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

WW-4C.2
Everest WRF
Class I Deep Injection Well System

Drilling and Testing Report

June 2009

MWH

Cape Coral FLORIDA

June 30, 2009

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

Subject: Everest WRF Class I Injection Well System, Drilling and Testing Report
City of Cape Coral, Lee County, Permit No. 254592-001-UC

Dear Mr. Rhodes:

In accordance with Specific Conditions (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 Everest WRF Class I Injection Well System. The report was prepared for the City by MWH Americas, Inc. (MWH.)

In accordance with Rule 62-5528.340(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 or 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

Attachments: Drilling and Testing Report
Distribution List

Certifications

PROFESSIONAL ENGINEER

The engineering features of the *WW-4C.2 Everest WRF Class I Deep Injection Well System Drilling and Testing Report* for the City of Cape Coral, June 2009, were prepared by, or reviewed by, a Licensed Professional Engineer in the State of Florida.

Ronald M. Cass, P.E.

6-21-09

Date

FL/64922

License No.

PROFESSIONAL GEOLOGIST

The geological evaluation and interpretations contained in the *WW-4C.2 Everest WRF Class I Deep Injection Well System Drilling and Testing Report* for the City of Cape Coral, June 2009, were prepared by, or reviewed by, a Licensed Professional Geologist in the State of Florida.

Neil A. Johnson, P.G.

6-11-09

Date

FL - 2052

License No.

City of Cape Coral
Everest WRF – WW-4C.2
Class I Injection Well Permit No. 254592-001-UC
Technical Advisory Committee/Distribution List

Mr. James Alexander, P.G.
FDEP, Underground Injection Program
Twin Towers Mail Station #3530
2600 Blair Stone Road
Tallahassee, FL 32399
Work Phone: 850/245-8653
Fax Phone: 850/487-3618

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. Ron Reese
U.S. Geological Survey
3110 SW 9th Avenue
Ft. Lauderdale, FL 33315
Work Phone: 954/377-5921

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
Work Phone: 239/574-0729
Fax Phone: 239/574-0731

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

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.
100 South Dixie Highway, Suite 300
West Palm Beach, FL 33401
Work Phone: 561/650-0070
Fax Phone: 561/650-0074

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

Document Control Sheet

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Intra-Discipline Review

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

Inter-Discipline Review

Discipline	Checked by (Reviewer)

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Rev	Date	Revision Description	Prepared (Lead Author)	Reviewed	Approved
1	5/27/09	Draft 1	Largey	Johnson	
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1	5/28/09	Draft 1	Largey	Weatherby	
2	6/10/09	Final	Largey	Johnson	

Distribution

Name	Name
See attached	

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Injection Well Program

1.1 INTRODUCTION

The City of Cape Coral (City) is increasing its wastewater treatment capability by expanding the Everest Water Reclamation Facility (WRF) in the eastern part of the City. The City of Cape Coral Everest WRF project site, shown on **Figure 1-1**, is located at 1740 Everest Parkway, Cape Coral, Lee County Florida.

The Everest WRF will treat domestic wastewater to reclaimed water standards to supplement the City's irrigation system. The planned completion date is 2010, with peak reclaimed water flows of 13.4 million gallons per day (MGD) by 2014. Excess reclaimed water not used by the City's irrigation system will be disposed of through deep well injection.

On November 1, 2006, the Florida Department of Environmental Protection (FDEP) issued Construction Permit No. 254592-001-UC (Permit) for the construction of one Class I injection well (IW-1) and an associated dual zone monitoring well (DZMW-1) for disposal of excess reclaimed water from the Everest WRF. On May 6, 2006 FDEP approved a minor modification changing the 44-inch diameter steel casing to 42 inches and the 36-inch steel casing to 34 inches. At the time of this report, construction and testing of IW-1 and DZMW-1 have been completed. Copies of the FDEP construction permit and minor modification to the permit are included as **Appendix A.**

The well designated as IW-1 in the construction permit application and drawings was constructed first. The injection interval is the Oldsmar Formation at a depth between approximately 2,650 and 3,700 feet below land surface (bls). The injection well will have a maximum injection rate of 15 MGD, approximately 10,471 gallons per minute (gpm).

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 Everest WRF site. The following information is included in this report:

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

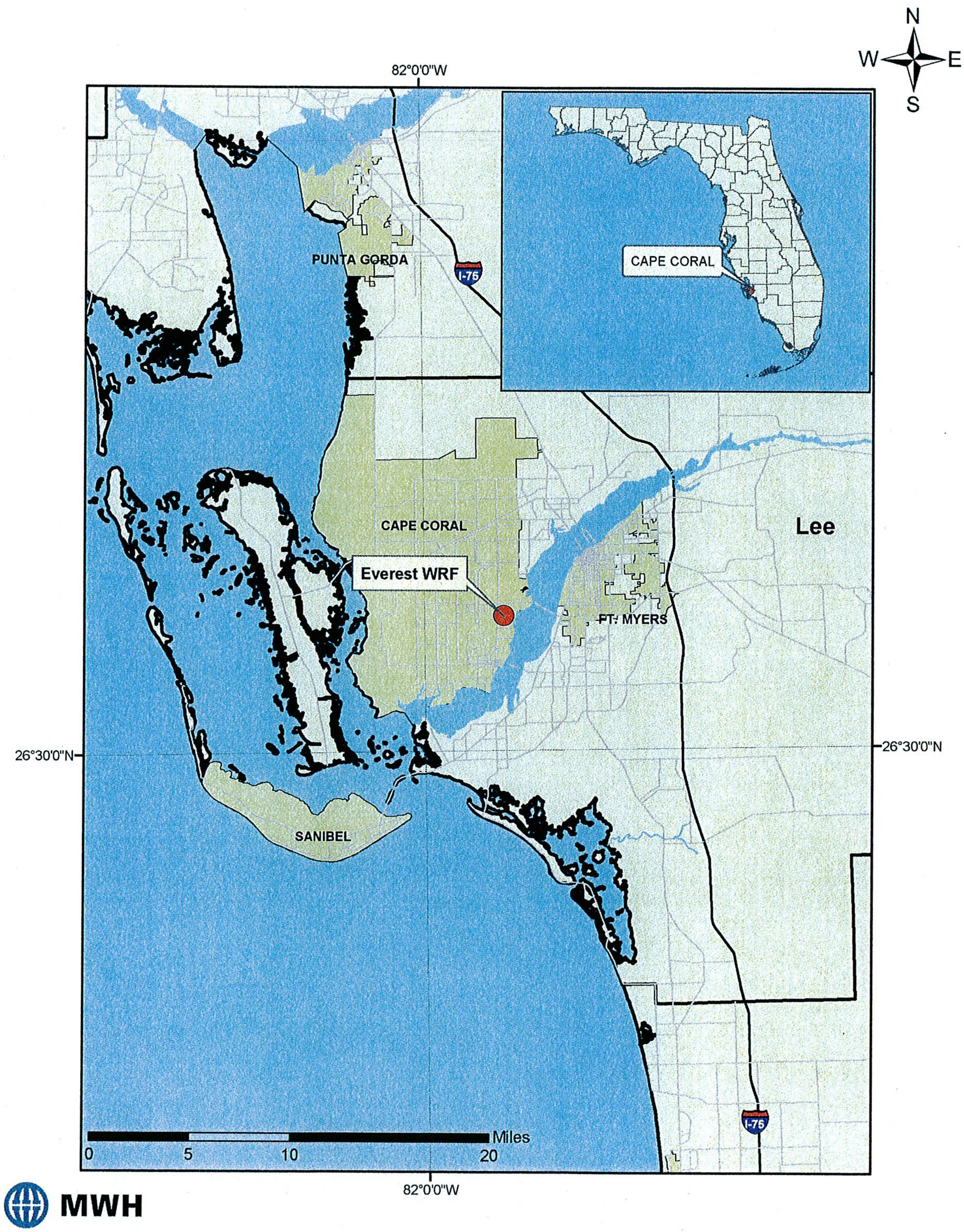

Figure 1-1
Site Location Map

1.3 SCOPE

Youngquist Brothers, Inc. (YBI) of Fort Myers, Florida 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 the Permit under General Condition 5.f.

1.4 PROJECT OVERVIEW

The project specifications contained provisions for the construction and testing of the injection well and associated monitor well. The Notice-to-Proceed was issued in January 2008. Major construction activities were completed in April 2009. The 24-inch diameter injection well was constructed to approximately 3,700 feet below land surface (bls). The dual-zone monitor well was constructed to a total depth of 1,870 feet bls.

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 the 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 geophysical logs at various points during the well construction including X-Y caliper, gamma ray, fluid conductivity, dual induction, borehole compensated sonic/VDL, temperature, flowmeter, and borehole televiewer
- Collecting and analyzing water samples collected during the packer tests to determine water quality variations with depth and to identify confining units above the injection zone.

- Conducting short term injectivity tests to estimate the ability of the well to accept fluids at the design flow rate
- 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 and Testing

2.1 INTRODUCTION

This section of the report describes the construction activities for IW-1 and DZMW-1. The locations of IW-1 and DZMW-1 at the Everest WRF 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.

Throughout construction activities, water samples were collected on a weekly basis from the six shallow monitoring wells (SMWs) constructed within the surficial aquifer surrounding the perimeter of the well 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 long-term adverse affects to the surficial aquifer system were observed as a result of well construction activities.

2.2 WELL CONSTRUCTION

Drilling and construction of IW-1 began on May 5, 2008. Drilling and construction of DZMW-1 began on December 15, 2008. Drilling operations were generally conducted on a 24 hours a day, 7 days per week schedule. Major construction activities were completed on March 18, 2009.

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 and minor modification. Refer to **Appendix A** for a copy of the permit and minor modification. 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.

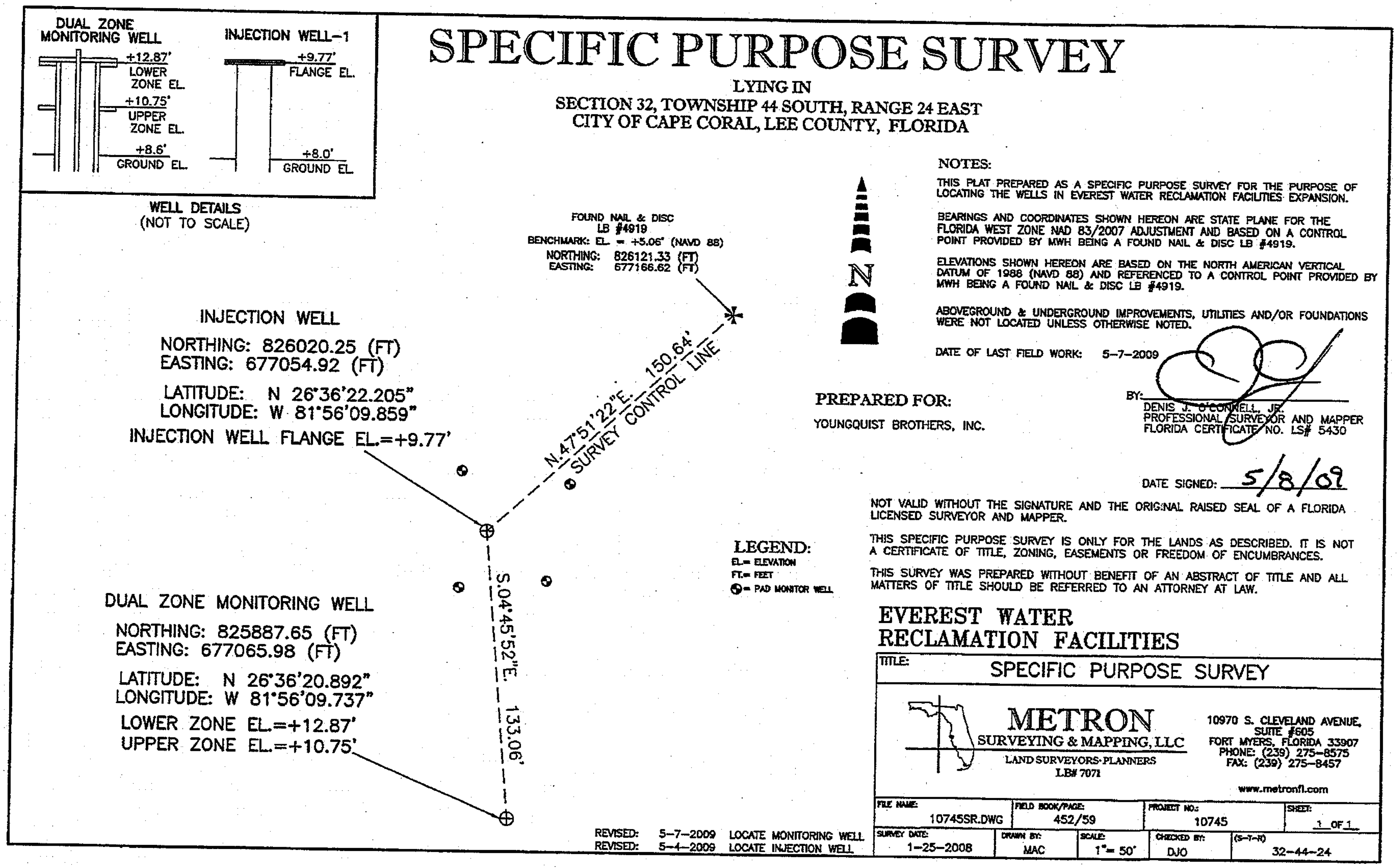

Figure 2-1
Site Survey

Drilling activities are summarized in the following sequence of events, which identify nominal depths.

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

Actual depths of casings are identified in the profile of the completed wells IW-1 and DZMW-1 presented in **Figure 2-2**. Injection well IW-1 was generally constructed as follows:

- Drill a nominal 58-inch diameter borehole to approximately 83 feet bls using the mud rotary method.
- Set and cement 52-inch diameter steel casing to a depth of 80 feet bls.
- Drill a 12.25-inch diameter pilot hole to approximately 490 feet bls using the mud rotary method.
- Drill a nominal 50-inch diameter borehole to approximately 481 feet bls using the mud rotary method.
- Set and cement 42-inch diameter steel casing to a depth of 481 feet bls.
- Drill a 12.25-inch diameter pilot hole to approximately 1,700 feet bls using the reverse air method.
- Back plug pilot hole with cement to 480 feet bls.
- Drill a nominal 40.5-inch diameter borehole to approximately 1,692 feet bls using the reverse air method.
- Set and cement 34-inch diameter steel casing to a depth of 1,690 feet bls.
- Drill a 12.25-inch diameter pilot hole to approximately 3,400 feet bls using the reverse air method and core at selected depths.
- Back plug pilot hole with cement to 1,705 feet bls.
- Drill a nominal 32.5-inch diameter borehole to approximately 3,250 feet bls using the reverse air method.
- Set and cement 24-inch diameter steel casing to a depth of 2,630 feet bls.
- Drill a 12.25-inch diameter pilot hole to approximately 4,397 feet bls using the reverse air method.
- Back plug pilot hole with cement to 4,365 feet bls.
- Drill a nominal 22-inch diameter borehole to approximately 3,700 feet bls using the reverse air method.

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

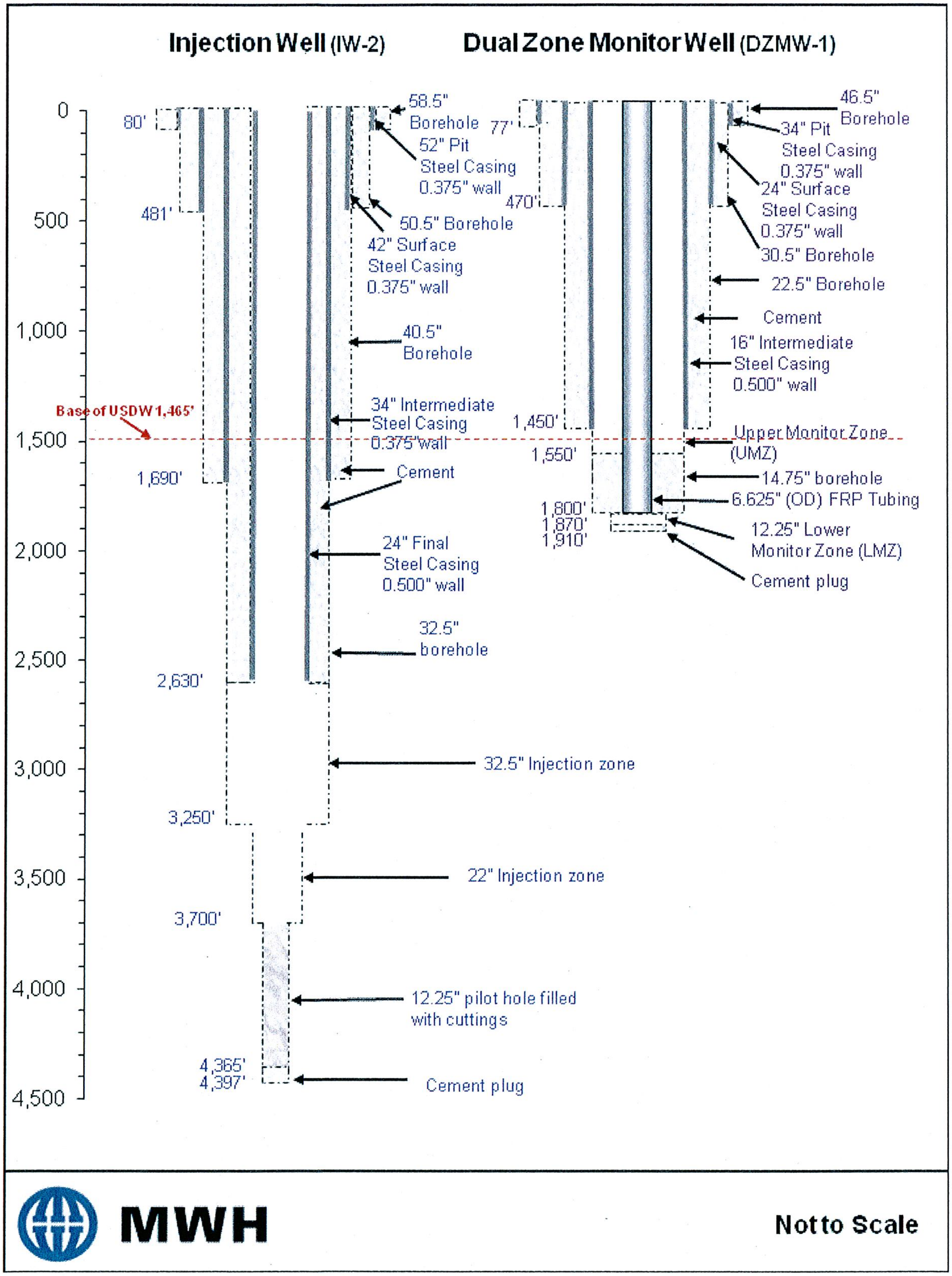

Figure 2-2
IW-1 and DZMW-1 Casing Details

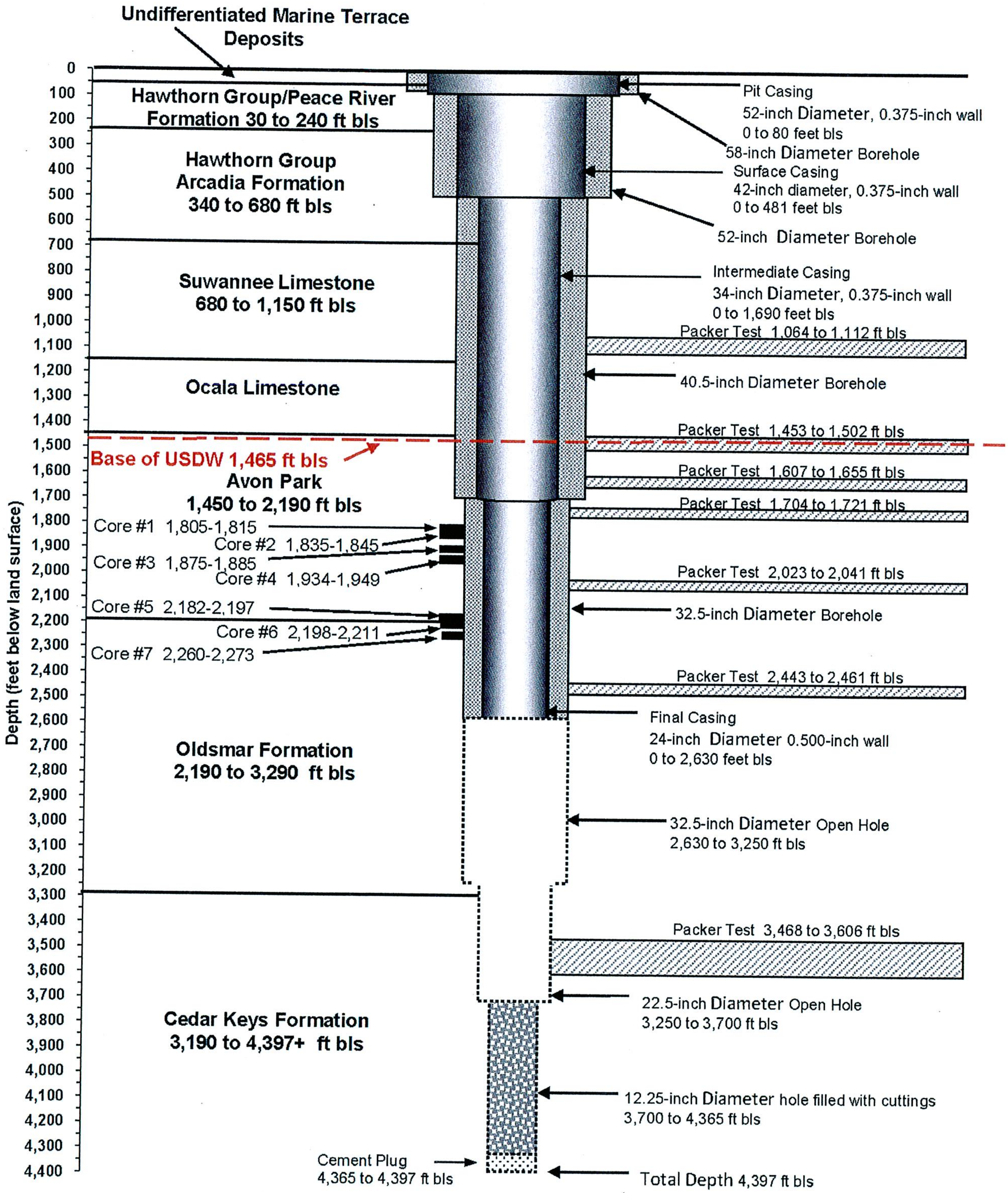

Figure 2-3
IW-1 Summary of Drilling and Testing

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 46.5-inch diameter borehole to approximately 80 feet bls using the mud rotary method.
- Set and cement in place 34-inch diameter steel pit casing to 77 feet bls.
- Drill a 12.25-inch diameter pilot hole to approximately 490 feet bls using the mud rotary method.
- Drill a 30.5-inch diameter borehole to approximately 475 feet bls using the mud rotary method.
- Set and cement in place 24-inch diameter steel casing to 470 feet bls.
- Drill a nominal 12.25-inch diameter borehole to approximately 1,910 feet bls using the reverse air method and core at selected depths.
- Back plug pilot hole with cement to 482 feet bls, upper and lower monitor zones filled with gravel.
- Drill a 22.5-inch diameter borehole to approximately 1,452 feet bls using the reverse air method.
- Set and cement in place 16-inch diameter steel casing to 1,450 feet bls.
- Drill a 14.75-inch diameter borehole to approximately 1,790 feet bls using the reverse air method.
- Drill a 12.25-inch diameter borehole to approximately 1,870 feet bls using the reverse air method.
- Set and cement in place 6.625-inch diameter fiberglass reinforced pipe FRP tubing to 1,800 feet bls using an external cementing packer, filling the annular space of the final casing with cement from 1,800 to 1,550 feet bls.

The upper monitor zone (UMZ) was established between 1,450 and 1,550 feet bls and the lower monitor zone (LMZ) between 1,800 and 1,870 feet bls. A summary of the DZMW-1 drilling and testing is presented in **Figure 2-4**. A summary of casing depths and materials is presented in **Table 2-1.**

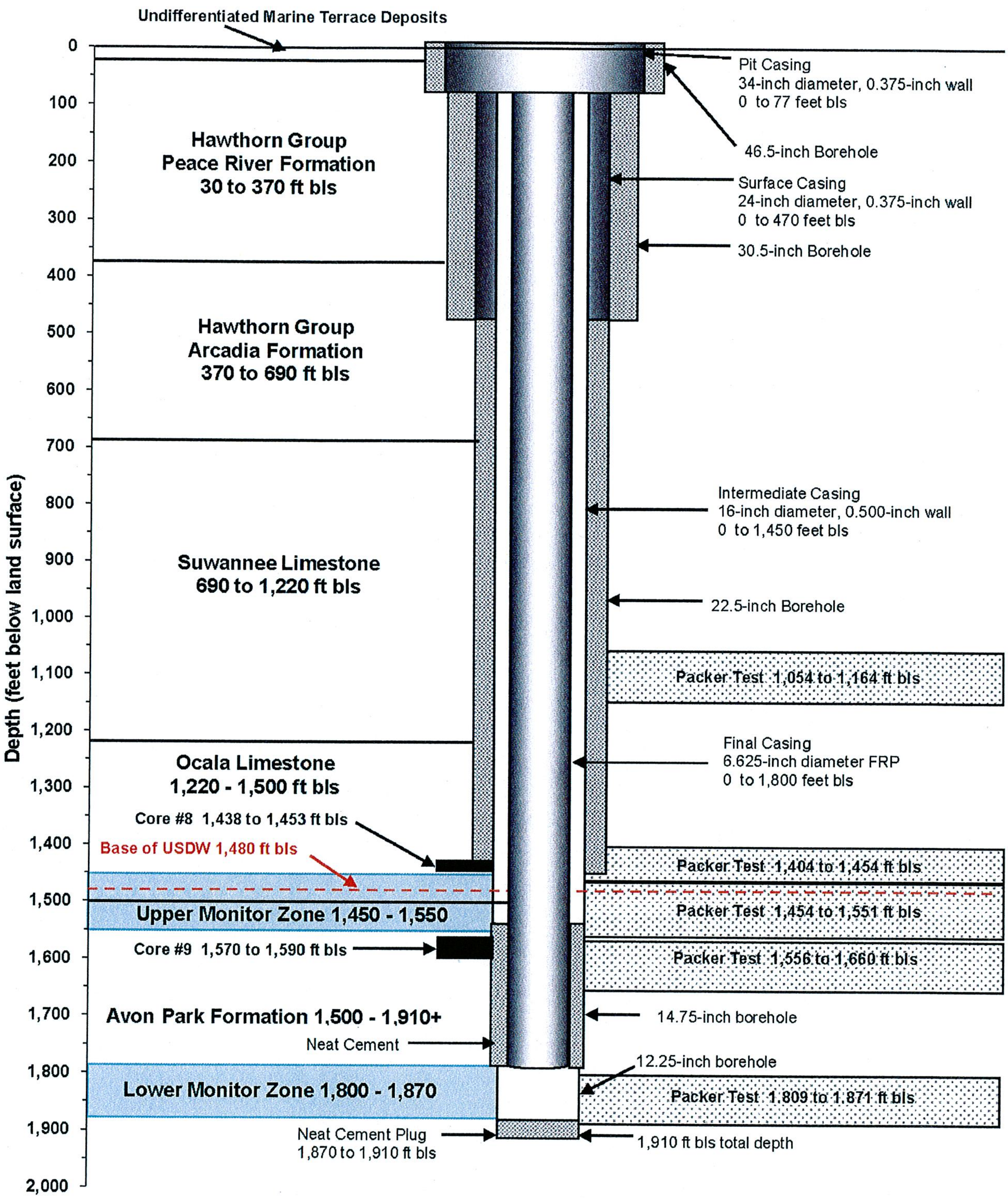

Figure 2-4
DZMW-1 Summary of Drilling and Testing

Table 2-1
Casing Summary

CASING	DIAMETER (Inches)		CASING THICKNESS (Inches)	CASING MATERIAL	CASING DEPTH (Feet)
	Inside	Outside			
Injection Well IW-1					
Pit	51.25	52.00	0.375	Steel	80
Surface	41.25	42.00	0.375	Steel	481
Intermediate	33.25	34.00	0.375	Steel	1,690
Final Casing	23.00	24.00	0.500	Steel	2,630
Total Depth	n/a	n/a	n/a	n/a	3,700
Dual-Zone Monitor Well DZMW-1					
Pit	33.25	34.00	0.500	Steel	77
Surface	23.25	24.00	0.375	Steel	470
Final Casing (Upper Monitor Zone)	15.00	16.00	0.500	Steel	1,450
FRP Tubing (Lower Monitor Zone)	5.47	6.63	0.580	FRP	1,800
Total Depth	n/a	n/a	n/a	n/a	1,870

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 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, depth measurements in the wells are referenced to land surface. As shown on **Figure 2-1** the North American Vertical Datum (NAVD, 1988) elevation of IW-1 and DZMW-1 are 8.0 and 8.6 feet, respectively.

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 activities or placement of other materials, as well as their quantities, were recorded. Detailed descriptions of test procedures and data collection, including results of deviation 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 the deviation surveys are presented in **Appendix B.**

2.4 GEOLOGIC SAMPLES

Samples of formation 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 lithology log. The limestone cuttings were classified in accordance with the scheme of Dunham (1962). These logs are presented in **Appendix C**. Two sets of formation cuttings were bagged in 10-foot intervals. One set of these samples was sent to the Florida Geological Survey in Tallahassee, Florida and the second set has been retained by the City.

2.5 CORES

During the drilling of the injection well pilot hole, seven conventional cores were recovered. Two conventional cores were recovered during the drilling of the dual-zone monitor well. The Contractor used a 4-inch inside diameter core barrel for this project. 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. 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. Cores recovered from IW-1 and DZMW-1 were taken over the intervals identified in **Table 2-2.**

Table 2-2
Core Intervals

Core Number	Core Interval (feet bls)	Core Recovery
Injection Well IW-1		
Core No. 1	1,805 to 1,815	35%
Core No. 2	1,835 to 1,845	46%
Core No. 3	1,875 to 1,885	70%
Core No. 4	1,934 to 1,949	30%
Core No. 5	2,182 to 2,197	80%
Core No. 6	2,198 to 2,211	50%
Core No. 7	2,260 to 2,273	90%
Dual-Zone Monitor Well DZMW-1		
Core No. 8	1,438 to 1,453	53%
Core No. 9	1,570 to 1,590	47%

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 Number	Tested Interval (feet bls.)	Vertical Hydraulic Conductivity (cm/sec)	Horizontal Hydraulic Conductivity (cm/sec)
Injection Well IW-1			
1	1,813.0 – 1,813.3	7.0×10^{-6}	3.1×10^{-5}
1	1,813.4 – 1,813.7	2.8×10^{-5}	
3	1,881.7 – 1,882.3	1.1×10^{-4}	1.0×10^{-4}
3	1,883.2 – 1,883.7	1.9×10^{-4}	2.5×10^{-4}
3	1,880.9 – 1,881.7	1.3×10^{-4}	1.4×10^{-4}
3	1,880.2 – 1,880.5	1.2×10^{-4}	1.5×10^{-4}
5	2,182.1 – 2,182.5	1.6×10^{-4}	4.4×10^{-4}
5	2,183.7 – 2,184.5	7.8×10^{-7}	2.0×10^{-7}
5	2,188.9 – 2,190.2	1.3×10^{-6}	1.3×10^{-6}
5	2,190.2 – 2,190.5	1.9×10^{-6}	1.9×10^{-6}
5	2,190.7 – 2,198.8	6.0×10^{-7}	2.2×10^{-6}
6	2,206.9 – 2,207.3	7.1×10^{-7}	8.0×10^{-8}
6	2,209.1 – 2,209.8	2.7×10^{-7}	1.2×10^{-9}
6	2,210.8 – 2,211.8	9.2×10^{-12}	1.7×10^{-10}
7	2,262.1 – 2,262.5	6.3×10^{-4}	
7	2,272.5 – 2,273.0	8.7×10^{-5}	3.7×10^{-4}
Dual-Zone Monitor Well DZMW-1			
8	1,439.3 – 1,439.5	1.0×10^{-6}	1.4×10^{-5}
8	1,440.9 – 1,441.3	2.5×10^{-6}	1.2×10^{-5}
9	1,572.3 – 1,573.3	1.7×10^{-6}	1.6×10^{-6}
9	1,573.3 – 1,573.9	2.2×10^{-6}	2.2×10^{-6}
9	1,574.0 – 1,575.6	1.5×10^{-6}	1.1×10^{-6}

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 borehole diameter and geometry.
- Gamma Ray - Measurement of the natural gamma ray radiation of the formation, used as a tie-in between logs.
- Dual Induction Log – An electrical resistivity log, which allows 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 a CD located at the end of the report in **Appendix E.**

2.6.1 Injection Well (IW-1) Geophysical Logging Program

Geophysical logs were conducted for each stage of drilling (land surface to 490; 490 to 1,700; 1,700 to 3,400; and 3,400 to 4,397 feet bls) of IW-1. **Table 2-4** summarizes the geophysical logging sequence for IW-1.

On May 9, 2008, prior to reaming and setting the 42-inch diameter surface casing to 481 feet bls in IW-1, a suite of geophysical logs was conducted, as described in **Table 2-4.** The caliper log showed the borehole diameter to be generally consistent from 13 to 14 inches and indicated a good casing seat at 584 feet bls in moderately indurated limestone.

After setting and cementing the surface casing, a 12.25-inch diameter pilot hole was advanced from the bottom of the surface casing to 1,700 feet bls. On May 22, 2008, prior to reaming and setting the 34-inch diameter intermediate casing to 1,690 feet bls in IW-1, geophysical logs were run to identify confining units, producing intervals, the base of the underground source of drinking water (USDW), and aid in casing seat determination.

The caliper log indicated a pilot hole diameter of approximately 15 inches from the bottom of the surficial casing to a depth of about 670 feet bls, 16 to 18 inches from 670 feet bls to 940 feet bls, 17.5 to 19 inches from 940 to 1,060 feet bls, 15 to 17 inches from 1,060 to 1,490 feet bls, 16 to 17 inches from 1,490 to 1,550 feet bls and 16 to 13 inches from 1,550 to 1,700 feet bls indicating a competent formation in this interval.

The DIL shows that a gradual decrease in electrical resistivity exists below 1,410 feet bls. Notable exceptions occur in areas with apparent voids. The gradual decrease in electrical resistivity also indicates an increase in specific conductance related to an increase in salinity.

Table 2-4
Summary of IW-1 Geophysical Logging

Date	Borehole Diameter (inches)	Logging Interval (feet bls)	Logging Suite	Purpose
5/09/08	12.25	0 - 490	XYC, GR, DIL, SP	Determine casing setting depth.
5/14/08	50.5	0 - 482	XYC, GR	Borehole geometry Calculate annular volume.
5/15/08	42-inch OD casing	0 – 470	FT	Determine cement top of each cementing stage
5/22/09	12.25	481 - 1,700	XYC, GR, DIL, SP, BHCS w/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 monitor zones.
6/16/08	40.5	481 - 1,692	XYC, GR	Borehole geometry Calculate annular volume.
6/18/08 to 6/21/08	34-inch OD casing	0 - 1,690	FT	Determine cement top of each cement stage.
7/20/08	12.25	1,690 - 3,400	XYC, GR, DIL, SP, BHCS w/ VDL, VS, FT_D, FT_S, CIL_D, CIL_S, FMS_D, FMS_S	Identify confining units Determine final casing setting depth Confirm injection zone.
9/29/08	32.5	1,400 - 3,250	XYC, GR, BHCS w/VDL	Confirm reamed hole characteristics Calculate casing annular volume
9/30/08	32.5	1,890 - 3,250	VS	Identify confining units Confirm injection zone.
10/07/08 to 10/31/08	24-inch OD casing	0 - 2,630	FT	Determine cement top of each cementing stage
11/11/08	24-inch OD casing	0 - 2,630	CBL, VS	Determine quality of cement bond to casing. Observe final casing
11/12/08	12.25	3,250 – 4,397	XYC, GR, DIL, SP, BHCS w/ VDL,	Identify confining units Confirm injection zone.
12/03/08	22-inch	3,250 - 3,700	XYC, GR	Determine borehole geometry
7/28/09	24-inch OD casing	0 – 3,700	VS	Final Video Survey

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 VDL = Variable Density Log VS = Video Survey	$_D$ = Dynamic $_S$ = Static

The borehole compensated sonic porosity log indicates a moderately to well indurated lithology from 1,120 to 1,700 feet bls.
The BHTV log compares well with the lithologic descriptions. Comparatively higher density responses correspond to dense limestone and dolomite.

Collectively, these factors indicate that the formation from 1,120 to 1,700 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 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. The Sonic Porosity and Dual Induction logs were used to calculate a log-derived Total Dissolved Solids (TDS) plot based on the method developed by Callahan (1996) using empirical data from South Florida compiled by Reese (1994). The log derived TDS plot was used to identify the base of the USDW at a depth of 1,465 feet bls in IW-1. The log derived TDS for well IW-1 is presented in **Figure 2-5**

After setting and cementing the 34-inch diameter intermediate casing to 1,690 feet bls, the 12.25-inch diameter pilot hole was advanced from the bottom of the intermediate casing to 3,400 feet bls. On July 20, 2008, prior to reaming and setting the 24-inch diameter final casing to 2,630 feet bls in IW-1, logs were conducted to identify confining units, producing intervals, and to aid in the casing seat determination.

Over the interval of 1,700 to 1,830 feet bls the caliper log indicated the borehole diameter varied from about 15-inches to a maximum diameter of about 30 inches at 1,740 feet bls. From 1,830 to 2,050 feet bls the borehole was nearly generally between 15 and 16 inches in diameter. Between 2,050 and 2,120 feet bls, the borehole diameters becomes somewhat erratic and ranges from 15 inches to greater than 24 inches. Over the interval of 2,120 to 2,950 feet bls the caliper log exhibits a diameter generally between 13 to 15 inches. Below 2,950 feet bls, the borehole diameter ranged from 13 inches to 14 inches.

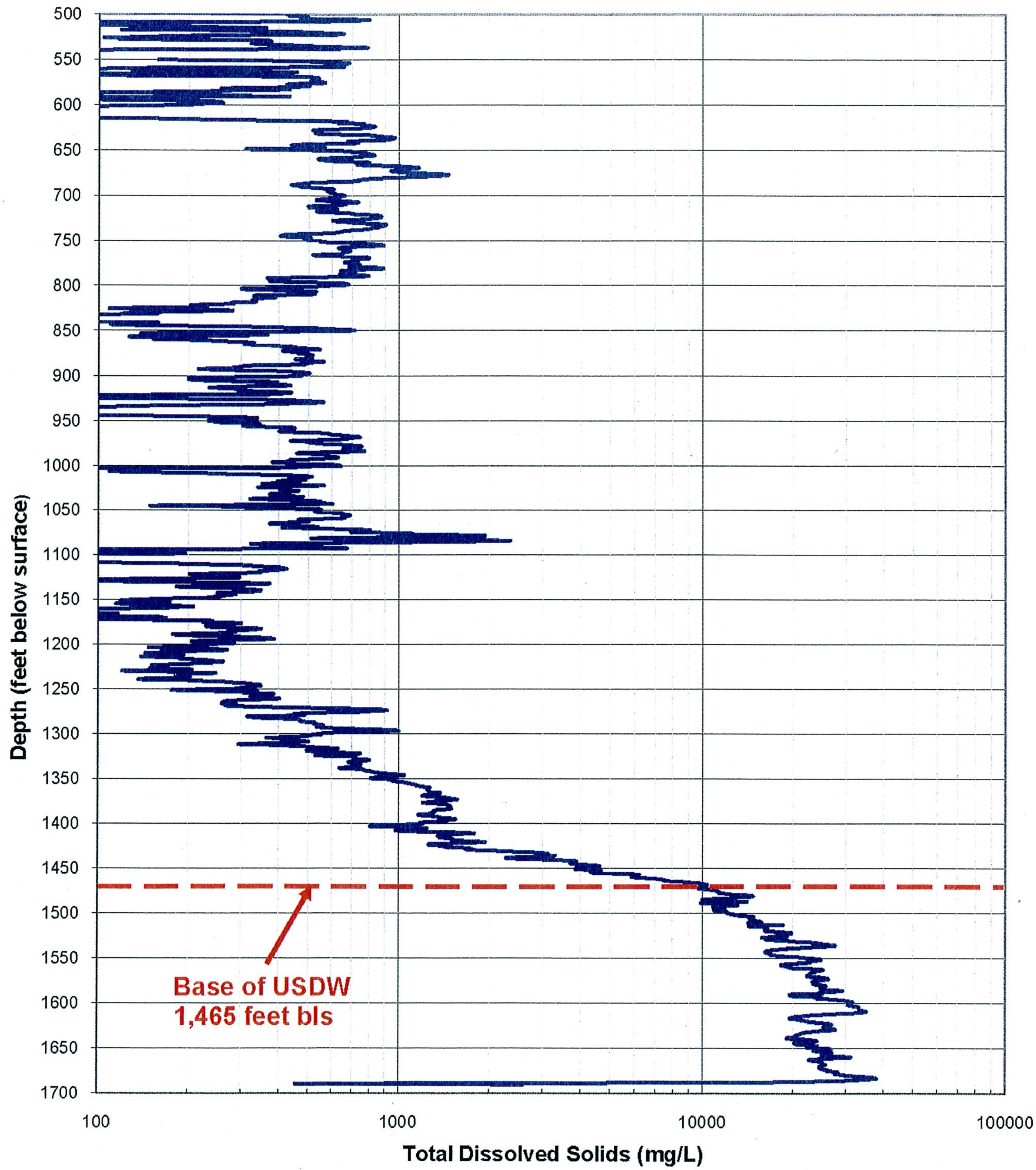

Figure 2-5
IW-1 Log Derived TDS

The BHCS log indicates a generally low sonic porosity between 2,510 and 2,660 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 2,080 feet bls indicate the sediments are locally potentially fractured or differentially dissolutioned. The sonic log between 2,000 and 2,080 feet bls also yielded signatures with shorter travel times consistent with well indurated limestone with low permeability.

The flowmeter log indicates that significant contributions to flow occur above 2,110 feet bls. Permeable zones below 2,110 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 2,510 and 2,660 feet bls, 2,130 and 2,200 feet bls, and 1,800 and 1,830 feet bls. This correlates well with the findings described above.

The geophysical logs conducted on the pilot hole did not indicate that a significant thickness of boulder zone was encountered during pilot hole drilling.

In order to evaluate additional horizons potentially capable of accepting injected fluids the 12.25-inch diameter pilot hole was advanced from the bottom of the final casing to 4,397 feet bls. On November 12, 2008, geophysical logs were conducted as identified in **Table 2-4** to identify confining units and intervals exhibiting a potential to accept injected fluids.

Over the interval of 3,250 to 4,397 feet bls the caliper log indicated the borehole diameter generally varied between 13 and 15 inches. Between 3,850 and 3,950 feet bls the borehole increased to a maximum diameter of almost 18 inches at approximately 3,900 feet bls. The BHCS log indicated a low sonic porosity over this interval. Due to the extremely high salinity of the formation fluids below 4,000 feet bls, the DIL log did not provide reliable information

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

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

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

Date	Borehole Diameter (inches)	Logging Interval (feet bls)	Logging Suite[1]	Purpose
12/19/08	12.25	0 - 490	XYC, GR, DIL, SP	Determine casing setting depth
12/19/08	32.5	0 - 470	XYC, GR	Borehole geometry Calculate annular volume
1/9/09	12.25	470 - 1,660	XYC, GR, DIL, SP, BHCS w/ VDL, BHTV, FT_D, FT_S, CIL_D, CIL_s, FMS_D, FMS_s	Determine casing setting depth.
2/3/09	12.25	1,660 – 1,910	XYC, GR, DIL, SP, BHCS w/ VDL, BHTV, FT_D, FT_S, CIL_D, CIL_s, FMS_D, FMS_s	Determine casing setting depth
2/26/09	22.5	470 - 1,452	XYC, GR	Borehole geometry Calculate annular volume
2/28/09 to 3/5/09	16-inch OD casing	0 - 1,450	FT	Determine cement top of each stage of cement.
3/13/09	14.75 12.25	1,400 – 1,870	XYC, GR	Borehole geometry Calculate annular volume.
3/16/09 To 3/19/09	6.625-inch FRP casing	0 - 1,460	FT	Determine cement top of each stage of cement
4/10/09	Cemented 6.625-inch FRP	1,250 – 1,800	CBL	Determine quality of cement bond
4/16/09	6.625-inchFRP 12.25 open hole	0 – 1,870	XYC,FT, VS	Final Logs

Notes: [1]Abbreviations for Geophysical Logs:

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

On December 19, 2008, after the pilot hole was advanced to 490 feet bls, a suite of geophysical logs was conducted 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 365 feet bls indicating the top of the Lower Hawthorn Aquifer. This is supported by a gauge hole as indicated by the caliper log. The 24-inch diameter casing was set to 470 feet bls.

After setting and cementing the surface casing to 470 feet bls, the 12.25-inch diameter pilot hole was advanced to 1,690 feet bls. On January 9, 2009, prior to reaming the pilot hole and setting the 16-inch diameter intermediate casing to 1,450 feet bls in DZMW-1, geophysical logs were conducted to identify confining units, producing intervals, and to aid in the casing seat determination. The 12.25 inch diameter pilot hole was later advanced from 1,660 to a total depth of 1,910 feet bls. On February 3, 2009, geophysical logging was conducted on the additional pilot hole.

With the exceptions of the intervals between 640 and 780 feet bls (17 to 19-inch diameter borehole) and 920 to 1,030 feet bls (17 to 19.5-inch diameter borehole) and an apparently washed out bedding plane at 1,130 feet bls, the caliper log shows a borehole with a diameter generally between 14 and 17 inches from 470 to 1,390 feet bls. The caliper log shows a borehole with a diameter generally between 13 and 15 inches from 1,390 to 1,450 feet bls

The BHCS and DIL logs indicate a very dense lithology from 470 to 1,050 feet bls. Between 1,050 and 1,150 feet bls these logs indicate a horizon with possibly moderate porosity. From 1,150 to 1,450 feet bls, the BHCS and DIL logs indicate a generally very dense lithology. The borehole televiewer supports the interpretation of the BHCS and DIL logs indicating generally very low porosity. These factors indicate that the formation from 470 to 1,450 feet bls is mechanically competent, and has characteristics which indicate a high potential for a good hydraulic and structural seal for the intermediate casing and cement.

The DIL 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 1,485 feet bls in DZMW-1. The DZMW-1 log derived TDS plot is presented in **Figure 2-6.**

The caliper log indicated a borehole with a diameter generally between 14 and 15 inches from 1,550 to 1,610 feet bls. Geophysical logging of the additional pilot hole revealed the pilot hole generally narrowing with depth from 18 inches at approximately 1,610 feet bls to 14 inches at 1,710 feet bls. From 1,710 feet bls to the final casing seat (1,800 feet bls) the pilot hole increases from 15 inches in diameter to almost 19 inches in diameter at 1,760 feet bls and then narrows with depth to approximately 17 inches at 1,800 feet bls.

With the exception of a horizon located from 1,690 to 1,710 feet bls showing potential moderate porosity, the BHCS and DIL logs indicate a generally very dense to dense lithology from 1,550 to 1,800 feet bls. The BHTV supports the interpretation of the BHCS and DIL logs indicating generally very low porosity. These factors indicate that the formation from 1,550 to 1,800 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 BHCS and DIL logs indicated a dominantly very dense to dense lithology over the interval between the proposed upper and lower monitor zones with the exception of an isolated horizon from 1,690 to 1,710 feet bls. The BHTV supports the interpretation of the BHCS and DIL.

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 640 and 480 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.

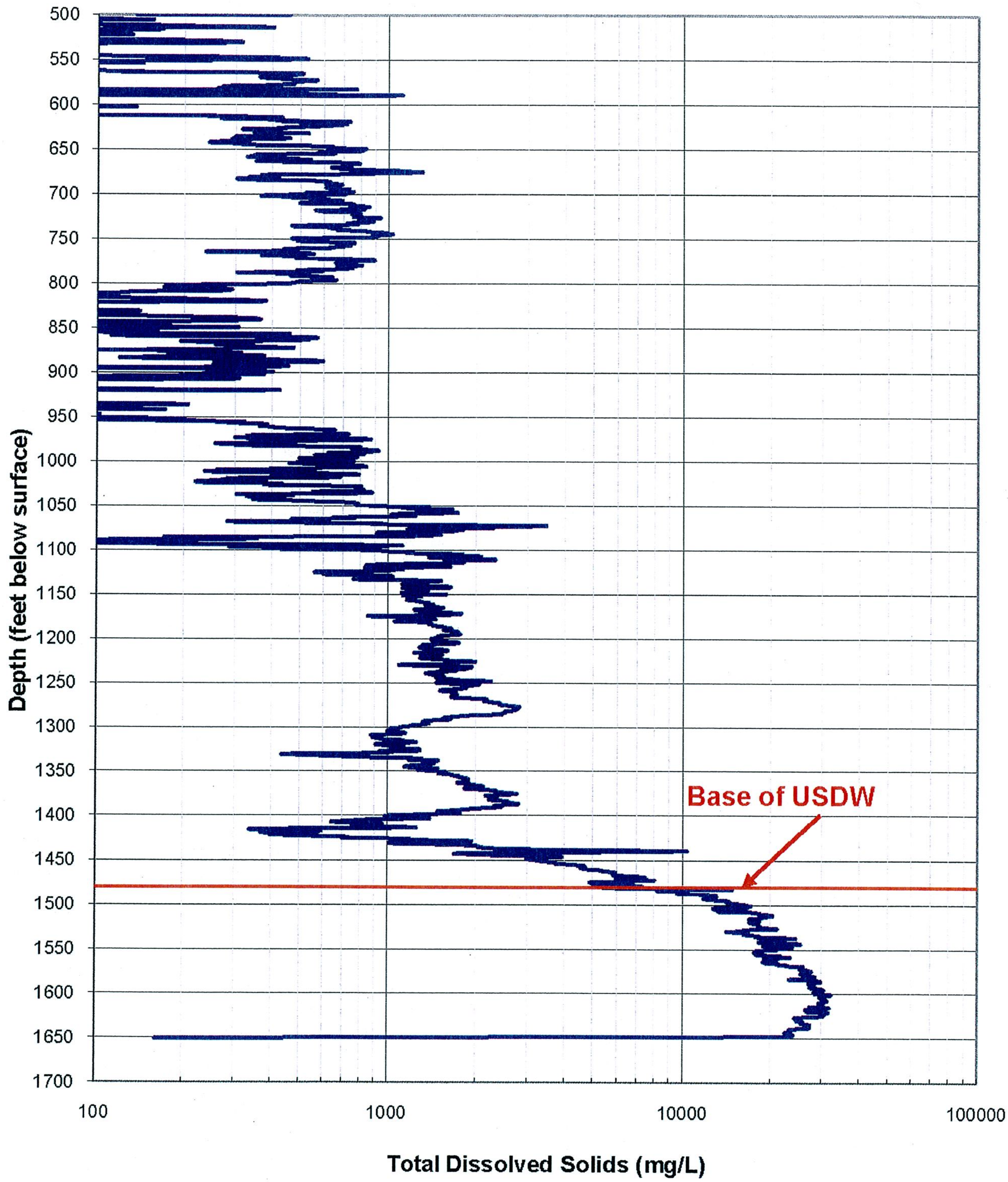

Figure 2-6
DZMW-1 Log Derived TDS

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 may provide an indication of relative water quality trends versus depth. Pilot hole water quality is presented in **Appendix F**.

2.8 VIDEO SURVEYS

As shown on **Table 2-4**, a video survey was conducted and recorded in the injection well 32.5-inch diameter reamed hole from 1,890 to 3,257 feet bls, in the final casing from land surface to 2,063 feet bls, and in the 24-inch diameter final casing from land surface to 3,702 feet bls. As shown on **Table 2-5**, a video survey was also performed on the dual–zone monitoring well final casing and lower monitor zone from land surface to 1,868 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 view. Air development was used to displace suspended solids from the well prior to performing the video 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. Logs describing the formation and structural features observed in the open hole of the injection well and monitor well 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. Specific capacity tests were conducted in IW-1 from 580 to 3,360 feet bls and in DZMW-1 from 540 to 1,890 feet bls. A valve assembly on the wellhead allowed the installation of a manometer to record positive head and also provided for water level measurement during specific capacity testing. The static water level was 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 to isolate an interval in the borehole for testing 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 information from geophysical logs, lithology, cores, video surveys, and other packer tests. Seven straddle packer tests were performed in IW-1. One of the straddle packer tests performed in the injection well aided in determining the base of the USDW. Two of the straddle packer tests performed in the injection well identified potential monitoring zones for DZMW-1. Five 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. The remaining packer tests were performed in DZMW-1 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 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 (also known as a memory gauge) 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 transmissivities 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 in **Appendix I** 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, 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 specific conductance. 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, and is presented in **Appendix K.**

Table 2-6
Transmissivity Derived From Packer Tests

Packer Interval (feet bls)	Pumping Rate (gpm)	Maximum Drawdown (feet)	Transmissivity[a] (feet²/day)
Injection Well IW-1			
1,064 to 1,112	65	152	18.6
1,453 to 1,502	23	124	8.2
1,607 to 1,655	23	103	9.7
1,704 to 1,721	0.75	74	1.304
2,023 to 2,041	39	108	14.62
2,443 to 2,461	0.8	163	0.712
3,468 to 3,606[b]	2.5		
Dual-Zone Monitor Well DZMW-1			
Packer Interval (feet bls)	**Pumping Rate**	**Maximum Drawdown**	**Transmissivity[c] (gpd/foot)**
1,054 - 1,164	106	50	820.5
1,404 - 1,454	2	158	2.7
1,453 – 1,551	18	128	52.6
1,556 - 1,660	6	90	23.5
1,809 – 1,871	28	93	85.1

a - Transmissivity calculated from residual drawdown data using Theis (recovery) method
b - Test conducted for water quality only
c Transmissivity calculated using the formula T = 2000 (Q/•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							
1,064 to 1,112	2,520	654	1,600	0.33	0.35	315	7.71
1,453 to 1,502	24,700	9,360	14,600	1.06	1.37	238	7.35
1,607 to 1,655	48,500	17,800	30,500	0.25	0.72	2,650	7.26
1,704 to 1,721	50,800	18,300	30,300	0.28	0.58	2370	6.49
2,023 to 2,041	59,600	19,200	31,600	0.03	0.47	2700	7.33
2,443 to 2,461	41,800	14,200	23,800	0.37	0.87	1920	6.58
3,468 to 3,606	232,000	104,000	152,000	15.4	17.7	2380	6.28
Dual-Zone Monitor Well DZMW-1							
1,054 - 1,164	5,500	1,620	2,910	0.26	0.56	202	7.55
1,404 - 1,454	6,440[2]	1,870	3,490	0.61	0.89	195	7.67
1,453 – 1,551	40,000	12,800	21,400	1.13	1.75	1260	7.25
1,556 - 1,660	37,900	15,000	20,600	0.01	0.05	1650	7.14
1,809 – 1,871	56,700	18,600	30,400	0.26	0.89	3280	7.08

2.11 INJECTIVITY TESTING

Five short term injectivity tests were conducted during construction and testing of IW-1. The tests were run on August 3, 2008, October 14, 2008, November 21, 2008, February 2, 2009, and March 23, 2009. The tests were conducted in order to evaluate the potential injectivity of the investigated intervals.

On August 3, 2008, two single-packer injectivity tests were conducted in the 12.25-inch diameter pilot hole over the intervals of 2,048 to 3,400 and 2,630 to 3,400 feet bls. The test conducted over the interval of 2,048 to 3,400 feet bls consisted of injecting potable water at approximately 1,000 gallons per minute (gpm) through 7-inch drill pipe with a wellhead pressure of approximately 105 pounds per square inch (psi). The single packer test conducted over the interval of 2,630 to 3,400 feet bls consisted of injecting potable water at approximately 1,000 gpm with a wellhead pressure of 125 psi

On October 14, 2008, a preliminary injectivity test was performed to estimate the operating capacity of the well. The injection well configuration at the time of the test consisted of 24-inch diameter final casing set and cemented to 2,630 feet bls and a 32.5-inch reamed hole to 3,250 feet bls. The maximum injection flow rate reached during this test was 8,600 gallons per minute (gpm) with a resultant wellhead pressure of 93 psi.

A short term injectivity test was conducted on November 21, 2008, with the 24-inch casing set and cemented to 2,630 feet bls, a 32.5-inch diameter reamed hole to 3,250 feet bls, and a 12.25-inch hole to 4,397 feet bls. Reclaimed water was injected into the well at a rate of 8,600 gpm and a wellhead pressure of 87 psi was observed.

An additional injectivity test was conducted on February 2, 2009. The well configuration for this test was 24-inch diameter final casing set and cemented to 2,630 feet bls, 32.5-inch reamed hole to 3,250 feet bls and a 22-inch reamed hole to 3,700 feet bls. Reclaimed water was injected into the well at a rate of 7,600 gpm resulting in a wellhead pressure of 85 psi. Modifications were made to the aboveground piping and the test was repeated on March 23, 2009, with the same well configuration. Reclaimed water was injected into the well at a rate of 8,500 gpm and a wellhead pressure of 86 psi was observed.

The data collected during the injectivity testing is presented in graphical format in **Appendix K.**

2.12 CASING

Casing heat numbers stamped on the casing were verified with the mill certificates prior to running casing in the borehole. 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 monitor well DZMW-1 16 and 6.625-inch casings were pressure tested as described below. The 24-inch injection well casing was pressure tested as part of the demonstration of mechanical integrity as described in Section 4, Final Testing.

On March 9, 2009, the DZMW-1 16-inch casing was internally pressurized to 50.0 psi. A pressure decrease of 0.8 psi was observed over the 60-minute test period. This pressure decrease represents a 1.6 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 March 20, 2009, the DZMW-1 6.625-inch casing was internally pressurized to 51.2 psi. A pressure increase of 2.4 psi was observed over the 60-minute test period. This increase represents a 4.7 percent change in the original pressure, which is within the allowable change of 5 percent. A copy of the test gauge certification records and results of the hydrostatic pressure test are contained in **Appendix N.**

2.13 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 (right log track) 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 November 11, 2008, a cement bond log was performed in the injection well 24-inch diameter final 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, 2009, 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.

2.14 MONITOR ZONE DEPTHS

The selection of monitor zones for DZMW-1 was established based on information available from the drilling and testing of IW-1 and DZMW-1 and was approved by FDEP. The upper monitor zone was established between 1,450 to 1,550 feet bls and the lower monitor zone between 1,800 and 1,870 feet bls. An as-built profile of DZMW-1 is presented in **Figure 2-2**.

2.14.1 Selection of the Upper Monitor Zone

The Upper Monitor Zone (UMZ), located from 1,450 to 1,550 feet bls, was selected based on the primary criterion of being the first flow zone near the base of the USDW. Packer testing of the interval from 1,454 to 1,551 feet bls in DZMW-1 was conducted at 18 gpm with a drawdown of 128 feet. Water quality analysis of the sample taken from the pump test of the UMZ in DZMW-1 resulted in a TDS concentration of 21,400 mg/L (**Table 2-7**).

2.14.2 Selection of the Lower Monitor Zone

The Lower Monitor Zone (LMZ), located from 1,800 to 1,870 feet bls, was selected based on the criterion of being the first flow zone above the confining intervals. Packer testing of the interval from 1,809 to 1,871 feet bls in DZMW-1 was conducted at 28 gpm with a drawdown of 93 feet. Water quality analysis of the sample taken from the packer test of the LMZ in DZMW-1 resulted in a TDS concentration of 30,400mg/L (**Table 2-7**).

2.15 REFERENCES CITED:

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

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

Section 3
Subsurface Conditions

3.1 HYDROGEOLOGY

The study area of northwestern Lee County is underlain by rocks of Cenozoic age to a depth of about 5,000 feet (Meyer, 1989). These rocks are composed of carbonates, with minor amounts of evaporites in the lower part and clastics in the upper part (Reese, 2000). In this section, the site-specific geologic and hydrogeologic information obtained during this project and the results of various tests made during construction of IW-1 and DZMW-1 will be discussed.

3.2 STRATIGRAPHY

Sediments encountered during the construction range in age from Late Pleistocene to Paleocene. MWH collected geologic formation samples (well cuttings) 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 generalized stratigraphic and hydrostratigraphic column of the site.

3.2.1 Pliocene-Pleistocene Series - Undifferentiated Deposits / Tamiami Formation

The undifferentiated deposits encountered during drilling 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 quartz sand with marine bivalvia and gastropoda shell and trace amounts of limestone. 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). The undifferentiated deposits / Tamiami Formation were observed to a depth of approximately 30 feet bls in IW-1 and DZMW-1.

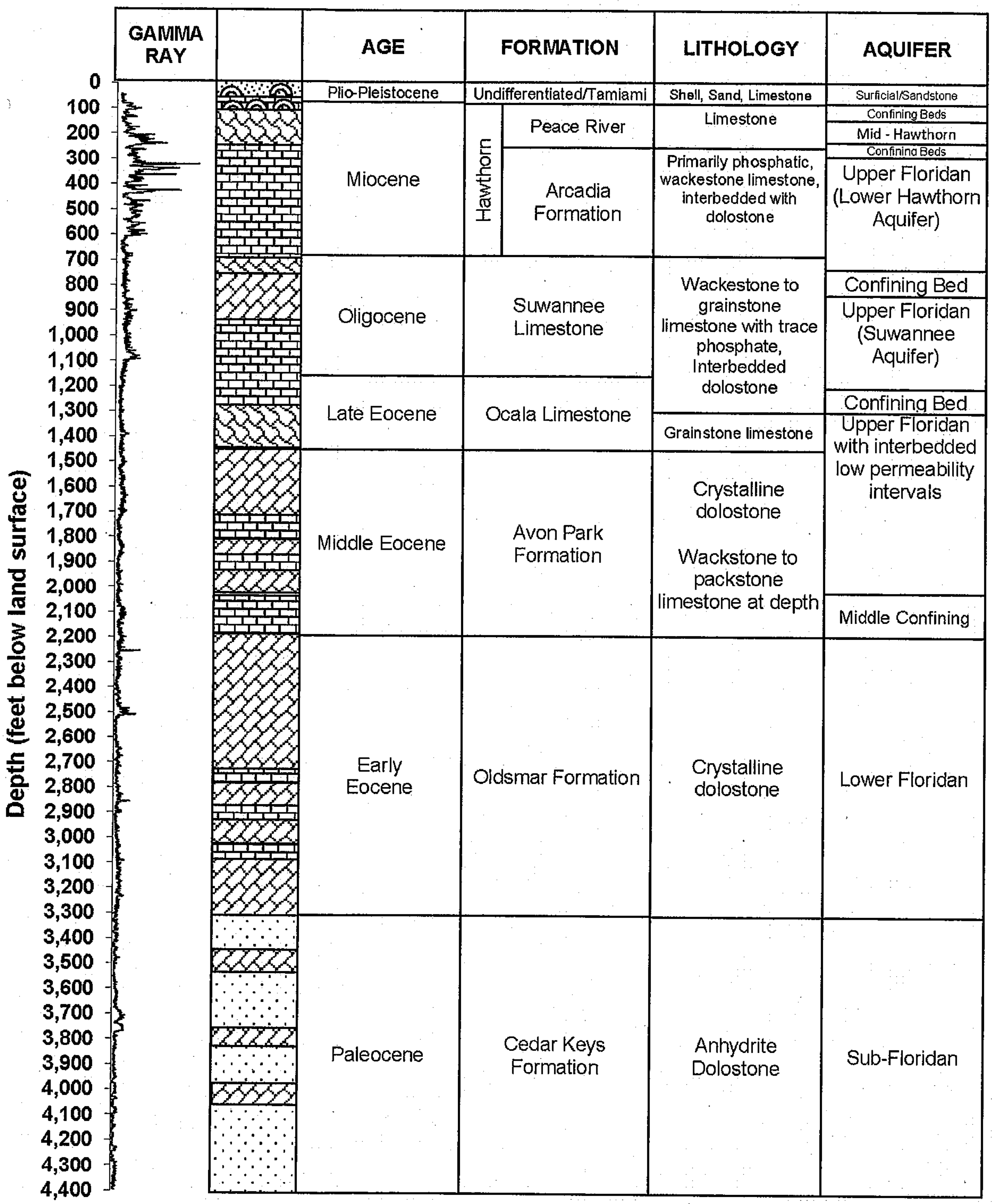

Figure 3-1

Generalized Stratigraphic and Hydrostratigraphic Column

3.2.2 Miocene Series - Hawthorn Group

The Hawthorn Group unconformably underlies the Tamiami Formation and is a lithologically complex sequence of silt, clay, calcareous clay, dolosilt, quartz sand, phosphate, limestone, and dolomite (Scott 1988). It is a regional stratigraphic unit of early Pliocene to Miocene age that underlies all of South Florida (Reese, 2000). The Hawthorn Group is comprised of an upper, primarily clay unit (Peace River Formation), and a lower, primarily carbonate unit (Arcadia Formation) (Scott 1988). Locally, the Peace River Formation contains the Cape Coral Clay member and Lehigh Acres Member (Missimer & Associates, 1993). The two formations are separated by a major regional disconformity. The Hawthorn Group occurs from approximately 30 to 680 feet bls in IW-1 and from approximately 30 to 690 feet bls in DZMW-1.

A regional disconformity separates the Peace River Formation from the Arcadia Formation (Scott, 1988). The contact between these two units can often be distinguished by the occurrence of a rubble bed of coarse to pebble-size quartz sand, phosphatic sand, and gravel (Bennett et.al, 2004). The lower 500 feet of the unit consists of 3 to 4 large scale, transgressive-regressive cycles. Each cycle consists of a lower thick limestone unit and an upper mixture of minor carbonate and clastic units (Missimer and Assoc., 1993).

3.2.2.1 Peace River Formation

The Peace River Formation of the Hawthorn Group consists of sandstones, sands, sandy limestones, dolomitic clays or dolosilts, and fossilized shell material (Scott, 1988). The formation occurs from approximately 30 to 240 feet bls in IW-1 and 30 to 250 feet bls in DZMW-1.

3.2.2.2 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 240 to 680 feet bls in IW-1 and from approximately 250 to 690 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 porosity. The dolostones are light to pale olive gray, well indurated and make up the majority of the formation. The formation is interbedded with yellowish gray marl or lime mud, and occasional light olive gray dolomitic silty clay. Phosphate granules are abundant throughout the Arcadia Formation. The base of the Arcadia Formation at both wells can be identified by a yellowish gray marl and immediate decrease in phosphate content in lithologic samples and attenuation of gamma ray activity on the geophysical logs.

3.2.3 Oligocene Series - Suwannee Limestone

The Suwannee Limestone (Cooke and Mansfield, 1936) of Oligocene Age in IW-1 occurs from 680 to 1,150 feet bls and from 690 to 1,220 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, interbedded with lime mud or marl. The Suwannee limestone is very pale orange micrite to biomicrite, containing a trace of phosphate, with a medium-grained calcarenite texture, sparsely interbedded with crystalline dolostone. The unit is composed of moderately to well-sorted foraminifera, pelloids, and abraded echinoderm and mollusk fragments. In IW-1 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 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 E**) as compared to the basal facies of the Arcadia Formation.

3.2.4 Eocene Series - Ocala Limestone

The Ocala Limestone (Dall and Harris, 1892) of late Eocene Age occurs from 1,150 to 1,450 feet bls in IW-1 and 1,220 to 1,500 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 biostratigraphy were methods used to identify the top of the Ocala Limestone. In the geophysical log traces, 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 1,150 feet bls in IW-1 and 1,220 feet bls in DZMW-1, with the first occurrence of the diagnostic foraminifera *Operculinoides ocalanus*. *Lepidocyclina ocalana* which is also a diagnostic foraminifera of the Ocala Limestone was first observed at 1,160 feet bls in IW-1.

3.2.5 Eocene Series - Avon Park Formation

The Avon Park Formation (Applin and Applin, 1944) of Late Middle Eocene age occurs from 1,450 to 2,190 feet bls in IW-1 and from 1,500 feet to greater than 1,900 feet bls (the base) of DZMW-1. The top of this formation is often identified by the occurrence of dark yellowish orange dolomite. At the Everest WRF location the upper sediments consisted mainly of very pale orange to pale orange packstone to grainstone limestones with some yellowish gray dolomitic limestone. In addition, this formation boundary coincides with a higher formation resistivity and a slight increase in gamma ray activity (**Appendix E**). A diagnostic foraminifera *Dictyoconus americanus* (Chen, 1965) was observed in IW-1 at 1,460 feet bls and in DZMW-1 at 1,500 feet bls.

The Avon Park Formation is a lithologically diverse unit. The upper stratum generally consists of very pale orange to pale yellowish brown limestone and dolomitic limestone and the lower stratum of the formation consists of dark yellowish brown crystalline dolostone with interbeds of very pale orange to pale yellowish brown low permeability mudstone to packstone limestone.

3.2.6 Eocene Series - Oldsmar Formation

In IW-1, the top of the Early Eocene age Oldsmar Formation was encountered at approximately 2,190 feet and extends to 3,290 feet bls. It is comprised mainly of mottled dark yellowish brown to grayish black and moderate yellowish brown, crystalline dolostones.

The Oldsmar Formation of Southwest Florida generally contains an intricate fractured solution channel network referred to as the "Boulder Zone." A well defined Boulder Zone 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.

A well defined Boulder Zone was not encountered during the drilling of IW-1. However several horizons displayed characteristics associated with the potential to accept injected fluids.

3.2.7 Paleocene Series - Cedar Keys Formation

In the IW-1 borehole, the top of the Paleocene age Cedar Keys Formation was encountered at approximately 3,290 feet bls to the total depth of the well at 4,397 feet bls. It is comprised mainly of massive, white to light grey anhydrite beds and interbeds of limestone, dolomite, and dolomitic limestone. The Cedar Keys Formation was massive and exhibited generally low to very 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** (A-A′ north to south) and **Figure 3-4** (B-B′ west to east) show generalized hydrostratigraphic cross-sections.

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 base of the surficial aquifer occurs at contact with the Cape Coral Clay Member of the Hawthorn Group at a depth of about 20 feet bls in IW-1 and DZMW-1. 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. 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 Intermediate Aquifer System (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 unit were identified during drilling and testing operations. The Sandstone Aquifer was encountered from 70 to 110 feet bls at IW-1 and from 70 to 100 feet bls 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.

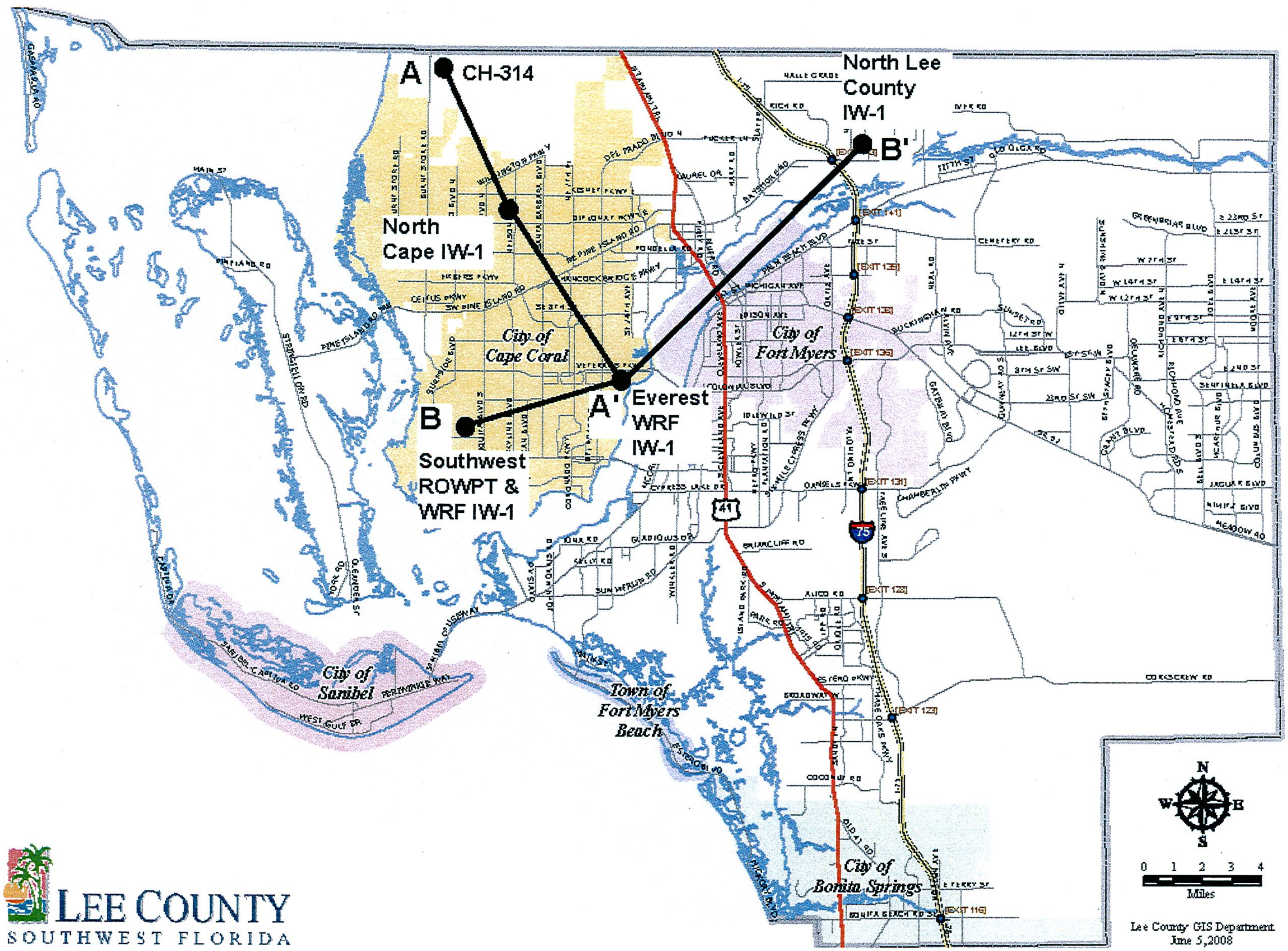

Figure 3-2
Cross Section Location Map

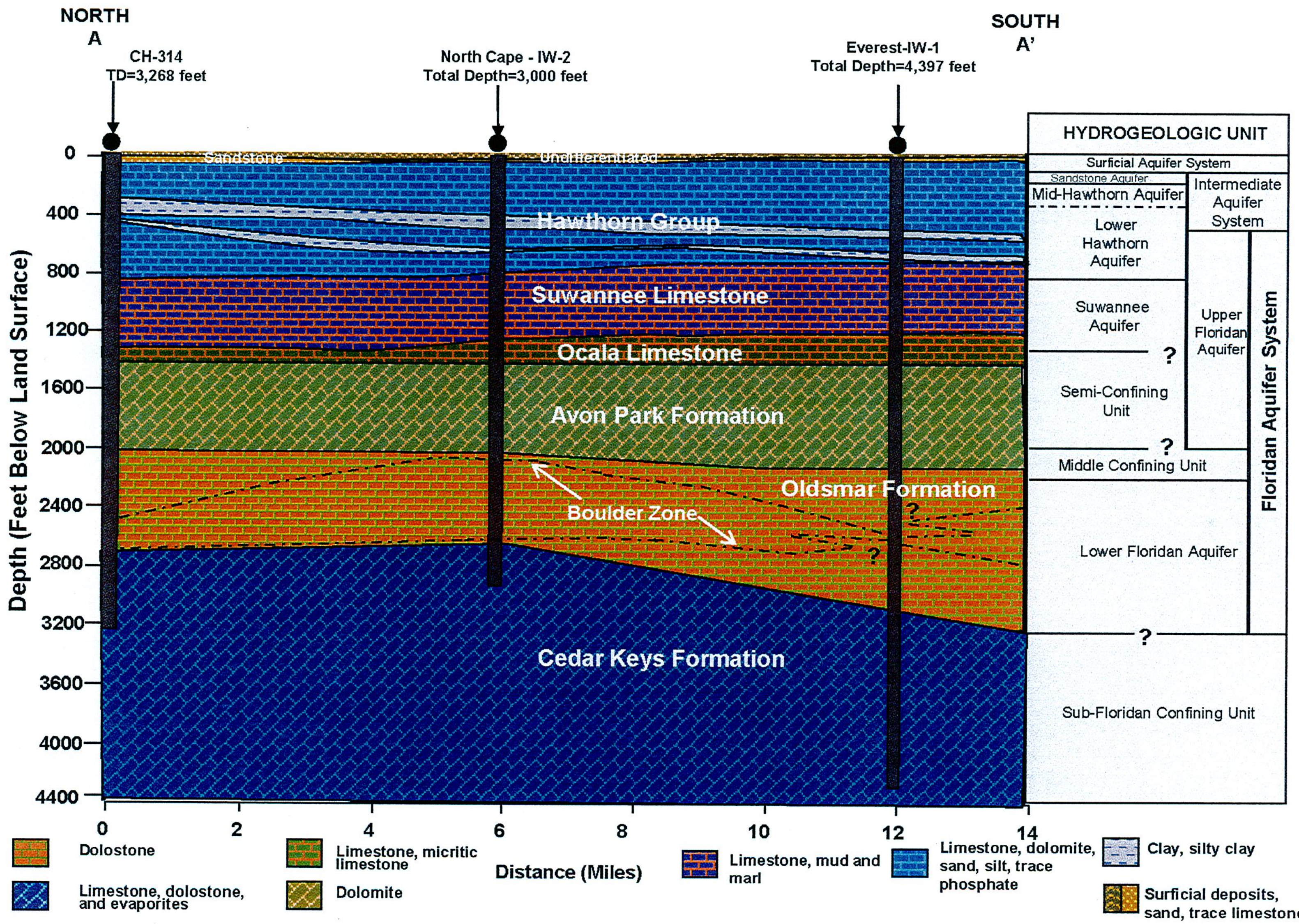

Figure 3-3
Generalized Hydrostratigraphic Cross Section A – A'

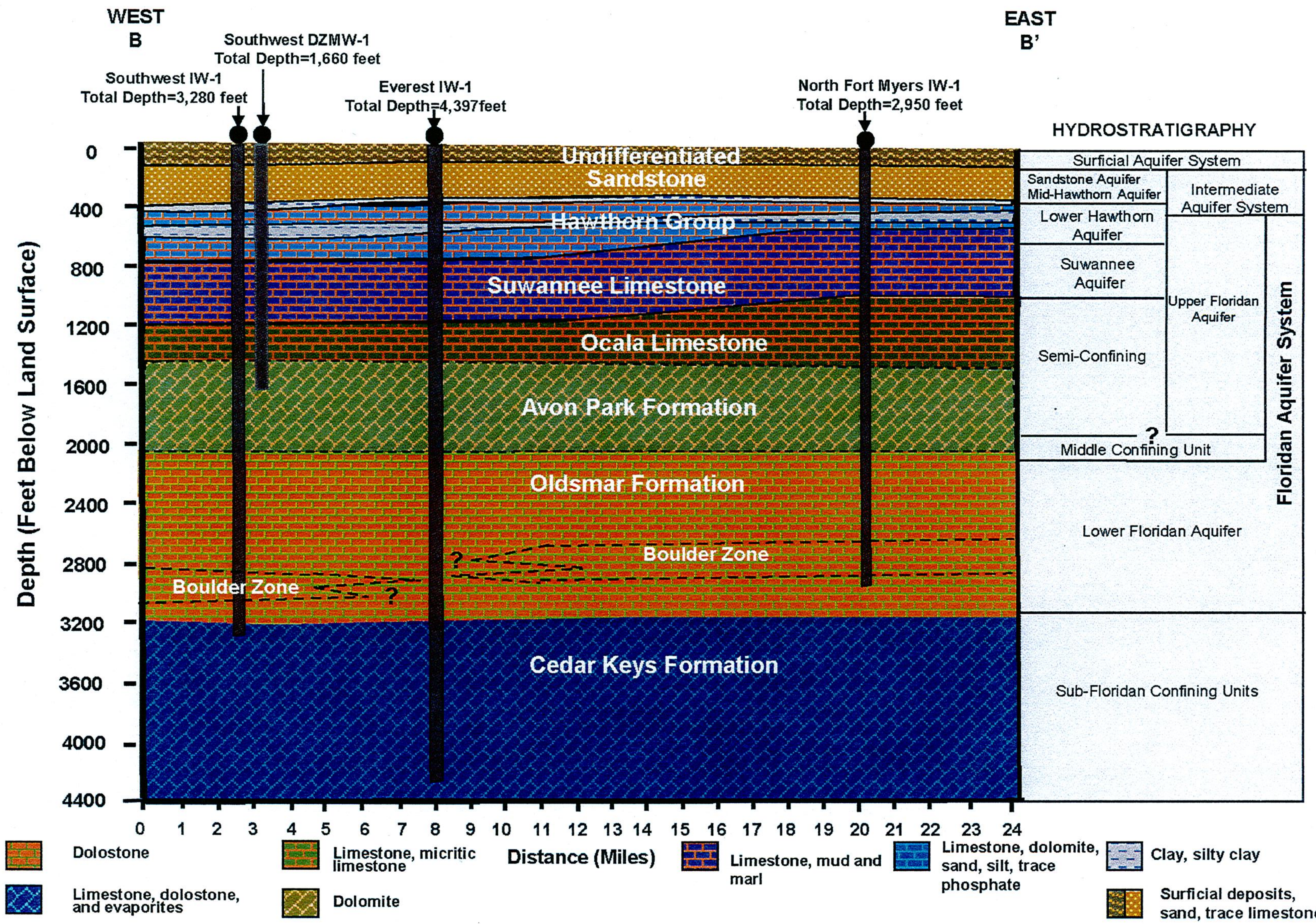

Figure 3-4
Generalized Hydrostratigraphic Cross Section B – B'

A second productive horizon, locally called the Mid-Hawthorn Aquifer, occurs from 240 to 280 feet bls at IW-1 and 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 and is confined below by approximately 100 feet of dolosilt at IW-1 and DZMW-1.

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 mainly 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 occurs from 380 to 2,010 feet bls at IW-1 and from 400 feet to the total depth (1,910 feet) of DZMW-1 that 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 430 to 770 feet bls at IW-1 and from 410 to 810 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 830 to 1,110 feet bls in IW-1 and 840 to 1,150 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 30 feet thick and consists of crystalline limestone in IW-1 and DZMW-1. This aquifer is composed of interbedded moderately biomicritic limestones, marls, and dolostones. The aquifer becomes less permeable with depth due to interbedding and 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.

A variably transmissive interval, interbedded with lower permeability zones within the Ocala Limestone and Avon Park Formation, was identified from 1,400 to 1,500 feet bls in IW-1 and 1,400 to 1,530 feet bls in DZMW-1. A semi-confining bed 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 fractures. 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 2,050 to 2,190 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, well indurated dolomitic limestone and microcrystalline dolostone. 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 groundwater of the UFA, from the groundwater 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). Groundwater 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 typical high permeability in the Boulder Zone due to the cavernous porosity and extensive fracturing present (Miller, 1986, Meyer, 1989 and Reese, 1994) was not encountered at the Everest WRF location.

In IW-1, the LFA was identified from 2,190 to 3,290 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 typically composed of well indurated dolostones exhibiting high secondary permeability and porosity in vuggy to cavernous dissolution features and fracturing. The LFA encountered at the Everest WRF location did not exhibit typical Boulder Zone characteristics. The LFA at this location is generally composed of dolostone and interbedded limestone. The dolostone is generally well indurated exhibiting low to medium permeability.

Although extensive fracturing and highly cavernous porosity was not encountered several horizons exhibited vuggy porosity, small to moderate cavities and fractures capable of accepting injected fluids. The BHCS and VDL logs supported the visual observations recorded on the video survey indicating higher porosity at 2,670; 2,835 to 2,860; 2,900; 3,020 to 3,070; 3,100; 3,350; and from 3,470 to 3,530 feet bls.

In the study area of Lee County, historic drilling data has suggested that the dolostones are hydraulically connected. (Meyer, 1989). The features observed at the Everest WRF location may be hydraulically associated with the regionally extensive highly transmissive Boulder Zone.

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 lowest depth containing waters of less than 10,000 mg/L of TDS.

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, TKN, 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 10,000 mg/L TDS. The base of the USDW was estimated by performing water quality analysis 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 1,120 feet bls. Using the sonic porosity log, the deep induction, and the 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 TDS curve was plotted using data appropriate for south Florida (**Figure 2-5**). Using this approach, the base of the USDW was estimated at 1,465 feet bls.

This data is supported by the water quality results of the packer tests conducted in IW-1 over the intervals of 1,064 to 1,112 feet bls and 1,453 to 1,502 feet bls which yielded TDS concentrations of 1,600 mg/L and 14,600 mg/L respectively. The data is further supported by the water quality results of the packer tests conducted in DZMW-1 over the intervals of 1,404 to 1,454 feet bls and 1,453 to 1,551 feet bls, which yielded total dissolved solids concentrations of 3,490 mg/L and 21,400 mg/L, respectively.

3.5 CONFINEMENT ANALYSIS

The approach to the evaluation of vertical confinement at the City of Cape Coral Everest WRF injection well IW-1 location is as follows. Available borehole geophysical, geological, and open hole testing data were used to identify intervals from 1,465 (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 intervals between 2,510 to 2,660 feet bls based upon a combination of lithologic observations and geophysical log review. Secondary confining sequences are present between 2,430 and 2,470 feet bls; 2,110 and 2,240 feet bls, 1,950 and 2,050 feet bls, 1,805 and 1,830 feet bls, and between 1,710 and 1,730 feet bls.

3.5.1 Identification of Confining Units

The presence of satisfactory confining sequences between 1,465 and 2,650 feet bls was established 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 August 8, 2008, is referred to as the "IW-1 Final Casing Seat Selection Request".

3.5.2 Geophysical Logs

The wire line geophysical logs conducted in 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 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 Formation Cuttings

Formation cuttings collected during the pilot hole drilling of IW-1 (land surface to 4,397 feet bls) and DZMW-1 (land surface to 1,910 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 grab 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 (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 (0.016 to 0.025 mm) or medium crystalline (0.0625 to 0.25 mm).

The macroporosity (visible porosity) of the samples was characterized as being either very low (less than 2 percent), low (2-5 percent), moderate (5-15 percent), high (15-25 percent), or very high (greater than 25 percent). 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 recovered from 1,805 to 2,273 feet bls in IW-1 and two cores were cut in DZMW-1 from 1,438 to 1,590 feet bls. The lithology of the cores was evaluated to determine if there were any significant biases in the cutting samples. The formation 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. Sections of each core were selected and submitted for laboratory analysis for hydraulic conductivity. The core descriptions and results from the laboratory core analysis 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 were analyzed for information on the hydraulic conductivity of potential confining units. The straddle packer data were analyzed using the Theis (1935) residual drawdown 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 tend to overestimate 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 to each other.

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 CONFINEMENT ANALYSIS

The confinement properties of the strata between the base of the USDW (approximately 1,465 feet bls) and 2,650 feet bls were evaluated using the above criteria and data. The confining intervals are discussed below.

Competent units have been identified in the intervals between 2,510 and 2,660 feet bls based upon a combination of lithologic observations and geophysical log review (Lithologic logs are presented in **Appendix C** and geophysical logs are presented in

Appendix E). Secondary confining sequences are present between 2,430 and 2,470 feet bls; 2,110 and 2,240 feet bls, and 1,950 to 2,050 feet bls.

Examination of the formation cuttings indicates that observed permeability is low to medium throughout the interval between 2,510 and 2,660 feet bls. In this interval the sediments are generally microcrystalline to fine grained limestone (wackestone to packstone) that is moderately cemented with some of the beds consisting of crystalline limestone (sparry calcite cement).

The borehole compensated sonic log indicates a generally low sonic porosity from 2,510 to 2,660 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 drilling of this interval are primarily well indurated dolomitic limestone with low visible permeability.

Conventional cores recovered over the intervals of 2,182 to 2,197 feet bls and 2,198 to 2,212 feet bls confirmed the presence of well indurated dolostone and limestone with low visible permeability. Additional cores recovered over the intervals of 1,875 to 1,885; 1,985 to 1,996; 2,062 to 2,073, 2,091 to 2,097 and 2,260 to 2,273 feet bls consist of generally well indurated dolostone with varying amounts of limestone, crystalline limestone, and dolomitic limestone expressing low visible permeability. Vertical hydraulic conductivities derived from cores recovered within the confining sequences ranged from 1.1×10^{-4}cm/sec to 9.2×10^{-12} cm/sec.

The borehole video survey confirms the presence of the dense limestone intervals between approximately 2,510 to 2,660 feet bls. There were numerous areas of generally gauge hole (caliper) over this interval that is verified by the video survey. Observations revealed generally well indurated sediments with few horizons showing occasional solution features. The video survey conducted over the intervals of 2,430 to 2,470 feet bls; 2,110 and 2,240 feet bls, and 1,950 and 2,050 feet bls also show numerous areas of generally gauged hole with well indurated sediments. Small cavities and fractures were observed at various depths within these intervals; however they appear to be locally restricted.

The flowmeter log indicates that significant contributions to flow occur above 2,110 feet bls. Permeable zones below 2,110 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 2,510 and 2,660 feet bls between 2,130 and 2,200 feet bls and between 1,800 and 1,830 feet bls. This correlates well with the findings described above.

Straddle packer tests were conducted from 2,023 to 2,041 feet and 2,443 to 2,461 feet bls to determine the hydraulic properties of the isolated intervals and quantify discrete horizon water quality. Calculated values of transmissivity from the straddle packer tests conducted within the confining sequences were 14.62 and 0.71 feet^2/day respectively. Straddle packer testing data with analyzes are included in Appendix I.

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. Background water samples were collected from IW-1 and DZMW-1, and a short-term injection test was conducted on IW-1. 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 Everest WRF for a twelve-hour period.

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 and lower monitor zones as well as 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 of the samples collected from injection zone of IW-1, as well as the upper and lower monitor zones of DZMW-1, are presented in **Appendix O.**

The sample collected from the lower monitor zone of DZMW-1 contained elevated concentrations of trichloroethylene, tetrachloroethylene, and toluene all exceeding the EPA maximum contaminant level (MCL). These exceedances are likely a function of contamination associated with the test pump assembly or introduced from the reverse-air drilling process and are not representative of ambient conditions.

A water sample from the City's Everest WRF, 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 O.**

Table 4-1
Summary of Background Water Quality Laboratory Results

PRIMARY DRINKING WATER STANDARDS						
Parameter	Units	Maximum Contaminant Level	IW-1 10/13/2008	DZMW-1 Upper 4/24/09	DZMW-1 Lower 4/2/2009	Test Source 1/8/2009
Inorganic Compounds						
Antimony	mg/L	0.006	0.0091	0.0026	0.0024	0.002
Arsenic	mg/L	0.01	0.039	0.0050	0.0033	0.002
Asbestos	MFL	7	< 7.40	<20.00	<0.20	< 0.18
Barium	mg/L	2	0.41	14	1.3	0.008
Beryllium	mg/L	0.004	<0.00010	<0.00010	<0.00010	0.0001
Cadmium	mg/L	0.005	<0.00070	<0.00070	<0.00070	0.001
Chromium	mg/L	0.1	<0.0018	0.0020	<0.0018	0.001
Copper	mg/L	1.3	0.0065	0.053	0.011	0.001
Cyanide	mg/L	0.2	<0.0047	<0.0047	<0.0047	<0.0047
Fluoride	mg/L	4	0.8	1.5	1.1	0.5
Lead	mg/L	0.015	0.0093	0.037	0.012	<0.001
Mercury	mg/L	0.002	<0.000060	<0.000060	<0.000060	<0.00006
Nickel	mg/L	0.1	0.0031	0.0020	<0.0020	0.001
Nitrate	mg/L as N	10	<0.01	<0.01	<0.01	1.11
Nitrite	mg/L as N	1	<0.01	<0.01	<0.01	<0.01
Total Nitrate & Nitrite	mg/L as N	10	<0.01	<0.01	<0.01	1.11
Selenium	mg/L	0.05	<0.0021	<0.0021	<0.0021	<0.002
Sodium	mg/L	160	10000	6600	9300	632
Thallium	mg/L	0.002	<0.001	<0.001	<0.001	<0.001

mg/L - milligrams per liter

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

PRIMARY DRINKING WATER STANDARDS						
Parameter	Units	Maximum Contaminant Level	IW-1 10/13/2008	DZMW-1 Upper 4/24/09	DZMW-1 Lower 4/2/2009	Test Source 1/8/2009
Organic Compounds						
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	<0.00062	<0.00064	<0.00063	<0.00076
Aroclors (Polychlorinated Biphenyls or PCBís)	mg/L	0.0005	<0.00013	<0.00014	<0.00014	<0.00014
Atrazine	mg/L	0.003	<0.00049	<0.00051	<0.00050	<0.00060
Benzo (a) pyrene	mg/L	0.0002	<0.000071	<0.000073	<0.000072	<0.000086
Carbofuran	mg/L	0.04	<0.00041	<0.00041	<0.00041	<0.00041
Chlordane	mg/L	0.002	<0. 00013	<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	<0.00069	<0.000071	<0.000070	<0.00084
Di (2-ethylhexyl) phthalate	mg/L	0.006	0.0034	<0.00089	<0.00088	0.020
Dibromochloropropane (DBCP)	mg/L	0.0002	<0.0000035	<0.0000035	<0.0000035	<0.0000036
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	<0.000099	<0.00010	<0.00010	<0.00010
Ethylene dibromide (EDB)	mg/L	0.00002	<0.0000046	<0.0000035	<0.0000045	<0.0000048
Glyphosate	mg/L	0.7	<0.013	<0.013	<0.013	<0.013
Heptachlor	mg/L	0.0004	<0.000035	<0.000035	<0.000036	<0.000036
Heptachlor epoxide	mg/L	0.0002	<0.000027	<0.000027	<0.000027	<0.000028
Hexachlorobenzene	mg/L	0.001	<0.00031	<0.00032	<0.00032	<0.00038
Hexcachlorocyclopentadiene	mg/L	0.05	<0.00024	<0.00025	<0.00024	<0.00029
Lindane	mg/L	0.0002	<0.000019	<0.000020	<0.000020	<0.000020
Methoxychlor	mg/L	0.04	<0.000043	<0.000043	<0.000043	<0.000044
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	<0.00014
Simazine	mg/L	0.004	<0.00064	<0.00066	<0.00065	<0.00078
Toxaphene	mg/L	0.003	<0.00059	<0.00059	<0.00060	<0.00061

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						
Parameter	Units	Maximum Contaminant Level	IW-1 10/13/2008	DZMW-1 Upper 4/24/09	DZMW-1 Lower 4/2/2009	Test Source 1/8/2009
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-Dichloroethane	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	0.00064
cis-1,2,-Dichloroethylene	mg/L	0.07	<0.00021	<0.00021	<0.00021	<0.00021
Dichloromethane	mg/L	0.005	<0.00041	<0.00023	<0.00023	<0.00023
Ethylbenzene	mg/L	0.7	<0.00021	<0.00021	<0.00021	<0.00021
Monochlorobenzene	mg/L	0.1	<0.00021	<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	200	<0.00024
Toluene	mg/L	1	<0.00022	<0.00022	2.9	<0.00022
Total trihalomethanes (TTHM)	mg/L	0.1	<0.00025	<0.00025	<0.00025	0.57
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	2.5	<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	1	<0.00046
Microbiological Characteristics						
Total Coliform	CFU/100ml	< 1	<1	<1	<1	<1
Radionuclides						
Combined Radium 226 & 228	pCi/L	5	see report	see report	see report	see report
Gross Alpha	pCi/L	15	70 +/- 4.3	3.4 +/- 2.3	36 +/- 3.5	6.3 +/- 2.3

mg/L - milligrams per liter
pCi/L - picocurie per liter
NTU - nephelometric turbidity unit

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

SECONDARY DRINKING WATER STANDARDS						
Parameter	Units	Maximum Contaminant Level	IW-1 10/13/2008	DZMW-1 Upper 4/24/09	DZMW-1 Lower 4/2/2009	Test Source 1/8/2009
Aluminum	mg/L	0.2	0.026	0.020	0.089	0.025
Chloride	mg/L	250	18,300	12,600	11,000	1060
Color	colornits	15	45	75	5	5
Copper	mg/L	1	0.0065	0.053	0.011	<0.001
Corrosivity (Langelier Index)	NA	NA	-0.23	0.05	1.13	0.17
Fluoride	mg/L	2	0.8	1.5	1.1	0.5
Foaming Agents	mg/L	0.5	0.77	0.037	0.11	0.076
Iron	mg/L	0.3	1.6	17	0.37	<0.015
Manganese	mg/L	0.05	0.087	0.42	0.022	0.007
Odor	TON	3	1	<1	8	3
pH	NA	6.5-8.5	6.82	7.02	7.7	7.71
Silver	mg/L	0.1	<0.00064	0.00092	<0.00064	<0.000001
Sulfate	mg/L	250	2,580	945	3,230	151
Total Dissolved Solids (TDS)	mg/L	500	28,500	19600	26,400	2100
Zinc	mg/L	5	0.048	0.061	0.059	0.021

UNREGULATED ORGANIC CONTAMINANTS						
Parameter	Units	Maximum Contaminant Level	IW-1 10/13/2008	DZMW-1 Upper 4/24/09	DZMW-1 Lower 4/2/2009	Test Source 1/8/2009
Aldicarb	mg/L	NA	<0.00054	not reported	<0.00054	not reported
Aldicarb sulfoxide	mg/L	NA	<0.00036	not reported	<0.00036	not reported
Aldicarb sulfone	mg/L	NA	<0.00045	not reported	<0.00045	not reported
Aldrin	mg/L	NA	<0.000043	<0.000043	<0.000044	not reported
Chloroethane	mg/L	NA	<0.00046	<0.00046	<0.00046	not reported
Chloroform	mg/L	NA	<0.00025	<0.00025	<0.00025	0.076
2-Chlorophenol	mg/L	NA	<0.00083	<0.00081	<0.0014	<0.00090
Dieldrin	mg/L	NA	<0.000064	<0.000065	<0.000065	not reported
Dimethylphthalate	mg/L	NA	<0.0024	<0.0023	<0.0041	<0.0026
Phenol	mg/L	NA	<0.00096	<0.00093	<0.0016	<0.001
2,4,6-Trichlorophenol	mg/L	NA	<0.0011	<0.0012	<0.0019	<0.0012

mg/L - milligrams per liter
TON - threshold odor number
NA – not applicable

Table 4-1 (Continued)

Summary of Background Water Quality Laboratory Results

MUNICIPAL WASTEWATER MINIMUM CRITERIA GROUNDWATER MONITORING PARAMETERS						
Parameter	Units	Maximum Contaminant Level	IW-1 10/13/2008	DZMW-1 Upper 4/24/09	DZMW-1 Lower 4/2/2009	Test Source 1/8/2009
Inorganics						
Ammonia	mg/L as N	NA	<0.01	0.94	0.07	0.02
Nitrogen (organic)	mg/L as N	NA	0.36	0.23	0.68	0.23
Nitrogen, Total Kjeldahl (TKN)	mg/L as N	NA	0.36	1.17	0.75	0.25
Phosphorus, Total	mg/L as P	NA	<0.01	<0.010	<0.010	0.43
Base / Neutral Organics		NA				
Anthracene	mg/L	NA	<0.00050	<0.00048	<0.00086	<0.00054
Naphthalene	mg/L	NA	<0.00069	<0.00067	<0.0012	<0.00075
Butylbenzylphtyallate	mg/l	NA	<0.00055	<0.00053	<0.00095	<0.00060
Phenantherene	mg/L	NA	<0.00030	<0.00029	<0.00052	<0.00033
Other		NA				
Temperature	°C	NA	29	29.4	32	not reported
Conductivity	µmhos/cm	NA	52,000	33800	37,000	not reported
Biological Oxygen Demand (BOD)	mg/L	NA	<2	<2	<2	2
Chemical Oxygen Demand (COD)	mg/L	NA	2030	1390	1400	259

mg/L - milligrams per liter
NA – not applicable

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, a temperature log, a television survey and a radioactive tracer survey (RTS). The hydrostatic pressure test was conducted at a pressure at least 50 percent greater than the maximum allowable operating pressure to confirm casing integrity. The temperature log identifies temperature variations in the well. The television survey provides visual verification of the final casing integrity. The RTS provides data on the external mechanical seal of the casing. The following describes the testing methods, results of the testing, and an interpretation of the data collected during the mechanical integrity tests.

4.3.1 Hydrostatic Pressure Testing

On March 25, 2009, the injection well 24-inch diameter final casing was internally pressurized to 190.0 psi. A pressure decrease of 1.0 psi was observed over the 60-minute test period. This decrease represents a 0.5 percent change in the original pressure, which is within the allowable change of 5 percent.

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

4.3.2 Injection Well Temperature Log

On March 30, 2009, a temperature log was conducted on IW-1 from the surface to a total depth of 3,700 feet bls. The temperature log recorded a fairly constant temperature increase from approximately 81 degrees Fahrenheit to approximately 92 degrees Fahrenheit at the base of the 24-inch final casing (approximately 2,630 feet bls). Between 2,630 and 2,640 feet bls the temperature decreases to about 90 degrees Fahrenheit and remained generally constant to a depth of 2,670 feet bls. From 2,670 to 3,130 feet bls the temperature increased to approximately 100 degrees Fahrenheit. A temperature decrease to about 99 degrees Fahrenheit was noted to a depth of 3,260 feet bls. From 3,260 to 3,700 feet bls the temperature gradually increased to about 108 degrees Fahrenheit. A copy of the temperature log is presented in **Appendix E.**

4.3.3 Injection Well Video Survey

A video survey of the IW-1 final casing and open hole was performed on March 28, 2009. The survey was performed from pad level to a depth of 3,702 feet bls. Water clarity was generally good, enabling the camera to capture clear images of final casing, casing seat and open hole section. The survey revealed that the casing was in excellent condition. A copy of the television survey is located on a DVD at the end of the report. A description of the observations is included in **Appendix G.**

4.3.4 Injection Well Radioactive Tracer Survey

On March 30, 2009, an RTS was conducted on IW-1. A detailed description and interpretation of the RTS is presented in the following text. 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. 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 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 106 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 23 seconds of ejection. The readings from the bottom detector increased from background approximately two minutes and 21 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 2,430 feet bls. The results of the log out of position showed no indication of tracer material movement up hole. The final casing was then flushed with potable water. Following the flushing an out of position log was conducted (LAF #1) from below the casing to 2,430 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 106 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 2.0 mCi slug of tracer material was then ejected. The readings from the middle gamma ray detector began to increase from background within 32 seconds of ejection. The readings from the bottom detector increased from background approximately one minute and 30 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 2,430 feet bls after the 30-minute test period. The middle and bottom detector readings increased as the tool was moved out of position. This increase is attributed to a small leak from the ejector port which is positioned above the middle and bottom detectors. No detection of the tracer material was seen at the upper gamma ray detector any time during the log out of position. 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 were 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 (2,680 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 April 27, 2009, a controlled short term injection test was conducted on IW-1 using reclaimed water from the City's Everest WRF facility. 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 2,620 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 DZMW-1 upper monitor zone (1,450 to 1,550 feet bls), and the DZMW-1 lower monitor zone (1,800 to 1,870 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 P.**

Background monitoring was initiated at 0700 hours on April 25, 2009. After the background monitoring phase was completed, the 12-hour injection test was started at 0800 hours on April 27, 2009. The test was conducted at an average rate of 10,471 gpm (8.1 ft/sec). The wellhead pressure was closely monitored and not allowed to exceed two thirds of the casing pressure test value of 190 psi (126.7 psi). After the pumping phase of the test was concluded, recovery readings were recorded for a period of greater than 24 hours starting at 2000 hours on April 27, 2009.

The data recovered from the two data loggers were very similar. The data recovered from Box 1 have been presented in this report as they appear to be slightly less noisy as compared to the data recorded by Box 2. Injection well IW-1 wellhead pressure, DZMW-1 upper monitor zone pressures, 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 P.** Tide data provided by the National Ocean Service, Fort Myers Station (Station ID: 8725520) is also located in **Appendix P.**

The IW-1 wellhead shut-in pressure was approximately 26 psi before the start of the test. The maximum recorded IW-1 wellhead pressure during the test was approximately 126.48 psi. This pressure was recorded after the injection rate was increased from approximately 10,300 gpm to 10,900 gpm.

All IW-1 wellhead pressure readings are within the allowable 2/3 of the pressure test (i.e., approximately 126.5 psi) conducted on the 24-inch diameter final casing. 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)
10,471	125	84

4.5 FINDINGS AND CONCLUSIONS

A graphical presentation of the data recorded by the In-Situ Hermit 3000 is presented as **Figure 4-1**. **Figure 4-2** presents the IW-1 wellhead pressure and reclaimed water injection flow rate. The IW-1 wellhead pressures and the downhole pressures recorded by the memory gauge are presented in **Figure 4-3.**

As the pumping phase of the injection test was initiated the wellhead pressure increased from approximately 26 psi before the start of the test to 124 psi as the flow stabilized at approximately 10,525 gpm. At 1232 hours, after pumping for 273 minutes the flow rate had decreased to 10,232 gpm. During the next 6 minutes of pumping the wellhead pressure decreased from 124 to 117 psi as the flow rate increased to 10,638 gpm. At 1550 hours, after pumping for 470 minutes the flow rate had decreased to 10,446 gpm and the IW-1 wellhead pressure had decreased to 113 psi. At 1600 hours the injection pumps were ramped up to provide a flow rate of 10,800 gpm and a wellhead pressure of 125 psi. Before the pumping phase was terminated at 2000 hours, the flow rate was measured at 10,478 gpm and the recorded wellhead pressure was 119 psi.

As described in Section 3.3.3.3, the typical high permeability in the Boulder Zone due to cavernous porosity and extensive fracturing was not encountered at the Everest WRF location. However several horizons exhibiting vuggy porosity, small to moderate cavities and fractures capable of accepting injected fluids were identified. These features may be hydraulically associated with the regionally extensive and highly transmissive Boulder Zone. The decreasing wellhead pressure observed during the injection test may be the result of fluids moving through the locally moderately transmissive features to the highly transmissive regions of the Boulder Zone. Such fluid movement would have the potential of transporting fine sediments, silts and clays away from the borehole to highly fractured and cavernous settings thereby increasing the injectivity of IW-1.

Monitor well DZMW-1 upper and lower monitor zone pressures remained generally static over the duration of the test as shown on **Figure 4-4.** As shown in **Figures 4-5** and **4-6,** the upper and lower monitor zone pressure changes correlate very well with the tide and barometric data.

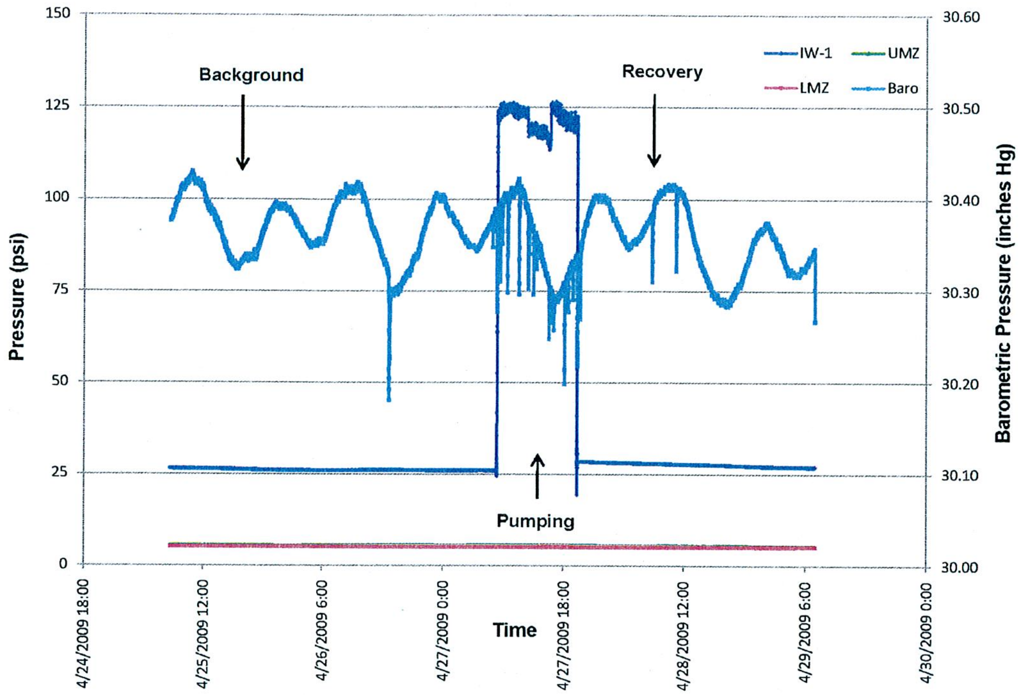

Figure 4-1
Injection Test IW-1, UMZ, LMZ and Barometric Pressures

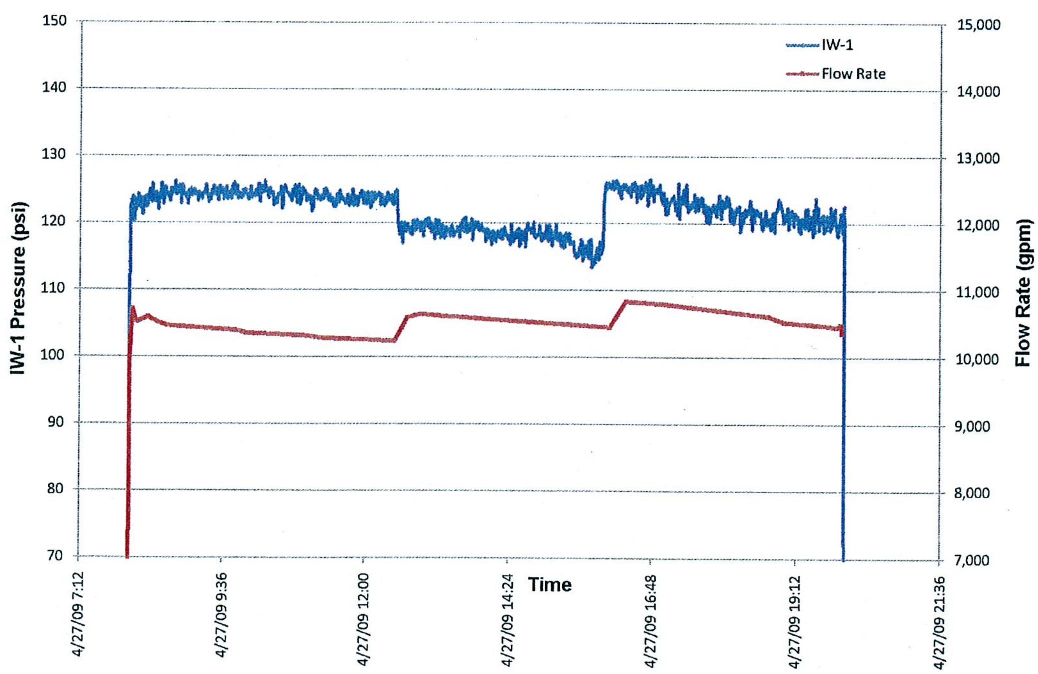

Figure 4-2
Injection Test IW-1 Pressure and Flow Rate

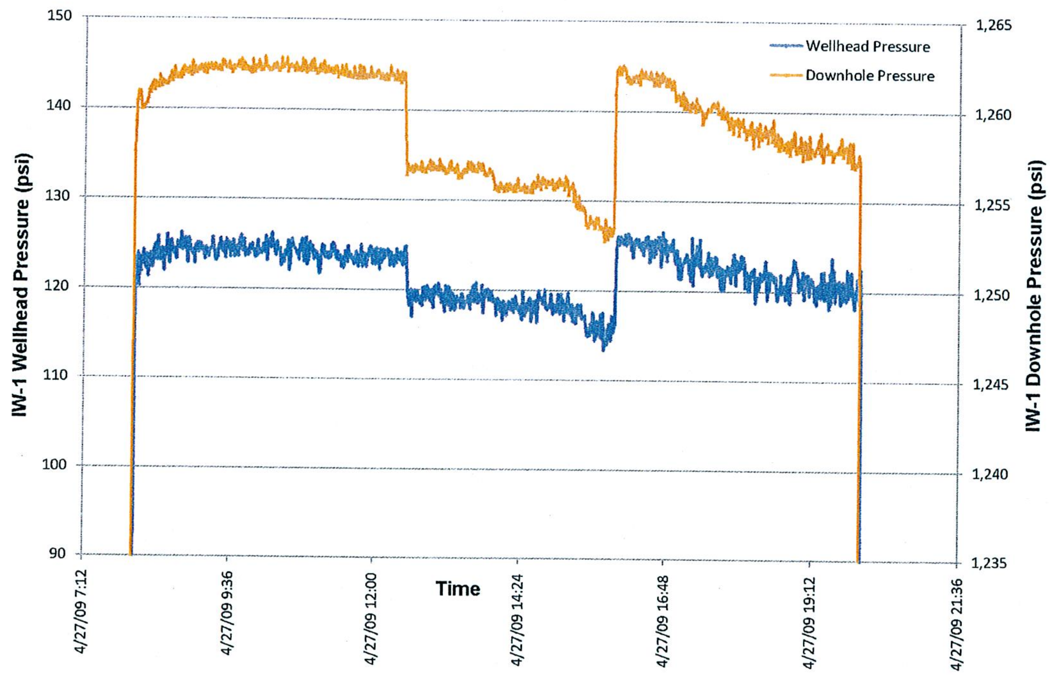

Figure 4-3
Injection Test IW-1 Wellhead and Downhole Pressures

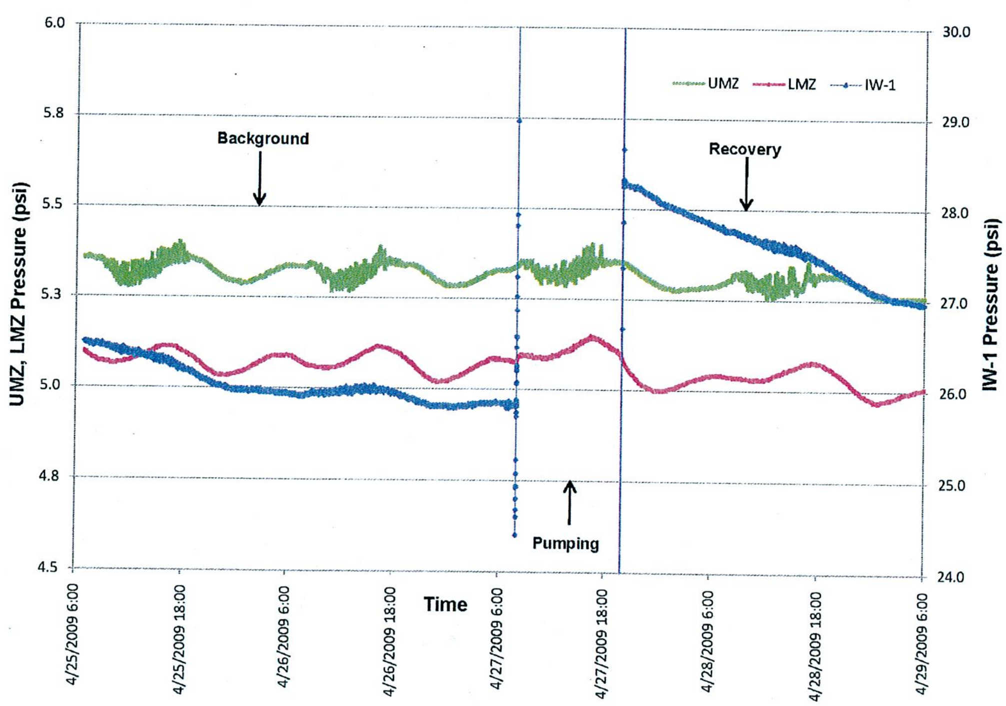

Figure 4-4
Injection Test UMZ and LMZ Pressures

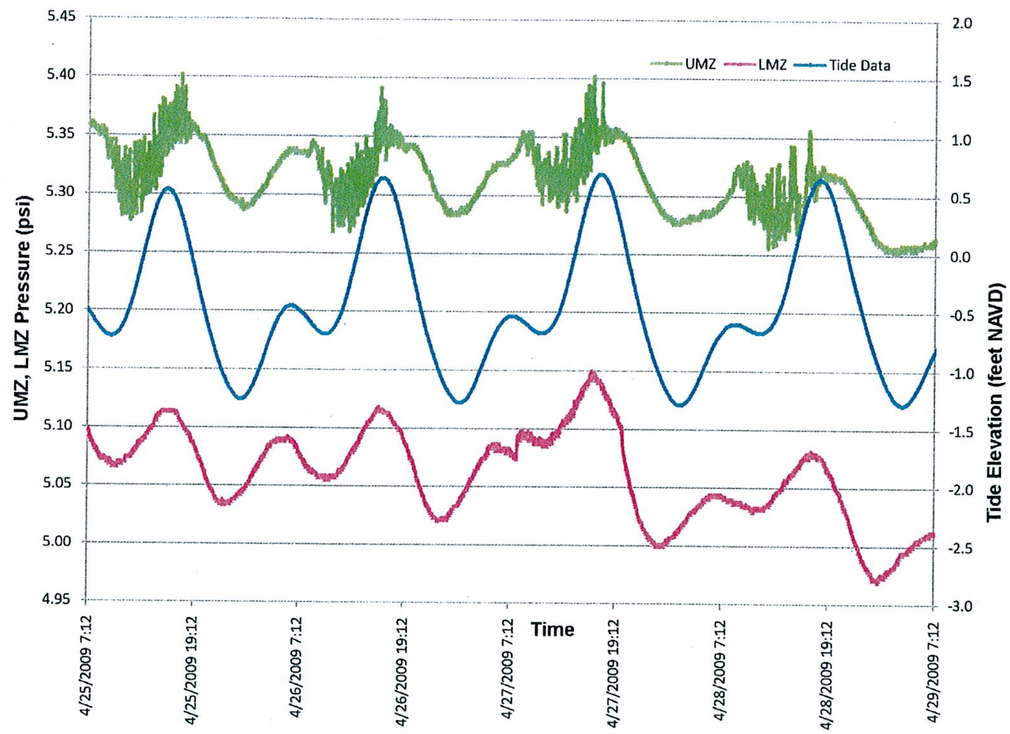

Figure 4-5
Injection Test UMZ, LMZ Pressures and Tide Data

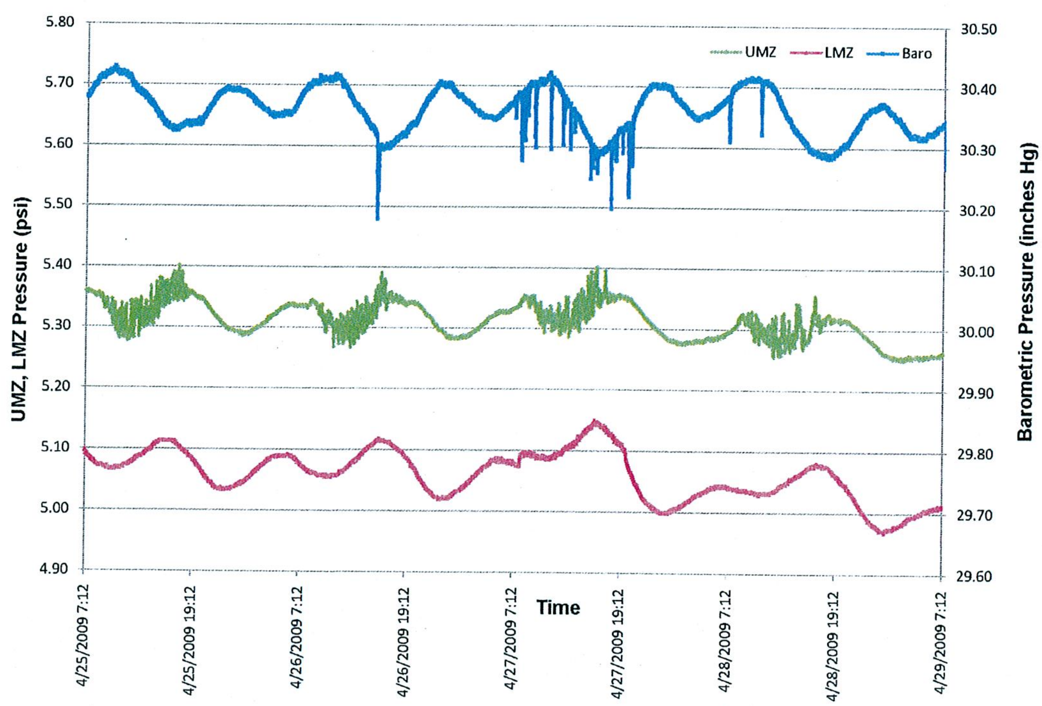

Figure 4-6
Injection Test UMZ, LMZ and Barometric Pressures

A detailed examination of the data reveals that minor pressure variations were recorded in the two monitoring zones. As presented in **Figure 4-7**, the upper monitor zone readings recorded during the pumping phase of the injection test appear somewhat noisy. This data noise is observed daily between approximately 0800 and 1900 hours (**Figures 4-5 and 4-6**). The upper monitor zone pressure changes do not appear to have been influenced by the injection activities

As the pumping phase was initiated, the immediate injection zone pressure increase appears to have been broadcast to the lower monitor zone. As presented in **Figure 4-8**, a slight pressure increase of 0.019 psi was detected at the beginning of the pumping phase. As the pumping phase was terminated a corresponding lower monitor zone decrease of 0.015 psi was recorded. The lower monitor zone pressure changes appear to have been influenced by the injection activities. We believe this is related to a transfer of downhole pressure through the rock matrix and not a function of mixing fluids. The maximum downhole pressure during the injection test was 1,263 psi, which is far below the pressure necessary to initiate fracturing.

The transmissivity of the injection zone is estimated to be at least 100,000 gallons per day per foot. The injection zone is capable of a flowrate of 8.1 feet per second at an injection pressure that will not promote fractures in the injection zone or confining sequences.

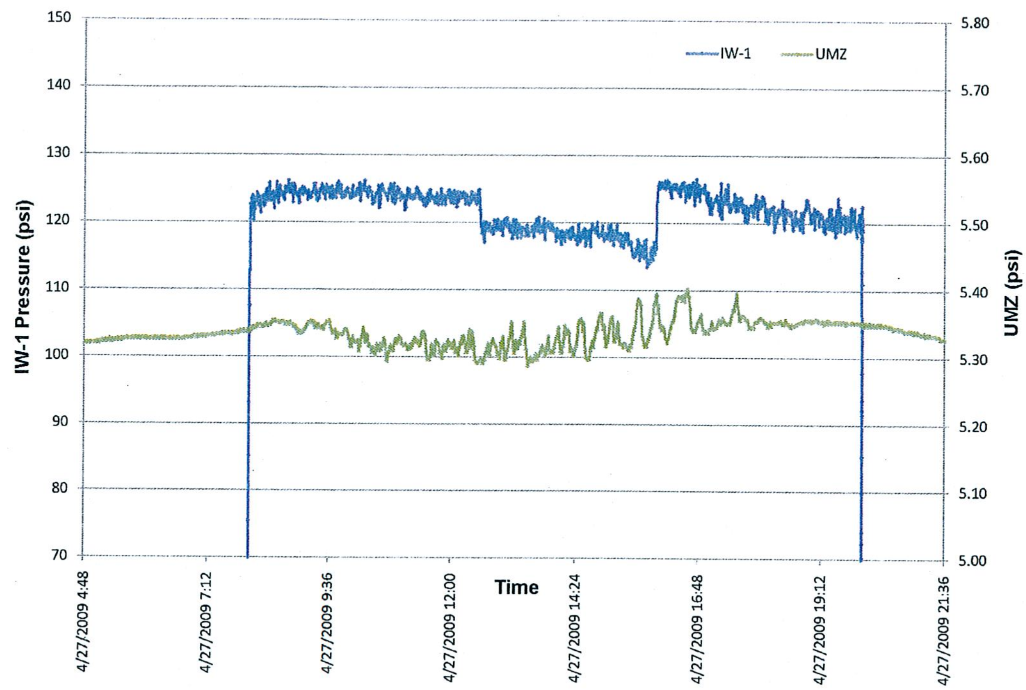

Figure 4-7
Injection Test IW-1 and UMZ Pressures

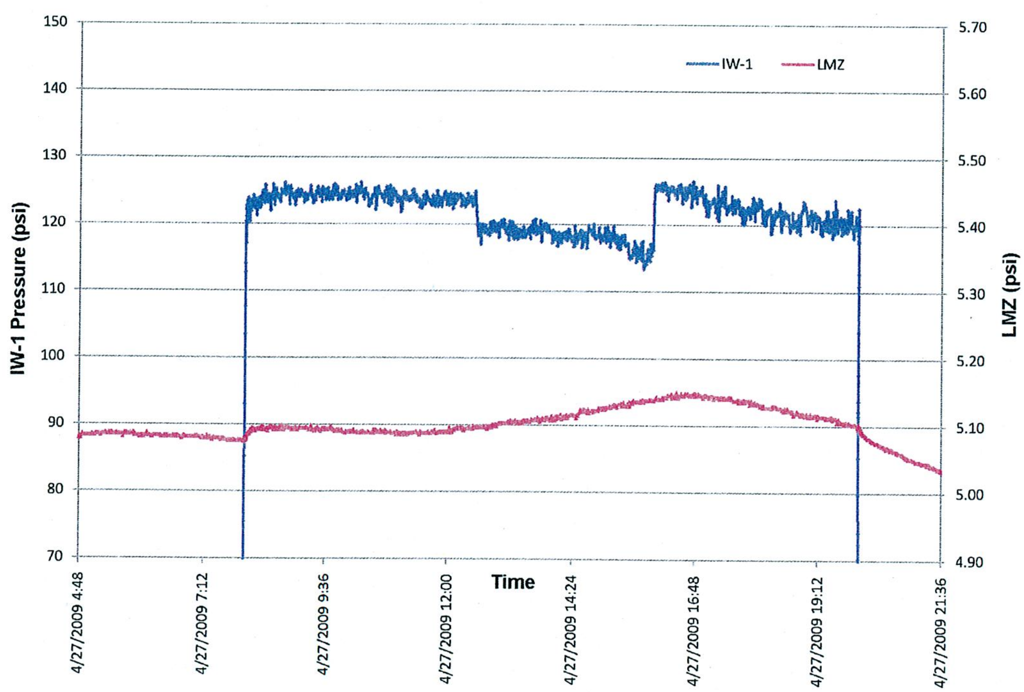

Figure 4-8
Injection Test IW-1 and LMZ Pressures

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 groundwater exceeds 10,000 mg/L TDS, occurs at 1,465 feet bls at IW-1.
- The confining sequence generally occurs between 2,510 and 2,660 feet bls, 2,430 and 2,470 feet bls, 2,110 and 2,240 feet bls, and between 1,950 and 2,050 feet bls.
- Vertical hydraulic conductivity determined from core testing within the confining sequences range from 1.1×10^{-4} cm/sec to 9.2×10^{-12} cm/sec.
- Transmissivities determined from packer testing within the confining sequences range from 14.62 $feet^2$ per day to 0.71 $feet^2$ per day
- These data demonstrate the existence of a transmissive injection zone below 2,630 feet bls saturated with saline water (containing more than 10,000 mg/L TDS).
- The injection well was tested at an average injection rate of 10,471 gpm (8.1 ft/sec, 15.0 mgd) with an average injection pressure of 125 psi.
- The injection zone is capable of accepting a flowrate equivalent to a velocity of 8.1 feet per second in IW-1 at an injection pressure that will not promote fractures in the injection zone or confining sequences.
- The IW-1 final casing (24-inch diameter) was successfully pressure tested at 190 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 1,450 to 1,550 feet bls and the lower zone from 1,800 to 1,870 feet bls.

5.2 CONCLUSIONS

The presence of favorable geologic conditions, a 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 excess reclaimed water at the City of Cape Coral Everest WRF in accordance with existing state and federal underground injection control regulations.

Based on the results of the geophysical logging and testing performed at the Everest WRF, 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 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 monitored monthly.
- 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.

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 operation are required before the City can apply for an operating permit. The construction permit for IW-1 expires October 3, 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 activities into the associated 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 are to be pumped from the monitor zones.

Dual-zone monitor well water quality is to be monitored through weekly and monthly samples collected 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.

The pressure in both zones of the dual-zone monitor well is to be continuously monitored and recorded relative to feet NAVD 88 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 injection well system, records should be maintained to evaluate injection well performance.

The pressure at the injection wellhead 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. 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.

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

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. The testing rates for injectivity testing should be established when 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 well is to be tested for mechanical integrity every five years in accordance with FAC Rule 62-528. Based on the date of testing during construction, the first MIT is to be performed before March 25, 2014. The proposed MIT plan 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 waste stream 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

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 pumping neat cement to a depth of 3,000 feet.

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 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 open hole with crushed limestone and the 6.625 -inch diameter casing with neat cement grout.
- Fill the upper zone open hole 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	200	$4,000
Neat Cement (sacks)	$20	6,500	$130,000
20% Contingency	---	1	$51,800
Total - Injection Well	---	---	**$310,800**
Dual-Zone Monitor Well DZMW-1			
Mobilization	$30,000	1	$30,000
Neat Cement (sacks)	$20	2000	$40,000
Crushed Limestone	$20	100	2,000
20% Contingency	---	1	$14,400
Total - Dual-Zone Monitor Well	---	---	**$86,400**
Total Cost			**$397,200**

Appendix