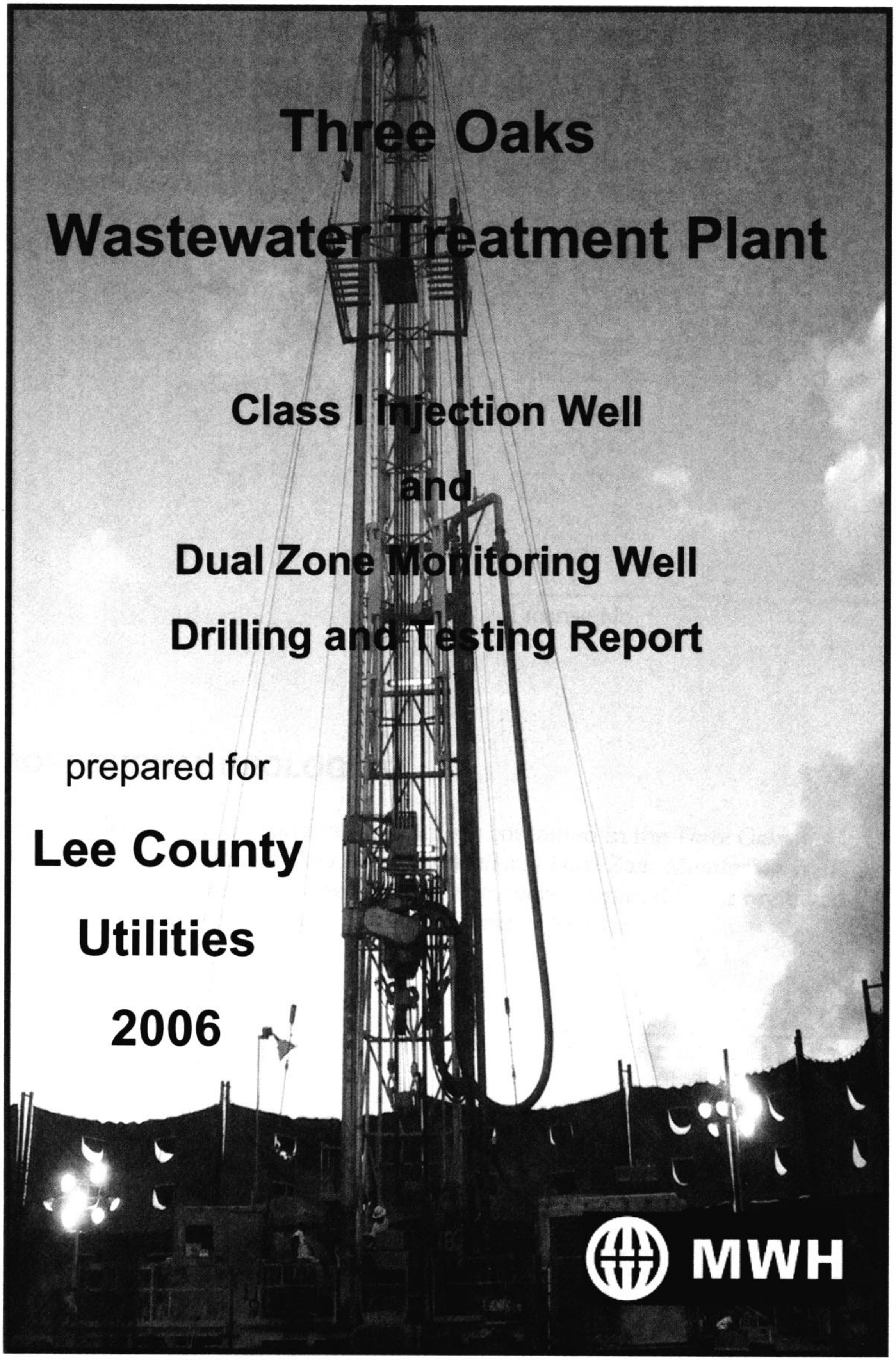

Three Oaks Wastewater Treatment Plant

Class I Injection Well and Dual Zone Monitoring Well Drilling and Testing Report

prepared for

Lee County Utilities

2006

MWH

Certifications

PROFESSIONAL ENGINEER

The engineering features of the *Three Oaks Wastewater Treatment Plant, Class I Injection Well and Dual Zone Monitoring Well Drilling and Testing Report* for Lee County, 2006 were prepared by, or reviewed by, a Licensed Professional Engineer in the State of Florida.

Philip L.Waller, P.E.

8-23-06
Date

33266
License No.

PROFESSIONAL GEOLOGIST

The geological evaluation and interpretations contained in the *Three Oaks Wastewater Treatment Plant, Class I Injection Well and Dual Zone Monitoring Well Drilling and Testing Report* for Lee County, 2006, were prepared by, or reviewed by, a Licensed Professional Geologist in the State of Florida.

Gordon P. Kennedy, P.G.

8/22/06
Date

1346
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THREE OAKS WASTEWATER TREATMENT PLANT
CLASS I INJECTION WELL/ DUAL ZONE MONITORING WELL
DRILLING AND TESTING REPORT

FIGURES

TABLES

APPENDICES

LIST OF ABBREVIATIONS

BHA	Bottom hole assembly
BHCS	Borehole Compensated Sonic
BHTV	Borehole Televiewer
bls	below land surface
CBL	Cement Bond Log
cm/sec	Centimeter per second
DIL	Dual Induction Log
DZMW	Dual Zone Monitoring Well
EPA	Environmental Protection Agency
(°F)	Fahrenheit
F.A.C	Florida Administrative Code
FDEP	Florida Department of Environmental Protection
FRP	Fiberglass reinforced tubing
ft/day	Feet per day
ft^2/day	Squared feet per day
gpd/ft	Gallons per day per foot
gpd/ft^3	Gallons per day per cubic foot
gpm	Gallons per minute
GRT	Gamma ray top
GRM	Gamma ray middle
GRB	Gamma ray bottom
ID	Inside diameter
ILD	Deep resistivity
ILM	Medium resistivity
IW	Injection Well
LAF	Log after flush
LCU	Lee County Utilities
LL3	Shallow resistivity
LMZ	Lower Monitoring Zone
LOP	Log out of position
MGD	Million gallons per day
mg/l	Milligrams per liter
mCi	MilliCurie
MIT	Mechanical Integrity Testing
MOR	Monthly Operating Report
MWH	MWH Americas, Inc.
mV	Millivolt
NAVD	North American Vertical Datum
NOAA	National Oceaning and Atmospheric Administration

NVGD	National Geodetic Vertical Datum
OD	Outside diameter
ohm-m	ohm-meters
PMW	Pad Monitoring Well
psi	pounds per square inch
PVC	Polyvinyl chloride
ROWTP	Reverse Osmosis Water Treatment Plant
RTS	Radioactive Tracer Survey
SC	Specific conductivity
SCBL	Sector Cement Bond Log
SFWMD	South Florida Water Management District
SG	Specific gravity
SP	Spontaneous potential
TAC	Technical Advisory Committee
TD	Total depth
TDS	Total Dissolved Solids
UMZ	Upper Monitoring Zone
USDW	Underground Source of Drinking Water
USGS	United States Geological Survey
VDL	Variable Density Log
YBI	Youngquist Brothers, Inc.
WWTP	Wastewater Treatment Plant
(%)	Percent
µS/cm	Micro-Siemens per centimeter
(Φ)	porosity

Section 1

Section 1

MWH

Section 1 Introduction

1.1 BACKGROUND

Lee County Utilities (LCU) owns and operates of the Three Oaks Wastewater Treatment Facility (WWTP) in central Lee County, Florida. The current capacity of the plant is 3.0 million gallons per day (MGD). Due to the continuing growth of the area, LCU plans to increase the capacity of the plant to 6.0 MGD and construct a deep injection well to dispose of the treated effluent.

The purpose of this report is to provide documentation of the construction and testing of the Class I non-municipal injection well system at the Three Oaks WWTP. The project site, shown on **Figure 1-1**, is located at 18521 Three Oaks Parkway, which is just west of I-75, approximately two miles south of Alico Road in Fort Myers, Florida.

On behalf of LCU, a Construction Permit Application for the Three Oaks WWTP deep injection well system was prepared and submitted by MWH Americas, Inc. (MWH) to the Florida Department of Environmental Protection (FDEP) for approval. On October 11, 2004, the FDEP issued Construction Permit No. 38436-178-UC (**Appendix A**). This permit allowed for the construction of a Class I injection well (IW-1) and associated dual zone monitoring well (DZMW-1) at the Three Oaks WWTP.

Youngquist Brothers, Inc. (YBI) of Fort Myers, FL conducted the drilling, construction, and testing activities of the deep injection well system. MWH was the LCU's onsite representative, providing construction observation and technical services required to comply with the construction permit. MWH also analyzed the test data. The test results are presented in this report.

Periodically, the injection well may be used to dispose of concentrate generated at the Pinewood Reverse Osmosis Water Treatment Plant (ROWTP). Accordingly, the Class I injection well was constructed as a tubing and packer well as required by the Florida Administrative Code (F.A.C.) 62-528.410. Fiberglass-reinforced pipe (FRP) was used as the injection tubing to minimize potential problems with corrosion from the injected fluids. The injection interval is the Boulder Zone of the lower Oldsmar Formation at a depth between approximately 2,100 and 2,860 feet below land surface (bls). The injection well will have a maximum injection rate of 7.4 MGD, approximately 5,139 gallons per minute (gpm).

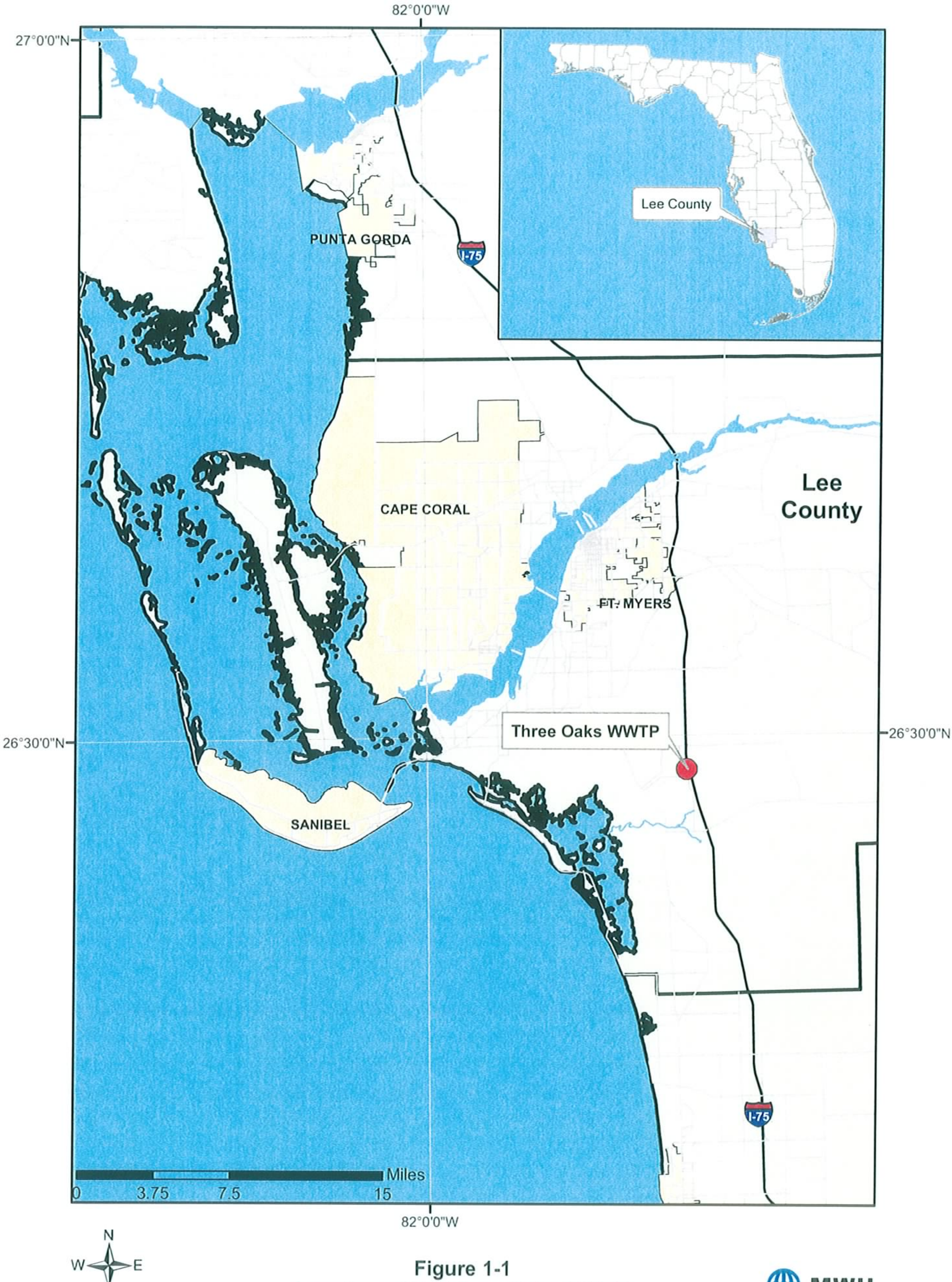

Figure 1-1
Location of the Three Oaks WWTP

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1.2 SCOPE

Construction and testing of the wells were performed in accordance with Chapter 62-528 F.A.C., recommendations of the FDEP Technical Advisory Committee (TAC), and requirements of the Permit. Construction and testing activities were conducted in accordance with Specific Condition 2 of the Permit. This report was prepared as required by Specific Condition 5f of the Permit.

1.3 PROJECT OVERVIEW

Construction of the deep injection well system included drilling and construction of six shallow pad monitoring wells (PMWs), installation of a temporary steel drilling pad, and construction and testing of IW-1 and DZMW-1. The Notice-to-Proceed was issued October 11, 2004. Major construction activities were completed August 15, 2005. Final Completion was reached October 16, 2005 following the successful performance of the injection test.

Construction and testing activities were reported weekly to the FDEP TAC. The FDEP 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).

Section 2

Section 2

Section 2
Construction Details

2.1 INTRODUCTION

This section of the report describes the construction activities for IW-1 and DZMW-1. The approximate locations of IW-1 and DZMW-1 at the Three Oaks WWTP site are shown on **Figure 2-1.** A summary of the construction activities for each well was prepared for each shift in the form of a daily shift report. The daily shift reports are provided in **Appendix B.**

2.2 SITE DEVELOPMENT

The construction site at the Three Oaks WWTP is essentially flat, with elevations ranging between 18.2 and 20.2 feet above the North American Vertical Datum of 1988 (NAVD 88).

2.2.1 Containment Pad

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

Prior to construction, the area where the containment pad was to be placed was graded to an elevation of 18.2 feet above NAVD 88. The pad was designed to support the greatest possible load that might be placed on it during well construction, and had dimensions of approximately 44 by 50 feet with a 2-foot high retaining wall on the perimeter. The total storage volume of the pad is approximately 27,000 gallons.

The retaining wall was designed to protect the surficial aquifer by containing fluid spills within the limits of the pad. The surficial aquifer was protected principally from saline formation water encountered during the drilling of IW-1 and DZMW-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.

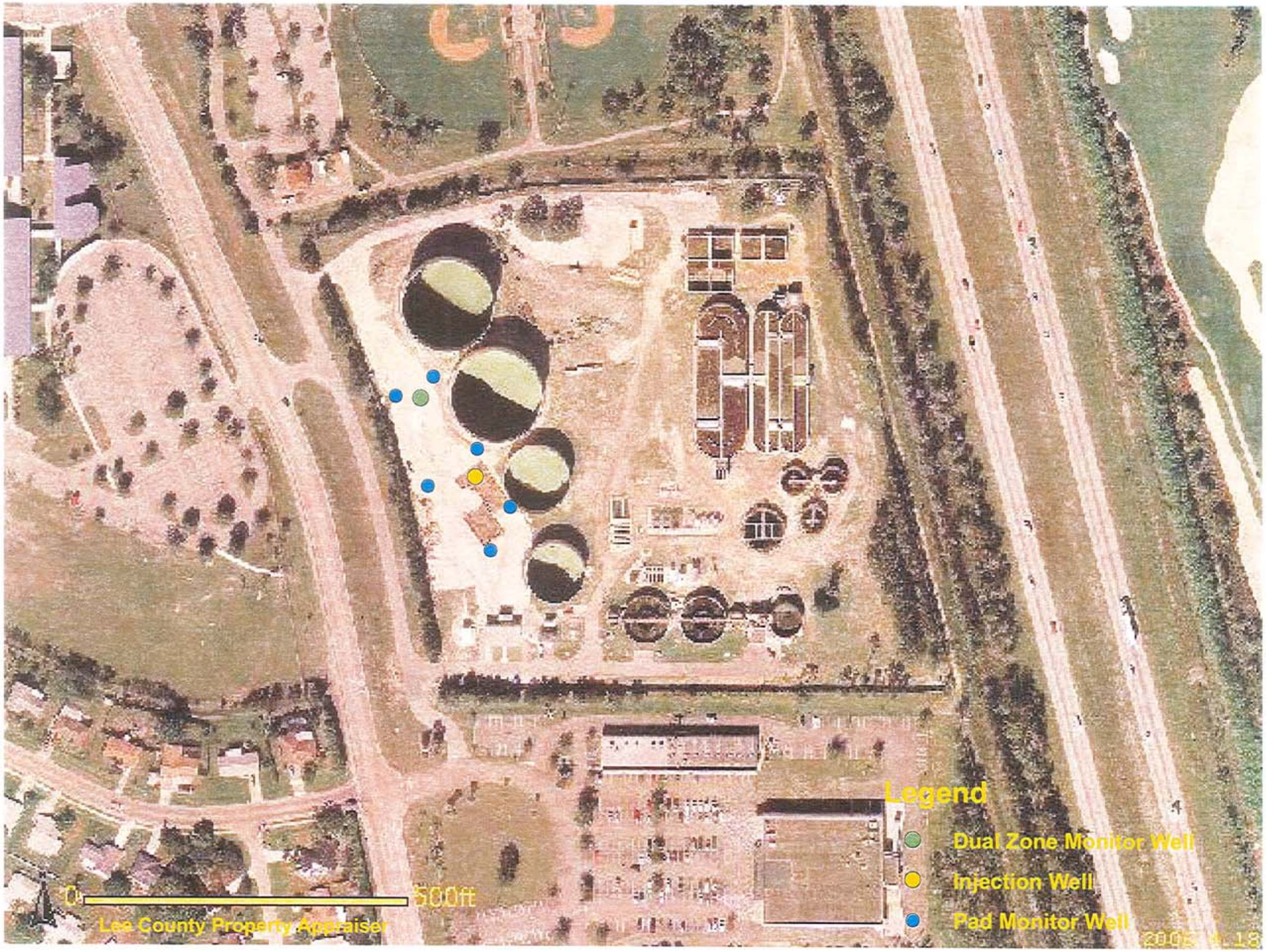
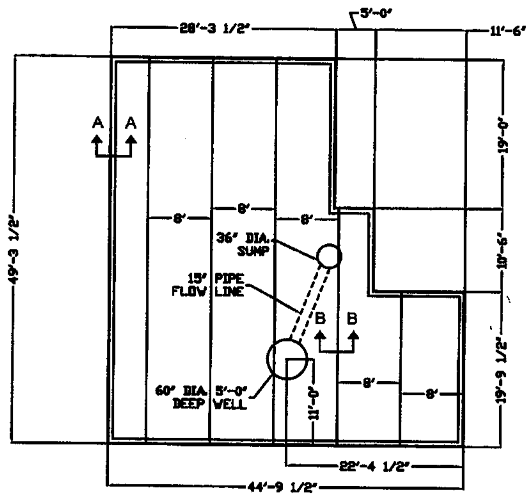
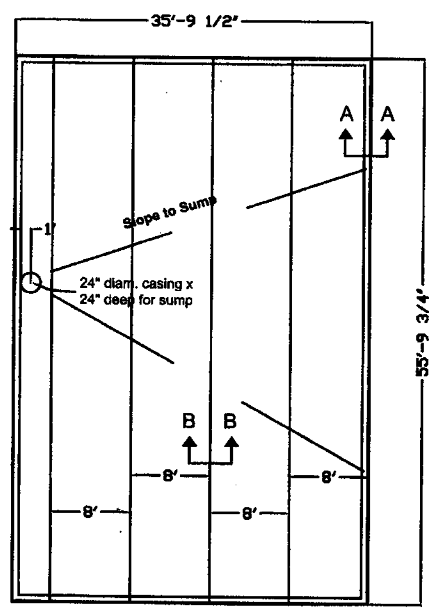


Figure 2-1
Locations of IW-1, DZMW-1, and Pad Monitor Wells
at the Three Oaks WWTP Site

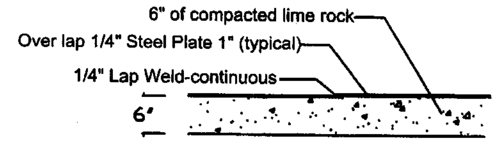
MWH



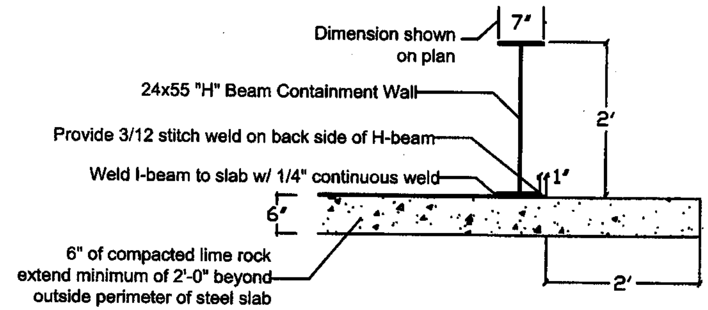
Steel Drilling Pad



Mud System Pad



Section B-B
Typical Lap Joint



Section A-A
Typical Wall Section

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:

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15465 Pine Ridge Rd.
Ft. Myers, Fl. 33908
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1-6-07

TKW CONSULTING ENGINEERS, INC
environmental • civil • structural

MWH

Figure 2-2
Steel Containment Pad

Not to Scale

2.2.2 Pad Monitor Wells

Six Pad Monitoring Wells (PMWs) were installed prior to the start of drilling activities for the Three Oaks WWTP injection well system. The purpose of the PMWs is to monitor the water quality of the surficial aquifer adjacent to the drilling pad during drilling. The pad wells were located to the northeast, northwest, central-east, central-west, southeast, and southwest of the drilling pad.

The approximate locations of the PMWs are shown in **Figure 2-1**. Each PMW was constructed to a depth of approximately 15 feet bls. The wells have approximately 10 feet of 2-inch diameter 20-slot Schedule 40 PVC casing at the base and 5 feet of 2-inch diameter Schedule 40 PVC blank casing from the top of screen to land surface. **Figure 2-3** shows a schematic diagram of a typical shallow PMW at the Three Oaks WWTP.

2.3 WELL CONSTRUCTION SEQUENCE

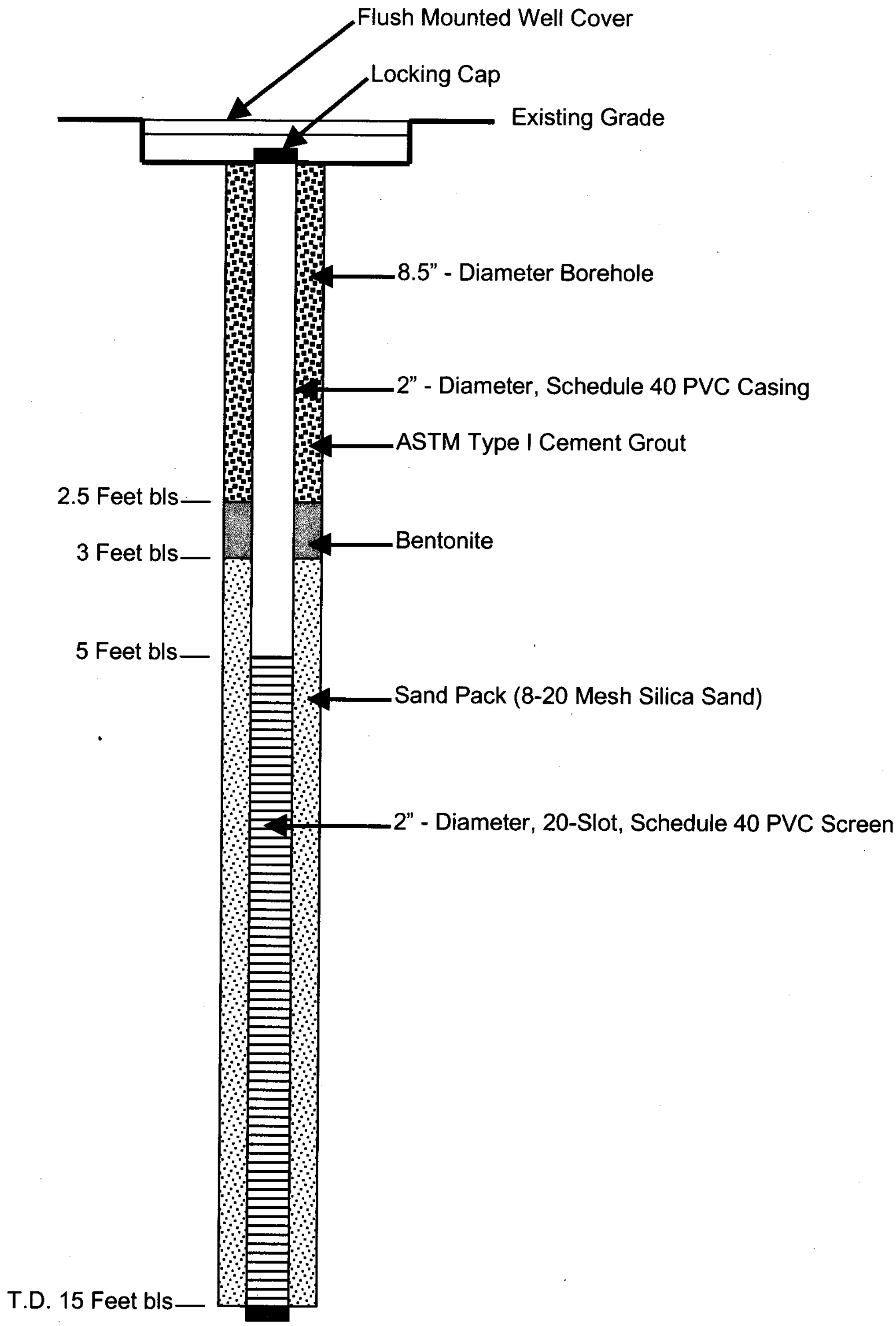
The drilling and construction operations for the Three Oaks WWTP injection well system began February 4, 2004. Major construction activities were completed August 15, 2005. Drilling operations were conducted on a 24 hours a day, 7 days per week schedule. On June 20, 2005, the drilling operations changed to 24 hours a day, 5 days per week schedule. Descriptions of the construction activities for IW-1 and DZMW-1 are provided below.

2.3.1 Operating Procedures

Drilling Methods

The surficial aquifer and clay intervals of the upper part of the Hawthorn Group were drilled using the direct rotary drilling method with bentonite based drilling mud. Drilling through the lower part of the Hawthorn Group, as well as the limestone and dolostone units below, was accomplished using a reverse circulation air-rotary drilling method to prevent loss circulation of drilling fluids and formation damage that would have occurred using the mud rotary drilling method. The reverse circulation drilling allowed for collection of cuttings that were not contaminated by drilling fluids and collection of formation water samples.

During drilling operations, all drilling fluid was contained in a closed system. The diameter of the drill bits used and depths to which the bits penetrated were a function of the hydrology and geology at the Three Oaks WWTP site, the design of the wells, and the regulatory requirements for the injection well project. Extensive sampling and testing were conducted in each borehole to aid in the final design of each well. Specifics of the testing program and data obtained from testing are presented in **Section 4**.



MWH

Figure 2-3

Shallow Pad Monitor Well (PMW)

Not to Scale

Pilot Hole Drilling

The various intervals penetrated were initially drilled as a pilot hole with a 12¼-inch diameter bit. The reason for drilling with a 12¼-inch diameter bit was to facilitate the reverse-air drilling process and to minimize negative effects of large diameter boreholes on geophysical logs. The 12¼-inch diameter borehole also provided an optimal diameter for use with the drilling contractor's inflatable packers.

Borehole Deviation Surveys

Directional (deviation) surveys were conducted on the pilot and reamed boreholes to ensure the boreholes did not deviate significantly from plum and prevent, hinder, or interfere with casing and cement grout placement. Surveys were performed every 80 feet during drilling to record the inclination of the drill pipe in the hole. The survey results were recorded with a pinhole punch on a paper disk, on which there are numbered rings corresponding to degrees. The average drift from vertical in IW-1 and DZMW-1 was of 0.29 and 0.31 angular degrees, respectively. The injection well and dual zone monitor well pilot and reamed boreholes inclination remained within the 0.5 degree specification limit. A summary of the deviation surveys conducted during drilling operations for IW-1 and DZMW-1 is presented in **Appendix C**.

Pilot Hole Cementing

Following pilot hole drilling, geophysical logging and packer testing, the pilot holes for both IW-1 and DZMW-1, were cemented. This cementing procedure was conducted to prevent the pilot hole from becoming a conduit of groundwater flow during subsequent borehole reaming operations and to aid the reaming bit in maintaining alignment with the pilot hole between formations. After cementing the pilot holes, each pilot interval was drilled to a diameter large enough to accommodate the casing and annulus in accordance with FDEP regulations.

Casing and Injection Tubing Installation

After drilling/reaming each borehole interval to the required size and depth, a steel casing string was installed in the borehole. Three casing strings were installed in IW-1 along with an FRP injection tubing as shown in **Figure 2-4**. Two casing strings were installed in the DZMW-1, also as shown in **Figure 2-4**.

Steel casing installation was accomplished by constructing and setting each casing string to the desired depth in the reamed borehole interval and placing cement grout in the annular space behind the casing string. Grouting was done to hold the casing string in place and to create a water-tight seal in the annulus. Each casing string was constructed by first suspending the bottom (initial) casing joint of the string in the borehole with the top of the joint above the drilling table using clamps and/or slips. A second casing joint was hoisted above and aligned with the initial joint in a vertical position. The two casing joints were then welded end-to-end. The partially constructed casing string was then lowered into the borehole and suspended with the top of the upper joint positioned above the drilling table using clamps and/or slips. This process was repeated until all of the casing joints were welded to the casing string and lowered into the borehole to the desired depth. As the casing string was constructed and lowered into place, steel centralizers were welded to the outer wall of the steel casing string to keep the casing string centered in the borehole and to help ensure that the subsequent cement grout seal was placed around the casing with no discernable voids. Cement grouting of the annulus was accomplished by positive displacement after the casing string was set and suspended to the desired depth.

The FRP tubing for the injection well was installed in a similar manner except that the joints were threaded (not welded), centralizers were strapped to the FRP string, and a corrosion inhibiting fluid was placed in the annular space behind the FRP tubing. During installation, the FRP threaded connections were tightened to the torque requirements by an onsite assembly team sent by the manufacturer. The FRP tubing was suspended from the surface and set into a positive-seal packer at the base of the final steel casing. This packer creates a hydraulic seal between the outer wall of the FRP tubing and the inner wall of the final casing, isolating the annulus from the injection zone. A summary of the casing used in IW-1 and DZMW-1 are presented in **Tables 2-1 and 2-2,** respectively. The mill certificates for the casing used in the construction of both wells are provided in **Appendix D.**

Table 2-1
IW-1 Casing Summary

Casing Name (Total Depth) (feet)	Diameter (inches)	Wall Thickness (inches)	Type of Casing	Standard Classification	Connection
Surface (490)	40 Outside Diameter (OD)	0.375	Spiral Welded/ Rolled Steel	ASTM A 139 Grade B	Beveled end Welded
Intermediate (1,530)	30 OD	0.375	Spiral Welded/ Rolled Steel	ASTM A 139 Grade B	Beveled end Welded
Final (2,100)	20 OD	0.500	Rolled Steel Seamless	ASTM A 53 Grade B	Beveled end Welded
Injection Tubing (2,100)	14.5 Inside Diameter (ID)	0.799	FRP	ASTM D2310	8-round Upset Joints

Table 2-2
DZMW-1 Casing Summary

Casing Name (Total Depth) (feet)	Diameter (inches)	Wall Thickness (inches)	Type of Casing	Standard Classification	Connection
Surface (490)	24 OD	0.375	Spiral Welded/ Rolled Steel Seamless	ASTM A 53 Grade B	Beveled end Welded
Intermediate (1,150)	16 OD	0.500	Rolled Steel Seamless	ASTM A 53 Grade B	Beveled end Welded
Final Upper (1,460)	6.625 OD	0.510	FRP	ASTM D2310	8-round Upset Joints

*N/A: Not Applicable

Welding of Casing

The factory-beveled ends of all steel casing joints were welded by certified welders to required specifications, using shielded metal arc welding techniques. Each connection was made using a minimum of 2 passes. The first pass was a hot pass, which served as the initial weld between the joints. This weld was subsequently ground, cleaned, and inspected. Subsequent passes served as filler, and were used to completely fill the beveled gap. Each pass was wire-brushed clean and inspected prior to the next pass.

The steel casing in each well was centralized in the borehole using steel straps welded at intervals of 0, 90, 180 and 270 degrees (°) around the circumference of the casing at approximately 200 feet vertical intervals. The FRP injection tubing was centralized with steel straps fastened at 0, 120, and 240° around the circumference of the tubing. Two sets of steel straps were attached to the FRP tubing using stainless-steel bands at approximately 30-foot intervals.

Cementing of Casing

For each size and type of casing the theoretical collapse pressure for the casing was calculated using casing dimensions, the mud/fluid weight inside the casing, and the weight of the cement in the annular space.

The bottom 250 feet of the surface and intermediate casings in both, the monitor and the injection well, were pressure grouted into place with neat cement (approximately 15.7 pounds per gallon, with a yield of approximately 1.18 cubic feet per sack). Following pressure grouting, a 12 percent (%) cement-bentonite gel (approximately 12.6 pounds per gallon, with a yield of approximately 2.2 cubic feet per sack) was placed into the annulus of the well by the tremie method. In certain cases, calcium chloride was used in the cement mix to accelerate the curing process.

The final casing string of IW-1 was cemented by placing neat cement into the annulus of the well by the tremie method. Following neat cement, a 12 % cement-bentonite gel (approximately 12.6 pounds per gallon, with a yield of approximately 2.2 cubic feet per sack) was also placed into the annulus of the well to the surface by the same method.

Samples of cured cement were taken during each cementing stage. Once the sample had cured, the borehole was geophysically logged for temperature to estimate the top of the cured cement stage. Following the temperature log, tremie pipe was used to tag the top of the cured cement and confirm the depth.

A summary of cement types and volume of cement used is presented in **Tables 2-3** and **2-4** for IW-1 and DZMW-1, respectively. Cement stages are designated in numerical order, with letter designations for small stages of cement performed at the onset of cementing operations. In addition, field records of all cementing operations are contained in **Appendix E**. The theoretical volume of cement required for a certain interval of annulus in a borehole was calculated using the caliper log run inside the reamed hole.

Table 2-3
Summary of Casing Setting Depths and Cement Volumes for IW-1

Casing	Diameter (inches)	Casing Thickness (inches)	Casing Depth (feet bls)	Date	Stage #	Type Of Cement	Volume Of Cement (ft^3)	Cement Fill Height (feet bls)
Surface (steel)	40 OD	0.375	490	2/12/05	1A	Neat	1,009	Surface
					1B	12% Gel	1,403	
Intermediate (steel)	30 OD	0.375	1,530	3/10/05	1A	Neat	976	
				3/10/05	1B	12% Gel	2,390	825
				3/11/05	2	12% Gel	2,115	439
				3/12/05	3	12% Gel	1,487	Surface
Final (steel)	20 OD	0.500	2,100	5/17/05	A	Neat	7	2,098.5
				5/17/05	B	Neat	7	2,098.5
				5/17/05	C	Gravel /Neat	14	2,098
				5/17/05	1	Neat	45	2,098
				5/18/05	D	Gravel	7	2,098
				5/18/05	E	Neat	7	2,095
				5/18/05	F	Neat	7	2,092
				5/18/05	G	Neat	7	2,088.5
				5/18/05	H	Neat	7	2,079
				5/19/05	2	Neat	420	1,930
				5/19/05	3	Neat	432	1,811
				5/19/05	4	12% Gel	943	1,501
				5/20/05	5	12% Gel	741	1,186
				5/20/05	6	12% Gel	741	883
				5/21/05	7	12% Gel	847	539
				5/21/05	8	12% Gel	847	186
				5/23/05	9	12% Gel	196	109
				5/23/05	10	12% Gel	264	5

Table 2-4
Summary of Casing Setting Depths and Cement Volumes for DZMW-1

Casing	Diameter (inches)	Casing Thickness (inches)	Casing Depth (feet bls)	Date	Stage #	Type Of Cement	Volume Of Cement (ft3)	Cement Fill Height (feet bls)
Surface (steel)	24 OD	0.375	490	6/17/05	1A	12% Gel	847	
					1B	Neat	903	Surface
Intermediate (steel)	16 OD	0.500	1,150	7/26/05	1A	12% Gel	628	
				7/26/05	1B	12% Gel	471	885
				7/27/05	2	12% Gel	931	666
				7/27/05	3	12% Gel	337	555
				7/28/05	4	12% Gel	185	465
				7/28/05	5	12% Gel	741	Surface
Final (FRP Tubing)	6.625 ID	0.500	1,460	8/7/05	A	Neat w/ Calcium	11	
				8/7/05	B	12% Gel	11	1,430
				8/7/05	1	12% Gel	336	1,241
				18/8/05	2	12% Gel	67	1,204

2.3.2 Injection Well (IW-1)

Three sizes of concentric steel casing (40, 30 and 20 inches in diameter) were set in IW-1. In addition, 14-inch ID FRP tubing was used in conjunction with a packer for the injection tubing inside the final casing. The following sections summarize the phases of construction of IW-1 and have been divided according to the types of casing that were set. An illustration of the completed well is provided in **Figure 2-4**, which can be seen at the end of this section.

Surface Casing (0 to 490 feet)

Mud-rotary drilling methods were used to drill a 12¼-inch diameter pilot hole from 0 to 510 feet bls. This interval is comprised of the surficial aquifer with clay intervals of the upper Hawthorn Group (described in **Section 3**). After total depth (TD) was reached, caliper/gamma ray, dual induction, and spontaneous potential (SP) logs were run in the pilot hole.

Following geophysical logging, the 12¼-inch diameter pilot hole was reamed with a 48½-inch diameter bit to a total depth of 495 feet bls. A caliper log of the borehole was run and reviewed. The 40-inch diameter steel surface casing was then set in the borehole to a depth of 490 feet bls and cemented in place in a single stage by pressure grouting.

Intermediate Casing (0 to 1,530 feet bls)

After installation of the surface casing, the rig was prepared for reverse circulation air-rotary drilling, and a 12¼-inch diameter pilot hole was drilled to 1,830 feet bls. During drilling, two 15-feet long by 4-inch diameter continuous cores were collected and later sent to a laboratory to be tested for hydraulic and physical properties. Core logs and test results are presented in **Section 4**. After drilling was completed, geophysical logging was conducted from 1,830 feet bls up to the bottom of the surface casing. Three packer setting depths were chosen to help identify confining intervals and potential monitor zones for DZMW-1. These intervals were determined from the geophysical logs, cores, lithologic log, and from the conditions observed during drilling that were indicative of confinement within the borehole.

Based on the results of all the packer tests, geophysical logs, and pilot hole water, quality testing the base of the Underground Source of Drinking Water (USDW) was identified as 1,346 feet bls.

The FDEP approved the selected intermediate casing seat at a depth of 1,530 feet bls on March 3, 2005, and the pilot hole was plugged with cement. Reaming of the pilot hole was then done with a 38½-inch diameter drill bit to a TD of 1,535 feet bls. A caliper log was performed on the borehole in the open interval from 490 to TD. Then, the 30-inch OD steel casing was set in the borehole to the approved depth, and cemented into place in three stages.

Final Casing and Injection Tubing (0 to 2,100 feet bls)

Reverse circulation air-rotary drilling of the 12¼-inch diameter pilot hole was continued from the bottom of the intermediate casing at 1,530 feet bls, to 3,015 feet bls. While drilling this interval, five 15-feet long by 4-inch diameter continuous cores were collected to aid in evaluation of low permeability intervals, which would be used to quantify the zones of confinement. Coring depth selection was based on the geological interpretation of cuttings (lithologic samples) airlifted from the borehole and drilling conditions. After TD of the 12¼-inch diameter pilot hole was reached, a suite of geophysical logs was run. The geophysical logs were then used in conjunction with the lithologic log and drilling characteristics to select four intervals for straddle-packer testing to further assess the confining characteristics of the specific intervals.

Following packer testing, a request was submitted to the FDEP for a final casing setting depth of 2,100 feet bls. This request was based on the lithologic logs, preliminary results of coring, geophysical logs, and results of the straddle packer tests. The FDEP approved the final casing setting depth April 12, 2005.

Plugging of the 12¼-inch diameter pilot hole followed. A cement basket was set to 2,425 feet bls to isolate the injection zone, then the pilot hole was cemented up to the bottom of the intermediate casing. Reaming for the installation of the 20-inch final steel casing then proceeded with a 28 ½-inch diameter bit from 1,530 to 2,100 feet bls. Reaming of the injection zone was completed with an 18½-inch diameter bit from 2,100 to 2,860 feet bls.

During reaming of the injection zone one of the joints in the drill string sheared. This separated the drill collars and the bottom hole assembly (BHA) from the rest of the drill string. Operations were conducted to remove the collars and BHA from the borehole, which were successful on April 29, 2005. The reaming of the injection zone then proceeded to the total depth of 2,860 feet bls. A caliper/gamma log was run to total depth of the reamed hole prior to setting the 20-inch final casing to 2,100 feet bls.

The final 20-inch OD steel casing was set into the injection well borehole. A YBI positive seal packer was welded onto the base of the first joint of casing prior to casing installation to provide a seal for the annulus against the formation. In addition, an external casing packer was welded to the base of the casing string to facilitate cementing. Cementing of the final casing was accomplished in 10 stages, with temperature logging conducted after each cement stage.

A cement bond log (CBL) was conducted in the final casing of IW-1 to confirm the presence and evaluate the bond of the cement to the casing and the borehole wall. The structural integrity of the final steel casing in IW-1 was examined by running a video survey of the installed casing string and pressure testing the casing. The pressure test was performed May 24, 2005, by sealing and pressurizing the inside of the final casing to 176 pounds per square inch (psi) for 60 minutes. The final casing string was sealed at the bottom by installing and inflating a recoverable packer. The well head was sealed with a valve and pressure was applied at the well head using compressed air. The test was conducted with less than 1% pressure normal variation during the test and showed there are no leaks in the final casing

Following the pressure test, the 14.5-inch ID FRP injection tubing was installed inside the 20-inch OD steel casing and set into a positive-seal packer, near the base of the final steel casing. After the FRP tubing was lowered into the well and before the he FRP tubing was set into the positive-seal packer, the annulus between the steel casing and the FRP tubing was flushed with three well volumes of fresh water. The annulus was subsequently filled with a 1.3% solution of Barricor, an anti-corrosive fluid, after the FRP tubing was set into the positive-seal packer.

In a manner like the final steel casing, the FRP tubing was pressure tested for one hour at 175 psi. The one-hour test was successfully conducted May 31, 2005. During the test, there was no pressure change observed or recorded.

2.3.3 Dual-Zone Monitor Well (DZMW-1)

Two sizes of concentric steel casing (24 and 16-inch OD) were used to construct DZMW-1. In addition to the steel casing, a 6.625-inch ID FRP tubing was installed. An illustration of the completed well is provided in **Figure 2-5.**

Surface Casing (0 to 490 feet bls)

The conventional mud-rotary drilling method was used to drill a 12¼-inch diameter pilot hole from the surface to 505 feet bls. Dual induction, SP, and caliper/gamma ray logs of the borehole were developed and reviewed to determine the contact between the Hawthorn Group and the Suwannee Limestone. Upon completion of geophysical logging, a 32 ½-inch bit was used to ream the pilot hole for placement and cementing of the 24-inch OD steel surface casing. A caliper/gamma ray log was run after TD was reached and the log was reviewed prior to setting the surface casing in the well. The surface casing was set and cemented to a depth of 490 feet bls in one stage, by pressure grouting.

Upper Monitoring Zone (UMZ) Casing (0 to 1,150 feet bls)

After cementing the 24-inch surface steel casing, the drilling rig was configured and prepared to use the reverse air circulation drilling method to penetrate a pilot hole through the lower Suwannee Limestone. A 12¼-inch diameter pilot hole was advanced from 490 to 1,610 feet bls. A suite of geophysical logs were run in the borehole, and based on their review, in conjunction with the lithologic logs and drilling conditions, three intervals were selected for packer testing. Packer testing was conducted to quantify the hydraulic conductivity and flow conditions in the potential upper and lower monitoring zones.

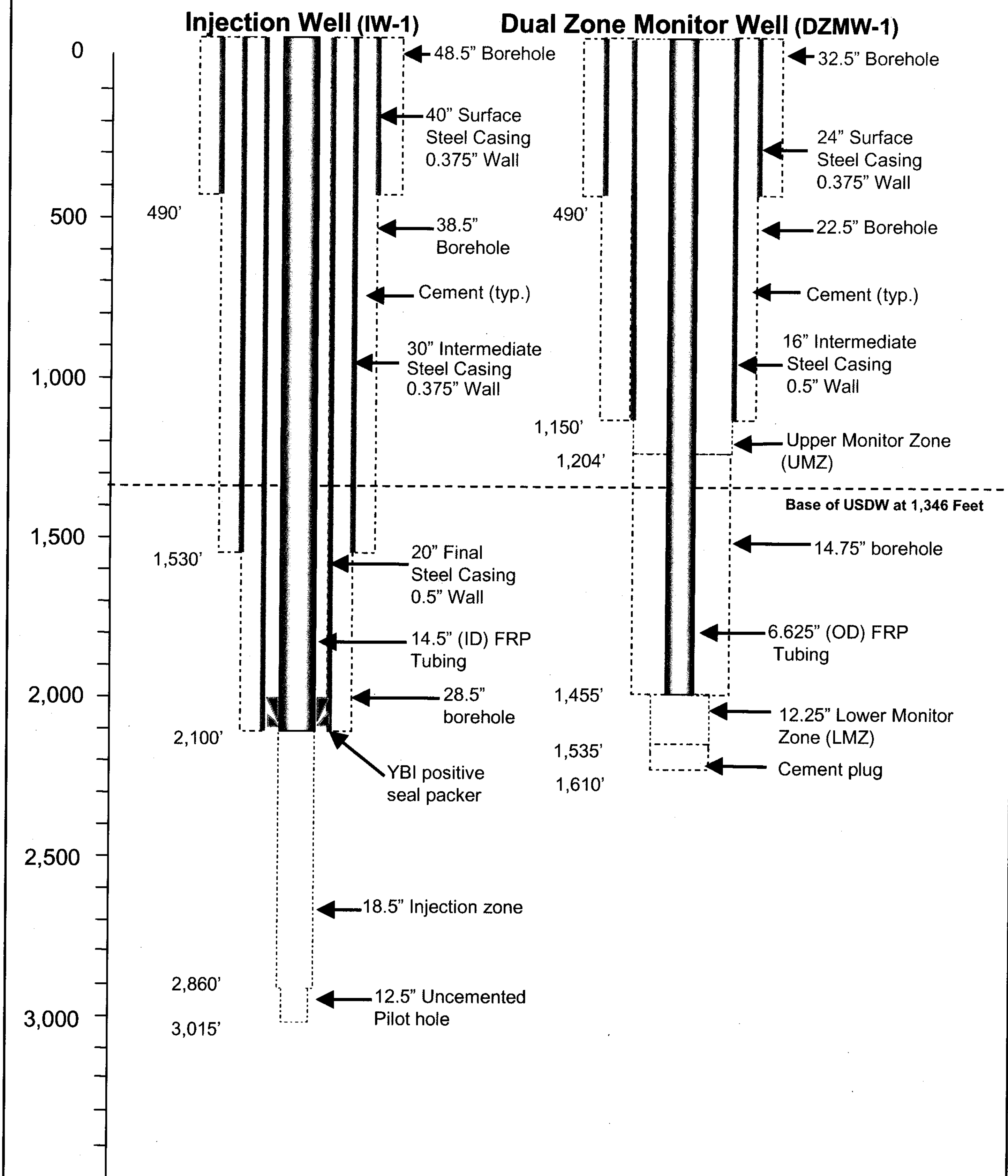
Straddle packers were set at 1,149 to 1,200 feet bls and 1,460 to 1,510 feet bls. A single packer was also placed at 1,510 feet bls to isolate the interval to 1,610 feet bls (TD). Packer tests of the borehole were performed to determine the water quality and hydraulic characteristics of the selected upper and lower monitor zone interval(s). Using results from the packer tests and geophysical logs, MWH proposed setting the upper monitor zone (UMZ) from 1,150 to 1,200 feet bls and the lower monitoring zone (LMZ) from 1,460 to 1,535 feet bls. The FDEP requested a fourth straddle packer to be placed at the interval of 1,320 to 1,380 feet bls to determine the bottom of the USDW. The UMZ and LMZ were approved by the FDEP on July 15, 2005.

Following aquifer testing, the pilot hole was cemented by placing gravel through the LMZ and UMZ. Reaming for the UMZ casing used a 22 ½-inch bit and the reverse air drilling method. The borehole was reamed to a depth of 1,155 feet bls and a suite of geophysical logs was conducted on the reamed hole to TD. The 16-inch OD intermediate steel casing was set and cemented in the borehole to a depth of 1,150 feet bls. The casing was cemented into place in five stages. The first stage of cement was placed by pressure grout and subsequent stages were completed using a tremie pipe in the annulus between the casing and the borehole wall.

Lower Monitoring Zone (LMZ) Final Casing (0 to 1,460 feet bls)

After the casing was set for the UMZ at 1,150 feet bls, a 14¾ -inch diameter borehole was drilled from 1,150 to 1,455 feet bls, and a 12¼-inch diameter borehole was drilled from 1,455 to 1,535 feet bls. Geophysical logging was conducted from the top of the UMZ casing to TD (1,150 to 1,535 feet bls).

The FRP casing was set from land surface to the top of the LMZ (1,455 feet bls). Cementing was conducted in two stages from 1,455 feet bls to the bottom of the UMZ (1,204 feet bls). The LMZ is the open hole interval from 1,455 to 1,535 feet bls. The UMZ is the open hole interval, outside the FRP, from below 1,150 feet bls to 1,204 feet bls.



MWH

Figure 2-4
Injection Well and Monitor Well Completion Details

Not to Scale

Section 3

Section 3

MWH
MONTGOMERY WATSON HARZA

Section 3
Geology and Hydrogeology

The geology and hydrology of Lee County has been described in reports by the Florida Geologic Survey (Klein, 1972), 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 Geology of Lee County Report. 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). They described the shelf as a relatively flat area in the Comanchee 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).

White (1970) divided the Florida peninsula into three geomorphic zones; the southern or distal zone, the central or mid-peninsular zone, and the northern or proximal zone. The Three Oaks site lies within the distal zone. The major physiographic feature in the area is the Immokalee Rise (White, 1970). The Rise appears to have formed during one of the Pleistocene interglacial episodes as a submarine shoal that developed offshore from higher land masses to the north. Numerous small lakes and ponds that surround the Immokalee Rise are described by White (1958): "... as in other areas where sand overlies limestone, a line of peripheral lakes has developed along the feather edge of the sand-covered area, to the extent that the sandy Immokalee Rise is ringed with small solution lakes". The occurrence of these peripheral lakes is so characteristic that the edge of the sand-covered area can be delineated by drawing a line on the map connecting the lakes.

3.1 STRATIGRAPHY

Sediments encountered during the construction of IW-1 and DZMW-1 range in age from Holocene to Eocene. Lithologic descriptions are based on samples collected from IW-1 and DZMW-1 and existing literature. Lithologic logs for IW-1 and DZMW-1 are provided in **Appendix F.** A general description of the lithostratigraphy and its relationship to the hydrostratigraphy of the site is provided below. Stratigraphic units are described in descending order. The general stratigraphy and hydrostratigraphy of the site are shown in **Figure 3-1**.

3.1.1 Undifferentiated Marine Terrace Deposits

During drilling of IW-1 and DZMW-1, undifferentiated Plio-Pleistocene surficial deposits consisted primarily of the following units, which extended to a depth of approximately 40 feet bls.

Pamlico Sand

The shallowest and youngest formation encountered in Lee County is the Pamlico Sand. The Pamlico Sand is Late Pleistocene in age (10,000 to 2.8 million years ago) and is present at the surface throughout much of South Florida. In the study area, this unit averages approximately 5 feet thick. The Pamlico Sand consists predominantly of fine to medium-grained quartz sand, with lesser amounts of shell, detrital clays and organic constituents. Shell fragments (mostly bivalves) and organic fragments (fossil roots) are commonly present. The permeability of the Pamlico Sand generally ranges from 10 to 100 ft/day depending primarily on the quantity of secondary constituents.

Undifferentiated Ft. Thompson/Caloosahatchee Unit

Undifferentiated strata of the Ft. Thompson and Caloosahatchee Formations underlie the Pamlico Sand in central Lee County. The undifferentiated unit is Pleistocene and varies lithologically. It includes fossil shell bearing quartz sands, marl, and yellow brown-to-gray moldic limestone. This unit typically ranges from 0 to 15 feet thick.

3.1.2 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 the Lee County area. 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.

An unconformity separates the upper Plio-Pleistocene deposits from the Hawthorn Group, which is approximately 540 feet thick, as observed at IW-1 and DZMW-1, and extends from 40 feet to a depth of 580 feet bls. The Peace River Formation is generally

Late Miocene in age and is found from 40 feet to 370 feet bls. The formation primarily consists of phosphatic grayish olive green to yellowish gray marine clay, which is soft and nodular, interbedded with pale greenish yellow, phosphatic and fossiliferous limestones. The Arcadia Formation is generally Early – Middle Miocene in age and observed from 370 feet to 580 feet bls. The formation is primarily light olive gray limestone with yellowish gray clay.

3.1.3 Suwannee Limestone

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 (Ceryak, etal, 1983). 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.

The contact between the Hawthorn group and the Oligocene age Suwannee Limestone may be an unconformity, but it is only marked by a gradational color change in lithology and absence of phosphate in the Suwannee. The contact is best seen by the abrupt increase in gamma ray activity in the lower section of the phosphatic Hawthorn Group. Gamma ray attenuation has been used in numerous studies in southwest Florida to determine this contact. The Oligocene unit within IW-1 and DZMW-1 is approximately 620 feet thick from 580 feet to 1,200 feet bls. It is composed primarily of well-consolidated limestones and dolostones. The limestone is yellowish gray micrite to biomicrite, with a well rounded medium grained calcarenite texture. The Suwannee Limestone is composed of moderately to well sorted foraminifera (*Dictyoconus cookei, Rotalia sp., and Amphistegina sp.*), pelloids, abraded echinoderm and mollusk fragments. Recrystallization in the dolostone is also present.

3.1.4 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. This terminology is still used by the U.S. Geological Survey and will be adhered to in this report.

The Late Eocene age Ocala Limestone is approximately 500 feet thick from about 1,200 feet to 1,700 feet bls. It is composed primarily of yellowish gray micrites to biomicrites containing the larger characteristic benthonic foramifera. These include, *Lepidocyclina* sp. *Operculinoides* sp., and *Heterostegina* sp. The gamma ray logs show less radioactivity in the Ocala Limestone than the overlying Suwannee Limestone except in the sporadic occurrences of dolostone. Textures range from poorly consolidated chalk to coquina-like grainstones, which further discerns the contact between the Suwannee and Ocala limestones.

3.1.5 Avon Park Limestone

The term "Avon Park Limestone" was originally used by Applin and Applin (1944) to describe rocks of late Middle Eocene age in northern and peninsular Florida. Miller (1986) defined the Avon Park Formation as "the sequence of predominantly brown limestones and dolomites of various textures that lies between the gray, largely micritic limestones and dolomites of the Oldsmar Formation and the white foraminiferal coquina of the Ocala Limestone." Duncan, et al (1994) describe the Avon Park Formation in southeast Florida as white to yellowish-gray limestones ranging from packstone to mudstone interbedded with light orange to grayish-brown dolostones that commonly contain organics".

The Middle Eocene age Avon Park Limestone is distinguished from the Ocala Limestone by a greater degree of lithification. The Avon Park Limestone extends from approximately 1,700 feet to a depth of 2,130 feet bls and is about 430 feet thick. The Avon Park Formation is a lithologically diverse unit. Strata consist primarily of yellowish gray limestone ranging in shade from dark to pale, which are moderately to well indurated. Induration increases towards the base of the formation. Medium light gray to dark gray, microcrystalline to crystalline dolostone are more common near the base of the formation. The dolostones are well indurated with abundant vugular dissolution and sucrosic crystallization.

3.1.6 Oldsmar Formation

Miller (1986) defined the Oldsmar Formation as "the sequence of white to gray limestone and interbedded tan to light-brown dolomite that lies between the pelletal, predominantly brown limestone and brown dolomite of the Middle Eocene and the gray, coarsely crystalline dolomite of the Cedar Keys Formation." Duncan, et al. (1994) recognized a stratigraphic marker bed (glauconite marker bed) at the top of the Oldsmar Formation. The Oldsmar Formation also commonly contains the guide fossil *Heliocostegina gyralis*.

In the IW-1 borehole, the top of the Early Eocene age Oldsmar Formation was encountered at approximately 2,130 feet and extends below the TD of IW-1, which was 3,015 feet bls. It is comprised mainly of mottled grayish orange to dusky yellowish brown and medium bluish gray, crystalline dolostones. Interbedding, within the massive dolostone, of dark yellowish brown limestone occurs in the upper part of the formation. The limestone is well indurated, biosparite, which is commonly re-crystallized.

The Oldsmar Formation of South Florida contains an intricate fractured solution channel network referred to as the "Boulder Zone." This fracture interval begins in IW-1 at a depth of approximately 2,240 feet bls, and is identified on geophysical logs by increased borehole diameters on caliper logs, long sonic transit times, and low resistivity. Long sonic transit times are due to the absence of rock and presence of caverns and massive dissolution features. Low resistivity is indicative of the conductive saline water in the Boulder Zone. Erratic drilling conditions, which behave similarly to drilling through alluvial boulders, best identify the Boulder Zone. The Boulder Zone is not alluvial in deposition, but originally marine, and represents an intricate network of vugs, caverns and fractures within the Lower Floridian aquifer. The Boulder Zone will serve as the injection zone in IW-1.

3.2 Hydrostratigraphy

The Southeastern Geological Society Committee on Florida Hydrostratigraphic Nomenclature (1986) established four major hydrogeologic units in peninsular Florida. In descending order, they are the Surficial Aquifer System, Intermediate Aquifer System, Floridan Aquifer System, and the sub-Floridan Confining Unit. In Lee County, the Floridan Aquifer System consists of the Upper Floridan aquifer, Middle Confining Unit, and Lower Floridan aquifer. According to Miller (1986), the Lower Floridan aquifer contains water with total dissolved solids (TDS) concentrations that are more than 10,000 milligrams per liter (mg/L). The Upper Floridan aquifer contains water with TDS concentrations that are generally less than 10,000 mg/L. Locally the aquifers in the Floridan Aquifer System are identified by the names of the principle formations they comprise. These are not formal names and are currently under review by the Florida Geological Survey Hydrostratigraphic Committee.

The hydrostratigraphic framework underlying the Three Oaks WWTP site, observed in IW-1 and DZMW-1, consists of the Surficial Aquifer System, the Intermediate Aquifer System and the Floridan Aquifer System. An aquifer is a saturated permeable geologic unit that can store and transmit significant quantities of water under ordinary hydraulic gradients (Freeze and Cherry, 1979). Confining zones are areas that have comparatively low hydraulic conductivity. Confining units limit the vertical transmission of water that occurs within or between aquifers. The hydrogeology at the Three Oaks WWTP site is shown in **Figure 3-1.** Although similar in depth to the stratigraphic units, the hydrogeologic properties of the subsurface can differ or remain constant within each stratigraphic unit.

Groundwater quality at the Three Oaks WWTP injection well location exhibits increasing mineralization with depth. Water sampled within the Surficial Aquifer

System and upper Intermediate Aquifer System has a TDS concentration of less than 1,000 mg/L. Brackish water contains a TDS of 1,000 to 10,000 mg/L and extends to the base of the USDW at a depth of approximately 1,346 feet as determined from borehole geophysical logs and packer testing. The USDW is defined as having a TDS concentration of 10,000 mg/L or less. A transitional zone of saline water, with a TDS concentration of 10,000 to 35,000 mg/L, is present to a depth of approximately 2,200 feet bls. Saline water of greater than 35,000 mg/L TDS is found from approximately 2,200 feet to the total depth of drilling at 3,015 feet bls in IW-1.

3.2.1 Surficial Aquifer System

The uppermost aquifer system in Lee County is the Surficial Aquifer System. This system is primarily composed of undifferentiated surficial clastic deposits and in some areas the Tamiami Limestone, which was not seen during drilling of IW-1 or DZMW-1. Infiltration of precipitation is the major recharge source for this aquifer. The hydrogeologic properties of this system are variable due to the presence of numerous clay layers that create localized semi-confining zones. Transmissivities generally vary between 1,300 and 26,700 square feet per day (ft^2/day) (MWH, 2003). The porosity is generally intergranular and sometimes moldic. The water within the Surficial Aquifer System is generally potable. Analyses of water samples from surficial pad monitor wells on the Three Oaks WWTP site resulted in TDS values of less than 460 mg/L and chloride concentrations generally less than 60 mg/L. At IW-1 and DZMW-1, this shallow aquifer system was observed to have a thickness of approximately 40 feet.

3.2.2 Intermediate Aquifer System

Below the Surficial Aquifer System lies the Intermediate Aquifer System extending from approximately 100 feet to 510 feet bls. This unit includes the Sandstone and Mid-Hawthorn aquifers and Lower Hawthorn Confining Unit. The Sandstone and Mid-Hawthorn aquifers can produce large quantities of water and are important sources of domestic supply to individual wells in Lee County.

Upper Hawthorn Confining Unit

Underlying the Surficial Aquifer System lies approximately 330 feet of soft, plastic calcareous silty clay interbedded with some permeable limestone. This unit correlates with the Peace River Formation of the Hawthorn Group and provides overall confinement between the Surficial and the Mid-Hawthorn aquifers.

Mid-Hawthorn Aquifer

The top of the Mid-Hawthorn aquifer, lies at approximately 370 feet bls in IW-1 and DZMW-1 and is about 30-feet thick. This aquifer tends to have variable transmissivity, ranging from approximately 500 to 9,000 ft^2/day (MWH, 2003). The variable transmissity is due to interbedding of thin layers of poorly consolidated micritic limestone and marine clay. Locally this aquifer has intergranular, moldic and minor fracture porosity.

Lower Hawthorn Confining Unit

Underlying and confining the Mid-Hawthorn aquifer is approximately 110 feet of mottled, plastic marine clay with lenses of micritic limestone known collectively as the lower Hawthorn Confining Unit. The low permeability of this zone is due to the high content of fine grain sediments and the dense packing of the matrix. Porous limestone beds within the confining unit do not yield significant quantities of water.

3.2.3 The Floridan Aquifer System

The Floridan Aquifer System is the deepest regional aquifer system within the area of the Three Oaks WWTP. The system is divided into upper and lower zones. The Upper Floridan aquifer is composed of a series of permeable carbonate sediments including the Lower Hawthorn, Suwannee, Ocala and Avon Park aquifers. The Lower Floridan aquifer consists of the highly transmissive Boulder Zone found within the Oldsmar Formation. The Intermediate Confining Unit separates the Upper and Lower Floridan aquifers. The individual aquifers are described below.

Lower Hawthorn Aquifer

The Lower Hawthorn aquifer occurs within the basal limestones of the Arcadia Formation of the Hawthorn Group. The predominant lithologies present are interbedded yellowish-gray fossiliferous limestones and pale olive dolomites. The limestones are generally moderately hard and have a moderate to high porosity. The Lower Hawthorn aquifer dolomites typically have a microsucrosic texture, are hard, sometimes cavernous, and have variable porosities. The top of the aquifer occurs at depths ranging from approximately 500 to 700 feet in Lee County. The top of the Lower Hawthorn aquifer is approximately 510 feet at the Three Oaks WWTP site, and extends to the depth of the Arcadia Formation of the Hawthorn Group.

Locally, the potentiometric surface of the aquifer ranges between 25 and 35 feet above the National Geodetic Vertical Datum (NGVD) based on a review of regional data. Wells tapping the aquifer typically flow at land surface due to the natural artesian pressure. The groundwater flow direction is generally to the southwest. The aquifer is recharged primarily from outside the county in central Florida. The transmissivity of the aquifer in central Lee County is approximately 20,000 to 30,000 gallons per day per foot (gpd/ft) (ViroGroup, 1993). Based on regional data, the aquifer storativity is about 2×10^{-5} and the vertical leakance is approximately 4×10^{-4} gallons per day per cubic foot (gpd/ft^3) (ViroGroup, 1993). Leakance is primarily from the underlying Suwannee aquifer through thin leaky confining units.

The Lower Hawthorn aquifer contains brackish quality water in Lee County. Dissolved chloride concentrations within the aquifer typically range from 500 to 1,000 mg/l. The Lower Hawthorn aquifer is used as a feedwater source in Lee County at a number of reverse osmosis water treatment plants, which produces potable water for municipal use.

Suwannee Aquifer

The Suwannee aquifer is comprised of porous rocks of the Suwannee Limestone Formation. There is variable hydraulic connection between the base of the Lower Hawthorn aquifer and the Suwannee aquifer. Separating the Suwannee aquifer from the overlying Hawthorn aquifer is a thin and somewhat discontinuous marl. The lithology of the Suwannee aquifer is complex. The major producing zones of this aquifer include isolated beds of relatively high porosity and permeability, which are intermingled with low permeability lime mud and marl. The permeable beds are generally composed of micrite to biosparite limestones, exhibiting intergranular and fractured porosity. Locally, the Suwannee aquifer is divided into Upper and Lower aquifer units, separated by a thin confining marl. The interval of the Lower Suwannee aquifer between 1,104 feet bls and 1,200 bls was chosen as the upper monitor zone of DZMW-1 and has a TDS of approximately 1,500 mg/L. The Suwannee aquifer is approximately 620 feet thick at IW-1 and DZMW-1.

Ocala Aquifer

The Ocala aquifer occurs within the Ocala Formation, which is approximately 500 feet thick at the Three Oaks WWTP site. The Ocala Formation is comprised of micrite to biomicrite and chalky limestones exhibiting a greater degree of induration demonstrating a lesser degree of permeability and porosity. The interval of the Ocala aquifer between 1,455 feet bls and 1,535 feet bls was chosen as the lower monitor zone of DZMW-1 and has a TDS of approximately 31,100 mg/L.

Avon Park Aquifer

The lower Ocala Limestone and upper Avon Park Limestone consists of well-indurated crystalline dolostones and well-consolidated limestones, which provide confinement between the Ocala and Avon Park aquifers. The Avon Park aquifer extends from approximately 1,700 feet bls to 1,850 feet bls, where it is confined below by the top of the Intermediate Confining Layer. The Avon Park aquifer is primarily well-indurated crystalline dolostones that display fabric selective and non-fabric selective dissolution, resulting in the formation of vugs and enlargement of bedding planes. This zone is highly permeable and porous in IW-1, with both sucrosic and fracture porosity.

Lower Floridan Aquifer System

The top of the lower Florida Aquifer System is located within the Avon Park Formation. Drilling at the site did not identify the base of the Lower Floridan Aquifer System, which is generally recognized by the first appearance of anhydrite deposits, which are characteristic of the Cedar Keys Formation. Porosity in the Lower Floridan aquifer is a mixture of primary intragranular, fabric selective, and nonfabric selective dissolution. Vug and cavern formation, as well as enlargement of bedding planes, is a result of this extensive dissolution. The Boulder Zone is included in this aquifer and was identified at the site as occurring at a depth of 2,130 feet bls. The Oldsmar Formation is the targeted injection zone, due to the highly permeable and saline nature of the Boulder Zone.

Intermediate Confining Unit

The Upper Floridan aquifer is separated from the Lower Floridan aquifer by the Intermediate Confining Unit. The Intermediate Confining Unit is comprised of low porosity, low permeability, well cemented, highly altered, dense dolomite in the upper Oldsmar Formation. This confining unit is found in the interval from 1,850 feet bls to approximately 2,100 feet bls within IW-1.

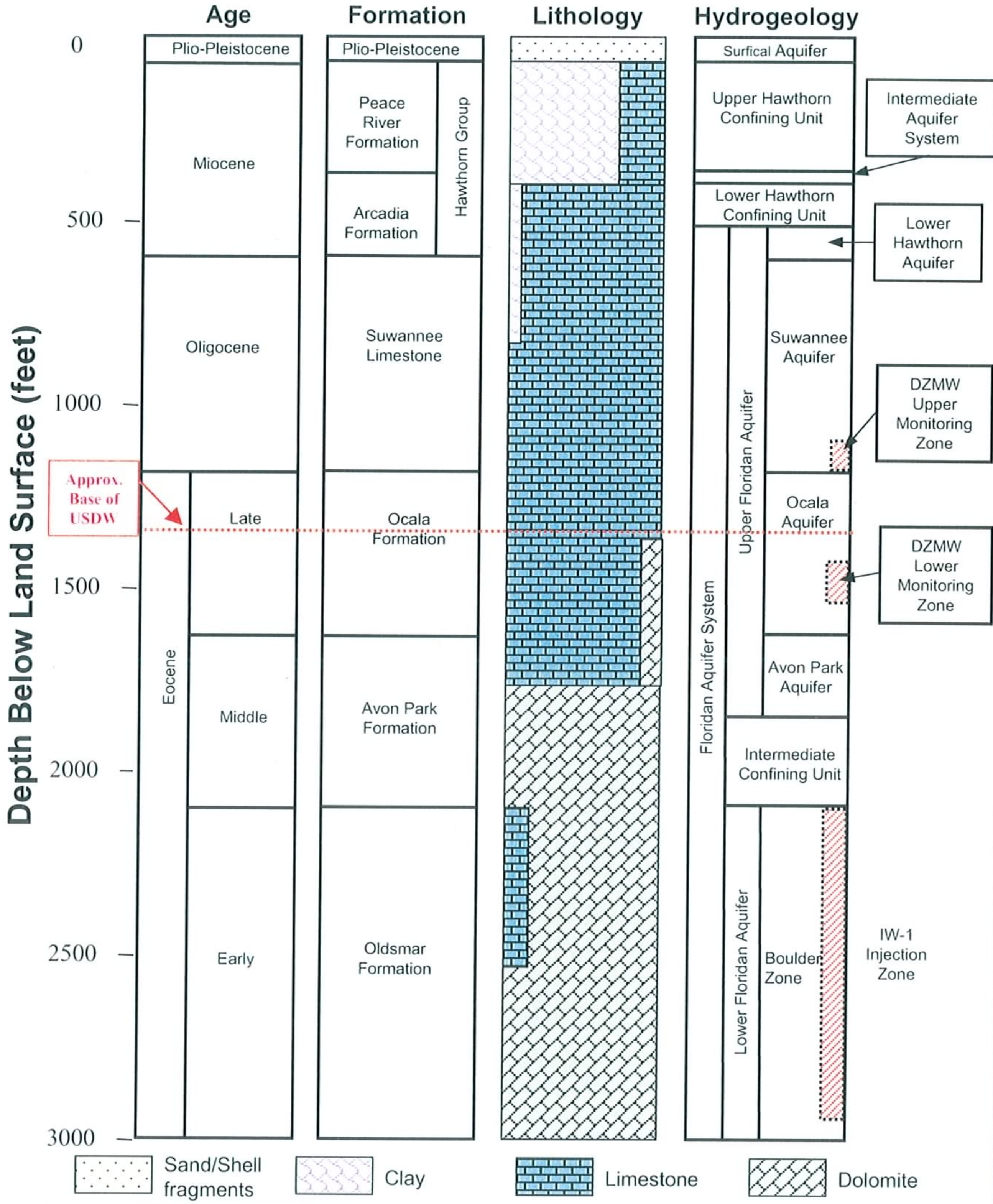


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Figure 3-1
Generalized Hydrogeology and Lithology in IW-1 and DZMW-1

Section 4

Section 4

MWH
MONTGOMERY WATSON HARZA

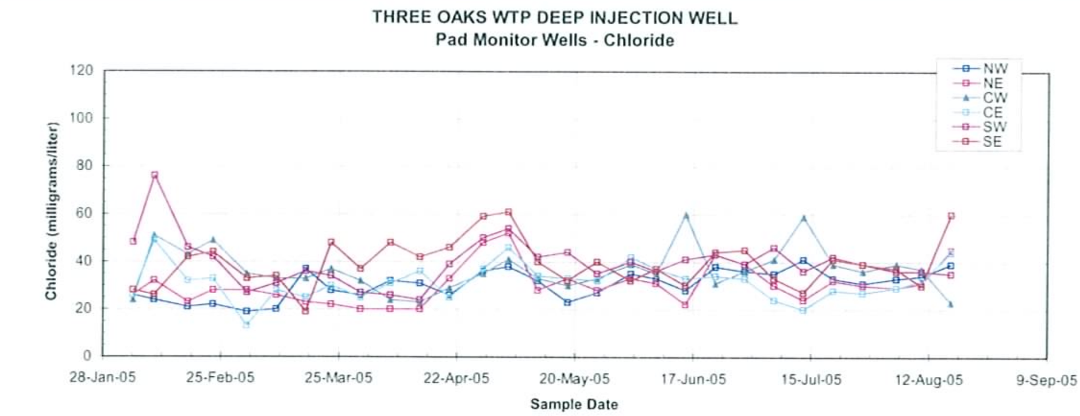
Section 4
Testing

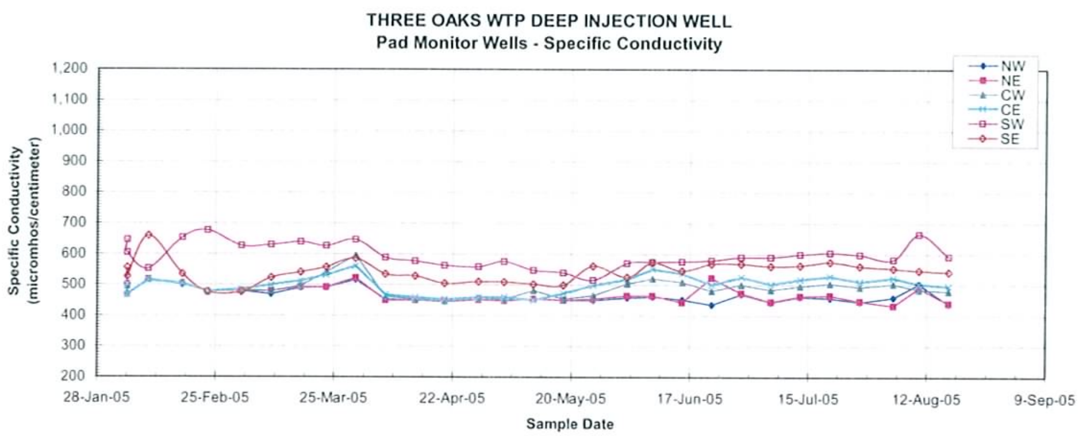
Testing during the drilling and construction of IW-1 and DZMW-1 consisted of water sampling and analyses during reverse circulation drilling, lithologic logging of the cuttings from drilling operations, geophysical logging, coring, and aquifer testing. The testing was conducted to characterize the geology and hydrogeology of strata encountered during the drilling of the wells. Results of the testing were used to identify the depth of the base of the USDW, to locate confining strata, and to determine the hydraulic conductivity of intervals penetrated by the borehole. Data obtained from testing was used to select casing seats in both wells, the injection zone in IW-1, and the UMZ and LMZ in DZMW-1.

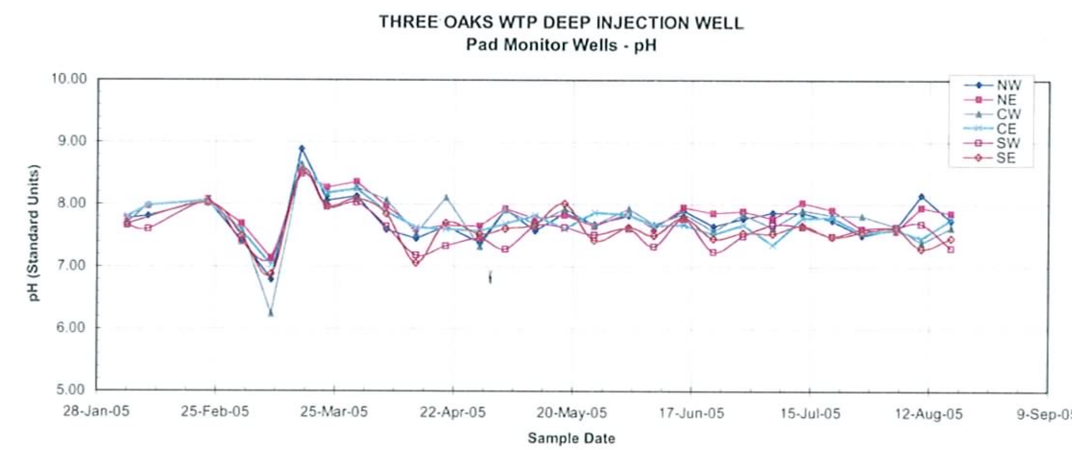
4.1 PAD MONITOR WELL WATER QUALITY

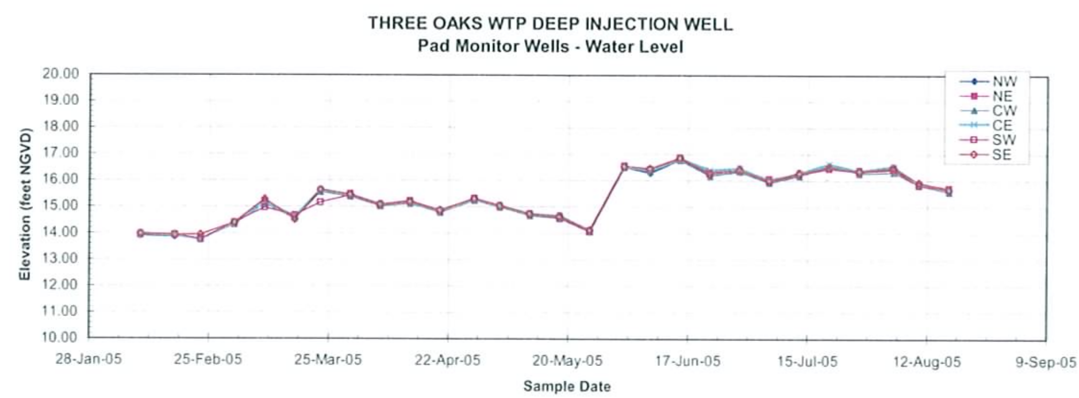
Throughout construction activities, water samples were collected on a weekly basis from the six PMWs constructed within the surficial aquifer surrounding the perimeter of the construction area. The approximate locations of the pad wells in relation to the construction site are shown in **Section 2** on **Figure 2-1**. Sampling and analyses were conducted weekly throughout the project to monitor the water quality of the surficial aquifer for potential impact from construction activities. Pad wells were left in place after well construction for future monitoring of the surficial aquifer around IW-1 and DZMW-1. The construction and monitoring of these pad monitor wells satisfies Specific Condition 2(d) of the construction permit.

The weekly samples from each pad monitor well were analyzed for temperature, pH, specific conductivity (SC), and chloride. The depth to water at each well was measured prior to each sampling to calculate the water table elevation. The PMWs were sampled the first time for analysis of pH, SC and chloride by a State-certified laboratory. **Figure 4-1** presents the water quality and water level elevations for the six pad monitor wells, during construction activities, at the site. The SC and chloride concentration average of all the pad monitor wells over the sampling period fluctuated from approximately 445 to 665 micro-Siemens per centimeter (μS/cm) and from 13 to 76 mg/L, respectively. Water level in the wells during construction fluctuated between 13.76 and 16.87 feet NGVD, with water level increases occurring after rainfall events. **Appendix G** contains a summary of the field and laboratory water quality results for the six pad monitor wells. Parameter levels did not exceed secondary water quality standards and no adverse affects to the surficial aquifer system were observed as a result of construction activities.









MWH

Figure 4-1
PMW Water Quality and Water Levels

4.2 LITHOLOGIC SAMPLING

Composite formation samples from IW-1 and DZMW-1 were collected during drilling operations every 10 feet from surface to TD. Each sample was characterized for rock type, color, consolidation, texture, cement (induration), hardness, fossil type, and observed porosity. Lithologic sampling aided in determining the contacts between formations, core intervals, selection of packer test intervals, and understanding the overall physical characteristics of formations penetrated by both boreholes. Detailed lithologic descriptions for the IW-1 and DZMW-1 boreholes are presented in **Appendix F.**

4.3 PILOT HOLE WATER QUALITY

Water quality samples were collected at 40-foot intervals, in IW-1 and DZMW-1 while using reverse circulation drilling. Sampling started at a depth of 520 feet bls and continued to TD in both wells. Samples were collected from the fluid circulation system. The samples were field analyzed for temperature, pH, SC, and chloride. These data were used to identify the depth of the base of the USDW and to select the injection zone. For samples analyzed in the field, TDS was calculated from the specific conductivity data.

Reverse-air circulation drilling was conducted to maintain borehole stability and minimize borehole skin damage to the aquifers of the Floridan Aquifer System that would have resulted from the direct rotary drilling method. Reverse circulation 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 an accurate representation of the water from the sampled interval. However, samples from reverse circulation drilling provide an indication of relative water quality trends versus depth.

Pilot hole water quality is presented in **Figure 4-2** for IW-1 and **Figure 4-3** for DZMW-1. The following observations were made about pilot hole water quality. An increase in specific conductivity and chloride concentration, with depth, was observed during reverse circulation drilling of IW-1 and DZMW-1. **Figure 4-2** displays a sharp increase in TDS (2,600 to 15,600 mg/L), conductivity (3,950 to 23,000 μS/cm), and chloride concentration (2,000 to 8,500 mg/L) from approximately 1,700 to 1,900 feet bls. **Figure 4-3** displays similar trends to those observed in IW-1.

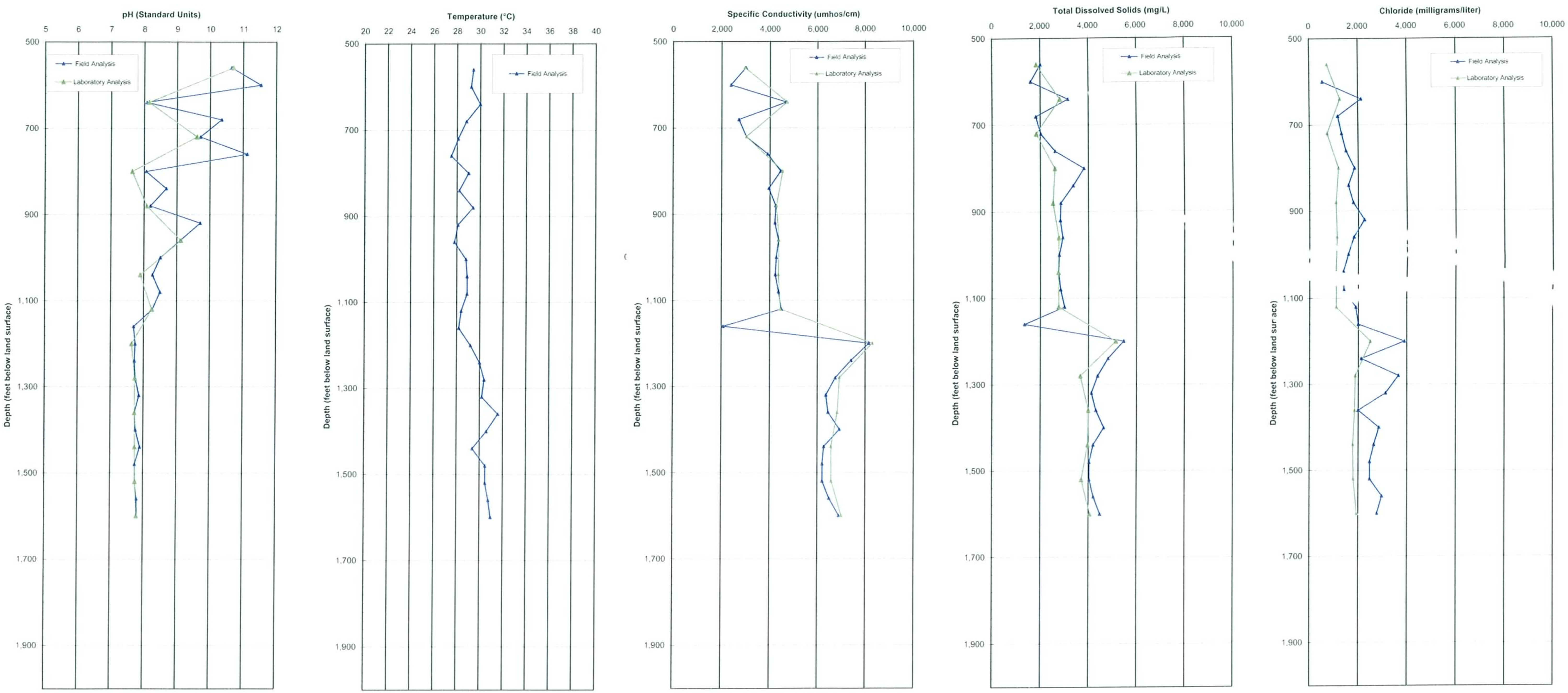


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Figure 4-3
DZMW-1 Circulation Fluid Water Quality

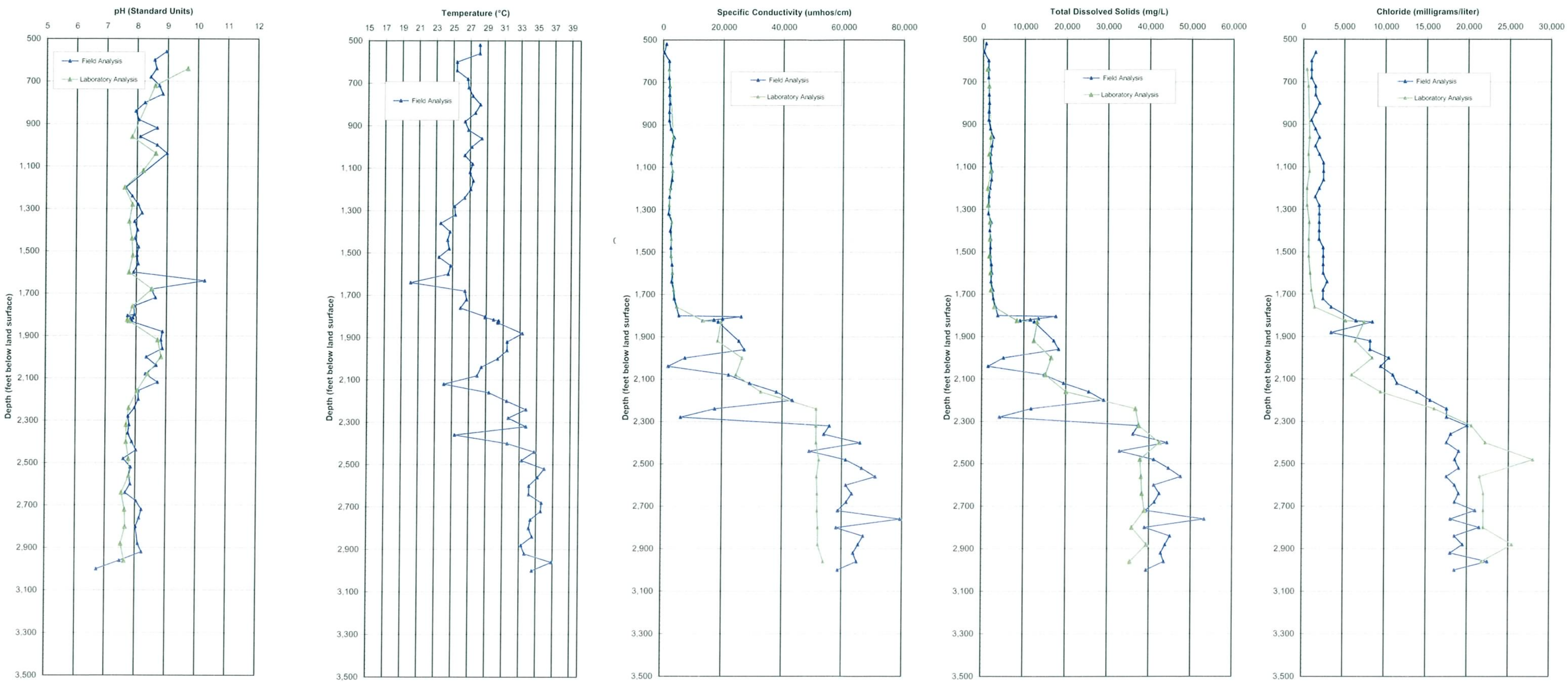

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Figure 4-2
IW-1 Circulation Fluid Water Quality

4.4 CORING

Core samples were collected to identify confinement in accordance with Specific Condition 6(c)(5) of the construction permit. The core samples obtained were also used to aid in the determination of the hydrogeological properties of the formation through correlation of the cored interval with the geophysical and lithologic logs.

The selection of the intervals to be cored was based on monitoring of the lithology and drilling operations for intervals that displayed characteristics of low hydraulic conductivity. **Figure 4-4** illustrates core and aquifer tested intervals in IW-1 and DZMW-1. Cores in IW-1 were used to demonstrate confinement below the base of the USDW, and were obtained using a 4-inch diameter, 15-foot long core barrel with a diamond core bit. Samples were boxed and labeled after they were removed from the core barrel. No cores were collected during drilling in DZMW-1.

Specific intervals were selected from each core and sent for a detailed geotechnical and hydrogeological analysis by Ardaman & Associates (Orlando, FL). The intervals were selected based on lithologic characteristics (relatively high degree of confinement) and sample length. Core properties analyzed were horizontal and vertical hydraulic conductivity (Kh and Kv, respectively), porosity (Φ), and specific gravity (SG). Copies of the laboratory reports can be found in **Appendix H.**

A generalized description and a summary of the laboratory results for each core is presented in **Table 4-1**. The vertical hydraulic conductivity for these samples ranges from 2.3×10^{-11} centimeter per second (cm/sec) to 1.3×10^{-5} cm/sec and the horizontal hydraulic conductivity for these samples ranges from 8.3×10^{-10} cm/sec to 2.5×10^{-5} cm/sec. All of these core samples have low to very low hydraulic conductivity. Detailed lithologic descriptions of the core samples can be found in **Appendix I.**

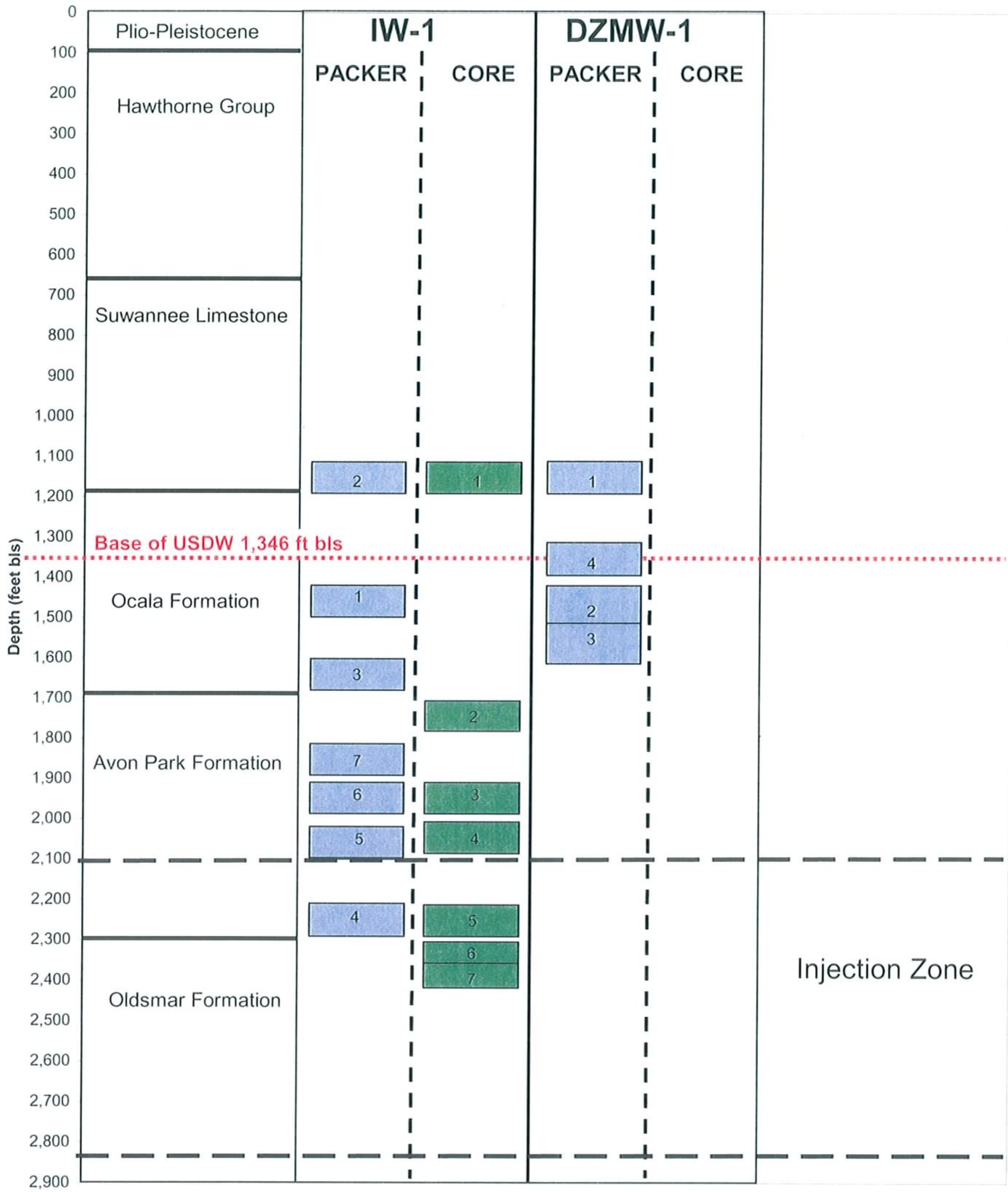

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Figure 4-4
Packer Testing and Coring Intervals

Table 4-1
Summary of Cores Recovered at Three Oaks WWTP in IW-1

Core #	Cored Interval (feet bls)	Generalized Geologic Description	Core Recovery (%)	Analysis No.	Vertical Hydraulic Conductivity (cm/sec)	Horizontal Hydraulic Conductivity (cm/sec)	Specific Gravity
1	1,170 to 1,185	Dolostone: light gray, microcrystalline, slightly sucrosic, well indurated.	64%	S1	$4.1X10^{-9}$	$9.8X10^{-9}$	2.84
2	1,765 to 1,780	Dolostone: medium light gray, very finely crystalline texture, well indurated.	28%	S2	$2.3X10^{-11}$	$3.8X10^{-9}$	2.81
				S3	$1.8X10^{-10}$	$3.0X10^{-10}$	2.82
				S4	$7.0X10^{-11}$	$5.6X10^{-10}$	2.82
3	1,964 to 1,979	Limestone: pale yellowish brown, microcrystalline, well indurated.	34%	S5	$1.2X10^{-8}$	N/A	2.81
				S6	$5.6X10^{-10}$	$3.2X10^{-9}$	2.84
4	2,020 to 2,036	Limestone: dark yellowish gray to yellowish gray, indurated.	69%	S7	$3.9X10^{-7}$	$4.5X10^{-7}$	2.75
				S8	$5.1X10^{-8}$	$6.7X10^{-8}$	2.79
				S9	$2.2X10^{-6}$	$5.0X10^{-6}$	2.70
				S10	$1.4X10^{-6}$	$3.4X10^{-6}$	2.73
				S11	$6.5X10^{-6}$	$7.8X10^{-6}$	2.70
				S12	$1.3X10^{-5}$	$2.5X10^{-5}$	2.71
5	2,251 to 2,265	Dolostone: medium light gray, well indurated, slightly vuggy, sucrosic secondary porosity.	34%	S13	$9.1X10^{-8}$	N/A	2.80
				S14	$4.0X10^{-11}$	N/A	2.80
6	2,325 to 2,340	Dolostone: mottled grayish orange to dusky yellowish brown, crystalline, well indurated, vuggy, sucrosic secondary porosity.	50%	S15	$3.3X10^{-10}$	$3.0X10^{-9}$	2.81
				S16	$9.4X10^{-9}$	$5.9X10^{-10}$	2.82
7	2,393 to 2,408	Dolostone: light olive gray and medium bluish gray, microcrystalline, well indurated, slightly vuggy, sucrosic secondary porosity.	33%	S17	$1.6X10^{-5}$	$8.3X10^{-10}$	2.83

N/A – Sample test could not be performed due to irregular shape or short length of core sample.

4.5 PACKER TESTS

After reviewing all relevant information including lithologic logs, geophysical logs, water quality data, specific capacity tests, and driller's logs, packer testing was conducted in IW-1 and DZMW-1 to characterize aquifer hydraulic parameters and water quality of specific intervals. Inflatable straddle packers were used to isolate discrete borehole intervals in each well. A single packer was used in some instances to isolate an interval below a specific depth to the TD of the borehole. Each packer test consisted of four steps: development, background sampling, testing and recovery.

A straddle-packer assembly was first lowered into the well with drill pipe. The packers of the straddle-packer assembly were set in place in the open borehole and inflated to seal the selected interval between the packers from the rest of the open borehole. The isolated interval was then pumped until field water-quality parameters had stabilized, indicating that the isolated borehole interval had been developed appropriately and the water pumped was representative of the interval. Parameters measured during development include pH, specific conductivity, chloride, and temperature. The development procedure purges drilling fluids and loose formation particulates from the selected interval.

After development, a pump rate was selected to stress the straddle-packer interval without causing cavitation at the pump. The water level was then allowed to recover for four hours before the test commenced. This completed the background portion of the test.

The packer testing consisted of pumping water from the straddle-packer interval at a constant rate for four hours. During the test the water level of the test interval was measured and water samples were collected. The drawdown readings were measured using a pressure transducer, and recorded by an In-Situ, Inc. Hermit 3000 data logger. Water level readings in the annular space, between the drill pipe and the casing/borehole wall, were also measured and recorded with an In-Situ pressure transducer and data logger. The In-Situ data logger allowed for real-time review of the data measured and recorded by the instrumentation. The pressure head was also measured below the bottom packer with a memory gauge.

Water samples for laboratory analysis of pH, chloride, specific conductivity, TDS, and sulfate were collected from each test interval prior to completion of pumping. Field measurements of pH, chloride, SC, and temperature were taken through the duration of each test. TDS was calculated from the field SC.

Following the pumping portion of a packer test, a four-hour recovery period was conducted. Residual drawdown was measured during the recovery by the pressure transducer, and recorded by an In-Situ, Inc. Hermit 3000 data logger.

Drawdown data from the packer tests were used to calculate the transmissivity and hydraulic conductivity. The drawdown curves were analyzed using several different methods including the Cooper and Jacob (1946), Hantush (1960), Hantush and Jacob (1955), Neuman and Witherspoon (1969), Theis (1935), and the Theis (1935) residual drawdown/recovery methods.

These aquifer characteristics aided in the evaluation of formation hydraulic conductivity in confining zones and potential monitoring zones. The analytical results including the time-drawdown curves for the tests are included in **Appendix J**. A summary of the aquifer tests performed and their purpose is presented in **Table 4-2.** This table also summarizes hydraulic parameters calculated from test data and summarizes water quality results from laboratory testing of samples obtained at the completion of each packer test. Water quality samples were collected during each test to characterize formation water quality and identify the base of the USDW. **Appendix K** provides laboratory analytical reports for the water samples taken from all packer tests.

Table 4-2
Packer Testing Summary

Borehole	Test Number	Test Interval (feet bls)	Test Objective	Pump Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)	Transmissivity (ft^2/day)	Average Hydraulic Conductivity (ft/day)	Conductivity (µS/cm)	Chloride (mg/L)	TDS (mg/L)	Sulfate (mg/L)
IW-1	2	1,150 to 1,190	Delineation of the base of the USDW based on water quality.	40.0	95.1	0.42	67.0	1.68	7,630	2,300	4,820	567
IW-1	1	1,440 to 1,480	Delineation of the base of the USDW based on water quality.	1.6	146.8	0.01	0.53	0.01	21,800	7,000	13,500	671
IW-1	3	1,630 to 1,670	Delineation of the base of the USDW based on water quality.	28.0	126.0	0.22	5.73	0.14	46,300	19,400	36,000	3,000
IW-1	7	1,819 to 1,837	Confining interval characterization based on hydraulic conductivity.	5.5	76.0	0.07	5.64	0.30	50,500	20,800	34,700	2,670
IW-1	6	1,920 to 1,948	Confining interval characterization based on hydraulic conductivity.	2.0	116.0	0.02	0.60	0.02	52,200	20,500	36,300	3,100
IW-1	5	2,072 to 2,100	Confining interval characterization based on hydraulic conductivity.	1.7	91.0	0.02	0.84	0.03	51,000	22,000	44,500	2,850
IW-1	4	2,271 to 2,299	Confining interval characterization based on hydraulic conductivity.	91.0	34.6	2.63	135	4.83	52,800	24,200	36,700	2,870
DZMW-1	1	1,149 to 1,200	Confirm UMZ selection based on water quality.	110.0	3.3	33.3	4,428	86.80	7,770	2,250	4,680	559
DZMW-1	2	1,460 to 1,510	Confirm LMZ selection based on water quality.	5.0	*	*	*	*	7,400	2,250	4,240	389
DZMW-1	3	1,510 to 1,610	Confirm LMZ selection based on water quality and flow rate.	11.0	126.5	0.09	5.35	0.11	42,500	16,800	26,300	1,680
DZMW-1	4	1,320 to 1,380	Delineation of the base of the USDW based on water quality only.	119.9	30.0	0.25	13.5	0.15	46,400	19,300	31,100	2,410

*Packer test was performed to collect water sample for water quality analysis. Water levels were not measured.

4.6 GEOPHYSICAL LOGGING

Geophysical logging was conducted in IW-1 and DZMW-1 to measure certain formation characteristics, define formation lithologies and lithologic boundaries, assess water quality, infer the relative hydraulic conductivity of the formation materials, to distinguish water-producing units from confining zones, and examine the seal provided by the casing and grouting program. This logging was done in accordance with Specific Condition 3(l) of the FDEP Construction Permit. Geophysical logs are presented in **Appendix L.**

The geophysical logs were compared to formation samples taken during drilling, used to identify geologic contacts, and used to provide certain hydrogeologic information pertaining to the formations. The data from the geophysical logs, in conjunction with water quality data, were utilized to determine intervals for packer testing, identify the base of the USDW, select the upper and lower monitoring zones in DZMW-1, select the injection zone in IW-1, and determine optimum casing setting depths for each well. Reamed borehole caliper logs were performed prior to casing installation to confirm borehole diameters, casing setting depths, and calculate theoretical cement volumes necessary to fill the annulus for proper casing installation. Temperature logs were performed after each cement stage to confirm the amount of lift that resulted from each cement stage. Geophysical logs were also run to assist in mechanical integrity testing of the wells. The geophysical logging program for mechanical integrity testing is presented in Section 5 of this report.

4.6.1 Geophysical Log Definitions

- **Caliper**: The caliper log measures the diameter of a borehole. 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.

- **Spontaneous Potential (SP)**: The SP log measures natural electrical potential differences between the formation and borehole fluids. Thickness, relative intrinsic permeability, and correlation of geologic units may be determined with this log.

- **Dual Induction**: 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) with 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 important information about fractures and solution features.

- **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.

- **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.

- **Fluid Conductivity**: The fluid conductivity log provides a measurement of water quality in the borehole, and is used to measure characteristics of formation fluid under static and dynamic flow conditions. Fluid conductivity logs are useful for delineating water-bearing zones and identifying vertical flow in the borehole.

- **Flowmeter Survey**: 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.

- **Digital Borehole Televiewer**: A digital borehole televiewer produces a 360° borehole 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.

- **Video**: A video survey can confirm interpretations of the geophysical logs. This log gives the geologist/engineer the opportunity to visually inspect formation characteristics, the integrity of casings, and other features apparent from within the borehole or well. To improve the clarity of the picture, videos can be filmed while the well is being pumped to remove as much particulate matter as possible.

- **Cement Bond Log**: The cement bond log (CBL) records amplitude, in millivolts, of the first arrival of a wave signal at a 3-foot receiver created by a calibrated, 1,000 millivolt (mV) output signal. 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. 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.

4.6.2 Injection Well (IW-1) Logging Program

Geophysical logs were run for each stage of drilling (0 to 510, 490 to 1,830, 1,530 to 3,010 feet bls) of IW-1. **Table 4-3** summarizes the geophysical logging sequence for IW-1.

Table 4-3
Summary of Geophysical Logging Performed During Construction of IW-1

Date	Borehole Diameter	Logging Interval (feet bls)	Type of log[1]	Purpose
2/6/05	12.25-inch pilot hole	0 to 510	C, GR, DIL, SP	Confirm surface casing setting depth.
2/11/05	48.5-inch reamed hole	0 to 495	C, GR	Confirm reamed hole characteristics and calculate cased hole annular volume.
2/21/05	12.25-inch pilot hole	490 to 1,830	C, GR, DIL, SP, BHCSw/VDL, DBT, FT_D, FT_S, CIL_D, CIL_s, FMS_D, FMS_s	Determine USDW to select intermediate casing setting depth and upper and lower monitor zones.
3/8/05	38.5-inch reamed hole	490 to 1,830	C, GR	Confirm reamed hole characteristics and calculate cased hole annular volume.
3/11/05	30-inch OD casing	490 to 1,530	FT	Determine cement top of each stage of cement.
4/1/05	12.25-inch pilot hole	1,530 to 3,015	C, GR, DIL, SP, BHCS w/ VDL, VS, FT_D, FT_S, CIL_D, CIL_s, FMS_D, FMS_s	Determine final casing setting depth and confirm injection zone.
4/15/05	28.5-inch reamed hole	1,530 to 2,100	C,GR	Confirm reamed hole characteristics, with a calculation of the cased hole annular volume, and final casing setting depth.
5/22/05	20-inch OD casing	0 to 2,100	FT, CBL	Determine cement top of each stage of cement. Determine quality of cement bond to casing.
5/24/05	20-inch OD casing	0 to 2,100	VS	Confirm structural integrity
5/24/05	14.5-inch ID FRP tubing and open hole.	0 to 2,850	VS	Final video of completed well

Notes: [1]Abbreviations for Geophysical Logs:

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

On **February 6, 2005**, prior to reaming and setting the 48½ -inch OD surface casing at 490 feet bls in IW-1, a suite of geophysical logs were run, as described in Table 4-5, to identify a mechanically secure depth for the surface casing seat in conjunction with the lithologic log. The caliper log showed the borehole diameter to be a consistent 12.25-inches from about 200 feet to 510 feet bls, and indicated a good casing seat at 490 feet bls.

After setting the surface casing, the 12¼ inch diameter pilot hole was advanced from 490 feet to 1,830 feet bls. On **February 21, 2005**, prior to reaming and setting the 38.5-inch OD intermediate casing at 1,530 feet bls in IW-1, geophysical logs were run to identify confining units, producing intervals, base of the USDW, and aid in casing seat determination. The caliper log shows borehole diameters ranging from 12¼ inches to 22½ inches from 490 to 1,800 feet bls, with the borehole diameter exceeding 25 inches below 1,800 feet bls. From 1,510 to 1,550 feet bls, the borehole diameter ranges from 14 to 16 inches with a 15-inch diameter borehole from 1,530 to 1,536 feet bls, indicating a competent formation in this interval.

The DIL shows resistivity averaging between 10 and 100 ohm-meters (ohm-m) at the top of the pilot hole (490 feet bls), and decreasing with depth to less than 2 ohm-m near TD of the boring. Notable exceptions occur in areas with apparent voids or fractures.

The BHTV log compares well with the lithologic description in the 490 to 1,820 foot bls interval of the borehole. Comparatively higher density responses correspond to dense limestone and dolomite. The BHCS porosity log shows increasing travel times (lower porosity) with depth, except in intervals with voids or fractures. Apparent porosity is greater than 60% at the top of the borehole, and less than 5% from 1,170 to 1,180 feet bls. From 1,510 to 1,550 feet bls, the BHCS porosity ranges from approximately 15% to 35%, with the interval from 1,527 to 1,530 feet bls recording a BHCS porosity close to zero. From 1,538 to 1,540 feet bls, the porosity is approximately 17%.

Collectively, the BHCS log and the logs discussed above indicate the formation, between the depth of approximately 1,500 and 1,530 feet bls, to be mechanically competent and with the characteristics that indicate a high potential for a good hydraulic and structural seal (low porosity and stable borehole wall).

Competent units were also identified in the interval between 1,170 and 1,530 feet bls based upon a combination of lithologic descriptions, core data, and geophysical log interpretation. The interpreted flow log shows that up to 55% of the flow originates from below 1,800 feet bls. The interval from 700 to 1,800 feet bls shows minimal contribution of flow into the borehole, indicating this 1,100 foot interval has a low transmissivity compared to the interval below 1,800 feet bls. The interval proposed for the intermediate casing seat is located in a 250-foot zone that only contributes about 2% of the total flow into the borehole.

The dual induction log was also used to identify an increasing saline water quality gradient with depth based on decreasing resistivity values in the geophysical logs associated with the base of the USDW in southern Florida. This log, in conjunction with the formation porosity calculated from the sonic log, provided an estimate of the formation water resistivity and was used to identify the base of the USDW at a depth of 1,346 feet bls. The estimated log-derived TDS values are presented in **Figure 4-5**.

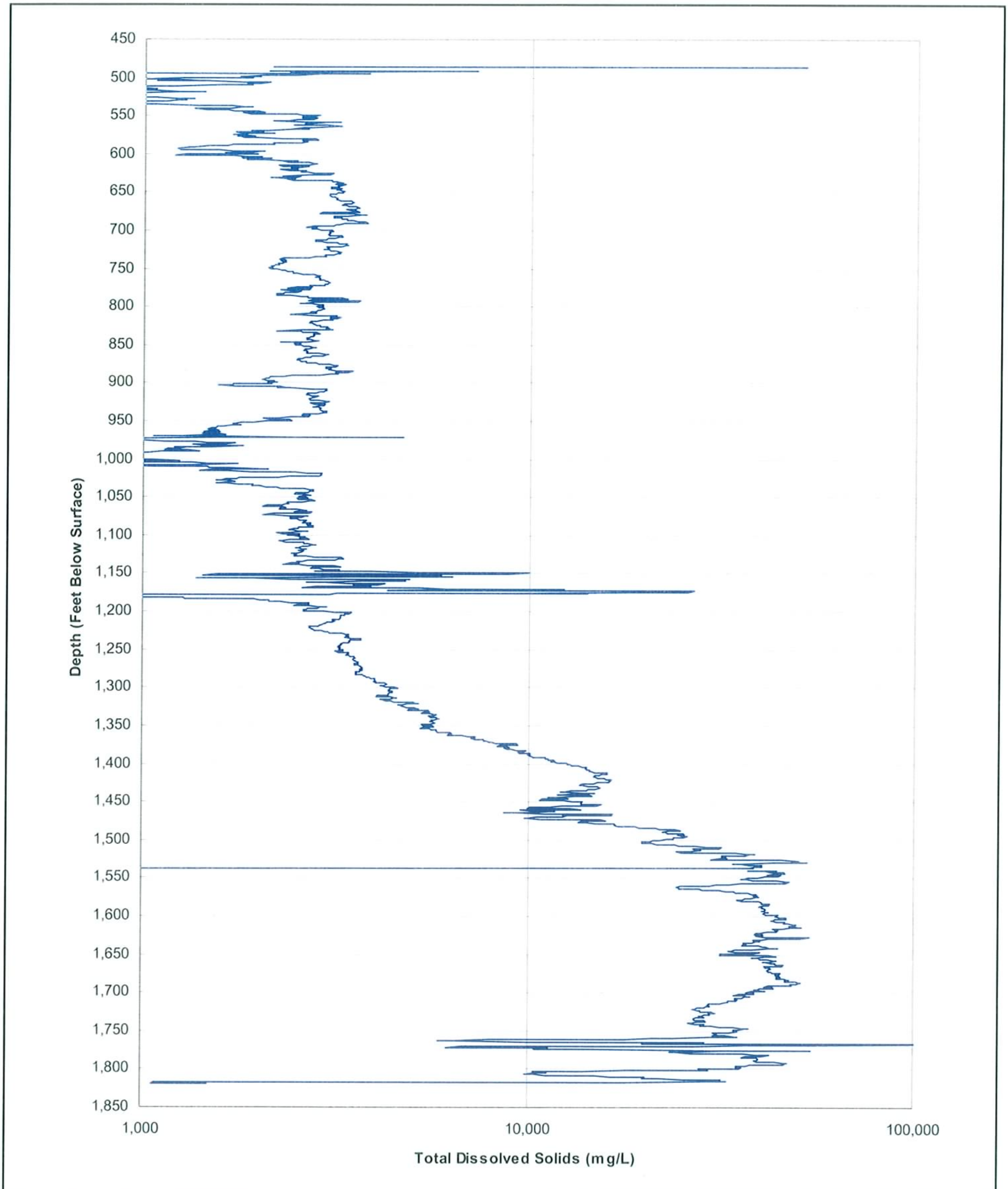


Figure 4-5
Log-Derived Plot of TDS vs Depth for IW-1

After setting the intermediate casing, the 12¼-inch diameter pilot hole was advanced from 1,530 to 3,015 feet bls. On **April 1, 2005**, prior to reaming and setting the 20-inch OD final casing to 2,100 feet bls in IW-1, logs were run to identify confining units, producing intervals, the base of the USDW, and to aid in casing seat determination. These logs were also useful to support the injection zone selection by documenting the injection zone characteristics.

The caliper log shows the borehole diameter ranging from 12½ -inches to a more than 30 inches (maximum caliper arm diameter is 30 inches) from 1,530 to 3,000 feet bls. The borehole is generally smooth from 1,530 to 2,162 feet bls, with diameters ranging from 13 to 21 inches, with pronounced diameter increases at 1,802 feet bls and 1,976 feet bls. Borehole diameters become erratic and range from 13 inches to greater than 30 inches from 2,162 to 2,248 feet bls and from 2,488 to 2,860 feet bls. Between these two intervals, from 2,248 to 2,488 feet bls, the borehole varies from 12½ to 19 inches in diameter. Below 2,860 feet bls, the borehole is nearly a constant diameter of 12½ -inches to the total depth of the pilot hole.

The BHCS porosity log shows relatively fast travel times from the top of the pilot hole to approximately 2,110 feet bls, exhibiting a calculated porosity of 20 to 30%, with increased porosity in fractured zones. The BHCS porosity log shows slower travel times (higher porosity) over large intervals below 2,110 feet bls. The intervals from 2,110 to 2,250 feet bls and 2,490 to 2,850 have slow travel times resulting in a calculated porosity of up to 100% due to large solution features and fractures. The interval between these two highly porous intervals has a variable calculated porosity, ranging from 5 to 95%.

The borehole flow logs are dominated by flow from the bottom of the borehole at approximately 2,490 feet bls. This flow pattern correlates with the deeper of the two highly permeable zones in the injection zone, which begins at 2,160 feet bls. This interval was pumped at 240 gpm during the flowing portion of the flow meter logs.

According to the static temperature log, the water temperature in the borehole ranges from 101.6° Fahrenheit (°F) at 1,530 feet bls to 107.3° F at 2,490 feet bls, which is the top of the lower of the two highly permeable units in the injection zone. At this point, there is a distinct "step" in the temperature log, so that by 2,500 feet bls, the temperature is 109.1° F. From this point on, the static temperature decreases slowly to the bottom of the borehole, where the temperature at TD is 107.4° F. The dynamic temperature log exhibits a similar pattern of temperature variation at the same points in the borehole, although the changes were not as pronounced.

The static and dynamic fluid conductivity logs show the specific conductivity increases to 2,490 feet bls, followed by a decrease to TD. This is similar to the temperature distribution in part because of the relationship between specific conductivity and temperature. Over the length of the borehole, the specific conductivity ranges from approximately 65,000 µS/cm to almost 75,000 µS/cm. These readings indicate a saline water column for the full length of the open borehole.

The DIL shows resistivity averaging between 2 and 300 ohm-meters (ohm-m) from the top of the pilot hole to approximately 2,490 feet bls. Notable exceptions, with increased resistivity, occur in areas with voids or fractures. In the interval from 2,490 to 2,618 feet bls, the deep and medium DIL ranges from 0.2 to 3 ohm-m, and becomes more variable from 2,618 to 2,850 feet bls, with deep and medium DIL ranging from 0.2 to 300 ohm-m. From 2,850 to 3,000 feet bls, the resistivity shown on the DIL ranges from 100 to 1,000 ohm-m.

A video survey was conducted in the pilot borehole between 1,530 and 3,000 feet bls to examine the appearance of the formations below the base of the intermediate casing. From 2,100 feet bls downward, the hole is comprised primarily of dolostone, which compares well with the lithologic description, and the caliper, and BHCS logs. At 2,100 feet bls, the video shows a competent formation. Below 2,110 feet bls, the video confirms significant vertical fracturing that extends to approximately 2,850 feet bls, with sparse, intermittent intervals of tight borehole.

After the final casing was installed, on **May 22, 2005**, a CBL with a variable density log (VDL) was run from surface to 2,100 feet bls in IW-1 to evaluate the quality of the cement seal in the annulus of IW-1, between the wall of the final casing and the borehole wall. The CBL, performed in IW-1 and DZMW-1, was conducted as part of the requirements of the construction permit. The CBL is presented in **Appendix L.**

Cementing of the 20-inch OD final casing in IW-1 was completed to within 186 feet of land surface, as demonstrated by temperature logging and a physical tag with the tremie pipe. The CBL tool was calibrated in the upper 186 feet of free pipe to determine the free pipe signal for comparison to the cemented portion of the 20-inch casing. The free pipe signal ranges from 9 to 36 mV from the surface to the top of cement at 186 feet bls.

From 186 feet to 539 feet bls, within the uncemented casing interval and continuing to the depth of the most recent cement lift before the CBL was conducted, the VDL log displays "chevrons" located approximately every 40 feet within the left portion of the VDL signature. These chevrons depict the welds between each joint of pipe. The sharp contrast of the uncemented casing is apparent and tends to fade with depth through the top of the last lift of cement prior to the CBL (at a depth of 539 feet bls). The amplitude values decrease with depth from 30 mV at the top to 4 mV at the bottom of this interval. In addition, the cement lift 8 (neat cement plus 12% bentonite) and was pumped only 28 hours prior to the CBL being run. This lift of cement may have been still hot and curing at the time the CBL was conducted.

From 539 feet bls to a depth of 822 feet bls, the CBL amplitude is relatively low (less than 5 mV) and transit times are relatively fast (700 to 800 μsec) with no cycle skipping. There is a loss of signal on the VDL within this same interval. From a depth of 822 feet to 1,342 feet bls, there are increased (slower) transit times coupled with active cycle skipping. The amplitude signals are low and approach 0 mV. Within this section there are two intervals (875 feet bls and 1178 feet bls) less than 10 feet in vertical length that display slightly higher amplitudes. Both of these areas are located just above the top of a cement lift (Stage 5 and 6). A VDL signal is also visible in these locations. Each of these signatures is associated with the top of a cement lift. In the next interval, from a depth of 1,342 feet bls to 1,530 feet bls, the transit times are faster with a slight increase in the amplitude signal. The amplitude continues to be less than 5 mV and is considered low.

In the final portion of the cemented interval, from 1,530 feet bls to 2,050 feet bls, a comparison of the BHCS with the VDL of the pilot hole lithologic formation and the VDL portion of the CBL indicate similar formational signatures at tighter, dolomitic intervals with higher intrinsic permeability. These intervals correlate with the caliper log, and are from 1,760 to 1,770 feet bls, 1,800 to 1,810 feet bls, and 1,950 to 1,990 feet bls. The VDL signature is weak in these sections indicating a good cement bond with the more permeable rock strata.

The CBL conducted in the open hole portion of IW-1 displays low amplitudes (less than 7.5 mV) and moderate transit times coupled with a weak VDL signal.

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

Geophysical logs were run for each stage of drilling of DZMW-1. Logs were conducted after each advance of the pilot hole and the reaming for the installation of each casing. **Table 4-4** summarizes the geophysical logging sequence for DZMW-1.

Table 4-4
Summary of Geophysical Logging Performed During Construction of DZMW-1

Date	Borehole Diameter	Logging Interval (feet bls)	Type of log[1]	Purpose
6/14/05	12.25-inch pilot hole	0 to 505	C, GR, DIL, SP	Confirm surface casing setting depth.
6/17/05	32.5-inch reamed hole	0 to 500	C, GR	Confirm reamed hole characteristics and calculate cased hole annular volume.
6/29/05	12.25-inch pilot hole	500 to 1,610	C, GR, DIL, SP, BHCS w/ VDL, DBT, FT_D, FT_S, CIL_D, CIL_s, FMS_D, FMS_s	Confirm casing setting depth and monitor zones.
7/26/05	22.5-inch reamed hole	500 to 1,155	C, GR	Confirm reamed hole characteristics and calculate cased hole annular volume.
7/26/05	16-inch OD casing	0 to 1,150	FT	Determine cement top of each stage of cement.
8/3/05	14.75-inch borehole	1,150 to 1,455	C, GR	Confirm reamed hole characteristics and calculate cased hole annular volume
8/3/05	12.25-inch borehole	1,455 to 1,535	C, GR	Confirm reamed hole characteristics and calculate cased hole annular volume
8/7/05	6.625-inch ID FRP casing	0 to 1,460	FT	Determine cement top of each stage of cement.
8/9/05	Cemented 6.625-inch ID FRP	0 to 1,460	CBL	Determine quality of cement bond

Notes: [1]Abbreviations for Geophysical Logs:

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

On **June 14, 2005**, after the pilot hole was advanced to 505 feet bls, a suite of geophysical logs were run, as described in Table 4-6, to establish a mechanically secure casing setting depth in conjunction with the lithologic log of the borehole.

The gamma log exhibited a decreased response beginning at approximately 485 feet bls indicating a decrease in clay material. At the same depth, the caliper log showed the borehole is stable. Therefore, the 24-inch casing was seat at 490 feet bls.

On **June 29, 2005**, after the pilot hole was advanced to 1,610 feet bls and prior to reaming the borehole for the 16-inch diameter intermediate casing, a suite of geophysical logs was run. These logs were used to identify the base of the Hawthorn Group, to establish a mechanically secure casing setting depth and to confirm the upper and lower monitor zones. After logging, the pilot hole was reamed with a 22.5-inch bit to 1,155 feet bls, 16-inch diameter steel casing was set to a depth of 1,150 feet bls, and 6-inch diameter FRP tubing was set to a depth of 1,455 feet bls.

The caliper log shows a consistent borehole diameter of 12.5-inches from 1,150 to 1,160 feet bls, and of 13-inches from 1,450 to 1,480 feet bls indicating a mechanically secure casing seat at 1,150 feet bls and at 1,455 feet bls for the upper (UMZ) and lower (LMZ) monitor zone, respectively.

The dual induction log shows deep and medium resistivity curves ranging from 10 to 20 ohm-meters to a depth 1,140 feet bls. From here the deep and medium resistivity increase to a maximum value of 218 ohm-meters at a depth of 1,180 feet bls. Both curves decrease sharply below 1,190 feet bls to a depth of 1,270 feet bls with a minimum value of 2.6 ohm-meters. From 1,270 feet bls to approximately 1,490 feet bls the resistivity values range from 3 to 20 ohm-meters. Below 1,510 feet to TD (1,610 feet bls) the resistivity becomes consistent between 1 and 2 ohm-meters. The shallow resistivity curve mimics the deep and medium resistivity curves with a difference of approximately 18 ohmmeters at a depth of 1,350 feet bls.

On August 9, 2005, a Sector Cement Bond Log (SCBL) was run in the cemented portion of the final 6-inch FRP casing in DZMW-1 to evaluate the quality of the cement seal in the annulus between the borehole wall of the final FRP casing and the borehole wall. The cement grout interval logged was from the bottom of the UMZ at 1,204 feet bls to 1,450 feet bls as supported by temperature logging and a physical tag with the tremie pipe. The bond log tool was calibrated from 980 feet bls to the top of the cement to determine the free pipe signal for comparison to the cemented portion of the casing. The free pipe signal ranges from 50 to 80 mV from the start of the log (980 feet bls) to the top of cement at 1,204 feet bls, within the uncemented casing interval. The VDL log displays "chevrons" located approximately every 30 feet showing an amplitude of approximately 30 mV. These chevrons depict the couplings between each joint of FRP pipe. Below the top of cement, the free pipe amplitude decreases to 1 mV and averages 10 mV to a depth of 1,258 feet bls. At approximately 1,258 feet bls the amplitude increases to approximately 15 mV, from the VDL log display and the temperature logs run during cementing, this depth matches the top of the first stage of cement. From 1,258 feet bls to a depth of 1,312 feet bls the amplitude decreases from 1mV to 4 mV. From 1,314 feet bls to 1,430 feet bls the amplitude averages 10 mV. At 1,430 feet bls the frequency signal matches the free pipe signal from the first 200 feet of the log to the end of logging depth (1,454 feet bls). The low amplitude frequencies throughout the entire portion of the cemented FRP denote a good bond between the cement grout and the 6.625-inch final casing.

4.7 BASE OF THE UNDERGROUND SOURCE OF DRINKING WATER

The base of the USDW is the depth where the TDS level equals 10,000 mg/L. This threshold was identified by water sampling and analysis during reverse circulation drilling, packer testing, and examination of geophysical logs including the calculated log-derived TDS geophysical log. Water samples collected from reverse circulation drilling operations in IW-1, resulted in an increase in TDS to 10,000 mg/L in the interval between 1,825 and 1,830 feet bls (Figure 4-2). The dual induction log decreased over the interval from 1,360 to 1,830 feet bls, with a sharp decrease from 1,360 to 1,400 feet bls. Decreasing resistivity is an indicator of increasing salinity because of the increased conductivity associated with higher salinity (dissolved solids) water. The BHCS log and ILD log from 490 to 1,820 feet bls were used to calculate a log-derived TDS plot based on the method of Miller (1986). The log-derived TDS plot is presented in **Appendix L.**

Based on the log-derived TDS values, the base of the USDW was first determined to be at approximately 1,390 feet bls. The base of the USDW was not observed directly in the water samples collected and field analyzed during drilling because of dilution with less saline water entering the borehole above the base of the USDW. The depth at the base of the USDW was confirmed by packer tests above and below the base of the USDW. Tests were conducted on the intervals from 1,150 to 1,190 feet bls and 1,440 to 1,480 feet bls. Laboratory water quality analysis resulted in a TDS of 4,820 mg/L in the interval from 1,150 to 1,190 feet bls, and a TDS concentration of 13,500 mg/L in the interval from 1,440 to 1,480 feet bls. The results, presented in **Table 4-4**, were used to revise the base of the USDW to 1,346 feet bls by linear interpolation.

4.8 SELECTION OF THE INJECTION ZONE OF IW-1

The injection zone in IW-1 was selected after pilot hole drilling was complete and was based on the geologic interpretation of the lithologic samples, results of water-quality testing, and the geophysical logs. Two zones of highly fractured, cavernous carbonate material were encountered during the pilot hole drilling of IW-1. The first zone begins at approximately 2,160 feet bls and extends to approximately 2,240 feet bls. The second zone begins at approximately 2,490 feet bls and extends to approximately 2,850 feet bls. The upper zone is in the interval of the Avon Park – Oldsmar Formation contact and the lower zone is in the Oldsmar Formation. The Oldsmar Formation is commonly used for injection throughout southern Florida. Lithologic samples from both intervals are highly fractured, vuggy dolostone and limestone. The fractured and cavernous nature of the formation in both zones was also observed on the caliper log, BHCS log, and video survey of IW-1.

4.9 CONFINEMENT

Confinement above the injection zone was determined from geophysical logs, lithologic samples, formation cores, and analyses of packer tests. In general, the logs and testing conducted on each borehole correlate well with each other. Evaluation of the testing results allowed for interpretation of zones of confinement and production within IW-1 and DZMW-1.

Confinement was identified throughout the interval between 1,810 and 2,100 feet bls based on the lithologic descriptions, core data, packer test results, geophysical logs, and the downhole video. Results from packer tests 5 through 7 demonstrated the hydraulic conductivity of this interval ranges from 0.017 to 0.072 ft/day. Core 2, 3, and 4 from this interval also indicate the formation is well consolidated with low permeability and porosity. The geophysical and video logs of the borehole, from approximately 1,810 to 2,100 feet bls indicate confining lithology. The BHCS log recorded low sonic porosity in this interval, indicative of a dense formation. The VDL log also shows this formation interval is consistently dense as indicated by consistently fast arrival times.

4.10 SELECTION OF THE UPPER MONITOR ZONE (UMZ)

The UMZ, from 1,150 to 1,204 feet bls, was selected based on the primary criterion of being the first flow zone above the base of the USDW. Packer testing in this depth interval in IW-1 had previously determined that this was a zone with good intrinsic permeability above the base of the USDW. Packer testing of this interval in DZMW-1 was conducted at 3.3 gpm with a drawdown of 110 feet (see **Appendix J** for the data analysis of aquifer testing performed on the UMZ). Water quality analysis of the sample taken from the pump test of the UMZ in DZMW-1 resulted in a TDS level 4,680 mg/L (Table 4-4).

4.11 SELECTION OF THE LOWER MONITOR ZONE (LMZ)

The LMZ, from 1,460 to 1,535 feet bls, was selected based on the criterion of being the first flow zone below the base of the USDW. The LMZ was pumped at 11 gpm with a drawdown of approximately 126.5 feet (see **Appendix J**). Water quality analysis of the sample taken from the packer test of the LMZ in DZMW-1 resulted in a TDS level 26,300 mg/L (Table 4-4).

4.12 AMBIENT WATER QUALITY SAMPLING

After construction activities were complete, background water quality sampling for analysis of primary and secondary drinking water standards was conducted on the injection zone of IW-1 and the monitoring zones (LMZ and UMZ) of DZMW-1. These zones were developed until at least three well volumes of water had been evacuated from each zone and the chloride concentration and specific conductivity measurements had stabilized. Sampling for the analysis of primary and secondary drinking water standards was conducted in accordance with the construction permit. **Appendix M** contains the certified laboratory water quality results for each well.

4.12.1 Injection Well (IW-1) and Dual Zone Monitor Well (DZMW-1) Ambient Water Quality

The injection zone of IW-1 was sampled for background water quality June 27, 2005. The UMZ and LMZ of DZMW-1 were sampled for background water quality August 23, 2005. The samples were analyzed for primary and secondary drinking water standards, as well as, the minimum criteria for sewage effluent set by the FDEP. **Tables 4-5** through **4-10** summarize the ambient water quality for IW-1, UMZ, and LMZ.

The laboratory reports of analytical results samples collected on August 23, 2005 (**Table 4.6**), indicated the presence of Tetrachloroethylene in the groundwater samples collected from the UMZ and LMZ of DZMW-1 and the detection of Toluene in the groundwater sample collected from LMZ of DZMW-1. The UMZ and LMZ of DZMW-1 were re-sampled on June 29, 2006 and analyzed for organic compounds, to confirm the presence of Toluene and Tetrachloroethene detected by the initial sampling and analysis. The re-sampling analytical results confirmed the presence of Toluene and Tetrachloroethylene detected in the initial sampling. The confirmation sampling results are provided in **Table 4-7.** In both instances, the primary drinking water standards for Tetrachloroethylene and Toluene were not exceeded.

On May 4, 2006, Lee County Utilities Well Operations personnel measured the groundwater level in the lower zone of the Dual Zone Monitoring Well. The groundwater level was measured using a Keck electric water level tape. Upon retrieval of the electric tape from the access port, an oil coating was observed on the portion of the electric tape that was submerged. The oil coating observed on the tape was clear (i.e. no coloration apparent) and exhibited a strong petroleum odor. The Toluene and Tetrachloethylene detected in the samples collected may be attributed to the petroleum oil observed in the lower zone of the Dual Zone Monitoring Well. The source of these two petroleum-based substances is believed to be residual cutting oil on the casing used to cut the final measured section of stainless steel casing. All visible oil inside the LMZ of DZMW-1 will be removed from the well casing and free water surface.

Table 4-5
IW-1 and DZMW-1 Ambient Water Quality Compared to State Drinking Water Standards for Inorganic Compounds

Contaminant	Units	Drinking Water Standards	IW-1 Injection Zone	DZMW-1 Lower Monitor Zone	DZMW-1 Upper Monitor Zone
Antimony	mg/L	0.006	0.007	0.004 U	0.004 U
Arsenic	mg/L	0.01	0.016	0.004	0.011
Asbestos	Million fibers per Liter	7	<0.37	<0.37	<1.80
Barium	mg/L	2	0.411 J3	0.033	2.80
Beryllium	mg/L	0.004	0.0002	0.0002	0.0001
Cadmium	mg/L	0.005	0.002 U	0.002 U	0.002
Chromium	mg/L	0.1	0.007	0.002 U	0.002 U
Cyanide	mg/L	0.2	0.005 U	0.007	0.005 U
Fluoride	mg/L	4.0	0.3	0.97	1.0
Lead	mg/L	0.015	0.019	0.007 U	0.017
Mercury	mg/L	0.002	0.001 U	0.001 U	0.001 U
Nickel	mg/L	0.1	0.011	0.002 U	0.002 U
Nitrate-N	mg/L as Nitrogen	10	1.38	0.02	0.01 U
Nitrite-N	mg/L as Nitrogen	1	0.01 U	0.01U	0.01 U
Total Nitrate and Nitrite	mg/L as Nitrogen	10	1.38	0.74	0.01 U
Selenium	mg/L	0.05	0.002 U	0.002 U	0.003 V
Sodium	mg/L	160	12,000	9,030	1090
Thallium	mg/L	0.002	0.004 U	0.004 U	0.007

Qualifier Definitions:
U = Below detection limit. Concentration is method detection limit.
V= The analyte was detected in both the sample and the associated method blank.
J3=The reported value failed to meet the established quality control criteria.

Table 4-6
IW-1 and DZMW-1 Ambient Water Quality Compared to State Drinking Water Standards for Volatile Organic Compounds

Contaminant	Drinking Water Standards (µg/L)	IW-1 Injection Zone (µg/L)	DZMW-1 Lower Monitor Zone (µg/L)	DZMW-1 Upper Monitor Zone (µg/L)
1,1,1-Trichloroethane	200	0.3 U	0.3 U	0.3 U
1,1,2-Tricholoroethane	5	0.3 U	0.3 U	0.3 U
1,2-Dichloroethane	3	0.2 U	0.2 U	0.2 U
1,2-Dichloropropane	5	0.3 U	0.3 U	0.3 U
1,2,4-Trichlorobenzene	70	0.5 U	0.5 U	0.5 U
Benzene	1	0.5 U	0.5 U	0.5 U
Carbon tetrachloride	3	0.3 U	0.3 U	0.3 U
cis-1,2-Dichloroethylene	70	0.2 U	0.2 U	0.2 U
Dichloromethane	5	0.5 U	0.5 U	0.5 U
Ethylbenzene	700	0.5 U	0.5 U	0.5 U
Monochlorobenzene	100	0.5 U	0.5 U	0.5 U
0-Dichlorobenzene	600	0.5 U	0.5 U	0.5 U
para-Dichlorobenzene	75	0.5 U	0.5 U	0.5 U
Styrene	100	0.5 U	0.5 U	0.5 U
Tetrachloroethylene	3	0.2 U	0.49	1.5
Toluene	1,000	0.5 U	4.7	0.5 U
trans-1,2-Dichloroethylene	100	0.5 U	0.5 U	0.2 U
Trichloroethylene	3	0.2 U	0.2 U	0.2 U
Vinyl chloride	1	0.5 U	0.5 U	0.5 U
Xylenes (total)	10,000	0.5 U	0.5 U	0.5 U

U = Below detection limit. Concentration is method detection limit.

Table 4-7
Confirmation Sampling of DZMW-1 Ambient Water Quality Compared to State Drinking Water Standards for Volatile Organic Compounds

Contaminant	Drinking Water Standards (µg/L)	DZMW-1 Lower Monitor Zone (µg/L)	DZMW-1 Upper Monitor Zone (µg/L)
1,1,1-Trichloroethane	200	0.18 U	0.18 U
1,1,2-Tricholoroethane	5	0.16 U	0.16 U
1,2-Dichloroethane	3	0.14 U	0.14 U
1,2-Dichloropropane	5	0.14 U	0.14 U
1,2,4-Trichlorobenzene	70	N/A	N/A
Benzene	1	0.10 U	0.10 U
Carbon tetrachloride	3	0.23 U	0.23 U
cis-1,2-Dichloroethylene	70	0.18 U	0.18 U
Dichloromethane	5	0.19 U	0.19 U
Ethylbenzene	700	0.10 U	0.10 U
Monochlorobenzene	100	0.10 U	0.10 U
0-Dichlorobenzene	600	0.11 U	0.11 U
para-Dichlorobenzene	75	0.072 U	0.072 U
Styrene	100	N/A	N/A
Tetrachloroethylene	3	0.18 U	0.7
Toluene	1,000	7.7	0.1 U
trans-1,2-Dichloroethylene	100	0.25 U	0.25 U
Trichloroethylene	3	0.11 U	0.11 U
Vinyl chloride	1	0.29 U	0.29 U
Xylenes (total)	10,000	0.13 U	0.13 U

U = Below detection limit. Concentration is method detection limit.
N/A = Parameter was not analyzed.

Table 4-8
IW-1 and DZMW-1 Ambient Water Quality Compared to State Drinking Water Standards for Synthetic Organics

Contaminant	Drinking Water Standards (µg/L)	IW-1 Injection Zone (µg/L)	DZMW-1 Lower Monitor Zone (µg/L)	DZMW-1 Upper Monitor Zone (µg/L)
2,4-D	70	1 U	1 U	1 U
2,4,5-TP (Silvex)	50	0.25 U	0.25 U	0.25 U
Alachlor	2	0.2 U	0.2 U	0.2 U
Atrazine	3	0.06 U	0.06 U	0.06 U
Benzo(a)pyrene	0.2	0.1 U	0.1 U	0.1 U
Carbofuran	40	0.5 U	0.5 U	0.5 U
Chlordane	2	0.05 U	0.05 U	0.05 U
Dalapon	200	1 U	1 U	1 U
Di(2-ethylhexyl)adipate	400	0.3 U	0.3 U	0.3 U
Di(2-ethylhexyl)phthalate	6	3.5 C2	1 U	1 U
Dibromochloropropane (DBCP)	0.2	0.005 U	0.005 U	0.005 U
Dinoseb	7	0.5 U	0.5 U	0.5 U
Diquat	20	1 U	1 U	1 U
Endothall	100	20 U	20 U	20 U
Endrin	2	0.01 U	0.01 U	0.01 U
Ethylene Dibromide (EDB)	0.02	0.005 U	0.005 U	0.005 U
Glyphosate	700	10 U	10 U	10 U
Heptachlor	0.4	0.01 U	0.01 U	0.01 U
Heptachlor epoxide	0.2	0.01 U	0.01 U	0.01 U
Hexachlorobenzene	1	0.05 U	0.05 U	0.05 U
Hexachlorocyclopentadiene	50	0.2 U	0.2 U	0.2 U
Methoxychlor	40	0.02 U	0.02 U	0.02 U
oxamyl (vydate)	200	0.5 U	0.5 U	0.5 U
Pentachlorophenol	1	0.1 U	0.1 U	0.1 U
Picloram	500	0.75 U	0.75 U	0.75 U
Polychlorinated byphenyl (PCB)	0.5	0.2 U	0.2 U	0.2 U
Simazine	4	0.07 U	0.07 U	0.07 U
Toxaphene	3	0.5 U	0.5U	0.5U

U = Below detection limit. Concentration is method detection limit.
C2 = Compound confirmed by analysis of a second aliquot of sample.

Table 4-9
IW-1 and DZMW-1 Ambient Water Quality Compared to State Secondary Drinking Water Standards

Contaminant	Units	Drinking Water Standards	IW-1 Injection Zone	DZMW-1 Lower Monitor Zone	DZMW-1 Upper Monitor Zone
Aluminum	mg/L	0.2	0.128 V	0.006 U	0.193
Chloride	mg/L	250	18,500	16,000	2,300
Color	Color Units	15	23	7	5
Copper	mg/L	1	0.009	0.002 U	0.002 U
Iron	mg/L	0.3	1.04	0.460 J3	0.394
Manganese	mg/L	0.05	0.047	0.013	0.143
Odor	Threshold odor number	3	1	1U	40
pH (Field)	Std. Units	6.5 - 8.5	7.31	7.41	8.02
Silver	mg/L	0.1	0.002 U J3	0.002 J3	0.002 U J3
Sulfate	mg/L	250	3,010	2,440	520
Total Dissolved Solids (TDS)	mg/L	500	37,300	27,400	4,650
Zinc	mg/L	5	0.067	0.007	0.008
Foaming Agents	mg/L	0.5	0.08	0.12	0.087

U = Below detection limit.
J3 = The reported value failed to meet the established quality control criteria
V= The analyte was detected in both the sample and the associated method blank.

Table 4-10
IW-1 and DZMW-1 Ambient Water Quality Compared to Minimum Criteria for Sewage Effluent

Contaminant	Units	IW-1 Injection Zone	DZMW-1 Lower Monitor Zone	DZMW-1 Upper Monitor Zone
Chloroethane	µg/L	0.5 U	0.5 U	0.5 U
Aldrin	µg/L	0.01 U	0.01 U	0.01 U
Dieldrin	µg/L	0.01 U	0.01 U	0.01 U
Diethylphthalate	µg/L	10 U	10 U	10 U
Dimethylphthalate	µg/L	10 U	10 U	10 U
Butybenzylphthalate	µg/L	10 U	10 U	10 U
Napthalene	µg/L	10 U	10 U	10 U
Anathracene	µg/L	10 U	10 U	10 U
Phenanthrene	µg/L	10 U	10 U	10 U
Phenol	µg/L	10 U	10 U	10 U
2,4,6-Trichlorophenol	µg/L	10 U	10 U	10 U
2-chlorophenol	µg/L	10 U	10 U	10 U
Organic Nitrogen	mg/L	1.07	0.74	0.37
Total Kjeldahl Nitrogen	mg/L	1.07	1.06	0.80
Total nitrogen	mg/L	1.08	1.07	0.81
Total Phosphorus	mg/L	0.010	0.025	0.140

U = Below detection limit.

4.13 INJECTION TEST

A short-term injection test was performed to provide an indication of the operating pressure of the well. The injection rate was maintained at a constant flow of 5,200 gpm; the anticipated maximum required injection rate for the Three Oaks WWTP. The construction permit requires that the test consist of the following:

- 48 hours of background
- 24 hours of injection
- 48 hours of post-injection background

During each phase of the test, flow, pressure, temperature and water levels were recorded in the injection well and the monitor zones of the dual zone monitor well. **Table 4-11** presents a summary of the monitored and measured parameters.

Table 4-11
Injection Test Monitored Parameters

Location	Parameter Monitored	Monitoring Method
Injection Well Wellhead	Pressure	• Manually with dial-type gauge • 2 transducers connected to a Hermit data logger
	Temperature	• Manually with dial-type gauge
	Atmospheric Pressure	• 2 transducers connected to a Hermit data logger
Injection Well Annulus	Pressure	• 2 transducers connected to a Hermit data logger • Manually with dial-type gauge
Top of Injection Zone	Pressure Temperature	• 2 Memory Gauges
Flowmeter	Injection rate Total volume injected	• Manually – Totalizer readings and flow rate
DZMW – Upper Monitor Zone	Pressure/Level	• 2 transducers connected to a Hermit data logger • Manually with dial-type gauge
DZMW – Lower Monitor Zone	Pressure/Level	• 2 transducers connected to a Hermit data logger
Tidal Data	Water Level	• NOAA water level records from station 8725520 (Fort Myers, FL)

4.13.1 Injection Test

Source water for the test was reclaimed water generated at the Three Oaks WWTP and stored onsite in a 10-MG reclaimed water tank. Temporary facilities were assembled to transfer water from the reclaimed water chamber to the wellhead. The temporary facilities consisted of a pump, PVC pipe, and an in-line flow meter.

Recording of background parameters, as described in **Table 4-11**, commenced at 11:20 A.M. on October 07, 2005. A short 15-minute pre-test was conducted at 5:15 PM to confirm that the pump was able to deliver the required flow rate and that the equipment was in working condition. The injection portion of the test was initiated at 7:20 A.M. on October 10, 2005. The initial flow rate was set to 5,200 gpm and was maintained constant throughout the test to simulate the maximum permitted flow. Injection continued for 24 hours and was ceased at 7:25 A.M. on October 11, 2005. After injection, pressure recovery measurements were measured for a further 48 hours.

4.13.2 Results of the Short Term Injection Test

During the test, the pressure at the wellhead increased from 18.7 psi measured during background, to a maximum of 36.9 psi during injection. After injection was ceased, the wellhead pressure decreased to 17.5 psi. This pressure increased to 18.2 psi after 48 hours of recovery. The injection pressure at the IW wellhead during the test is shown in **Figure 4-6**, along with annular, lower and upper monitor zone pressure.

The downhole pressure was recorded by two transducers placed at the top of the injection zone, just inside the liner at 2,092 feet below land surface. The change in pressure recorded between static and flowing conditions at this depth is the pressure required to inject reclaimed water into the injection zone. Pressure at this location increased by approximately 4.0 psi during injection testing, as shown in **Figure 4-7.**

The total pressure observed at the wellhead is the sum of the static water level (including any buoyancy effects), headloss due to friction through the casing, and the injection pressure at the formation. Given that the total pressure observed at the wellhead was 36.9 psi, the shut-in pressure was measured to be 17.5 psi, and the formation injection pressure increase was measured to be 4.0 psi, the headloss through the FRP tubing is estimated to be approximately 15.0 psi. This is consistent with the calculated headloss using the Hazen-Williams equation.

The downhole temperature recorded prior to the pre-test above the injection zone was 105.6°F. This temperature decreased abruptly at the commencement of the pre-test to 83.9°F. The downhole temperature gradual increased after the pre-test during background measurements to 103.1°F, and abruptly decreased at the commencement of injection to 83.1°F. After completion of injection, water temperature gradually increased to 97.7°F after 48 hours of measured background as shown in **Figures 4-7 and 4-8.**

The pressure in the annulus of the injection well showed a maximum of 9.9 psi at the commencement of the pre-test and decreased to –7.8 psi during the first two hours of background. At the start of the injection test, pressure increased to -2.7 psi. During the first hour of injection the pressure dropped to -7.8 psi and remained constant for the next 72 hours. The pressure in the annulus decreased due to the cooling of the FRP tubing as a result of the injectant's cooler temperature. As the tubing cooled it contracted slightly, increasing the volume of the annulus. Due to the relative inexpandability of the annulus fluid, the resulting pressure change is significant. **Figure 4-8** shows the direct correlation between the annulus pressure and the downhole temperature.

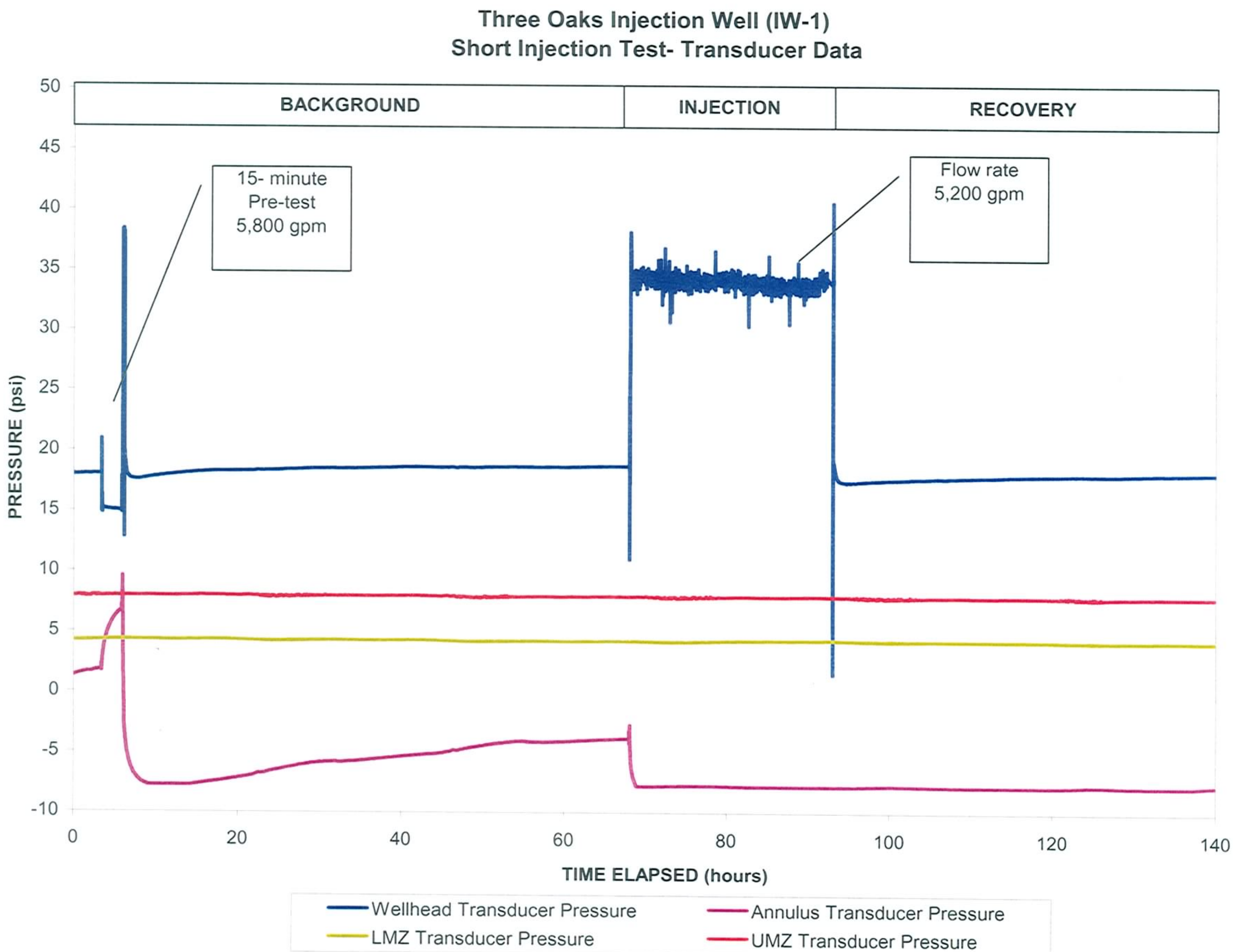
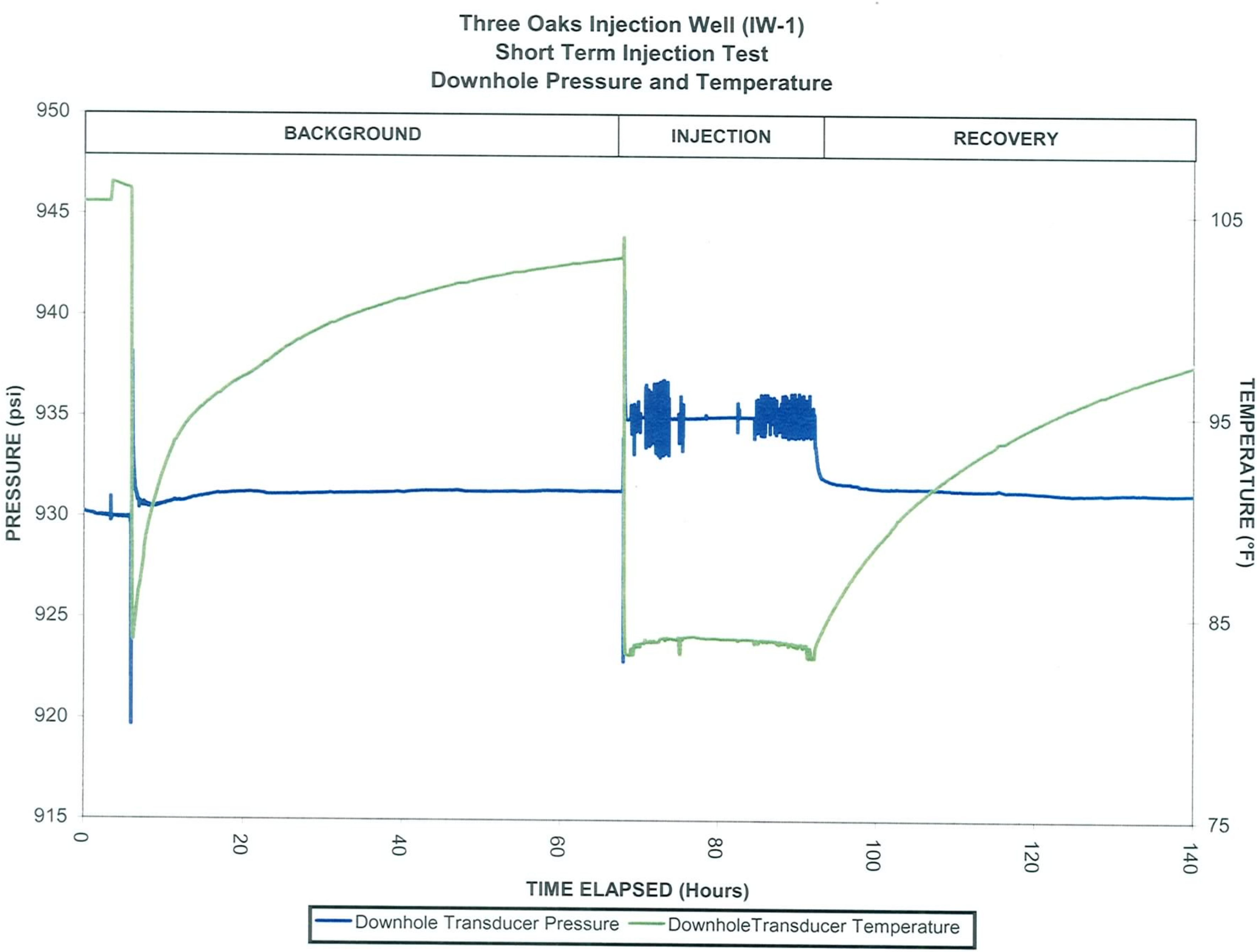

Three Oaks Injection Well (IW-1)
Short Injection Test- Transducer Data
BACKGROUND
INJECTION
RECOVERY
15- minute
Pre-test
5,800 gpm
Flow rate
5,200 gpm
PRESSURE (psi)
50
45
40
35
30
25
20
15
10
5
0
-5
-10
0
20
40
60
80
100
120
140
TIME ELAPSED (hours)
Wellhead Transducer Pressure
Annulus Transducer Pressure
LMZ Transducer Pressure
UMZ Transducer Pressure

Figure 4-6



Three Oaks Injection Well (IW-1)
Short Term Injection Test
Downhole Pressure and Temperature
BACKGROUND
INJECTION
RECOVERY
PRESSURE (psi)
950
945
940
935
930
925
920
915
TEMPERATURE (°F)
105
95
85
75
0
20
40
60
80
100
120
140
TIME ELAPSED (Hours)
Downhole Transducer Pressure
DownholeTransducer Temperature

Figure 4-7

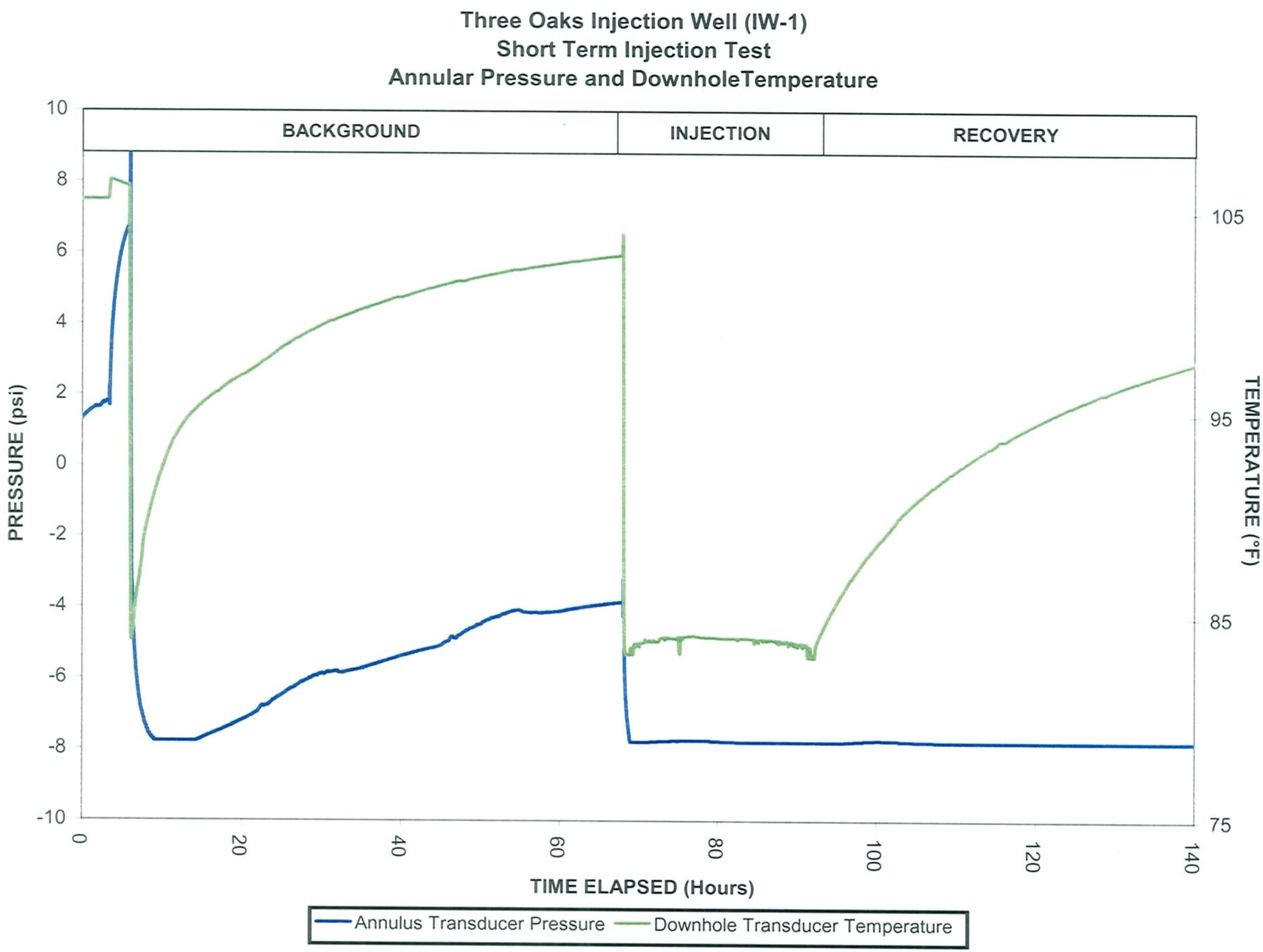

Three Oaks Injection Well (IW-1)
Short Term Injection Test
Annular Pressure and DownholeTemperature
BACKGROUND
INJECTION
RECOVERY
PRESSURE (psi)
10
8
6
4
2
0
-2
-4
-6
-8
-10
TEMPERATURE (°F)
105
95
85
75
0
20
40
60
80
100
120
140
TIME ELAPSED (Hours)
Annulus Transducer Pressure
Downhole Transducer Temperature

Figure 4-8

Both the lower and upper monitor zones of the dual zone monitor well experienced minimal pressure variations of less than 0.2 psi. The slight variations were compared to tidal fluctuations as measured in Fort Myers, FL (National Oceanic and Atmospheric Administration (NOAA) water level records from station 8725520) as shown in **Figure 4-9** and **Figure 4-10.** The slight variations in water levels of both zones of the monitor well indicate a response to tidal fluctuations recorded in Fort Myers, Fl.

Barometric pressure was measured at the injection wellhead and is displayed on **Figure 4-11.** No correlation between the measured barometric pressure and other measured parameters can be discerned.

4.13.3 Summary and Conclusions

The pressure at the wellhead increased from 18.7 psi measured during static background, to a maximum of 36.9 psi over the 24-hour injection test. After the injection period, the wellhead pressure decreased to a minimum of 17.2 psi. The buoyancy effects were minimal during the test because the fresh water injected during the Radioactive Tracer Survey (RTS), conducted prior to the injection test, was still present in the well and would have a similar density to the reclaimed water used for the test.

The injection well may be required as a back up to periodically dispose of concentrate generated at the Pinewoods ROWTP. Although this flow will be combined with effluent from the Three Oaks WWTP, there may be times when only concentrate will be injected. During operation, the concentrate produced by the Pinewoods ROWTP is estimated to have a TDS of 12,000 mg/L. As a result of buoyancy effects, the injection pressure associated with concentrate disposal is estimated to be 3 to 5 psi lower than the observed pressure following the short-term injection test.

Minimal pressure variations within the upper and lower monitor zones displayed similar trends to local tidal variations. The upper and lower monitor zones did not display a pressure change in response to the injection test, demonstrating confinement from the injection zone.

The annular pressure of the injection well decreased upon injection of cooler fresh water into the warmer saline water of the injection zone. At the time of the test the annular pressure tank had not been installed, therefore, a small change in volume resulting from the 20°F-temperature change caused a significant change in pressure in the annulus.

Three Oaks Injection Well (IW-1)
Short Term Injection Test
Upper Monitoring Zone Vs Tidal Fluctuations

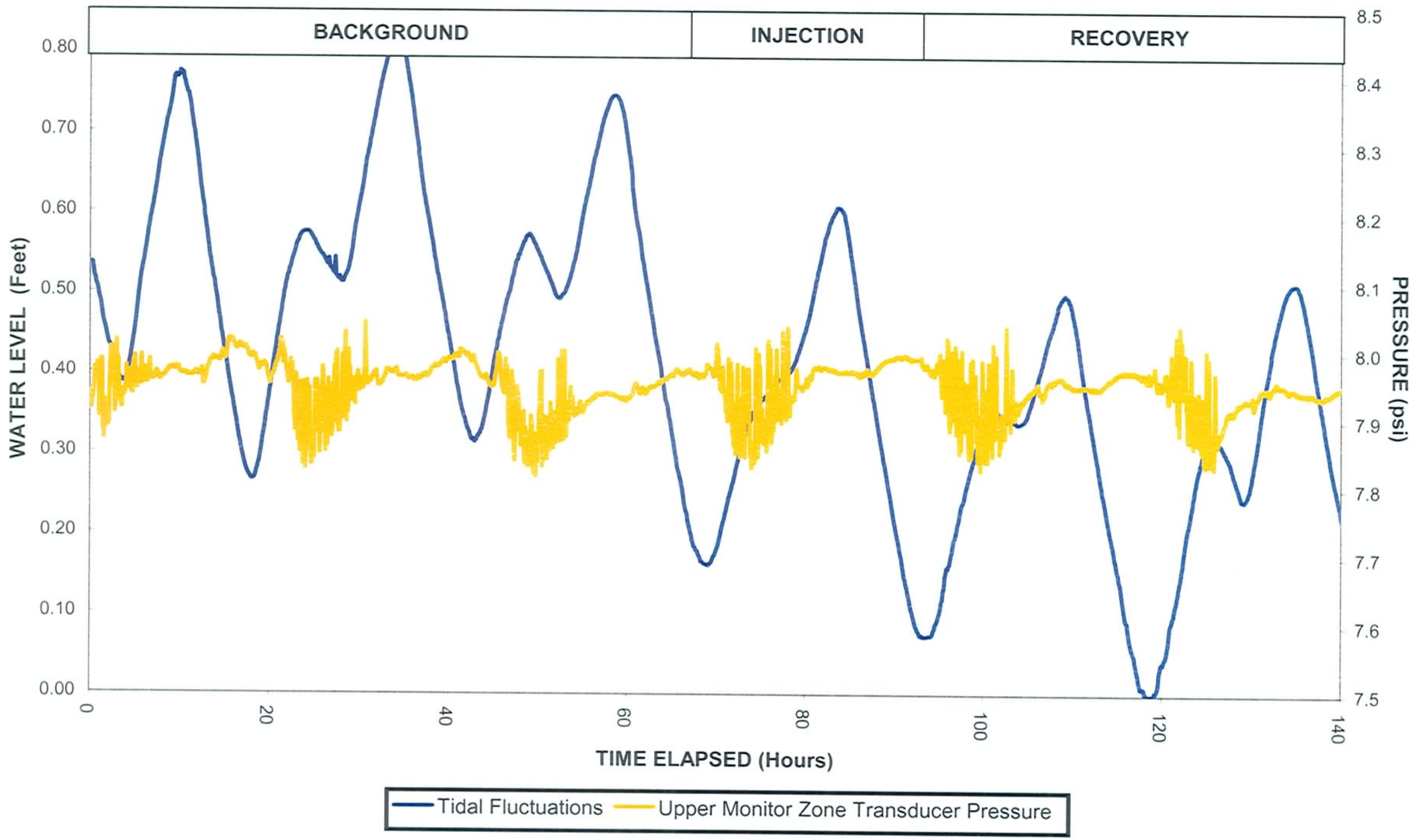


Figure 4-9

Three Oaks Injection Well (IW-1)
Short Term Injection Test
Lower Monitoring Zone Vs Tidal Fluctuations

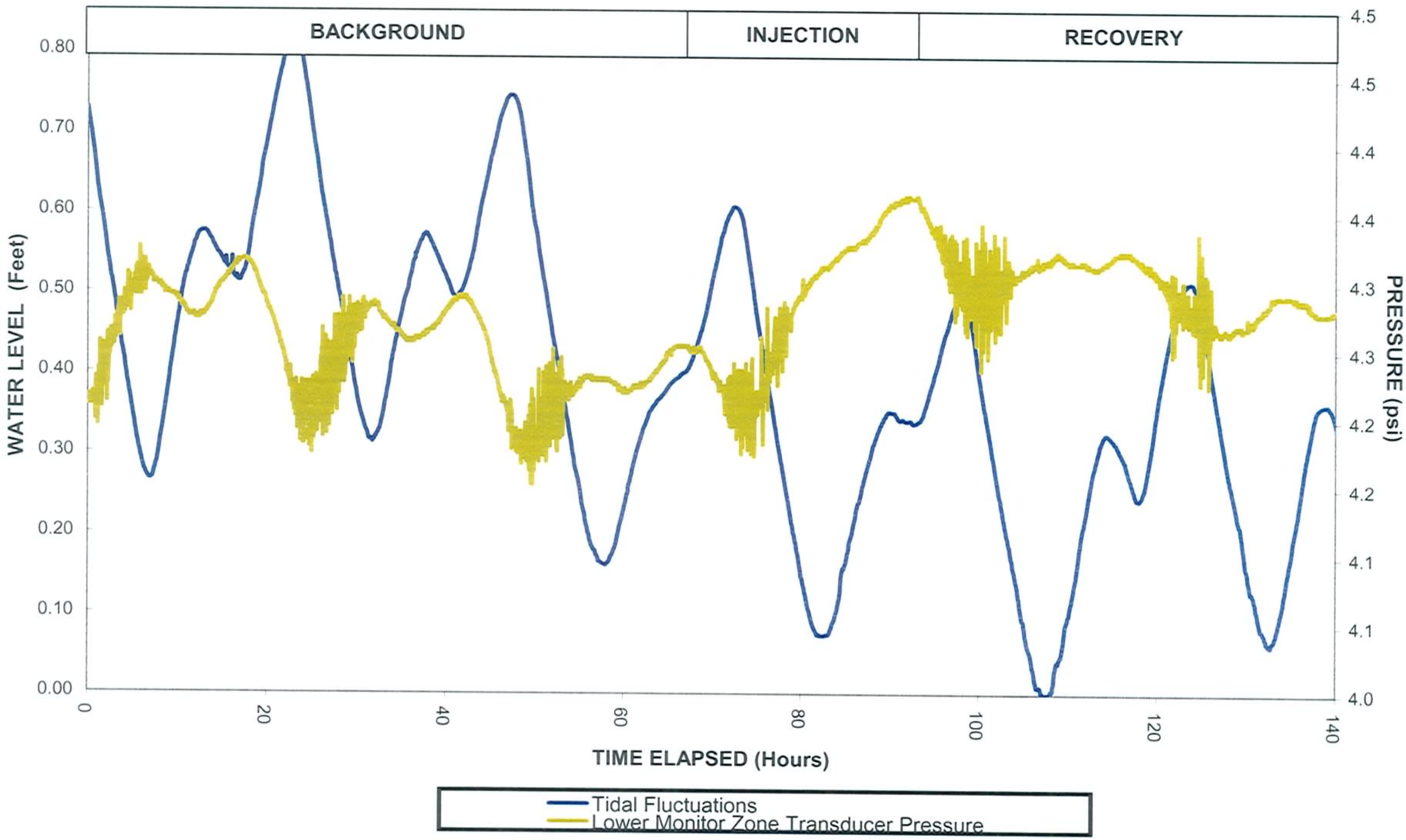


Figure 4-10

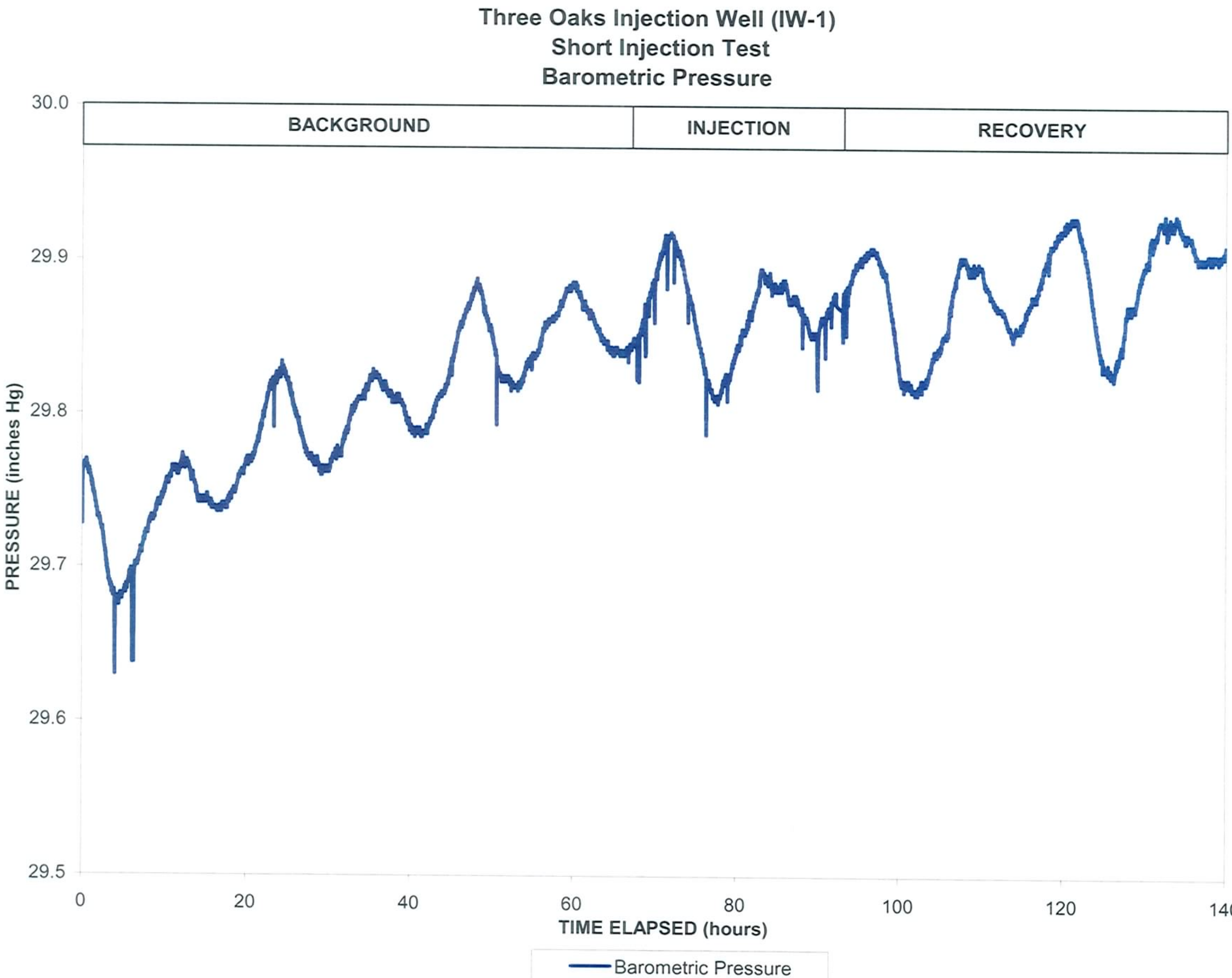

Three Oaks Injection Well (IW-1)
Short Injection Test
Barometric Pressure
BACKGROUND
INJECTION
RECOVERY
PRESSURE (inches Hg)
30.0
29.9
29.8
29.7
29.6
29.5
0
20
40
60
80
100
120
140
TIME ELAPSED (hours)
Barometric Pressure

Figure 4-11

Section 5

Section 5

Section 5
Mechanical Integrity Testing

Mechanical integrity testing (MIT) was performed in IW-1 and DZMW-1 to demonstrate the construction integrity of the wells. The testing was conducted to validate the absence of leaks in the casing, tubing, packer, and to demonstrate there is no upward migration of fluids behind the casing in the injection well. These criteria must be satisfied in accordance with Specific Condition 3(c) of the construction permit. Pressure tests and video surveys were run in IW-1 and DZMW-1. A radioactive tracer survey (RTS), with background temperature and gamma ray logs was run in IW-1. The information provided through this MIT provides baseline information against which MIT results can be evaluated in the future. A description of the testing and results for each well is provided below.

5.1 MECHANICAL INTEGRITY TESTING PROGRAM FOR IW-1

Mechanical integrity of IW-1 was evaluated through the following tests and logging procedures conducted during construction:

- Pressure test of the 20-inch steel casing
- Pressure test of the annulus between the FRP tubing and 20-inch casing
- Radioactive tracer survey (RTS)
- Background cased temperature
- Background cased gamma ray
- Casing collar locator log
- Video television survey

5.1.1 Pressure Tests

Final 20-inch OD Steel Casing Pressure Test (cemented)

The pressure test on the final casing of IW-1 was performed May 24, 2005, prior to FRP tubing installation. This pressure test was conducted using an inflatable packer set at the base of the final casing (2,100 feet bls) to create a seal between the interior of the casing and the formation below. The top of casing was sealed and equipped with a pressure gauge and valve. Once the well was sealed, the pressure in the casing was increased to 176 psi. The valve was then closed, and the pressure was monitored for one hour. The pressure at the end of the hour was 174.5 psi, which represents less than a 1 percent decrease in the pressure from the start of the test. The pressure test was successfully completed within the 5 percent tolerance established by the FDEP. The results of the pressure test and pressure gauge calibration certifications are presented in **Appendix N.**

14.5-inch FRP Tubing Pressure Test (annular)

The pressure test on the 14.5-inch OD FRP tubing of IW-1 was performed May 31, 2005. This pressure test was conducted on the annulus between the 14.5-inch OD FRP tubing and the final 20-inch OD, steel casing. The wellhead of IW-1 was sealed and equipped with a pressure gauge and valve. The pressure in the annulus was increased to 175 psi, and the valve was closed. The pressure was monitored every minute for one hour. At the end of the hour, the pressure was 175 psi, which represents no decrease in pressure from the start of the test. The pressure test was successfully completed within the 5 percent tolerance established by the permit.

5.1.2 Radioactive Tracer Survey (RTS)

On August 1, 2005, a RTS was used to evaluate the external mechanical integrity of the final casing of IW-1. This log was performed after the final 14.5-inch OD FRP tubing and packer were installed in the well. The purpose of the survey was to determine if there is any hydraulic communication between the injection zone and the intervals above the injection zone. The RTS is performed by first logging background temperature and gamma radiation in the well, and then logging gamma radiation in response to ejecting a solution of Iodine^{131} under pumping conditions. This is conducted approximately 5 feet from the base of the final casing with levels of radiation in the well measured over time. Given the spacing of the gamma ray detectors on the geophysical logging tool, the movement of the tracer fluid can be tracked closely as it disperses within the well. The radioactive tracer tool is configured with three detectors:

- Gamma ray top (GRT)
- Gamma ray middle (GRM), and
- Gamma ray bottom (GRB).

The detectors are arranged above and below the ejector, as shown on **Figure 5-1**.

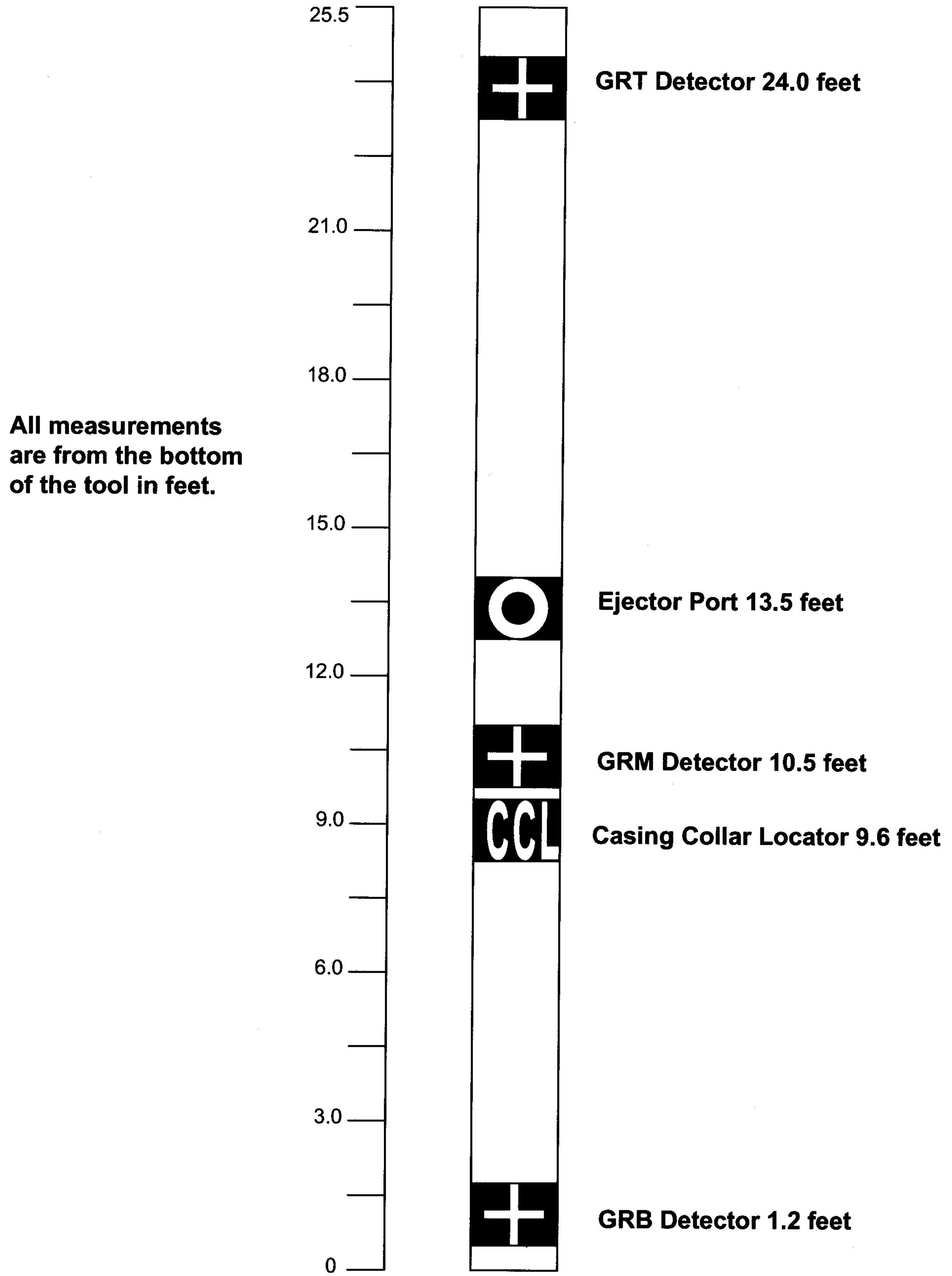


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Figure 5-1

YBI Geophysical Radioactive Tracer Tool

The RTS was performed chronologically, as follows:

High-Resolution Temperature Log

A high-resolution temperature log was performed to evaluate the internal casing mechanical integrity and external hydraulic seal. Externally, it is used to detect fluid movement behind the casing in the annular space. Internally, it is used to detect leaks in the casing wall. The high-resolution temperature log is used as a baseline log, against which future MIT logs can be evaluated. The logs were run over the entire length of well. The high-resolution temperature log can be seen in **Appendix L.**

Background Gamma Ray/Casing Collar Locator Log

These logs were run to determine background gamma ray emission and to precisely locate the bottom of the casing prior to RTS logging. The logs were run over the entire length of well and can be found in **Appendix L.**

Dynamic Flow Testing

Two dynamic flow tests were run while injecting water at a rate of 45 gpm (a velocity of 5 feet per minute). In the first test, the tool was positioned with the ejector port 5 feet above the bottom of the casing with water being pumped into the well. A slug of radioactive $Iodine^{131}$, measuring 1.0 milliCurie (mCi), was ejected. Radioactive slug movement was monitored for one hour. During this period, the tool was stationary and the injection rate of water was held constant. After the one-hour monitoring period, a log out-of-position (LOP) survey was performed beginning at the ejection point to 200 feet above the highest detection of the $Iodine^{131}$. Upon completion of the LOP, the well was flushed with water. After the completion of the flushing, the tool was run to the base of the casing and a log after flush (LAF) was performed over the same interval as described above. The LOP and the LAF logging surveys can be found in **Appendix L.**

The second test was performed in an identical manner to the first test in order to confirm the results from the first test.

Dynamic Test 1 – First Hour

A slug of $Iodine^{131}$ was ejected into IW-1 at 09:45 AM, at 2,095 feet bls, 5 feet above the bottom of the casing. This 1.0 mCi slug was ejected over a 8.5 second interval while fresh water was pumped into the well at 45 gpm. Pumping continued at 45 gpm, for the full hour of the dynamic test. **Table 5-1** below summarizes the data collected during this portion of the RTS.

Table 5-1
Dynamic Test 1 – First Hour
Summarized Results

RTS Tool Specifics		
Tool Detector/Ejector	**Initial Measuring Depth (feet bls)**	**Detector Response to Tracer**
Ejector	**2,095.0**	1.0 mCi tracer released at 09:45 hours
GRT	2,084.5	None Detected
GRM	2,098.0	2 seconds
GRB	2,107.3	2 minutes

The GRM and GRB detectors both detected downward movement of tracer fluid within 1 and 3 minutes, respectively, of its ejection. Within 3 minutes the GRM detector started a slow and continuous decline in gamma ray activity. After 11 minutes the GRB detector started a slow but continuous decline in gamma ray activity, indicating the slug of $Iodine^{131}$ was moving down into the injection zone. The downward movement of tracer fluid is confirmed by the lack of gamma ray activity observed at the GRT detector, which continued to record background readings for the entire hour of monitoring.

Dynamic Test 1 – Log Out of Position (LOP)

Following the monitoring period, a LOP survey was performed by moving the tool upward from its monitoring position to 1,895 feet bls, while continuing to inject water at 45 gpm. This log was designed to detect whether any tracer traveled behind the casing during the monitoring period. **Table 5-2** below summarizes the data collected during this portion of the testing.

Table 5-2
Dynamic Test 1 – Log Out of Position
Summarized Results

Tool Detector	Initial Measuring Depth (feet bls)	Upper Detectable Limit of Tracer (feet bls)	Final Measuring Depth (feet bls)
GRT	2,084.5	None	1,895
GRM	2,098.0	2,096	1,895
GRB	2,107.3	2,096	1,895

The GRM and GRB detectors indicate a slight stain on the casing wall at the point of ejection and return to background within 2 feet of the ejection point. The GRT detector shows no indication of upward movement of fluid behind the casing wall.

Ejection No. 1 – Log After Flush (LAF)

Following the LOP portion of the test, fresh water was pumped into the well to discharge the tracer into the formation and clean the stained portions of casing wall. **Table 5-3,** below, summarizes the data collected during this portion of the testing.

Following the flushing of the casing, the stain was removed from the casing wall, but the 'dribbling', against the inner casing wall, is apparent on the log, at the base of the casing. The GRT detector measured gamma readings that match background values, which indicates there is no upward movement of radioactive tracer material.

Table 5-3
Dynamic Test 1 – Log After Flush
Summarized Results

Tool Detector	Initial Measuring Depth (feet bls)	Upper Detectable Limit of Tracer (feet bls)	Final Measuring Depth (feet bls)
GRT	2,084.5	None	1,895
GRM	2,098.0	None	1,895
GRB	2,107.3	None	1,895

Dynamic Test 2 – First Hour

A second dynamic test was conducted to confirm the results of the previous test. The test method was performed the same as the previous dynamic test with a 1.0 mCi slug ejected over an 8.5 second interval.

The second dynamic test commenced, with a slug of $Iodine^{131}$ ejected into IW-1 at 11:12 AM at 2,095 feet bls, 5 feet above the bottom of the casing. This 1.0 mCi slug was ejected while fresh water was pumped into the well at 45 gpm. **Table 5-4** summarizes the data collected during this portion of the RTS, which is nearly identical to the data collected during the first dynamic test, demonstrating good repeatability.

Table 5-4
Dynamic Test 2 – First Hour
Summarized Results

RTS Tool Specifics		
Tool Detector/Ejector	**Initial Measuring Depth (feet bls)**	**Detector Response to Tracer**
Ejector	**2,095.0**	1.0 mCi tracer released at 11:12 hours
GRT	2,084.5	None Detected
GRM	2,098.0	20 seconds
GRB	2,107.3	1 minutes 40 seconds

Dynamic Test 2 - LOP

Following the monitoring period, a LOP survey was performed by moving the tool upward from its monitoring position to 1,895 feet bls. This log was also designed to detect whether any tracer traveled behind the casing during the monitoring period. **Table 5-5** below summarizes the data collected during this portion of the testing.

Table 5-5
Dynamic Test 2 – Log Out of Position
Summarized Results

Tool Detector	Initial Measuring Depth (feet bls)	Upper Detectable Limit of Tracer (feet bls)	Final Measuring Depth (feet bls)
GRT	2,084.5	None	1,895
GRM	2,098.0	2,096	1,895
GRB	2,107.3	2,096	1,895

After Flush/Final Background Check

In the final portion of the RTS, water was pumped into the well to flush and clean the tracer tool. The tracer tool was also flushed of all excess tracer material below the base of the casing, with the remaining 4 mCi of Iodine131 being released at 2,130 feet bls. The well was logged from 2,853 feet bls to the surface to compare background to final gamma ray radiation. **Table 5-6** below summarizes the data collected during this final portion of the testing.

Table 5-6
After Flush Pass/Final Background Check
Summarized Results

Tool Detector	Initial Measuring Depth (feet bls)	Upper Detectable Limit of Tracer (feet bls)	Final Measuring Depth (feet bls)
GRT	2,084.5	2,094	0
GRM	2,098.0	2,094	0
GRB	2,107.3	2,094	0

Post Test Gamma Ray/Casing Collar Locator Log

Following the completion of the dynamic testing of the RTS, a gamma ray/casing collar log was run over the entire length of well as an after-flush final background pass. The after-flush final background log can be found in **Appendix L.**

RTS Summary

Based on the results of the RTS, no fluid migrated behind the wall of the casing, or within the borehole, due to channeling or inadequate cementing. The initial and final background passes showed similar responses. This similarity in the initial, background, and after the test gamma ray logs indicate the injection well has external mechanical integrity, as required by FAC Chapter 62-528.

5.1.3 Video Television Surveys

A video television survey was performed on the final steel casing of IW-1 on May 23, 2005. The casing was clean with no visible flaws detected in the casing or the welds.

A video television survey was performed on the injection tubing and open hole of IW-1 May 27, 2005, and submitted to the FDEP. The casing was clean with no visible flaws detected in the casing or the couplings. A copy of the video television surveys is included in **Appendix O.**

5.2 MECHANICAL INTEGRITY TESTING PROGRAM FOR DZMW-1

After the installation of the final casing, the mechanical integrity of the monitor well was investigated and completed with a casing pressure test.

The required pressure test and television survey demonstrated the internal mechanical integrity of the final casing.

5.2.1 Pressure Tests

Final 16-inch Diameter Steel Casing Pressure Test (cemented)

The pressure test on the final casing of DZMW-1 was performed August 3, 2005, prior to drilling the lower monitor zone. The test used an inflatable packer set near the base of the casing, at 1,137 feet bls to create a seal between the interior of the casing and the formation below. The top of casing was sealed and equipped with a pressure gauge and valve. The pressure in the casing was increased to 150 psi. The valve was shut, and pressure was monitored every minute for one hour. The pressure at the end of the hour was 154 psi, which represents a 2.6 % increase in the pressure from the start of the test. The pressure test was successfully completed within the 5 percent tolerance in accordance with the FDEP construction permit. The results of the pressure test and pressure gauge calibration certification are presented in **Appendix N.**

6.625-inch FRP Tubing Pressure Test

The pressure test on the 6.625-inch diameter FRP tubing of DZMW-1 was performed August 15, 2005. This pressure test used an inflatable packer set at the base of the FRP tubing to create a seal between the interior of the casing and the formation below. The top of casing was sealed and equipped with a pressure gauge and valve. The pressure in the casing was increased to 103 psi. The valve then was shut, and the pressure was monitored every minute for one hour. The pressure at the end of the hour was 98 psi, which represents a 4.8% decrease in pressure from the start of the test. The pressure test was successfully completed within the 5 percent tolerance in accordance with the FDEP construction permit.

5.3 EVALUATION OF MECHANICAL INTEGRITY

Demonstration of mechanical integrity was performed on IW-1 and DZMW-1 to verify the integrity of the final casing, injection tubing and monitor casings. In addition, the MIT confirmed the effectiveness of the hydraulic seal at the base the casing. The MIT on IW-1 required performance of a pressure test to demonstrate there are no leaks in the casing, and a video survey to provide visual inspection of the interior of the final casing in the injection well. In order to demonstrate there is no fluid movement behind the casing, a high-resolution temperature log and RTS were performed during the MIT in the injection well. The Three Oaks IW-1 and DZMW mechanical integrity testing program was conducted in accordance with the FDEP Chapter 62-528.300 (6), (b)2, and (c) of the Florida Administrative Code, as stipulated in the construction and testing permit's Specific Condition 2(r).

Section 6

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Section 6

Section 6
Summary and Conclusions

IW-1 and DZMW-1 were constructed for the Lee County Utilities to serve the Three Oaks WWTP. Construction activities began February 04, 2004, and were substantially complete September 16, 2005.

The injection well will be used primarily to dispose of excess reclaimed water from the WWTP. However the well may also be used as a back up to periodically dispose of concentrate generated at the Pinewoods Reverse Osmosis Water Treatment Plant. The dual-zone monitor well will monitor groundwater quality in two intervals: one below and one above the base of the USDW to warn of any upward migration of injection concentrate.

IW-1 was constructed with a final 20-inch OD, steel casing string set to a depth of 2,100 feet bls, with a 18.5 inch diameter open hole drilled below the final casing to a depth of 2,860 feet bls. The well was completed using 14.5-inch ID FRP tubing set to 2,095 feet bls, five feet above the bottom of the final steel casing with a YBI positive seal packer assembly. The annulus between the final 20-inch steel casing and the 14.5-inch ID FRP is filled with corrosion inhibitor fluid, which will be maintained under positive pressure. The annular pressure will be continuously monitored during well operations for changes in pressure that may indicate a hole or leak in the casing.

DZMW-1 was constructed approximately 149 feet north of the injection well with two discrete monitoring zones. The UMZ was constructed to monitor the interval below the 16-inch OD, steel casing at 1,150 to 1,204 feet bls. The LMZ was constructed with 6.625-inch OD FRP tubing to 1,455 feet bls, to monitor the interval from 1,455 to 1,535 feet bls.

Construction and testing were conducted in accordance with the FDEP construction permit 38436-178-UC and the applicable sections of Chapter 62-528, FAC, with construction contract specifications as prepared by MWH, Americas Inc.

The FDEP and TAC approved the construction testing program prior to issuance of the construction permit. A comprehensive testing program was conducted during construction of IW-1 and DZMW-1 to evaluate:

- The site geology and hydrogeology
- Casing setting depths
- The depth at the base of the USDW
- Production intervals for UMZ and LMZ selection, and
- Injection zone selection.

The testing program consisted of lithologic sampling, pilot hole water quality sampling, coring, packer testing, geophysical logging, and background ambient water quality testing.

The base of the USDW in the IW-1 was identified to be at 1,346 feet bls based on sonic porosity and dual induction logs, and packer testing water quality analyses. The UMZ and LMZ were constructed above and below the base of the USDW, respectively.

The testing program identified the top of the injection zone at 2,100 feet bls. The injection zone is characterized by high intrinsic permeability, highly fractured zones, caverns, and massive dissolution features. Significant confinement was identified throughout the interval between approximately 1,810 and 2,100 feet bls based on the lithologic descriptions core data, packer test results, geophysical logs, and the downhole video.

Pressure testing and an RTS were conducted successfully to demonstrate the mechanical integrity of IW-1. Mechanical integrity of the 6.625-inch ID FRP final tubing of DZMW-1 was demonstrated through pressure testing. Each well met the standards and conditions established in Chapter 62-528, FAC and permit No. 38436-178-UC.

A short-term injection test was conducted on IW-1 for a period of 24-hours. From the results of the test, the pressure at the injection well wellhead will be approximately 37 psi at a flow rate of 5,200 gpm (7.4 MGD).

Prior to the FDEP approval for operational testing of the injection well the following activities must be completed by Lee County:

1. Construction of injection well above-ground piping and metering infrastructure,
2. Preparation of as-built well construction specifications (drawings),
3. Preparation of draft operation and maintenance manual with emergency procedures, and
4. Inspection by the FDEP of the completed facility.

Following the FDEP's approval of the information provided in this report and completion of the activities listed above, FDEP will likely authorize Lee County Utilities to commence operational testing of the well.

During operational testing, IW-1 and DZMW-1 must be monitored in accordance of rule 62-528.425 and 62-528.430 F.A.C. and as stipulated in the FDEP construction permit. Performance data and water quality should be recorded and reported in both IW-1 and DZMW-1, as indicated in **Table 6-1** through **Table 6-4.** Continuous monitoring and recording devices should be used to monitor injection flow rate, injection pressure and annular pressure in IW-1. Continuous monitoring and recording devices should also be placed in the LMZ and UMZ to monitor pressures and/or water levels in DZMW-1.

Water quality from the UMZ and LMZ and the reject water from the wastewater treatment plant should be sampled on a monthly basis. The analytical results as stipulated in the FDEP permit, should be submitted to FDEP prior to the last day of each month in the Monthly Operating Report (MOR).

Table 6-1
Performance Data Required During Operational Testing of IW-1

Parameter	Units	Reporting Frequency
Injection Pressure	psi	Daily/Monthly
- Maximum Injection Pressure		Daily/Monthly
- Minimum Injection Pressure		Daily/Monthly
- Average Injection Pressure		Daily/Monthly
Flow Rate	gpm	Daily/Monthly
- Maximum Flow Rate		Daily/Monthly
- Average Flow Rate		Daily/Monthly
- Minimum Flow Rate		Monthly
Annular Pressure	psi	Daily/Monthly
- Maximum Annular Pressure		Daily/Monthly
- Minimum Annular Pressure		Daily/Monthly
- Average Annular Pressure		Monthly
Annular Fluid added/removed	gallons	Daily/Monthly
Annular Pressure added/removed	psi	Daily/Monthly
Total Volume WWTF Effluent Injected	gallons	Daily/Monthly
Total Volume WTP Concentrate Injected	gallons	Daily/Monthly
Total Volume ROWTP Concentrate Injected	gallons	Daily/Monthly

Table 6-2
Water Quality Data Required During Operational Testing of IW-1

Injectate Water Quality	Units	Reporting Frequency
WWTP Effluent		
TKN	(mg/L)	Monthly
Ammonia as N	(mg/L)	Monthly
Nitrate and Nitrite as N	(mg/L)	Monthly
Gross Alpha	pCi/L	Monthly
Radium 226	pCi/L	Monthly
Radium 228	pCi/L	Monthly
WTP and ROWTP Concentrate		
TKN	(mg/L)	Monthly
pH	(std. units)	Monthly
Specific Conductance	(μS/cm)	Monthly
Chloride	(mg/L)	Monthly
Sulfate	(mg/L)	Monthly
Field Temperature	(deg. C)	Monthly
Total Dissolved Solids	(mg/L)	Monthly
Sodium	(mg/L)	Monthly
Calcium	(mg/L)	Monthly
Potassium	(mg/L)	Monthly
Magnesium	(mg/L)	Monthly
Iron	(mg/L)	Monthly
Carbonate	(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
Municipal Wastewater Indicator Parameters**		Annually

**Analysis should be provided prior to operational testing or testing with concentrate and then annually, thereafter.

Table 6-3
Performance Data Required During Operational Testing of DZMW-1

Parameter	Units	Reporting Frequency
Maximum Water Level or Pressure	Ft. NGVD /psi	Daily/Monthly
Minimum Water Level or Pressure	Ft. NGVD /psi	Daily/Monthly
Average Water Level or Pressure	Ft. NGVD /psi	Monthly

Table 6-4
Water Quality Data Required During Operational Testing of DZMW-1

Injectate Water Quality	Units	Reporting Frequency*
TKN	(mg/L)	Weekly
pH	(std. units)	Weekly
Ammonia as N	(mg/L)	Weekly
Specific Conductance	(µS/cm)	Weekly
Chloride	(mg/L)	Weekly
Sulfate	(mg/L)	Weekly
Field Temperature	(deg. C)	Weekly
Total Dissolved Solids	(mg/L)	Weekly
Sodium	(mg/L)	Monthly
Calcium	(mg/L)	Monthly
Potassium	(mg/L)	Monthly
Magnesium	(mg/L)	Monthly
Iron	(mg/L)	Monthly
Carbonate	(mg/L)	Monthly
Bicarbonate	(mg/L)	Monthly
Gross Alpha	pCi/L	LMZ only -- Monthly
Radium 226	pCi/L	LMZ only -- Monthly
Radium 228	pCi/L	LMZ only -- Monthly

*Water quality data may be reduced to monthly analyses after a minimum six months of data if the conditions of Rule 62-528.450(3)(d), F.A.C, have been met and with Department approval.

Section 7

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References

Applin, P. L., and Applin, E. R., 1944. Regional subsurface stratigraphy and structure of Florida and southern Georgia: *American Association of Petroleum Geologists Bulletin*, Vol. 28, p. 1673-1753.

Applin, P.L. and Applin, E.R., 1965. The Comanche Series and Associated Rocks in the Subsurface in Central and South Florida: *United States Geological Survey* Professional Paper 447, 82 p

Ceryak, R., Knapp, M. S., and Burnson, T., 1983. The geology and water resources of the upper Suwannee River Basin, Florida, *Florida Dept. of Natural Resources, Bureau of Geology,* Report of Investigation No. 87

Cooke, C.W., and Mansfield, W., 1936. Suwannee Limestone of Florida (abstract). *Geological Society of America Proceedings*, 1935

Cooper, H.H. Jr., and Jacob, C.E., 1946. A generalized graphical method for evaluating formation constants and summarizing wellfield history. *Transactions, American Geophysical Union*, Vol. 27, pp. 526-534.

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

Driscoll, F.G., 1986. Groundwater and Wells: Second edition, Johnson Division, St. Paul, Minnesota.

Duncan, J. G., Evans, W. L. III and, Taylor, K. L, 1994. Geologic framework of the lower Floridan aquifer system, Brevard County, Florida, *Florida Geological Survey*. Bulletin 64.

Fetter, C.W., 1994. Applied Hydrogeology, Prentice Hall, Englewood Cliffs, New Jersey.

Fish, J.E. and Stewart, M, 1991. Hydrogeology of the Surficial Aquifer System, Dade County, Florida. *U.S. Geological Survey, Water-Resources Investigations Report* 90-4108.

Freeze, R.A. and J.A. Cherry, 1979. Groundwater, Prentice-Hall, Englewood Cliffs, New Jersey.

Hantush, M.S. and C.E. Jacob, 1955. Non-Steady Radial Flow in an Infinite Leaky Aquifer. *Transactions, American Geophysics Union*, Vol. 36, pp. 95-100.

Klein, Howard, 1972. The shallow aquifer of southwest Florida: *Florida Bureau of Geology,* Map Series 53.

Miller, J.A., 1986. Hydrogeological 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.

Neuman, S.P. and Witherspoon, P.A., 1969. Theory of Flow in a Confined Two Aquifer System: *Water Resources Research*, Vol. 5, No. 4, pp. 803-816

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

Sproul, C.R., Boggess, D.H., and Woodward, H.J., 1972. Saline-water intrusion from deep aquifers sources in the McGregor Isles area of Lee County, Florida: *Florida Division Geology Information* Circular 75, 30 p.

Theis, C.V., 1935. The Relation of the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-water Storage. *Transactions, American Geophysical Union*, Vol. 19, pp. 519-524.

Wedderburn, L.A., Knapp, M.S., Waltz, D.P., and Burns, W.S., 1982. Hydrogeologic reconnaissance of Lee County, Florida: *South Florida Water Management District* Technical Publication 86-1, 193 p.

White, W.A., 1970. The geomorphology of the Florida peninsula: *Florida Bureau of Geology,* Bulletin no. 51, 164 p.

White, W.A., 1958. Some Geomorphic Features of Central Peninsular Florida. *Florida Geological Survey,* Geological Bulletin, 41.