recovered during the drilling of the dual-zone monitor well. These cores were described and select samples were sent to an independent laboratory for analysis. The results of the analyses are used to demonstrate confinement above the injection zone. Core depths were selected by the Engineer primarily on the basis of reviewing and interpreting information from other nearby wells and information obtained during the drilling of the injection well including weight on bit, rate of penetration and lithology. The Contractor used a 4-inch inside diameter core barrel for this project. Cores recovered from IW-1 and DZMW-1 were taken over the intervals identified in **Table 2-2.**

Table 2-2
Core Intervals

WELL	CORE I.D.	INTERVAL (feet bls)	RECOVERY %
IW-1	Core No.1	1,760 to 1,769	57%
IW-1	Core No.2	1,824 to 1,834	9%
IW-1	Core No.3	1,845 to 1,858	62%
IW-1	Core No.4	1,880 to 1,891	64%
IW-1	Core No.5	1,945 to 1,957	77%
IW-1	Core No.6	1,985 to 1,996	18%
IW-1	Core No.7	2,062 to 2,073	56%
IW-1	Core No.8	2,091 to 2,097	83%
DZMW-1	Core No.9	1,535 to 1,545	30%
DZMW-1	Core No.10	1,560 to 1,570	80%

Samples were selected from the recovered cores and sent for analysis to an independent laboratory, Ardaman and Associates. These samples were tested for several parameters including permeability, porosity and specific gravity. Core laboratory analysis results and geologic core descriptions are presented in **Appendix D.** A summary of the hydraulic conductivity from the laboratory analyses of the cores is presented in **Table 2-3.**

Table 2-3
Hydraulic Conductivity Derived From Cores

CORE I.D.	INTERVAL (feet bls)	HYDRAULIC CONDUCTIVITY Vertical (cm/sec)	HYDRAULIC CONDUCTIVITY Horizontal (cm/sec)
Injection Well IW-1			
Core No. 1	1762.0-1763.0	7.3×10^{-7}	1.5×10^{-6}
Core No. 1	1763.7-1764.2	5.6×10^{-7}	2.7×10^{-6}
Core No. 1	1764.2-1765.0	5.4×10^{-7}	6.9×10^{-7}
Core No. 2	1833.0-1833.5	5.7×10^{-5}	3.7×10^{-5}
Core No. 3	1887.7-1888.2	3.0×10^{-5}	3.4×10^{-5}
Core No. 5	1945.5-1946.9*	1.2×10^{-5}	1.1×10^{-5}
Core No. 5	1948.5-1949.3	3.4×10^{-5}	4.3×10^{-5}
Core No. 5	1950.0-1950.7	6.9×10^{-5}	5.8×10^{-5}
Core No. 5	1953.0-1953.8	5.5×10^{-4}	5.8×10^{-4}
Core No. 6	1988.5-1989.5	1.1×10^{-5}	1.7×10^{-5}
Core No. 7	2064.0-2064.6	7.6×10^{-10}	4.1×10^{-10}
Core No. 7	2065.0-2065.5	2.2×10^{-7}	7.8×10^{-11}
Core No. 8	2093.0-2093.8	3.0×10^{-10}	3.4×10^{-10}
Core No. 8	2093.8-2094.3	9.2×10^{-4}	1.7×10^{-10}
Core No. 8	2095.0-2095.5	5.4×10^{-6}	2.1×10^{-10}
Core No. 8	2096.0-2097.0	1.7×10^{-6}	1.6×10^{-4}

*Core sample 1945.5-1946.9 was mislabeled as 1445.5-1446.9 when sent to the laboratory for analysis

Dual-Zone Monitor Well DZMW-1			
Core No. 9	1536.2-1536.6	1.7×10^{-5}	2.0×10^{-5}
Core No. 10	1564.7-1565.1	1.1×10^{-5}	8.8×10^{-6}
Core No. 10	1565.8-1566.5	5.8×10^{-5}	5.8×10^{-5}

2.6 GEOPHYSICAL LOGS

At the completion of each stage of drilling, geophysical logs were conducted. The purpose of these logs was to assist in casing seat selection, identify confining sequences and to help identify the location of monitoring zones. The geophysical logs performed, including a brief description of the information provided by the logs, are as follows:

- X-Y Caliper - Identification of hole diameter and hole geometry.
- Gamma Ray - Measurement of the natural gamma ray radiation of the formation, used as a tie-in between logs.
- Dual Induction Log - A resistivity log. Identifies differentiation between limestone and dolomite beds and formation water quality, and, along with the gamma ray log, is useful in the correlation of lithologic units.
- Borehole Compensated Sonic Variable Density Log (VDL) - Identification of the confining sequences, as well as identification of zones that could cause problems during cementing.
- Flow Meter Surveys - Determination of where fluid may be entering or exiting the borehole.
- Temperature - Provides a profile of static and dynamic temperature of the borehole, may be useful in determining changes in fluid movement.
- Borehole Televiewer (BHTV) - Determination of where structural features (bedding planes, fractures, vugs and voids) are located.
- Cement Top Temperature - Verification of the annular space fill-up after each cementing stage.
- Cement Bond Log - Used to assess the quality of the bond between the inner casing and the cement grout around the casing. The resulting curve of the log is a function of casing size and thickness, cement strength and thickness, degree of cement bonding and tool centering.

During the geophysical logging and testing of the wells, the Engineer was on site to witness the logging and verify quality control procedures. The quality control maintained during the testing program was, to a large extent, provided by Youngquist Brothers Geophysical Logging Division. Industry standard quality control measures were observed and are documented on the logs. Detailed information of the tool calibration program utilized by Youngquist Brothers Geophysical Logging Division is also included in **Appendix E.**

Geophysical logs were transmitted to TAC members on a weekly basis during construction. Copies of the logs in both pdf and las format are included on CDs located at the end of the report.

2.6.1 Injection Well (IW-1) Logging Program

Geophysical logs were run for each stage of drilling of IW-1. **Table 2-4** summarizes the geophysical logging sequence for IW-1.

On October 15, 2007, prior to reaming and setting the 52-inch OD surface casing at 486 feet bls in IW-1, a suite of geophysical logs were run, as described in Table 4-5, to identify a mechanically secure depth for the surface casing seat in conjunction with the lithologic log. The caliper log showed the borehole diameter to be a consistent 12.25 to 14 inches to 514 feet bls, and indicated a good casing seat at 475 feet bls in moderately indurated limestone.

After setting and cementing the surface casing, a 12.25-inch diameter pilot hole was advanced from 475 feet to 1,649 feet bls. On October 28, 2007, prior to reaming and setting the 36-inch OD intermediate casing at 1,686 feet bls in IW-1, geophysical logs were run to identify confining units, producing intervals, base of the underground source of drinking water (USDW), and aid in casing seat determination.

The caliper log shows borehole diameters ranging from 12.25 inches to the maximum caliper arm diameter of 28 inches from 485 to 1,749 feet bls. From 1,675 to 1,749 feet bls, the borehole diameter ranges from 12.5 to 14 inches, indicating a competent formation in this interval.

The DIL shows resistivity averaging between 3 and 2,000 ohm-meters (ohm-m) near the top of the pilot hole, and decreasing with depth to approximately 3 ohm-m near TD of the boring. Notable exceptions occur in areas with apparent voids or fractures.

Table 2-4
Summary of IW-1 Geophysical Logging

Date	Borehole Diameter (inches)	Logging Interval (feet bls)	Logging Suite	Purpose
10/15/07	12.25	0 - 514	XYC, GR, DIL, SP	Determine casing setting depth.
10/21/07	52	0 - 486	XYC, GR	Borehole geometry Calculate annular volume.
10/28/07	12.25	485 - 1,649	XYC, GR, DIL, SP, BHCSw/VDL, BHTV, FT_D, FT_S, CIL_D, CIL_s, FMS_D, FMS_s	Determine base of USDW Identify confining units Select casing depth Select potential upper and lower monitor zones.
11/16/07	40.5	0 - 1,686	XYC, GR	Borehole geometry Calculate annular volume.
11/20/07 thru 11/25/07	36-inch OD casing	0 - 1,686	FT	Determine cement top of each cement stage.
12/22/07	12.25	1,686 - 3,280	XYC, GR, DIL, SP, BHCS w/ VDL, VS, FT_D, FT_S, CIL_D, CIL_s, FMS_D, FMS_s	Identify confining units Determine casing depth Confirm injection zone.
4/25/08	34.5- 2,950, 22 to 3,280	1,686 - 3,280	XYC, GR	Borehole geometry Calculate annular volume
3/29/08 thru 4/4/08	24-inch OD casing	0 - 2,951	FT	Determine cement top of each cementing stage
4/4/08	24-inch OD casing	0 - 2,941	CBL, VS	Determine quality of cement bond to casing. Observe condition of final casing
4/10/08 4/22/08	18-inch OD FRP	0 - 3,280	CBL, VS	Determine quality of cement bond to casing.

Abbreviations for Geophysical Logs

BHCS = Borehole Compensated Sonic XYC = Caliper CBL = Cement Bond Log CIL = Fluid Conductivity DIL = Dual Induction Log BHTV = Digital Borehole Televiewer	FT = Fluid Temperature FMS = Flowmeter Survey GR = Gamma Ray SP = Spontaneous Potential	Subscript $_D$ = Dynamic Subscript $_s$ = Static VDL = Variable Density Log VS = Video Survey

The BHTV log compares well with the lithologic description in the 485 to 1,749 feet bls interval of the borehole. Comparatively higher density responses correspond to dense limestone and dolomite. The BHCS porosity log shows alternating slow and fast travel times to approximately 1,749 feet bls, corresponding to high and low apparent porosity, respectively. Below 485 feet bls, travel times indicate a moderately dense formation, with an average apparent porosity of less than 50 percent, with exceptions in intervals with voids or fractures.

Competent units were also identified in the interval between 1,650 and 1,749 feet bls based upon a combination of lithologic descriptions and geophysical log interpretation. Collectively, the logs discussed above indicate the formation, between the depth of approximately 485 and 1,749 feet bls, to be mechanically competent and with the characteristics that indicate a high potential for a good hydraulic and structural seal (moderate density and stable borehole wall).

The dual induction log was also used to identify an increasing saline water quality gradient with depth based on decreasing resistivity values in the geophysical logs associated with the base of the USDW in southern Florida. This log, in conjunction with the formation porosity calculated from the sonic log, provided an estimate of the formation water resistivity and was used to identify the base of the USDW at a depth of 1,500 feet bls in IW-1.

After setting and cementing the intermediate casing, the 12.25-inch diameter pilot hole was advanced from 1,686 to 3,280 feet bls. On December 22, 2007, prior to reaming and setting the 24-inch OD final casing to 2,950 feet bls in IW-1, logs were run to identify confining units, producing intervals, and to aid in casing seat determination. These logs were also useful to support the injection zone selection by documenting the injection zone characteristics.

The caliper log shows the borehole diameter ranging from 12.5 inches to more than 48 inches (maximum caliper arm diameter is 48 inches) from 1,686 to 3,280 feet bls. The borehole varies between 13inches and 19-inches between 1,686 feet bls and 2,050 feet bls. The borehole is nearly gauge from 2,050 feet bls to 2,875 feet bls, with an average diameter of approximately 13 inches to 14 inches, except for the interval from 2,460 to 2,660, which has maximum of diameter of 17 inches. Borehole diameters become erratic and range from 13 inches to greater than 48 inches from 2,660 to 3,160 feet bls. Borehole diameters below 3,160 feet bls to the total depth of the borehole are nearly gauge, with few exceptions.

The BHCS log indicates a generally decreasing sonic porosity from 2,450 to 2,665 feet bls. The sonic signature over this interval is more indicative of a very well indurated limestone or mudstone (slower travel times) than a dolostone (cycle skipping and faster travel times). Sonic signatures above this confining sequence to 2,100 feet bls and below it from 2,665 feet bls to a total depth of the well (3,280 feet bls) indicated the sediments are locally potentially fractured or differentially dissolutioned. The sonic log from 1,760 to 2,100 feet bls also yielded signatures with shorter travel times consistent with well indurated limestone and low permeability.

The flowmeter log indicates that significant contributions to flow occur above 1,700 feet bls. Permeable zones below 1,700 feet bls are present, but are not represented on the flowmeter log due to the higher salinity (i.e. higher specific gravity) of the water in these zones and the inability to adequately stress the lower zones.

The dual induction log shows lower resistivity, indicative of well indurated limestone, between 1,760 and 2,100 feet bls and between 2,450 and 2,650feet bls.

As displayed on the static temperature log, the water temperature in the borehole ranges from 92.1 degrees Fahrenheit (°F) at 1,660 feet bls to 94.9 °F at 2,140 feet bls. The static temperature gradually increases to 96.0 °F at 3,170 feet bls. At this point, there is a distinct "step" in the temperature log, so that by 3,240 feet bls, the temperature is 97.8° F. The dynamic temperature log exhibits a similar pattern of temperature variation at the same points in the borehole, although the changes were not as pronounced.

2.6.2 Dual Zone Monitoring Well (DZMW-1) Logging Program

Geophysical logs were run for each stage of drilling of DZMW-1. Logs were conducted after each advance of the pilot hole and after the reaming for the installation of each casing. **Table 2-5** summarizes the geophysical logging sequence for DZMW-1.

Table 2-5
Summary of DZMW-1 Geophysical Logging Program

Date	Borehole Diameter	Logging Interval (feet bls)	Logging Suite	Purpose
5/10/08	12.25	0 - 500	XYC, GR, DIL, SP	Determine casing setting depth.
5/13/08	32.5	0 - 503	XYC, GR	Borehole geometry Calculate annular volume.
5/22/08	12.25	500 - 1,660	XYC, GR, DIL, SP, BHCS w/ VDL, DBT, FT_D, FT_S, CIL_D, CIL_S, FMS_D, FMS_S	Determine casing setting depth.
6/18/08	22.5	500 - 1,325	XYC, GR	Borehole geometry Calculate annular volume
6/20/08 to 6/22/08	16-inch OD casing	0 - 1,325	FT	Determine cement top of each stage of cement.
6/29/08	12.25 14.75	1,325- 1,660	XYC, GR	Borehole geometry Calculate annular volume.
7/1/08	6.625-inch ID FRP casing	0 - 1,350	FT	Determine cement top of each stage of cement.
7/3/08	Cemented 6.625-inch ID FRP	0 - 1,350	CBL	Determine quality of cement bond

Abbreviations for Geophysical Logs:

BHCS = Borehole Compensated Sonic XYC = Caliper CBL = Cement Bond Log CIL = Fluid Conductivity DIL = Dual Induction Log DBT = Digital Borehole Televiewer	FT = Fluid Temperature FMS = Flowmeter Survey GR = Gamma Ray SP = Spontaneous Potential	Subscript $_D$ = Dynamic Subscript $_S$ = Static VDL = Variable Density Log VS = Video Survey

On March 10, 2008, after the pilot hole was advanced to 500 feet bls, a suite of geophysical logs were run to establish a mechanically secure casing setting depth in conjunction with the lithologic log of the borehole.

The gamma log exhibited a decreased response beginning at approximately 500 feet bls indicating the top of the Lower Hawthorn Aquifer. This is supported by a guage borehole indicated by the caliper log. The 24-inch casing was set at 500 feet bls.

On May 22, 2008, a suite of geophysical logs was run in the pilot hole to 1,660 feet bls. These logs were used to identify the base of the Hawthorn Group, to establish a mechanically secure casing setting depth and to confirm the upper monitor zone. After logging, the pilot hole was reamed with a 22.5-inch bit to 1,406 feet bls and 16-inch diameter steel casing was set to a depth of 1,325 feet bls.

The caliper log shows a borehole diameter of 16 to 18 inches from 1,315 to 1,335 feet bls, indicating a mechanically secure casing seat at 1,325 feet bls for the upper monitor zone (UMZ).

The DIL shows resistivity averaging between 10 and 400 ohm-meters (ohm-m) from 500 to 1,050 feet bls, then decreasing with depth to less than 1 ohm-m near TD of the boring. Notable exceptions occur in areas with apparent voids or fractures.

The logs discussed above indicate the formation, between the depths of approximately 500 and 1,410 feet bls, to be mechanically competent and with the characteristics that indicate a high potential for a good hydraulic and structural seal (moderate density and stable borehole wall). The interval from 1,325 to 1,406 feet bls was used as the open-hole interval for the upper monitoring zone.

Below 1,470 feet bls, the caliper log shows a maximum diameter of approximately 21 inches at a depth of 1,584 feet bls narrowing with depth to approximately 18 inches at 1,610 feet bls. Between 1,610 and 1,660 feet bls the borehole diameter narrows with depth to 14 inches at 1,660 feet bls. The borehole compensated sonic porosity log and variable density log indicate a moderate to dense lithology from 1,520 to 1,610 feet bls. MWH's opinion is that these factors indicate that the formation from 1,460 to 1,610 feet bls is mechanically competent and has characteristics which indicate a high potential for a good hydraulic and structural seal for the casing and cement. The interval from 1,610 to 1,660 feet bls was used as the open-hole interval for the lower monitoring zone.

2.7 PILOT HOLE WATER QUALITY

Water quality samples were collected at 40-foot intervals, in IW-1 and DZMW-1 during reverse air drilling. Sampling started at a depth of 562 and 540 feet bls in IW-1 and DZMW-1, respectively, and continued to the total depth in both wells. Samples were collected from the fluid circulation system. The samples were field analyzed for temperature, pH, specific conductivity, and chloride. These data were used to aid in locating the base of the USDW and the injection zone. For samples analyzed in the field, TDS was calculated from the specific conductivity data.

Reverse air drilling was conducted in a closed system to contain the fluids generated from the well drilling operations. In the closed circulation system, the water discharged from the pilot hole was a mixture of formation water from the entire open borehole; not the discrete interval penetrated. As such, the water quality measurements are not a quantitative representation of the formation fluids at the sampled interval. However, samples from reverse circulation drilling provide an indication of relative water quality trends versus depth. Pilot hole water quality is presented in **Appendix F**.

2.8 VIDEO SURVEYS

Video surveys were conducted and recorded in the injection well pilot hole from 1,700 to 3,284 feet bls; in the final casing from land surface to 2,951 feet bls; and in the injection tubing from land surface to 2,941 feet bls. A video surveys was also performed on the dual–zone monitoring well final casing from land surface to 1,648 feet bls. Color video surveys were made with the camera lens in two positions - downhole with a radial view and uphole with a horizontal rotating position. Air development was used to displace suspended solids from the well prior to performing the television survey. The open hole survey allowed the viewer to visually inspect the formations encountered in the borehole, as well as to observe potential fractures and water-producing zones. Acceptable picture clarity was obtained in the surveys. A log describing the formation and structural features observed in the open hole of the injection and monitor wells are presented in **Appendix G**. A DVD copy of each video survey is located at the end of the report.

2.9 SPECIFIC CAPACITY TESTING

Specific capacity testing was conducted during pilot hole drilling. The short specific capacity tests were conducted at a minimum of every 80 feet while drilling with reverse air circulation. A valve assembly on the wellhead allowed the installation of a manometer to record positive head and also provided for water level measurements during specific capacity tests. The pretest static water levels were recorded prior to beginning each test. The pumping rate and drawdown during pumping were also recorded. The specific capacity testing plots for IW-1 and DZMW-1 are presented in **Appendix H**

2.10 PACKER TESTS

Straddle packer tests were performed after the completion of pilot hole drilling in the injection well and dual-zone monitor well. Two inflatable packers (plugs) were set in the borehole and water was pumped from between the packers. Packer tests were conducted at intervals to either support demonstration of confinement, determine water quality so as to define the base of the USDW, or identify potential monitoring zones. The packers were used to isolate zones to perform drawdown and recovery tests. The straddle packer intervals were selected based on reviewing and interpreting information from geophysical logs, lithology, cores and other packer tests. Eight straddle packer tests were performed in IW-1. Two of the straddle packer tests performed in the injection well aided in determining the base of the USDW and to identifiy potential monitoring zones for DZMW-1. The other six straddle packer tests were performed to demonstrate confinement. Three straddle packer tests were performed in DZMW-1. One of the straddle packer tests performed in DZMW-1 aided in determining the base of the USDW. Two straddle packer tests were performed in DZMW-1 well to identify the upper and lower monitor zones.

The packers were lowered into the pilot hole to the selected interval on the 7.625-inch (outside) diameter drill pipe, inflated and seated against the formation. A 4-inch diameter submersible pump was lowered into the drill pipe approximately 200 feet to introduce hydraulic stress on the formation fluids within the isolated interval. Prior to starting the tests, each zone was developed free of any drilling fluids by means of air lifting and pumping until the water quality stabilized. The isolated zone was then allowed to recover from development before beginning the pumping test. During background, drawdown and recovery water level measurements were recorded using a pressure transducer attached to a data logger (In-situ Hermit 3000). In addition to the Hermit data logger, a pressure recorder located below the bottom packer was used for backup and quality control. The method of analysis used on the data collected and recorded during the packer tests was the Theis (1935) recovery method. Residual drawdown data are generally more reliable than pumping test data because recovery occurs at a constant rate, whereas a constant discharge during pumping is often difficult to achieve.

According to Theis (1935), the residual drawdown after a pumping test with a constant discharge is expressed as:

$$\Delta s = \frac{2.30Q}{4\Pi T}$$

Where: Δs = residual drawdown difference

per log cycle of $\frac{t}{t'}$

t = time since pumping started
t′ = time since pumping stopped
Q = well discharge rate
T = transmissivity of the aquifer

The calculated hydraulic transmissivity from the packer tests are presented in **Table 2-6.** The packer test data plots are presented in **Appendix I.** The raw packer test data is included on a CD located at the end of the report. Based on the stabilization of the fluid specific conductance prior to starting the packer tests and the drawdown characteristics of the data shown in this appendix, all of the hydraulic conductivity values presented from the packer tests are considered valid.

Water samples obtained during the packer tests were analyzed in the field for temperature, chloride and conductivity. Additional water samples were collected during the drawdown phase of the packer test and sent to an independent laboratory for analysis. The samples were analyzed and laboratory reports are presented in **Appendix J.** A summary of the packer test water quality data is presented in **Table 2-7.** Log derived water quality graphs were prepared to compare to the packer test water quality test. This graph shows good correlation, with the estimated log-derived TDS values presented in **Appendix K**.

Table 2-6
Transmissivity Derived From Packer Tests

Packer Interval (feet bls)	Pumping Rate (gpm)	Maximum Drawdown (feet)	Transmissivity[a] ($feet^2$/day)
Injection Well IW-1			
1,410-1,460	9	110.10	3.22
1,610-1,660	27	74.31	21.20
1,775-1,792	2.5	137.45	0.58
1,972-2,000	5	67.7	1.03
2,001-2,029	8	198.33	0.84
2,465-2,485	4	195.90	0.78
2,500-2,530	17	160.37	7.01
2,600-2,630	10	89.62	5.35
Dual-Zone Monitor Well DZMW-1			
Packer Interval (feet bls)	**Pumping Rate (gpm)**	**Maximum Drawdown (feet)**	**Transmissivity[b] (gpd/foot)**
1,320-1,360	18	80.51	11.15
1,443-1,501	13	68.51	9.39
1,606-1,660	40	90.64	19.22

[a]Transmissivity calculated from residual drawdown data using Theis (recovery) method
[b]Transmissivity calculated using the formula $T = 2000\ (Q/\Delta s)$, Driscoll, 1986

Table 2-7
Summary of Packer Test Water Quality

Packer Interval (feet bls)	Cond. (μS/cm)	Chloride (mg/L)	TDS (mg/L)	Ammonia (mg/L)	TKN (mg/L)	Sulfate (mg/L)	pH (su)
Injection Well IW-1							
1,410-1,460	3,950	1,180	2,770	0.52	0.58	351	8.06
1,610-1,660	39,000	17,200	28,600	0.52	0.83	1,840	7.20
1,775-1,792	42,000	12,800	21,800	0.26	0.31	1,960	7.24
1,972-2,000	49,500	18,000	29,400	0.20	0.37	2,940	6.74
2,001-2,029	5,1200	17,600	29,100	0.15	0.35	2,360	6.55
2,465-2,485	22,500	6,800	11,400	0.53	0.50	1,150	7.00
2,500-2,530	37,400	13,600	22,100	0.39	0.47	2,120	7.14
2,600-2,630	50,800	18,600	29,900	0.19	0.39	2,860	7.00
Dual-Zone Monitor Well DZMW-1							
1,320-1,360	22,400	7,010	11,700	0.78	1.22	338	7.38
1,443-1,501	20,900	7,760	13,300	0.95	1.21	293	7.47
1,606-1,660	45,900	17,400	29,300	0.43	0.78	2,630	7.34

2.11 CASING

Casing heat numbers stamped on the casing were verified with the mill certificates prior to running casing in the hole. Copies of the casing mill certificates are presented in **Appendix L**. Cementing plans for each casing string were proposed by the Contractor and reviewed by the Engineer prior to cementing. After accepting the proposed plan, casing was set and cemented. A copy of the cement reports for each casing run is presented in **Appendix M**.

Final casing installations were pressure tested. The injection well 24-inch well casing and the monitor well 16-inch and 6.625-inch casings were pressure tested as identified below. The injection well 18-inch injection tubing was pressure tested as part of the demonstration of mechanical integrity as described in Section 4, Final Testing.

On April 7, 2008, the injection well 24-inch casing was internally pressurized to 150 psi. A pressure decrease of 0.5 psi was observed over the 60-minute test period. This decrease represents less than 0.1 percent change in the original pressure, which is within the allowable change. A copy of the test gauge certification records and certified results of the hydrostatic pressure test are contained in **Appendix N**.

On April 22, 2008, the injection well 18-inch injection well tubing was internally pressurized to 150 psi. A pressure decrease of 1.0 psi was observed over the 60-minute test period. This decrease represents less than 1.0 percent change in the original pressure, which is within the allowable change of 5 percent. A copy of the test gauge certification records and certified results of the hydrostatic pressure test are contained in **Appendix N.**

On June 25, 2008, the monitor well 16-inch casing was internally pressurized to 50 psi. A pressure decrease of 1.0 psi was observed over the 60-minute test period. This increase represents a 2.0 percent change in the original pressure, which is within the allowable change of 5 percent. A copy of the test gauge certification records and certified results of the hydrostatic pressure test are contained in **Appendix N**.

On July 7, 2008, the monitor well 6.625-inch casing was internally pressurized to 50 psi. A pressure decrease of 0.75 psi was observed over the 60-minute test period. This increase represents a 1.5 percent change in the original pressure, which is within the allowable change of 5 percent. A copy of the test gauge certification records and certified results of the hydrostatic pressure test are contained in **Appendix N**.

2.12 CEMENT BOND LOGS

Cement bond logs are used to assess the quality of the bond between the casing and the cement grout. The resulting curve of the log is a function of casing size and thickness, cement strength and thickness, degree of cement bonding and tool centering.

The travel time curve (left log track) is run to determine if the tool is properly centered. The critical travel time is the time recorded when the tool is absolutely centralized in high signal areas, areas with no cement (free pipe). Factors affecting the travel time curve are cycle skipping that can be caused by fast signal arrivals and materials that are so dense they actually have a faster transit time than the casing. The basic transit time of steel is slower than some dolomites and limestones.

On the amplitude curves (center log track), a time gate is set at the time corresponding to the expected arrival of the casing signal, and the amplitude of the signal in that gate is recorded. A high amplitude indicates a larger casing signal, and therefore a poorer cement bond; a low amplitude indicates a good bond.

The variable density display displays the entire wave signal. If there is no bond, an arrival is seen at the time corresponding to the casing velocity. As the cement becomes thicker and stronger (compressive strength), the casing signal becomes weaker.

On April 4, 2008, a cement bond log was performed in the injection well 24-inch casing. From the travel time log it can be seen that good tool centralization was maintained for the entire log. The variable density display shows no strong casing signal on any section of the 24-inch casing. The cement bond log conducted in IW-1 demonstrated that there is a good cement seal around the 24-inch diameter casing and that there are no channels or conduits that would allow fluid movement adjacent to the casing.

On April 10, 2008, a background cement bond log was performed in the injection well 18-inch FRP tubing before cementing. The casing was then cemented and a final cement bond log was conducted on April 22, 2008. The logs were then compared and showed the presence of cement behind the 18-inch casing. The cement bond logs conducted in IW-1 demonstrated that there is a good cement seal around the 18-inch diameter casing and that there are no channels or conduits that would allow fluid movement adjacent to the casing.

On July 3, 2008, a cement bond log was performed in the monitor well 6.625-inch FRP casing. The cement bond log conducted in DZMW-1 demonstrated that there is a good cement seal around the 6.625-inch diameter casing and that there are no channels or conduits that would allow fluid movement adjacent to the casing.

2.13 TUBING AND PACKER

A positive seal packer was installed in the 24-inch casing at a depth of 2,941 feet bls. The 18-inch injection tubing is seated on the packer and is centered by centralizers. The

18–inch tubing was then cemented in place to surface. A copy of the packer specifications is presented in **Appendix O.** An as-built profile for IW-1 showing the location of the positive seal packer is presented in **Figure 2-2.**

2.14 MONITOR ZONE DEPTHS

The selection of monitor zones for DZMW-1, as approved by FDEP, was established based on information available from the drilling and testing of IW-1 and DZMW-1. The upper monitor zone was established between 1,325 and 1,406 feet bls and the lower monitor zone between 1,610 and 1,660 feet bls. An as-built profile of DZMW-1 is presented in **Figure 2-4**.

Section 3
Subsurface Conditions

3.1 Hydrogeology

The study area of southwestern Lee County is underlain by rocks of Cenozoic age to a depth of about 5,000 feet (Meyer, 1989). These rocks are composed primarily of carbonates with minor amounts of evaporites in the lower part and clastics in the upper part (Reese, 2000). This Section examines the stratigraphy and identified aquifer systems encountered during drilling and testing operations for the South Cape Injection Well System IW-1 and DZMW-1, the stratigraphy will be discussed from youngest to oldest in age.

3.2 Stratigraphy

Sediments encountered during the well construction range in age from Late Pleistocene to Paleocene. MWH Americas collected geologic formation samples (well cuttings) from the pilot hole during drilling operations for both wells and described them based on their dominant lithologic or textural characteristics, and, to a lesser extent, color using the scheme of Dunham (1962). Detailed lithologic logs are provided in Appendix C. A detailed description of the lithostratigraphy and its relationship to the hydrostratigraphy of the study area is provided below. **Figure 3-1** provides a stratigraphic and hydrostratigraphic column of the site.

3.2.1 Pliocene - Pleistocene Series

The undifferentiated deposits encountered during drilling operations include predominantly siliciclastic and carbonate deposits of the Pamlico Sand Formation and the Undifferentiated Fort Thompson/Caloosahatchee Formation. Undifferentiated Plio-Pleistocene surficial deposits consisted primarily of sand with mollusk shells and trace amounts of heavy metals and phosphate. This unit was observed to a depth of approximately 30 feet bls in IW-1 and approximately 30 feet bls in DZMW-1.

3.2.2 Pliocene Series - Tamiami Formation

The Tamiami Formation (Mansfield, 1939) unconformably underlies the undifferentiated Pliocene-Pleistocene deposits in Lee County and is lithostratigraphically poorly defined, containing mixed carbonate-siliciclastic lithologies consisting of numerous named and unnamed members (Missimer & Associates, 1993).

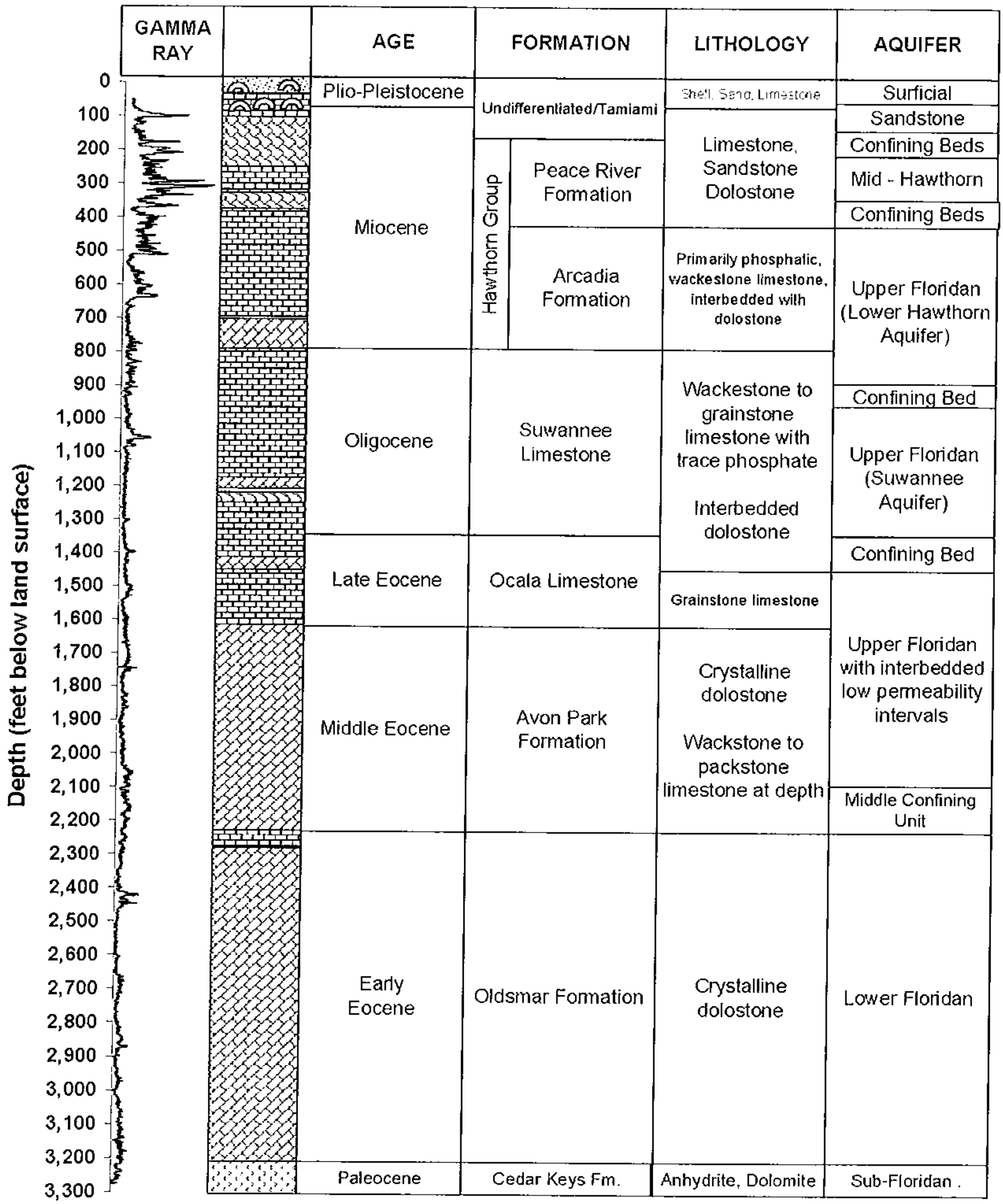


Figure 3-1
Generalized Stratigraphic and Hydrostratigraphic Column

The top of this formation was discerned by the appearance of light olive gray fossiliferous biomicritic, sandy limestone indicative of the Ochopee Limestone member of the Tamiami Formation (Wedderburn, et al, 1982). The unnamed member of the Tamiami Formation occurs from 30 to 130 feet bls in IW-1 and 10 to 40 feet bls in DZMW-1. The Ochopee Limestone member occurs from 130 to 220 feet bls in IW-1 and 130 to 180 feet bls in DZMW-1.

3.2.3 Miocene Series - Hawthorn Group

The Hawthorn Group unconformably underlies the Tamiami Formation, and is a heterogeneous unit that generally consists of a sequence of silt, clay, calcareous clay, dolosilt, quartz sand, phosphate, limestone, and dolomite (Missimer & Associates, 1993). It is a regional stratigraphic unit of Miocene to late Oligocene age that underlies all of South Florida (Reese, 2000). The Hawthorn Group is comprised of an upper, primarily clay unit (Peace River Formation), and a lower, primarily carbonate unit (Arcadia Formation) (Missimer & Associates, 1993). The Hawthorn Group occurs from approximately 130 to 700 feet bls in both IW-1 and DZMW-1.

A regional disconformity separates the Peace River Formation from the Arcadia Formation (Scott, 1988, and Missimer, 1997). The lower 500 feet of the unit consists of 3 to 4 large scale, transgressive-regressive cycles (Missimer & Associates, 1993). Each cycle consists of a lower thick limestone unit and an upper mixture of minor carbonate and clastic units (Missimer & Associates, 1993).

3.2.3.1 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 et al., 2004). The formation occurs from approximately 30 to 380 feet bls in IW-1 and 30 to 360 feet bls in DZMW-1.

3.2.3.2 Arcadia Formation

The lower part of the Hawthorn Group, the Arcadia formation, consists predominantly of limestone and dolostone containing varying amounts of quartz sand, clay and phosphate grains (Scott, 1988). The Arcadia Formation is important from a resource viewpoint as a water supply source for the City of Cape Coral. Hydrologically, it incorporates several aquifers and confining units identified within the Hawthorn Group (Scott, 1988).

The Arcadia Formation ranges from approximately 380 to 700 feet bls in IW-1 and from approximately 360 to 640 feet bls in DZMW-1. The formation at both locations is lithologically complex, containing limestone and dolostone beds of varying thickness. The limestones are light to yellowish gray micrites and biomicrites with moderate to good vuggy porosity. The dolostones are yellowish gray to light olive gray, well indurated, and contain sparry calcite and micritic cements. Phosphate granules are abundant throughout the Arcadia Formation. The base of the Arcadia Formation at both wells can be identified by an immediate decrease in phosphate content in lithologic samples and attenuation of gamma ray activity on geophysical logs.

3.2.4 Oligocene Series - Suwannee Limestone

The Suwannee Limestone (Cooke and Mansfield, 1936) of Oligocene Age in IW-1 occurs from 700 to 1,220 feet bls and from 640 to 1,210 feet bls in DZMW-1. The contact between the Hawthorn Group and the Suwannee Limestone was identified based on interpretations from the lithology and geophysical logs. A regional disconformity separates the Hawthorn Group from the Suwannee Limestone (Scott, 1988).

The contact between these two formations in the study area is described as a moderately consolidated limestone. The Suwannee limestone is very pale orange micrite to biomicrite with a medium-grained calcarenite texture, sparsely interbedded with carbonate marl. The unit is composed of moderately to well-sorted foraminifera, pelloids, and abraded echinoderm and mollusk fragments. In IW-I and DZMW-1, the contact between the Hawthorn Group and the Suwannee Limestone is marked by a change in lithology and attenuation of the natural gamma activity, as depicted in **Appendix G**, primarily due to the decrease in phosphate content in the upper Suwannee Limestone. In addition, the Suwannee Limestone at the site is characterized by higher sonic transit times (**Appendix G**) as compared to the basal facies of the Arcadia Formation.

3.2.5 Eocene Series - Ocala Limestone

The Ocala Limestone (Dall and Harris, 1892) of late Eocene Age occurs from 1,220 to 1,470 feet bls in IW-1 and 1,210 to 1,470 feet bls in DZMW-1. It was difficult to distinguish the Suwannee Limestone from the Ocala Limestone based solely on lithologic descriptions. The Ocala Limestone shares the same lithology (very pale orange, fossiliferous, soft, poorly consolidated, micritic, limestone) as the Suwannee Limestone. Geophysical logs and bistratigraphy were methods used to identify the top of the Ocala Limestone. In the geophysical log traces (**Appendix G**), the Ocala Limestone is identified by an abrupt lack of gamma ray activity due to the absence of phosphate and lower sonic transit times as compared to the Suwannee Limestone. Biostratigraphic designation for identifying the top of the Ocala Limestone occurred at a depth of 1,220 feet bls in IW-1 and 1,210 in DZMW-1, with the first occurrence of the diagnostic foraminifera (<u>*Heterestegina sp. Lepidocyclina ocalana, Operculinoides sp.*</u>)

3.2.6 Eocene Series - Avon Park Formation

The Avon Park Formation (Applin and Applin, 1944) of Late Middle Eocene age occurs from 1,470 to 2,040 feet bls in IW-1 and from 1,470 to the base of DZMW-1. The top of this formation was identified by the occurrence of very pale orange limestone. In addition, this formation boundary coincides with a higher formation resistivity and a slight increase in gamma ray activity (**Appendix G**). Biostratigraphic designation for the Avon Park was used to distinguish the top of this formation in IW-1 and DZMW-1. Diagnostic benthic foraminifera <u>*Dictyoconus cookei*</u> and <u>*Operculinoides sp*</u> was first observed at 1,490 feet bls in IW-1 and 1,470 in DZMW-1.

The Avon Park Formation is a lithologically diverse unit. The upper stratum consists of very pale orange vuggy limestone while the lower stratum of the formation consists of very pale orange to yellowish yellowish gray low permeability dolomitic limestone.

3.2.7 Eocene Series - Oldsmar Formation

In IW-1, the top of the Early Eocene age Oldsmar Formation was encountered at approximately 2,040 and extends to 3,270 feet bls. It is comprised mainly of mottled dark yellowish brown to grayish black and moderate yellowish brown, crystalline dolostones.

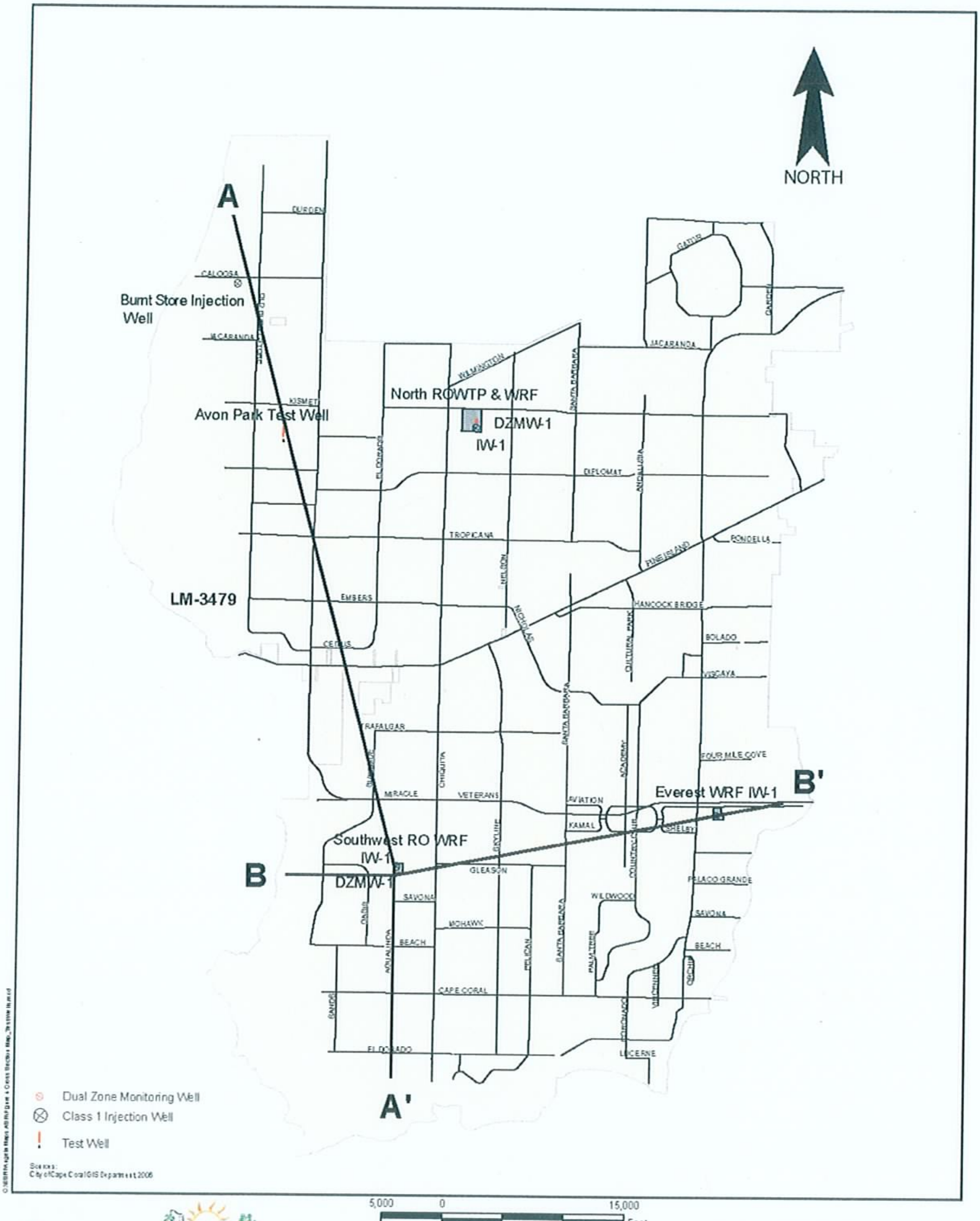
The Oldsmar Formation of South Florida contains an intricate fractured solution channel network referred to as the "Boulder Zone." This fracture interval begins in IW-1 at a depth of approximately 2,950 feet bls, and is identified on geophysical logs by increased borehole diameters on caliper logs, long sonic transit times, and low resistivity. Long sonic transit times are due to the absence of rock and presence of caverns and massive dissolution features. Low resistivity is indicative of the conductive saline water in the Boulder Zone. Erratic drilling conditions, which behave similarly to drilling through alluvial boulders, best identify the Boulder Zone. The Boulder Zone is not alluvial in deposition, but originally marine, and represents an intricate network of vugs, caverns and fractures within the Lower Floridan aquifer. The Boulder Zone will serve as the injection zone in IW-1.

3.2.8 Paleocene Series - Cedar Keys Formation

In the IW-1 borehole, the top of the Paleocene age Cedar Keys Formation was encountered at approximately 3,270 to the total depth of the well, 3,280 feet bls. It is comprised mainly of massive, white to light grey anhydrite beds and trace amounts of dolomite, dolomitic limestone. The Cedar Keys formation, when encountered was massive, soft and exhibited low permeability and good induration.

3.3 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). These aquifer systems are composed of multiple, discrete aquifers separated by low permeability "confining" units that occur throughout this Tertiary/Quaternary age sequence. **Figure 3-2** is a plan view map showing the injection well and cross-section locations (A – A′ and B – B′). **Figure 3-3** (north to south) and **Figure 3-4** (west to east) shows hydrostratigraphic cross-sections.



MWH Cape Coral FLORIDA

Figure 3-2
Cross Sections Location Map

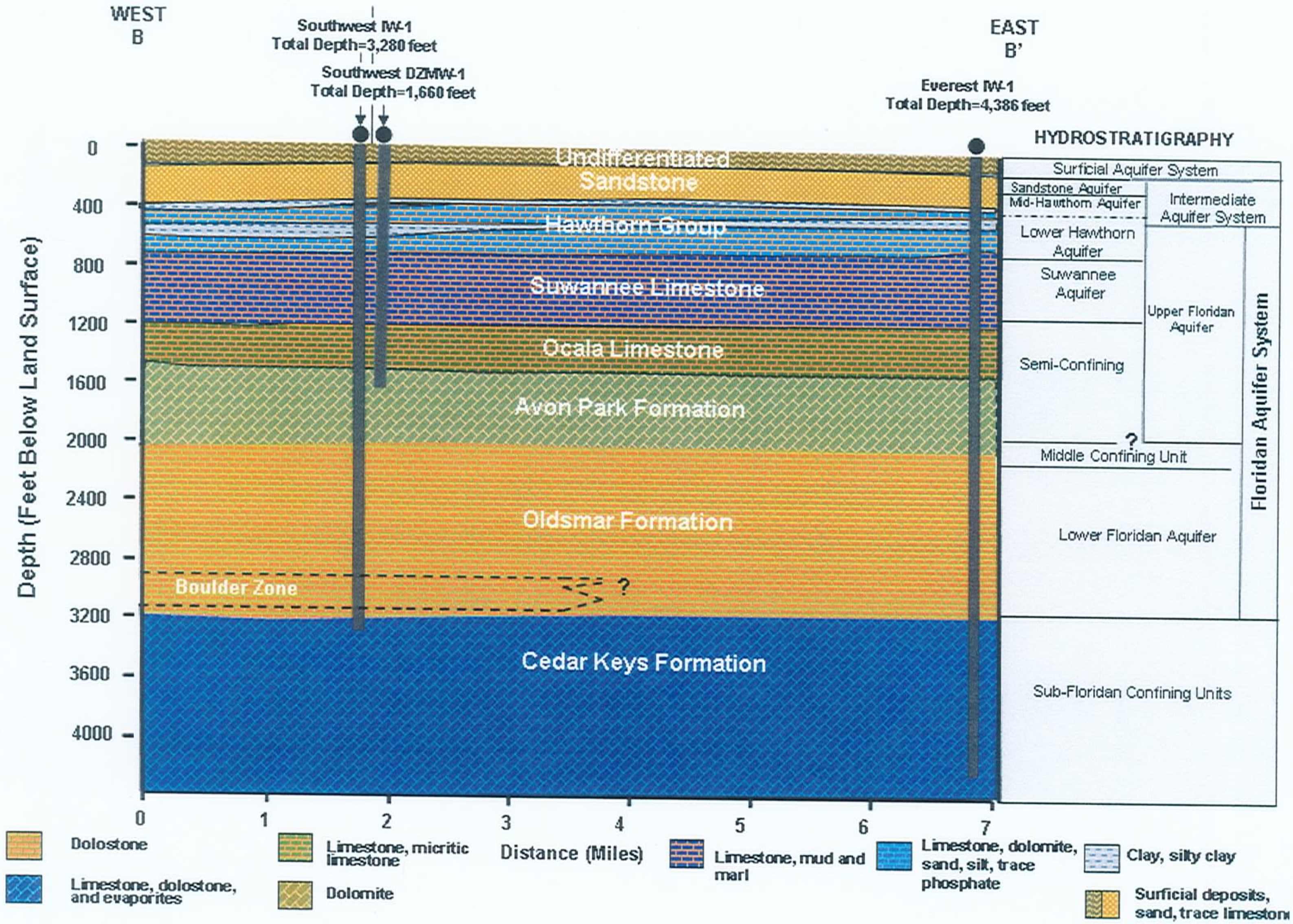


Figure 3-3
Generalized Stratigraphic Cross Section (A – A')

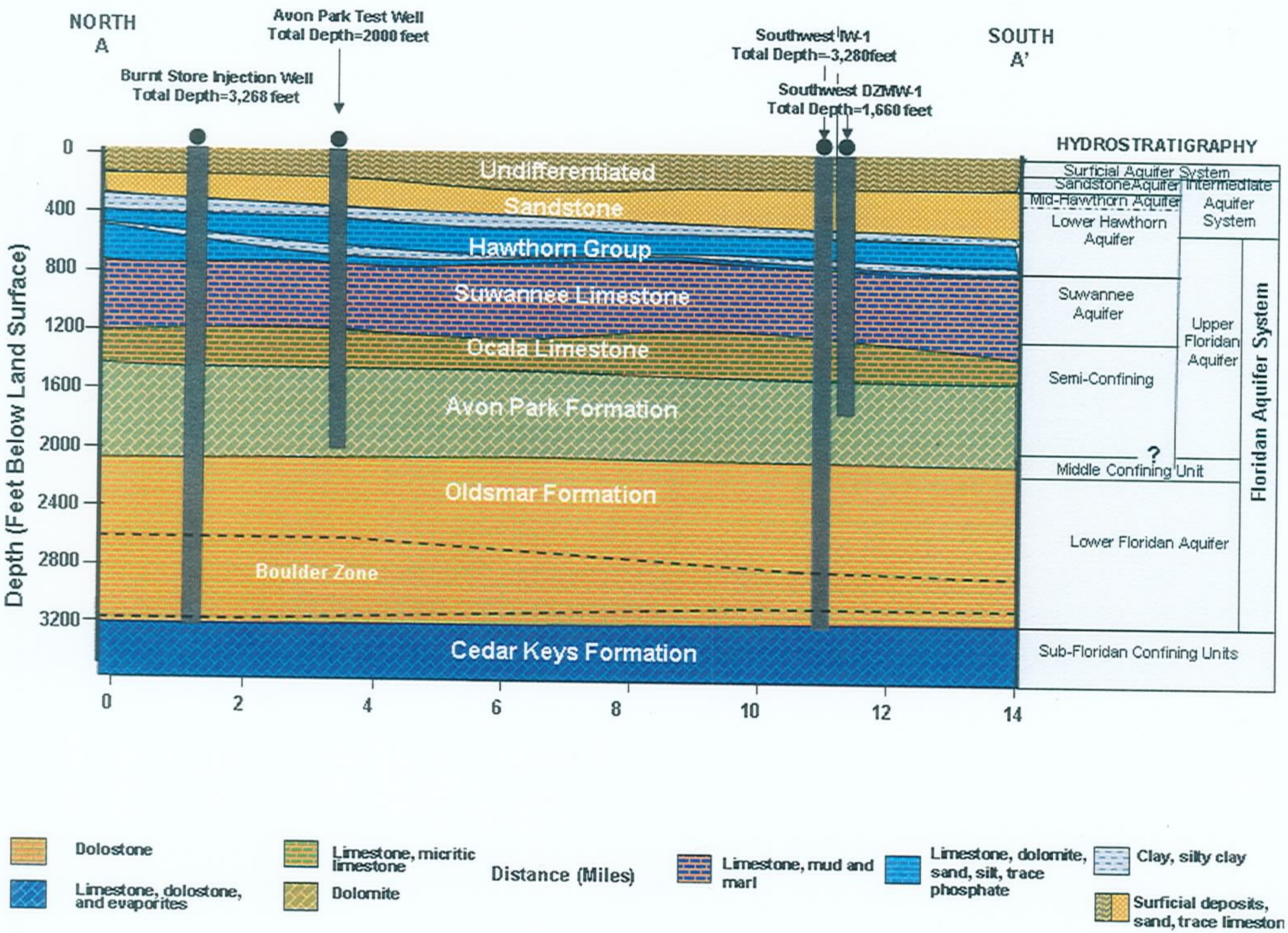


Figure 3-4
Generalized Stratigraphic Cross Section (B – B')

3.3.1 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). In the vicinity of IW-1 and DZMW-1, the SAS occurs within the undifferentiated Plio-Pleistocene water saturated sediments of the Pamlico Sand Formation, Undifferentiated Fort Thompson/Caloosahatchee strata, and the moderately permeable fossiliferous limestone of the Tamiami Formation. The aquifer is unconfined and in direct contact with atmospheric pressure. Recharge to the aquifer originates principally from rainfall with some secondary recharge emanating from leakage from surface water bodies and as movement of groundwater flows up gradient through the sites. Discharge from the surficial aquifer occurs through evapotranspiration, drainage to surface water bodies, downward leakance to deeper aquifers, lateral groundwater flow, and pumping of wells.

3.3.2 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 crop out and contains water under confined conditions (Miller, 1986).

Two productive horizons separated by a low permeability interaquifer confining units were identified during drilling and testing operations. The Sandstone Aquifer was encountered from 30 to 130 feet bls at IW-1 and from 30 to 130 at DZMW-1 and occurs within the Lehigh Acres member of the Peace River formation. The aquifer consists of sandy, micritic limestones, confined above by light olive clays of the Cape Coral Clay member and below by unnamed olive gray dolosilt/clay, locally referred to as the Middle Hawthorn Confining Zone.

A second productive horizon, locally called the Mid-Hawthorn Aquifer, occurs from 380 to 430 feet bls at IW-1 and from 360 to 420 feet bls at DZMW-1. The Mid-Hawthorn aquifer occurs within limestones in the upper part of the Arcadia Formation of the Hawthorn Group (Knapp et al., 1986 and Miller, 1986). This aquifer is currently the major source of water supply to residents served by domestic self-supply wells in Cape Coral, Florida.

3.3.3 Floridan Aquifer System

The top of the FAS, as defined by the Southeastern Geological Society AdHoc Committee on Florida Hydrostratigraphic Unit Definition (1986) coincides with the top of vertically permeable carbonates, interbedded with low permeability carbonates of early Miocene to late middle Eocene-age. The FAS is comprised of 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 (MCU) and the lower Floridan Aquifer (LFA) based on hydraulic characteristics. The FAS in the area of the City of Cape Coral, Florida is composed predominantly of limestone, dolomitic limestone and dolomite. The system occurs within the lower Arcadia Formation, Suwannee and Ocala Limestones, Avon Park Formation, and the Oldsmar Formation. The Paleocene age Cedar Keys Formation with evaporitic gypsum and anhydrite forms the lower boundary of the FAS (Miller, 1986).

3.3.3.1 Upper Floridan Aquifer

Locally, the UFA was encountered from 380 to 2,010 feet bls at IW-1 and from 460 to the total depth of the well, 1,660 feet bls at DZMW-1. The unit chiefly consists of permeable zones in the lower Hawthorn Group, Suwannee Limestone, Ocala Limestone and the upper Avon Park Formation.

Permeable and confining zones were identified within the UFA using geophysical logs (i.e. fluid resistivity, flowmeter and temperature), borehole video survey (evidence of vuggy porosity), specific capacity testing, cores, lithology, and packer testing. The most transmissive part of this upper zone occurs near the top, coincident with an unconformity at the top of the Oligocene age formations (Miller, 1986).

The first transmissive horizon includes the lower portion of the Basal Hawthorn Unit (Reese, 2000), and occurs from 380 to 700 feet bls at IW-1 and from 360 to 640 feet bls at

DZMW-1. This aquifer is locally named the Lower Hawthorn Aquifer. The predominant lithologies present are interbedded yellowish-gray to very pale orange fossiliferous limestones and pale yellowish brown to medium light gray dolostones. The limestones are generally moderately hard and have a moderate to high porosity. The Lower Hawthorn Aquifer's dolostones have a microsucrosic texture, are very hard, and have variable porosities. This aquifer is currently the major source for public water supply to the residents in Cape Coral, Florida.

A transmissive interval within the Suwannee Limestone was identified from 750 to 1,130 feet bls in IW-1 and 640 to 1,090 feet bls in DZMW-1. This aquifer is locally named the Suwannee Aquifer. A semi-confining bed between the Suwannee and Lower Hawthorn Aquifer is approximately 10 to 20 feet thick and consists of crystalline limestone. This aquifer is composed of interbedded moderately biomicritic limestones, marls, and dolostones. The aquifer becomes less permeable with depth due to interbedding, increased lime muds, 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. The interval between 1,325 and 1,406 feet bls was chosen as the upper monitor zone of DZMW-1 and has a TDS of approximately 2,750 mg/L.

A variably transmissive interval, interbedded with lower permeability zones within the Ocala Limestone and Avon Park Formation was identified from 1,320 to 2,010 feet bls in IW-1. A semi-confining bed of approximately 20 to 30 feet of low permeability dolostone separates this interval from the above Suwannee Aquifer. This interval is comprised of pale yellowish brown to dark yellowish brown dolostones of variable permeability. Permeability within this interval is dependent upon the presence or absence of secondary porosity features, such as vugs and/or fracturing. Low permeability confining zones within this interval lack secondary porosity features and are well indurated.

3.3.3.2 Middle Confining Unit

The MCU was identified from 2,010 to 2,050 feet bls in IW-1. The top of the MCU was not encountered at DZMW-1. The MCU consists of the lower section of the Avon Park Formation. This section is micritic, low porosity limestone absent of any dissolution features. Confinement is evident by parallel short, medium, and long fluid resistivity traces on the dual induction log, indicating the lack of water movement in the formation. Sonic transit times recorded on the borehole compensated sonic log are relatively fast through the interval, indicating a dense formation void of large pore spaces. Miller (1986) observed that portions of the Avon Park Formation are fine grained and have low permeability, thereby acting as interaquifer confining units within the FAS. In general, this unit has relatively low permeability, and it generally separates the brackish ground water of the UFA, from the ground water that closely resembles seawater in the LFA (Meyer, 1989).

3.3.3.3 Lower Floridan Aquifer

The LFA consists of the Oldsmar Formation, and the upper part of the Cedar Keys Formation (Meyer, 1989). Ground water in the LFA is compared closely to the chemical nature of modern seawater. The transmissivity of the lower dolostone (locally called the Boulder Zone; Miller, 1986) is slightly higher than the overlying dolostones (Meyer, 1989). The high permeability in the Boulder Zone is due to the cavernous porosity and extensive fracturing present (Miller, 1986, Meyer, 1989 and Reese, 1994). In the study area of Lee County, drilling data suggests that the dolostones are hydraulically connected, although head data and aquifer tests to confirm this interpretation are lacking (Meyer, 1989).

In IW-1, the LFA was identified from 2,050 to 3,270 feet bls in the Oldsmar formation. The top of the LFA was identified by an increase in resistivity and a decrease in sonic travel times. This aquifer is composed of well indurated dolostones and exhibit high secondary permeability and porosity in vuggy to cavernous dissolution features and fracturing, which are supported by information obtained by Reese (1998). The Boulder Zone in IW-1 was encountered at 2,950 feet bls and continued to 3,160 feet bls.

3.4 Water Quality

Water samples were collected from isolated sections of the borehole during the straddle packer tests. The water samples from the packer tests were analyzed for selected parameters to establish background water quality and to identify the depth of the base of the USDW 10,000 mg/L of total dissolved solids (TDS) interface).

The tests were conducted in intervals considered suitable as confining zones and intervals suitable for monitoring zones. During the packer tests, a sample of the formation water from the tested interval was collected just prior to shutting off the pump. Water samples from the packer tests were analyzed for TDS, chloride, sulfate, specific conductivity, ammonia as nitrogen, total nitrogen, and pH. A summary of the packer test water quality data has been presented in **Table 2-6.** Packer test water quality laboratory reports are presented in **Appendix J.**

A potential USDW is defined as water having less than or equal to 10,000 mg/L TDS. The base of the USDW was estimated by performing water quality analyses on samples obtained from packer tests, drill stem water quality, and geophysical log interpretation. The Dual Induction geophysical log is also used in estimating TDS. The Dual Induction log showed a gradual decrease in resistivity below 1,460 feet bls. Using the sonic porosity log, the deep induction, and equations from the United States Geological Survey Water-Resources Investigations Report 94-4010, Hydrogeology and the Distribution and Origin of Salinity in the Floridan Aquifer System, Southeastern Florida (Reese, 1996), a log-derived TDS curve was plotted using constants appropriate for south Florida (**Appendix K**). Using this approach, the base of the USDW was estimated at 1,502 feet bls.

This data is supported by the water quality results of the packer tests conducted in IW-1 over the intervals of 1,410 to 1,450 feet bls and 1,610 to 1,650 feet bls which yielded TDS concentrations of 2,770 mg/L and 28,600 mg/L, respectively. Packer tests conducted in DZMW-1 over the intervals of 1,320 to 1,360 feet bls and 1,442 to 1,500 feet bls, yielded TDS concentrations of 11,700 mg/L and 13,300 mg/L, respectively.

3.5 Confinement Analysis

The approach to the evaluation of vertical confinement at the City of Cape Coral Southwest ROWTP and WRF IW-1 location is as follows. Available borehole geophysical, geological data and open hole testing data were used to identify intervals from 1,502 (base of the USDW) to 2,650 feet bls, which exhibit confining properties. The vertical confinement provided by each interval was then evaluated. Particular attention was paid to locating beds of limestone, dolomite, clay, or marl that have low matrix vertical hydraulic conductivities and are not penetrated by fractures and/or solution cavities. Such tight beds provide the primary vertical confinement of the injected fluids. Competent units have been identified in the interval between 2,460 and 2,665 feet bls based upon a combination of lithologic descriptions and geophysical log review. A secondary confining sequence is present between 1,650 and 2,070 feet bls.

3.5.1 Identification of Confining Units

The presence of satisfactory confining sequences between 1,650 and 2,650 feet bls was established at the Southwest ROWTP and WRF site during the drilling of IW-1 and DZMW-1. A letter previously submitted to the TAC documented the presence of this confinement on site. This letter dated January 7, 2008, is referred to as the "IW-1 Final Casing Seat Selection Request".

3.5.2 Geophysical Logs

The wire line geophysical logs for IW-1 were examined in detail for the presence of units of rock that could provide vertical confinement for injected fluids. A combination of sonic, caliper, and resistivity logs was used to identify well-cemented limestone and/or dolostone beds that would be expected to have low matrix porosities and hydraulic conductivities. Borehole video surveying logs were used to locate fractures and/or cavernous zones that could be conduits for vertical fluid flow. Information on the orientation and thickness of beds was also obtained from the borehole video survey logs.

The development and conditioning of the wells prior to logging is not an issue for the sonic, caliper, gamma ray, temperature, resistivity, and borehole televiewer logs as these logs were designed to and are often run in mudded boreholes. Fine scale features, such as bed contacts, are readily distinguishable on the borehole televiewer log, which indicates that borehole conditions did not have a significant adverse effect on log quality.

Flowmeter, temperature, and fluid resistivity/conductivity logs provide information on the location of flow zones and changes in the salinity of formation water. Temperature and fluid resistivity/conductivity logs did not provide useful information concerning vertical confinement. Flowmeter logs are of limited value for identifying individual beds with low vertical hydraulic conductivities because a single zone of high hydraulic conductivity very often dominates the flow for the entire tested interval.

3.5.3 Characterization of Well Cuttings

Cuttings collected during the pilot hole drilling of IW-1 (land surface to 3,280 feet bls) and DZMW-1 (land surface to 1,660 feet bls) were examined in detail for lithology, macroporosity (visible porosity), and apparent matrix hydraulic conductivity using a stereomicroscope. Copies of the geologic logs are presented in **Appendix C**. The cuttings were composite samples collected at 10-foot intervals during the construction of the well. The lithology of the limestone cuttings was characterized using the limestone classification scheme of Dunham (1962). The most common grain types were silt to fine-sand sized rounded carbonate grains that are described as either pelloids (fecal pellet-shaped grains of indeterminate origin) or as bioclasts (transported fossil fragments). The mineralogy of the samples (calcite versus dolomite) was confirmed by reaction with dilute hydrochloric acid. Dolomite was classified according to crystal size as being cryptocrystalline (crystals are not visible with the low powered microscope) or microcrystalline (crystals are visible with the low-powered microscope), finely crystalline (1/64 to 1/16 mm), or medium crystalline (1/16 to 1/4 mm).

The macroporosity (visible porosity) of the samples was characterized as being either very low (< 2%), low (2-5%), moderate (5-15%), high (15-25%), or very high (>25%). The apparent matrix hydraulic conductivity was qualitatively evaluated as being very low to high based on the porosity, size of the pores, and likely degree of interconnection of the pores.

3.5.4 Core Examination and Data Analysis

Seven cores were taken from 1,760 to 2,097 feet bls in IW-1 and two cores were collected in DZMW-1 from 1,535 to 1,571 feet bls. The lithologies of the cores were evaluated to determine if there were any significant biases in the cutting samples. The well cuttings appeared to have somewhat less intergranular carbonate mud than the cores. In some limestone cuttings, the carbonate mud appeared to have been washed out of the samples during drilling. Some limestone cuttings, particularly grainstone and packstone lithologies, thus appear to be more porous than they actually are. The cores were also examined for the presence of fractures or solution features (vugs) that might be conduits for vertical fluid flow. The core descriptions are presented in **Appendix D**. Sections of each core were selected and submitted for laboratory analyses of hydraulic conductivity. Results from the laboratory core analyses for samples collected are presented in **Appendix D**.

3.5.5 Packer Test Data

Straddle packer test data collected during the drilling of IW-1 and DZMW-1 were analyzed for information on the hydraulic conductivity of potential confining units. The straddle packer data were analyzed using the Theis (1935) recovery method. The transmissivity values calculated from both the pumping and recovery phase data for each test were similar.

It should be noted that the transmissivity and average hydraulic conductivities values calculated from the packer test data are largely a function of horizontal hydraulic conductivities. Packer test data thus tend to over estimate vertical hydraulic conductivities. For example, a packer test performed on an interval containing one or more high hydraulic conductivity beds interbedded between very low hydraulic conductivity beds would give a high transmissivity and average hydraulic conductivity value whereas the interval would have a very low vertical hydraulic conductivity. The results from each packer test are contained in **Appendix I.**

3.5.6 Stratigraphic Correlation

The geologic and geophysical logs of IW-1 and DZMW-1 indicate excellent correlation as would be expected from wells in such close proximity.

3.5.7 Criteria for Identification of Confinement Intervals

Beds or intervals of rock that are likely to offer good vertical confinement were identified using the following criteria:

- Low sonic transit times and derived sonic porosities.
- Variable density log (VDL) pattern consisting of either straight parallel vertical bands, where lithology is relatively uniform, or a "chevron" pattern of continuous parallel bands, where the formation consists of interbedded rock

with differing densities and/or degrees of consolidation. Fractured rock typically has an irregular VDL log pattern.

- Low hydraulic conductivities calculated using packer pump test data.
- Low macroporosity (i.e., visible pore spaces) and a high degree of cementation (hardness) as observed in microscopic examination of cuttings and core samples.
- Borehole diameters on caliper logs close to the bit size. Fractured dolomite and limestone is commonly manifested by an enlarged borehole.
- Relatively high resistivities, which in the middle and lower Floridan Aquifer System are often indicative of tight dolomite and or limestone beds.
- Absence of fractures on the video survey and borehole televiewer log.

3.6 Confining Intervals

The confinement properties of the strata between the base of the USDW (1,502 feet bls) and 2,665 feet bls were evaluated using the above criteria and data. The confining intervals are discussed below.

3.6.1 Interval From 1,650 to 2,070 feet bls

The interval between 1,650 and 2,070 feet bls consists of well indurated dolomitic limestone with low visible permeability. Conventional cores recovered over the intervals of 1,760 to 1,771 feet bls and 1,824 to 1,835 feet bls confirmed the presence of well indurated dolomitic limestone with low visible permeability. Additional cores recovered over the intervals of 1,880 to 1,891; 1,945 to 1,956; 1,985 to 1,996; and 2,062 to 2,073 feet bls consist of generally well indurated dolostone with varying amounts of limestone, crystalline limestone, and dolomitic limestone expressing low visible permeability. The geological and geophysical data for this interval are characteristic of good vertical confinement.

3.6.2 Interval From 2,460 to 2,665 feet bls

Examination of the drill cuttings indicates that permeability is low to medium throughout the interval between 2,460 and 2,665 feet bls. In this interval the sediments are generally microcrystalline to fine grained dolomitic limestone and limestone (packstone) that is moderately cemented with some of the beds consisting of crystalline limestone (sparry calcite cement). Dolomitic limestone beds were observed near the base of the confining sequence with very little vugular and intracrystalline porosity and a low permeability. Many of the beds exhibited only vugular and intracrystalline porosity with an overall low permeability.

The BHCS log indicates a generally decreasing sonic porosity from 2,450 to 2,665 feet bls. The sonic signature over this interval is more indicative of a very well indurated limestone or mudstone (slower travel times) than a dolostone (cycle skipping and faster travel times). The lithologic samples collected during pilot hole drillingof this interval are primarily well indurated dolomitic limestone with low visible permeability.

Sonic signatures above this confining sequence to 2,100 feet bls and below it from 2,950 feet bls to the total depth of the well (3,280 feet bls) indicate the sediments are locally potentially fractured or differentially dissolutioned.

The geological and geophysical data for this interval are characteristic of good vertical confinement.

3.6.3 Confinement Summary

During the drilling and testing of these wells at the City of Cape Coral Southwest ROWTP and WRF, an extensive program was implemented to identify confinement between the base of the USDW (1,502 feet bls) and the final casing seat (2,950 feet bls). A number of cores and packer tests were performed over a relatively small interval.

The dolomitic limestone and limestone present from 2,450 to 2,665 feet bls in the well have geological and geophysical characteristics indicative of generally good confinement. The majority of this interval consists of crystalline dolostone with low visible permeability. The video survey shows dense limestone intervals with small cavities and fractures, these cavities appear to be locally restrictive. No evidence of fractures or cavernous zones that could be conduits for the upward migration of injected fluids.

The combined hydrogeological, geological and geophysical data provide reasonable assurance that confinement exists between the base of the USDW and the top of the injection zone.

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Section 4
Final Testing

4.1 GENERAL

After the injection well construction was completed, the injection well was tested for mechanical integrity, which also included collection of background water samples from IW-1 and DZMW-1, and performance of short-term injection test on IW-1. The mechanical integrity testing (MIT) includes a hydrostatic pressure test of the injection tubing, a temperature log, a video survey and a radioactive tracer survey (RTS). The short-term injection test consisted of injecting reclaimed water from the City's Southwest Water Reclamation Facility for a twelve hour period.

Throughout construction activities, water samples were collected on a weekly basis from the six PMWs constructed within the surficial aquifer surrounding the perimeter of the construction area. Sampling and analyses were conducted weekly throughout the project to monitor the water quality of the surficial aquifer for potential impact from construction activities. No adverse affects to the surficial aquifer system were observed as a result of construction activities.

4.2 BACKGROUND WATER QUALITY

Water samples were obtained from both the upper and lower monitor zones of DZMW-1 and the IW-1 injection zone. Prior to sampling, the DZMW-1 upper zone was developed by using the reverse air procedure. After development a submersible pump was used to purge a minimum of three well volumes before samples were collected. The DZMW-1 lower monitor zone and the IW-1 injection zone were developed by using the reverse air procedure. After development a submersible pump was used to purge a minimum of three well volumes before samples were collected. The samples were analyzed for a variety of constituents to establish the "natural" or background quality of the water. Background water quality laboratory analytical results from injection zone of IW-1, as well as the upper and lower monitor zones of DZMW-1, are presented in **Appendix P.**

A sample of the City's Southwest Water Reclamation Facility reuse stream, the source of the injection test water, was also collected and analyzed. A summary of the laboratory results is presented in **Table 4-1**. Copies of the laboratory reports are presented in **Appendix P**

Table 4-1
Summary of Background Water Quality Laboratory Results

PRIMARY DRINKING WATER STANDARDS						
Analytical Results for City of Cape Coral Southwest						
Parameter	Units	Maximum Contaminant Level	IW-1 5/1/2008	Test Source 7/14/2008	MW-1 Upper 7/15/2008	MW-1 Lower 7/10/2008
Inorganic Compounds						
Antimony	mg/L	0.006	< 0.002	< 0.002	< 0.002	< 0.002
Arsenic	mg/L	0.05	0.012	< 0.002	< 0.002	<0.002
Asbestos	MFL	7	< 0.74	< 0.18	< 0.74	< 0.74
Barium	mg/L	2	0.070	0.010	2.76	1.73
Beryllium	mg/L	0.004	< 0.0001	< 0.0001	< 0.0002 I	0.0003 I
Cadmium	mg/L	0.005	< 0.001	< 0.001	< 0.001	< 0.001
Chromium	mg/L	0.1	< 0.001	< 0.001	< 0.001	< 0.001
Copper	mg/L	1.3	< 0.002	< 0.001	< 0.001	< 0.001
Cyanide	mg/L	0.2	< 0.0047	< 0.0047	< 0.0047	< 0.0047
Fluoride	mg/L	4.0	0.9	0.6	1.8	2.4
Lead	mg/L	0.015	< 0.001	< 0.001	0.023	0.015
Mercury	mg/L	0.002	< 0.001	< 0.001	< 0.001	< 0.001
Nickel	mg/L	0.1	0.004	< 0.001	< 0.001	0.002
Nitrate	mg/L as N	10	0.02	12.8	< 0.01	0.02
Nitrite	mg/L as N	1	< 0.01	<0.01	< 0.01	< 0.01
Total Nitrate & Nitrite	mg/L as N	10	0.02	12.8	<0.01	0.02
Selenium	mg/L	0.05	< 0.003 I	< 0.002	< 0.002	< 0.002
Sodium	mg/L	160	11,000	265	3,140	10,000
Thallium	mg/L	0.002	0.008	< 0.001	< 0.001	< 0.001
2,4,5-TP (Silvex)	mg/L	0.05	< 0.00019	< 0.00019	< 0.00019	< 0.00019
2,4-D	mg/L	0.07	< 0.00022	< 0.00022	< 0.00022	< 0.00022
Alachlor	mg/L	0.002	< 0.00066	< 0.00063	< 0.00064	< 0.00062
Atrazine	mg/L	0.003	< 0.00052	< 0.00050	< 0.00051	< 0.00049
Benzo (a) pyrene	mg/L	0.0002	< 0.000075	< 0.000073	< 0.000073	< 0.000071
Carbofuran	mg/L	0.04	< 0.00041	< 0.00041	< 0.00041	< 0.00041
Chlordane	mg/L	0.002	< 0.00012	< 0.00013	< 0.00013	< 0.00013
Dalapon	mg/L	0.2	< 0.0023	< 0.0023	< 0.0023	< 0.0023
Di (2-ethylhexyl) adipate	mg/L	0.4	< 0.00073	< 0.00070	< 0.00071	< 0.00069
Di (2-ethylhexyl) phthalate	mg/L	0.006	0.0017	0.024 L	< 0.00089	< 0.00086
Dibromochloropropane (DBCP)	mg/L	0.0002	< 0.0000034	< 0.0000035	< 0.0000035	< 0.0000034
Dinoseb	mg/L	0.007	< 0.00023	< 0.00023	< 0.00023	< 0.00023
Diquat	mg/L	0.02	< 0.0019	< 0.0019	< 0.0019	< 0.0019
Endothall	mg/L	0.1	<0.0028	< 0.0028	< 0.0028	< 0.0028
Endrin	mg/L	0.002	< 0.000097	< 0.00010	< 0.00010	< 0.000099
Ethylene dibromide (EDB)	mg/L	0.00002	< 0.0000045	< 0.0000047	< 0.0000045	< 0.0000044
Glyphosate	mg/L	0.7	< 0.013	< 0.010	< 0.010	< 0.010

Table 4-1 (Continued)
Summary of Background Water Quality Laboratory Results

PRIMARY DRINKING WATER STANDARDS Analytical Results for City of Cape Coral Southwest						
Parameter	Units	Maximum Contaminant Level	IW-1 5/1/2008	Test Source 7/14/2008	MW-1 Upper 7/15/2008	MW-1 Lower 7/10/2008
Heptachlor	mg/L	0.0004	< 0.000035	< 0.000036	< 0.000035	< 0.000035
Heptachlor epoxide	mg/L	0.0002	< 0.000026	< 0.000027	< 0.000027	< 0.000027
Hexachlorobenzene	mg/L	0.001	< 0.00033	< 0.00032	< 0.00032	< 0.00031
Hexcachlorocyclopentadiene	mg/L	0.05	< 0.00025	< 0.00025	< 0.00025	< 0.00024
Lindane	mg/L	0.0002	< 0.000019	< 0.000020	< 0.000020	< 0.000019
Methoxychlor	mg/L	0.04	< 0.000042	< 0.000044	< 0.000043	< 0.000043
Oxamyl (vydate)	mg/L	0.2	< 0.00013	< 0.00013	< 0.00013	< 0.00013
Pentachlorophenol	mg/L	0.001	< 0.00039	< 0.00039	< 0.00039	< 0.00039
Picloram	mg/L	0.5	< 0.00023	< 0.00023	< 0.00023	< 0.00023
Polychlorinated biphenyl (PCB)	mg/L	0.0005	< 0.00013	< 0.00014	< 0.00014	< 0.00013
Simazine	mg/L	0.004	< 0.00068	< 0.00065	< 0.00066	< 0.00064
Toxaphene	mg/L	0.003	< 0.00058	< 0.00060	< 0.00059	< 0.00059

mg/L – milligrams per liter
MFL- million fibers per liter greater than 10 microns

Table 4-1 (Continued)
Summary of Background Water Quality Laboratory Results

PRIMARY DRINKING WATER STANDARDS Analytical Results for City of Cape Coral Southwest						
Parameter	Units	Maximum Contaminant Level	IW-1 5/1/2008	Test Source 7/14/2008	MW-1 Upper 7/15/2008	MW-1 Lower 7/10/2008
Volatile Organic Compounds						
1,1,1-Trichloroethane	mg/L	0.2	< 0.00021	< 0.00021	< 0.00021	< 0.00021
1,1,2-Trichloroethane	mg/L	0.005	< 0.00044	< 0.00044	< 0.00044	< 0.00044
1,1-Dichloroethylene	mg/L	0.007	< 0.00023	< 0.00023	< 0.00023	< 0.00023
1,2,4-Trichlorobenzene	mg/L	0.07	< 0.00041	< 0.00041	< 0.00041	< 0.00041
1,2-Dichlorethane	mg/L	0.003	< 0.00029	< 0.00029	< 0.00029	< 0.00029
1,2-Dichloropropane	mg/L	0.005	< 0.00040	< 0.00040	< 0.00040	< 0.00040
Benzene	mg/L	0.001	< 0.00020	< 0.00020	< 0.00020	< 0.00020
Carbon tetrachloride	mg/L	0.003	< 0.00024	< 0.00024	< 0.00024	< 0.00024
cis-1,2,-Dichloroethylene	mg/L	0.07	< 0.00021	< 0.00021	< 0.00021	< 0.00021
Dichloromethane	mg/L	0.005	< 0.00023	< 0.00023	< 0.00023	< 0.00023
Ethylbenzene	mg/L	0.7	< 0.00021	< 0.00021	< 0.00021	< 0.00021
Monochlorobenzene	mg/L	0.1	< 0.00030	< 0.00030	< 0.00030	< 0.00030
o-Dichlorobenzene	mg/L	0.6	< 0.00021	< 0.00021	< 0.00021	< 0.00021
para-Dichlorobenzene	mg/L	0.075	< 0.00023	< 0.00023	< 0.00023	< 0.00023
Styrene	mg/L	0.1	< 0.00021	< 0.00021	< 0.00021	< 0.00021
Tetrachloroethylene	mg/L	0.003	0.00024	< 0.00024	< 0.00024	< 0.00024
Toluene	mg/L	1	< 0.00022	< 0.00022	< 0.00022	< 0.00022
Total trihalomethanes (TTHM)	mg/L	0.10	< 0.00025	0.200	< 0.00025	
trans-1,2-Dichlorethylene	mg/L	0.1	< 0.00035	< 0.00035	< 0.00035	< 0.00035
Trichloroethylene	mg/L	0.003	< 0.00036	< 0.00036	< 0.00036	< 0.00036
Vinyl chloride	mg/L	0.001	< 0.00032	< 0.00032	< 0.00032	< 0.00032
Xylenes (total)	mg/L	10	< 0.00046	< 0.00046	< 0.00046	< 0.00046

Table 4-1 (Continued)
Summary of Background Water Quality Laboratory Results

Parameter	Units	Maximum Contaminant Level	IW-1 5/1/2008	Test Source 7/14/2008	MW-1 Upper 7/15/2008	MW-1 Lower 7/10/2008
Physical Characteristics						
Turbidity	NTU	1	3.4	2.6	35.0	14.4
Microbiological Characteristics						
Total Coliform	CFU/100ml	< 1	< 1	< 1	< 1	< 1
Radionuclides						
Combined Radium 226 & 228	pCi/L	5	See attached report	See attached report	See attached report	See attached report
Gross Alpha	pCi/L	15	See attached report	See attached report	See attached report	See attached report
Beta particles and photon emitters	mrem/yr	4	See attached report	See attached report	See attached report	See attached report
Uranium	mg/L		See attached report	See attached report	See attached report	See attached report
Treatment Chemicals						
Bromate	mg/L	0.000010				
Chlorite	mg/L	0.0001				
Haloacetic acids (HAAS)	mg/L	0.060	< 0.00018	0.049	<0.00018	<0.00018

mg/L - milligrams per liter

pCi/L - picocurie per liter

m/Rem/yr - millirem per year

NTU - nephelometric turbidity unit

SECONDARY DRINKING WATER STANDARDS
Analytical Results for City of Cape Coral Southwest

Parameter	Units	Maximum Contaminant Level	IW-1 5/1/2008	Test Source 7/14/2008	MW-1 Upper 7/15/2008	MW-1 Lower 7/10/2008
Aluminum	mg/L	0.2	< 0.009	< 0.009	0.114	0.101
Chloride	mg/L	250	20,200	375	5,990	18,400
Color	color units	15	5	5	10	5
Copper	mg/L	1	< 0.002 I	< 0.001	< 0.001	< 0.001
Corrosivity (Langelier Index)			0.60	-0.18	0.41	0.36
Fluoride	mg/L	2	0.9	0.6	1.8	2.4
Foaming Agents	mg/L	0.5	0.064	0.070	0.22	0.086
Iron	mg/L	0.3	0.840	< 0.015	1.05	0.372
Manganese	mg/L	0.05	0.009	0.016	0.078	0.025
Odor	TON	3	2	1	1.4	27
pH	SU	6.5-8.5	7.30	7.62	7.59	7.05
Silver	mg/L	0.1	< 0.001 J3	< 0.001	< 0.001	< 0.001
Sulfate	mg/L	250	3,180	73	414	3,010
Total Dissolved Solids (TDS)	mg/L	500	32,800	928	11,000	28,800
Zinc	mg/L	5	0.065	0.029	0.013	0.016

mg/L - milligrams per liter

TON - threshold odor number

Table 4-1 (Continued)
Summary of Background Water Quality Laboratory Results

UNREGULATED ORGANIC CONTAMINANTS
Analytical Results for City of Cape Coral Southwest

Parameter	Units	Maximum Contaminant Level	IW-1 5/1/2008	Test Source 7/14/2008	MW-1 Upper 7/15/2008	MW-1 Lower
Group I						
Aldrin	mg/L		< 0.000042	< 0.000044	< 0.000043	< 0.000043
Dieldrin	mg/L		< 0.000063	< 0.000066	< 0.000065	< 0.000065
Group II						
Chloroethane	mg/L		< 0.00046	< 0.00046	< 0.00046	< 0.00046
Chloroform	mg/L		< 0.00025	0.019	< 0.00025	< 0.00025
Group III						
2-Chlorophenol	mg/L		< 0.00086	< 0.00084	< 0.00085	< 0.00077
Dimethylphthalate	mg/L		< 0.0025	< 0.0024	< 0.0025	< 0.0022
Phenol	mg/L		< 0.001	< 0.00097	< 0.00098	< 0.00089
2,4,6-Trichlorophenol	mg/L		< 0.0011	< 0.0011	< 0.0011	< 0.0010

MUNICIPAL WASTEWATER MINIMUM CRITERIA GROUNDWATER MONITORING PARAMETERS
Analytical Results for City of Cape Coral Southwest

Parameter	Units	Maximum Contaminant Level	IW-1 5/1/2008	Test Source 7/14/2008	MW-1 Upper 7/15/2008	MW-1 Lower 7/10/2008
Inorganics						
Ammonia	mg/L as N		0.14	< 0.01	0.71	0.30
Nitrogen (organic)	mg/L as N		< 0.10	0.54	0.17	0.33
Nitrogen, Total Kjeldahl (TKN)	mg/L as N		0.16	0.54	0.88	0.63
Phosphorus, Total	mg/L as P		< 0.025	2.51	0.043	< 0.010
Base / Neutral Organics						
Anthracene	mg/L		< 0.00052	< 0.00050	<0.00051	< 0.00046
Naphthalene	mg/L		< 0.00072	< 0.00070	< 0.00071	< 0.00064
Butylbenzylphtyallate	mg/l		< 0.00057	< 0.00055	< 0.00056	< 0.00051
Phenantherene	mg/L		< 0.00031	< 0.00030	< 0.00031	< 0.00028
Other						
Temperature	°C		32.7	n/a	31.7	32.7
Conductivity	µmhos/cm		52,800	1,790	17,700	50,500
Biological Oxygen Demand (BOD)	mg/L		< 2	< 2	< 2	< 2
Chemical Oxygen Demand (COD)	mg/L		1,740	97	620	1,830

4.3 MECHANICAL INTEGRITY TESTING

In accordance with FAC Rule 62-528, the injection well was tested for mechanical integrity. Testing consisted of a hydrostatic pressure test of the injection well final casing and injection tubing, a temperature log, a television survey and a radioactive tracer survey (RTS). The hydrostatic pressure tests, which were conducted at a pressure at least 50 percent greater than the maximum allowable operating pressure, identifies casing and injection tubing integrity. The temperature log identifies temperature variations in the well. The television survey provides visual verification of internal tubing integrity. The radioactive tracer survey provides data on the external mechanical seal of the casing. The following describes the testing methods, results of the testing and presents the interpretation of the data collected during the mechanical integrity tests.

4.3.1 Hydrostatic Pressure Testing

On April 22, 2008, the IW-1 18-inch injection tubing was internally pressurized to 150.0 psi. A pressure decrease of 1.0 psi was observed over the 60-minute test period. This decrease represents a 0.7 percent change in the original pressure, which is within the allowable change of 5 percent. David Rhodes, P.G. (FDEP) and John Largey (MWH) witnessed the casing pressure test.

A copy of the test gauge certification records and results of the hydrostatic pressure test are contained in **Appendix N.**

4.3.2 Injection Well Temperature Log

On July 31, 2008, a temperature log was conducted on IW-1 from the surface to a total depth of 3,286 feet bls. The temperature log recorded a fairly constant temperature increase from approximately 82 °F 20 feet bls to approximately 98 °F at the base of the 18-inch FRP injection tubing (approximately 2,940 feet bls). Between 3,940 feet bls and 2,980 feet bls the temperature decreases to about 97 °F. From 2,980 to 3,286 feet bls the temperature increased to approximately 99 °F. John Largey of MWH witnessed the test. A copy of the temperature log is presented in **Appendix E**.

4.3.3 Injection Well Television Surveys

A video survey of the IW-1 injection tubing was performed on June 27, 2008. The survey was performed from pad level to a depth of 3,272 feet bls. Water clarity was good, enabling the camera to capture clear images of the tubing interior, packer assembly, casing seat and open hole section. The survey revealed that the tubing was in excellent condition. A copy of the television survey observations is included in **Appendix G.**

4.3.4 Injection Well Radioactive Tracer Survey

On July 31, 2008, a radioactive tracer survey was conducted on IW-1. The test began with Youngquist Brothers, Inc., Geophysical Logging Division conducting a background Gamma Ray Log (GRL) and a casing collar locator (CCL). The background GRL, which was "memorized", was reprinted on each "out of position" logging run to serve as a means of comparison. A schematic diagram of the logging tool is represented at the top of the radioactive tracer survey log. Each logging run is identified at the top of the log. After the completion of the background Gamma Ray Log, the logging tool ejector was calibrated to 0.09 millicuries (mCi) per second discharge, and the reservoir was loaded with 5 millicuries of radioactive Iodine-131. The radioactive tracer survey was witnessed by John Largey representing MWH. Copies of the flowmeter calibration certificate and tracer (Iodine-131) assay are presented in **Appendix E.** A copy of the IW-1 RTS log is also included in **Appendix E.** A sketch of the RTS tool is included with the RTS log.

The first test conducted (TEST #1) injected at a rate of 55 gallons per minute (gpm) using potable water. The test was conducted by positioning the tracer ejector five feet above the bottom of the casing, setting the recorder in the time drive mode, and ejecting a 1.0 mCi slug of tracer material. The readings from the middle gamma ray detector began to increase from background within 22 seconds of ejection. The readings from the bottom detector increased from background approximately two minutes and 20 seconds after ejection. No increase in gamma detection by the top gamma ray detector was seen during the 60-minute monitoring period. The tools were then logged out of position (LOP #1) to a depth of 2,745 feet bls. The results of the log out of position showed no indication of tracer material movement up hole. The injection casing was then flushed with potable water. Following the flushing an out of position log was conducted (LAF #1) from below the casing to 2,745 feet bls. This log shows that no tracer material had moved up behind the casing. These results are interpreted as providing evidence that the casing integrity is sound and there are no channels behind the casing.

A second test (TEST #2) was then conducted at an injection rate of 55 gpm. This test also used potable water as the injection fluid. The tracer ejector was positioned five feet above the bottom of the casing and the recorder was placed in the time drive mode. A 1.0 mCi slug of tracer material was then ejected. The readings from the middle gamma ray detector began to increase from background within 21 seconds of ejection. The readings from the bottom detector increased from background approximately 2 minutes and 21 seconds after ejection. No detection of the tracer material was seen at the upper gamma ray detector any time during 30 minutes of time drive monitoring. The tools were logged out of position (LOP #2) to a depth of 2,749 feet bls after the 30-minute test period. The results of the log out of position showed no indication of tracer material movement up hole. The injection casing was then flushed with potable water. Following the flushing, a final background and log after flush log was conducted (FINAL GAMMA RAY) on the total depth of the well. This log shows that all tracer material had been flushed out of the casing because the gamma ray levels on all three detectors returned to background levels. These results are interpreted as providing evidence that the casing integrity is sound. The background logs were recorded over traces of the initial background log and showed excellent repeatability on all detectors. It can be seen where the remaining tracer material was dumped (3,260 feet bls).

4.3.5 MIT Conclusions

Based on the results of the temperature logs, hydrostatic pressure tests, video surveys and radioactive tracer survey, IW-1 has been demonstrated to have mechanical integrity.

4.4 Injection Test

On September 2, 2008, a controlled short term injection test was conducted on IW-1 using reclaimed water from the City's Southwest WRF. The test consisted of a background phase, a pumping phase and a recovery phase. An Integra-QMR memory gauge was placed at a depth of 2,930 feet bls in IW-1 to monitor pressures near the base of the final casing. Transducers were also placed such that wellhead pressures of IW-1, the dual-zone monitoring well (DZMW-1) upper monitor zone (1,325 to 1,406 feet bls) and lower monitor zone (1,610 to 1,660 feet bls) could be monitored. In order to ensure the recovery of test data a fully redundant data acquisition system was used. Two independent sets of transducers were installed at each pressure monitoring point. The test data were recorded by two independent In-Situ Inc., Hermit 3000 data loggers. The data loggers also recorded local barometric pressures. The transducer sets and data loggers were designated Box 1 and Box 2. Copies of the calibration certificates for the pressure transducers and flowmeter are provided in **Appendix Q.**

Background monitoring was initiated at 9:20 AM on August 30, 2008. After the background monitoring phase was completed the 12-hour injection test was started at 9:10 AM on September 2, 2008. The test was conducted at two different injection rates. Injection began at the lower rate, which averaged 6,900 gpm (10.2 ft/sec). The 6,900 gpm injection rate was maintained for approximately eleven hours. An injection rate of approximately 8,100 gpm (12.0 ft/sec) was maintained for the last hour of the test. A copy of the injection test log is included in **Appendix Q**. After the pumping phase of the test was concluded recovery readings were recorded starting at 9:27 PM on September 2, 2008 and continued for approximately 34 hours.

The data recovered from the two data loggers was very similar. The data recovered from Box 2 have been presented in this report as they appear to be slightly less noisy as compared to the data recorded by Box 1. Injection well IW-1 wellhead and downhole pressures, DZMW-1 upper and lower monitor zone pressures and barometric pressure recorded by the Hermit 3000 data logger over all three phases of the test (background, pumping, and recovery) are presented in **Appendix Q**. Tide data recorded by The National Ocean Service, Fort Myers Station (Station ID: 8725520) is also located in **Appendix Q**.

The IW-1 wellhead shut-in pressure was approximately 30 psi before the start of the test. The maximum recorded IW-1 wellhead pressure during the test was 58.3 psi. This pressure was recorded immediately after pumping at the higher rate began. During the lower rate pumping interval the average IW-1 wellhead pressure was approximately 48.6 psi which increased to an average of approximately 53.9 psi during the final higher pumping rate hour. A graphical presentation of the data recorded during the injection test is presented in **Appendix Q, Exhibit 1**.

All IW-1 wellhead pressure readings are well within the allowable 2/3 of the pressure test (i.e., approximately 100 psi) conducted on the 24-inch diameter final casing and the 18-inch diameter FRP injection tubing. A summary of the injection rates and wellhead pressures is presented in **Table 4-2.**

Table 4-2
IW-1 Injection Test Summary

Injection Rate (gpm)	Wellhead Pressure (psi)	Specific Injectivity (gpm/psi)
6,900	48.6	142
8,100	53.9	150

4.4.1 Findings and Conclusions

Plots of the data collected during the injection test are presented in **Appendix Q** as Exhibits 1 through 8. **Exhibit 1** presents the injection wellhead pressure, upper and lower monitor zone pressures, and barometric pressure during the background, pumping and recovery phases of the test. Monitor well DZMW-1 upper and lower monitor zone pressures remained generally static over the duration of the test as shown in **Exhibits 2 and 3.** As presented in **Exhibits 4 and 5,** a detailed examination shows the upper and lower monitor zone pressure changes correlate very well with the tidal data and with changes in the barometric pressure as presented in **Exhibits 6 and 7.** The IW-1 wellhead and downhole pressures show excellent correlation as shown in **Exhibit 8.**

The transmissivity of the injection zone is estimated to be 322,500 gpm per day per foot. The injection zone is capable of accepting the permitted flowrate of 10 ft/s and the maximum design flowrate equivalent to a velocity of 12 feet per second at a reasonable injection pressure that will not promote fractures in the injection zone or confining sequences.

Section 5
Findings and Recommendations

5.1 FINDINGS

The following list summarizes the findings identified during the construction of the injection and monitor wells.

- The base of the USDW, the point where the water contains 10,000 mg/L TDS, occurs at 1,502 feet bls at IW-1.
- The confining sequences generally occur between 1,650 and 2,070 feet bls and between 2,460 and 2,665 feet bls.
- Vertical hydraulic conductivity determined from core testing ranged from 5.5×10^{-4} to 3.0×10^{-10} cm/sec.
- Transmissivity determined from packer testing within the confining sequences ranges from 0.8 $feet^2$ per day to 5.3 $feet^2$ per day
- The data demonstrates the existence of an extremely transmissive injection zone below 2,665 feet bls saturated with saline water (containing more than 10,000 mg/l TDS).
- The injection well was tested at injection rates of 6,900 gpm (10.2 ft/sec, 9.9 mgd) and 8,100 gpm (12.0 ft/sec 11.7 mgd) with average injection pressures of 48.6 psi and 53.9 psi respectively.
- The injection zone is capable of accepting the maximum design flowrate equivalent to a velocity of 12 feet per second in IW-1 at a reasonable injection pressure that will not promote fractures in the injection zone or confining sequences.
- The IW-1 final casing (24-inch OD) was successfully pressure tested at 150 psi.
- The IW-1 FRP injection tubing (18-inch OD) was successfully pressure tested at 150 psi.
- The testing program has demonstrated that IW-1 has mechanical integrity.
- One dual-zone monitor well was drilled with the upper monitor zone located from 1,325 to 1,406 feet bls and the lower zone from 1,610 to 1,660 feet bls.

5.2 CONCLUSIONS

The presence of favorable geologic conditions, a highly transmissive injection zone filled with water having greater than 10,000 mg/L TDS, suitable confining sequence, and suitable monitor zones will permit the use of the injection well for disposal of RO concentrate and excess reclaimed water at the City of Cape Coral Southwest ROWTP and WRF in accordance with existing state and federal underground injection control regulations.

Based on the results of the geophysical logging and testing injection well IW-1 has mechanical integrity and is ready to begin operational testing.

5.3 RECOMMENDATIONS

Operation of the dual-zone monitor well should begin within one month after the construction of the surface facilities is complete. Injection well operational testing may begin operating under the construction permit after operational testing approval is issued by FDEP.

The following recommendations are in accordance with requirements of FAC Rule 62-528 for the safe operation of an injection well system. These procedures should be carried out conscientiously to ensure compliance with the injection well construction permit (refer to **Appendix A**) and all regulatory requirements and to ensure successful operation of the well. Additional information on monitoring and reporting data is discussed in Section 5.4.

- Dual-zone monitor well pressure is to be continuously monitored.
- Injection wellhead pressure is to be continuously monitored.
- Flow to the injection well is to be continuously monitored.
- Dual-zone monitor well water quality is to be monitored weekly.
- Waste stream water quality is to be monitoredmonthly.
- Injection well injectivity tests are to be performed monthly.
- A complete analysis of the waste stream is to be performed yearly.
- Injection well mechanical integrity tests are to be performed every five years.
- An interim mechanical integrity test consisting of a hydrostatic pressure test of the FRP injection tubing is to be conducted every 2.5 years.

5.4 WELL OPERATION, MAINTENANCE, AND FUTURE TESTING

When the injection well is operational, a variety of data will be collected to satisfy statutory/permit requirements and to assist in managing the system. This Section discusses the basic requirements for data collection to maintain permit compliance during both the initial testing and long-term operation of the injection well system. Initially, the injection well will be operating under the construction permit. A minimum of six months of operational testing are required before the City can apply for an operating permit. The construction permit for IW-1 expires October 31, 2011. It is essential that the performance data collection begin upon operational startup to establish baseline information that both satisfies regulatory requirements and serves for future data comparison and performance analyses. These records should be permanently maintained.

5.4.1 Monitor Well Data Collection

The purpose of monitor zone data collection is to detect changes in water quality attributable to the injection fluids into the nearby injection well. To collect the water quality samples, the monitor zones at the dual-zone monitoring well will be equipped with two sampling pumps, one for each zone. Interconnection of piping from the different zones and wells is not permitted by FDEP. Prior to collecting water samples for analysis, at least three well volumes must be pumped from each monitor zone.

Dual-zone monitor well water quality is to be monitored through weekly and monthly samples from the two dual-zone monitor well zones. Samples are to be collected and analyzed as shown in **Table 5-1.** The results of these analyses are to be sent to the FDEP monthly.

Table 5-1
DZMW-1 Water Quality Monitoring

Parameters	Reporting Frequency
Specific Conductivity (µmhos/cm)	Weekly
Total Dissolved Solids (mg/L)	Weekly
pH (std. units)	Weekly
Chloride (mg/L)	Weekly
Sulfate (mg/L)	Weekly
Field Temperature (°C)	Weekly
Ammonia (mg/l)	Weekly
Total Kjeldahl Nitrogen (TKN) (mg/L)	Weekly
Sodium (mg/L)	Monthly
Calcium (mg/L)	Monthly
Potassium (mg/L)	Monthly
Magnesium (mg/L)	Monthly
Iron (mg/L)	Monthly
Bicarbonate (mg/L)	Monthly
Gross Alpha	Monthly (lower monitor zone only)
Radium 226	Monthly (lower monitor zone only
Radium 228	Monthly (lower monitor zone only

The pressure in both zones of the dual-zone monitor well is to be continuously monitored and recorded relative to feet NGVD or psi. Daily and monthly average, maximum and minimum pressures are to be reported to FDEP monthly.

5.4.2 Injection Well Data Collection

Beginning with the start of the use of the injection well, records should be maintained to evaluate injection well performance.

The pressure at the injection wellheads is to be continuously monitored and recorded. Daily monthly average, maximum and minimum pressures are to be reported to FDEP monthly.

The flowrate into the injection well is to be continuously monitored and recorded. The daily and monthly total volume of WRF effluent and the daily and monthly total volume of RO concentrate are to be recorded and reported to the FDEP on a monthly basis. Daily average, maximum, and minimum flow rates, as well as the total volume of fluid pumped into the well are to be reported to the FDEP on a monthly basis.

5.4.3 Injectivity Testing

Periodic determination of the injectivity of a well is used as a measure of the efficiency of a well and is a permit requirement as a management tool for the injection well system. The injectivity test involves injecting fluid into a well at three (or more) injection rates and recording the injection pressure for each rate. The shut-in pressure of the injection well is to be measured before each different injection rate. The injectivity is calculated by dividing the injection rate by the required injection pressure (wellhead injection pressure minus shut-in wellhead pressure). The result is expressed as gallons per minute per pounds per square inch (gpm/psi).

Factors affecting the injection wellhead pressure are a function of:

- The density differential between the injected fluid and the formation water in the injection zone;
- The friction loss in the casing; and
- The bottom hole pressure (injection zone transmissivity).

The density differential is fairly constant as long as the temperature and density of the injection and formation fluids remain constant. Friction loss in the casing and bottom hole pressure can vary as a result of changes in the flow rate, physical condition of the injection zone and physical condition of the pipe. In general, pressure builds slowly with time (for a given pumping rate) as the casing "ages". Similarly, plugging of an injection zone can cause a gradual pressure build-up over time. Testing is required to be conducted quarterly for the life of the well. The testing rates for injectivity testing should be established as soon as the well is placed in operation. The test procedure should be easily repeatable.

A specific injectivity test is required to be performed monthly. The pumping rates should be established after the well is in operation. Flow to the wells and wellhead pressures are to be recorded during this period. A pressure fall off is to be conducted as part of the monthly specific injectivity test. Test results are to be reported to the FDEP upon completion of the testing.

5.4.4 Mechanical Integrity

An injection well has mechanical integrity when there is no leak in the casing and no fluid movement into the underground source of drinking water through channels adjacent to the well bore. Mechanical integrity testing includes a pressure test, a radioactive tracer survey, a high-resolution temperature log and a television survey. This testing will be used, along with the monitoring data of the upper and lower monitor zones, to demonstrate the absence of fluid movement above the injection zone.

The injection wells are to be tested for mechanical integrity every five years in accordance with FAC Rule 62-528. As an alternatively designed industrial tubing and packer Class I injection well with the injection tubing cemented in place and interim mechanical integrity test consisting of a hydrostatic pressure test of the injection tubing is required midway between the five year mechanical integrity testing interval. Based on the date of testing during construction, the first interim MIT is to be performed before October 7, 2010, and the next MIT is to be performed before April 7, 2013. The proposed MIT plans must be approved by FDEP prior to performing mechanical integrity testing. Request for approval should be made approximately six months prior to the required completion date.

5.4.5 Waste Stream Analysis

During operational testing the injectate stream water quality is to be monitored through monthly sampling. Samples are to be collected from the WRF and the WTP concentrate streams and analyzed as shown in **Table 5-2.** The results of these analyses are to be sent to the FDEP monthly.

Table 5-2
Waste Stream Water Quality Monitoring

Parameters	Reporting Frequency
WRF Effluent Water Quality	
Ammonia (mg/l)	Monthly
Total Kjeldahl Nitrogen (TKN) (mg/L)	Monthly
Nitrate and Nitrite as N (mg/l)	Monthly
ROWTP Concentrate Water Quality	
Specific Conductivity (•mhos/cm)	Monthly
Total Dissolved Solids (mg/L)	Monthly
pH (std. units)	Monthly
Chloride (mg/L)	Monthly
Sulfate (mg/L)	Monthly
Field Temperature (°C)	Monthly
Total Kjeldahl Nitrogen (TKN) (mg/L)	Monthly
Sodium (mg/L)	Monthly
Calcium (mg/L)	Monthly
Potassium (mg/L)	Monthly
Magnesium (mg/L)	Monthly
Iron (mg/L)	Monthly
Bicarbonate (mg/L)	Monthly
Gross Alpha	Monthly
Radium 226	Monthly
Radium 228	Monthly

5.5 PLUGGING AND ABANDONMENT PLAN

In the event that the injection well has to be abandoned, the well must be effectively sealed (or plugged) to prevent upward migration of the injection zone fluid or the interchange of formation water through the borehole or along the casing. The plugging program will require the services of a qualified drilling contractor with equipment capable of installing drill pipe to a depth of 2,950 feet and pumping neat cement.

The following procedures would be followed to abandon the injection well:

- Obtain a permit from the FDEP
- Suppress the wellhead pressure with drilling mud
- Remove the wellhead assembly
- Fill the open hole with crushed limestone
- Place a sand cap on the crushed limestone to the bottom of the 24-inch casing
- Fill the 24-inch casing and 18-inch injection tubing with neat cement

The following procedures would be followed to abandon the dual-zone monitor well:

- Obtain a permit from the FDEP
- Suppress the wellhead pressure with drilling mud
- Remove the wellhead assembly
- Fill the deep zone with crushed limestone and the 6.625 -inch diameter casing with neat cement grout
- Fill the shallow zone with crushed limestone and the 16-inch diameter casing with neat cement grout

A cost estimate for plugging and abandoning the wells is presented in **Table 5-3.**

Table 5-3
Plugging and Abandonment Cost Estimate

Injection Well IW-1			
Mobilization	$50,000	1	$50,000
MIT	$75,000	1	$75,000
Crushed Limestone (cu-ft)	$20	2,000	$40,000
Neat Cement (sacks)	$20	2,500	$50,000
20% Contingency	---	1	$43,000
Total - Injection Well	---	---	**$258,000**
Dual-Zone Monitor Well DZMW-1			
Mobilization	$30,000	1	$30,000
Neat Cement (sacks)	$20	1500	$30,000
20% Contingency	---	1	$12,000
Total - **Dual-Zone Monitor Well**	---	---	**$72,000**
TOTAL COST			**$330,000**