Design & Permitting for the Leachate Treatment Facility Expansion at the Lee/Hendry Landfill
CN-09-03

Lee County Regional
Solid Waste Disposal Facility
Class I Deep Injection Well System

Drilling and Testing Report

February 2012

LEE COUNTY
SOUTHWEST FLORIDA

MWH

LEE COUNTY
SOUTHWEST FLORIDA

BOARD OF COUNTY COMMISSIONERS

March 16, 2012

Mr. David Rhodes, P.G.
FDEP, Underground Injection Control Division
P.O. Box 2549
Fort Myers, FL 33902

RE: Lee/Hendry County Regional Solid Waste Facility
Class I Injection Well Final Drilling and Testing Report
UIC Permit 299459-001-UC/1I

Dear Mr. Rhodes:

I have reviewed the Report for the Class I Deep Injection Well System Drilling and Testing Report prepared by MWH, dated February 2012, and in accordance with Rule 62-528.340(4), F.A.C, provide the following certification:

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

If you have any questions, please do not hesitate to contact my office at 239-533-8000 or Gordon Kennedy with MWH at 239 236-0017.

Sincerely,

Lindsey J Sampson

Lindsey J. Sampson
Director, Solid Waste Division

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Enclosure
cc: Keith Howard, SWD
Laura A. Gray, SWD
David Baar, MWH
Gordon Kennedy, MWH
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Document Control Sheet

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Project Title:	**Lee County Regional Solid Waste Disposal Facility Class I Deep Injection Well System**
Document Title:	**Drilling and Testing Report**

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Intra-Discipline Review

Scope Element	Prepared (Author)	Checked by (Reviewer)
Construction	G. Young/ S. Bodmann	Johnson/ Rectenwald/ Kennedy
Data Collection and Analysis	G. Young/ S. Bodmann/ Todd Tubbert/ Sam Randazzo	Johnson/ Rectenwald/ Kennedy
Hydrogeology	G. Young/ S. Bodmann/ Todd Tubbert	Johnson/ Rectenwald/ Kennedy
Figures	G. Young/ S. Bodmann	Johnson/ Rectenwald/ Kennedy
Tables	G. Young/ S. Bodmann/ Todd Tubbert	Johnson/ Rectenwald/ Kennedy

Document Control

Rev	Date	Revision Description	Prepared (Lead Author)	Reviewed	Approved
1	5/27/11	Draft 1	G. Young/ S. Bodmann	Kennedy	
2	9/22/11	Draft 2	Largy, Bodman, Kennedy	Rectenwald	
3	1/23/12	Final	Largy, Bodman, Kennedy	Rectenwald	Baar, Kennedy

Distribution

Name	Name
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Certifications

PROFESSIONAL ENGINEER

The engineering features of the *Lee County Regional Solid Waste Disposal Facility Class I Deep Injection Well System Drilling and Testing Report*, 2012 were prepared by, or reviewed by, a Licensed Professional Engineer in the State of Florida.

David Baar

David Baar, P.E.

Feb 6, 2012

Date

38531

License No.

PROFESSIONAL GEOLOGIST

The geological evaluation and interpretations contained in the *Lee County Regional Solid Waste Disposal Facility Class I Deep Injection Well System Drilling and Testing Report* for Lee County, 2012, were prepared by, or reviewed by, a Licensed Professional Geologist in the State of Florida.

GORDON P KENNEDY
NO. 1346

Gordon Kennedy

Gordon P. Kennedy, P.G.

2/17/12

Date

1346

License No.

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Section 1
Injection Well Program

1.1 INTRODUCTION

This report summarizes the construction activities and testing results for the Class I injection well disposal facilities constructed at the Lee County Regional Solid Waste Disposal Facility (LCRSWDF) located in western Hendry County, 3 miles north of State Road 82.

A Deep Injection Well (DIW) system was identified as the preferred method of disposal for non-hazardous leachate. This type of disposal requires an injection well built to Class I Industrial standards, with a tubing and packer well design. The design rate of the well is approximately 0.5 MGD, however the well is sized to accommodate disposal of 1.4 MGD at 10 feet/second velocity.

The general location of the LCRSWDF IW-1 site is shown in **Figure 1-1**. The DIW system consists of one Class I injection well, IW-1, constructed with a 11.75-inch inner diameter (ID) final casing set to 2,396 feet bls, lined with a 6.21-inch ID FRP tubing seated at a depth of 2,391 feet bls and completed to a total depth of 3,280 feet bls. Associated with IW-1 is a dual-zone monitor well (DZMW) constructed approximately 140 feet to the west at the LCRSWDF location.

Shallow water table aquifer monitor wells also were constructed and monitored throughout construction of the DIW facilities to ensure the area water table quality was not affected by construction operations.

The wells were constructed to meet the requirements of the FDEP Class I Injection Well standards and the specific conditions of the UIC construction permit issued by FDEP on August 27, 2010 (**Appendix A**). Contractor bids for well construction were opened on June 9, 2010 and Notice to Proceed was issued to the Contractor, Youngquist Brothers, Inc. of Fort Myers, Florida, on October 13, 2010.

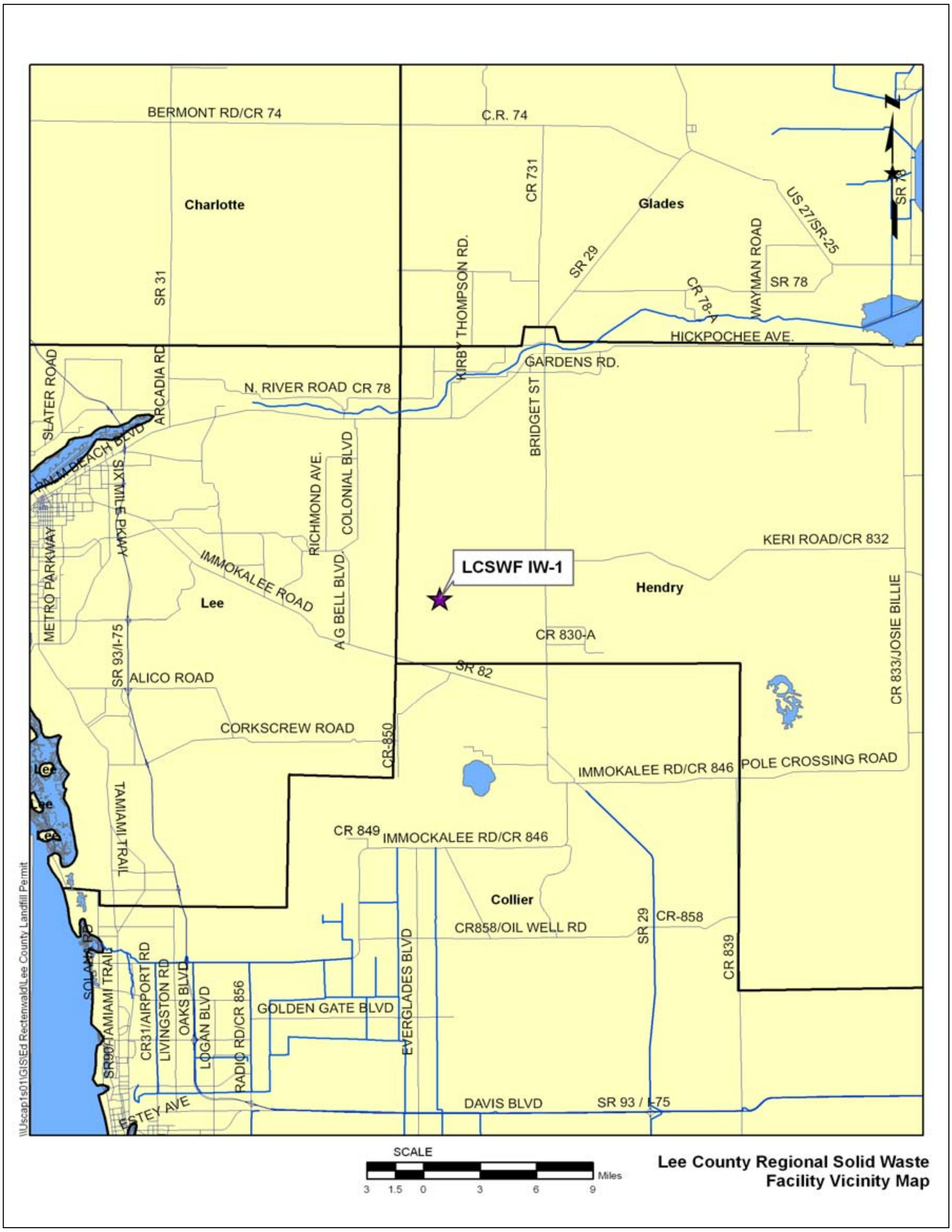


Figure 1-1
Site Location Map

1.2 PURPOSE

Technical hydrogeologic oversight during the construction and testing of a Class I DIW System consisting of IW-1 and a dual zone monitor well-1 (DZMW-1) at the LCRSWDF were provided to verify that the requirements of the FDEP Class I Injection Well Construction Permit were met and to provide hydrogeological evaluation and interpretation of the data collected. The Scope of Services was provided to Lee County Solid Waste Division under the terms and conditions of the existing Professional Services Agreement dated April 21, 2009 (Contract No. 4770).

The purpose of this report is to summarize the information obtained during the construction and testing of IW-1 and DZMW-1 at the Lee County Regional Solid Waste Disposal Facility 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.

1.3 SCOPE

Youngquist Brothers, Inc. of Fort Myers, FL, the contractor, conducted drilling, construction, and testing activities for the DIW System. MWH was the County's onsite representative, providing the construction observation and technical services that are required to comply with the FDEP UIC construction permit.

Weekly reports documenting the construction and testing of the wells were submitted in accordance with Chapter 62-528 F.A.C., to the FDEP, and the Technical Advisory Committee (TAC). The TAC includes members of local, state, and federal agencies, including state and local representatives of the FDEP, the South Florida Water Management District (SFWMD), and U.S. Environmental Protection Agency (USEPA). Construction and testing activities were reported in accordance with Specific Condition

5 of the construction permit. This final report was prepared as required by Specific Condition 5f of the construction permit.

Technical Services during Construction as outlined in the scope of services consists of:

1) Project Management,
2) Pre-construction activities,
3) Engineering services during construction and
4) Post Construction Activities, including the preparation of a final Well Construction Completion Report, Draft O&M Manual, and Request to Start Operational Testing.

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 on October 11, 2010. Major construction and testing activities were completed on June 14, 2011. The 12.25-inch diameter pilot hole drilled for IW-1 was constructed to a total depth of 3,280 feet bls. The DZMW-1 was constructed to a total depth of 2,080 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 drilling 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 depths 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 injection 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 wells are located at the Lee/Hendry County Regional Solid Waste Disposal Facility (LCRSWDF) site shown on **Figure 2-1.** A summary of the construction activities for each well was prepared in a daily report. The daily reports have been previously submitted to the Department and the TAC with the Weekly Summary Reports. Copies of the daily reports are found in the Weekly Reports provided in **Appendix B**.

2.2 SITE DEVELOPMENT

The construction site at the LCRSWDF is essentially flat, with an elevation of approximately 33 feet above the National Geodetic Vertical Datum of 1929 (NGVD).

2.2.1 Containment Pad

A temporary steel containment pad, illustrated on **Figure 2-2,** was constructed for use during the drilling of Well IW-1 to provide support for drilling equipment and to contain all fluids from the borehole and/or construction activities. Following completion of Well IW-1, the containment pad was moved to the site of DZMW-1.

The pad was designed to support the greatest possible load that might be placed on it during well construction, and has dimensions of approximately 45 feet by 45 feet with a 2-foot high retaining wall on the perimeter. The retaining wall was designed as a sealed system to protect the surficial aquifer by containing any fluid spills within the limits of the pad. The surficial aquifer was protected by the pad principally from saline formation water encountered during the drilling of Well IW-1. A pump was installed into the containment pad to remove fluids from the pad to an onsite storage system and/or for removal to the approved offsite disposal location.

2.2.2 Pad Monitor Wells

Six pad monitoring wells (PMWs) were installed to monitor the surficial aquifer water quality during drilling activities. The pad monitor wells were located to the northwest, north central, northeast, southwest, south central, and southeast of the drilling pad. The six PMWs were installed and developed on November 22-23, 2010, and sampled by Sanders Laboratory on November 23rd for baseline background water quality. The approximate locations of the PMWs are shown in Figure 2-1. Each PMW was constructed to a depth of approximately 17 feet bls. The wells have 10 feet of 2-inch diameter 20-slot Schedule 40 polyvinyl chloride (PVC) casing from 7 to 17 feet bls, and 2-inch diameter Schedule 40 PVC blank casing from the top of screen to land surface.

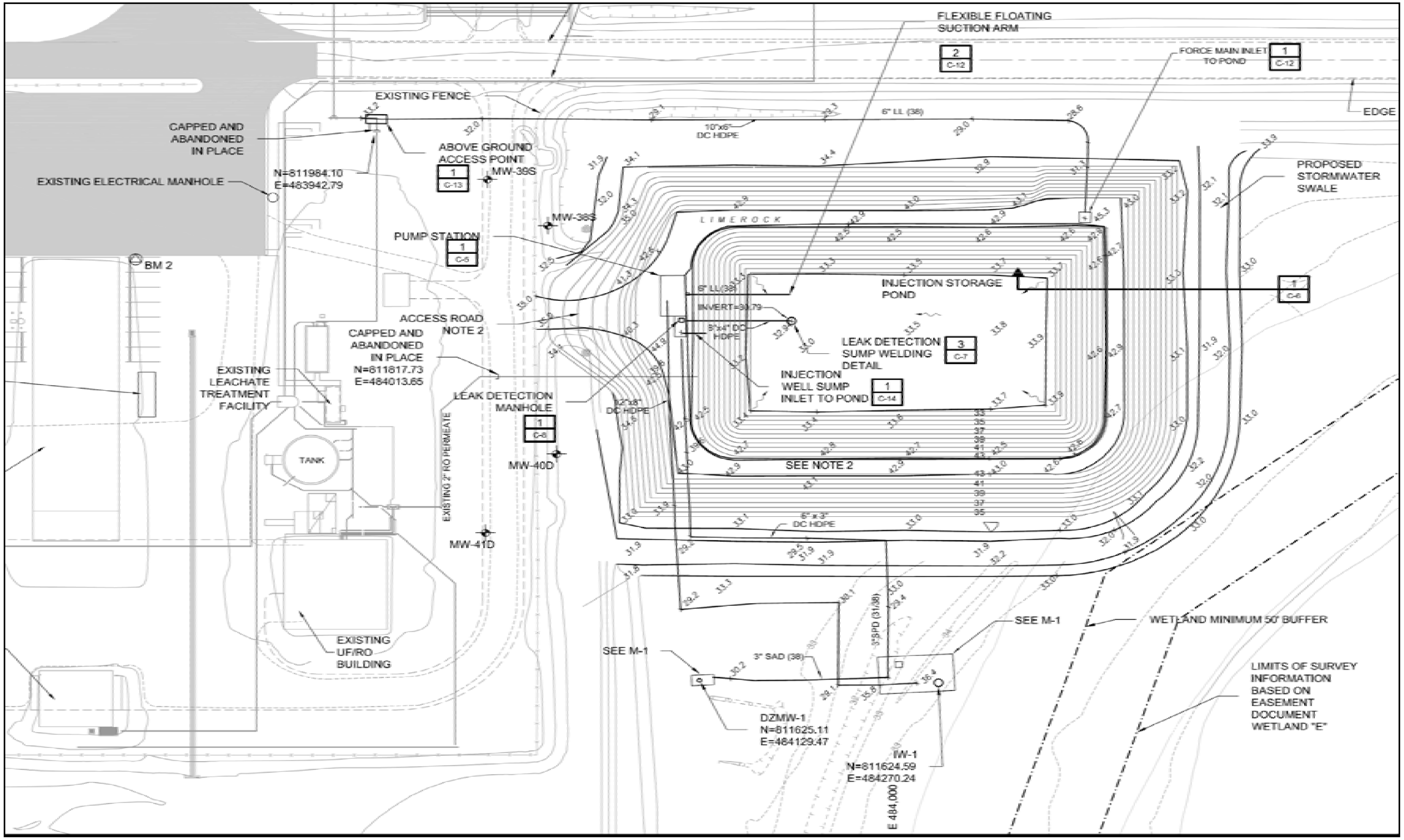
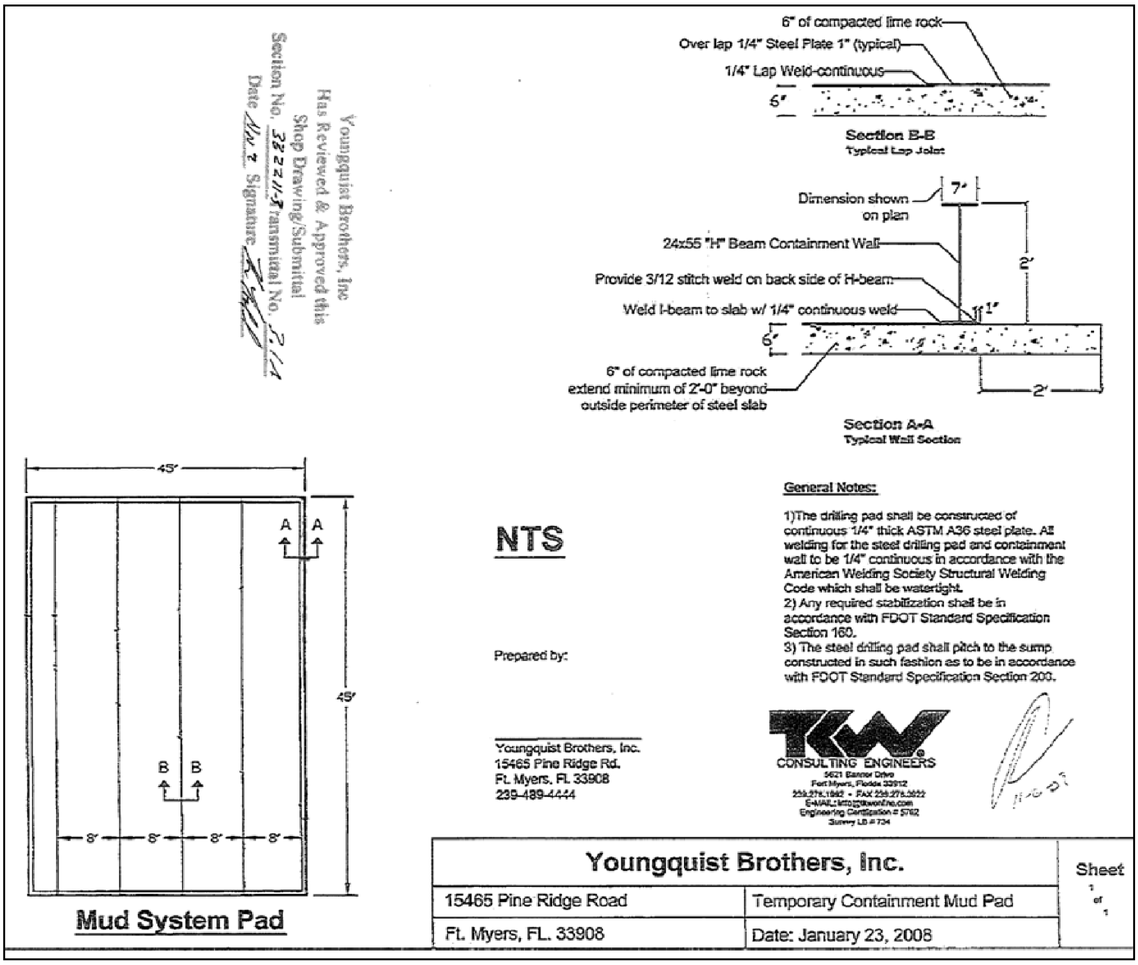


Figure 2-1
Injection Well System Site Survey



General Notes:

1)The drilling pad shall be constructed of continuous 1/4" thick ASTM A36 steel plate. All welding for the steel drilling pad and containment wall to be 1/4" continuous in accordance with the American Welding Society Structural Welding Code which shall be watertight.
2) Any required stabilization shall be in accordance with FDOT Standard Specification Section 160.
3) The steel drilling pad shall pitch to the sump constructed in such fashion as to be in accordance with FDOT Standard Specification Section 200.

Prepared by:

Youngquist Brothers, Inc.
15465 Pine Ridge Rd.
Ft. Myers, FL 33908
239-489-4444

Youngquist Brothers, Inc.		Sheet 1 of 1
15465 Pine Ridge Road	Temporary Containment Mud Pad	
Ft. Myers, FL. 33908	Date: January 23, 2008	

Figure 2-2
Temporary Steel Containment Pad

Throughout construction activities, water samples were collected on a weekly basis from six shallow monitoring wells (SMWs) constructed within the surficial aquifer and 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. SMW laboratory results have been previously submitted to the Department and the TAC with the Weekly Summary Reports. Based on the SMW data collected throughout the project, there are no adverse affects to the surficial aquifer system observed as a result of construction activities.

2.3 WELL CONSTRUCTION

Drilling and construction of IW-1 began on December 1, 2010. Drilling and construction of DZMW-1 began on April 16, 2011. Drilling operations were generally conducted on a 24 hours a day, 7 days per week schedule. Major construction and testing activities were completed on June 14, 2011.

The monitor well, DZMW-1, was constructed approximately 140 feet west of IW-1 as shown in Figure 2-1. Geophysical logging and testing were performed during drilling of the wells. Well construction was in accordance with the FDEP construction permit. A copy of the FDEP Construction permit is provided in Appendix A. The drilling of IW-1 and DZMW-1 proceeded generally as identified in the project specifications and as approved by FDEP.

The project specifications outlined a drilling plan that was adjusted based on site specific conditions. The plan included setting steel casing at selected depths in order to maintain the formation during drilling and to facilitate testing.

Drilling activities are summarized below as a sequence of events and the associated nominal depths below land surface bls. A chronology of construction activities is presented in **Table 2-1**

To consistently record downhole depth, all well measurements are recorded in terms of depth below land surface (bls). Actual casing depths are identified in the completed well profiles for IW-1 and DZMW-1 presented in Figure 2-2. Injection well IW-1 was generally constructed as follows:

Drill a nominal 50-inch diameter borehole to approximately 199 feet bls using the mud rotary method.

- Set and cement 44-inch diameter steel casing to a depth of 195 feet bls.
- Drill a 12.25-inch diameter pilot hole to approximately 1,150 feet bls using the mud rotary method.
- Drill a nominal 42-inch diameter borehole to approximately 1,138 feet bls using the mud rotary method.
- Set and cement 34-inch diameter steel casing to a depth of 1,135 feet bls.
- Drill a 12.25-inch diameter pilot hole to approximately 1,945 feet bls using the reverse air method.
- Back plug pilot hole with cement to 1,135 feet bls.
- Drill a nominal 32-inch diameter borehole to approximately 1,945 feet bls using the reverse air method.
- Set and cement 24-inch diameter steel casing to a depth of 1,940 feet bls.
- Drill a 12.25-inch diameter pilot hole to approximately 3,280 feet bls using the reverse air method and core at selected depths.
- Drill a nominal 22-inch diameter borehole to approximately 2,400 feet bls using the reverse air method.
- Set and cement 12-inch diameter steel casing to a depth of 2,396 feet bls.
- Set 6.2 inch ID FRP tubing and packer assembly at 2,391 feet bls.

Some difficulties were encountered with setting and sealing the injection tubing positive seal packer. On May 13, 2011 3.5-inch steel tubing was used to place an inflatable packer inside the FRP tubing at a depth of approximately 2,390 feet bls. The packer was inflated against the FRP tubing inside wall and the weight of the 3.5-inch steel tubing was used to seat the positive seal packer. A summary of the IW-1 drilling and testing is presented in **Figure 2-3**.

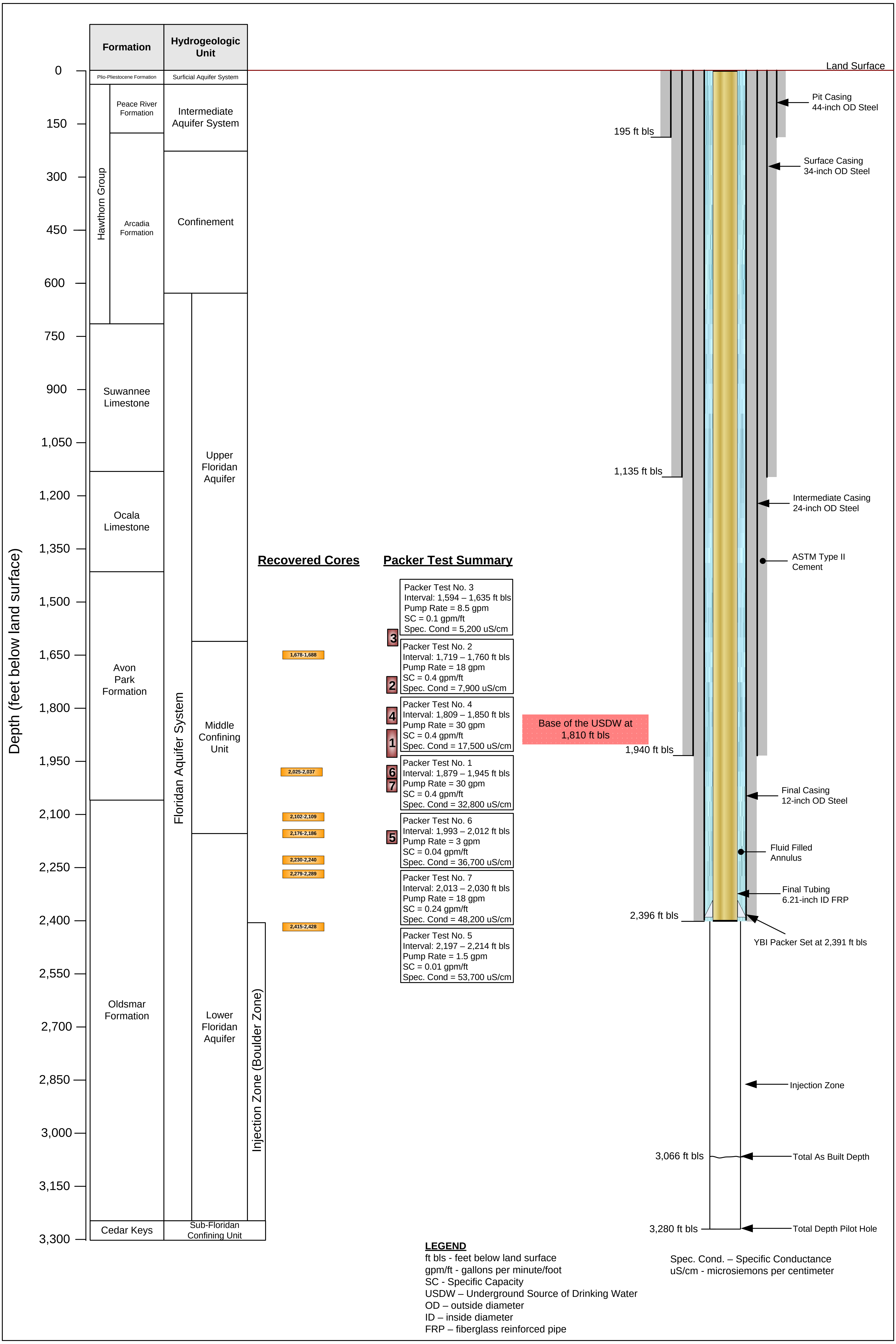
Table 2-1
Construction Chronology: IW-1 and DZMW

Start Date	End Date	Activity
10-13-10	10-13-10	Notice To Proceed
11-1-10	11-30-10	Mobilization
12-1-10	12-1-10	Spud IW-1 with 50.5 inch bit
12-1-10	12-3-10	Drilled 50.5 inch borehole to 199 feet bls for pit casing
12-3-10	12-3-10	Set and cemented 195 feet of 44-inch steel pit casing
12-5-10	12-7-10	Drilled 12.25-inch Pilot Hole to
12-8-10	12-8-10	Geophysical Logging Suite
12-8-10	12-17-10	Ream nominal 42-inch diameter borehole
12-18-10	12-18-10	Set 1,135 ft of 34-inch casing
12-19-10	12-19-10	Cemented 34-inch casing to land surface in 1 stage
12-20-10	12-21-10	Switched over to reverse-air
12-22-10	12-23-10	Drilled 12.25-inch pilot hole to 1,678 feet bls
12-24-10	12-24-10	Shut in well
12-25-10	12-25-10	No activity
12-26-10	12-26-10	Core No. 1 - Interval 1,678-1,688 feet bls
12-27-10	12-27-10	Drilled 12.25-inch pilot hole from 1,678 to 1,945 feet bls
12-28-10	12-28-10	Geophysical Logging Suite
12-29-10	12-30-10	Packer Test No. 1 - Interval 1,879-1,945 feet bls
12-30-10	12-31-10	Packer Test No. 2 – Interval 1,719-1,759 feet bls.
1-1-11	1-2-11	Packer Test No. 3 – Interval 1,544-1,635 ft bls
1-3-11	1-4-11	Packer Test No. 4 – Interval 1,809-1,850 feet bls.
1-5-11	1-12-11	Reamed borehole with 32.5 inch bit 1,123 to 1,945 feet bls
1-13-11	1-13-11	XY Caliper Log of nominal 32.5-inch reamed hole
1-13-11	1-14-11	Run 24-inch casing to 1,940 feet bls
1-14-11	1-16-11	Cemented 24-inch casing
1-17-11	1-17-11	Drilled 12.25-inch pilot hole 1,945 to 2,025 feet bls
1-18-11	1-19-11	Core No. 2 - Interval 2,025-2,037 feet bls
1-19-11	1-19-11	Drilled 12.25-inch pilot hole 2,025 to 2,102 feet bls
1-20-11	1-21-11	Core No. 3 - Interval 2,102-2,114 feet bls
1-23-11	1-22-11	Drilled 12.25-inch pilot hole 2,102 to 2,176 feet bls
1-23-11	1-23-11	Core No. 4 - Interval 2,176-2,186 feet bls

Start Date	End Date	Activity
1-24-11	1-24-11	Drilled 12.25-inch pilot hole 2,176 to 2,230 feet bls
1-25-11	1-25-11	Core No. 5 - Interval 2,230-2,240 feet bls
1-26-11	1-26-11	Drilled 12.25-inch pilot hole 2,230 to 2,279 feet bls
1-26-11	1-27-11	Core No. 6 - Interval 2,279-2,289 feet bls
1-27-11	1-30-11	Drilled 12.25-inch pilot hole 2,279 to 2,416 feet bls
1-30-11	1-30-11	Core No. 7 – Interval 2,416-2,426 feet bls
1-31-11	2-1-11	Fished for core bit
2-2-11	2-13-11	Drilled 12.25-inch pilot hole 2,416 to 3,280 feet bls
2-14-11	2-16-11	Wiper trips and dredging to clear pilot hole
2-16-11	2-17-11	Geophysical logging suite
2-18-11	2-19-11	Packer Test No 5 - Interval 2,197-2214 feet bls
2-20-11	2-21-11	Packer Test No 6 - Interval 1,993-2,012 feet bls
2-21-11	2-22-11	Packer Test No 7 - Interval 2,013-2,030 feet bls
2-23-11	2-26-11	Clearing 12.25-inch pilot hole from 2,840 to 3,280 feet bls
2-26-11	2-26-11	Ran video survey to 2,749 ft bls, borehole blocked at 2,749 feet.
2-26-11	3-16-11	Clear/drill 14.75 inch pilot hole for geophysical logging suite
3-3-11	3-3-11	Ran video survey to total depth
3-17-11	3-17-11	Replaced Top Head Drive
3-18-11	3-18-11	Video Survey from 1,940 to 3,280 feet bls.
3-18-11	3-21-11	Reamed with 17.5-inch bit from 1,940 to 2,370 feet bls
3-22-11	3/26/11	Reamed with 22-inch bit from 1,940 to 2,394 feet bls
3/26/11	3-28-11	Cleared borehole with 14.75 -inch bit from 2,394 to 3,066 feet bls
3-28-11	3-29-11	Installed 12 inch diameter Final Casing
3-30-11	3-30-11	Preliminary pressure test of 12 inch diameter Final Casing
3-31-11	4-5-11	Cement 12.75-in OD Final Casing from 2,396 to 242 feet bls
4-6-11	4-6-11	Cement Bond Log on Final Casing
4-7-11	4-10-11	Casing cooling and preliminary pressure test Final Casing
4-11-11	4-11-11	FDEP observed pressure test and video survey of Final Casing
4-12-11	4-12-11	Set nominal 7-inch FRP to 2,391 feet bls
4-13-11	4-15-11	Mobilize to DZMW-1 location
4-16-11	4-17-11	**Begin Drilling DZMW** – Drilled nominal 42-inch borehole from 0 to 205 feet bls
4-18-11	4-18-11	Set and cement 34-inch pit casing to 200 feet bls
4-19-11	4-21-11	Drill 12.25-inch diameter pilot hole from 200 to 1,161 feet bls
4-21-11	4-22-11	Geophysical Logging suite
4-22-11	4-26-11	Ream nominal 32-inch diameter borehole from 200 to 1,140 feet bls.
4/27/11	4/29/11	Run Caliper/Gamma ray log in 34-inch reamed borehole. Set and cement 24-inch steel casing from surface to 1,135 feet bls.
4/30/11	5/3/11	Drill 12.25-inch pilot hole using reverse air method from 1,124 (cement tag) to 1946 feet bls.

Start Date	End Date	Activity
5/4/11	5/4/11	Core No. 1 – Interval 1,946 – 1,963 feet bls. Drilled 12.25-inch pilot hole from 1946 to 1982 ft bls.
5/5/11	5/5/11	Core No. 2 – 1,982 – 1,997 feet bls. Drilled 12.25-inch pilot hole from 1982 to 2080 feet bls (TD).
5/6/11	5/6/11	Geophysical logging suite in pilot hole from 1,135 to 2,080 feet bls.
5/7/11	5/8/11	Attempt Video Survey & BHTV – not possible due to poor WQ. Air Develop.
5/9/11	5/9/11	Packer Test No 1 (single) - Interval 2,018 to 2,080 feet bls.
5/10/11	5/10/11	Develop / video survey from 1,406 to 2,037 feet bls.
5/11/11	5/11/11	Develop / video survey from 1,136 to 1,406 feet bls.
5/12/11	5/12/11	Packer Test No. 2 Interval 1,815 to 1,862 feet bls.
5/13/11	5/14/11	Packer Test No. 3 - Interval 1,691 to 1,738 feet bls. Seated FRP injection tubing in IW-1 on 5/13/11.
5/15/11	5/15/11	No Site Work.
5/16/11	5/16/11	Develop IW-1 injection zone.
5/17/11	5/17/11	IW-1 - Background water quality samples taken. Final Video log performed. Topped off cement in 12-inch steel casing annulus.
5/18/11	5/18/11	IW-1 - Tag cement at 18 feet bls. / No further work onsite besides general housekeeping.
5/19/11	5/20/11	IW-1 - Complete DIW wellhead fabrication. DZMW-1 – Aluminum hole cover measuring 15 x 15 inches lost down hole, trip in 12.25-inch bit to chase cover to bottom.
5/21/11	5/21/11	DZMW-1 – Fill pilot hole from 1,983 to 2,080 feet bls with gravel. Cement pilot hole Stage 1 with 17 barrels of neat cement. Tag Stage 1 cement at 1,909 feet bls. Fill pilot hole from 1,909 to 1,803 feet bls with gravel. Cement pilot hole Stage 2 with 100 barrels of 12 percent gel cement. Tag Stage 2 cement at 1,541 feet bls. Cement pilot hole Stage 3 with 100 barrels of 12 percent gel cement.
5/22/11	5/24/11	IW-1 – Conduct preliminary annular pressure test – lost 2.5 psi in hour. DZMW-1 Tag Stage 3 pilot hole cement at 1,178 feet bls. Reamed 22-inch diameter hole from 1,135 to 1,815 feet bls.
5/25/11	5/26/11	IW-1 – Conducted FDEP witnessed annular pressure test. Start pressure 153.5 psi, ending pressure 152.0 psi – lost 2.5 psi in hour. DZMW-1 - Ran XY Caliper log on 22-inch hole. Installed16-inch OD Intermediate Casing.
5/26/11	5/28/11	Cement 16-inch steel casing to approximately 250 ft bls. Ran CBL.
5/29/11	5/29/11	Pressure test 16-inch Steel Casing.
5/30/11	5/31/11	Reamed 14.75-inch hole from 1,793 to 2,005 ft bls, drilled 12.25 inch

Start Date	End Date	Activity
		hole from 2,005 to 2,080 feet bls (TD).
6/1/11	6/1/11	Ran X-Y Caliper / Gamma ray log from 1,973 to total depth 2,080 feet bls. Set bottom of California Packer at 2,022feet bls. Run before cementing CBL on 6-inch FRP casing
6/2/11	6/3/11	Cement 6-inch FRP in place. First cement shot 1.75 barrels of neat cement with 3 percent CaCl tagged at 2,000 feet bls. Second cement shot 2 barrels of neat cement with 3 percent CaCl tagged at 2,000 feet bls tagged at 1,990 feet bls. Stage 1 pumped 25 barrels of neat cement tagged at 1,885 feet bls. Stage 2 pumped 2.5 barrels of neat cement. Tag 6-inch FRP casing Stage 2 cement at 1,868 feet bls
6/3/11	6/6/11	Begin Developing UMZ. Perform after cement CBL. Conduct pressure test on 6-inch FRP. Release California Packer plug with 320psi. Begin Developing LMZ.
6/6/11	6/6/11	End LMZ development. Collect LMZ primary and secondary water quality samples. Continue developing UMZ. Demobilizing drilling rig.
6/8/11	6/8/11	End UMZ development. Collect UMZ primary and secondary water quality samples. Install DZMW Wellhead.
6/10/11	6/12/11	Collected background data prior to Injection Test
6/12/11	6/12/11	Conducted 12-hour Injection Test
6/12/11	6/14/11	Collected Injection Test recovery data
6/14/11	6/14/11	Performed step drawdown test on Upper Monitor Zone
6/14/11	6/14/11	Performed Radioactive Tracer Survey
6/16/11	6/16/11	Collected final samples from pad monitor wells



Packer Test Summary

Packer Test No. 3
Interval: 1,594 – 1,635 ft bls
Pump Rate = 8.5 gpm
SC = 0.1 gpm/ft
Spec. Cond = 5,200 uS/cm

Packer Test No. 2
Interval: 1,719 – 1,760 ft bls
Pump Rate = 18 gpm
SC = 0.4 gpm/ft
Spec. Cond = 7,900 uS/cm

Packer Test No. 4
Interval: 1,809 – 1,850 ft bls
Pump Rate = 30 gpm
SC = 0.4 gpm/ft
Spec. Cond = 17,500 uS/cm

Packer Test No. 1
Interval: 1,879 – 1,945 ft bls
Pump Rate = 30 gpm
SC = 0.4 gpm/ft
Spec. Cond = 32,800 uS/cm

Packer Test No. 6
Interval: 1,993 – 2,012 ft bls
Pump Rate = 3 gpm
SC = 0.04 gpm/ft
Spec. Cond = 36,700 uS/cm

Packer Test No. 7
Interval: 2,013 – 2,030 ft bls
Pump Rate = 18 gpm
SC = 0.24 gpm/ft
Spec. Cond = 48,200 uS/cm

Packer Test No. 5
Interval: 2,197 – 2,214 ft bls
Pump Rate = 1.5 gpm
SC = 0.01 gpm/ft
Spec. Cond = 53,700 uS/cm

LEGEND
ft bls - feet below land surface
gpm/ft - gallons per minute/foot
SC - Specific Capacity
USDW – Underground Source of Drinking Water
OD – outside diameter
ID – inside diameter
FRP – fiberglass reinforced pipe

Spec. Cond. – Specific Conductance
uS/cm - microsiemons per centimeter

Figure 2-3 LCRSWDF IW-1 Schematic and Hydrogeologic Summary

The drilling of DZMW-1 proceeded generally as identified in the project specifications. Drilling activities are summarized in the outline below. The monitor zones depths were based on 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 generally constructed as follows:

- Drill a nominal 42-inch diameter borehole to approximately 205 feet bls using the mud rotary method.
- Set and cement in place 34-inch diameter steel pit casing to 200 feet bls.
- Drill a 12.25-inch diameter pilot hole to approximately 1,161 feet bls using the mud rotary method.
- Ream a nominal 32.5-inch diameter borehole to approximately 1140 feet bls using the mud rotary method.
- Set and cement in place 24-inch diameter steel casing to 1,135 feet bls.
- Drill a nominal 12.25-inch diameter borehole to approximately 2,080 feet bls using the reverse air method and core at selected depths.
- Back plug pilot hole with cement to 1,178 feet bls, upper and lower monitor zones filled with gravel.
- Ream a nominal 22-inch diameter borehole to approximately 1,815 feet bls using the reverse air method.
- Set and cement in place 16-inch diameter steel casing to 1,813 feet bls.
- Ream a 14.75-inch diameter borehole to approximately 2,005 feet bls using the reverse air method.
- Drill a 12.25-inch diameter borehole to approximately 2,080 feet bls using the reverse air method.
- Set and cement in place nominal 6.625-inch diameter fiberglass reinforced pipe FRP tubing to 2,022 feet bls using an external cementing packer, filling the annular space of the final casing with cement from 2,022 to 1,868 feet bls.

The upper monitor zone (UMZ) was established between 1,813 and 1,868 feet bls and the lower monitor zone (LMZ) between 2,015 and 2,080 feet bls. A summary of the DZMW-1 drilling and testing is presented in **Figure 2-4**. A summary of casing depths and materials used in the construction of IW-1 and DZMW-1 is presented in **Table 2-2.**

Table 2-2
Casing Summary

Casing	Diameter (Inches)		Casing Thickness (Inches)	Casing Material	Casing Depth (Feet)
	Inside	Outside			
Injection Well IW-1					
Pit	43.25	44.00	0.375	Steel	195
Surface	33.25	34.00	0.375	Steel	1,135
Intermediate	23.25	24	0.375	Steel	1,940
Final Casing	11.75	12.75	0.500	Steel	2,396
FRP Tubing	6.21	6.96	0.380	FRP	2,391
Total Depth					3,280
Dual-Zone Monitor Well DZMW-1					
Pit	33.25	34.00	0.375	Steel	200
Surface	23.25	24.00	0.375	Steel	1,135
Final Casing (Upper Monitor Zone)	15.00	16.00	0.500	Steel	1,813
FRP Tubing (Lower Monitor Zone)	5.43	5.97	0.270	FRP	2,022
Total Depth					2,080

2.4 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. which included the following: water quality analyses were performed by Sanders Laboratories and rock core analyses were performed by Ardaman & Associates, Inc.

Except where noted, depth measurements in the wells are referenced to land surface. The elevations of the IW-1 and DZMW-1 drilling pads were approximately 32 to 33 feet NGVD.

The Engineer and the Contractor prepared independent daily progress reports during well construction. In addition to recording daily drilling progress, the reports included the following:

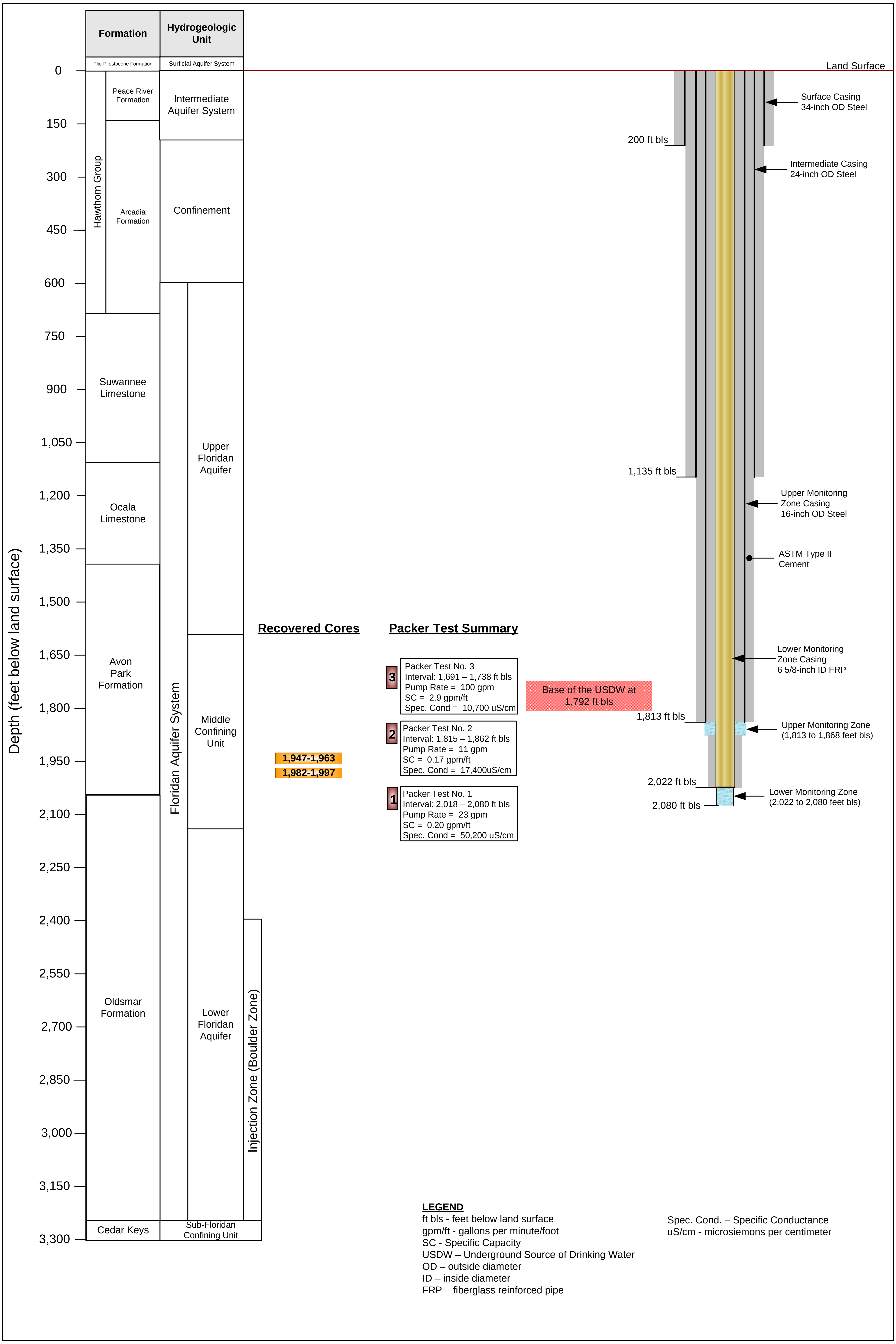


Figure 2-4 LCRSWDF DZMW Schematic and Hydrogeologic Summary

MWH
BUILDING A BETTER WORLD

- Pertinent drilling information such as weight on bit, penetration rates, and relative hardness of the formations,
- Problems encountered during drilling,
- Activities related to the installation of well casings, cementing activities and/or placement of other materials, and their quantities,
- Detailed descriptions of test procedures and data collection, and
- The length and configuration of tools introduced into the borehole.

Copies of the daily and weekly progress reports were transmitted to the TAC members on a weekly basis. Copies of the weekly reports are provided in **Appendix B**

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

2.5 GEOLOGIC SAMPLES

Samples of formation cuttings were collected and analyzed during the drilling of the injection well and dual zone 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. These logs are presented in **Appendix D**. Formation cuttings were bagged in 10-foot intervals and sent to the Florida Geological Survey in Tallahassee, Florida.

2.6 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 all coring activities. These cores were lithologically described onsite and select samples were sent to an independent laboratory for analysis. The results of the analyses are used herein 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 2-3.**

Table 2-3
Core Intervals

Core Number	Core Interval (feet bls)	Core Recovery (%)
Injection Well IW-1		
Core No. 1	1,678-1,688	66
Core No. 2	2,025-2,037	83
Core No. 3	2,102-2,114	71
Core No. 4	2,176-2,186	48
Core No. 5	2,230-2,240	90
Core No. 6	2,279-2,289	99
Core No. 7	2,416-2,426	69
Dual-Zone Monitor Well DZMW-1		
Core No. 1	1,946-1,963	74
Core No. 2	1,982-1,997	81

Samples were selected from the recovered cores and sent for analysis to an independent laboratory, Ardaman and Associates, Inc. These samples were tested for several parameters including vertical and horizontal permeability, porosity, and specific gravity. Core laboratory analysis results and geologic core descriptions are presented in **Appendix E**. A summary of the hydraulic conductivity from the laboratory analyses of the cores is presented in **Table 2-4**.

Table 2-4
Hydraulic Conductivity Derived From Cores

Core Sample Number	Tested Interval (feet bls.)	Vertical Hydraulic Conductivity (cm/sec)	Horizontal Hydraulic Conductivity (cm/sec)
Injection Well IW-1			
1A	1,679.7 – 1,680.2	5.6 x 10^{-8}	7.8 x 10^{-8}
2A	2,031.8 – 2,032.8	2.1 x 10^{-5}	5.1 x 10^{-5}
2B	2,032.3 – 2,033.0	8.6 x 10^{-5}	1.3 x 10^{-4}
2C	2,033.7 – 2,034.5	2.8 x 10^{-5}	7.2 x 10^{-5}
3A	2,104.0 – 2,104.5	5.3 x 10^{-4}	6.6 x 10^{-7}
5A	2,230.8 – 2,231.4	3.5 x 10^{-10}	2.4 x 10^{-10}
5B	2,231.4 – 2,231.9	1.7 x 10^{-6}	6.6 x 10^{-6}
5C	2,235.9 – 2,236.3	2.9 x 10^{-8}	8.6 x 10^{-6}
5D	2,236.7 – 2,237.1	1.4 x 10^{-6}	2.4 x 10^{-6}
6A	2,279.5 – 2,280.2	4.7 x 10^{-10}	2.4 x 10^{-11}
6B	2,280.7 – 2,281.8	1.5 x 10^{-10}	3.3 x 10^{-10}
6C	2,282.5 – 2,283.1	1.0 x 10^{-11}	7.4 x 10^{-11}
6D	2,284.0 – 2,284.6	7.1 x 10^{-5}	2.1 x 10^{-8}
6E	2,285.4 – 2,286.2	3.9 x 10^{-11}	1.3 x 10^{-6}
7A	2,416.1 – 2,416.8	7.8 x 10^{-12}	1.3 x 10^{-10}
7B	2,416.8 – 2,417.2	2.2 x 10^{-4}	1.8 x 10^{-10}
7C	2,420.5 – 2,421.3	3.9 x 10^{-10}	4.6 x 10^{-6}
7D	2,421.3 – 2,421.8	2.5 x 10^{-10}	2.2 x 10^{-6}
7E	2,423.1 – 2,423.8	5.4 x 10^{-8}	Not Reported
Dual-Zone Monitor Well DZMW-1			
1A	1,950.6 – 1,951.6	1.9 x 10^{-5}	2.5 x 10^{-5}
1B	1,957.0 – 1,957.6	8.1 x 10^{-6}	5.3x 10^{-6}
1C	1,958.1 – 1,958.8	2.9 x 10^{-5}	2.8 x 10^{-5}
2A	1,984.6 – 1,985.2	9.8 x 10^{-6}	1.2 x 10^{-5}
2B	1,986.6 – 1,987.3	3.6 x 10^{-11}	6.7 x 10^{-11}
2C	1,991.9 – 1,992.8	5.8 x 10^{-6}	2.5 x 10^{-5}

2.7 GEOPHYSICAL LOGS

Geophysical logging of the borehole was completed at the completion of each stage of drilling. The purpose of these logs was to assist in casing seat selection, identify potential confining sequences and flow zones and track water quality and lithologic changes. The geophysical logs performed and a brief description of the information provided by each logging tool, is as follows:

X-Y Caliper - The XY Caliper log measures the diameter of a borehole in two planes perpendicular to each other. The caliper log can provide information on structural features of a lithology, the consistency of the borehole diameter, washouts, swelling clays, and rock obstructions. Secondary porosity features, such as fractures and solution features may be apparent on the caliper log. This log may also provide information concerning the general mechanical strength of the formation.

Gamma Ray - The gamma ray log measures natural gamma radiation produced by the decay of uranium daughter products in formation material. Rock formations that typically contain these products include clay and phosphate. These components are important to identifying geologic formations, and yield information about the origins of formational layers.

Dual Induction Log – The dual induction log is used to measure the electrical properties of the formation. The electrical resistivity of the formation is affected by the formation porosity and water chemistry. These logs give important information concerning the water quality in the formation (particularly the transition found at the base of the USDW), porosity of the formation, water producing, and confining zones, and mixing of formation water with drilling fluid in the borehole. The log consists of three resistivity traces:

Deep Resistivity (ILD): Measures resistivity of the formation material with a wide receiver spacing that penetrates deep into the formation.

Medium Resistivity (ILM): Measures resistivity of the formation with a medium receiver spacing that examines the formation material close to the borehole, where drilling fluids may have invaded the formation.

Shallow Resistivity (LL3): This log reads the lateral resistivity with closely spaced electrodes that measure resistivity primarily within the borehole and on the borehole wall.

Borehole Compensated Sonic (BHCS) Variable Density Log (VDL) - The BHCS log uses sonic pulses to determine competency of the borehole. This log is strongly affected by porosity and the mechanical strength of the formation. The more porous the borehole wall, the slower the travel time of the acoustic signal.

The VDL provides a visual representation of the borehole along with important information about fractures and solution features.

Flow Meter Surveys - The fluid velocity log measures the rate of fluid movement in the borehole. The flowmeter can detect "cross-flow" or water moving from one aquifer to another due to pressure differentials, as well as, identify producing intervals when the well is being pumped.

Temperature - The temperature log measures the temperature of the fluid that fills the borehole. The log is used to measure characteristics of the formation fluid under static and dynamic flow conditions, and provides information about the movement of the fluids within the borehole, along with the source of fluids.

Digital Borehole Televiewer (BHTV) - A digital borehole televiewer produces a 360 degree ultrasonic image from measurement of the acoustic properties around the borehole wall. This log is similar to the BHCS log, but has a much higher frequency of measurement with more complete coverage of the circumference of the borehole. Due to the high resolution of this tool, it can be used to identify bedding and fractures.

Cement Top Temperature - Verification of the annular space fill-up after each cementing stage.

Cement Bond Log - This log detects potential voids in the grout sheath around the casing by measuring the acoustic properties of the cemented casing. The CBL aids in the determination of the external mechanical integrity of the well, and provides an indication of the quality of the hydraulic seal between the final casing and the well bore. The cement bond log (CBL) records amplitude, in millivolts (mV), of the first arrival of a wave signal at a 3-foot receiver created by a calibrated, 1,000 mV output signal. Amplitude is at a maximum in unsupported pipe and a minimum in well-cemented casing. The amplitude is a function of the attenuation of the transmitted signal due to the coupling of cement to casing. Attenuation rates depend on the cement compressive strength, the casing diameter, casing thickness, and the degree of cement bonding.

During the geophysical logging and testing of each well, 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 F.**

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 in **Appendix F.**

2.7.1 Injection Well (IW-1) Geophysical Logging Program

Geophysical logs were conducted for each stage of drilling (200 to 1,150 feet bls; 1,150 to 1,945 feet bls; and 1,940 to 3,280 feet bls) of IW-1. **Table 2-5** summarizes the geophysical logging sequence for IW-1. On December 8, 2010, prior to reaming and setting the 34-inch outer diameter (OD) surface casing to 1,135 feet bls in IW-1, a suite of geophysical logs was conducted, as described in **Table 2-5**. The caliper log showed the borehole diameter to be variable from 12.5 to 14 inches over the depth interval between 195 and 380 feet bls. This interval corresponded with minor gamma ray activity indicating transition from the Plio-Pleistocene sediments into the Hawthorn group clays. Gamma ray activity was observed from approximately 300 to 700 feet bls.

From 380 to 1,150 feet bls the pilot hole was generally consistent in size averaging between 12.5 and 13 inches indicating a good casing seat at 1,135 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 1,135 feet bls. On December 28, 2010, prior to reaming and setting the 24-inch diameter intermediate casing to 1,940 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.

Table 2-5
Summary of IW-1 Geophysical Logging

Date	Borehole Diameter (inches)	Logging Interval (feet bls)	Logging Suite	Purpose
12/8/10	12.25	195 – 1,150	SP/DIL, GR, XYC	Select the surface casing setting depth
12/18/10	42.5	195 – 1,139	XYC, GR	Estimate borehole volume
12/28/10	12.25	1,135 – 1,945	**S:** FCL, FT, SP/DIL, GR, XYC, BHCS/ VDL, FMS, LDTDS; **D:** FCL, FT, FMS, BHTV	Locate the base of the USDW, examine water quality, select packer test intervals and identify the intermediate casing depth
1/13/11	32.5	1,135 – 1,945	XYC, GR	Estimate borehole volume
1/16/11	24-inch Casing	0-1,940	FT	Determine cement top of each cementing stage
2/17/11	12.25	1,940 – 2,842	**S:** FCL, FT, SP/DIL, GR, XYC, BHCS/ VDL, FMS, LDTDS; **D:** FCL, FT, FMS, VS	Examine water quality, select packer test intervals, determine the final casing depth and identify the injection zone interval
3/17/11-3/18/11	14.75	1,940 – 3,280	**S:** FCL, FT, SP/DIL, GR, XYC, BHCS/ VDL, FMS, LDTDS; **D:** FCL, FT, FMS, VS	Examine water quality, select packer test intervals, determine the final casing depth and identify the injection zone interval
3/27/11	22.5/14.75	1,940 – 3,050	XYC, GR	Estimate borehole volume
4/5/11	12-inch Casing	0-1,940	FT	Determine cement top of each cementing stage
4/6/11	12-inch Casing	0-1,940	CBL	Determine quality of cement bond
4/11/11	12-inch Casing	0 – 2,389	VS	Final casing observation
5/17/11	7-inch FRP Tubing	0 - 3,045	VS	Completed well observation
6/14/11	7-inch FRP Tubing	0 - 3,054	XYC, RTS, HRT	Mechanical Integrity Testing

Abbreviations for Geophysical Logs:

BHCS = Borehole Compensated Sonic
BHTV = Digital Borehole Televiewer
CBL = Cement Bond Log
DIL = Dual Induction Log
D= Dynamic (pumping)
S= Static
RTS = Radioactive Tracer Survey
FCL = Fluid Conductivity Log
FT = Fluid Temperature
FMS = Flowmeter Survey
GR = Gamma Ray
HRT = High resolution Temperature Log
LDTDS = Log Derived TDS
SP = Spontaneous Potential
VDL = Variable Density Log
VS = Video Survey
XYC = Caliper

The caliper log indicated a pilot hole diameter of between approximately 12.0 and 12.6 inches from the bottom of the surficial casing to a depth of about 1,945 feet bls indicating a competent limestone over this interval.

The DIL shows that a gradual decrease in electrical resistivity exists below 1,710 feet bls. The gradual decrease in electrical resistivity also indicates an increase in specific conductance related to an increase in salinity.

The borehole compensated sonic porosity and VDL log indicates a moderately to well indurated dense lithology which exhibits horizontal areas of less consolidated sediments or erosion plains from 1,135 to 1,945 feet bls. The BHTV log compares well with the lithologic descriptions. Comparatively higher density responses correspond to dense limestone.

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 increasingly saline water quality gradient with depth indicated by decreasing resistivity values in the geophysical logs. This type of a gradient is indicative of 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 approximately 1,810 feet bls in IW-1. The log derived TDS plot for well IW-1 is presented in **Figure 2-5**

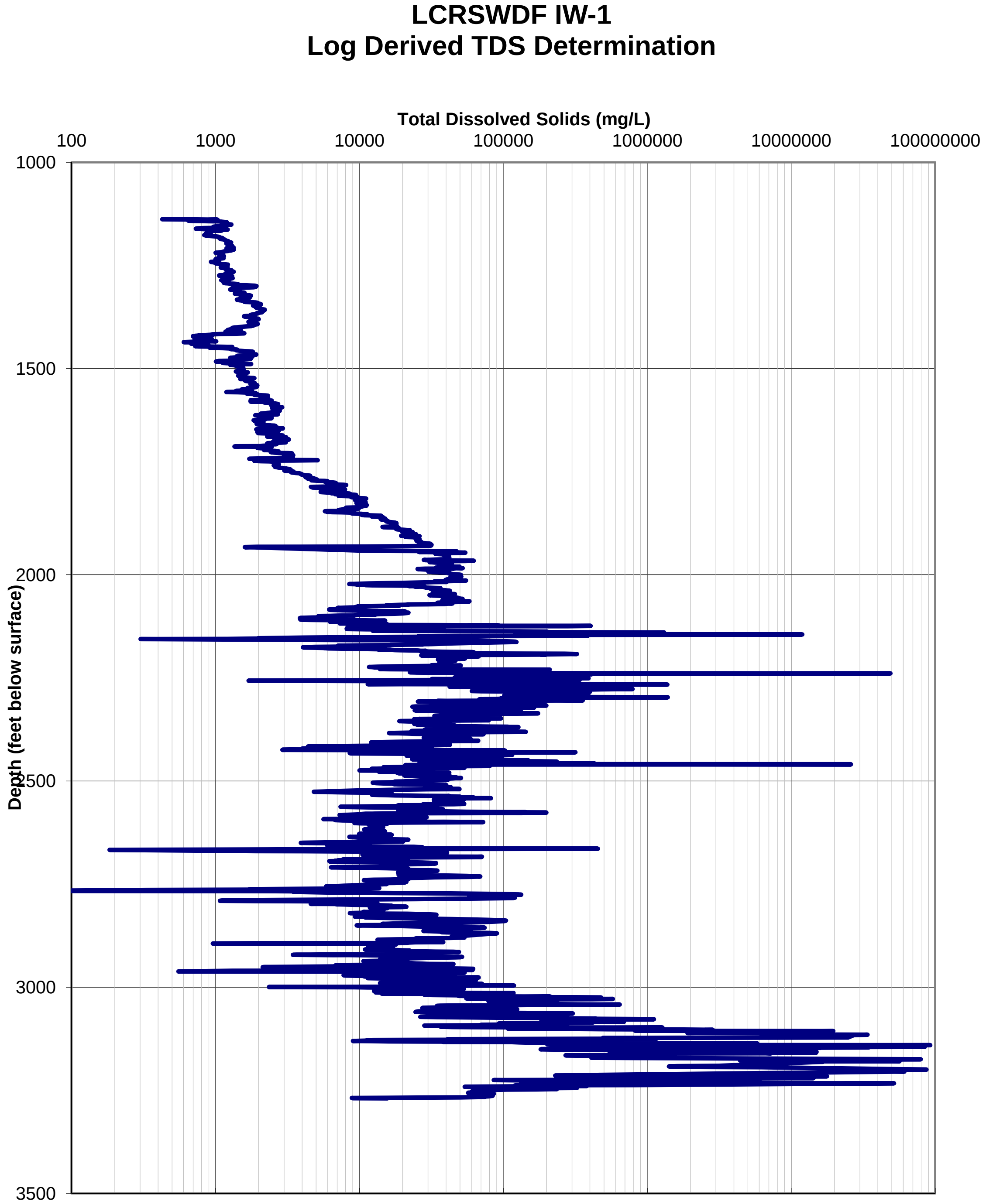


Figure 2-5
IW-1 Log Derived TDS Plot

After setting and cementing the 24-inch OD intermediate casing to 1,940 feet bls, the 12.25-inch diameter pilot hole was advanced from the bottom of the intermediate casing to 3,280 feet bls. On February 16 and 17, 2011, geophysical logging was conducted in the 12.25-inch diameter pilot hole from 1,945 to 2,842 feet bls where the pilot hole was blocked. The pilot hole was reamed out to a nominal 14.75-inch diameter and a second set of geophysical logs were run on March 17 and 18 2011, from 1,940 to 3,280 feet bls. After reaming the borehole to a nominal diameter of 22 inches and prior to setting the 12.75-inch OD final casing to 2,396 feet bls in IW-1, logs were conducted to identify confining units, receiving intervals, and to aid in the casing seat determination.

A generally gauge borehole is indicated on the XY caliper log over the intervals of 1,950 feet to 2,070 feet bls, 2,084 feet to 2,096 feet bls, 2,130 feet to 2,150 feet bls, 2,170 feet to 2,220 feet bls, 2,240 feet to 2,254 feet bls, and 2,264 feet to 2,400 feet bls.

The BHCS VDL shows reflections from 2,268 feet to 2,400 feet bls indicative of a moderately dense dolomite, with travel times ranging from 60 to 80 µsec/ft. Transit times less than 60 µsec/ft are present in the intervals from 2,132 to 2,150 feet, 2,230 to 2,256 feet, and 2,264 to 2,333 feet bls, for a total of 113 feet. A transit time of less than 60 µsec/ft is indicative of dense, low permeability dolomite. Consistent parallel reflections on the VDL track were most notable from 1,980 to 2,012 feet bls, 2,196 to 2,216 feet bls, and 2,388 to 2,396 feet bls

The static up/down flowmeter log appears to indicate that flow begins moving downward from approximately 2,160 feet bls in the borehole. This zone appears to contribute most of the flow in the borehole. Flow downward stops under static conditions at a depth of approximately 2,870 feet bls. Permeable zones below 2,160 feet bls are present, but do not appear to contribute to the overall flow in the borehole due to the higher salinity (i.e. higher specific gravity) of the water in these zones.

2.7.2 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 2-6** summarizes the geophysical logging sequence for DZMW-1.

Table 2-6
Summary of DZMW-1 Geophysical Logging Program

Date	Borehole Diameter (inches)	Logging Interval (feet bls)	Logging Suite	Purpose
4/22/11	12.25	200 – 1,161	SP/DIL, GR, XYC	Select the surface casing setting depth
4/28/11	32	200 – 1,140	XYC, GR	Estimate borehole volume
5/6/11	12.25	1,135 – 2,080	**S:** FCL, FT, SP/DIL, GR, XYC, BHCS/ VDL, FMS, LDTDS; **D:** FCL, FT, FMS	Locate the base of the USDW, examine water quality, select packer test intervals and identify the upper and lower monitor zones
5/8/11-5/11/11	12.25	1,135 – 2,080	VS	Identify the upper and lower monitor zones
5/25/11	22	1,020 – 1,815	XYC, GR	Estimate borehole volume
5/27/11	16-inch Casing		FT	Determine cement top of each cementing stage
5/28/11	16-inch Casing	0 – 1,813	CBL	Determine quality of cement bond
6/1/11	14.75	1,793 – 2,080	XYC, GR	Estimate borehole volume
6/1/11	6-inch FRP Casing	0 – 2,022	CBL	Establish baseline before cementing FRP casing
6/3/11	6-inch FRP Casing	0 – 2022	FT	Determine cement top of each cementing stage
6/4/11	6-inch FRP Casing	0 – 2,000	CBL	Determine quality of cement bond

Abbreviations for Geophysical Logs:

BHCS = Borehole Compensated Sonic
BHTV = Digital Borehole Televiewer
CBL = Cement Bond Log
DIL = Dual Induction Log
FCL = Fluid Conductivity Log
FT = Fluid Temperature
FMS = Flowmeter Survey
GR = Gamma Ray
HRT = High resolution Temperature Log
LDTDS = Log Derived TDS
RTS = Radioactive Tracer Survey
SP = Spontaneous Potential
VDL = Variable Density Log
VS = Video Survey
XYC = Caliper

D= Dynamic (pumping)
S= Static

On April 22, 2011, after the pilot hole was advanced to 1,161 feet bls, a suite of geophysical logs was conducted to confirm a mechanically secure casing setting depth in conjunction with the lithologic log of the borehole. The 24-inch diameter casing was set to 1,135 feet bls.

After setting and cementing the surface casing to 1,134 feet bls, the 12.25-inch diameter pilot hole was advanced to 2,080 feet bls. Between March 8 and March 11 2011, prior to reaming the pilot hole and setting the 16-inch diameter intermediate casing to 1,813 feet bls in DZMW-1, geophysical logs were conducted to identify confining units, flow zones, and to aid in the casing seat determinations

The caliper log shows a borehole with a diameter generally between 13 and 15 inches , with the exception of the interval between approximately 1,500 and 1,580 feet bls, which has a 15 to 17-inch diameter borehole. From 1,630 to 1,725 feet bls the borehole diameter is very nearly gauge hole at approximately 13 inches. The caliper log shows a maximum diameter of approximately 19 inches at a depth of 1,730 feet bls, which is a cavern feature that is approximately 8 feet thick. Between 1,870 and 2,015 feet bls the borehole is relatively gauge having a diameter of 14 inches or less, and the borehole diameter narrows with depth to 13 inches at 2,000 feet bls.

The borehole compensated sonic porosity log and variable density log indicate a moderately to very dense lithology from approximately 1,600 to 1,800 feet bls. These factors indicate that the formation from 1,134 to 1,815 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 borehole compensated sonic porosity log and variable density log indicate a moderate to dense lithology from 1,870 to 2,015 feet bls, with very dense beds between 1,990 and 2,005 feet bls.

The dual induction log was also used to identify an increasingly saline water quality gradient with depth indicated by decreasing resistivity values in the geophysical logs. This type of a gradient is indicative of the base of the USDW in southern Florida. The Sonic Porosity and Dual Induction logs were used to calculate a log-derived 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 approximately 1,735feet bls in DZMW-1. The DZMW-1 log derived TDS plot is presented in **Figure 2-6.**

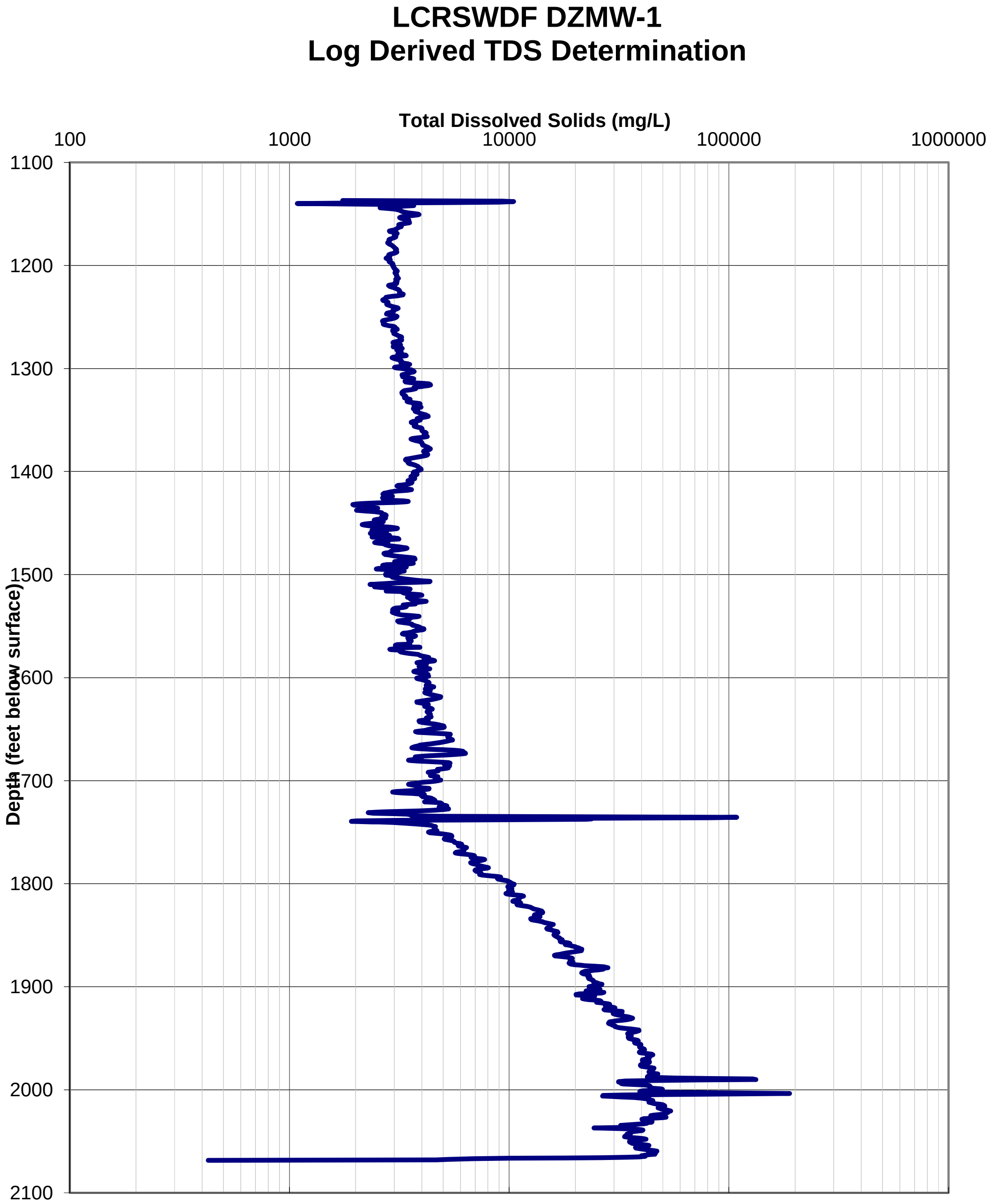


Figure 2-6
DZMW-1 Log Derived TDS Plot

2.8 PILOT HOLE WATER QUALITY

Water quality samples were collected at 45-foot intervals in IW-1 and DZMW-1 during reverse air drilling. Sampling started at a depth of 1,172 in IW-1 and DZMW-1, and continued to the total depth in both wells. Samples were collected from the fluid circulation system discharge point. The samples were field analyzed for temperature, pH, specific conductivity, and chloride. These data were used as an indication of the depth base of the USDW and the injection zone. For samples analyzed in the field, TDS was calculated from the specific conductivity data.

Reverse air drilling was conducted in a closed system to contain the fluids generated from the well drilling operations. In the closed circulation system, the water discharged from the pilot hole was a mixture of formation water from the entire open borehole; not the discrete interval penetrated. As such, the water quality measurements are not a quantitative representation of the formation fluids at the sampled interval. However, samples from reverse circulation drilling may provide an indication of relative water quality trends versus depth. Pilot hole water quality results for IW-1 and DZMW-1 are presented in **Appendix G**.

2.9 VIDEO SURVEYS

As shown on **Table 2-5**, a video survey was conducted and recorded in the injection well 12.25-inch diameter pilot hole from 1,940 to 2,842 feet bls, in the 14.75-inch diameter pilot hole from 1,940 to 3,276 feet bls, and in the nominal 7-inch diameter final FRP tubing from land surface through the open hole to a depth of 3,045 feet bls. As shown on **Table 2-6**, a video survey was also performed on the dual–zone monitoring well 12.25-inch pilot hole from 1,135 to 2,075 feet bls. Color video surveys were generally 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 dual zone monitor well are presented in **Appendix H**. A DVD copy of each video survey is located at the end of the report.

2.10 SPECIFIC CAPACITY TESTING

Specific capacity testing was conducted during pilot hole drilling. The short specific capacity tests were conducted every 90 feet while drilling with reverse air circulation. Specific capacity tests were conducted in IW-1 from 1,172 to 2,837 feet bls where they were discontinued through the boulder zone and in DZMW-1 from 1,172 to 2,080 feet bls. A manometer attached to a valve assembly on the temporary wellhead was utilized to observe and record positive head water level measurements during specific capacity testing. The static water level was recorded prior to beginning each test. The pumping rate, duration, and drawdown during pumping were also recorded. The specific capacity testing plots for IW-1 and DZMW-1 are presented in **Appendix I.**

2.11 PACKER TESTS

Single and straddle packer tests were performed within the pilot hole of the injection well and dual-zone monitor well at select intervals to support demonstration of confinement, determine water quality, or identify potential monitoring zones. The straddle packer intervals were selected based on information from geophysical logs, lithology, cores, video surveys, and other packer tests. Typical procedure included either one inflatable element (Single Packer) or two inflatable elements (Straddle Packer) set within the borehole to isolate a depth interval from which to collect discrete formation water samples and perform drawdown and recovery tests. One single and six straddle packer tests were performed in IW-1. The single packer test along with two of the straddle packer tests performed in the injection well aided in determination of the base of the USDW. The other four straddle packer tests performed in the injection well identified potential productive zones for monitoring or zones where confinement might exist. Three straddle packer tests were performed in DZMW-1. The packer tests performed in DZMW-1 aided in determining the base of the USDW and selecting the upper and lower monitor zones.

The packers were lowered into the pilot hole to the selected interval on 7.625-inch OD drill pipe, inflated, and seated against the formation. A submersible pump was lowered into the drill pipe and used 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 monitored water quality parameters stabilized. The isolated zone was then allowed to recover from development before beginning the pumping test. During background, drawdown and recovery tests, water level measurements were recorded using pressure transducers set inside the drill pipe and in the annular space outside the drill pipe. Transducers were attached to a data logger unit (In-situ Hermit 3000) through which water levels were monitored and recorded. 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 methods of analysis used on the data collected and recorded during the IW-1 packer tests were the Theis (1935) straight-line residual drawdown/recovery method for a confined aquifer, Cooper-Jacob (1946) straight-line method for a confined aquifer, and Hantush (1960) early-time solution method for semi-confined aquifers with aquitard storage. For the DZMW-1 packer tests the methods of analysis used on the data collected and recorded during the IW-1 packer tests were the Moench (1985) constant head method for a leaky confined aquifer, Cooper-Jacob (1946) straight-line method for a confined aquifer, and Hantush (1960) early-time solution method for semi-confined aquifers with aquitard storage. 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. Aqtesolv software was used to facilitate the interpretation of the data. The transmissivities calculated from the packer test data are presented for each analytical method in **Table 2-7.** The packer test data plots generated from the Aqtesolv software are presented in **Appendix J.** The raw packer test data are also included in **Appendix J** 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 development phase of the packer tests were analyzed in the field for temperature, chloride, and specific conductance. Additional water samples were collected at the end of the drawdown (pumping) phase of the packer test and sent to an independent laboratory for analysis. The samples were analyzed and laboratory reports are presented in **Appendix K.** A summary of the packer test water quality data is presented in **Table 2-8.** The log derived Total

Dissolved Solids water quality graphs show good correlation compared to the packer test water quality test results.

Table 2-7
Transmissivity Derived From Packer Tests

Packer Test Interval (feet bls)	Pump Rate (gpm)	Maximum Drawdown (feet)	Transmissivity (gal/day/ft)			
			Theis	Cooper-Jacob	Hantush	Average
Injection Well IW-1						
1,594 to 1,635 Packer Test 3	8.5	158.0	17.5	17.5	9.8	14.9
1,719 to 1,759 Packer Test 2	18	144.9	33.6	48.8	21.5	34.6
1,809 to 1,850 Packer Test 4	29	77.3	149.9	96.0	204..4	150.1
1,879 to 1,945 Packer Test 1	30	74.5	126.7	142.5	18.8	96.0
1,993 to 2,012 Packer Test 6	3	70.0	13.2	13.2	11.1	12.5
2,013 to 2,030 Packer Test 7	18	82.3	66.6	69.3	57.7	64.5
2,197 to 2,214 Packer Test 5	1.5	102.5	4.1	4.1	3.3	3.8
Dual-Zone Monitor Well DZMW-1						
Packer Test Interval (feet bls)	**Pump Rate (gpm)**	**Maximum Drawdown (feet)**	**Transmissivity (feet²/day)**			
			Moench	**Cooper-Jacob**	**Hantush**	**Average**
1,691 to 1,738 Packer Test 3	100	34	6,172	6,600	5,545	6,106
1,815 to 1,862 Packer Test 2	11	66	66	56	75	66
2,018 to 2,080 Packer Test 1	23	114	151	78	151	81

Table 2-8
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							
1,594 to 1,635 Packer Test 3	5,160	1,460	2,970	0.29	0.48	713	7.8
1,719 to 1,759 Packer Test 2	7,910	2,300	4,250	0.41	0.64	1,010	7.2
1,809 to 1,850 Packer Test 4	17,500	5,000	10,700	0.67	0.82	1,820	7.6
1,879 to 1,945 Packer Test 1	31,000	11,400	19,200	0.72	1.06	2,940	7.7
1,993 to 2,012 Packer Test 6	36,300	13,200	27,700	0.16	0.91	1,970	7.1
2,013 to 2,030 Packer Test 7	45,400	18,500	32,000	0.71	0.76	3,710	7.15
2,197 to 2,214 Packer Test 5	53,000	19,100	40,900	0.96	2.05	3,100	7.0
Dual-Zone Monitor Well DZMW-1							
1,691 to 1,738 Packer Test 3	10,700	4,720	7,500	0.14	1.15	973	7.61
1,815 to 1,862 Packer Test 2	17,400	7,500	10,400	0.28	0.66	1,460	7.41
2,018 to 2,080 Packer Test 1	50,200	21,500	34,700	0.33	1.40	3,080	7.20

2.12 CASING INSTALLATION AND TESTING

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. The cementing of the IW-1 and DZMW-1 casings are described below. A summary of cementing of the IW-1 and DZMW-1 casings is presented in **Table 2-9**

Table 2-9
Summary of Casing Cementing

Date	Stage	Cement Type	Volume Pumped (cubic feet)	Theoretical Fill (feet bls)	Tag Depth (feet bls)	Percent Fill	Cumulative Total (cubic feet)
Injection Well IW-1 44-inch Casing							
12/3/10	1	neat	712.5	0 -199	0	100%	712.5
Injection Well IW-1 34-inch Casing							
12/19/10	1	neat	791.0	1,135-935	na	100%	791.1
12/19/10	1	6% gel	3,382.8	935-0	0	100%	4,173.8
Injection Well IW-1 24-inch Casing%							
1/14/11	1	Neat	841.5	1,940-1,656	1,737	71%	841.5
1/15/11	2	6% gel	1,464.2	1,737- 1,218	1,371	71%	2,305.7
1/15/11	3	12% gel	1,464.2	1371-851	923	86%	3,769.9
1/15/11	4	12% gel	1,329.6	923-461	464	99%	5,099.5
1/16/11	5	12% gel	1,374.5	461-0	50	100%	6,473.9
Injection Well IW-1 12-inch Casing							
4/1/11	Shot 1	neat 50 lb CaCl	28.1	2,393-2,379	2385	60.0%	28.1
4/1/11	Shot 2	neat 100 lb CaCl	50.5	2,385-2,360	2360	100.0%	78.5
4/2/11	1	neat	392.7	2,360-2,174	2,260	51.4%	471.2
4/2/11	2	neat	297.3	2,260-2,144	2,209	41.5%	768.6
4/2/11	3	neat	280.5	2,209-2,096	2,161	44.0%	1,049.1
4/3/11	4	6% gel	673.2	2,161-1,885	2,160	0.8%	1,722.3
4/3/11	5	neat 133 lb CaCl	56.1	2,160-2,139	2,159.5	5.0%	1,778.4
4/3/11	Shot 6	neat CaCl	56.1	2,159-2,138	2,159.5	0.0%	1,834.5
4/4/11	Shot 7	neat 3% CaCl	53.3	2,159-2,140	2,159.3	2.6%	1,887.8
4/4/11	Shot 8	12% gel 3% CaCl	48.8	2,159-2,140	2,159	1.1%	1,936.6
4/4/11	-	Gravel	67.3	2,159-2,130	2,150	33.3%	2,003.9
4/4/11	Shot 9	neat 3% CaCl	56.1	2,150-2,126	2,129	90.0%	2,060.0
4/4/11	10	6% gel	561.0	2,129-1,898	2,096	13.0%	2,621.0

Table 2-9 (Continued)
Summary of Casing Cementing

Date	Stage	Cement Type	Volume Pumped (cubic feet)	Theoretical Fill (feet bls)	Tag Depth (feet bls)	Percent Fill	Cumulative Total (cubic feet)
Injection Well IW-1 12-inch Casing (Continued)							
4/5/11	11	6% gel	572.2	2,096-1,860	1,912	82.7%	3,193.2
4/5/11	12	12% gel	3,607.2	1912-200	242	103.9%	6,800.4
5/17/11	13	12% gel	525.7	242-0	2	94.7%	7,326.1
Dual-Zone Monitor Well DZMW-1 34-inch Casing							
4/18/11	1	12% gel	813.5	200-0	0	100.0%	813.5
Dual-Zone Monitor Well DZMW-1 24-inch Casing							
4/29/11	1	neat and 6% gel	3,035.0	1,140-0	0	100.0%	3,035.0
Dual-Zone Monitor Well DZMW-1 16-inch Casing							
5/26/11	1	neat	600.3	1,815-1,440	1,495	81.3%	600.3
5/27/11	2	6% gel	841.5	1,495-990	1,090	80.0%	1,441.8
5/27/11	3	12% gel	1,318.4	1,090-250	234	100.0%	2,760.1
6/5/11	4	12% gel	319.8	241-0	0	100.0%	3,079.9
Dual-Zone Monitor Well DZMW-1 Nominal 6-inch Casing							
6/2/11	Shot 1	3% CaCl	9.8	2,015-1,998	2,000	85.7%	9.8
6/2/11	Shot 2	3% CaCl	11.2	2,000-1,990	1,990	100.0%	21.0
6/2/11	1	3% CaCl	140.3	1,990-1,875	1,885	90.0%	161.3
6/3/11	2	neat	14.0	1,885-1,873	1,868	120.0%	175.3

- The IW-1 44-inch casing was cemented in one stage. The casing was pressure grouted and the cement was circulated to surface and was visually confirmed.
- The IW-1 34-inch casing was cemented in one stage. The casing was pressure grouted with 3,383 cubic feet of 6 percent gel followed by 791 cubic feet of neat cement. The cement was circulated to surface and was visually confirmed.
- The IW-1 24-inch casing was cemented in five stages. For the first stage the casing was pressure grouted with 841 cubic feet of neat cement. The following four stages were pumped using a tremi pipe placed in the annular space. After each stage a temperature log was conducted and the cement physically tagged to determine the actual fill. On the final stage the cement was circulated to surface and was visually confirmed. The difference in the theoretical and actual volume

pumped is due to caliper tool's limitations, loss of cement to the formation, and small irregularities in the borehole wall.

- The IW-1 12-inch casing was cemented in 13 stages. All stages were pumped using a tremi pipe placed in the annular space. The first stage consisting of 393 cubic feet of neat cement was pumped after two small shots of neat cement with calcium chloride were pumped in order to set the tri-seal cementing basket. After each stage a temperature log was conducted and the cement physically tagged to determine the actual fill. Due to high losses of cement to the formation, the interval from 2,159 to 2,130 feet bls was filled with gravel followed by additional cementing stages. On the final stage the cement was circulated to surface and was visually confirmed. The difference in the theoretical and actual volume pumped is due to caliper tool's limitations, loss of cement to the formation, and small irregularities in the borehole wall.
- The DZMW-1 34-inch casing was cemented in one stage. The casing was pressure grouted and the cement was circulated to surface and was visually confirmed.
- The DZMW-1 24-inch casing was cemented in one stage. The casing was pressure grouted and the cement was circulated to surface and was visually confirmed.
- The DZMW-1 16-inch casing was cemented in four stages. For the first stage, the casing was pressure grouted with 600 cubic feet of neat cement. The following three stages were pumped using a tremi pipe placed in the annular space. After each stage a temperature log was conducted and the cement physically tagged to determine the actual fill. On the final stage the cement was circulated to surface and was visually confirmed. The difference in the theoretical and actual volume pumped is due to caliper tool's limitations, loss of cement to the formation, and small irregularities in the borehole wall.
- The DZMW-1 6-inch casing was cemented in 4 stages. All stages were pumped using a tremi placed in the annular space. The first stage consisting of 140 cubic feet of neat cement was pumped after two small shots of neat cement with calcium chloride were pumped in order to set the California Packer cementing assembly. After each stage a temperature log was conducted and the cement

physically tagged to determine the actual fill. The difference in the theoretical and actual volume pumped is due to caliper tool's limitations, loss of cement to the formation, and small irregularities in the borehole wall.

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 5.97-inch casings were pressure tested as described below. The 12.75-inch OD final casing and 6.96-inch OD tubing in IW-1 were pressure tested as part of the demonstration of mechanical integrity as described in Section 4, Final Testing.

On May 29, 2011, the DZMW-1 16-inch casing was internally pressurized to 52.5 psi. A pressure decrease of 1.0 psi was observed over the 60-minute test period. This pressure decrease represents a 0.5 percent change in the original pressure, which is within the allowable change of 5.0 percent. A copy of the test gauge certification records and certified results of the hydrostatic pressure test are contained in **Appendix N**.

On June 4, 2011, the DZMW-1 5.97-inch OD FRP tubing was internally pressurized to 56.0 psi. A pressure decrease of 0.1 psi was observed over the 60-minute test period. This increase represents a 0.2 percent change in the original pressure, which is within the allowable change of 5.0 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.

A Cement Bond Log (CBL) was performed in the injection well 12-inch diameter casing on April 6, 2011. The cement bond log conducted in IW-1 demonstrated that there is a good cement seal around the 12-inch diameter casing and that there are no channels or conduits that would allow fluid movement adjacent to the casing.

Cement Bond Logs were performed in the dual-zone monitor well on the 16-inch casing on May 28, 2011. On June 2, 2011, a cement bond log was performed in the DZMW FRP tubing before cementing the casing in place. An after cementing CBL was conducted on the 6-inch FRP casing on June 4, 2011. The change in amplitude between the before cementing and after cementing bond logs demonstrates that there is a good cement seal around the 6-inch diameter casing between the upper and lower monitor zones 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 1,813 and 1,868 feet bls and the lower monitor zone between 2,022 and 2,080 feet bls. An as-built profile of DZMW-1 is presented in **Figure 2-4**.

2.14.1 Selection of the Upper Monitor Zone

The Upper Monitor Zone (UMZ), located from 1,813 and 1,868 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 1,815 to1,862 feet bls in DZMW-1 was conducted at

11 gpm with a drawdown of 66 feet. Water quality analysis of the sample taken from the packer test of the UMZ in DZMW-1 resulted in a TDS concentration of 10,400 mg/L (**Table 2-8**).

2.14.2 Selection of the Lower Monitor Zone

The Lower Monitor Zone (LMZ), located from 2,022 to 2,080 feet bls, was selected based on the criterion of being the lower most productive interval above the confining intervals. Packer testing of the interval from 2,018 to 2,080 feet bls in DZMW-1 was conducted at 23 gpm with a drawdown of 114 feet. Water quality analysis of the sample taken from the packer test of the LMZ in DZMW-1 resulted in a TDS concentration of 34,700 mg/L (**Table 2-8**).

Section 3
Geology and Hydrogeology

3.1 REGIONAL GEOLOGIC SETTING

The geology and hydrology of Lee and Hendry Counties has been described in reports by the Florida Geologic Survey (Klein, 1972, Missimer and Scott, 2001), the South Florida Water Management District (Wedderburn et al, 1982), and by various authors and consultants. References noted on this Section are defined in Section 7. Information on the regional geology and hydrology are included to provide a framework for understanding the local hydrologic conditions encountered while drilling IW-1. The stratigraphic terminology used in this section conforms to that used in Bulletin 59 (Scott, 1988) and Special Publication No. 49 (Missimer and Scott, 2001). Hydrostratigraphic nomenclature generally follows that of the Florida Geological Survey Special Publication 28.

The State of Florida lies on the Florida Platform on the southeastern edge of the North American continent. The platform extends 400 miles north to south and nearly 400 miles east to west at its widest point. More than half of the platform is presently under water, leaving a narrow peninsula of land extending from the mainland. The major subsurface structural element in the region is the South Florida Shelf (Applin and Applin, 1965). Applin and Applin describe the shelf as a relatively flat area in the Comanche Rocks (Cretaceous) which, “trends S 45° E, extends nearly 200 miles across the peninsula from Charlotte County on the Gulf Coast to Key Largo, Monroe County, on the Atlantic Coast”. The elevation of the top of this feature is approximately -8,500 feet NAVD throughout Lee County. A nearly 5,000-foot thick sequence of primarily middle Mesozoic to recent carbonate rocks forms the Florida Platform in southern Florida (Miller, 1986). These rocks are composed of carbonates, with lesser amounts of evaporites in the lower part and siliciclastics in the upper part (Reese, 2000).

A description of the geologic formations, aquifers and confining units encountered during construction of the injection well system is provided below. The general stratigraphy and hydrostratigraphy of the site are shown in **Figure 3-1**. As part of the construction permit application process, data was compiled from previous injection well projects to determine the anticipated depths of the geologic formations that should be encountered while drilling IW-1. Depth estimates were developed based on geologic and hydrogeologic information from the Lehigh Acres and the Immokalee Water and Sewer District injection wells, which are the nearest injection wells to the LCRSWDF (MWH, 2010). Regional cross sections were developed to identify the subsurface features that would be encountered at the planned well site. **Figure 3-2** is a plan view map showing the traces for north-south and east-west cross-sections presented in **Figures 3-3 and 3-4**, respectively. An updated formation top table is provided in **Table 3-1** and the cross sections were updated to reflect the subsurface conditions actually encountered during drilling of LCRSWDF Injection Well System.

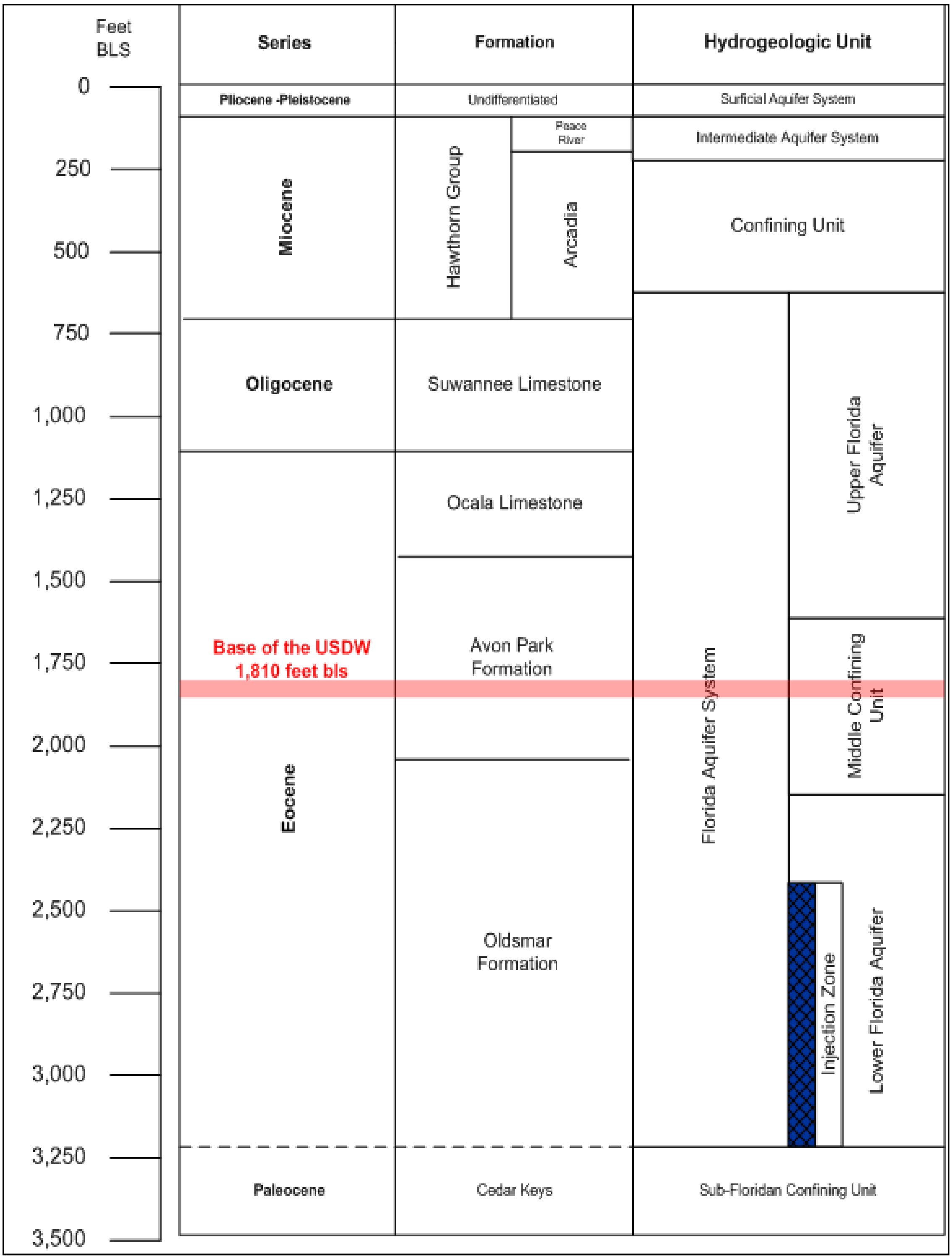


Figure 3-1

Generalized Hydrostratigraphic Column

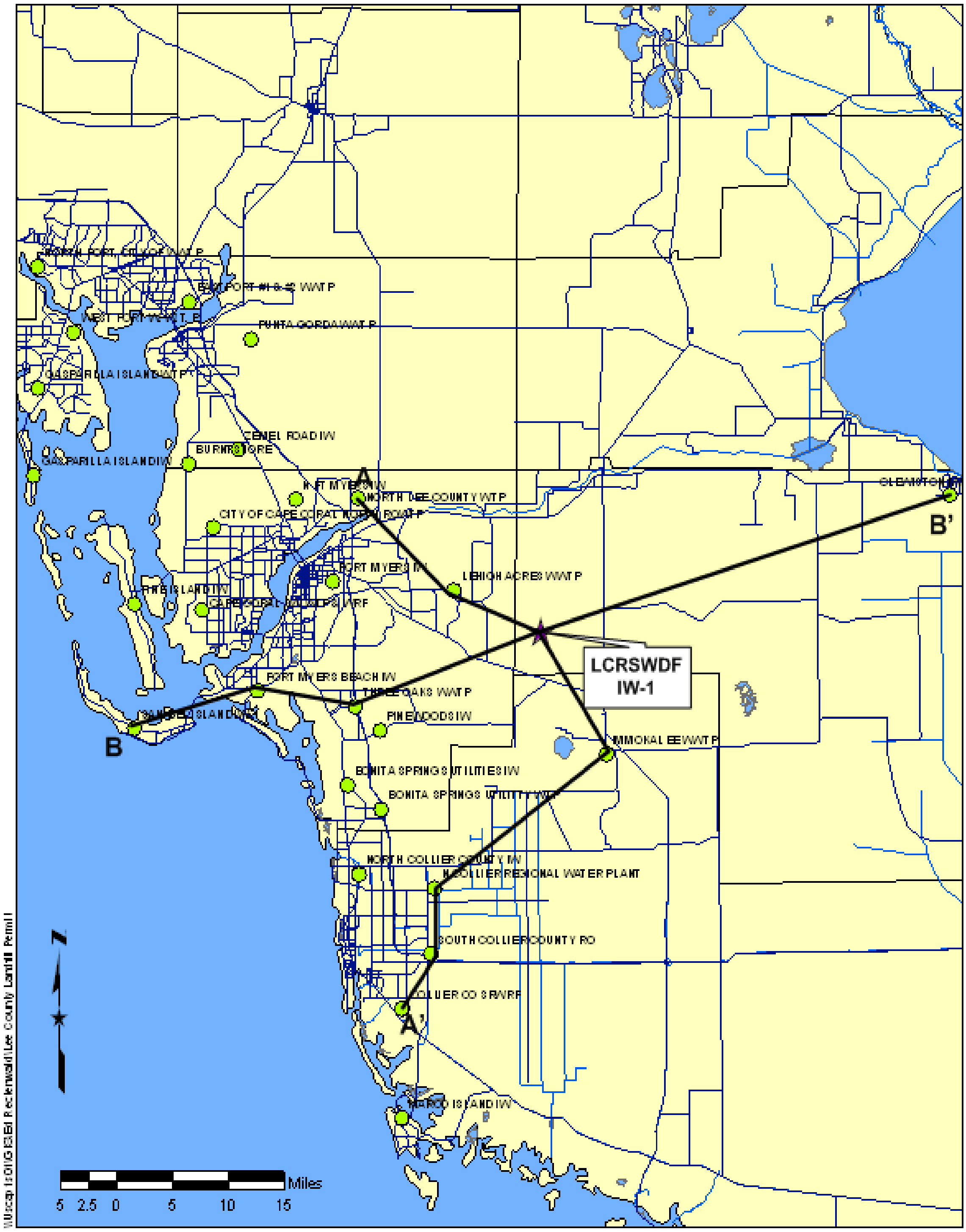


Figure 3-2
LCRSWDF IW-1 Line of Cross Section

Figure 3-3

LCRSWDF North-South Cross Section

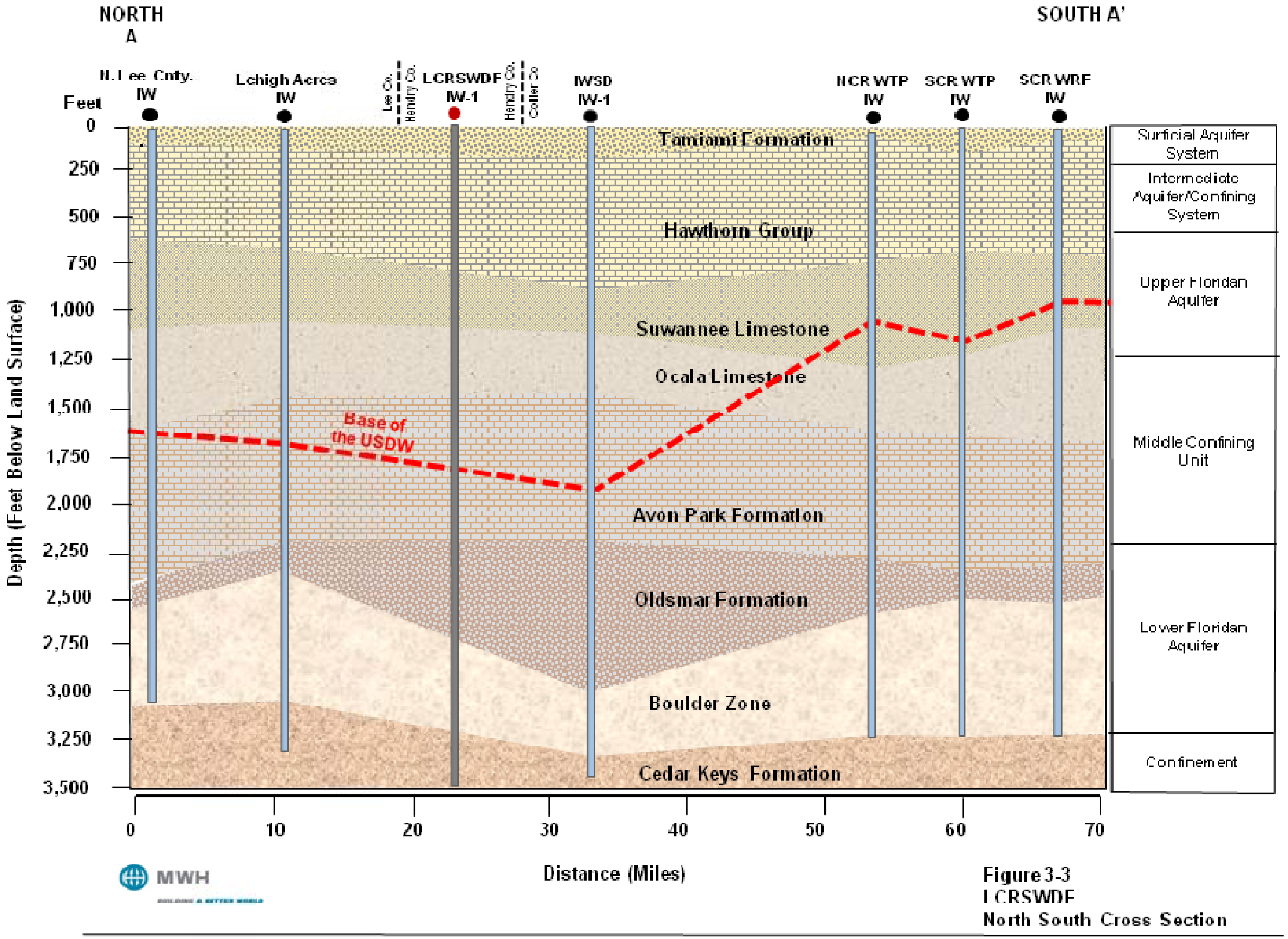


Figure 3-4

LCRSWDF East-West Cross Section

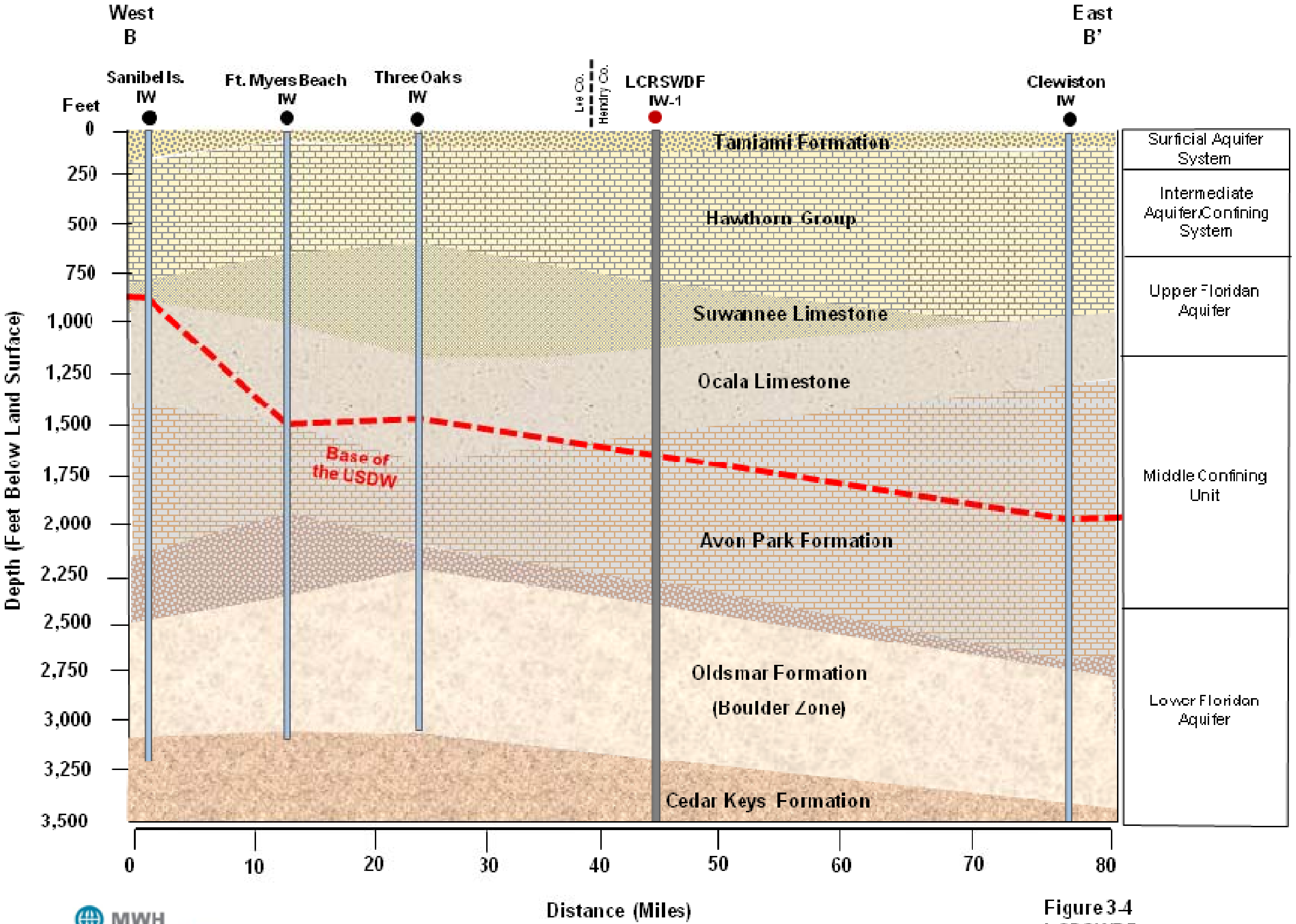


Figure 3-4
LCRSWDF
East-West Cross Section

Table 3-1
Depth of Formation Tops and Major Features at LCRSWDF
Compared to Nearby Injection Wells

Formation	Lehigh Acres IW (feet bls)	Projected Depths at LCRSWDF (feet bls)	Actual Depths at LCRSWDF (feet bls)	IWSD-IW (feet)
Pliocene-Pleistocene	0	0	0	0
Hawthorn Group	60	91	60	122
Suwannee Limestone	650	763	730	875
Ocala Limestone	1,110	1,107	1,120	1,105
Avon Park Formation	1,470	1,455	1,400	1,440
Oldsmar Formation	2,160	2,155	2,060	2,150
Cedar Keys	NE		3,240	NE
Additional Information				
Base of USDW	1,700	1,830	1,810	1,960
Boulder Zone			2,400	3040 - 3265
Final Casing Depth	2,370		2,396	2,983

NE = Not Encountered

3.2 STRATIGRAPHY

Sediments encountered during the construction of the LCRSWDF DIW System range in age from Holocene to Paleocene. Lithologic descriptions are based on formation samples (well cuttings) collected from IW-1 and DZMW-1 at 10-foot intervals during drilling operations. The lithology is described based on the dominant rock type, physical and textural characteristics, such as porosity and color, using the scheme of Geological Society of America Munsell color chart (2009). Lithologic descriptions for IW-1 and DZMW-1 are provided in **Appendix D**.

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 Formations. 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 and Tamiami Formation deposits are present from land surface to a depth of approximately 60 feet bls.

3.2.2 Miocene Series - Hawthorn Group

Dall and Harris (1892) first used the term “Hawthorn beds” for phosphatic sediments being quarried for fertilizer near the town of Hawthorne in Alachua County, Florida. The unit has been extensively studied, mapped and discussed by Florida geologists since the early 1900’s because of its economic importance. The formation was upgraded to Group status by Scott (1988) and divided into two formations (Peace River and Arcadia) in Southwest Florida. The Peace River Formation is comprised of phosphatic olive green calcareous/dolomitic clays with a large percentage of siliciclastic materials. The underlying Arcadia Formation has a larger carbonate component and tends to have sandy phosphatic limestone and dolomite lower in the section. A regional disconformity separates the Peace River Formation from the Arcadia Formation (Scott, 1988). The Hawthorn Group unconformably underlies the Tamiami Formation. It is a regional stratigraphic unit of early Pliocene to Miocene age that underlies all of South Florida (Reese, 2000). Locally, the Peace River Formation is comprised of the Cape Coral Clay member and the Lehigh Acres Sandstone member (Missimer & Associates, 1993). The Hawthorn Group is approximately 650 feet thick at the project site and occurs from 60 to 708 feet bls.

3.2.2.1 Peace River Formation

In Hendry County, the Peace River Formation consists of dolomitic clays, sands, sandstones, and sandy limestones, and fossilized shell material. At the project site, the formation occurs from approximately 60 to 190 feet bls in IW-1 and from 60 to 180 feet 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 ranges from approximately 190 to 708 feet bls in IW-1. The formation is lithologically complex, containing limestone and dolosilt beds of varying thickness. The limestones are light to yellowish gray micrites and biomicrites with moderate to good porosity. The formation is interbedded with yellowish gray marl or lime mud, and light olive gray dolosilt. Phosphate granules are locally abundant in the Arcadia Formation. The base of the Arcadia Formation is identified by a decrease in phosphate content and attenuation of gamma ray activity on the geophysical logs.

3.2.3 Oligocene Series - Suwannee Limestone

The Oligocene Age Suwannee Limestone occurs from approximately 730 to 1,120 feet bls in IW-1. Cooke and Mansfield (1936) introduced the term Suwannee Limestone to describe an interval of yellowish limestones exposed in the banks of the Suwannee River in northern Florida. In the type area the Suwannee Limestone is normally a very pale orange, moderately indurated, porous calcarenite that contains numerous fossil foraminifera, mollusks, and echinoids. Sproul, et al (1972), working in the McGregor Isles area of Lee County described the Suwannee Limestone as a pale yellowish brown nodular limestone with no phosphorite. According to Wedderburn, et al, (1982) the upper boundary of the Suwannee Limestone occurs at the contact between the slightly sandy carbonates of the Suwannee Limestone and the phosphatic and sandy sediments of the Hawthorn Group. A regional disconformity separates the Hawthorn Group from the Suwannee Limestone (Scott, 1988).

At the project site, the contact between the Hawthorn group and Suwannee limestone is marked by interbedded marl and clay at the base of the Hawthorn group, a gradational color change in lithology and absence of phosphate in the Suwannee. The contact is identified by an abrupt decrease in gamma ray activity in Suwannee limestone. The formation is primarily a yellowish gray micrite to biomicrite, having a calcarenite texture, and a variable, but relatively high porosity, with interbedded lower porosity marl in the lower part of the formation. The Suwannee Limestone is composed of moderately to well sorted allochems such as foraminifera (*Dictyoconus cookei*, *Rotalia sp., and Amphistegina sp.*), pelloids, abraded echinoderm and mollusk fragments. In addition, the Suwannee Limestone at the site is characterized by higher sonic transit times (**Appendix F**) as compared to the basal facies of the Arcadia Formation.

3.2.4 Eocene Series - Ocala Limestone

Dall and Harris (1892) first used the term "Ocala Limestone" for limestone that was being mined near the town of Ocala in Marion County, Florida. Applin and Applin (1944) recognized two distinct units within the Ocala Limestone, an upper coquinoid member and a lower more fine-grained micritic member. The contact between the late Eocene age Ocala Limestone and the Suwannee Limestone occurs at approximately 1,120 feet bls at the LCRSWDF site. It is marked by a subtle transition from mostly yellowish gray limestones to very pale orange micrites and biopelmicrites. Although a characteristic of the Ocala limestone is an abundance of benthonic foramifera, including, Lepidocyclina sp. Operculinoides sp., and Heterostegina sp., these large foraminifera were not abundant at the project site. The gamma ray logs show less radioactivity in the Ocala Limestone than the overlying Suwannee Limestone, which is a geophysical characteristic of the Ocala limestone. Sonic logs also show lower sonic transit times as compared to the Suwannee Limestone. Textures range from poorly consolidated chalk to coquina-like grainstones, which further discerns the contact between the Suwannee and Ocala limestones. The Ocala Limestone is approximately 280 feet thick at the project site, occurring from approximately 1,120 to 1,400 feet bls

3.2.5 Eocene Series - Avon Park Formation

The top of the Middle Eocene age Avon Park Formation (Applin and Applin, 1944) occurs at approximately 1,400 feet bls at the project site. The boundary between the Ocala limestone and Avon Park Formation is also subtle, marked by a transition from very pale orange limestone to light gray limestone. The Avon Park Formation is distinguished from the Ocala Limestone by a greater degree of lithification. In addition, this formation boundary coincides with a higher formation resistivity and a marked downhole increase in gamma ray activity (**Appendix F**).

At the LCRSWDF site the Avon Park Limestone extends from approximately 1,400 feet to a depth of 2,060 feet bls and is about 660 feet thick. . The Avon Park Formation is a lithologically diverse unit. The upper sediments consist mainly of very pale orange and light gray micritic limestone. The lower stratum of the formation consists of white to very pale orange, low permeability micrite (mudstone) with interbedded moderate to dark yellowish brown crystalline dolomite. The dolostones are well indurated with sucrosic texture, and vugular and intercrystalline porosity. Although the lower part of the Avon Park formation may contain a thicker dolomite section, the base of the formation was placed at the last occurrence of limestone which overlies a thick sequence of dolomite having generally uniform lithologic characteristics.

3.2.6 Eocene Series - Oldsmar Formation

In IW-1, the top of the early Eocene age Oldsmar Formation was encountered at approximately 2,060 feet and extends to 3,240 feet bls. It is comprised mainly of mottled dark yellowish brown to grayish black and moderate yellowish brown, crystalline dolostone. The dolomite is generally microcrystalline, dense, and very hard, having low permeability. Vugs and sucrosic textures are locally present, which may increase the permeability to some degree.

The Oldsmar Formation of Southwest Florida generally contains an intricate fractured solution channel network referred to as the “Boulder Zone.” The highly permeable Boulder Zone is identified on geophysical logs by greatly enlarged borehole size on caliper logs, long sonic transit times, very low resistivity, and changes on temperature and flowmeter logs (Haberfeld, 1991). 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, highly 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 encountered during the drilling of IW-1. 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 identified at approximately 3,240 feet bls. The lithostratigraphy of the formation was described in detail by Chen (1965). It is comprised of dolomitic limestone and massive, white to light grey anhydrite beds and interbeds of limestone, dolomite, and dolomitic limestone. The formation contact is identified in IW-1 by the distinct lithologic transition from dark dolomites to pale yellowish brown, microcrystalline dolomite with nodules of anhydrite observed in the video at 3,240 feet bls. The massive, thick beds of low permeability anhydrite that are characteristic of the Cedar Keys Formation, and form the base of the Floridan Aquifer System, were not reached while drilling IW-1.

3.3 HYDROGEOLOGIC FRAMEWORK

Three major aquifer systems underlie the project site: 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. Generalized hydrostratigraphic columns were presented in Figures 3-1, 3-3, and 3-4.

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). The SAS, in Lee County, as described by (Missimer and Associates, 2002), is composed of two aquifers. The uppermost aquifer is the unconfined water table aquifer, which extends from the top of the saturated zone down to the first regional confining unit. The water table occurs in the saturated portions of the Pamlico Sand formation and undifferentiated sediments of the Caloosahatchee, Fort Thompson and Tamiami Formations. The aquifer varies from having high transmissivities (300,000 gpd/ft) in cavernous, fossiliferous limestone to low transmissivities (5,000 gpd/ft) in quartz sand, shell, and thin limestone layers.

The Lower Tamiami Aquifer is a semi-confined aquifer that underlies the water table aquifer. The Lower Tamiami Aquifer occurs within the permeable limestone and sandstone of the Ochopee Member of the Tamiami Formation. The lower Tamiami Aquifer ranges in transmissivity from 50,000 to 1,360,000 gpd/ft, increasing in transmissivity from west to east (Missimer & Associated, Inc., 1990). The lower Tamiami Aquifer is an important source of water for irrigation and Public Water Supply (PWS) in portions of Lee, Hendry, and Collier Counties. At the project site the SAS is present from near land surface to approximately 50 feet bls.

3.3.2 Intermediate Aquifer System

Aquifers that lie beneath the SAS and above the FAS in southwestern Florida are grouped within the IAS (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986). The IAS does not crop out and contains water under confined conditions (Miller, 1986). The IAS in Lee County is comprised of the Sandstone Aquifer and the Mid-Hawthorn Aquifer. The Sandstone Aquifer underlies the Lower Tamiami Aquifer and lies within the Peace River Formation of the Hawthorn Group. The aquifer occurs in quartz sand, sandstone, and sandy limestone of the Peace River Formation. The Sandstone Aquifer is semi-confined above from the overlying SAS by thin, low permeable units within the upper Peace River Formation. Transmissivities for the Sandstone Aquifer have been reported ranging from 500 to 373,000 gpd/ft (Missimer & Associates, 1992). The Sandstone Aquifer is the major source of water for irrigation and domestic self-supply in Western Hendry County. The Sandstone Aquifer was encountered from approximately 60 to 230 feet bls at the project site.

3.3.3 Floridan Aquifer System

The FAS is defined as a vertically continuous sequence of permeable carbonate rocks of Tertiary age that are hydraulically connected in varying degrees, and whose permeability is generally several orders of magnitude greater than that of the rocks that bound the system above and below (Miller, 1986). The system is subdivided into the upper Floridan Aquifer (UFA), middle confining unit (MCU) and the lower Floridan

Aquifer (LFA) based on hydraulic characteristics. The LFA includes permeable zones that occur in the Oldsmar Formation including the highly transmissive “boulder zone” found within the lower section of the formation. The FAS 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, or sub-Floridan confining unit of the FAS (Miller, 1986).

3.3.3.1 Upper Floridan Aquifer

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 a vertically continuous permeable early Miocene to Oligocene-aged carbonate sequence. At the LCRSWDF IW-1 site, the UFA occurs from approximately 630 to 1,610 feet bls and consists of permeable zones within the lower Hawthorn Group, Suwannee Limestone, Ocala Limestone and the upper Avon Park Formation.

The first transmissive horizon includes the lower portion of the Basal Hawthorn Unit (Reese, 2000), and occurs from 630 to 710 feet bls in IW-1. This aquifer is locally named the Lower Hawthorn Aquifer. The predominant lithology present are interbedded yellowish-gray fossiliferous limestone and light gray limestone interbedded with marl. The Lower Hawthorn aquifer’s limestone have a variable texture, are very hard, and have good porosities. This aquifer is a major source for public water supply in Western Lee County.

A transmissive interval within the Suwannee Limestone was identified from 730 to approximately 1,000 feet bls. This aquifer is locally named the Suwannee Aquifer. A semi-confining bed between the Suwannee and Lower Hawthorn Aquifer is approximately 20 feet thick and consists of yellowish gray marl and light olive green clay in IW-1. This aquifer is composed of interbedded moderately biomicritic limestone and marl. The aquifer becomes less permeable with depth due to interbedding and increased lime mud and fine grained material. A semi-confining bed of low permeability marl occurs in the lower part of the Suwannee Aquifer. A variably transmissive interval of the UFA, interbedded with lower permeability zones occurs within the Ocala Limestone and upper part of the Avon Park Formation from approximately 1,000 to 1,610 feet bls in IW-1.

3.3.3.2 Middle Confining Unit

The MCU extends from approximately 1,600 feet to 2,160 feet bls in IW-1. Additional confinement lying below the top of the LFA forms a second section of confinement lying above the injection zone. The MCU consists of low permeable limestone and dolomite in the Avon Park Formation and upper part of the Oldsmar formation. The lithology is primarily micritic, low porosity limestone, well indurated dolomitic limestone and microcrystalline dolostone. Sonic transit times on the borehole compensated sonic log are relatively low, generally 90 μsec/ft or lower, indicating a dense formation devoid of pore spaces. Sonic porosity is generally 25% or less. The low permeable nature of the MCU at the project site is supported by the core analyses presented in **Section 2, Table 2-4** and **Appendix E**. A confinement analysis describing the physical characteristics and extent of confinement above the planned injection zone is provided below.

Miller (1986) observed that portions of the Avon Park Formation are fine grained and have low permeability, thereby acting as inter-aquifer confining units within the FAS. The MCU generally separates the brackish groundwater of the UFA, from the groundwater that closely resembles seawater in the LFA (Meyer, 1989). At the LCRSWDF site, the transition from brackish water to greater than 10,000 TDS (USDW), occurs in the MCU and is observed as a gradual decrease in resistivity in the Dual Induction log from 1,650 feet to 1,950 feet. Additional discussion on the location of the USDW is provided below.

3.3.3.3 Lower Floridan Aquifer and Injection Zone

The LFA occurs in the permeable strata of the Oldsmar Formation, and the upper part of the Cedar Keys Formation (Meyer, 1989). Groundwater in the LFA compares 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 dolostone (Meyer, 1989). The typical high permeability in the Boulder Zone is due to the cavernous porosity and extensive fracturing present (Miller, 1986, Meyer, 1989 and Reese, 1994). The LFA in South Florida typically occurs in well indurated dolostone exhibiting high secondary porosity and permeability due to vuggy to man-size cavernous porosity, dissolution features and fracturing. The LFA at the project site exhibited very well developed Boulder Zone characteristics.

In IW-1, the LFA is identified from 2,160 to approximately 3,240 feet bls. The top of the LFA at the project site is identified at the first major flow having water quality similar to seawater. The flow zone was readily identified during reverse air drilling water quality sampling at the depth where chloride concentrations increased from 2,750 to 18,125 mg/l. The flow zone was very apparent in the flowmeter log and other geophysical logs such as temperature log, BHC sonic and VDL logs.

The static up/down flowmeter log indicates that flow begins moving downward from approximately 2,160 feet bls in the borehole. This zone appears to contribute most of the flow observed in this section of the borehole. Flow downward stops under static conditions at a depth of approximately 2,870 feet bls. The fluid conductivity and temperature logs show a shift at approximately 2,160 ft bls under both static and dynamic conditions and appear to indicate a shift in water temperature at approximately 3,020 feet bls and conductivity at a depth of approximately 3,150 feet bls in the borehole. Permeable zones below 2,160 feet bls are present, but do not appear to contribute to the overall flow in the borehole due to the higher salinity (i.e. higher specific gravity) of the water in these zones.

Identification of the injection zone is based on lithologic characteristics, XY caliper log signatures indicating greatly enlarged borehole, and a predominately downward flow direction. The logs indicate alternating areas of poorly to well indurated dolomite that is extensively fractured, cavernous, or differentially dissolutioned between 2,405 feet and 3,020 feet bls. Dredging was conducted during pilot hole drilling to remove rock slides and boulders that continued to fall down hole, particularly between 2,700 and 2,900 feet. This drilling pattern is characteristic of the “boulder zone”, which is the primary injection zone in South Florida.

Extensive fracturing and highly cavernous porosity was encountered during drilling and several horizons exhibited vuggy porosity. The BHCS and VDL logs supported the visual observations recorded on the video survey indicating higher porosity at 2,500 to 2,510, 2,520 to 2,536, 2,580 to 2,598, 2,606 to 2,960, and from 3002 to 3012.feet bls.

3.4 WATER QUALITY

Water quality was evaluated during drilling by collecting drill stem samples throughout the reverse air drilling process Water samples were also collected from isolated sections of the borehole during packer testing. The water samples from the packer tests were analyzed for selected parameters to establish background water quality and to identify the USDW, or 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 K.

The base of the USDW was identified using a variety of data sources including reverse-air drilling data, geophysical log interpretations, and packer testing. TDS concentrations were calculated from laboratory results for conductivity in the pilot hole reverse-air drilling samples. The TDS concentration estimated using this method indicated a trend of increasing TDS, but did not exceeded 10,000 milligrams per liter (mg/L) at the base of the Intermediate Casing pilot hole. This is likely due to the relatively low apparent porosity and permeability of the sediments encountered, and dilution of the reverse air water column.

The Dual Induction log shows a prominent decrease in resistivity from approximately 20 ohms at 1,700 feet to less than 2 ohms at 1,900 feet bls. The Sonic Porosity and Dual Induction logs were used to calculate a log-derived TDS plot based on the method developed by Callahan (1996) using empirical data from South Florida compiled by Reese (1994). Using this method, the base of the USDW is identified in IW-1 at approximately 1,810 feet bls (**Section 2, Figure 2-5**) and in DZMW-1 at 1,792 feet bls (**Section 2, Figure 2-6**). An average depth of the USDW for the site is therefore approximately 1,800 feet.

These USDW identifications are supported by the packer test water quality results from IW-1 and DZMW-1. In IW-1, Packer Tests #2 and #3 conducted in the intervals from 1,594 to 1,635 ft and 1,719 to 1,759, respectively, contained water having a TDS concentration of less than 10,000 mg/l. The packer tests conducted below 1,810 feet (Packer Tests #1 and #4) contained water having a TDS concentration greater than 10,000 mg/l (**Section 2, Table 2-8**). In the DZMW-1, Packer Test #3 (1,691 to 1,738 feet bls) had a TDS OF 7,500 mg/l, and Packer Test #2 (1,815 to 1,862 feet bls) had a TDS concentration of 10,400 mg/L, indicating that the base of the USDW occurred between 1,738 and 1,815 feet.

3.5 CONFINEMENT ANALYSIS

Documentation of confinement is required by Specific Condition 6.(5) of the FDEP Construction Permit, and provides reasonable assurance that the injected water will not migrate into overlying sources of drinking water. Confinement is provided by strata having low vertical hydraulic conductivity, the physical property indicating the ability of the rock to transmit water. Confinement is evaluated qualitatively based on observed physical characteristics of the rocks and quantitatively based on geophysical properties of the rocks. The direct measurement of vertical hydraulic conductivity is obtained from core analysis. The location and thickness of confining units which overly the injection zone were evaluated by a variety of methods discussed below to demonstrate that the injection zone is hydraulically separated from the USDW. The presence of satisfactory confining sequences located between approximately 1,950 and 2,400 feet bls was initially documented in the IW-1 Final Casing Seat Selection Request letter submitted to the Technical Advisory Committee (TAC) on March 23, 2011.

3.5.1 Criteria Used for Identification of Confining Units

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

- Lithology consisting of dense, low permeability dolomite or limestone having low macroporosity (i.e., visible pore spaces) and a high degree of cementation (hardness) as observed in examination of cuttings and core samples.
- Relatively gauge borehole diameters on the video and on caliper logs, indicating solid competent formation materials. Fractured dolomite and limestone is commonly manifested by an enlarged borehole.
- Absence of fractures on the video survey or borehole televiewer log.
- Absence of flow indicators on the Flowmeter logs.
- Low sonic transit times (DT) and derived sonic porosities.
- Variable Density Logs (VDL) having consistent, parallel, banded or chevron pattern reflections.
- Low Transmissivities calculated from the Packer Test data.
- Low hydraulic conductivities determined from Core Analysis.

The confinement properties of the strata between the base of the USDW (approximately 1,810 feet bls) and 2,400 feet bls were evaluated using the above criteria and data. In general, the criteria listed above starts with generally qualitative data (lithologic, video and core descriptions) and ends with available quantitative data (geophysical logs, core laboratory analysis, and packer testing) for this evaluation. Lithologic logs are presented in **Appendix D**, core descriptions and analyses are presented in **Appenidx E**, geophysical logs are presented in **Appendix F** and packer test flow data is presented in **Appendix J**. A summary of the confining units identified at the project site is provided in **Table 3-2,** including depth interval, thickness, and hydraulic properties determined from geophysical logs, packer tests, and core analysis that indicate confinement.

Table 3-2
Description of Confinement

Unit	Depth Interval (feet bls)	Thickness (feet)	Packer Test Transmissivity (gpd/ft) & Test Number	Sonic Porosity (%)	Sonic Transit Time (usec/ft)	Core Data		
						Core Number	Porosity (%)	Vertical Hydraulic Conductivity (cm/sec)
Injection Well IW-1								
A	1,964 to 2,010	46	12 (PT 6)	15-35	70 -100	--	--	--
B	2,030 to 2,070	40	--	25	90	2	27- 29	8.6×10^{-5} max 2.1×10^{-5} min
C	2,130 to 2,150	20	--	0-5	50 - 60	--	--	--
D	2,170 to 2,220	50	4 (PT 5)	5-30	60 - 90	--	--	--
E	2,230 to 2,254	24	--	5	50 - 60	5	6 - 29	1.4×10^{-6} max 3.5×10^{-10} min
F	2,264 to 2,400	136	--	5	50 - 90	6	3 - 10	7.1×10^{-5} max 1.0×10^{-11} min
Total:		316						
G	3,020 to 3,245	NA	Sub Floridan	<10	50 - 60			
Dual Zone Monitor Well (DZMW-1)								
A	1,980 to 2,010	30	--	10 - 30	60 - 90	2	14 - 28	2.5×10^{-5} max 6.7×10^{-11} min

Notes: Lithology is dolomite in all intervals except Unit A, which is limestone with minor interbedded dolomite.
-- = No Data; NA = Not Applicable

The confining units are identified by letter designation A through G. Units A through F comprise the total confinement above the injection zone, while Unit G represents the sub-Floridan confining unit that marks the base of the Floridan aquifer. It is included in this discussion to compare physical properties below the injection zone to confining units above the injection zone. The total thickness of the confining units above the injection zone is approximately 316 feet.

3.5.2 Confinement Analysis

Examination of the drill cuttings indicates the presence of a moderately to well indurated, low to medium porosity, dolomite with minor occurrences of dense micritic limestone over the entire interval between the intermediate casing seat at 1,940 feet and the final casing depth at 2,396 feet bls. In this interval, the lithology is generally fine to microcrystalline, vuggy, low permeability dolomite (Units B through G), with minor interbedded low porosity limestone (micrite to pelmicrite) in Unit A that is moderately to well cemented. Core samples collected from Core No. 5 (2,230 feet to 2,240 feet bls) and No. 6 (2,279 feet to 2,289 feet bls) consist of dense dolomite, as described in **Appendix E**. Low vertical hydraulic conductivity values were obtained from these cores during core analysis as discussed below.

Competent, gauge borehole is indicated on the XY caliper log between 1,950 feet to 2,070 feet bls (Unit B), 2,084 feet to 2,096 feet bls, 2,130 feet to 2,150 feet bls (Unit C), 2,170 feet to 2,220 feet bls (Unit D), 2,240 feet to 2,254 feet bls (Unit E), and 2,264 feet to 2,400 feet bls (Unit F). The borehole video survey confirms the presence of dense dolomite intervals between 1,960 feet and 2,400 feet bls. The intervals appear as a generally gauge hole (XY caliper) with a smooth to rough texture as a result of a moderate to high occurrence of vugs. The video log also indicates that rock intervals between the confining sequences described in Table 3-2 contains some fractured and cavernous horizons. Fractured or cavernous intervals are present from 2070 to 2130, 2150 to 2170, and 2220 to 2265, except in the interval noted as Unit E. Vertical fissures and bedding plane features appear to be localized and should not impact the overall integrity of the confining sequences identified.

The flowmeter log indicates that no significant contributions to flow occur above 2,160 feet bls. A significant flow zone is present at approximately 2,160 feet, and a minor flow zone is present at approximately 2,260 feet. Between 2,260 and 2,400 feet bls there do not appear to be any zones present that are contributing flow to the borehole.

Sonic transit times (DT) ranging from 60 to 90 µsec/ft are indicated in the BHCL over much of the interval between the base of the Intermediate Casing and the Final Casing setting depth. Transit times less than 60 µsec/ft are present in the intervals from 2,132 to 2,150 feet (Unit C), 2,230 to 2,256 feet (Unit E), and 2,264 to 2,333 feet bls (Unit F) for a total of 113 feet. A transit time of less than 60 µsec/ft is indicative of dense, low permeability dolomite. Consistent parallel reflections on the VDL track were most notable from 1,980 to 2,012 feet bls (Unit A), 2,196 to 2,216 feet bls (Unit D), and 2,388 to 2,396 feet bls (Unit F).

Straddle packer tests were conducted from 2,197 to 2,214 feet (Packer Test No. 5) and 1,993 to 2,012 feet bls (Packer Test No. 6) to determine the hydraulic properties of the isolated intervals and quantify discrete horizon water quality. Packer Test No. 6, conducted in Unit A and Packer Test No. 5 conducted in Unit D, yielded low transmissivity values. of 12 and 4 gpd/ft, respectively, as shown in the packer test data listed in **Table 3-2** and **Section 2, Table 2-7**. Straddle packer testing data with analyses are included in **Appendix J**.

Conventional cores were recovered in confining Units B, E, and F, and provide direct measurements of porosity and vertical permeability. The cores were collected at the depth intervals of 2,025 to 2,037 feet bls, 2, 230 to 2,240 feet bls, and 2,279 to 2,289 feet bls, and confirmed the presence of well indurated dolostone and limestone with low visible permeability. Vertical hydraulic conductivities measured from cores recovered within the confining sequences ranged from 2.1×10^{-5} cm/sec to 1.0×10^{-11} cm/sec.

3.5.3 Confinement Summary

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. The summary of confinement presented in Table 3-2 lists six units of variable thickness, having a total thickness of 316 feet. The units exhibit hydraulic properties that are characteristic of sediments that act as confinement and restrict the vertical movement of water.

Section 4
Final Testing

4.1 GENERAL

Background water samples were collected from the IW-1 injection zone on May 17, 2011 and from the DZMW-1 lower and upper monitor zones on June 6, 2011, and June 8, 2011, respectively. A short-term injection test was conducted on IW-1. After construction was completed, the injection well was tested for mechanical integrity. 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 storm water / rainwater collected in a Class III leachate collection cell.

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 samples collected from the IW-1 injection zone and the DZMW-1 lower monitor zone contained elevated concentrations of tetrachloroethylene, exceeding the EPA maximum contaminant level (MCL). The sample collected from the DZMW-1 upper monitor zone contained an elevated concentration of barium. 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 facility’s Class III leachate collection cell, the source of the injection test water, was collected and analyzed for chloride, dissolved oxygen, iron, pH, sodium, specific conductance, sulfate, TDS total suspended solids (TSS) and temperature on June 3, 2011. A summary of the laboratory results is presented in **Table 4-1**. Copies of the laboratory reports are presented in **Appendix N.**

Table 4-1

Summary of Background Water Quality Laboratory Results

PRIMARY DRINKING WATER STANDARDS						
Parameter	Units	Maximum Contaminant Level	IW-1 5/17/11	DZMW-1 Upper 6/8/11	DZMW-1 Lower 6/6/11	Test Source 5/3/11
Inorganic Compounds						
Antimony	mg/L	0.006	<0.0035	<0.0035	<0.0035	
Arsenic	mg/L	0.01	0.0057	<0.0026	<0.0026	
Asbestos	MFL	7	<7.90	<7.90	<0.20	
Barium	mg/L	2	0.050	4.0	0.093	
Beryllium	mg/L	0.004	<0.00010	<0.00010	<0.00010	
Cadmium	mg/L	0.005	<0.00020	<0.00020	<0.00020	
Chromium	mg/L	0.1	0.0084	0.0021	<0.00060	
Copper	mg/L	1.3	0.0092	0.012	<0.0010	
Cyanide	mg/L	0.2	<0.0047	<0.0047	<0.0047	
Fluoride	mg/L	4	0.7	0.9	0.9	
Lead	mg/L	0.015	0.0055	0.010	<0.0029	
Mercury	mg/L	0.002	<0.000060	<0.000060	<0.00060	
Nickel	mg/L	0.1	0.0066	<0.0016	<0.0016	
Nitrate	mg/L as N	10	<0.01	0.01	<0001	
Nitrite	mg/L as N	1	<0.01	<0.01	<0.01	
Total Nitrate & Nitrite	mg/L as N	10	<0.01	0.01	<0.01	
Selenium	mg/L	0.05	<0.0043	<0.0043	<0.0043	
Sodium	mg/L	160	12,000	3,700	11,000	26
Thallium	mg/L	0.002	<0.0012	<0.0012	<0.0012	

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 5/17/11	DZMW-1 Upper 6/8/11	DZMW-1 Lower 6/6/11	Test Source 5/3/11
Organic Compounds						
2,4,5-TP (Silvex)	mg/L	0.05	<0.00019	<0.00019	<0.00019	
2,4-D	mg/L	0.07	<0.00022	<0.00022	<0.00022	
Alachlor	mg/L	0.002	<0.00060	<0.00061	<0.00062	
Atrazine	mg/L	0.003	<0.00047	<0.00049	<0.00049	
Benzo (a) pyrene	mg/L	0.0002	<0.000068	<0.000070	<0.000071	
Carbofuran	mg/L	0.04	<0.00041	<0.00041	<0.00041	
Chlordane	mg/L	0.002	<0.00013	<0.00013	<0.00013	
Dalapon	mg/L	0.2	<0.0023	<0.0023	<0.0023	
Di (2-ethylhexyl) adipate	mg/L	0.4	<0.00066	<0.00068	<0.00069	
Di (2-ethylhexyl) phthalate	mg/L	0.006	<0.00083	<0.00085	<0.00086	
Dibromochloropropane (DBCP)	mg/L	0.0002	<0.0000035	<0.0000036	<0.0000036	
Dinoseb	mg/L	0.007	<0.00023	<0.00023	<0.00023	
Diquat	mg/L	0.02	<0.0019	<0.0019	<0.0019	
Endothall	mg/L	0.1	<0.0028	<0.0028	<0.0028	
Endrin	mg/L	0.002	<0.00010	<0.00010	<0.00010	
Ethylene dibromide (EDB)	mg/L	0.00002	<0.0000046	<0.0000047	<0.0000047	
Glyphosate	mg/L	0.7	<0.013	<0.013	<0.013	
Heptachlor	mg/L	0.0004	<0.000035	<0.000036	<0.000036	
Heptachlor epoxide	mg/L	0.0002	<0.000027	<0.000027	<0.000027	
Hexachlorobenzene	mg/L	0.001	<0.00030	<0.00031	<0.00031	
Hexcachlorocyclopentadiene	mg/L	0.05	<0.00023	<0.00024	<0.00024	
Lindane	mg/L	0.0002	<0.000020	<0.000020	<0.000020	
Methoxychlor	mg/L	0.04	<0.000043	<0.000044	<0.000044	
Oxamyl (vydate)	mg/L	0.2	<0.00013	<0.00013	<0.00013	
Pentachlorophenol	mg/L	0.001	<0.00039	<0.00039	<0.00039	
Picloram	mg/L	0.5	<0.00023	<0.00023	<0.00023	
Polychlorinated biphenyl (PCB)	mg/L	0.0005	<0.00014	<0.00014	<0.00014	
Simazine	mg/L	0.004	<0.00061	<0.00063	<0.00064	
Toxaphene	mg/L	0.003	<0.00059	<0.00060	<0.00060	

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 5/17/11	DZMW-1 Upper 6/8/11	DZMW-1 Lower 6/6/11	Test Source 5/3/11
Volatile Organic Compounds						
1,1,1-Trichloroethane	mg/L	0.2	<0.00031	<0.00031	<0.00031	
1,1,2-Trichloroethane	mg/L	0.005	<0.00022	<0.00022	<0.00022	
1,1-Dichloroethylene	mg/L	0.007	<0.00035	<0.00035	<0.00035	
1,2,4-Trichlorobenzene	mg/L	0.07	<0.00012	<0.00012	<0.00012	
1,2-Dichloroethane	mg/L	0.003	<0.00021	<0.00021	<0.00021	
1,2-Dichloropropane	mg/L	0.005	<0.00024	<0.00024	<0.00024	
Benzene	mg/L	0.001	<0.00015	<0.00015	<0.00015	
Carbon tetrachloride	mg/L	0.003	<0.00036	<0.00036	<0.00036	
cis-1,2,-Dichloroethylene	mg/L	0.07	<0.00025	<0.00025	<0.00025	
Dichloromethane	mg/L	0.005	<0.00043	<0.00043	<0.00043	
Ethylbenzene	mg/L	0.7	0.00032	<0.00017	<0.00017	
Monochlorobenzene	mg/L	0.1	<0.00017	<0.00017	<0.00017	
o-Dichlorobenzene	mg/L	0.6	<0.00015	<0.00015	<0.00015	
para-Dichlorobenzene	mg/L	0.075	<0.00018	<0.00018	<0.00018	
Styrene	mg/L	0.1	0.00046	<0.00017	<0.00017	
Tetrachloroethylene	mg/L	0.003	0.094	<0.00026	0.025	
Toluene	mg/L	1	0.0033	<0.00026	<0.00026	
Total trihalomethanes (TTHM)	mg/L	0.1	<0.00015	<0.00015	<0.00015	
trans-1,2-Dichlorethylene	mg/L	0.1	<0.00030	<0.00030	<0.00030	
Trichloroethylene	mg/L	0.003	<0.00017	<0.00017	<0.00017	
Vinyl chloride	mg/L	0.001	<0.00025	<0.00025	<0.00025	
Xylenes (total)	mg/L	10	0.0019	<0.00041	<0.00041	
Microbiological Characteristics						
Total Coliform	CFU /100ml	<1	<1	<1	<1	
Fecal Coliform	CFU /100ml	<1	Not Reported	Not Reported	Not Reported	
Radionuclides						
Radium 226	pCi/L	5 (226&228 combined)	38 +/- 0.79	5.2 +/- 0.28	12 +/- 0.41	
Radium 228	pCi/L	5 (226&228 combined)	2.0 +/- 0.5	0.6 +/- 0.4	0.4 +/- 0.3	
Gross Alpha	pCi/L	15	72 +/- 4.3	11 +/- 2.4	38 +/- 3.3	

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 5/17/11	DZMW-1 Upper 6/8/11	DZMW-1 Lower 6/6/11	Test Source 5/3/11
Aluminum	mg/L	0.2	0.035	0.37	0.020	
Chloride	mg/L	250	19,000	7,520	16,100	34
Color	Color units	15	5	20	15	
Copper	mg/L	1	0.0092	0.012	<0.0010	
Corrosivity (Langelier Index)	NA	NA	0.15	0.23	0.46	
Fluoride	mg/L	2	0.7	0.9	0.9	
Foaming Agents	mg/L	0.5	0.34	0.078	0.098	
Iron	mg/L	0.3	1.9	8.5	0.36	0.27
Manganese	mg/L	0.05	0.13	0.11	0.037	
Odor	TON	3	20	2	2	
pH	NA	6.5-8.5	7.36	7.36	7.29	8.18
Silver	mg/L	0.1	<0.00050	<0.00050	0.00056	
Sulfate	mg/L	250	3,340	1,810	3,870	39
Total Dissolved Solids (TDS)	mg/L	500	35,600	11,900	34,000	280
Zinc	mg/L	5	0.10	0.070	0.23	

UNREGULATED ORGANIC CONTAMINANTS						
Parameter	Units	Maximum Contaminant Level	IW-1 5/17/11	DZMW-1 Upper 6/8/11	DZMW-1 Lower 6/6/11	Test Source 5/3/11
Aldicarb	mg/L	NA	<0.00054	<0.00054	<0.00054	
Aldicarb sulfoxide	mg/L	NA	<0.00036	<0.00036	<0.00036	
Aldicarb sulfone	mg/L	NA	<0.00045	<0.00045	<0.00045	
Aldrin	µg/L	NA	<0.000043	<0.000044	<0.000044	
Chloroethane	mg/L	NA	<0.00036	<0.00036	<0.00036	
Chloroform	mg/L	NA	<0.00024	<0.00024	<0.00024	
2-Chlorophenol	mg/L	NA	<0.00083	<0.00083	<0.00083	
Dieldrin	mg/L	NA	<0.000065	<0.000066	<0.000066	
Dimethylphthalate	mg/L	NA	<0.0024	<0.0024	<0.0024	
Phenol	mg/L	NA	<0.00096	<0.00096	<0.00096	
2,4,6-Trichlorophenol	mg/L	NA	<0.0011	<0.0011	<0.0011	

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

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

MINIMUM CRITERIA GROUNDWATER MONITORING PARAMETERS						
Parameter	Units	Maximum Contaminant Level	IW-1 5/17/11	DZMW-1 Upper 6/8/11	DZMW-1 Lower 6/6/11	Test Source 5/3/11
Ammonia	mg/L as N	NA	0.44	0.30	0.01	
Nitrogen (organic)	mg/L as N	NA	1.12	0.64	1.39	
Nitrogen, Total Kjeldahl (TKN)	mg/L as N	NA	1.56	0.94	1.39	
Phosphorus, Total	mg/L as P	NA	<0.010	<0.010	<0.010	
Calcium	mg/L	NA	550	360	480	
Potassium	mg/L	NA	Not Reported	Not Reported	Not Reported	
Magnesium	mg/L	NA	Not Reported	Not Reported	Not Reported	
Bicarbonate	mg/l	NA	Not Reported	Not Reported	Not Reported	
Total Suspended Solids (TSS)	mg/L	NA	Not Reported	Not Reported	Not Reported	1.9
Temperature	°C	NA	32.2	32.6	35.0	31.0
Conductivity	µmhos/cm	NA	53,300	17,400	45,400	447
Biological Oxygen Demand (BOD)	mg/L	NA	<2	10*	<2	
Chemical Oxygen Demand (COD)	mg/L	NA	566	212	681	

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 injection tubing 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 April 11, 2011, the injection well 12-inch diameter final casing was internally pressurized to 154.5 psi. A pressure decrease of 2.5 psi was observed over the 60-minute test period. This decrease represents a 2 percent change in the original pressure, which is within the allowable change of 5 percent from the starting pressure. David Rhodes, P.G. (FDEP) and Susan Bodmann, P.G. (MWH) witnessed the casing pressure test.

On May 25, 2011, the injection well nominal 7-inch diameter injection tubing was internally pressurized to 153.5 psi. A pressure decrease of 1.5 psi was observed over the 60-minute test period. This decrease represents a 1- percent change in the original pressure, which is within the allowable change of 5 percent. Gabriele Starrach (FDEP) and Gordon Kennedy, P.G. (MWH) witnessed the tubing pressure test.

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

4.3.2 Injection Well Temperature Log

On June 14, 2011, a high resolution temperature log was conducted on IW-1 from the surface to a total depth of 3,502 feet bls. The temperature log recorded a fairly constant temperature increase from approximately 94 degrees Fahrenheit to approximately 109 degrees Fahrenheit at 2,250 feet bls. Between 2,250 and 2,394 feet bls, the base of the 12-inch final casing, the temperature decreases to about 103 degrees Fahrenheit. A sharp increase in temperature to about 110 degrees Fahrenheit was recorded from the base of the 12-inch final casing to a depth of approximately 2,418 feet bls. From 2,418 feet bls the temperature remained generally constant at approximately 110 degrees Fahrenheit to the total logged depth of 3,052 feet bls. 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 injection tubing was performed on May 17, 2011. The survey was performed from pad level to a depth of 3,045 feet bls. Water clarity was good, enabling the camera to capture clear images of the tubing interior, packer assembly, casing seat and open hole section to the depth that the video was terminated due to poor visibility. 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 H.**

4.3.4 Injection Well Radioactive Tracer Survey

On June 14, 2011, an RTS was conducted on the completed 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 0.15 millicuries (mCi) per second discharge, and the reservoir was loaded with 2.5 millicuries of radioactive Iodine-131. The tool was then lowered back downhole. The CCL identified the tubing packer at a depth of 2,391 feet bls. Potentially due to the configuration of the tubing packer and the final casing and the proximity of the tubing packer to the base of the final casing the CCL was not able to identify the base of the 12-inch diameter final casing. As previously documented in this report the base of the 12-inch final casing has been determined to be 2,396 feet bls. Copies of the flowmeter calibration certificate and tracer (Iodine-131) assay are presented in **Appendix F**. A copy of the IW-1 RTS log is included in **Appendix F.** A sketch of the RTS tool is included with the RTS log.

The first test conducted (TEST #1) injected water at a rate of 6 gallons per minute (gpm) using the supply well source. The test was conducted by positioning the tracer ejector five feet above the bottom of the final casing, setting the recorder in the time drive mode, recording one minute of background data, and ejecting a 0.5 mCi slug of tracer material. The readings from the middle gamma ray detector began to increase from background within 26 seconds of ejection. The readings from the bottom detector increased from background approximately ten minutes after ejection. No increase in gamma detection by the top gamma ray detector was seen during the 60-minute monitoring period. The tool was then logged out of position (LOP #1) to a depth of 2,150 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 water for 13 minutes at 96 gpm. Following the flushing an out of position log was conducted (LAF #1) from below the casing to 2,200 feet bls. There is evidence that the casing was stained by the tracer slug ejected for TEST 1 and it is evident that the tracer material entered the formation below the base of the 12-inch final casing. This log indicates 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 6 gpm. This test also used supply well 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. After recording one minute of background data 1.0 mCi slug of tracer material was ejected. The readings from the middle gamma ray detector began to increase from background within 20 seconds of ejection. The readings from the bottom detector increased from background approximately 3 minutes and 40 seconds after ejection. No detection of the tracer material was seen at the upper gamma ray detector any time during 50 minutes of time drive monitoring. The tool was logged out of position (LOP #2) to a depth of 2,200 feet bls after the 50-minute test period. 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 well was then flushed with 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 (2,750 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 June 12, 2011, a controlled short term injection test was conducted on IW-1 using storm water / rainwater collected in a Class III leachate collection cell. 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 2,383 feet bls in IW-1 to monitor pressures near the base of the final casing. Transducers were also placed such that wellhead and annular space pressures of IW-1, the DZMW-1 upper monitor zone (1,813 to 1,868 feet bls), and the DZMW-1 lower monitor zone (2,015 to 2,080 feet bls) water levels 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. Copies of the calibration certificates for the pressure transducers and flowmeter are provided in **Appendix P.**

Background monitoring was initiated at 1317 hours on June 10, 2011. After the background monitoring phase was completed, the 12-hour injection test was started at 1013 hours on June 12, 2011. The test was conducted at an average rate of 918 gpm (9.7ft/sec), based on totalizer readings taken during injection test**.** The wellhead pressure was closely monitored and not allowed to exceed two thirds of the casing pressure test value of 153 psi (102 psi). After the pumping phase of the test was concluded, recovery readings were recorded for a period of greater than 24 hours starting at 2215 hours on June 12, 2011.

The data recovered from the two data loggers were very similar. Injection well IW-1 wellhead and annular pressures, 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**. **Figure 4-1** presents the data recorded during the injection test. 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 0 psi before the start of the test. The maximum recorded IW-1 wellhead pressure during the test was approximately 83.0 psi occurring during initial pumping startup. The maximum recorded IW-1 wellhead pressure after startup during the test was approximately 65.2 psi occurring at a flow rate of approximately 1,120 gpm.

All IW-1 wellhead pressure readings are within the allowable 2/3 of the pressure test (i.e., approximately 102 psi) conducted on the 7-inch outer diameter injection tubing. A summary of the injection rates and wellhead pressures is presented in **Table 4-2.**

Table 4-2
IW-1 Injection Test Control Points

Monitored Data and Control Location	Parameter Monitored	Collection Method
IW-1 Wellhead and Annulus	Pressure	Manual gauge readings Transducers & Hermit data logger
IW-1 Bottom Hole (2, 383 ft bls)	BH Pressure BH Temperture	Integra-QMR memory gauges hung on wireline
Upper Monitor Zone	Pressure	Transducer & Hermit data logger
Lower Monitor Zone	Pressure	Transducer & Hermit data logger
Barometric Data	Atmospheric Pressure	Hermit data logger
Tidal Data	Tidal data at Fort Myers FL	NOAA tidal records
Flowmeter	Injection Rate Totalizer Volume	Manually – McCrometer rate and totalizer Flow Meter

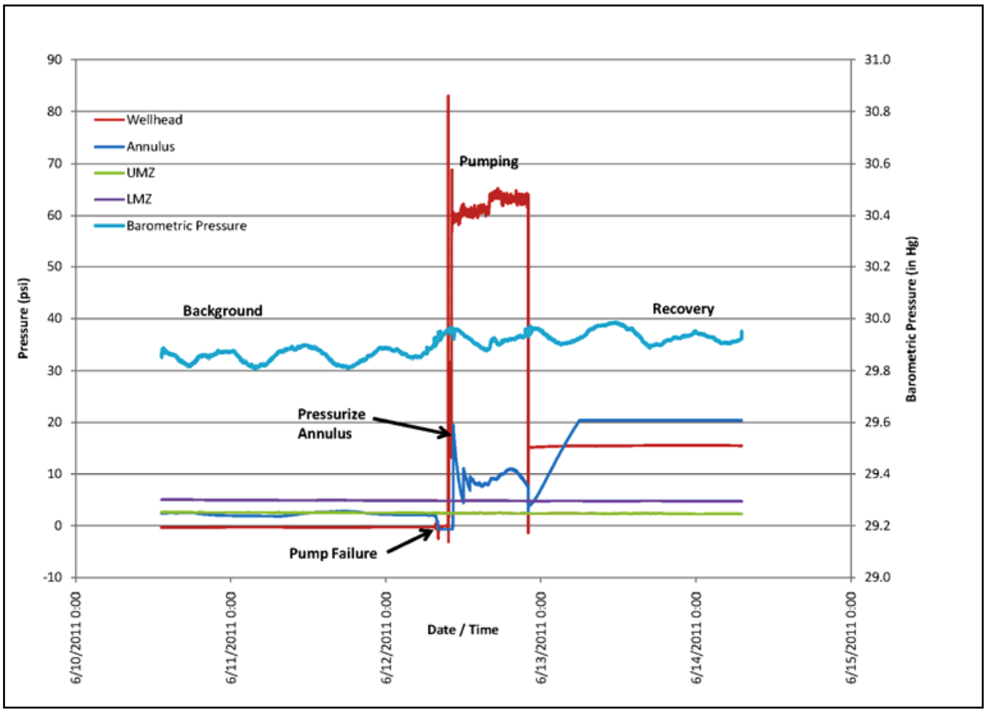


Figure 4-1
Summary of Injection Test Data

4.5 FINDINGS AND CONCLUSIONS

Figures illustrating the data collected are presented below**.** A graphical presentation of the data recorded by the In-Situ Hermit 3000 is presented as **Figure 4-1**.

As the pumping phase of the injection test was initiated the wellhead pressure increased from 0 psi before the start of the test to 62 psi as the flow stabilized. After pumping for approximately 6.5 hours the wellhead pressure had increased to 65 psi and remained generally stable for the remainder of the test. Before the pumping phase was terminated at 2215 hours the recorded wellhead pressure was 64 psi.

As the pumping phase of the injection test was initiated the downhole pressure increased from about 1065 psi before the start of the test to about 1,069 psi. As the flow stabilized the pressure decreased to about 1,066 psi and remained generally stable for the remainder of the test. The maximum downhole pressure during the injection test was 1,070 psi, which is far below the pressure necessary to initiate fracturing.

The increase in wellhead pressure is generally associated with friction losses during pumping. This is supported by the small increase in downhole pressure recorded during the injection test.

The IW-1 wellhead pressures and the downhole pressures recorded by the memory gauge are presented in **Figure 4-2.**

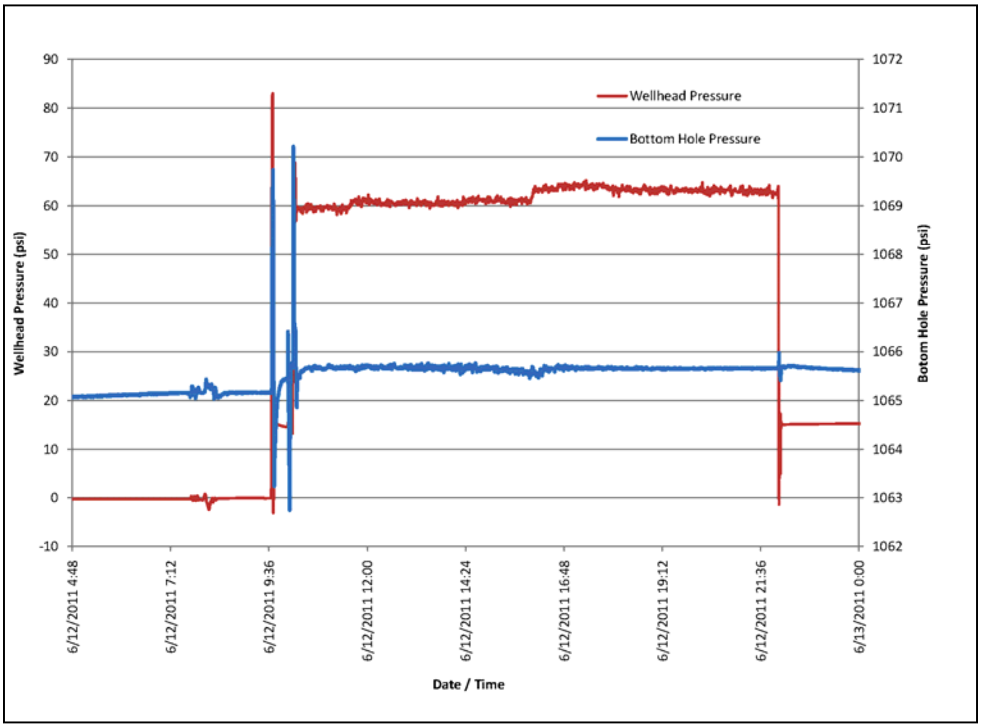


Figure 4-2
Injection Test IW-1 Wellhead and Downhole Pressures

Monitor well DZMW-1 upper and lower monitor zone pressures remained generally stable over the duration of the test as shown on **Figure 4-3.** 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 0700 and 1900 hours. The upper monitor zone pressure changes do not appear to have been influenced by the injection activities.

As shown in **Figures 4-4** and **4-5**, the upper and lower monitor zone pressure changes correlate very well with the tide and barometric data.

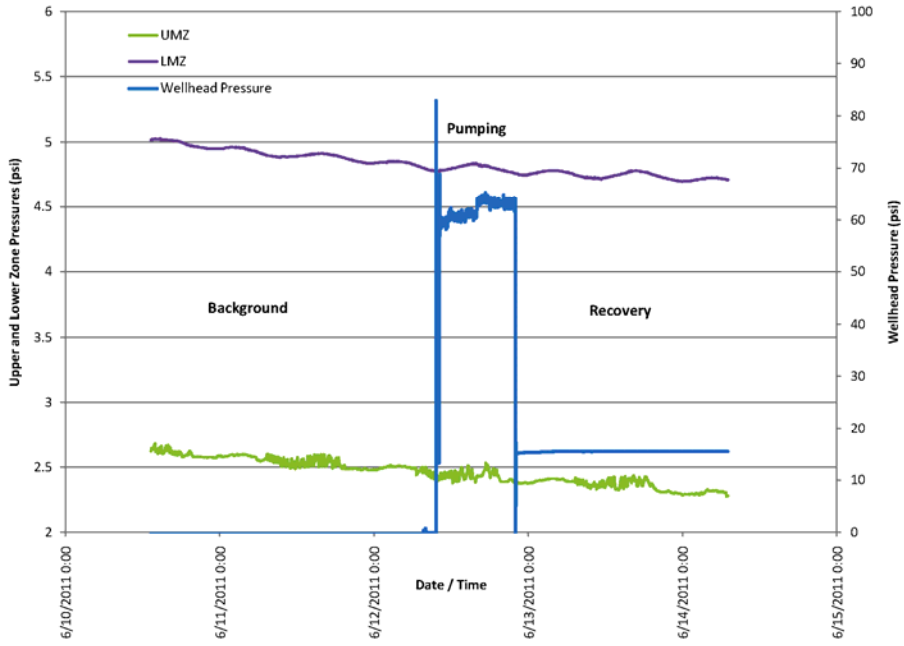


Figure 4-3
IW-1 Wellhead and UMZ and LMZ Pressures

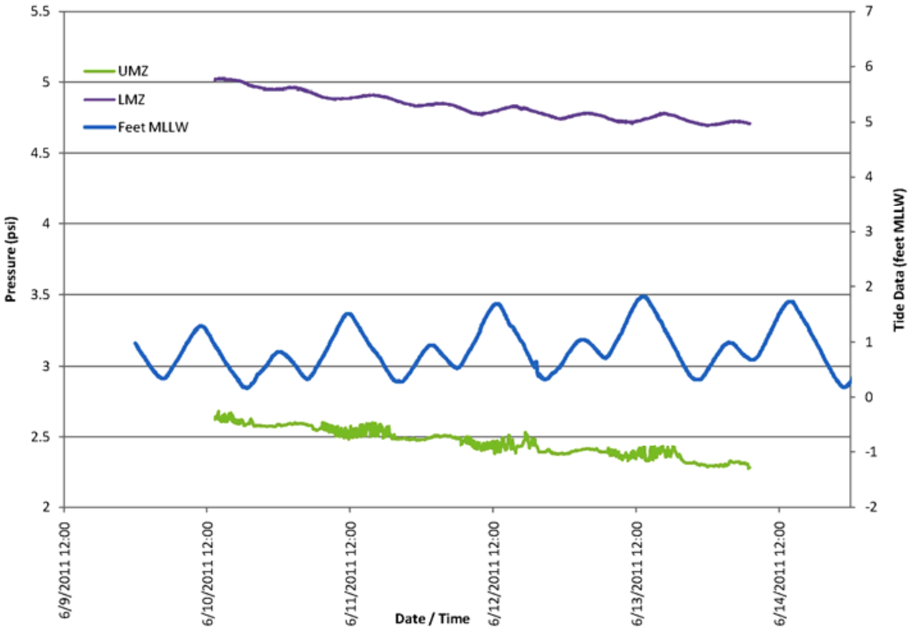


Figure 4-4
Injection Test UMZ, LMZ Pressures and Tide Data

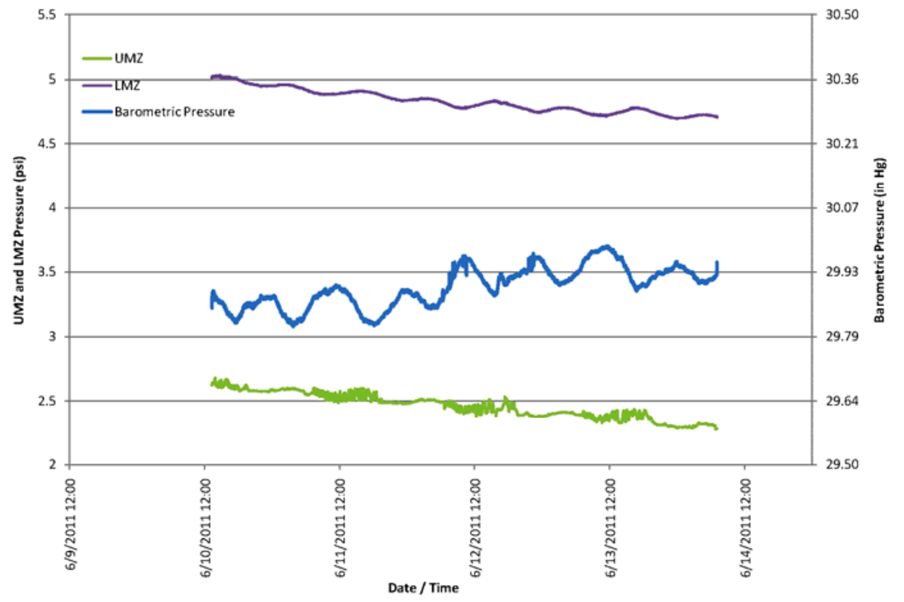


Figure 4-5
Injection Test UMZ, LMZ Pressures and Barometric Pressure

As the pumping phase was initiated, the annular space between the injection tubing and the final casing was pressurized to about 18 psi. As presented in **Figure 4-6,** the annular pressure demonstrated a steady decrease in pressure to 4.4 psi at 1202 hours when it was re-pressurized to 11 psi. The annular pressure decreased to 6.8 psi at 1304 hours and was re-pressurized to 9.5 psi. For the remainder of the injection test the annular pressure was somewhat erratic but re-pressurization was not again required. The annular pressure was recorded at 7.6 psi just prior to the end of pumping. As the pumping phase was terminated a corresponding drop in annular pressure to 2.5 psi was recorded. During the recovery phase the annular pressure increased to 20.4 psi, the maximum pressure reading capable of being recorded by the transducer. As in figure 4-6 the increase in annular pressure during the recovery phase correlates very well with an increase in temperature recorded by the downhole memory gauge.

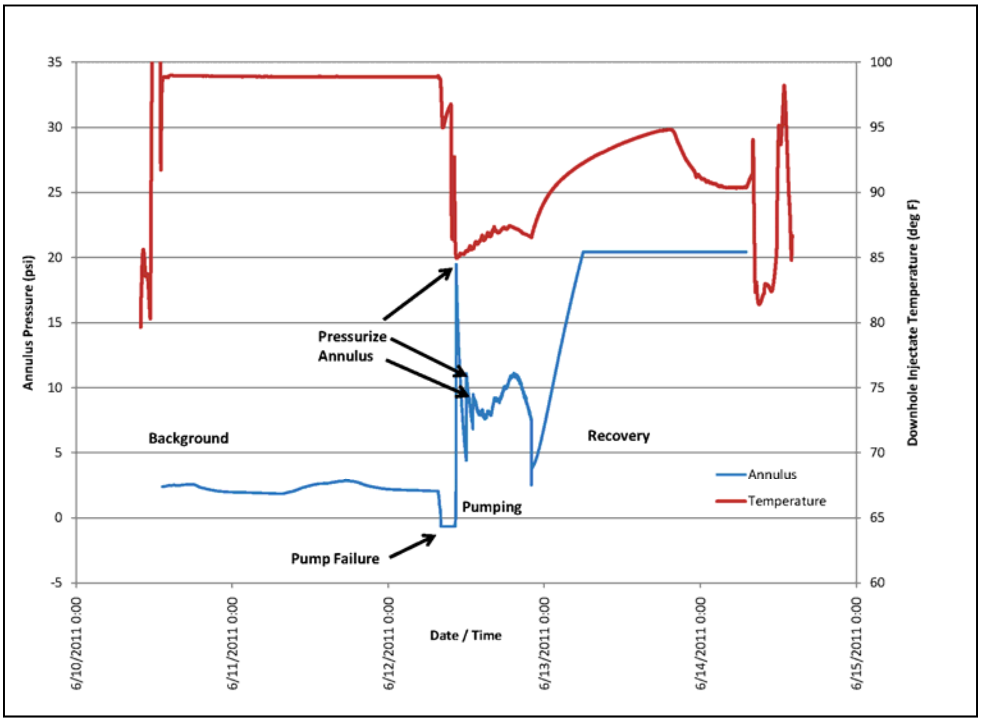


Figure 4-6
Injection Test IW-1 Annular Pressures and Downhole Temperature

Based on the well developed injection zone at the site, the transmissivity of the injection zone is considered to be extremely high, and likely comparable to transmissivities ranging from 1.0 to 4.0 million gpd/ft documented in the "Boulder Zone" of Eocene age on the east coast (Haberfeld, 1991). 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.

Section 5
Conclusions and Recommendations

5.1 CONCLUSIONS

The following list summarizes the findings identified during the construction of the Lee County Regional Solid Waste Disposal Facility (LCRSWDF) Deep Injection Well System.

- The base of the USDW, where the groundwater exceeds 10,000 mg/L TDS, occurs at 1,810 feet bls at IW-1.
- The confining sequence above the injection zone occurs between 1,964 feet and 2,400 feet bls, consisting of six units having a total thickness of approximately 316 feet.
- Vertical hydraulic conductivity determined from core analyses within the confining sequences range from 2.1 x 10^{-5}cm/sec to 1.0 x 10^{-11} cm/sec.
- Transmissivities determined from packer testing within the confining sequences range from 4 gpd/ft to 12 gpd/ft.
- A highly transmissive injection zone containing highly saline water occurs between approximately 2,400 and 3,020 feet bls.
- The IW-1 final casing (12-inch diameter) was successfully pressure tested at 154.5 psi. The IW-1 FRP tubing (7-inch outer diameter) was successfully pressure tested at 153.5 psi.
- The Radioactive Tracer Survey, temperature log, and pressure testing results demonstrate that LCRSWDF IW-1 has mechanical integrity.
- An injection test was performed on IW-1 at a rate of 918 gpm (9.7 ft/sec, 1.32 mgd) with an average injection pressure of 65 psi. The bottom hole pressure measured near the base of the FRP tubing was less than 1 psi.
- The injection zone is capable of accepting a flowrate equivalent to a velocity of 9.7 feet per second in IW-1 at an injection pressure that will not promote fractures in the injection zone or confining sequences.
- One dual-zone monitor well was drilled with the Upper Monitor Zone located from 1,813 feet to 1,868 feet bls, and the Lower Monitor Zone from 2,022 feet to 2,080 feet bls.

- 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 non-hazardous leachate water at the LCRSWDF in accordance with existing state and federal underground injection control regulations.
- A Request to Start Operational Testing was submitted to the FDEP on August 18, 2011, approval was granted by the Department on August 30th and operational testing began on September 1, 2011.

5.2 RECOMMENDATIONS

The following recommendations are in accordance with the 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 (**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. The maximum pressure the well can be operated at is 102 psi, which is two-thirds the pressure at which the final casing was hydrostatically pressure tested (154.5 psi).
- Flow to the injection well is to be continuously monitored. The maximum rate the well can be operated at is 918 gpm (1.32 MGD), based on the average pumping rate used during the injection test.
- Dual-zone monitor well water quality is to be monitored weekly.
- Injectate water quality is to be monitored monthly.
- Injection well injectivity tests are to be performed monthly.
- A complete analysis of the injectate is to be performed yearly.
- Injection well mechanical integrity tests are to be performed every five years.

5.3 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 County can apply for an operating permit. The construction permit for IW-1 expires August 26, 2015. 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.

5.3.1 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 zone.

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 (**Table 5-1**).

Table 5-1
DZMW-1 Water Quality and Pressure Monitoring

Parameter	Units	Reporting Frequency
DZMW-1		
Maximum Water Level or Pressure	ft NAVD or psi	Daily/Monthly
Minimum Water Level or Pressure	ft NAVD or psi	Daily/Monthly
Average Water Level or Pressure	ft NAVD or psi	Daily/Monthly
Water Quality		
Ammonia	mg/L	Weekly
Total Kjeldahl Nitrogen (TKN)	mg/L	Weekly
Specific Conductivity	(µmhos/cm)	Weekly
Total Dissolved Solids (TDS)	mg/L	Weekly
pH	Std units	Weekly
Chloride	mg/L	Weekly
Sulfate	mg/L	Weekly
Field temperature	°C	Weekly
Sodium	mg/L	Monthly
Calcium	mg/L	Monthly
Potassium	mg/L	Monthly
Magnesium	mg/L	Monthly
Iron	mg/L	Monthly
Bicarbonate	mg/L	Monthly
Gross Alpha*	pCi/L	*Monthly
Radium 226*	pCi/L	*Monthly
Radium 228*	pCi/L	*Monthly
BOD5	mg/L	Monthly
COD	mg/L	Monthly
Total Suspended Solids (TSS)	mg/L	Monthly
Fecal Coliform	Cts/100 mL	Monthly
*Lower Monitor Zone Only		

5.3.2 Injection Well Data Collection

Records starting from FDEP's authorization to begin operational testing 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. The pressure and flow monitoring requirements are listed in **Table 5-2** and in the construction permit.

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

Table 5-2
IW-1 Monitoring Parameters

Parameter	Units	Reporting Frequency
IW-1		
Injection Pressure	psi	Daily/Monthly
Maximum Injection Pressure	psi	Daily/Monthly
Minimum Injection Pressure	psi	Daily/Monthly
Average Injection Pressure	psi	Daily/Monthly
Annular Pressure	psi	Daily/Monthly
Maximum Annular Pressure	psi	Daily/Monthly
Minimum Annular Pressure	psi	Daily/Monthly
Average Annular Pressure	psi	Daily/Monthly
Flow Rate	gpm	Daily/Monthly
Maximum Flow Rate	gpm	Daily/Monthly
Average Flow Rate	gpm	Daily/Monthly
Minimum Flow Rate	gpm	Daily/Monthly
Total Volume Leachate Injected	gallons	Daily/Monthly
Fluid added to/removed from Annulus	gallons	Daily/Monthly
Pressure added to/removed from Annulus	psi	Daily/Monthly
Leachate Water Quality		
Ammonia as N	mg/L	Monthly
Total Kjeldahl Nitrogen (TKN)	mg/L	Monthly
Nitrate and Nitrite as N	mg/L	Monthly
Total Nitrogen	mg/L	Monthly
Specific Conductivity	(µmhos/cm)	Monthly

Total Dissolved Solids (TDS)	mg/L	Monthly
pH	Std units	Monthly
Chloride	mg/L	Monthly
Sulfate	mg/L	Monthly
BOD5	mg/L	Monthly
COD	mg/L	Monthly
Total Suspended Solids (TSS)	mg/L	Monthly
Fecal Coliform	Cts/100 mL	Monthly
Field temperature	°C	Monthly
Sodium	mg/L	Monthly
Calcium	mg/L	Monthly
Potassium	mg/L	Monthly
Magnesium	mg/L	Monthly
Iron	mg/L	Monthly
Bicarbonate	mg/L	Monthly
Gross Alpha	pCi/L	Monthly
Radium 226	pCi/L	Monthly
Radium 228	pCi/L	Monthly
Primary and Secondary Drinking Water Standards		Annually (may be a combined sample from the leachates being injected)

5.3.3 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 should be 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 casing. 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.

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 well and wellhead pressures are to be recorded during this period. Pressure fall off is to be recorded as part of the monthly specific injectivity test.

5.3.4 Mechanical Integrity

An injection well has mechanical integrity when there is no injection fluid movement horizontally into the adjacent formation through the well injection casing or vertically up from the bottom of the injection casing. 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 May 25, 2016, which is 5 years following pressure test conducted on the FRP tubing. 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 Plugging and Abandonment Plan/Financial Responsibility

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.
- Remove the YBI packer and FRP Injection tubing.
- Fill the open hole with crushed limestone to 15 feet below the final casing, confirming the depth of fill with a tremie pipe or wire line.
- Place a sand cap on the crushed limestone to 10 feet below the bottom of the 12-inch casing.
- Fill the open hole and 12-inch diameter casing to land surface 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 lower 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.

Cost estimates for plugging and abandoning the injection well and monitor well zones were presented in the application materials (MWH Americas, 2010) and the Final Operations & Maintenance Manual (MWH Americas, 2011). The cost estimate for plugging and abandoning the injection well system should be updated annually, according to Specific Condition 10 of the Construction Permit.

Section 6
References

6.0 REFERENCES CITED

Applin, P. L., and Applin, E. R., 1944, Regional Subsurface Stratigraphy and Structure of Florida and Southern Georgia: American Association of Petroleum Geologists Bulletin, v. 28, p. 1673-1753.

Bennett, M.W., 2002, Immokalee Water & Sewer District Wastewater Treatment Plant Collier County, Florida. Technical Publication WS-14. SFWMD, West Palm Beach, FL

Bennett, M.W., Anderson S., and Rectenwald E. 2004, Preliminary Report: Hydrogeologic Investigation of the Floridan Aquifer System, R.D. Keene County Park, Orange County, Florida. Water Supply Department, SFWMD, West Palm Beach, FL

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.

Ceryak, R., Knapp, M., and Burnson, T, 1983, The Geology and Water Resources of the Upper Suwannee River Basin, Florida, Report of Investigation no. 87, Bureau of Geology, Division of Resource Management, Florida Department of Natural Resources, 1983.

Chen, C.S., 1965, The Regional Lithostratigraphic analysis of Paleocene and Eocene Rocks of Florida: Florida Geological Survey Bulletin 45, 105 p.

Cooke, C.W., and Mansfield, W. C., 1936, Suwannee limestone of Florida: Geological Society of America Proceedings, p. 71-72.

Cooper, H.H. and C.E. Jacob, 1946. A generalized graphical method for evaluating formation constants and summarizing well field history, Am. Geophys. Union Trans., vol. 27, pp. 526-534.

Dall, W.H., and Harris, G.D., 1892, Correlation papers - Neocene: United States Geological Survey Bulletin 84, 349 p

Dunham, R. J., 1962, Classification of Carbonate Rocks According to Depositional Texture. In: Ham, W. E. (ed.), Classification of carbonate rocks: American Association of Petroleum Geologists Memoir, p. 108-121.

Hantush, M.S., 1960. Modification of the theory of leaky aquifers, Jour. of Geophys. Res., vol. 65, no. 11, pp. 3713-3725.

Haberfeld, J. L. (1991), Hydrogeology of Effluent Disposal Zones, Floridan Aquifer, South Florida. Ground Water, 29: Pages 186–190.

Knapp, M.S., Burns, W.S., and Sharp, T.S., 1986, Preliminary Assessment of the Groundwater Resources of Western Collier County, Florida: West Palm Beach, South Florida Water Management District Technical Publication 86-1, 106 p.

Mansfield, W. C., 1939, Notes on the Upper Tertiary and Pleistocene mollusks of peninsular Florida: Florida Geol. Survey Bull. 18, 75 p., 4 pls., 2 figs.

Meyer, F.W., 1989, Hydrogeology, Ground-Water Movement, and Subsurface Storage in the Floridan Aquifer System in southern Florida: U.S. Geological Survey Professional Paper 1403-G, 59 p.

Miller, J. A., 1986, Hydrogeologic framework of the Floridan Aquifer system in Florida and in parts of Georgia, Alabama, and South Carolina: U.S. Geological Survey, Professional Paper 1403-B, 91 p., 33 plates.

Missimer & Associates, Inc., 1990, Safe yield determination by three-dimensional hydraulic modeling of the Lower Tamiami aquifer beneath Golden Gate Estates, Collier County, Florida: Consultants Report to Collier County, 158 p.

Missimer & Associates, 1993, Phase II Collier County Aquifer Storage and Recovery Project Preliminary Report: 47 p.

Missimer, T.M., 1997, Late Oligocene to Pliocene evolution of the central portion of the South Florida Platform: Mixing of Siliciclastic and Carbonate Sediments: Ph.D. Dissertation, University of Miami, 2 Volumes, 993 p.

Moench, A.F., 1985. Transient flow to a large-diameter well in an aquifer with storative semiconfining layers, Water Resources Research, vol. 21, no. 8, pp. 1121-1131

MWH, 2010, LCRSWDF IW-1 Permit Application Report, Consultants Report Prepared for Lee County Solid Waste Division, 58 p.

MWH, 2012, LCRSWDF Class I Deep Injection Well System Operation and Maintenance Manual, Consultants Report Prepared for Lee County Solid Waste Division, 42 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.

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

Reese, R. S., 1998, Hydrogeology and the Distribution and Origin of Salinity in the Floridan Aquifer System, Southwestern Florida, Water Resource Investigations Report 99-4253, 86p.

Reese, R.S., 2000, Hydrogeology and the Distribution of Salinity in the Floridan Aquifer System, Southwestern Florida: U.S. Geological Survey Water-Resources Investigations Report 98-4253, 86 p.

Scott, T. M., 1988, The lithostratigraphy of the Hawthorn Group (Miocene) of Florida: Florida Geological Survey Bulletin 59, 148 p.

Southeastern Geological Society (SEGS) Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986, Hydrogeological units of Florida: Florida Geological Survey Special Publication 28, 8 p.

Sproul et al, 1972, Saline water intrusion from deep artesian sources in the McGregor Isles area of Lee County, Florida: Florida Bureau of Geology Information Circular 75, 34 p.

Theis, C. V. (1935). “The relation between lowering of the piezometric surface and rate and duration of discharge of a well using groundwater storage.” Transactions of the American Geophysical Union, 16, 519-524

Wedderburn, L.A., Knapp, M.S., Waltz, D.P., and Burns, W.S., 1982, Hydrogeologic Reconnaissance of Lee County, Florida: West Palm Beach, South Florida Water Management District Technical Publication 82-1, 192 p.